CAT 2 Principles of Ultrasound

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ASU CAT 2 Training Overview

Ultrasound has been used for years for many different applications. From ultrasonic welding, mixing, motion detection, medical application like imaging & physical therapy just to name a few. The use of Ultrasound can all be tied back to one man who in 1901 demonstrated a direct conversion heterodyne receiver as a method for making continuous radiotelegraphy signals audible. His name was Reginald Aubrey Fessenden and he was a born-on October 6th, 1866 in East-Bolton, Quebec. He entered the Bishop College School in Port Hope, Quebec at the age of 14 years old where he was granted a mathematics mastership where he taught mathematics to younger and older students.

He created a process called Heterodyning which is a signal processing technique in which new frequencies are created by combining two frequencies. By shifting one frequency range into another, the new frequency goes through the process of modulation & demodulation. This process is used in a nonlinear signal processing device that combines the two frequencies to make two new frequencies. In the case of an Ultrasonic Detection Device the two frequencies are High and Low Frequencies. The unit will then filter out the Low Frequency and allows the High Frequency to stand alone. This process has been used in everything from Morse Code, Radio Receivers, Music synthesis to mixers and has been applied to Ultrasonic Detection Devices since the 1950's.

Ultrasonic detection equipment has become a trusted source for trending and troubleshooting over the last few decades. The ability now to run the sound waves through a sound analysis software has opened a new realm of things for the CBM Analyst's. No longer is Ultrasound a simple Go or No Go test as it can be used for determining Stray Voltage in a motor, Inner & Outer Race faults, Cage Faults, Ball Pass Faults, Corona, Track, Arcing, Loose Connection, Delamination of Windings in a Transformer. These issues can be determined by simply looking at the images of the sound wave. Each one will have a distinct image that shows the Harmonic Marks that tell us the Fault Frequency of those Harmonics. In addition, the use of a Time Signal will show the harmonics and the Amplitude of the Sinusoidal Wave.

Company Overview

IRISS is the global leader in Electrical Maintenance Safety Devices & Solutions (EMSD). We help our customers reduce downtime related costs & maximize efficiency by reducing inspection times. EMSD's warn you of potential equipment failures before they occur, maintain the energized compartment's in a closed, safe and guarded condition ensuring workers are never exposed to the dangers of Arc Flash or electrocution, & automate asset inspection data collection process driving more efficiency improvements. Our EMSD solutions reduce risk, minimize cost and maximize efficiency.

Mission Statement:

At IRISS, we provide our customers unsurpassed quality at every touch point. We focus on what we do best by continuously improving infrared (IR) window technology, building reliable products, exceeding customer expectations, remaining a science-based R&D company, and protecting our polymer IR windows through Our Unconditional Lifetime Warranty.

IRISS industrial-grade IR windows facilitate safer, more efficient inspections of energized electrical equipment when compared to traditional crystal windows. Our award-winning, IR window designs feature a durable transparent polymer lens that allows visual, UV, and short/mid/longwave IR spectrum inspections. And…is available in custom shapes, sizes, and color to fit the needs of any application.
As a solution providers, the team at IRISS brings a multitude of experience from world-class maintenance programs together to meet the individual needs of commercial, industrial, marine, power generation and government maintenance programs.

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Mission:

IRISS is a business born out of recognition of the need of the global condition-based maintenance industry to safely perform energized inspections on electrical assets. It is our mission to exceed client expectations by continuing to set the industry standard for products, services and support for the electrical maintenance market through innovative Electrical Maintenance Safety Devices (EMSDs) and solutions, that leverage our unique industry experience.

Vision:

To become a driving force and the global leader in Electrical Maintenance Safety Devices (EMSDs) and training solutions.

Values:

Obsessed with Finding a Better Way:
We design and build quality into all products, services and operational systems. Our clients demand and deserve unsurpassed quality in every aspect of how we interface with them. It is our duty to not just meet their needs but to exceed their requirements on every project.

I.C.A.S.T. Course:

The I.C.A.S.T. course is one of the first steps in training that is available from IRISS. This course will stress the benefits of the different technologies and how they work in an integrated CBM Program. The course will offer help to the site in developing their program to insure the simplest collection of data. It is also the precursor course to CAT 1 and should be taken prior to scheduling a CAT 1 course as its focus is on insuring that the CBM Analyst s know what applications the equipment can be used for, how to operate the equipment, how to collect data, and how-to analyze the data in the software. This 20-hour course can be customized to focus on one application or all the applications. This course will also count toward the recommend number of hours of use recommended by ISO standards 13379, 17027, 18436-7, and 29821-1, that an CBM Analyst should've prior to taking a CAT 1 Certification Course. This is important as the ASNT-TC-1A CAT 1 Courses have generally been taught as a Theory class and they do not go as in-depth on the software and data collection process. The ISO Standards have changed this.

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ISO Standard 18436 & ASNT SNT TC-1A, Are standards for personnel Qualification and Certification in Nondestructive Testing.

ISO 18436-3:2012 Condition monitoring and diagnostics of machines -- Requirements for qualification and assessment of personnel -- Part 3: Requirements for training bodies and the training process.

ISO 18436-3:2012 defines the requirements for bodies operating training programs for personnel who perform machinery condition monitoring, identify machine faults, and recommend corrective action. Procedures for training of condition monitoring and diagnostics personnel are specified.

ISO 18436-6:2014 Condition monitoring and diagnostics of machines -- Requirements for qualification and assessment of personnel -- Part 6: Acoustic emission.

ISO 18436-6:2014 specifies the requirements for qualification and assessment of personnel who perform machinery condition monitoring and diagnostics using acoustic emission.

A certificate or declaration of conformity to ISO 18436-6:2014 will provide recognition of the qualifications and competence

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of individuals to perform acoustic emission measurements and analysis for machinery condition monitoring using acoustic emission equipment. This procedure may not apply to specialized equipment or other specific situations.
ISO 18436-6:2014 specifies a three-category classification program that is based on the technical areas delineated herein.

ISO 18436-8:2013 Condition monitoring and diagnostics of machines -- Requirements for qualification and assessment of personnel -- Part 8: Ultrasound.

ISO 18436-8:2013 specifies the requirements for qualification and assessment of personnel who perform machinery condition monitoring and diagnostics using ultrasound.

A certificate or declaration of conformity to ISO 18436-8:2013 provides recognition of the qualifications and competence of individuals to perform ultrasound measurements and analysis for machinery condition monitoring using ultrasound equipment. It is possible that this procedure is not applicable to specialized equipment or other specific situations.

ISO 18436-8:2013 specifies a three-category classification program that is based on the technical areas delineated herein, consistent with ISO 18436-1 and ISO 18436-3. (Source www.iso.org/standard/50608.html).

Recommended Practice No. ANST SNT-TC-1A 2016 Personnel Qualification & Certification in Nondestructive Testing.

1.0 Scope

1.1 It is the recognized that that the effectiveness of nondestructive testing (NDT) applications depends upon the capabilities of the personnel who are responsible for, and performs, NDT. This recommended Practice has been prepared to establish guidelines for qualifications and certification of NDT personnel whose specific jobs are requires appropriate knowledge of the technical principles underlying the nondestructive tests they perform, witness, monitor, or evaluate.
1.2 This document provides guidelines for the establishment of qualification and certification program.
1.3 These guidelines have been developed by the American Society for Nondestructive Testing, Inc., to aid employers in recognizing the essential factors to be considered in qualifying personnel engaged in any of the NDT methods listed in Section 3.
1.4 It is recognized that these guidelines may not be appropriate for certain employers' circumstances and/or applications. In developing a written practice as required in Section 5, the employer should review the detailed recommendations presented herein and modify them, as necessary, to meet particular needs. Such modification may alter but shall not eliminate basic provisions of the program such as training, experience, testing and recertification. Supporting technical rationale for modification of detailed recommendation should be provided in an Annex to the written practice.

4.0 Levels of Qualification

4.1 There are three basic levels of qualification. The employer may subdivide these levels for situations where additional levels are deemed necessary for specific skills and responsibilities.
4.2 While in the process of being initially trained, qualified and certified, an individual should be considered a trainee. A trainee should work with certified induvial. The trainee should not independently conduct, interpret, evaluate, or report the results of any NDT test.
4.3 The three basic levels of qualification are as follows:

4.3.1 NDT Level I. An NDT Level I individual should be qualified to properly perform specific calibrations, specific NDT, and specific evaluations for acceptance or rejection determination according to written instructions and to record results. The NDT Level I should receive the necessary instruction and supervision from a certified NDT Level II or III induvial.

4.3.2 NDT Level II. An NDT Level II individual should be qualified to set up and calibrate equipment and to interpret and evaluate results with respect to applicable codes, standards, and specifications. The NDT Level II should be thoroughly familiar with the scope and limitations of the methods for which qualified and should exercise assigned responsibility for on-the-job training and guidance of trainees and NDT CAT 1 personnel. The NDT Level II should be able to organize and report the results of the NDT tests.

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4.3.3 NDT Level III. An NDT Level III individual should be capable of developing, qualifying, and approving procedures, establishing and approving procedures, establishing and approving techniques, interpreting codes, standards, specifications, and procedures; and designating the particular NDT methods, techniques, and procedures to be used. The NDT Level III should be responsible for the NDT operations for which qualified and assigned and should be capable of interpreting and evaluating results in terms of existing codes, standards, and specifications. The NDT Level III should have sufficient practical background in applicable materials, fabrication, and product technology to establish techniques and to assist in the establishing acceptance criteria when none are otherwise available. The NDT Level III Should have general familiarity with other appropriate NDT methods, as demonstrated by an ASNT Level III Basic examination or other means. The NDT Level III, in the methods in which certified, should be capable of training and examining NDT Level I and II personnel for certification in those methods. (Source SNT-TC-1A 2016)

Keys to a Successful Program

Being able to turn on an Ultrasound Unit does make someone an CBM Analyst any more than someone who goes through training but never uses the equipment makes them knowledgeable. The key to an ultrasound equipment is receiving proper training and time to use that equipment. This will help the CBM Analyst gain more confidence in the equipment and themselves.

Understanding the physics of ultrasound is key factor to success of a program. If an CBM Analyst does not understand how the ultrasonic waves interact with different mediums or how they travel through said mediums they will struggle to acquire the proper signal, which can lead to misinterpretation of the sound waves and data collected.

It is just as important that the CBM Analyst have the physical capabilities to carry out the use of the equipment. This means they must be able to carry, operate, move around tight spaces, stand for hours at a time, can hear, can see, and the comprehensive skill to analyzing all the information gathered. A great classroom test is to ask everyone to hold up their phones for everyone to see. If someone holds up a flip style phone, then they might not be comfortable using modern technology. This does not eliminate them from being able to perform the inspection it just means they may require more hands-on learning rather than lectured material or manuals.

The CBM Analyst must also have the knowledge of the safety hazards they should be concerned with while testing. Some examples are; Fork trucks, atmospheric conditions, electrical hazards, steam leaks, moving equipment, limited visibility, falls, slipping, foot holds, three points of contact, fire hazards, temperatures, and confined spaces to name a few.

Knowledge of the asset being tested is another key component to a successful ultrasound program. The CBM Analyst must know what type of motor they are testing so they know if it is a VFD controlled motor that would show stray voltage at the frequency its being driven at. This would also allow the CBM Analyst to pick out fault frequencies with the inner, or outer race, the bearing themselves or if there is a cage fault. On electrical systems, they would need to know the voltage of the asset being tested.

CBM Analyst s must also know the techniques for properly testing so they can isolate anomalies from background noise. These techniques insure the CBM Analyst is actually locating the anomaly and not Antagonistic ultrasound. Over time as the CBM Analyst uses their equipment and software their experience will broaden, and they will feel more comfortable utilizing the equipment and software.

Applications for Ultrasound

With so many applications that Ultrasound can be utilized for and its ease of use, it has quickly become a mainstay of many programs throughout the World. It is also a great complimentary technology that can be used for confirmation of an issue, trouble shooting, or a sorting tool for other technologies to be deployed. The ability to trend, compare, benchmark, and analyze like equipment allows for expedited test results. With so many companies now using ultrasound as one of its Pd/M tools the science has improved greatly since it was first used for trouble shooting or pass-fail test results.

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Who Can Use Ultrasound?

No matter the type of facility the equipment is used in, the applications are the same. Even the equipment in different type of industry are similar it is just what they are used for that's different. For ultrasound testing we do not care if the electrical equipment is powering a conveyor or a mixer. We just need the voltage its driven at. In the case of motors RPM and number of bearings will help us confirm fault frequencies. In pressurized systems, we can use the decibels to determine annual cost avoidance of each induvial leak. So, it does matter if it's a Wastewater Treatment, Warehouse, Mine, or a Power Generation Station as Ultrasound is only looking for ultrasound anomalies and not the type of industry that's using it.

ASU CAT 2 Module 2-1 Principles Ultrasound

Introduction

Sound is one of the human senses that allows us to experience the World around us in sound waves. All of these sounds are translated by our ear and interpreted by are brain as something pleasant or painful. This excitation of the human hearing experience allows us to perceive the sound as louder, quieter, higher or lower pitch and even different tones. Sound is often referred to as an acoustics emission.

The term acoustics applies to the mechanical waves in gases, liquids and solids. These mechanical waves include vibration, sound, ultrasound and infrasound. So, if we break down sound and look at what it actually is, it is an oscillation in pressure waves traveling through a medium that displaces atoms and causes them to vibrate and transfer the energy into atoms around them.

By understanding how we experience sound it will helps us to understand why we need ultrasound detection equipment to listen in the ultrasonic range for fault detection. This realm of sound is one we cannot experience ourselves so we must use a device that can heterodyne the signal to give us the ability to listen to this frequency range. Just like infrared can see what we cannot see, or vibration can feel what we cannot feel, ultrasound lets us hear what we cannot hear.

As the knowledge of ultrasound has expanded over the last 4 decades it has only been in the last 10 years that the detection and determination of harmonic occurrences has taken a huge leap forward. Understanding the principles of ultrasound is paramount if a CBM program is going to be able to do more than just determine when to lube a bearing or how much a leak is costing the site.

What Can Produce Ultrasound

Many things will produce ultrasound and it's the job of the CBM Analyst to identify what ultrasonic emissions are occurring in the area they will be working prior to collecting data and sound waves. The identification of these antagonistic ultrasound anomalies will help the CBM Analyst to insure they can properly isolate themselves from the source of the antagonistic ultrasound so, they can continue on with little to no interference from these anomalies.

Ultrasound can be produced by frictional occurrences that are happening inside of an asset or occurring in atmosphere. Interior frictional occurrences can happen in motor, gear boxes, bearing housings, pistons, hydraulic rams, and fan housings. Exterior Frictional occurrences can happen on conveyor rolls, belts, belt splices, finger guards, chains, and sprockets to name a few.

Ultrasound can also be produced by turbulent occurrences that just like frictional occurrences can happen both internally and exteriorly. Internal occurrences such as vacuum leaks, valve leaks of all types of material, steam trap discharges, pump cavitation, and back pressure issues to name a few.

There are two other categories we need to understand as well. These categories fall under the antagonistic ultrasound anomalies categories. The first of these two antagonistic categories are man-made antagonistic ultrasound. The source of these man-made

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antagonistic ultrasound can be generated by ultrasonic motion detectors, ultrasonic pest repellents, bad ballast, control panel displays, and heat syncs to name a few things that will produce antagonistic ultrasound. The second category of antagonistic ultrasound is natural generated ultrasound. These happen often in nature from bats, to blades of grass rubbing together in a breeze, snowflakes, raindrops impacting on the ground, bug noises which sound electrical to even mice chirping.

It is critical that the CBM Analyst understand all the things that can produce ultrasound around them any time they are using ultrasound. This course will teach the CBM Analyst how to properly use their equipment, its features, accessories, inspection techniques to minimize, isolate or eliminate these antagonistic ultrasound anomalies.

Friction

Friction can happen in many ways, from two surfaces sliding against each other, to an object moving through a gas or a liquid. Friction produced ultrasound can be picked up using a contact module or and non-contact module depending on the medium the sound is traveling through. In the case of a bearing we would encounter a sound very similar to that of static, white noises, rushing stream or a smooth sound when listen to it. Lack of lubrication and incipient stages of bearing wear will produce a slight ticking or popping sound as the area in question makes contact with the inner and outer race.

This can change if the bearing becomes deformed, is improperly lubricated, improperly loaded or improperly aligned causing the bearing to slide instead of rolling as designed. This will produce a very distinct scrapping sound when using an ultrasound device determine the life span of the bearing. Not only can the user use decibel levels to set action levels but by recording the sound wave and analyzing it using sound analysis software. This can show distinct harmonic patterns that can determine the exact harmonic occurrence either in Hertz or in Seconds. The CBM Analyst can then calculate the ball pass frequency, cage fault, inner race, outer race, stray voltage and loose connection in the motor junction box.

In the case of friction traveling in atmosphere the CBM Analyst will need to know that this can be caused by such things as chains on a sprocket, belt rub on conveyor, finger guards rubbing on conveyor rollers, mis-tracked belts, loose belts, bad couplings, debris in the roller, or bad rollers on a conveyor. These airborne events can actually be more effectively detected using airborne modules to detect them from a distance. This is especially beneficial if the area is guarded or long runs of conveyance where a contact test would take too long collect the data on.

Turbulence

Turbulence is an unpredictable fluctuation in a fluid or gas as a higher pressure overtakes a lower pressure. This fluctuation causes a source of ultrasound which the CBM Analyst can use to look for the source of a leak. These leaks can be found using both a non-contact module and contact module. The use of the non-contact module has traditionally been used for both pressure and vacuum leaks however the lesser known leak detection is the use of a contact module to detect the turbulence inside of a vessel that is under vacuum.

Since these sources of turbulence make this a valuable tool for the detection of both pressure and vacuum leaks. It also allows the CBM Analyst to not only test for air leaks but, any gas that is under pressure or vacuum. However, the CBM Analyst will need to use caution when testing for explosive gases that are leaking, as many of these units are not intrinsically rated and as such should not be used in these environments.

Impacting

The effects of impacting can be detected using both a contact and non-contact module. Often in the case of contact testing the CBM Analyst may hear the sound of a pipe effected by water hammer striking another structure from several hundred feet away. This could even occur when the CBM Analyst is using the non-contact module. A metal pipe would have a distinct ringing sound very similar to that of a hammer striking the pipe.

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Water Hammer may also be a source of impacting that the CBM Analyst will detect when using an ultrasound device. This is generated not only by the effects of the water hammer in the piping but also as the pipe shakes and rattles in the brackets or walls that it is affixed too.

Bats & Wasps

The CBM Analyst may even find themselves encountering noises that may sound similar to that of an electrical event. This is the case when it comes to the sound of a Wasp. On several occasions I have been glad to have an arc flash suit on when opening cabinets due to the fact there were wasp nest inside of the asset. Bats can even be heard when using ultrasound at night. The distinct ticking sound of their sonar location can be heard very clearly at 40 kHz.

Man-Made

Even man-made devices can produce antagonistic ultrasound that the CBM Analyst will need to consider, isolate or ignore when using ultrasound devices. In one case a tugboat crew using an ultrasound device for lubrication was claiming to hear voices while using the ultrasound device. After extensive investigation into all sorts of frequency ranges used in the World today, it was shown that nothing should be affecting them in this way. A short time later while teaching a group of students at a plant in Michigan City I experienced the very same event. As I was listening to a bearing, a voice could suddenly be heard. As I turned around to check out where it was coming from, I noticed a PA speaker with a rag stuck in right above me. So, after looking into the Realistic PA Speaker it was discovered that they actually broadcast into the high frequency range beyond 50 kHz.

At another location a student I was working with in his office was complaining about his new flat panel monitor giving him a headache. He thought maybe it was his eyes adjusting to the new screen until we broke out his ultrasound device and we could hear a strange sound coming from the back side of the monitor reaching up to 35 decibels. Control panels also generally produce an antagonistic ultrasound as well as heard in the 3rd. sound wave from the left but perhaps the worst offenders are ultrasonic pest repellents or motion detectors.

In May of 2016 I received a panicked call from a family member that a bat was in their house. I knew from my research that I could locate a bat using an ultrasound device, so I headed up there to find the bat. Once I walked into the house, I turned on my ultrasound device and was instantly bombarded with 99 decibels of a pulsing sound (4th Sound wave). As I swept around the living, I noticed that the sound was originating from behind a nightstand. As I looked under the nightstand, I noticed a Black & Decker device plugged into the wall with a flashing red light that pulsed with the same frequency as the pulse I was hearing with the ultrasound device.

After unplugging and continuing on to search for the bat I determined the bat had left out the window it flew in through. Prior to the device being unplugged the family members dog wouldn't stay in the living room and the family members fainting and dizzy spells immediately stopped. There is a lot of evidence that high frequency sound can have a negative impact on not only animals but humans too. Maybe the US Embassy in Cuba wasn't an attack on the personnel but rather high frequency sound pollution. Since these sound waves still produce a pressure wave the ear would still be affected but the body can't hear the sound so no one would know that they are being affected.

Acoustic Impedance; Propagation

There is one factor that can affect how much sound is heard in the human hearing range or in ultrasound range? Its Acoustic Impedance! Acoustic Impedance is the measurement of how much a medium will affect the sound energy as it travels through said medium.

There are 6 main ways that the sound wave will be impeded, and they are Transmission, Reflection, Refraction, Diffraction, Absorption and Scattering. Each of these will affect how much sound energy the Ultrasound can and will detect when using the

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different modules and it is a key part of understanding of the principles of ultrasound detection.

Acoustic Impedance; Transmission

Sound waves exist as variations of pressure in a medium such as water. They are created by the vibration of an object, which causes the air surrounding it to vibrate. Sound waves travel through air in much the same way as they do water. In fact, since water waves are easy to see and understand, they are often used as an analogy to illustrate how sound waves behave.

Acoustic Impedance; Angle of Incidence

The **Angle of Incidence** is the angle between an incident wave interfacing on the surface of a secondary medium and the line perpendicular to the secondary surface at the point of incidence, called the normal. The ray incident can be formed by any type of X-ray, optical, microwave, acoustic etc. The Angle of Incidence at which sound initially interacts with secondary medium and is reflected in the incipient medium is known as the glancing angle. This also creates what is known as Angle of Reflection and Angle of Refraction that can occur during the Mode Conversion.

Calculating the Angle of Reflection with respect to an airborne ultrasonic detection is not necessary. It can confuse the CBM Analyst however if it is not taken into account when tracking down the source of the emission. This will be explained more in-depth in the next slide.

Sound waves exist as variations of pressure in a medium such as water. They are created by the vibration of an object, which causes the air surrounding it to vibrate. Sound waves travel through air in much the same way as they do water. In fact, since waves in water are easy to see and understand, they are often used as an analogy to illustrate how sound waves behave.

Acoustic Impedance; Mode Conversion Incident Wave

Mode conversion takes place when a sound wave interfaces with a different medium other than its incipient medium. These differences in mediums causes what is known as acoustic impedances which is defined in Merriam-Webster Dictionary as the ratio of pressure to volume displacement at a given surface in a sound-transmitting medium (https://www.merriam-webster.com/dictionary/impedance). As the energy travels through it incipient medium it is known as an Incident Wave. When it reacts with the second medium the Incident Wave will change its characteristic through the process known as Mode Conversion. This is caused by the difference between the two mediums elasticity and density. These slight differences is what allows for Mode Conversion to occur.

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Acoustic Impedance; Mode Conversion Shear Wave

Another one of these Mechanical Waves is known as a Transverse Wave. The Incident Wave changes from a longitudinal wave to a Shear Wave. This wave also has an oscillatory nature to it, but it travels in a perpendicular direction to the Incident Waves motion. This occurs at the interface with the secondary medium.

Acoustic Impedance; Mode Conversion Surface Wave

The Mode Conversion of the Incident Wave will also produce a Rayleigh Wave which is otherwise know a Surface Wave. These waves are a combination of the Incident Wave and the Shear Wave it produces. This wave travels along the interface of the incipient medium & the secondary medium at a perpendicular angle to the impact of the incident wave.

Acoustic Impedance; Mode Conversion Plate Wave

The Mode Conversion in addition to the above-mentioned waves also produces a Lamb Wave better known as a Plate Wave. This type of wave can occur in three mediums if the material is thinner than that of the second medium. This wave is more useful for those doing Non-Destructive Testing for flaw detection. These waves are very indistinguishable from the shear or surface waves.

Acoustic Impedance; Mode Conversion Refracted Wave

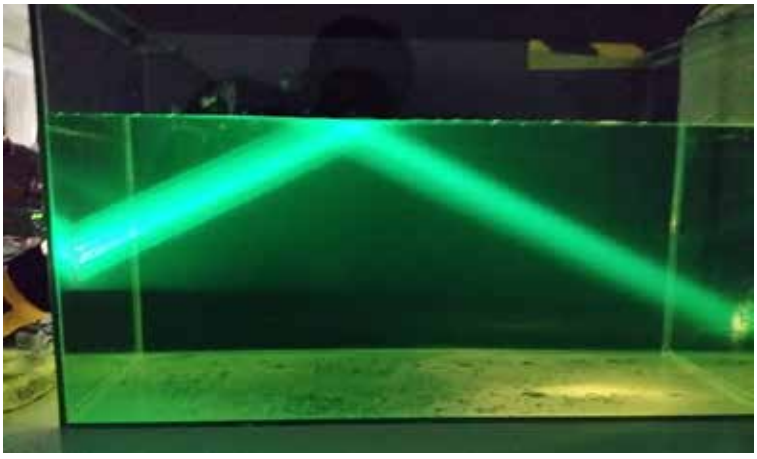
A Refracted Wave is what happens to a sound wave as it passes through the second medium and changes it path and exits into the third medium. The second medium can either speed up or slow down the sound wave as it passes through the second medium. This is due to the elasticity and density of the second medium.

Acoustic Impedance; Mode Conversion Reflected Wave

The first Mode Conversion to discuss is the Reflected Wave. This is as it sounds, a reflection of the Incident Wave. Both waves are categorized as a Longitudinal Wave as they are experienced in the incipient medium. A Longitudinal Wave creates a displacement of particles as it travels parallelly to the waves path. This energy can either travel in the form of an oscillatory motion or via a series of Compressions & Rarefactions. This is just one category of Mechanical Waves that sound can produce.

Acoustic Impedance; Reflection

When a sound wave is produced, it will travel through its incipient medium until it encounters the secondary medium and depending on its characteristics a couple of things can occur. In the case of a smooth surfaces the sound wave will reflect off the secondary medium with little to no acoustic impedance. So, the reflected sound wave can be mistaken for the source of the emission if the CBM Analyst does not know the proper techniques to isolate the source of the emission.



Acoustic Impedance; Scattering

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When sound waves encounter a rough surface or varying composition, they can be scattered in several different directions with different intensity causing the sound wave to appear to come from several different directions since they are deviating from each other's path of travel.

Electromagnetic waves are one of the best-known energy waves that can be affected by scattering. Scattering of sound and light waves is important to understand when using ultrasound devices. Since sound waves are affected by scattering, we could one day see the application of the Brillouin Scattering Principle.

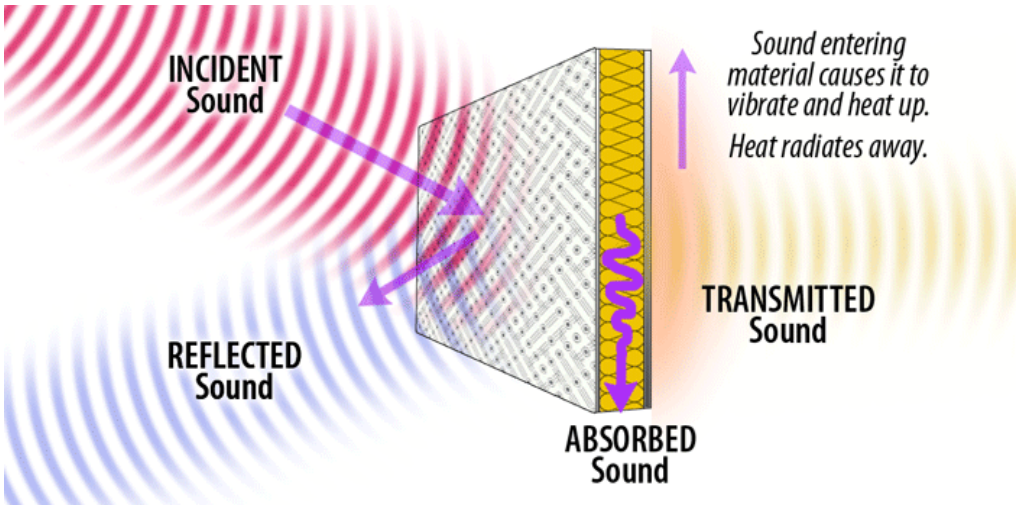
The Brillouin Scattering Principle was named after Léon Brillouin was a French Physicist who specialized in quantum mechanics, radio wave propagation in the atmosphere and solid state physics. His work with radio wave propagation lead him to calculate the refracted index of light waves in different mediums. So, if we apply this principle to ultrasound, we could eventually one day see a table similar to that of the Emissivity Table used by Infrared Analyst.

Acoustic Impedance; Diffraction

According to the Huygens–Fresnel principle diffraction refers to various phenomena that occur when a wave encounters an obstacle or a slit. The sound waves ability to bend around the corners of an impediment or opening in the region of geometrical shadowing from the hindrance. In classical physics, the diffraction phenomenon is described as the interference of waves. The features of the surface will cause the acoustic impedance of the reflected wave as it sends it in multiple directions. This accounts for the decrease in decibels at the Angle of Incidence. So, this causes only part of the sound energy to return to the transducer. The rougher the surface the more the sound energy will be Diffraction.

Acoustic Impedance; Absorption

Acoustic Absorption refers to the interaction of the incident wave with the secondary medium and its abilities to take in sound energy, as opposed to reflection or diffraction of the energy. Part of the absorbed energy is said to be transformed into heat and the other part is transmitted through the absorbing medium.
It is also said that the energy is lost more than it is absorbed.



Acoustic Attenuation of Sound

In physics, Acoustic Attenuation is known as the gradual loss of flux intensity through a medium. For instance, water and air attenuates both light and sound at different rates of attenuation. The use of hearing protection helps to reduce this flux from effecting the ears. This is called acoustic attenuation and it can be measured in decibels (dBs). This is also seen in the

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telecommunications and electrical engineering as the acoustic attenuation directly effects the propagation of waves and signals in electrical circuits and in air.

Inverse Distance Law of Sound

The other major factor that can affect the amount of sound heard besides, the mediums density and temperature is the Inverse Distance Law of Sound. Inverse Distance Law of Sound can be applied when using airborne modules form a distance and then the CBM Analyst may notice a difference in the decibels, they are receiving but other factors will come into play like humidity and wind speed.

If we look at the effect of Inverse Distance Law of Sound in the real world of the human hearing experience, we would find that the further away from the sound source we get the quieter the sound will get. If we think of this sound energy as a pebble being thrown into a still pond, we would see that at the crest of the wave would be taller closest to the initial impact and as it travels outward, we would see the circumferences of the wave expanding and cover more surface area as well as the crests of the waves getting smaller. If we use this analogy to think about the propagation of sound through a medium it will help us to understand the effects of the Inverse Distance Law of Sound.

When talking about the Inverse Distance Law of Sound we must assume that the sound pressure is exactly the same in a controlled environment free of any obstruction or reflective material. This summation can be achieved a little more effectively than an environment that has obstructions and reflective surfaces that will attenuate or intensify the sound pressure.

If we consider the sound source to produce a spherical wave front emitting out from it as it travels away from the source, it loses 6 decibels every time the distance is doubled. If we take a reading at 1 foot (.3o48 m) from the source of a leak and double our distance to 2 feet (.6096 m) the CBM Analyst would notice a 6-decibel depreciation.

The CBM Analyst would also notice a larger area the sound could be detected from the further distance. That's because at the distance of 1 foot (.3o48 m) the energy is only detectable 1 square foot area when the input amplitude is reduced on the unit.

Inverse Distance Law of Sound Calculator

Use this Calculator to determine your expected decibel loss after your distance of inspection away from the sound source.

Distance from sound source	1 foot (.3o48 m)	2 feet (.6096 m)	4 feet (1.2192 m)	8 feet (2.4384 m)	16 feet (4.8768 m)	32 feet (9.7536 m)	64 feet (19.5072 m)	128 feet (39.0144 m)	256 feet (78.0288 m)
Sound Pressure (-decibels)	78	72	66	60	54	48	42	36	30
Number of times doubled	1 X	2 X	3 X	4 X	5 X	6 X	7 X	8 X	9 X

Use this Calculator to determine your expected decibel gain from your distance of inspection to the sound source.

Distance from sound source	1 foot (.3o48 m)	2 feet (.6096 m)	4 feet (1.2192 m)	8 feet (2.4384 m)	16 feet (4.8768 m)	32 feet (9.7536 m)	64 feet (19.5072 m)	128 feet (39.0144 m)	256 feet (78.0288 m)
Sound Pressure (+decibels)	88	82	76	70	64	58	52	34	28
Number of times doubled	1 X	2 X	3 X	4 X	5 X	6 X	7 X	8 X	9 X

As we double our distance to 2 feet (.6096 m) we have not only doubled the distance, but the detectable area is also doubled. If we double the distance from 2 feet (.6096 m) to 4 feet (1.2192 m) not only will we lose another 6 decibels but the detectable are would now be three times large. Doubling up the distance from 4 feet (1.2192 m) to 8 feet (2.4384) again we lose 6 decibels but now the detectable area is 4 times large than from 1 foot away.

This process will continue on till the energy from the sound source attenuates and dissipates all of its energy.

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Inverse Distance Law of Sound Calculator will allow you to see how many decibels drop off or increase as you change the distance from the point of source. It will even allow for the calculation of the acoustic. Check out this website to see another calculator.
http://hyperphysics.phy-astr.gsu.edu/hbase/Acoustic/invsqs.html#c3

Acoustic Impedance; Density's Effect

Airborne/Structure Borne Ultrasonic testing is based on how materials allow for time-varying deformations or vibrations. All materials are formed from atoms, which may be forced into vibrational motion about their equilibrium positions. There are many waves with different patterns of travel through these mediums. As the energy travels through a medium it experiences absorption and reemission of the wave energy by the atoms of the material. When the electromagnetic wave impinges upon the atoms in the medium, the atoms absorb the energy of that wave. This causes the electrons in the atoms to vibrate in what is known as a Vibrational Motion. The absorption of this energy by the atoms which creates a new electromagnetic wave that is emitted with the same frequency as the first electromagnetic wave. This process keeps repeating till the wave loses it energy or encounters a new medium.

The actual speed of an electromagnetic wave traveling through a medium is directly proportional to the temperature, elasticity, and density of that medium. Different mediums will cause a different amount of delay due to the absorption and reemission properties of the medium they are traveling in. So, the warmer & denser the material, the closer together the atoms are and the faster the sound will travel through that medium. In the example of outer space, the medium is a vacuum and the atoms are spread so far apart that sound wave motion cannot occur.

Most of the time these are irrelevant (Background or Antagonistic Ultrasound) when preforming ultrasonic testing. Ultrasound is focused on listening for the mechanical waves that are created by the many atoms that move in unison. When a medium is not stressed by tension or compression exceeding its elastic limit, the particles spring back to their original position and this is known as an elastic oscillation. It is these elastic properties of the particles in the medium, combined with their inertia, that allows for the oscillation in of the medium.

Acoustic Impedance; Temperature's Effect

There are many more formulas and as an ultrasound CBM Analyst we need to know these theories behind what we are doing but we will never need to calculate these values in the field. Since ultrasound CBM Analysts are usually testing by making contact or getting within inches of most anomalies this will have little to no direct effect on their readings. The Inverse Distance Law can be applied when using airborne modules form a distance and then the CBM Analyst may notice a difference in the decibels, they are receiving but other factors will come into play like humidity and wind speed. The other major factor that can affect the amount of sound heard is temperature.

Sound Velocities of Common Materials			
Material	Velocity (m/s)	Material	Velocity (m/s)
Aluminum	6320	Acetate Resin	2670
Zinc	4170	Phosphor Bronze	35830
Silver	3600	Turpentine	4430
Gold	3240	Glass	5440
Tin	3230	Incoloy Alloy	5720
Iron/Steel	5900	Magnesium	6310
Brass	4640	Monel Alloy	6020
Copper	4700	Nickel	5630
SUS	5790	Steel 4330 (mild)	5850
Acrylic Resin	2730	Steel 330	5660
Water (20°C)	1480	Titanium	6070
Glycerin	1920	Zirconium	4650
Soluble Glass	2350	Nylon	2620

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The effects of Temperature on acoustic impedance can have a direct effect on how the sound wave will travel through a medium but, with the distance and ultrasound CBM Analyst is testing at this will really only affect the detection of ultrasound anomalies from a distance using a parabolic dish. If we look at this chart, we can see at 95° f (35° c) the speed of sound through air is 351.88 m/s and the density of air is 1.1455 kg/m3 (kilogram per cubic decimeter). So, with the air being less dense sound will travel faster and lose less energy that if the sound wave was traveling through air at -13° f (-25° c) where the speed of sound would be 315.77 and density of 1.4224 kg/m3.

Temperature T °f (°C)	Speed of sound c (m/s)	Density of air ρ (kg/m3)	Characteristic specific acoustic impedance z0 (Pa·s/m)
95 (35)	351.88	1.1455	403.2
86 (30)	349.02	1.1644	406.5
77 (25)	346.13	1.1839	409.4
68 (20)	343.21	1.2041	413.3
59 (15)	340.27	1.2250	416.9
50 (10)	337.31	1.2466	420.5
41 (5)	334.32	1.2690	424.3
32 (0)	331.30	1.2922	428.0
23 (−5)	328.25	1.3163	432.1
14 (−10)	325.18	1.3413	436.1
5 (−15)	322.07	1.3673	440.3
-4 (−20)	318.94	1.3943	444.6
-13 (−25)	315.77	1.4224	449.1

Acoustic Impedance; Formula's

Acoustic Impedance is measured in International Systems of Units which measures this affect using pascal second per cubic meter (Pa·s/m3) or the rayl per square meter (rayl/m2). This unique way of measuring the mediums effect on the sound energy traveling through it is very similar in properties to the Electrical Impedance which measure the opposition of a medium to an electrical flow as an electrical voltage is applied to it. The formula for calculating Acoustic Impedance uses the relationship between the acoustic pressure wave in the medium and then takes the acoustic volume flow rate through the surface as it strikes perpendicularly to the secondary medium.

For a linear time-invariant system, the relationship between the acoustic pressure applied to the system and the resulting acoustic volume flow rate through a surface perpendicular to the direction of that pressure at its point of application is given by;

$p(t) = [R * Q](t)$, or equivalently by $Q(t) = [G * p](t)$,

- p is the acoustic pressure;
- Q is the acoustic volume flow rate;
- *is the **convolution** operator;
- R is the **acoustic resistance in the time domain;**
- G = R −1 is the **acoustic conductance in the time domain** (R −1 is the convolution inverse of R).

The Fourier (Named for mathematician and physicist Joseph Fourier) and Laplace transforms (Named for the Astronomer Pierre-Simon Laplace) are both very similar in their abilities to calculate the effects of acoustic impedance of different mediums on the sound wave pressure as it travels through that medium. In the realm of Airborne and Structure Borne Detection this can be

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measured by using decibels to show the intensity of the sound wave energy as it travels these different mediums. This has a direct correlation on those using pulse echo flaw detection devices in the NDT realm. Fourier also was accredited for coming up with the means to look at frequency vs amplitude of electromagnetic pressures known today as a Fast Fourier Transform better known an FFT or Frequency Spectrum Analysis.

Laplace Transform $$Z(s) \stackrel{\text{def}}{=} \mathcal{L}[R](s) = \frac{\mathcal{L}[p](s)}{\mathcal{L}[Q](s)},$$

Fourier Transform $$Z(\omega) \stackrel{\text{def}}{=} \mathcal{F}[R](\omega) = \frac{\mathcal{F}[p](\omega)}{\mathcal{F}[Q](\omega)},$$

Acoustic impedance, denoted Z, is the Laplace transform, or the Fourier transform, or the analytic representation of time domain acoustic resistance.

Analytic Representation $$Z(t) \stackrel{\text{def}}{=} R_{\mathrm{a}}(t) = \frac{1}{2}\left[p_{\mathrm{a}} * \left(Q^{-1}\right)_{\mathrm{a}}\right](t),$$

- $\mathcal{L}$ is the Laplace transform operator;
- $\mathcal{F}$ is the Fourier transform operator;
- subscript “a” is the analytic representation operator;
- Q^{-1} is the convolution inverse of Q.

The Analytic Representation encompasses the use of the Hilbert Transform using the negative components of the Fourier Transform of a real valued function and are considered to be redundant due to their Hermitian Function since it contains complex conjugate values.

Decibels

The **decibel** (symbol: dB) is a unit used to express the relative intensity of a sound on a scale from 0 dB (Least perceivable) to 130 dB (Pain Level). One of these values is often a standard reference value, in which case the decibel is used to express the level of the other value relative to this reference. There are two different scales used when expressing a ratio in decibels depending on the nature of the quantities: field quantity ratio or power quantity ratio. (Field quantity ratio is also referred to as root-power ratio or amplitude ratio.) When expressing power quantities, the number of decibels is ten times the logarithm to base 10 of the ratios of two power quantities. That is, a change in power by a factor of 10 corresponds to a 10-dB change in level. When expressing field quantities, a change in amplitude by a factor of 10 corresponds to a 20-dB change in level. The extra factor of two is due to the logarithm of the quadratic relationship between power and amplitude. The decibel scales differ so that direct comparisons can be made between related power and field quantities when they are expressed in decibels.

The definition of the decibel is based on the measurement of power in the telephony of the early 20th century in the Bell System in the United States. One decibel is one tenth (Deci-) of one bel, named in honor of Alexander Graham Bell; however, the bel is seldom used. Today, the decibel is used for a wide variety of measurements in science and engineering, most prominently in acoustics, electronics, and control theory. In electronics, the gains of amplifiers, attenuation of signals, and signal-to-noise ratios are often expressed in decibels.

In the International System of Quantities, the decibel is defined as a unit of measurement for quantities of type level or level difference, which are defined as the logarithm of the ratio of power- or field-type quantities.

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Merriam-Webster defines Decibel;

1. a: a unit for expressing the ratio of two amounts of electric or acoustic signal power equal to 10 times the common logarithm of this ratio.
   b: a unit for expressing the ratio of the magnitudes of two electric voltages or currents or analogous acoustic quantities equal to 20 times the common logarithm of the voltage or current ratio.
2. a unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average pain level.
3. degree of loudness; also: extremely loud sound —usually used in plural.

Since the human hearing experience is sensitive enough to hear all sounds, greatest noise levels are gauged more heavily into some measurements using frequency weighting. This is based of Steven's Power Law which states the following;

Decibels

Source: http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/db.html#c1

The sound intensity I may be expressed in decibels above the standard threshold of hearing I_0 .

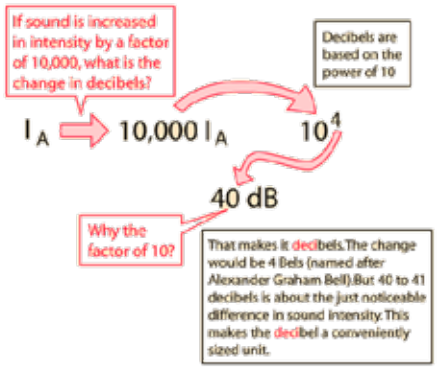
The expression $I(dB) = 10 \log_{10}\left[\frac{I}{I_0}\right]$ Intensity in decibels is

Stevens's Power Law is a proposed relationship between the magnitude of a physical stimulus and its perceived intensity or strength. It is often considered to supersede the Weber–Fechner law on the basis that it describes a wider range of sensations, although critics argue that the validity of the law is contingent on the virtue of approaches to the measurement of perceived intensity that are employed in relevant experiments.

In addition, a distinction has been made between local psychophysics, where stimuli are discriminated only with a certain probability, and global psychophysics, where the stimuli would be discriminated correctly with near certainty (Luce & Krumhansl, 1988).

The Weber–Fechner law and methods described by L. L. Thurstone are generally applied in local psychophysics, whereas Stevens's methods are usually applied in global psychophysics.

$$I(dB) = 10 \log_{10}\left[\frac{10{,}000 I_0}{I_0}\right] = 10 \cdot 4dB = 40dB$$



The logarithm involved is just the power of ten of the sound intensities expressed as a multiple of the threshold of hearing intensity. Example: If I= 10,000 times the threshold, then the ratio of the intensity to the threshold intensity is 104, the power of ten

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is 4, and the intensity is 40 dB:

Multiplying the logarithm by a factor of 10 makes it decibels instead of Bels, and is included because about 1 decibel is the just noticeable difference in sound intensity for the normal human ear.

Decibels provide a relative measure of sound intensity. The unit is based on powers of 10 to give a manageable range of numbers to encompass the wide range of the human hearing response, from the standard threshold of hearing at 1000 Hz to the threshold of pain at some ten trillion times that intensity.

Another consideration which prompts the use of powers of 10 for sound measurement is the rule of thumb for loudness: it takes about 10 times the intensity for a sound to appear twice as loud.

The amplitude of a sound wave of a given frequency and wavelength is a measure of its intensity. In other words, intensity is the amount or degree of strength of a sound in each area or volume. Sound can be gauged in decibels which is most commonly used in acoustics as a unit to measure the intensity of the pressure wave.
The human hearing experience is said to have a large dynamic range.

ASU CAT 2 Module 2-2 General Equipment Knowledge

Heterodyning

Heterodyning is the process of combining two or more frequencies to create a new and different one. It was first shown in 1901 by Reginald Aubrey Fessenden. This process allows the ultrasonic unit to translate a high frequency sound wave to a low frequency sound wave that can be heard in the human hearing range. This is done by shifting one frequency range into another new one. It also involves the modulation and demodulation of the signal. The process begins with the pressure wave from the raw signal interacting on the piezoelectric crystals in the transducer. That electrical signal is then oscillated splitting the high frequency from the low frequency. Its then amplified and tuned to a specific frequency range which oscillates the signal again, and then it is amplified one more time thus converting it into a translation of high frequency to an audible signal.

Reginald Aubrey Fessenden (October 6, 1866 – July 22, 1932) was a Canadian-born inventor, who did much of his work in the United States and claimed U.S. citizenship through his American-born father. During his life, he received hundreds of patents in various fields, most notably ones related to radio and sonar.

Fessenden is best known for his pioneering work developing radio technology, including the foundations of amplitude modulation (AM) radio. His achievements included the first transmission of speech by radio (1900), and the first two-way radiotelegraphic communication across the Atlantic Ocean (1906). In 1932 he reported that, in late 1906, he also made the first radio broadcast of entertainment and music, although a lack of verifiable details has led to some doubts about this claim.

There are many different types of Predictive Maintenance and Condition Based Maintenance Test Equipment on the market today. Some are easier to pick up and use right away like a spot radiometer, and others like vibration analysis are very accurate at picking the slightest of vibration that can indicate a fault, but it takes a lot of studying and practice to become proficient at it. Ultrasound is right in the middle when it comes the time it takes to become proficient at its use and understanding what you are hearing. From the use of Ultrasound to pick up Partial Discharge to use it for analysis of the sound waves to determine the difference a tracking fault vs an arcing issue. These tools all have their specialty applications, but Ultrasound is one of the easiest to start using and learn how to analysis what is going on.

The Benefits of Ultrasound

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The biggest benefit to ultrasound testing equipment is its ability to do so many things. From electrical analysis of 480 transformers, MCC's, switchgear to testing transmission lines with a parabolic dish. It can even be used to test bearing for inner & outer race, ball pass, cage, and stray voltage issue in motors and VFD's. It has proven to be a great condition analysis tool when it comes to valve leaks and steam trap testing as well. It is also being used for air leak surveys for annual cost avoidance to reduce energy consumption and reduce the sites carbon footprint.

This make Ultrasound one of the most versatile Pd/M & CBM testing devices on the market and it works hand in hand with other technologies to help find, confirm, or deny the existence of a fault. It can pick up the earliest indications of faults in equipment and eliminates background noise through is ability to heterodyne the signal it receives allowing the user to isolate the source of the emission quickly and effectively.

Knowledge is the Key

The key to any testing is the CBM Analyst's knowledge and understanding of both the equipment they are using and the assets they are testing. Without proper exposure to field training the CBM Analyst will not be able to experience the real World of NDT testing that is difficult to experience in the classroom or manual. If the CBM Analyst only understands how to turn a unit on but, not operate it, then it will be frustrating for them to try and interpret what the sound coming from the asset actual is or why it is happening.

It is also important to know what that device can be used for and what applications it can test as well. It is just as import to know what frequencies work best as well and what modules to use. The CBM Analyst must also know where the best sound will be picked up when making contact and the angle of approach when doing airborne scans.

Finding The Correct Tool for The Job!

When considering doing an ultrasound survey it is important to know the difference between the responses of the module and what frequencies they work best at. Not all units are set up for the ability to change frequency and this limits their ability to pick up frequency that are near their peak response. Also, specialty modules like the Flex Probe or Parabolic Dish can be used for application that may be hard to reach.

Sensitivity Validation vs Calibration

The CBM Analyst must perform a Sensitivity Validation prior to and at the conclusion of each usage to ensure the equipment wasn't damaged during the testing. This activity must also be logged and documented should that site ever have a catastrophic failure due to an asset that was being tested by that unit. The following is the procedure used to perform a sensitivity validation on a Sonus XT. The same steps can be used for another type of ultrasound testing equipment.

ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories is the main ISO standard used by testing and calibration laboratories. In most countries, ISO/IEC 17025 is the standard for which most labs must hold accreditation in order to be deemed technically competent. In many cases, suppliers and regulatory authorities will not accept test or calibration results from a lab that is not accredited. Originally known as ISO/IEC Guide 25, ISO/IEC 17025 was initially issued by the International Organization for Standardization in 1999. There are many commonalities with the ISO 9000 standard, but ISO/IEC 17025 is more specific in requirements for competence and applies directly to those organizations that produce testing and calibration results and is based on somewhat more technical principles. Laboratories use ISO/IEC 17025 to implement a quality system aimed at improving their ability to consistently produce valid results. It is also the basis for accreditation from an accreditation body.

Ultrasound Sensitivity Validation Procedure

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The following procedure Illustrates how to perform a QA validation on of the Ultrasonic Testing Devices. This is different from the Calibration which is recommended annually on each unit. The Sensitivity Validation Procedure is a method through which the user can ensure that the Ultrasonic Unit, Modules and Headphones are in proper working order. Use the Sensitivity Validation Log to enter the readings as this will ensure that the user can quickly identify a failing unit or module. This procedure can be used to check the validity of Ultrasonic Units between Calibrations and in no means, is it to replace the recommended Calibration of any Ultrasonic Unit. A drop-in decibel of 1-5 dB's is usually related to Tone Generators not being fully charged. A drop between 6-10 dB's can usually be attributed to equipment damage. The user will be able to determine this through the following steps:

- If only one module shows a decrease, then it is the module that will need to be repaired.
- If all modules show a decrease, then it's the Ultrasonic Unit itself that's in error.

The Sensitivity Validation procedure meets the intent of ISO 17025 & ASTM Standard E 1002-11 and should be performed before each use. The following items will be required to perform the Sensitivity Validation Procedure.

Equipment List:

1. Ultrasonic Unit
2. Headphones
3. Tone Generator
4. Contact Module
5. Airborne Module
6. Parabolic Dish
7. Flex Probe

Procedural Steps:

1. To begin, clear off a spot on a table or desk to perform the Sensitivity Validation Process

2. Always turn on your Tone Generator to the Highest Setting when preforming a Sensitivity Validation. Place the TG on its back side with the light facing up.

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3. Plug in the Headphones and place them on the table and keep them plugged in the entire time. This will verify the headphones are in working order. You do not need to wear the headphones during this process.

4. Power up the Ultrasonic Unit and ensure the Light and Max Reading are working.

5. Place the Contact Module in the front of the unit and touch it to the Sensitivity Validation Test Point and let the weight of the unit rest there with little movement.

6. Us the Max dB Value and Log that dB's, and the Volume Level on the Sensitivity Log Sheet.

7. Log the Ultrasonic Units Serial Number and Module serial number and results on the Log sheet.

Date	Unit Serial #	Contact Mod#	dB's	Volume #	Non-Contact Mod#	dB's	Volume
6/26/2017	10035	10035	53.2	-22	10035	52.7	-22
6/27/2017	10035	10035	53.2	-22	10035	52.7	-22
6/28/2017	10035	10035	53.2	-22	10035	52.7	-22

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Replace the Contact Module with the Parabolic Dish or Flex probe and repeat the steps above to complete the QA/Sensitivity Validation Procedure. You will need to position both of these module's one foot from the end of the module for this process.

Use this sheet to log your findings each day of class.

Date	Unit Serial #	AP50 SN#	dB's	Volume	CP52 SN#	dB's	Volume	PD55 SN#	dB's	Volume	L53 SN#	dB's	Volume	Performed by

Your Ultrasound Device

One of the most important things to remember about Pd/M & CBM Testing Equipment is to ensure that the Calibration is maintained annually. The CBM Analyst must also ensure that the unit stays charged and what type of batteries the units takes. Nickel Cadmium batteries will develop a memory and over time and lose their ability to maintain a charge. Lithium Ion batteries won't develop a memory, but some can malfunction and catch fire in the case if the spare batteries contacts are resting against something else metal. It is also important that the modules get put away in the proper place and are not just thrown into the case to get jostled around and possible damage the modules. Also, always try and ensure that you do not leave anything hanging out of the case before you go to close it.

How Transducers Work

Ultrasound transducer only receive exterior ultrasounds and not to transmit ultrasound. The process of receiving airborne or structure borne ultrasound involves the use of piezoelectric transducers. Piezoelectricity is defined as the property exhibited by some nonconducting crystals of becoming electrically polarized when mechanically strained or becoming mechanically strained when an electric field is applied

The piezoelectric effect was studied by Carl Linnaeus and Franz Aepinus in the mid-18th century. It was then researched by both René Just Haüy and Antoine César Becquerel where they noticed a relationship between mechanical stress and electric charge. However, their experiments by both proved inconclusive.

It wasn't until the 1880's that two brothers Pierre & Jacques Curie where able to demonstration the direct piezoelectric effect. They used their knowledge of pyroelectricity and understanding of the crystal structures to predict crystal behavior. They used several different crystals to take note of the effect of piezoelectricity on tourmaline, quartz, topaz, cane sugar, and Rochelle salt. They found that Quartz and Rochelle salt exhibited the most piezoelectricity.

It was not until Gabriel Lippman applied the converse piezoelectric effect in 1881 to the Curies research to account for the change in shape of these crystals and how they produced a voltage that the curries did not account for. The Curies set about to confirm the converse effect and were able to prove quantitatively the complete reversibility of electro-elasto-mechanical deformations in piezoelectric crystals. For the next several decades, piezoelectricity became a laboratory curiosity. Then 1910 there was publication of Woldemar Voigt's Lehrbuch der Kristallphysik (Textbook on Crystal Physics), which went into detail how 20 natural crystal classes were capable of piezoelectricity.

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Piezoelectricity is useful in many applications, such as the production and detection of sound, generation of high voltages, and electronic frequency generation. It is also used in everyday items, such as the ignition source for cigarette lighters, and push-start propane barbecues, as well as the time reference source in quartz watches.

Scanning Module

The Scanning Module is designed to detect airborne emissions at distances up to 50 feet. This makes a great module for the detection of electrical anomalies, pressure & vacuum leaks. It also works well for non-contact conveyor systems for the detection of bad roller, belt rub and misaligned belts. The sound wave is easily picked up with the transducer since it is the second medium the pressure wave interacts with. The first one being the atmosphere its traveling through. These modules only detect the and do not transmit any ultrasound.

Focusing Probe

The Focusing Probe is an accessory designed to put on over the Scanning Module to help narrow the field of listening. It can be used to seal up on the suspected source of the emission and help to confirm the source of the emission. It is not designed for distances greater than 10 feet.

Long Range Horn

The Long-Range Horn slides over the Scanning Module and allows for the enhance of the detection distance. It is not a module just an accessory used to help isolate the emission. It can detect some anomalies up to 75 feet away.

Parabolic Dish

The Parabolic Dish allows the CBM Analyst to test up to 150 feet away. With the Red Dot sight, the CBM Analyst can easily see where the location of the anomaly is emitting from. The dish can actual detached from the handle. This makes so a much smaller footprint for storage.

Contact Module

The Contact Module was designed to pick up the structure borne ultrasound. Since the Contact Module is made of metal it has little to no acoustic impedance since the two mediums have similar characteristics. This module is suited for testing Bearings, Gear Boxes, Valves, and Steam Traps. The Contact Module is also known as a Wave Guide since it allows the sound wave to travel up to the piezoelectric crystal to be translated.

Never Do The Following

The use of a contact module for ultrasound is a great tool for finding fault conditions in all types of assets. Sometimes it may be difficult to pinpoint the location of the sound with and the temptation to try testing an asset while ignoring the rules of safety may push some to try it anyways. This complacency can be fatal! The CBM Analyst & Technician should never break the plain of energized electrical gear or make contact on energized equipment with a contact module. The Analyst should also avoid sticking the contact module into any hole that looks big enough to slide the contact probe into as you never know what's on the other side. The CBM Analyst & Technician should also never operate an ultrasound device while working on a ladder. It becomes impossible to capture data or adjust the unit while standing on a ladder since you can no longer maintain 3 points of contact.

CBM Recommended Technologies

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One technology does not rule out the use of another. Ultrasonic devices use sound phenomenon as a basis of inspection. The CBM Analyst & Technician must also be knowledgeable about leak physics and machinery basics. Airborne Ultrasonic Inspection is a multi-use inspection system. That can perform many tests, monitoring and trouble-shooting tasks with efficiency and ease. Often it will stand alone as part of a comprehensive Preventative / Predictive Maintenance program. However, we often say that one technology does not preclude the use of other technologies. Every technology has its areas of strengths and weaknesses. We understand that there will be situations where airborne ultrasound will be called upon to support other technologies. In this section, we are going to briefly discuss other forms of nondestructive tests. When we get into our section on Leaks, we will talk about a few other nondestructive tests that are used.

Here is the introduction from ISO 18436-8:2013 (E)

The use of ultrasound technology in condition monitoring is one of the key activities in predictive maintenance programmed for most industries. Other non-intrusive technologies including acoustic emission, infrared thermography, vibration analysis, lubricant analysis, wear debris analysis, and motor current analysis is used as complementary condition analysis tools. Those in the manufacturing industry who have diligently and consistently applied these technologies have experienced a return on investment far exceeding their expectations. However, the effectiveness of these programmed depends on the capabilities of individuals who perform the measurements and analyses the data. This part of

ISO 18436 defines the requirements for personnel to become qualified to apply the non-intrusive machine condition monitoring and diagnostics technology of ultrasound. A programmed, administered by an assessment body, has been developed to train and assess the competence of personnel whose duties require the proper theoretical and practical knowledge of machinery condition monitoring and diagnostics.

This part of ISO 18436 defines the requirements against which personnel in the non-intrusive machinery condition monitoring and diagnostics technologies associated with ultrasound for machinery condition
monitoring is qualified and the methods of assessing such personnel.

Online Systems

Online monitoring is taking off in use since so many facilities are running lean and do not have the manpower to test the assets. The fact that several pieces of equipment can be surveilled 24/7 and gives the program manager a piece of mind that they can deploy resources to specific assets when need in between scheduled testing.

E Sentry Systems

The E Sentry Connect ™ is a next generation intuitive asset information tagging system. The E Sentry Connect system utilizes Near Field Communication (NFC) contactless Smart Card technology that allows smart phone devices with NFC to easily access critical data relating to the equipment being inspected and save up-to-date inspection data directly to the assets E Sentry Connect tag via a free App from IRISS. The E Sentry Connect system has been designed to be operated on 2 platforms, a standalone system and a subscription-based cloud system allowing historical data back-up and complete access to the current status of all assets utilizing E Sentry Connect tags.

E Sentry Connect Cloud allows you to document and access information relating to IR & Ultrasound inspection parameters on Electrical distribution assets. Data is stored on the asset tag directly and backed up to the cloud for future reference and maintenance trend analysis. Routes can be set and monitored. Users can submit data using their android app covering a wide set of data including temperature, barometric pressure, voltage and more. This information can be easily exported for further review and used to provide information to system administrators allowing them to generate maintenance routes for their staff to ensure optimal equipment efficiency and safety.

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The Power of Sound Analysis Software

Although decibels can be used to trend bearings they cannot, however, be used to trend electrical systems until enough historical information has been gathered. This is where the use of sound analysis software like Sound Analysis Software is used to look for harmonic indications which can then determine what faults are present. The use of the Time Signal and FFT can pick out the exact harmonics and their repetitive value. This can help the CBM Analyst determine if there is a bad bearing, inner & outer race, or a cage fault in a motor. It can even determine whether an electrical fault is a corona discharge or and arcing fault.

These events all have distinct fault signatures in time signal, spectrum analysis and 3D Surfacing. Much like an EKG each event will have tell-tale signs that can be seen that will tell the CBM Analyst what they are looking at. The reporting abilities of this software can help the CBM Analyst explain to management or a client what is actually happening instead of saying they simply heard something.

Manual Report

Some users have designed their very own reports in Word or Excel Spreadsheets. The following items should be logged on the reports. Date, Time, CBM Analyst s Name, Temperatures, Humidity, Decibel, Indications of fault, Asset ID, Asset Brand, Voltage, Horsepower, Pressure, Visual condition seen and any other useful information to use in CMMS or SAP.

ASU CAT 2 Module 2-3 Data Acquisition and Mining

Data Acquisition of Ultrasound is an area some companies have trouble with. One site I helped get up and running decided that they would request two 2.5-day training session from me. The class was designed for 10-20 students. So, I was in shock when I arrived and was told that they wanted ten 4-hour sessions training 20 students per session totaling 200 students for the week. They wanted everyone on site trained so they could collect the data and sound waves with the device. I lobbied hard with my point of contact letting them know that it wasn't effective to train 200 people on how to use their ultrasound device, historical database software and the sound analysis software. I had a couple of the supervisors also lobbying to make it a smaller class, but we were overruled.

After the week of training had been completed, I again mentioned that I felt that the training was ineffective as there hadn't been enough time for the students to learn all of the material, they should have had to properly run the program. I was told by my contact for the site that he would be doing all of the route loading, downloading, and analysis so they only needed to know how to collect the data and sound waves, as he didn't find any value in having the operators know what they were listening for.

Several months later I received a phone call from the site. It was my point of contact and he was heated. He was getting readings from the field of 121 and 0 decibels. He didn't know why or what was causing this issue. I informed him that this was caused by having too much or too little amplitude coming into the device. I asked him what the data collectors were hearing when they were in the field. Their answer to that question still leaves me shaking my head. They stated "I don't have them using the headphones! I don't need them to listen to the bearings. I only need them to collect the data and sound waves for me to analysis them in the office!" I informed him that this was the part of the problem and that they need to make sure the glorified data collectors were watching the number of bars of amplitude to ensure they weren't collecting too much or too little amplitude which in turn would eliminate these default values he was seeing.

They then informed me that the people doing the collection were using an advanced screen which didn't allow them to see the amplitude the device was receiving. I let them know that this was a major issue with how the data and sound wave collection was being performed and that the other 6 sites with their company were having no trouble at all since their sites only put 10 people in for the full 2.5 days of training instead of 4 hours of training a piece for 200 people.

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Eventually this induvial was moved out of control of the program at this site and the 2 supervisors who rallied to my side at the first training took over the program. The program has now gone on to a dedicated team in the main site that travels to the outlaying sites to do the more advanced Ultrasound, IR and other Pd/M & CBM technology testing. This would later afford them recognition in the reliability landscape for Program of the Year.

Principles of Data Acquisition & Mining

The old adage is Garbage in Garbage out and this is what happens when the CBM Analyst captures sound waves and data with too much amplitude on the ultrasound device. One company's default value shows up when downloaded to their software. It show a 120 dB's when there is too much amplitude captured and 0 dB's when too little amplitude is received. This will also directly affect the CBM Analyst sound wave that is captured during the collection. When the analyst goes back to analyze the sound wave, they will notice in the case of too much amplitude that the Time Signal will display with cropped off peaks and it will just be a solid color across the entire Time Signal.

This makes it impossible to translate the Time Signal into any useful information in the Frequency Spectrum. This in turn prevents the CBM Analyst from being able to denote any harmonic indications in either the Time Signal or Frequency spectrum. When the sound wave is captured with too little amplitude the opposite effect occurs with little to no indications of the harmonic faults showing up even though the CBM Analyst heard them in the field.

So, it is of major importance that the CBM Analyst & Technician know where they set the volume on their devices when capturing data and sound waves as it is a huge waste of time to have to go back out and recapture the data and sound waves again not to mention having to remove all the data points that are in their software that are invalid. In the case of a service provider there may be issues with going back on site if they have already left without checking their data. In the case of the CBM Analyst & Technician being on site they may not have the time to go backout do to work load, so the data becomes worthless as it cannot be used to be mined to establish baseline values or take action on their level based off of historical and analytical information from the sound analysis.

The last key step to any ultrasound program is to use the data collected in the field and mine it for the valuable information it can provide. We can quickly establish the Baseline using averaging of like equipment decibels values to determine what the average value is and setting their Action Levels based off this data. However, there is also the option to use selective averaging as well for the determination of the baseline. If the CBM Analyst uses their data on an excel spreadsheet they can quickly filter any and all values that are higher than 16 decibels above the overall average. They can then delete this and redo their average to find the selective average value of like bearings and set their Action Levels accordingly.

This will reduce the risk the Delta Value Methods presents when setting up an Action Levels for bearings. This method is flawed and should be avoided at all cost as too many programs over the years have just left their values set with the Delta Value Method and one bearing may already being failing as its 20 decibels above the selective average.

In the long term the best Baseline and Action Levels are established with the Historical Method which is just an averaging over a longer sampling of time giving the program a truer representation of what their values should be. This will also eliminate a program calling a bearing bad at only 16 decibels above the baseline.

One example I was involved in was working with a large online sales company at their distribution sites around the United States. We had determined pretty quickly that their Baldor Motors driving with VFD's had an average of 35 decibels. Since, their bearings were sealed we established that their first Action Level would be set to 55 decibels for their Low Alarm and 70 for their High Alarm value. After collecting over 35,000 test points of data this value only changed by a value of 1 to 36 decibels.

So, without proper Data Acquisition and Mining the collection of this data becomes meaningless and a waste of time and effort as the CBM Analyst reverts back to becoming like Scotty and just fighting fires instead of predicting failures and scheduling repairs before it fails catastrophically.

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Contact Module Positioning

When using the Contact modules, the CBM Analyst or Technician needs to ensure that they are taking their readings from a location that will give them the best data and sound wave. When it comes testing a bearing the best choice for testing is on the zerk fitting since it is a direct line to the bearing race. If there is no zerk fitting the next best spot is the bolt on the fan shroud or the end cap. This however can be risky at the CBM Analyst or Technician will need to be careful not to accidently slip off the end cap and into the shaft. The fan shroud may look like a good place to take a reading but, it is actually ineffective since the fan is producing a high level of antagonistic ultrasound as it cuts through the air causing a source of turbulence and friction.

If the CBM Analyst or Technician is testing steam traps or valves they will want to avoid testing on the thread fitting near the trap or valve. The reason for this is that the tip will not rest flush to the surface leaving an air gap between the tip and the groves of the threads. They will also have to take into account the rounded surface of the pipe they are making contact with. With some contact modules the tip is rounded, and this can cause the module to slip of the pipe if too much pressure is applied. So, it's important apply gentle pressure when testing pipes to avoid slipping off the pipe.

For electrical inspection the CBM Analyst or Technician can use it to test the exterior of the housing of the electrical assets. This can help pinpoint where the problem is originating from when an anomaly was detected with an airborne module. By, making contact on multiple sides of the cabinet to try and triangulate where the loudest spot is. The CBM Analyst or Technician should never make contact on an electrical connections or grounding to avoid electrocution.

Airborne Module Positioning

When using the airborne modules, the CBM Analyst or Technician will need to keep in mind that some of these modules have different angles and distance of detection capabilities. This is critical in trying to achieve the Critical Angle of an ultrasound anomaly. For example, a CBM Analyst preforming an inspection on transmission lines would have a hard time identifying or detecting a possible electrical fault on the transmission lines with the standard airborne module which receive the signal at a 135° wide Field of Listening and an effective distance of 30 feet. With transmission lines be more than double that off the ground usually this would become an impossible task for this module to achieve.

If the Long-Range Horn was applied to the Airborne module the user would experience a field of listening of 60° at a distance of up to 60 feet. This doubles the effective distance of detection by the ultrasound unit but, may only just begun to pick up something as these electrical events are usually produce a very low level of ultrasonic emissions that point away from the ground.

Since most of these events have a critical angle that points up towards the atmosphere the Critical Angle is very hard to achieve from the ground so the CBM Analyst would be better of using a Parabolic Dish which will take the field of listening down to 15° and a distance of 100 feet easily. In the case of pressured gases these distances would increase greatly as pressurized events will produce a much large amount of ultrasound.

Things to Consider When Looking for Leaks

- What type of leak is it? Pressure, vacuum, gas, nitrogen, etc.
- What restriction will have to be overcome? Is it a header 30 feet up?
- Do atmospheric conditions need to be monitored while preforming the survey?
- Will you need a scissor lift, tags, or camera to perform the survey?
- Is there Antagonistic ultrasound?

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- Capture the reading from the leak 1 foot / .3048 meters away from the source.

Accessibility to leaks is a key part to any survey. The inspector must take into account their distance first and foremost, as that will help them to decide which accessory or module to use. The pressure of the leak will also affect the effective range of detection of the module.

The Airborne Modules is good for detecting the source of the leak out to 30 feet (9.144 meters). While the Focusing Probe is great for confirming the location of a pressure or vacuum leak up close, it is of little use over 5 feet (1.524 meters) away. The Long-Range Horn is great to add onto the scanning module since it will increase the range of detection to a 100 feet (30.48 meters) away but not for more than 150 feet (45.72 meters) away. At a distance further than 150 feet (45.72 meters) away, the Parabolic Dish would be the best option as it can potential detect a leak 300 feet (91.44 meters) and it would be limited in distance based off the pressure of the leak.

Leak inspection can be either an airborne or structure borne event. This is why the inspector must take this into consideration when planning the leak survey. If a compressor valve is leaking by or a valve is by passing an airborne module will not pick up the sound because it is occurring in the first medium which is in the interior of the body and the housing is the second medium.

This would require that the inspector use a Contact Module to test for the source of the leakage. Airborne inspection are the easiest to perform as the inspector is in the first medium and the Scanning Module is the second medium. The Long-Range Horn and Focusing Probe could also be used in this test procedure to help identify the source of the ultrasound emission versus the antagonistic ultrasound.

Sensor Positioning for Mechanical Testing

When testing bearings, the CBM Analyst can use the zerk fitting as the best test point to take readings as this is a straight shot to the bearings. This will also ensure that the contact module is a 90° angle to the bearing assembly. The tip of the contact module and the zerk fitting should be cleaned off prior to making contact so as not to introduce foreign particles into the zerk. The Analyst should use a frequency setting between 28-32 kHz for RPM's of 300 or greater and 20-25 kHz for anything below 300 RPM.

- Always clean the surface area and contact module
- First recommend test point is the zerk fitting for testing
- Second recommend test point is the bolts on the shroud or the end bell.
- Always test at a 90° angle
- Do not press down on the contact module
- Mark and document the test points
- Train the personnel on these items

Sensor Positioning for Compressor Testing

Compressor Testing can be done with both the Contact & Airborne Modules. When using the Airborne Module, the CBM Analyst would set the device to 40 kHz to maximize the effective detection of air egress or ingress. The analyst could also switch to a Contact Module and switch the frequency to somewhere between 20-25 kHz to also listen to the bearings and valves.

Sensor Positioning for Compressor Valves

To test the compressor valves the use of a contact module would again be the go-to module for testing the rise and fall of the compressor's pistons and valve. This rise and fall will cause and increase in pressure and suction, which in turn will cause and increase and decreasing of decibels that are detected as the turbulence increases and decreases. The CBM Analyst can take it a step further and record the sound waves, then measure the time it takes for the valves to open and close. They could then compare them against the other valves to determine is one of them is hanging up.

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Sensor Positioning for Heat Exchangers, Chillers, and Condensers

Heat Exchangers, Chillers and Condensers can also be tested using the Contact & Airborne Modules. With both the Contact & Airborne Modules being used in several different methodologies it becomes a very effective test platform for both online and off-line testing.

Sensor Positioning for Hydraulic Valve Testing

Hydraulic systems are a test application that allows for the use of both the Contact & Airborne Modules. In the case of the use of the Airborne Module the CBM Analyst will be to use caution as external hydraulics leaks can cause serious injuries to personnel and a safe distance should be maintained at all times. The Contact Module is great at detecting valves that are leaking by or hung up as well as detecting issues with cavitation in pumps and rams.

Sensor Positioning for Steam Traps

Just like testing a bearing the CBM Analyst will place the contact module at a 90° angle to the surface of the pipe. They will also need to ensure that they don't apply too much pressure as this could cause the module to slip off the piping. They will position the module downstream of the traps body and listen for the trap to cycle and record the sound wave for analysis. The best frequency setting will be between 20-25 kHz. Never test on the thread fittings as this surface will not give a solid surface for the contact module test on as there will be an air gap between the tip and threads which will cause some of the signal to be attenuated.

- Research the Trap Types
- Know the pressure and temperature levels that the system is operating at.
- Know the discharge orifice location
- Adjust volume to eliminate background sounds inherent to system
- Compare Similar Traps
- Wait for Trap to Cycle

Sensor Positioning for Valve Testing

Similar to Steam Trap testing the testing of valves will require a 90° angle over 4 test points when possible to compare the upstream and downstream decibel readings to determine the source of the highest decibel reading.

Sensor Positioning for Electrical Inspection

When it comes to electrical inspection Infrared, Ultrasound and TEV detection devices are the best tools to use to test electrical equipment. Ultrasound and TEV can be used to listen to what's occurring inside of equipment by making contact on the exterior of the cabinet or scanning and seam or opening. If the site has VPDS installed it becomes a lot more efficient and minimizes any loss of signal caused by Diffraction.

This is causing a loss of clarity in the signal clarity that can interfere with the ability to analyze sound waves in an Frequency Spectrum, while the Time Signal can still show some Harmonic occurrences of the emission as it isn't as dependent on the Critical Angle since it is capturing the emission as it happens in Real Time and is a transformation of the signal.

Sensor Positioning of the Ultrasound Ports

The use of Ultrasound Inspection devices is one of the safest ways to determine the condition of an asset without having to open any equipment. This saves the CBM Analyst from having to wear an Arc Flash Suit with an open panel. Being able to inspect

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electrical equipment use to involve scanning the seams and openings of equipment and recording the sound wave to analysis what the condition inside is. The one problem that the CBM Analyst runs into is the diffraction of the sound wave and the inability to establish the Critical Angle of the event.

With the use of VP-12 US and VPDS the CBM Analyst can overcome the diffraction of signal. This will help to expedite the inspection process by eliminating the tracing of the seams of panels on equipment. This also gives the CBM Analyst a certain test point to go to every time for repeatable values. The process of doing energized inspection has long been cumbersome and time consuming. Usually requiring both personnel to gown up in the arc flash suits with one person to open the panels and the other to do the ultrasound inspection. By having windows and Ultrasound ports, this step is no longer needed. This also reduces the risk of heat stroke or exhaustion from wearing the arc flash suit in warm environments.

Capturing Sound Waves for Analysis

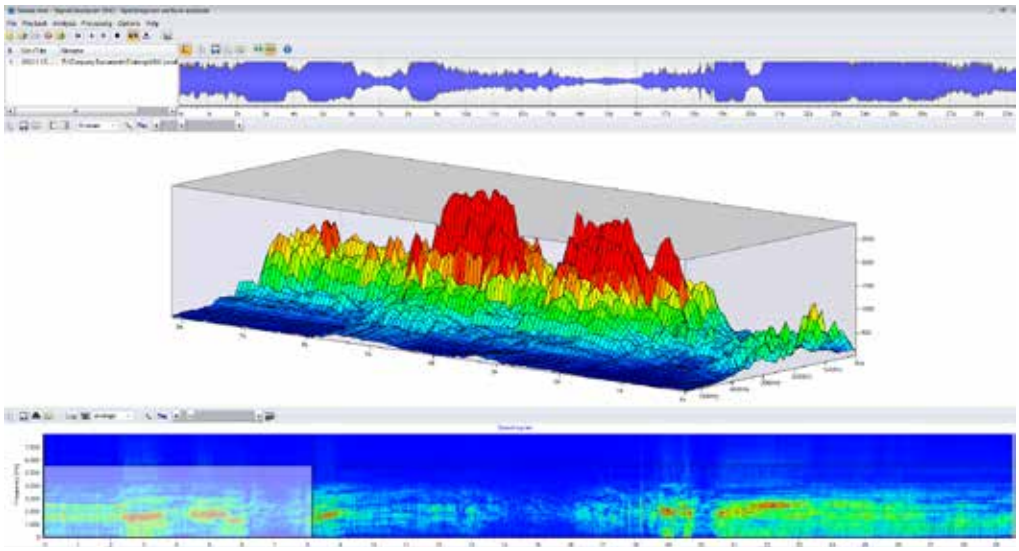
Although decibels can be used to trend bearings they cannot, be used to trend electrical systems until enough historical information has been gathered. This is where the use of sound analysis software like Sound Analysis Software is used to look for harmonic indications which can then determine what faults are present. The use of the Time Signal and FFT can pick out the exact harmonics and their repetitive value.

This can help the CBM Analyst determine if there is a bad bearing, inner & outer race, or a cage fault in a motor.
It can even determine whether an electrical fault is a corona discharge or and arcing fault. These events all have distinct fault signatures in time signal, spectrum analysis and 3D Surfacing. Much like an EKG each event will have tell-tale signs that can be seen that will tell the CBM Analyst what they are looking at. The reporting abilities of this software can help the CBM Analyst explain to management or a client what is actually happing instead of saying they simply heard something.

So, why should the CBM Analyst use sound analysis software similar to the Sound Analysis Pro? Well, it helps with seeing clear patterns that develop when the CBM Analyst determines that there are intervals that are occurring. These occurrences can determine what part of a bearing is failing, discharge rate of a steam trap or what type of electrical failure is occurring. With the report feature the CBM Analyst can submit sound waves and images for their plant or client to review.

Sonus Vue Pro is the most powerful Ultrasound Analysis software currently available. With higher functionality then the Sonus App the CBM Analyst can diagnosis the anomaly much more effectively.

Accurate measurement of signals is another strong point of the Sonus Vue. It makes all the sense, if one considers that the simplest way to tell two signals a part is to measure them. May that be frequency, amplitude or phase or other statistical properties, they can all be very accurately evaluated. With it is possible to specify analysis parameters such that your memory may run out, or it may take very long for the computation to complete.



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Signal analysis software allows the user to quickly analyze the basic and more advanced signal properties of a sound wave. Especially when it comes to comparing signals and looking for their distinct Harmonics. This type of software is part of the development process for signal analysis-based fault detection, machine monitoring and always when there is a need to detect statistically significant and persistent differences between signals.

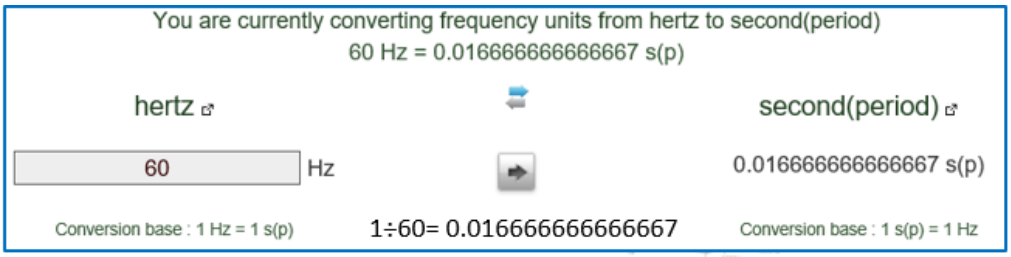
The accurate determination of harmonic patterns of the signals is another reason why Sound Analysis Software is so important for helping in the determination of fault conditions. It makes all the sense in the World, if one considers that the simplest way to tell two signals a part is to measure and compare them in an overlay view. May that be the frequency, amplitude, phase or other statistical properties, they can all be very accurately evaluated and compared against other like equipment's sound waves.

When it comes to Sound Analysis Software it is possible that the analysis parameters can zap your computer or laptops memory causing the system to take a very long for the computation to be completed. The computer should have at least 8 GB of RAM to effectively operate theses this type of software effectively.

Sound Analysis can tell so much more about what is occurring with assets then trending decibels alone can. For years trending of decibels was the only way to determine when to lubricate bearings, while electrical assets where just reported to have just heard something. With the sound wave recordings and analysis software 20 years ago, companies could finally start to see what was occurring and try to determine the harmonic faults that were showing up. Sometimes though the CBM Analyst couldn't see any harmonic faults in the Frequency Spectrum (FFT) while the Time Signal (Timewave Form) would show a pattern but, it's value couldn't be determined due to the fact that software would only go to a tenth of a second.

This made the ability of analysis sound waves in Time Signal next to impossible. Now with newer sound analysis software like Sonus Vue Pro Desktop we can look at the fault frequency of a Time Signal value into the millionths of a second. This game changing feature will allow us to look in the Time Signal domain and give us even more diagnostic capabilities to determine the difference between loose winding which present at a value of 120 Hz or .0083333333 seconds vs a dirty power fault which presents at 121 Hz or .008264462 seconds and can range up to 122 Hz which comes out to .008196721 seconds.

Sonus Vue Pro Desktop is the first software platforms that goes out beyond a tenth of a second of time finally allowing us to calculate fault frequency in a Time Signal analysis screen. This new ability allows the CBM Analyst to determine the differences between the existence of electrical faults which occur outside of the North Americas at .02 seconds (50 Hz) or in the North Americas at .0166666667 seconds (60 Hz) which indicates the presence of a line frequency fault condition. If the fault shows up at outside the North Americas .01 (100 Hz) or .0083333333 (120 Hz) in the North Americas, this would be an indication of the presence of a 2-time line frequency event which are indicators of Loose Connection or Delamination of Windings.



We can calculate these occurrences by dividing 1 Hz by the harmonic occurrence found in the Frequency Spectrum to determine what the harmonic occurrence will be in the Time Signal. In the case of a 60 Hz Harmonic the value we would then look for is 0.016 or 0.017 seconds of time. If the Frequency Spectrum was showing up with a 120 Hz signature, we would use the same formula and divide 1 by 120 which would result in a value of 0.08333333333333333 harmonic. This same process can be used in the Mechanical Application for fault detection of Stray Voltage, Outer Race, Inner, Ball Pass and Cage Faults for example.

The Analyst has several options to choose from when viewing the sound wave. The default value is the Dual Time Signal which will display both the left and right channels.

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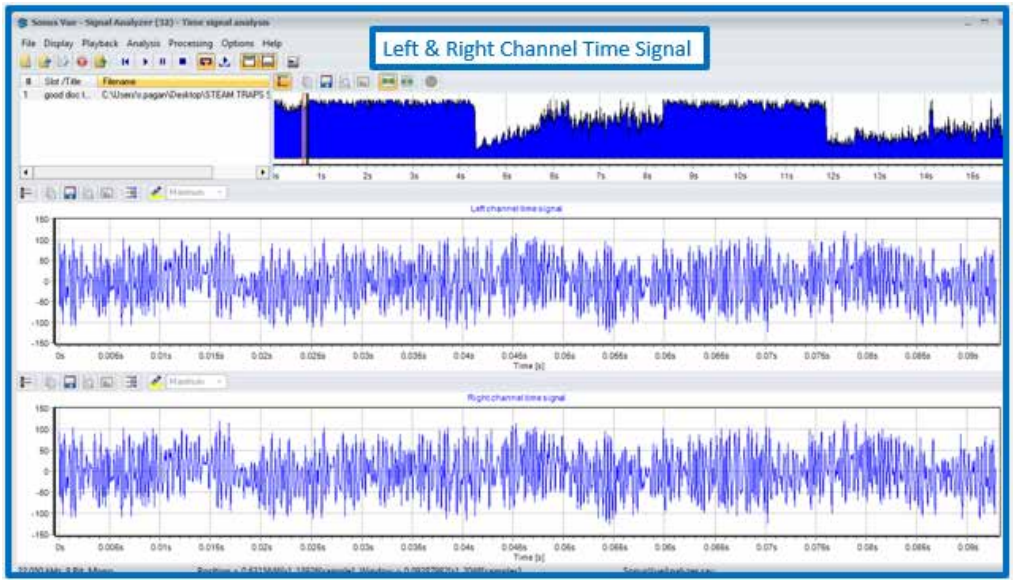
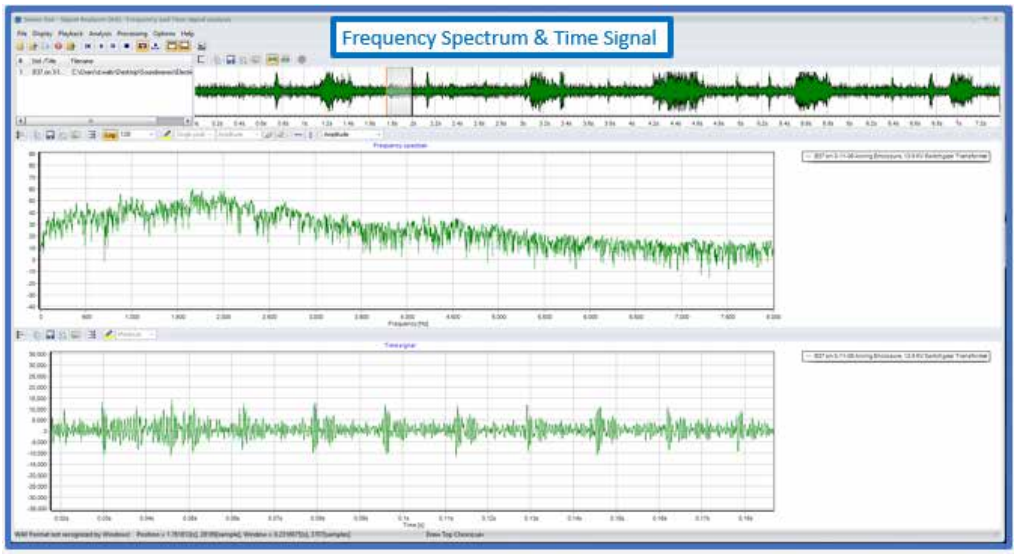
Left & Right Channel Time Signal

The Dual Left and Right Time Signal screen allows the CBM Analyst to view the sound wave in a linear phase. Since the linear phase is a straight-line view of the sound energy. Ultrasound devices that record mono signal will show up as a nonlinear phase and only the right Time Signal will show up since they have no left and right symmetry.



Frequency Spectrum & Time Signal

The Frequency Spectrum & Time Signal views allows the analyst to look for harmonic occurrences in both the Frequency Spectrum which will be in Hertz and in Time Signal in Seconds. We can calculate the timing of the occurrence from Hertz to seconds which gives the analyst to ability to detect the fault condition even if the critical angle hasn't been achieved and the harmonics aren't showing in the Frequency Spectrum but, are still clearly visible in the Time Signal view.



Dual Frequency Spectrum

The Dual Frequency Spectrum give the analyst the ability to zoom in on of the views while leaving the other on the full-length view. This allows the analyst to look at a zoomed in area while still displaying the entirety of the frequency spectrum on another view.

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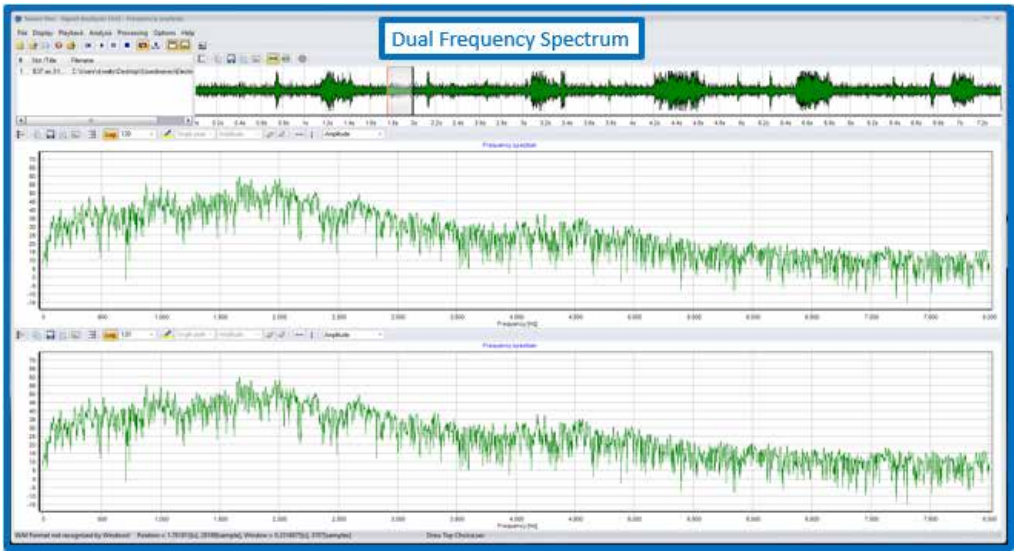
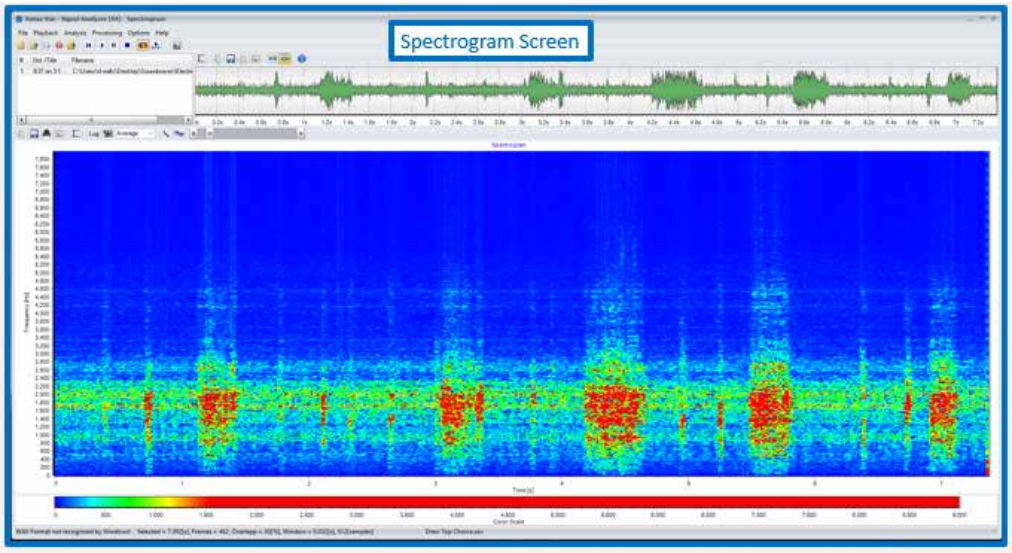


Spectrogram Screen

Spectrograms give the analyst the ability to analyze the signal with three parameters at the same time: Time, Amplitude and Frequency. The time is on the X axis, the Frequency is on the Y axis and amplitude is defined with the Color. To display the Spectrogram the analyst will need to first select the Spectrogram View. This will open a blank screen initial which requires an additional step of going back into the Analysis Tab and clicking on Compute.



Spectrogram Analysis Screen

The Spectrogram Analysis Screen combines the Frequency Spectrum, Time Signal and the Spectrogram Screen for use in determining harmonic indications. On the right side of the spectrum we a frequency spectrum with frequency going from bottom to the top and amplitudes going from right to left. When we click anywhere in the spectrogram the frequency spectrum and time series below the spectrogram updates. We can also drag the cursor lines displayed on the spectrogram to pick out harmonic indications.

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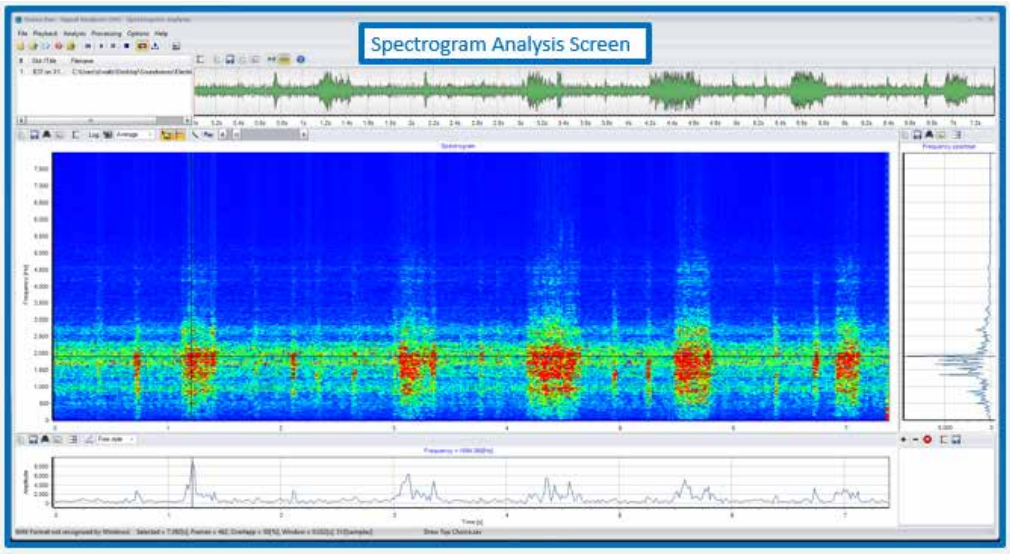
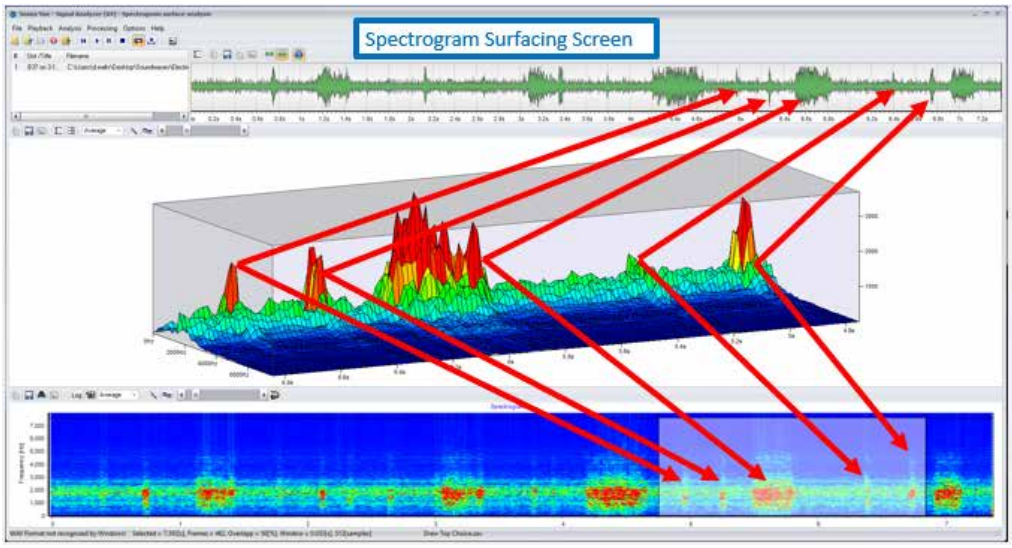


Surfacing Screen

Spectrogram Surface analysis is another variant of the spectrogram analysis except that in this case the amplitude parameter is represented with color and height in the surface chart. The Spectrogram Surface is computed in the same way as the spectrogram. This exciting view gives the analyst a view in 3D of the same 3 Axis's as the Spectrogram Analysis but, now shows the Amplitude in a vertical height. The view can even be zoomed in on or spun around 360° to get a better look at what is occurring with this asset. In this example we can clearly see where the red spikes of Amplitude match up with the burst of energy seen in the full-length Time Signal at the top of the screen and the same burst of energy in the Spectrogram below. This view makes for a stunningly compelling report image showing the indication of a fault condition.



Expanding The Amount of Time Displayed

Expanding the amount of the time viewed in the fields below allows the analyst the ability to go from looking at the entire sound wave to a smaller amount of time. We recommend only using 2 tenths of a seconds of time to perform analysis since most harmonics' occurrence can be seen repeating several times.

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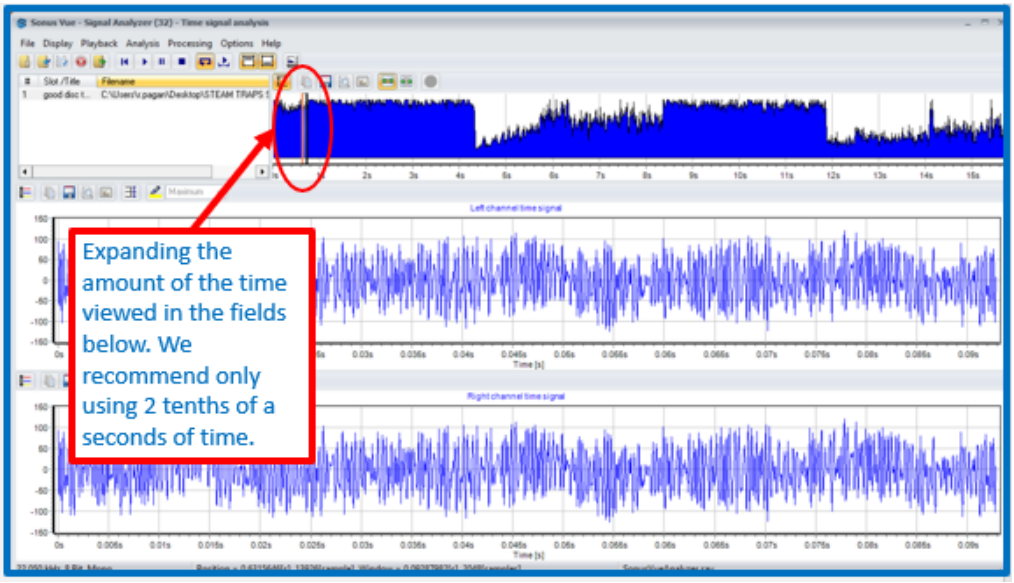
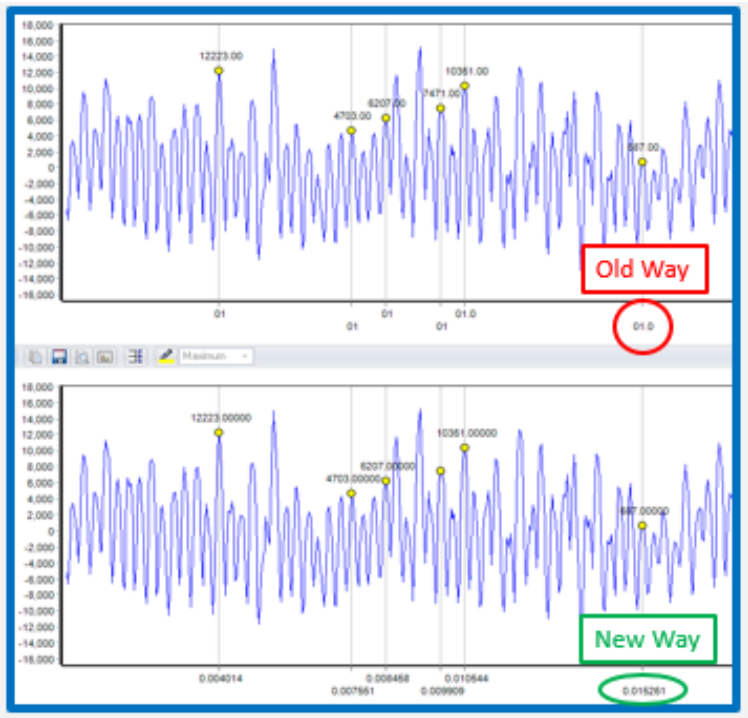


Why Time Signal Analysis is so Helpful.



This will also be really useful when it comes to looking for bearing fault conditions which can be very close together with their fault values. If we take a look at the differences between looking at a tenth of a second time displayed in the top Time Signal Screen. This represents the maximum capability of most sound analysis software platforms on the market. The bottom Time Signal screen shows the same sound wave with the same harmonic markers displayed out to a hundred thousandths of a second!

Older software platforms do not have this feature making it impossible to determine the exact fault frequency that is being displayed. With this new powerful feature, we can now display what we weren't able too before. If we apply this new ability to bearing testing, we will also be able to more effectively determine what faults are occurring.

This also becomes more important when looking for bearing faults in a VFD since the line frequency of the motor changes and the values can often be very close to that of the ball pass fault harmonic indication. Without the ability to look beyond a tenth of a thousandth of a second, we would not be able to disseminate the differences between the two fault conditions.

Marking Harmonic Indications

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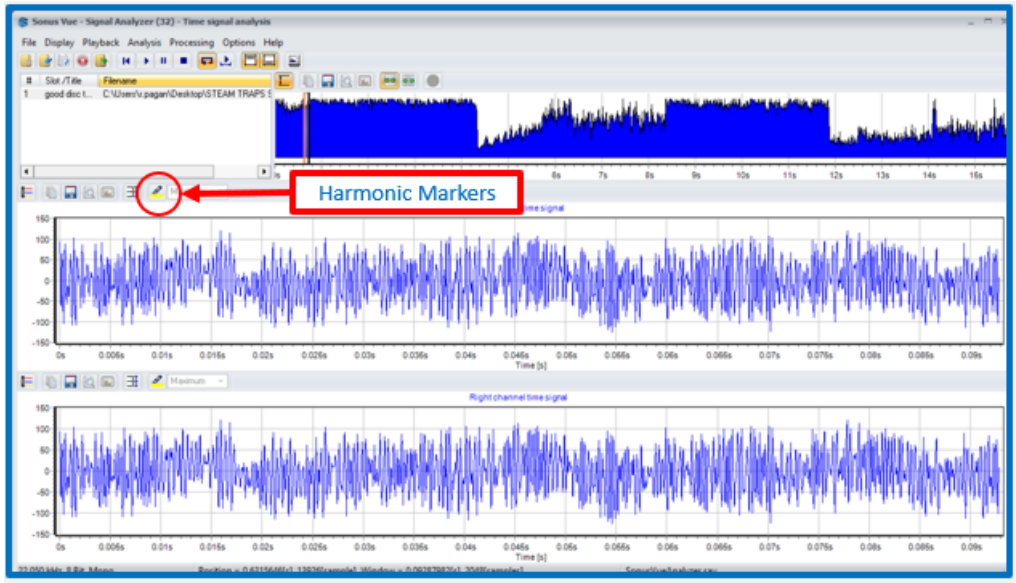
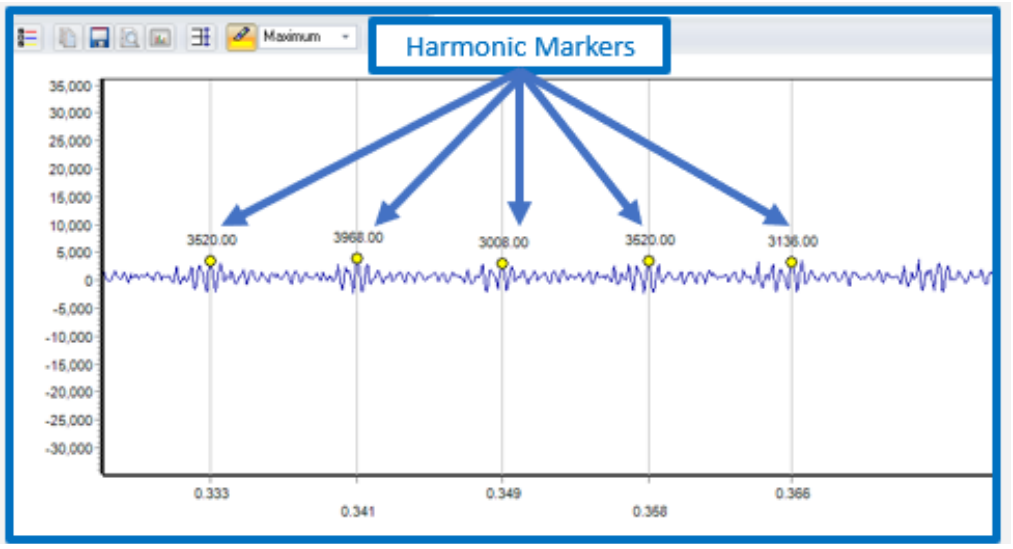
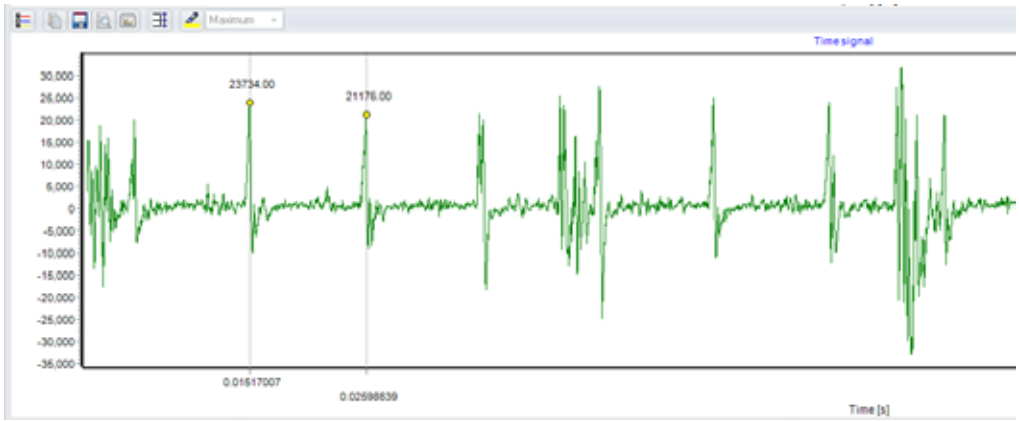
Harmonic Markers allow the analyst the ability to find and detect fault conditions in the assets sound wave.



The Analyst can now mark the exact distance between the patterns of the harmonic indication in both Time and Hertz to determine what the value is between these harmonic indications. This can identify the exact fault condition based off of its harmonic values of indication. We can then determine everything from an electrical fault conditions to a bearing fault conditions.



Move your cursor over the peak you wish to mark and left click. You can mark multiple harmonics.



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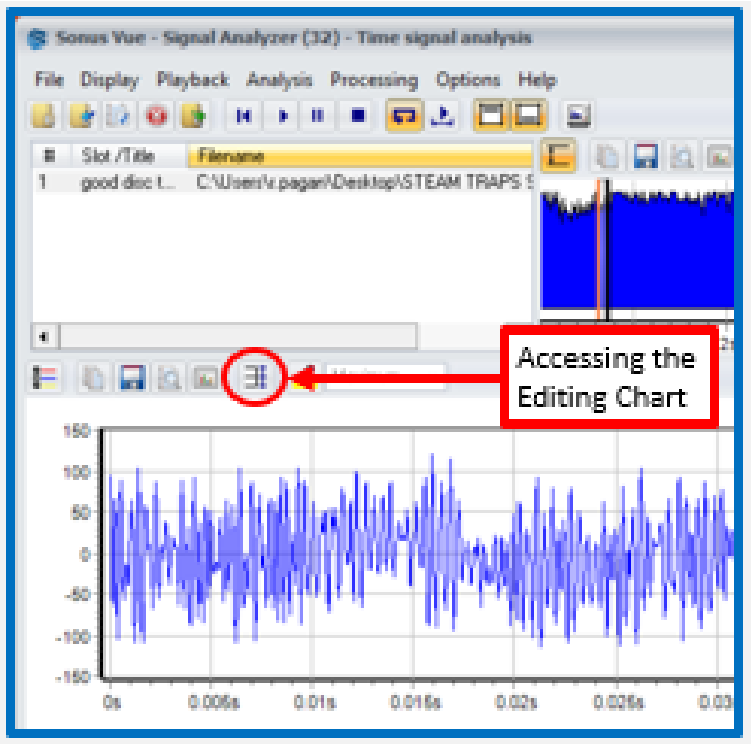
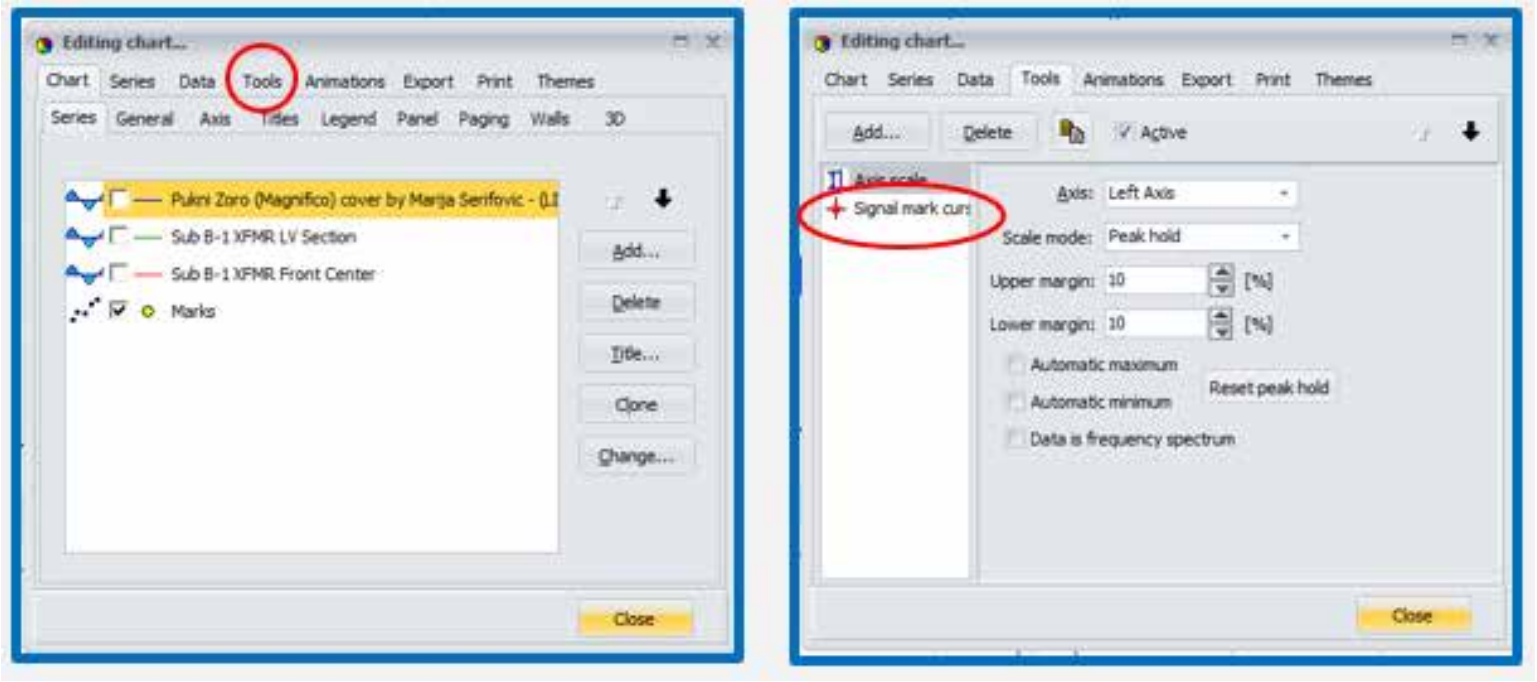
Accessing the Editing Chart

To access the editing chart simply hit the edit graph icon located in the tool ribbon above the display screens



This will open up the Edit Chart window, which allows the user to customize the X & Y Axis or change the views of the screen to 3D and the Tools option which is used to change the values of the harmonic markers value of indication.



To set the Harmonic Markers display value, choose the Signal mark cursor. This will then display the 2 different tab setting that can be used to changes the configuration and display of the harmonic marker. Choose the Display tab then, change the Time to a millionth of a second. This will allow the inspector to pinpoint the exact fault occurrence that is displayed.

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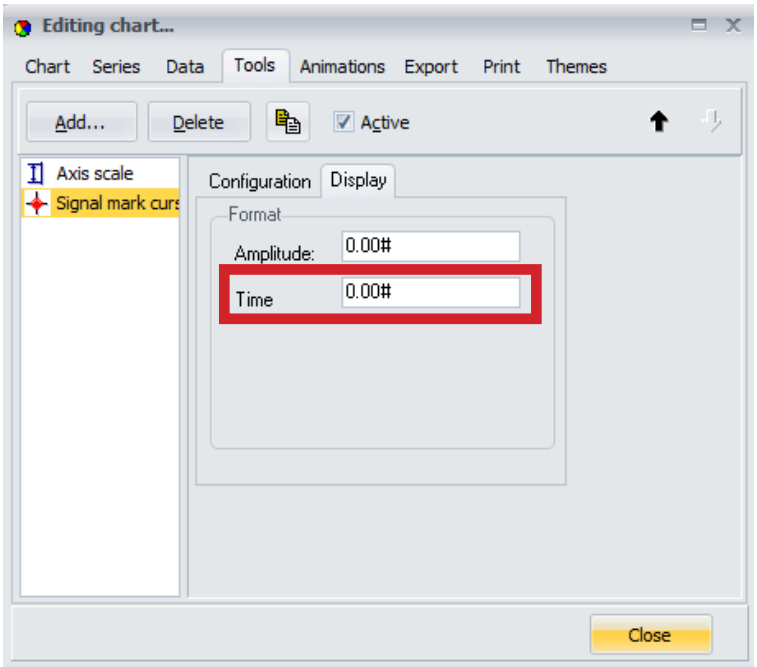
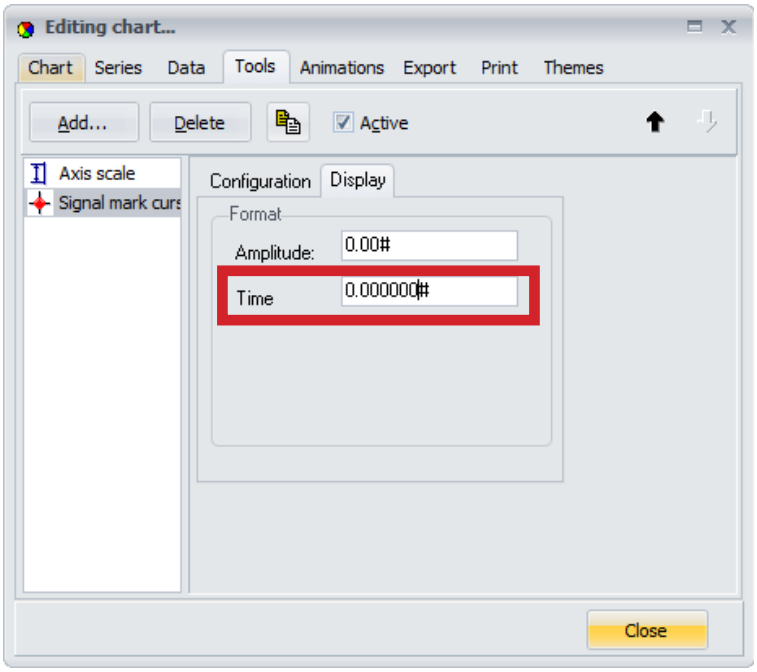




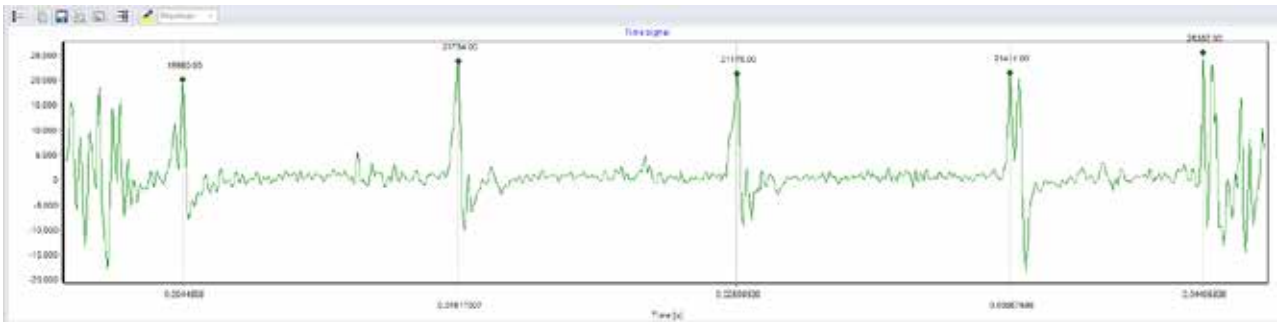
Calculating Bearing Faults

Bearing Coefficient Calculator

NTN Bearings

Outer Race Coefficient	Inner Race Coefficient	Fundamental Train Freq. Coefficient	Ball Spin Freq. Coefficient	RPM	Outer Race Fault	Inner Race Fault	Cage Fault (FTF)	Ball Pass Fault (BSF)	
3.06000	4.94	0.38	8	1730	88.23	142.44	10.96	230.67	in Hz
					5293.8	8546	657	13840	in CPM
					0.011334	0.007021	0.091269	0.004335	Time Series Equivalent

If we use this bearing fault calculator and we know the number of balls and turning speed, we can generate the harmonic values not only in Hertz but in Cycles Per Second which allow us to pick apart these sound waves to see exactly what is occurring. We can then use our calculator to determine the difference in the harmonics we are seeing. This leap forward in sound analysis will make it easier for users to see and determine the exact fault condition.



The Measurement of Ultrasound

The Measurement of Ultrasound has predominantly been measured in **dBµV**, **dBu**, **or dBV** values. **dBµV** is used in Voltage, Radio Power, Radio Energy, Radio Field Strength and it take the Root Mean Square which is used to measure sound voltage at various frequencies. **dBu** and **dBV** are used in Voltage for professional audio equipment.

With several different sciences using decibels as a measurement there are several different scales that can be used beside the above mention values currently used in ultrasound devices. The breakdown of the scales is generally as follows. **(Appendix A)**

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- Voltage
- Acoustics
- Audio Electronics
- Radar
- Radio Power, Energy & Field Strength
- Antenna Measurements

The use of decibels to measure the intensity of an anomaly can be applied to many things for the measurement of the amplitude of an anomaly. Using decibels to set action level can allow a program to react more effectively to the needs of the asset. It can even aid the site on determining the severity of a compressed gas leak. It can help to prioritize which leaks should be fixed first. Decibels can be compared when performing valve testing to determine if a valve is leaking by or closed and holding back properly. It can even be used to determine the exact location of a heat exchanger tube leak.

ASU CAT 2 Module 2-4 Data Storage and Management

One of the keys to a successful CBM Program is to develop a database that is easy for the CBM Technician to use. If data collection routes are built without a proper flow, the route collection can be more time consuming than it needs to be. It's also important to ensure that like equipment is grouped together as most ultrasound software platforms do not allow the user to delineate or sort the different sizes of motors for example. This will affect the baseline values since they will range in decibel value since a 20 hp motor will have a lower decibel value than a large 100 hp motor it is important to group like equipment together for easier comparison analysis.

So, it's very important that not only should the route be set up effectively but the database too, since it's the key to success. By establishing a database with routes that have like equipment and flows smoothly when actually walking the route, the program can get off on the right foot.

The frequency of testing should be based off the Criticality of the assets, which in turn will driving the frequency of testing. By using a FMEA, Risk Appetite or Criticality Ranking to assign the frequency of testing to those assets, a CBM Program can ensure that they are testing at the appropriate interval of time to prevent a cataclysmic failure and maintain a safe work environment.

What Assets Do You Own?

This question can be asked at any site to the operators, maintenance staff, engineering and management and they may not all be able to answer the question. They will only know the assets they operate or the bad actors off the top of their head. So, it is

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important when starting to set up a database that a list of all the assets be gathered and a criticality ranking of the assets should be performed. This will ensure that the most critical of assets is tested most frequently.

Lack of Asset Knowledge

Most organizations do not know what assets they own

- Only **40%** of the organizations we studied have an actionable EAM based Asset Registry (ISO 14224)

Most organizations cannot formally distinguish the top 10% of their critical assets

- Only **30%** of the organizations we studied had an accurate and up to date criticality rankings of their assets

Most organizations lack a formal understanding of asset failure modes

- Only **20%** of the organizations we studied have formally failure modes analysis in place

Most organizations do not know why the PM tasks and inspections are being done

- Only **20%** of the organizations we studied have a technically/economically sound basis for the PM tasks and inspections that are mapped out from their failure modes analysis

Maintenance Process

Going back to the basics is a common methodology to get everyone involved in the changes to how maintenance and reliability programs can re-center themselves. The program will need to look at how they start off again with their maintenance and what it will take to make those changes. This could include selecting new vendors, different personnel, test equipment, baseline values and action levels. The program will also need to build documentation and plans to management that proves their plans will produce a ROI and decrease downtime and maximize uptime.

Maintenance Program Requirements

For any job to be done correctly it must have adequate tools to get the job done right. There also needs to be an accurate determination of what maintenance need to be performed and how it must be done. Their also need to be an understanding of the impact of common maintenance practices on the site's operation. The maintenance program also needs ensure that the staff are properly trained on their tools, testing devices, software, and best practices to help ensure continuous improvement capabilities are in place. The last step is to convoy to the maintenance personnel that they are as much of a stakeholder as those who benefit from the process.

Reliability Centered Maintenance (RCM)

The Society of Automotive Engineers (SAE) was the first to develop and use the RCM methodology. It has expanded over the last several decades as engineers moved out of the automotive industry into other segments. The primary objective of RCM is to preserve system function. RCM helps identify the most effective approach to maintenance.

In 2004 the Publicity Available Specification published the standard known as PA55. This Standard was then used as the basis of the new ISO Standard 55000 in August of 2010 and eventually went through 4 years of revision to be accepted.

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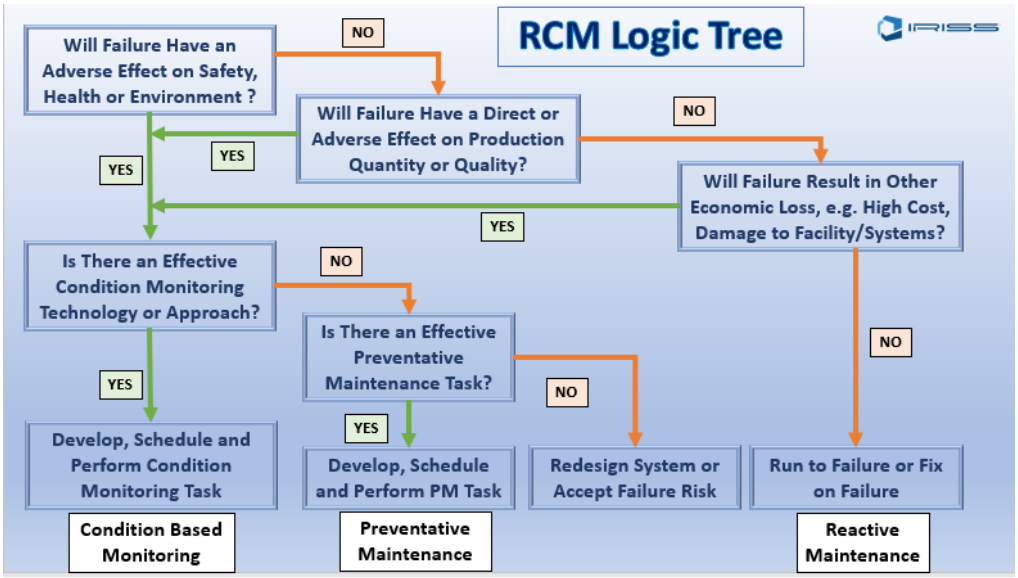
The ISO 55000 Standard for Reliability Centered Maintenance (RCM) is intended for use by any organization that has or makes use of physical assets or systems that it wishes to manage responsibly. RCM is a specific process used to identify the policies which must be implemented to manage the failure modes which could cause the functional failure of any physical asset in a given operating context. This document is intended to be used to evaluate any process that purports to be an RCM process, in order to determine whether it is a true RCM process. This document supports such an evaluation by specifying the minimum characteristics that a process must have in order to be an RCM process.

Seven questions need to be answered satisfactorily and in the following sequence to determine if an organization is following RCM standards:

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?



Maintenance Strategy for Reliability

It is surprising how many companies are still running totally on Reactive Maintenance programs in this day and age but, there are still sites out there that have not embraced the culture of RCM. We cannot eliminate the need for Reactive Maintenance but,

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we can reduce it significantly if we start looking at using an integration of Preventive Maintenance (PM), Predictive Maintenance (Pd/M), Proactive (PA), and Condition Based Maintenance (CBM).

Risk Appetite

According to the Institute of Risk management Risk appetite can be defined as 'the amount and type of risk that an organization is willing to take in order to meet their strategic objectives. Organizations will have different risk appetites depending on their sector, culture and objectives. A range of appetites exist for different risks and these may change over time.
While risk appetite will always mean different things to different people, a properly communicated, appropriate risk appetite statement can actively help organizations achieve goals and support sustainability.
While risk appetite is about the pursuit of risk, risk tolerance is about what an organization can actually cope with. Organizations have to take some risks and avoid others. To do so, they need to be clear about what successful performance looks like. This question may be easier to answer for a commercial organization than for a government department but can usually be asked by boards in all sectors.
Note: The higher an organizations Risk appetite the lower the asset management costs, adversely the lower the appetite the higher the costs!!

Criticality Ranking

The process of assigning a numerical value & level of ranking of the concern to an assets based on the failure modes, to help determine what steps should be taken when a fault condition is determined in that asset.
It is also used to determine the frequency of PA, PM, Pd/M or CBM work or performing route-based data collection.

	Consquences					Probability					Detection Device		Fault Condition
						1	2	3	4	5			
						1-3 Points	4-8 Points	9-14 Points	15-19 Points	20-25 points			
Severity	Classification	Safety	Equipment Mantenance Cost	Prodcution	Enviromental	Extremely Unlikely	Very Unlikely	Unlikely	Likely	Very Likely	Ultrasound	Infrared	
5	Disastrous	Multipule structures with large external effects beyond the sites inhabited zones(several fatalities)	Extensive damage totaling more than $8 Million	Major loss which is not recoverable and more than 3 Days Lost Prodcution	Major effect on surrounding enviroment, Long term evacutations of the area,EPA Fines and Lawsuits filed	5	10	15	20	25	Yes	Yes	Arcing Dirty Power
4	Catastrophic	One Structure with several deadly effects (A couple of Falalities and sevral injuries)	Major damage totaling $6 - $8 Million	Major Loss with up to 50 % unrecoverable or more than 3 Days Lost Production	Major Pollution to the surrounding enviroment, Short term evacutations of the area, Fines from the EPA and Lawsuits filed	4	8	12	16	20	Yes	Yes	Tracking Delamination of Windings
3	Major	Deadly effects on 1 person and or several disfiguremnts	Localized damage totaling $2 - $6 Million	Medium loss not totally recoverable through normal prodcution with less than 24 hour Production Loss	Moderate pollution on the site with no evacutations. Fines from the EPA	3	6	9	12	15	Yes	Yes	Treeing Loose Connection
2	Minor	Permament disability, Lost Time Injury, Non-Permanent Injury	Minor Damage Totaling $200,000 - $2 Million	Minor loss, recoverable through normal prodcution with only 2 - 8 hours Production Loss	Spill or release of pollutant that has to be reported to the EPS but no effects on the enviroment.	2	4	6	8	10	Yes	No	Corona
1	Moderate	No Permament Disabilities, no lost time injuries, no treatments	Slight damage totaling less than $200,000	Little to no effect on production with less than 2 hours Production Loss	Minor spill or release of pollutant that doesn't require contactign the EPA	1	2	3	4	5	Yes	No	Partial Dischare

Using this Criticality Ranking chart a company can insert their own factors of the Consequences. For example, financial values under the Equipment/Maintenance Cost to better represent their impacts.

This chart is broken down with the Y Axis scaling a rating of Severity and Classification from 5 to 1.

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A Severity of 5 would be classified as a Disastrous event.
A Severity of 4 would be classified as a Catastrophic event.
A Severity of 3 would be classified as a Major event.
A Severity of 2 would be classified as a Serious event.
A Severity of 1 would be classified as a Moderate event.

The X Axis is broken down with the Consequences and Probability with points from 1-25. The Consequences are broken down to 4 factors which can then be filled in against the Severity and Classification Value. These factors are Safety, Equipment/Maintenance Cost, Production and Environmental.

Probability is broken down into 5 values.
1-4 points is Extremely Unlikely to fail
4-8 points is Very Unlikely to fail.
9-14 points is Unlikely to fail.
15-19 points is Likely to fail.
20-25 points is Very Likely to fail.

How to Apply Criticality Ranking

By adding the Severity Ranking Value against the Probability Ranking Value, we can come up with a Ranking Point value from 1 (being the lowest threat of failing) to 25 (being the highest threat of failing). A site can then use these statistical Ranking Point values to help determine when an asset can be placed under a every other year, Quarterly PM, Monthly PM, Monthly PdM or Constant CBM intervals of time for inspection. The higher the severity the more frequently the asset should be tested.

1-3 Points	(Extremely Unlikely) = Annual inspection interval
4-8 Points	(Very Unlikely) = Quarterly PM
9-14 Points	(Unlikely) = PM Monthly
15-19 Points	(Likely) = PdM Monthly
20-25 Points	(Very likely) = Constant CBM

How to Apply FMEA

To determine what maintenance should be performed, the site should use the centerpiece of Reliability Centered Maintenance (RCM) methodology known as FMEA. This methodology has been used over the last half a century to effectively improve the reduction of unscheduled downtime while increasing productions throughput. The most effective way to help improve FMEA is for the Asset Engineer to evaluate the old assets failure modes and work with the OEM's to improve the design of the assets to remove or reduce the identified failure modes.

Failure Modes and Effects Simulation / System (FMES) is used in reliability analysis for producing automatically generated failure mode and effects analysis (FMEA). The **Risk Priority Number, or RPN**, is a numeric assessment of **risk** assigned to a process, or steps in a process, as part of Failure Modes and Effects Analysis (FMEA), in which a team assigns each failure mode numeric values that quantify likelihood of occurrence, likelihood of detection, and severity of impact.

Assign 1-10 for the capability of DETECTION of the failure mode. 1 being detectable every time, 10 being impossible to detect. Multiply the values for SEVERITY, OCCURRENCE, and DETECTION and the becomes the RPN, risk priority number.

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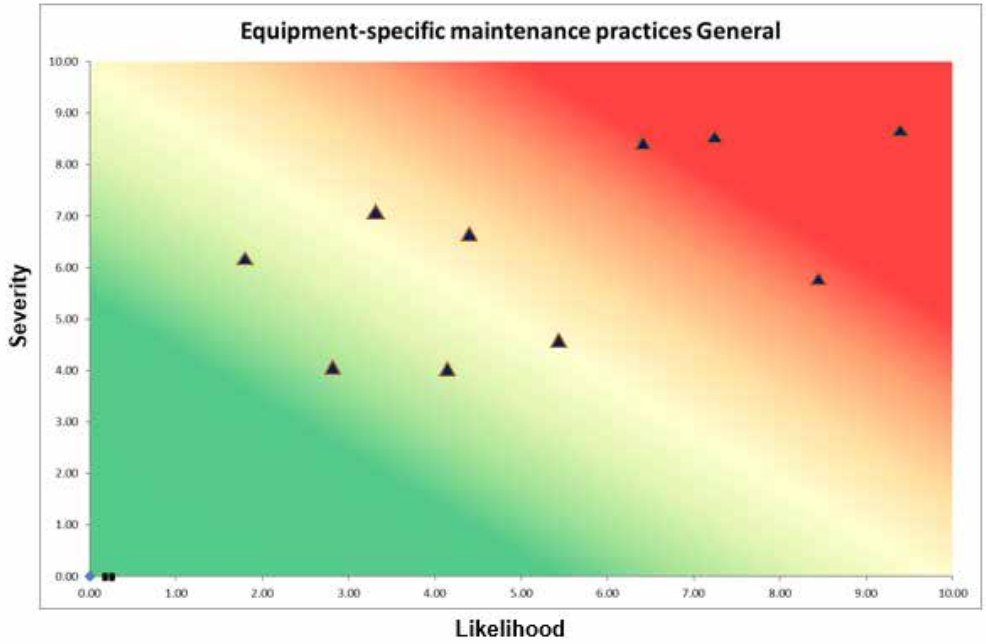
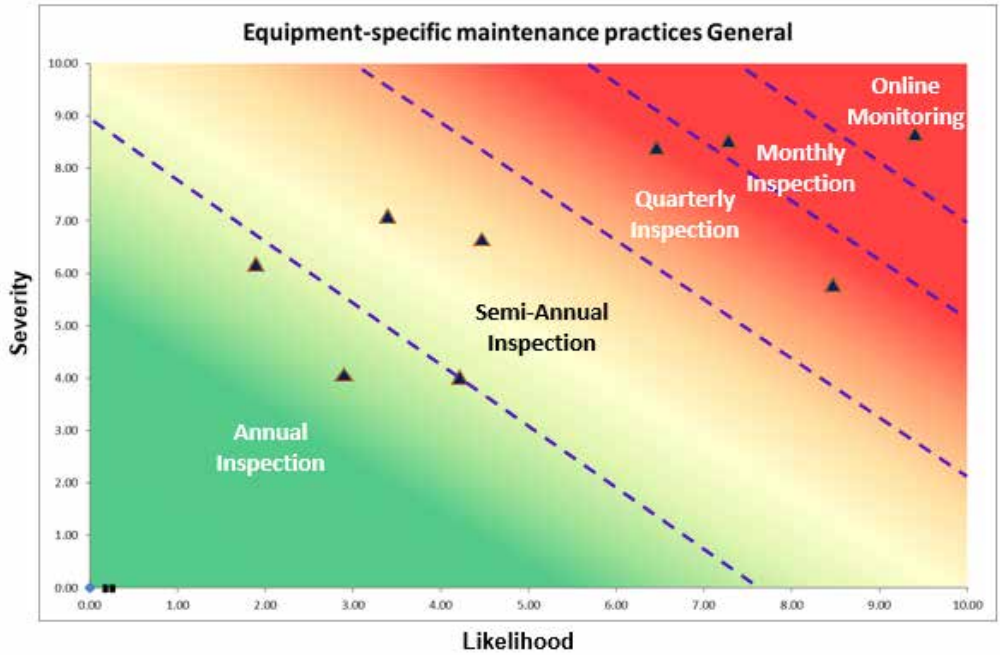


RPN is calculated using a number of different methods, the simplest of methods is to use the likelihood of failure multiplied by the severity of failure. This number can then be used to assess the required maintenance systems to ensure that the RPN is managed within acceptable parameters. The above graphic shows an example of an RPN Heat map or simple risk matrix.



The above graphic shows an RPN heatmap with an overlaid “Risk appetite.

Advantage of Ranking Assets

By documenting the steps of the process, it creates a record useful information for troubleshooting if problems develop. This step is a great step to allow for group review to look at and continuously improve on it. If the original champion of the program moves on to another site, the documentation allows for lesser experienced personnel to step up and follow the blueprint laid out in the plan. The documentation becomes very critical for the future of the program as it will include the steps of the process of ranking assets, procedures, and checklists.

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By getting the operators, mechanics, schedulers & planners, reliability engineer and management involved in the ranking of assets it eliminates the bias that arises when trying to refocus a program. Operators tend to only see the importance of their machine while the mechanic takes ownership of the line, they are good at fixing in a pinch. The Planner & Scheduler only focus on what they feel puts them behind on closing out tickets. While the reliability engineer worries about ensuring that all assets have the correct parts on hand to minimize unscheduled downtime and management worries about the cost of the lost throughput due to unscheduled downtime.

The benefit of having everyone involved is to not only develop ownership but to approach it in an objective and non-threatening manner. The process mapping can then be used to train new employees, safety training and staff meetings. Continuous improvement is another key to any programs success so it's important to ask for input on possible revisions as there will be no shortage of input once the staff feels engaged in the process. The results should be used to update the map as this will solidify the improvements.

Managing the Database

Once the ranking has been put into action the database can be created and should be done with ease of mind for understanding the naming scheme and the flow of data collection. For the best results "Like" assets should be grouped together to ensure effective actions levels can be set up when trending the decibel values. The other key to a Database is how it is structured. This can vary depending on the size of the company as some large companies will have a global approach with each site using identical asset tagging identifiers. So, not only can assets be trended locally but globally site by site to see if a certain system may have a FMEA across the World that will need to be redesigned.

The builder off the database should consult with the CBM Technician to see how the database will be collected. This way the CBM Technician isn't going up and down different floor following the process flow instead the best flow of collection of data based off where they are physically at. This will also help to unify the naming scheme, so everyone is on the same page when it comes to identifying the names of the test points.

Once the Database is built the hard work begins of choosing the right personnel for the job at hand then getting them properly trained. The first Tier of a CBM program is the CBM Technician. They will be responsible for the routine data collection. This will also require that their training includes lessons on how to insure they collect the correct data and don't bring back bad data, sound waves or images that cannot be used or analyzed.

The second tier of a CBM program is the CAT 1 Analyst. This person maybe your front-line person for collecting the routes, but without certification they are nothing more than a data collector as ISO doesn't recommend having a CBM Technician doing the review of the data collected in the field. Hence the importance of an ISO Certification Courses to provide a base of the theory of the technology they will be using to determine fault condition in their assets.
The third tier of a CBM program is the CAT 2 CBM Analyst. This level of CBM Analyst will be responsible for the data has been collected, performing data mining, setting action levels, analysis of sound waves, harmonic indication determination, and reporting on the findings to management.

The fourth tier of the CBM program is what we call a CAT 3 Master CBM Analyst and they will be a CAT 3 in one or more of the technologies. They will oversee all data, sound waves and images collected by the CBM Technician and Analyst. They will be responsible for taking this information to management to report of the CBM Programs findings and make recommendations on the assets in question and forecast MTBF (Mean Time Between Failure).

Forecasting the MTBF will allow for a more accurate determination of how much longer an asset has before it stops running. This question has been asked for years by Production and Management alike when the CBM Technician tries to let them know that an asset if failing. Without a proper database to see the trends in decibels, amplitude increases in the sound patterns and determination of harmonic fault conditions the program will struggle to give a sold answer and usually default back to old practices of either running to failure or replacement prematurely.

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Disposition of Anomalies

The establishment of Benchmarks, Baseline Values and Action Levels are paramount for identifying the disposition (Tendency) of the assets being tested. This can even involve how the asset is installed or set up versus other similar assets.

When looking for a fault condition the use of the comparison method for sound wave analysis is at the fore front of determining what faults are occurring. By comparing the asset to it previous sound recording or against another like asset when no historical data is present the CBM Analyst can line up the sound waves in a Frequency Spectrum or Time Signal Analysis to see if a clear difference is present. They can they also look at multiple sound wave images. However, keep in mind without a 3D view in either of these views it will be difficult to clearly see all of the fault conditions present.

Diagnosis and Prognosis

When it comes to understanding asset health, we need to think about how the data that is collected can be used to diagnosis a fault condition or to give a prognosis of that assets remaining life span. By establishing Benchmarks, Baselines, Action Levels, and Corrective Actions Steps a CBM program can quickly monitor what is occurring across the plant's assets. The definitions for Diagnosis and Prognosis have been intertwined in the medical field for years. In the CBM realm we are no different than the medical team overseeing our patient's life only we are over seeing asset life span.

"The distinguishing difference between diagnosis and prognosis is that prognosis implies the prediction of a future state. Thus, to accomplish prognosis requires both diagnostic and predictive tools, the former to sense the current state of damage and the latter to predict the future state based on projected usage and applicable life-prediction routines." **(Materials Damage Prognosis, ed. by James M. Larsen et al., 2005)**

Benchmarking

One of the most important of any CBM program is the data that is collected. That however cannot be the only step a program takes as this data must be analyzed. Data Mining will assist that program in understanding what the historical values or averages are for certain types of assets. One on the Data Mining projects that I was involved with encompassed 42 different sites for an online sales company. Over a 4-year period we collected decibel readings on their Baldor ½ HP VFD Motors driving their conveyance which lead to the setting of baselines and Action Levels that are now the standard for that company Worldwide.

At the first site I visited the data from these motors were averaged to determine the baseline value of the decibels. Since there was no previous data to mine, the data was evaluated, and the low and high out layers were removed from the average creating a selective average value of 35.2 decibels for the baseline.

Report Structuring

The key to any program is the database. How will you store your data you collect in the field? Does your equipment have software to use to store the data? Can you export the data to an excel spreadsheet so you can quickly identify out layers? Charting these values is a valuable visual aid for reporting issue to Plant Management and can help guide decisions that need to be made as well as forecast the future of that asset's life span. When using sound analysis software producing reports with the images from that platform can also give the CBM Team the added ammo they need to make their stand on why it's time to repair or replace and asset.

Setting Action Levels

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It is important to set Action Levels that prevent catastrophic failures. Action Levels should be used to determine when it is time to lubricate a bearing, when bearing is damaged, or when they are approaching catastrophic failure. For leaks, the value of decibels can be established to determine the urgency for repair. Electrical inspection is one that actually cannot be set up Action Levels initially. So, if something is heard in an electrical asset, a sound wave should be recorded for analysis of harmonic indications of a known fault condition. The key to this is collecting good Data to use for setting these values and what Criteria is involved in setting those values.

Recommending Corrective Action

ISO 9001:2015 10.2 Covers Corrective Actions

10.2 Nonconformity and corrective action.
The 2015 update requires that when a nonconformity occurs, including any arising from customer complaints, organizations to take the following steps:

1. Immediate containment actions. IE: React to the nonconformity and as appropriate, take action to control and correct it and deal with the consequences.
2. Identify Root Cause / Similar products or processes consideration. IE: Evaluate the need for action to eliminate the cause(s) of the nonconformity, so that it does not recur or occur elsewhere, by: Reviewing and analyzing the nonconformity, Establishing the cause(s), Determining if any similar nonconformities exist, or could potentially occur elsewhere.
3. Implement Corrective Action to address root cause(s) and review effectiveness.
4. Update Risks and Opportunities planning and any changes to the management system as appropriate. It is also noted that corrective actions must be appropriate to the effects of the nonconformities under review and that documented information (records) must be retained as evidence of: The nature of the nonconformities, any subsequent actions taken, and the results of corrective actions taken.

Tracking Corrective Action Outcome

Tracking Corrective Action is the final step to ensuring that repairs have been made. Some CMMS software platforms can keep track of the repairs and generate reports. Manually logging them can work too but is a tedious process for reporting the results. Results can only be measured when personnel are held accountable for the corrective actions. We have all worked in or seen a plant where there are no checks and balances after finding are brought to the attention of everyone. I once performed and Air Survey for a flour mill in early 2000's and when the Maintenance Manager moved on the program died off and the equipment sat on the shelf for 7 years.

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When suddenly I received a phone call from that mill asking to come down and help their staff out with their unit they had just found. I ran them through the equipment and took them out to the field where I noticed some air leak tags that were placed there by me seven years earlier. None of the leaks had been fixed and the values on the tags weren't lower than the last time I had detected them.

ASU CAT 2 Module 2-5 Condition Monitoring Principles

Many companies have made a slow transition over the last half a century through the different theories of how to run their maintenance programs. If we look to the parodies of Television to the Real World, there is one show that I always found interesting. That's Star Trek! In the 1960's every plant in the World's maintenance programs was fighting the fires of run to failure. Oddly enough so was Scotty on Star Trek who was the Chief Engineering of the Enterprise. Anytime anything broke down he would run to fix. Captain Kirk would call him on the intercom and ask him how long it would take. Scotty would always give the captain the typical line that it would take a couple of days and Kirk would telling him didn't have that long cause they were in danger. Scotty would quip back "Captain I'm Giving it all I've got!"

He would then proceed to get the engineering team working hard on the task at hand and before the danger could end their lives Scotty and his engineering department would pull off the miracle job and finish the job in time to save the day. Although this practice is still in use today fewer and fewer companies are letting their assets fail this way.

In the 1980's The Next Generation aired on TV with a new Chief of Engineering. His name was Chief O'Brien and he was repeatedly seen on the show preforming Star Fleet's Time-Based Maintenance known as PM's regularly. Oddly enough around this time there was a shift in the World of Plant Maintenance to PM based maintenance. This did help to minimize the amount of reactive maintenance that was occurring in plants but, this still did eliminate all of the failures from occurring.

In the early part of the 90's Geordi La Forge was prompted to the head on the Engineering Department and he started using his visor that could see in IR, Corona Spectrum, Ultraviolet Light and many other spectrums to try and detect faults before they would cause a catastrophic. Again, a Parody occurred, and the industrial world started to use Infrared Camera's, Vibration Analysis, Ultrasound, Motor Current Analysis and other devices for predictive maintenance.

In the mid 90's Chief O'Brien shipped out for an isolated outpost on the edge of the Gamma Quadrant named Deep Space 9. This old bucket of bolts near a planet that was once at war with the former owners of this space station had a big task at hand. He not only had to fix the station up but start up a Condition Based Monitoring program from scratch since so much of the station was in need of major work from the damage inflected as the previous occupant's abandoned the space station. Not only was there initial damage but booby traps and computer virus that threatened catastrophic failure of the station in every episode.

Around that time companies start shifting to the term Reliability Centered Maintenance Programs. Using a combination of Reactive, Predictive, Predictive, and CBM maintenance based of the Criticality of the Asset. This helped to properly schedule the appropriate frequency of everything from lubrication of bearing to the tightening and testing of electrical connections.

This is great a great process for companies to assign work orders for repair and testing with Ultrasound and other testing devices but there is a more important factor which needs to be taken into account. That factor is proper Data Acquisition! Without proper training the maintenance personnel assigned to collect the Data can capture bad data and bad data is like having no data at all.

CBM Principles

The basic principles behind a CBM program is the value that is added by taking a program out of a fire fighting mode of

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maintenance and guiding it instead into a condition-based approach. This can also help programs that are in the PM (Preventative Maintenance) a time-based program that dictates when to do everything from lubrication of a bearing to tightening of the feet on a motor. Or in a program that that has started a Pd/M (Predictive Maintenance) which trend decibels to sets action levels to add lubrication, or a replacement asset if its trending towards failure.

A CBM program incorporates all of these aspect, as either something will just fail, or they are not as critical to rank and do not warrant constant monitoring of the asset since it will have no large impact when it fails. The benefit of a CBM Program is that it will help to organize and educate everyone on how to properly perform maintenance on the equipment, proper lubrication practices, proper inventory controls, and reduce and eliminate waste. This will insure minimal unscheduled downtime when everyone at the site is properly aligned with the vision and goals of the new program.

Condition Based Monitoring Inspection Methods

Condition Based Monitoring Inspection Methods utilize condition-based monitoring technologies to inspect electrical distribution, motors, pumps, fan bearing, conveyance, pressurized gas leaks, steam traps, valve and hydraulic assets. These inspection methods determine the condition of the individual assets or systems being inspected and include but are not limited to:

- IRT = Infrared Thermography
- ASU = Airborne Structure borne Ultrasound
- MCA = Motor Current Analysis
- TEV = Partial Discharge Testing
- PQM = Power Quality Meters
- UVL = Ultraviolet “Corona” Imaging
- VIB = Vibration Analysis
- ALN = Alignment Testing
- OA = Oil Analysis
- NDT = Non-Destructive Testing

CBM Program Technologies

One Technology Does Not Rule Out **the Use** of Another but enhances a programs ability to pinpoint the fault condition. Airborne Ultrasonic **uses** sound anomalies as a basis of inspection. Airborne Ultrasonic Inspection is a multi-use inspection system and it can perform many testing, monitoring and trouble-shooting tasks with efficiency and ease. Often it will stand alone as part of a comprehensive CBM program. Every technology has its areas of strengths and weaknesses. We must understand that there will be situations where airborne ultrasound will be called upon to support other technologies and vice versus. **ISO 18436-8:2013 (E)**

The use of ultrasound technology in condition monitoring is one of the key activities in predictive maintenance programmed for most industries. Other non-intrusive technologies including acoustic emission, infrared thermography, vibration analysis, lubricant analysis, wear debris analysis, and motor current analysis is used as complementary condition analysis tools. Those in the manufacturing industry who have diligently and consistently applied these technologies have experienced a return on investment far exceeding their expectations.

However, the effectiveness of these programmed depends on the capabilities of individuals who perform the measurements and

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analyses the data. This part of ISO 18436 defines the requirements for personnel to become qualified to apply the non-intrusive machine condition monitoring and diagnostics technology of ultrasound.
A programmed, administered by an assessment body, has been developed to train and assess the competence of personnel whose duties require the proper theoretical and practical knowledge of machinery condition monitoring and diagnostics.
This part of ISO 18436 defines the requirements against which personnel in the non-intrusive machinery condition monitoring and diagnostics technologies associated with ultrasound for machinery condition
monitoring is qualified and the methods of assessing such personnel.

Motor Current Analysis

Motor Current Analysis works by sensing an electrical signal that contains the components of the current and unique fluctuations of fault conditions that can be used to diagnosis the exact anomaly present in that motor. It can detect such conditions as Stator inter turn faults, bearing faults due to stray voltage, drive train related, rotor eccentricity related, broken rotor end ring faults, and rotor bar issues.

Power Quality Management

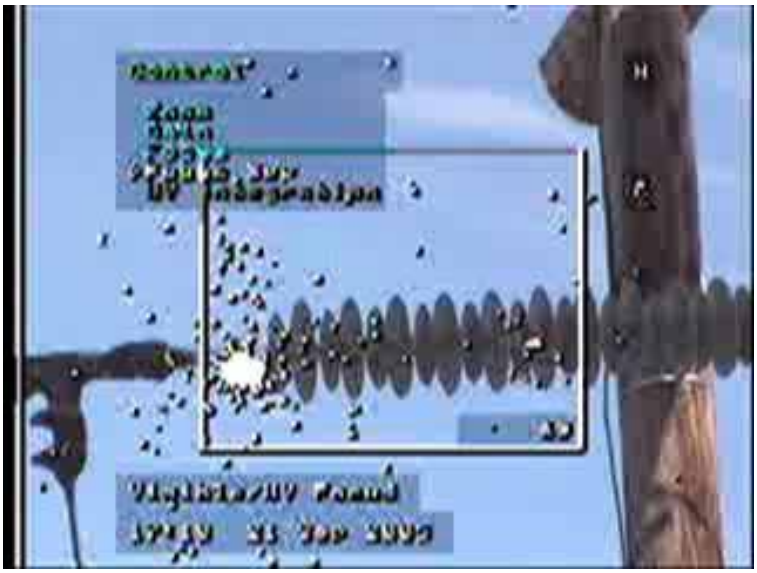
Power Quality Testing can be used on single phase and three phase systems to determine voltage, current or frequency issue that can cause harmonic resonance, unbalance, voltage sags or voltage swells in a systems. These can all indicate fault conditions in an electrical systems and if left uncorrected can cause much bigger problems than flickering lights.

Infrared Thermal Imaging

Infrared Cameras are most predominantly used for electrical inspection with steam systems being the next biggest used applications. Although it can be used for some many other applications these are the two most commonly used. Its ability to map out thermal patterns makes it a great visual aid for the CBM Analyst to determine where the source is coming from. It is very import thou that the CBM Analyst receives proper training on the use of an IR Camera and the theory behind it so, they don't mistake their reflection for an issue or the fact that a true temperature cannot determined when testing a motor for bearing faults since the internal temperature can be so much hotter inside of the motor house than the external temperature is indicating.

Corona Cameras

Corona cameras for years were a 6 figures testing device but, in the last decade they have become smaller and much less expense. These cameras are used for testing systems and are dependent on the system being over a 1,000 volts since corona cannot be produce below 1,000 volts.



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Types of Electrical Maintenance Safety Devices

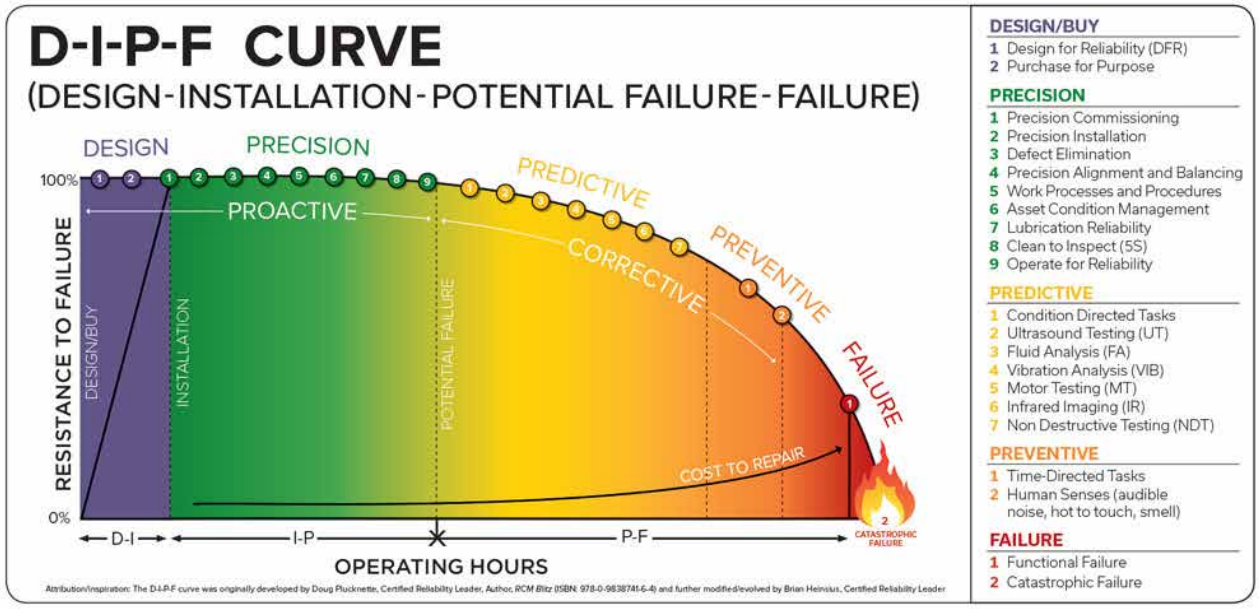
When it comes to EMSD's the most common of them are the IR Window, Ultrasound Ports and Online Monitoring. IR Windows allow the CBM Analyst to use an infrared and in some cases UV Cameras to safely scan electrical assets without needed to remove the panel. Newer IR Windows offer a clear polymer that allows the CBM Analyst to even peer through to look for visual indication of a fault condition.

Another great EMSD is the Ultrasound Ports. This device allows the CBM Analyst the ability to listen in on what is happening inside of the electrical asset while minimizing their exposure. Since this is still and open precaution should be taken to ensure that there isn't a significant pressure differential when opening the cover as a burst of air could stir up debris. The invention of VPDS Ports is the safest option since it remains sealed and the CBM Analyst simply has to plug in the headphone jack to the VPDS Port and the ultrasound device can listen in using the embedded transducer minimizing if not totally eliminating the Antagonistic Ultrasound that is present from the room.

Online Monitoring is growing in popularity with companies for several reasons. One reasons is job verification. The use of NFC Tags like E-Sentry allow the Program Manager to verify that the CBM Analyst are physical at the location of the asset and logging their findings. Second reason can be attributed to the lack of personnel to perform routine data collection. The third reason for the use of online monitoring is to constantly monitor critical assets. The fourth and final reasons is probably the biggest one. The monitoring of assets that are in dangerous or areas with restricted entry.

D-I-P-F Curve

For years the World of Maintenance and Reliability would use the mindset of the P to F Curve to help determine Asset Life. This, however, has been improved to the D-I-P-F Curve. By improving how we look at our assets as we get ready to design them, install them, test them for potential failure and lastly detect the end of life failures.



This now takes into account the first step of working with the OEM or Vendor to **Design** the asset to work for your application and not the other way around. Things like position of the zerk fitting or type of lubrication you need packed in the bears can be specified at this stage. The **Installation** of the asset is the next stage, and this isn't just about the installation of the asset it's also the installation of the training and mind set of a CBM Program. Reliability Engineering is already in use with the D-I-P-F Curve and that knowledge needs to be installed in the CBM Analyst, Operators, Production and Management for the program to achieve its goals of reducing unscheduled downtime and increased throughput. Both the Design and Installation fall under the Proactive realm on the curve.

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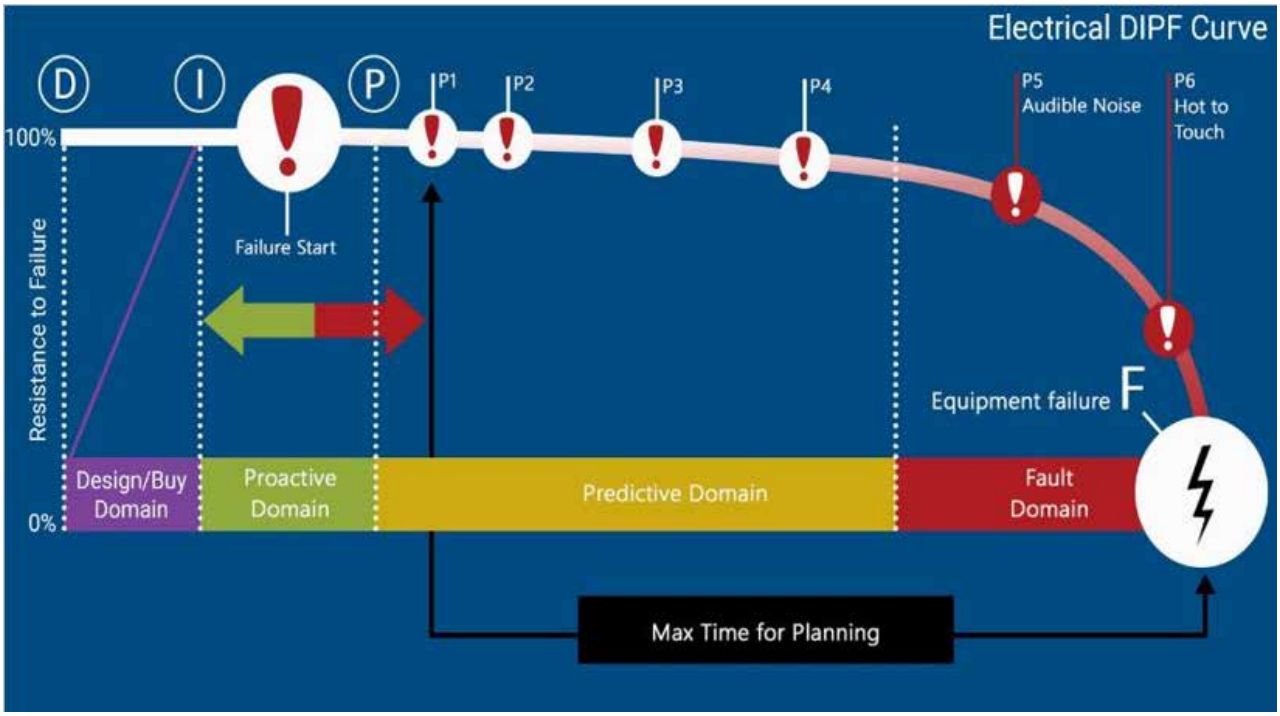
When we entire into the **Potential Failure** on the curve we are now looking at the deployment of the predictive testing devices. This is the Predictive realm and that leaves the last realm of the preventive stage in the curves Potential Failure stage. These are time-based task that are either recommended by the OEM or the Company itself. The final stage of the D-I-P-F Curve is the **Failure** stage. This is where the Functional Failure occurs, and the asset reaches it end of usually life.

Some D-I-P-F curves have the beginning stages of failure starting almost immediately after installation. This can be due to improper installation. as more often than not most OEM have a QA process in place with tight tolerances to pass before being accepted. Using an Ultrasound device on a motor that was just installed could be the perfect tool for the commissioning of the motor for acceptance testing as it would pick up on the very first indication of a problem. This would also be a good time to capture the baseline data on the motor after its installed.

In the case of an electrical asset, the same principles can be applied using the D-I-P-F Curve as the motor example. Again, we have the initial design of the asset and the request for an IR Window and VPDS Port can be requested. During the commissioning, a baseline of the Infrared and Ultrasound can be taken for future comparison. After the installation, the failure could start up and the Ultrasound device would the first device to detect Partial Discharge events.



The D-I-P-F Curve of failure illustrate the probability of a failure against time and can be split into two broad categories, age-related and random. It should be noted that the most common failure mode is type F, which starts out with a fairly high “infant mortality decreasing to a constant failure probability.

P1 Stage

The first detection of a fault condition would be detected in the P1 Stage and ultrasound device may detect the silent presence of an anomaly. 90% of the time electrical assets will make no sound so, the inspector should record the sound wave to look for harmonic indications of a fault condition. Once the presence of a 60 Hz Harmonic (in North America) or a 50 Hz Harmonic (elsewhere in the World) has been found the CBM Program Scheduler can put in a work order for further testing to take place using MCA or IRT devices. If the site has Ports for testing with IRT, MCA or PQM testing they can quickly deploy the CBM Analyst out to test the asset without having to shut down the asset to remove the panel and preform an energized inspection. If nothing is present with the IRT and there is a slight increase in the resistance when testing with MCA, the program should flag the asset for

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follow up testing in 30 Days.

P2 Stage

After the 30 Days is up and the asset has hit the work orders for follow up testing on the asset that we detected during the prior months inspection we, would go back out with the same test method of using Ultrasound as the lead testing device and capture the sound wave again and take note of the decibels but not to focus on them for anything other than insuring we are lined up with the truest form of the incident wave as we scan the seams if we do not have and VPDS or Ultrasound Port to test through.
If the asset has an infrared window the CBM Scheduler should also schedule the IRT to be sent out at the same time as the ASU device so they could be compared. If the ASU is showing presence of a sound the CBM analyst will again record the sound waves and look for harmonics in the sound wave but, with the addition of the IRT Camera being present the analyst could then scan through the IR Window to see if there is an increase in temperature or a new thermal pattern is showing up.

If both technologies are showing the presence of a fault condition the sound wave from the ASU Device and the Image from the IRT should be looked at back at the office to determine what fault is present. Once the report has been generated and the work order closed out the scheduler should schedule an MCA test be done again and if the voltage testing shows signs of failure the correlation of the fault condition can be made and confirmed.

P3 Stage

By the time the we reach the P3 Stage the Scheduler and Planner should be checking inventory for the replacement parts and components they will need to effectively make the repair of the asset at the next scheduled shutdown. All though the asset has now been tested twice in 30 days another follow up inspection should be performed to ensure that the fault condition isn't becoming a threat to fail before the end of its useful life.

Now on the 60th day we would redeploy the ASU device and the IRT Camera to re-inspect the asset, ensuring to taking the same exact steps that were taken 30 days prior. If the sound wave is showing significant amount of bursting, that stops, and starts randomly, they would generally notice a significant rise in temperature and a larger thermal pattern than months before, which would indicate that the asset is getting much worse. If the Analyst can look through the IR Window to see if they can notice any visual indications of decolorizations or paths that have been etched into the connections, they would be able to report that this asset is much closer to failure vs last month's testing.

Again, the MCA device can be sent out to confirm the finds of the ASU & IRT devices. At this stage we are still operating in the a Predictive/Corrective Stage and we can minimize how much the repairs may cost as the longer this anomaly persist, the more damage it is doing to the asset and should be taken down and repaired sooner than later.

Failure Stage

If this asset is left to hit the Failure stage, we would no longer need our Predictive devices to tell that some is defiantly wrong with this asset. The asset would be hot to the touch as well as having a distinct smell and audible noise associated with this fault condition. This asset will fail violently if not taken offline and repaired immediately. The Cost of the repair is now also increasing ten-fold as the fault condition is starting to create collateral damage in the asset. This asset has now official reached its end of useful life and is now also consuming more electricity to overcome its fault condition which in turn increase its operational cost while operating in this stage of failure.
There is also a safety aspect to consider when the asset is operating in the Failure Stage as routine maintenance at this point could be deadly since the asset isn't operating as designed and any work at this point could cause the sudden failure and possible fatality of the worker. This can be seen if we apply the Heinrich Safety Triangle to the D-I-P-F Curve. There is a direct correlation between the two when we apply the behavior and result to the curve.

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Design Strategies for Asset Management

A major part of asset management is the design strategies and procurement which relies heavily on the input from the Original Equipment Manufacturer (OEM). We must consider the OEM impact upon the ultimate design, reliability, and success of a project. These directly impact the following statistics:

1. As much as 60% of failures & safety issues can be prevented by making changes in design
2. 80% or more of a facility's life cycle cost is fixed during the plan, design, and build phases
3. 30-40% of equipment breakdowns are related to poor equipment design or condition

"Field tests and surveys have shown that 22% of breakers operate at less than 100% efficiency (slow trip), and more than 10% have been shown not to open at all. "

Source: Electrical Safety Workshop Conference Proceedings, 2009; Field Measured Total Clearing Time of Protective Devices and its Effect on Electrical Hazards; Heid & Widup

For the last three years, the hardest segment of the workforce for employers to staff with skilled talent hasn't been registered nurses or engineers or even web developers. It's been the skilled trades – the welders, electricians, machinists, etc. that are so prevalent in manufacturing and construction.

If these skilled-trades workers are difficult to find now, as Manpower's survey indicates, just wait a few years. The skills gap is likely to become more acute. As over 50 percent of skilled-trade workers in the U.S. were 45 years and older, according to EMSI, (Executive Management Services Inc) and 18.6 percent were between the ages of 55 and 64.

I was recently sent an article that hit home with me so much that I opened my presentation about the importance of training at our Dealers Conference. It was striking to me that in 1941 the World was at War and the job market was tough. Similarly, we have found ourselves in a similar situation.

This article was written in 1941for the Bliss College Go Getter by Elmer Wallace Parsons. It speaks to the heart of what I have always stressed, that training is important to get a head of coworkers and your competition.

Vocations

How much more complex has the question of choosing one's vocation become in the last quarter of a century? The chances of climbing high on the ladder of achievement in the business and professional world without specialized training are indeed slim.

Of course, you cannot entirely overlook the factors of luck and "pull". These factors are unquestionably a great asset in the enabling one to make a start but though you have the native ability you will find that you need to be trained well-in some particular line of work. This is the essential if you are to compete with the thousands of others seeking the very type of position you desire. You can no longer be content with being as good as the next person. You must be better. Employers today are looking for those who can do the best work not those who are just average. And specialized with the large number being trained for specialized work in every line of employment you might mention, concerns can well afford to be particular.

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For a second point, don't let the stiff race and amount race and amount of unemployment defeat your own self confidence. You must be sure of yourself! If you have no confidence in your own self, how can you expect others to have confidence in your own self, how can you expect others to have the confidence in you? Don't be mistaken or mislead. Self-confidence carried to a particular self-sustaining point is not conceit. It is an essential characteristic.

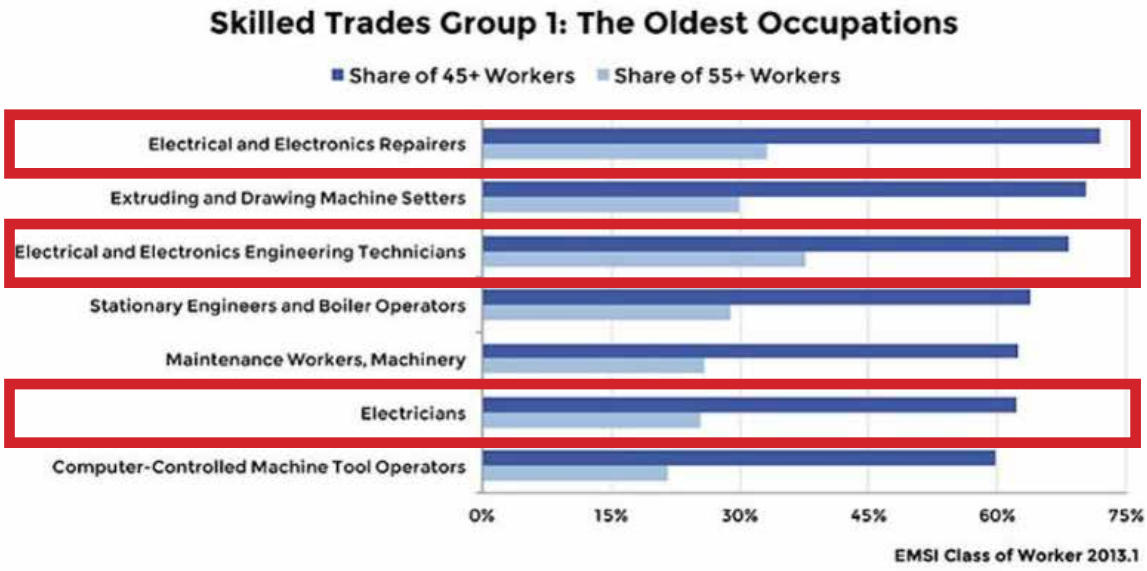
Lastly, don't be discouraged. You must have "stick-to-itiveness."

Advancement will not come with a snap of the finger any more than Rome was built in a day. It is a slow process dependent upon your past achievements and your general attitude toward your position and your associates. I believe Longfellow brought out this point aptly in the last stanza of "A Psalm of Life".

"Let us then be up and doing,
With a heart for any fate;
Still achieving, still pursuing,
Learn to labor and wait."

Written by the late Elmer Wallace Parsons Co-Editor and my Grandfather.

The oldest skills group in the U.S. is electrical and electronics engineering technicians, with 38 percent of jobs held by workers 55 years and older. Meanwhile, a third of electrical and electronics repairers are at least 55, while 72 percent are 45 years and older.



Breaking down the 21 occupations into three groups – the oldest, the not-so-old, and the youngest. Group 1 encompasses occupations where at least 60 percent of the workforce is 45-plus years old. Included in the list are electricians, by far the largest of all the skilled trades with more than 600,000 jobs in the U.S.

This is one of the main reasons to start a CBM program now as it takes a while to get the program off the ground and soaring. As the employees age out of the work force the program will still be able to go soaring along since the reactive maintenance is no longer the norm. It is very important to start your CBM Program sooner than later to help accommodate for the future of Lean Maintenance.

A Recent Emerson Study on The Effect of Regular, Skilled Preventive Maintenance and Remote Monitoring of Critical Power system Reliability on Mean Time Between Failures (MTBF) showed the following Results:

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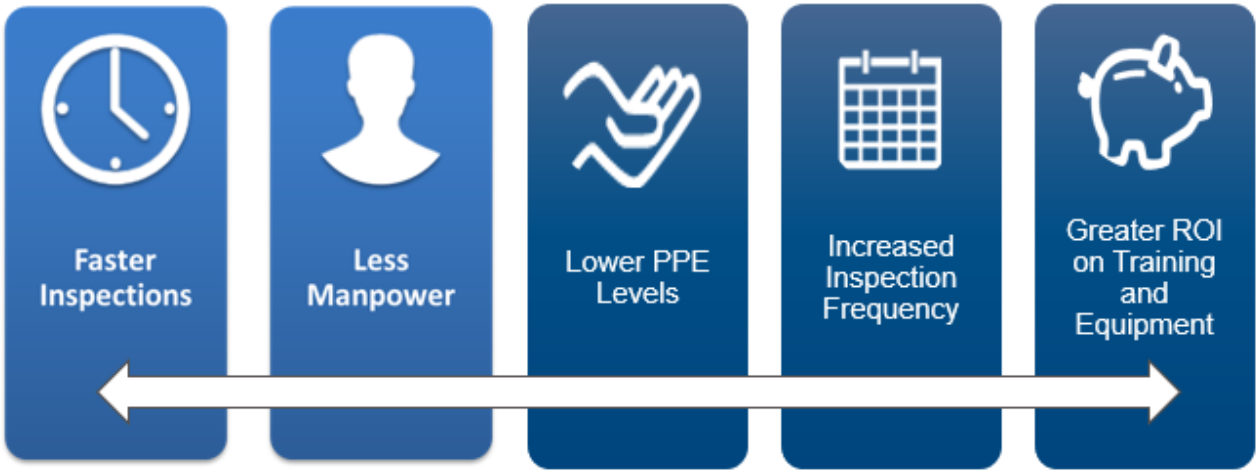
The ROI of a CBM Program

By implementing a CBM Program there are several key items that will be able to be listed as an ROI. First of these is the lowering of PPE levels. This one might not seem like much, but the liability insurance premium may show otherwise. It will also require less manpower to maintain a CBM Program as the inspections of electrical asset will no longer require a two-man team to remove panels and inspect the assets. This will in turn increase the speed at which inspection can be done. This will decrease the cost of man hours required to perform this task.

The program can then start to inspect more frequently than what is performed currently. Since most site only check their electrical systems annually, based off of the recommendation of their insurer another savings may be identified here when you notify them that you have changed to a safer, more frequent interval of test methods, using IRT Cameras and ASU Devices to determine asset health. This ROI should be invested in more training for the CBM Analyst and others on site. It is often a large enough ROI to upgrade your test equipment which may also be reaching its end of useful life.



Some other tangibles of the CBM Program implementation are the removal of high-risk behavior, maintaining closed & guarded assets, conducting inspection under a full load, and testing normally inaccessible equipment. The last tangible from the ROI of a CBM Program is the most import one of all and that's the elimination of over 99% of Arc Flash Triggers!

Benchmarking

Benchmarking is the one of the last steps or first steps a CBM program can take when it comes to assessing the data collected in the field. By establishing a Benchmark, the CBM program can set the known values of what decibel or temperature levels the asset should be under during normal operating conditions. These values can also be collected during a commissioning of an asset.

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All of this will require that data be collected and analyzed to determine what the benchmark value should be set at. Further analysis of this data when setting Benchmarks will also show any out layers that may already be failing. If a CBM Program doesn't take the time to look into the data and just uses the Delta Value approach taught by one manufacturer, they will not be able to standardize the decibel value, and this can have cataclysmic results for a CBM Program that is just starting out. It is paramount that he dat be reviewed and like assets compared to determine what the truest value should be.

Merriam-Webster defines **Benchmarking** as;
1 a : something that serves as a standard by which others may be measured or judged a stock whose performance is a benchmark against which other stocks can be measured
b : a point of reference from which measurements may be made
c : a standardized problem or test that serves as a basis for evaluation or comparison (as of computer system performance)
2 usually **benchmark**: a mark on a permanent object (such as a concrete post set into the ground) indicating elevation and serving as a reference in topographic surveys and tidal observations

ASU CAT 2 Module 2-6 Applications

Ultrasound testing devices have been around for years. Many companies have ultrasound devices that they have only used for one application the entire time that they have owned it. This can be directly related to lack of training. During my 15 years of teaching ultrasound classes around the World I have noted this fact by a simple response at the end of the class from the students. That response was always "Wow! I didn't know I could use it for more than _Insert Application Here. I

can't wait to get back to the shop and tell my company what all we can use this device for." A lot of times when I would show up on site the manager would say "Let me find that unit. We haven't used it in a while, and I know it's around here somewhere. Insert Employee Name Here retire and he was our guru on that thing but, no one has touched since he left!" I would always ask a follow up question to this response. "How long have they been gone?" They would always reply "It's been a couple of years and we want to get this program up and running again that why you are here!"

If maintenance, planning, scheduling, operation, production and management at the site don't know what the unit can do, it while just sit there collecting dust and the knowledge of that equipment fades away. It's important to get everyone at least aware of what ultrasound can do for a CBM Program. This why you should start to strategize how you will implement your program when you complete and pass this course. As a CAT 2 ASU CBM Analyst you are responsible not only to test, trend, document and analyze the data you also need to be the educator and champion of the ASU Program. This is why it is so important for you to fully understand what applications, test methods and the theory of ultrasound can be used for.

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What is Ultrasound

Airborne and Structure-borne ultrasound instruments detect sounds that are not heard by normal human hearing. Average human hearing detects sound in the 20 Hz to 20 kHz range. Ultrasonic sound waves are a higher frequency, lower energy waves that are received by the ultrasound detection equipment.

Detection of High Frequency (around 40kHz) Ultrasound is a powerful method for maintenance inspection of plant and machinery. Many failure conditions give early indication by the producing ultrasonic emissions. These include pressure leaks, electrical discharge and deterioration of bearings and other machinery.

Leak Detection

Leak inspections are one of the simplest of test methods that can be performed using an ultrasound device. It also can be the biggest return on investment for any CBM Program. However, identifying the source of the leak is just the first step of the process as they must be fixed in order to reduce their cost to a facility and maintain the life of the compressors. As each leak contributes to wasted energy and carbon emissions. When it comes to specialized gases the site would be able to save several times more in losses since some gases are becoming scarce.

The use of Ultrasound for leak detection can potential identify the biggest ROI for the purchase of this equipment and training for personnel that will be using the ultrasound device. The key word in the last sentence is potential. Finding the leaks only identifies the loss and isn't considered as savings since it still there leaking. In order to get actually see the ROI the leaks must be fixed.

Compressor Testing

Not only can ultrasound be used to find airborne leaks on a compressor, it can also be used to detect frictional occurrences of a bad bearing, pistons, and crankshaft in the drive system by using a contact module. Leaks in cylinder heads & valves can also be tested using the contact module. The testing of the compressor can help pick up a fault condition that were previously unknown or thought to be impossible to determine.

Heat Exchanger Testing

Heat exchanges are used for a wide variety of processes and are one of the most neglected assets by some companies. Examples of some of the neglect comes from a lack of being able to shut it down due to the high demand it's under. This is why it is important that a CBM Program take into account the ability of ultrasound for online testing. It always better though to perform the offline testing methods we will discuss in an upcoming module.

Valve Testing

With so many different of design that valves come in the CBM Analyst just need to apply the test methods they learn in this course to their testing methodology and it won't matter what type of valve they are testing as the theory will be the same.

Steam System Testing

Steam Systems are the second largest contributor to energy efficiency loses in a plant. Steam is a costly process that many sites never really have a handle on the waste and just like a compressed system a blind eye is cast on it and the leaks just become part of the process. The testing of Steam Systems with ultrasound devices is predominantly a contact test method. Just like testing valves the comparison method can be used to hear the differences between similar steam traps. Some of the keys to a successful

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steam trap test is to know what pressure the system is operating at and then use a spot radiometer or IR Camera to check the temperature to determine if there is the proper temperature differential between upstream and downstream. The Ultrasound can then be used to determine efficiency by recording a sound wave and playing it back on sound analysis software. When reviewing the sound wave, the CBM Analyst should use the Time Signal Analysis Format to count the number of Discharges Per Minute.

Mechanical Inspection

Mechanical inspection is one that has expanded of the years from just being trouble shooting tool to a full-on diagnostic assist. By recording soundwaves, the CBM Analyst can determine the difference between inner, outer race faults, to bearing faults and cage faults. With the deployment of VFD's there has been another item that ultrasound is successful at determining and this is one of the top contributors to VFD failures. Its stray voltage! It will show up with the same harmonic value as the line frequency driving the motor. Loose connection in a pecker head will also generate a distinct 2-time line frequency harmonic that can be seen in the Time Signal analysis.

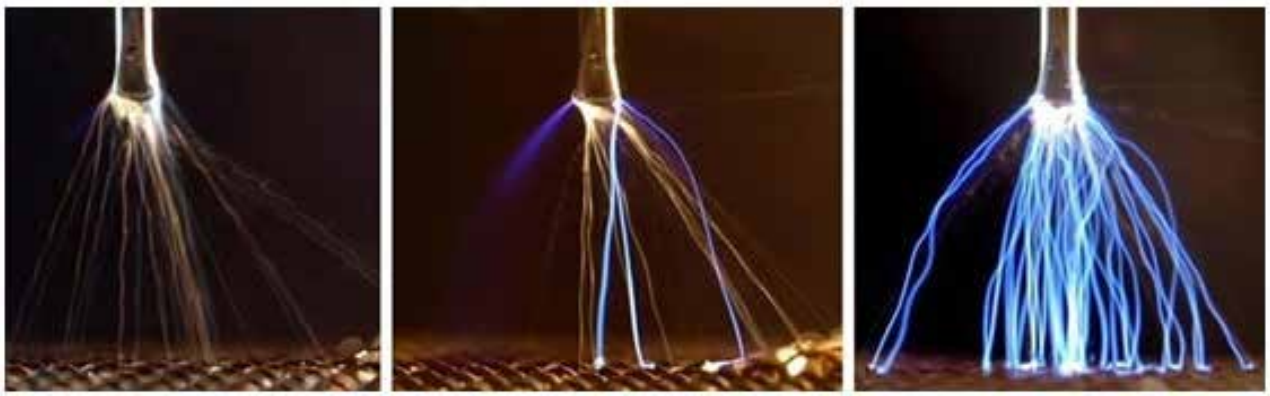
Add the ability to trend the bearings and the CBM Analyst can start setting up lubrication routes based off of actually data and not a time-based interval. This greatly reduces the chance of over lubrication of motors. One key though to any lubrication route is to know the type of motor being tested. Some companies are actually shipping their motors to clients with the grease fittings attached even though the motor bearings are sealed. This has led to many motors receiving lubrication and shorting out once the lubrication starts entering into the windings.

Electrical Inspections

The use of Ultrasound and TEV devices give the CBM Analyst a full range of options when it comes to testing their electrical assets. With their ability to determine Partial Discharge, Corona, Treeing, Tracking, Arcing, Mechanical Looseness, Vibration in Windings, Delamination of Windings, and Dirty Power this is the most efficient tool for detecting faults in energized gear.

Partial Discharge

Partial Discharge Testing has taken a huge leap in the last 5 years with device that allow the user to touch them to metal glad gear and trace back to the source of a TEV (Transient Earth Voltage) event. These are low intensity discharges that will produce a source of ultrasound. It will produce damage which can lead to a more extensive fault condition that if left uncorrected will eventually go phase to phase then phase to ground and arc flash.



Signatures of Fault Conditions

In the interpretation of the site sound waves, it is important to understand the importance of the sound quality for diagnosis. This includes understanding the difference in sound wave pattern of:

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- Corona
- Tracking
- Arcing
- Dirty Power
- Loose Windings
- Mechanical Looseness
- Delamination of Windings
- 60 cycle hum
- Stray Voltage
- Outer Race Fault
- Inner Race Fault
- Cage Fault
- Ball Pass Fault
- Back Pressure
- Bad Slow Speed Bearing
- Steam traps discharge rate
- Normal operating sound signature

It is very important that the CBM Analyst look for the harmonic patterns that fault conditions will present with when the analysis the sound waves, they have captured. This can be the key to determining the difference between Dirty Power too Delamination of a Winding in a dry transformer.

ASU CAT 2 Module 2-6 A Leak Detection

Leak inspection are one of the simplest of test methods that can be performed using an ultrasound device. It also can be the biggest return on investment for any CBM program as each leak contributes to wasted energy and carbon emissions.

However, identifying the source of the leak is just the first step of the process as they must be fixed in order to reduce their cost to a facility and maintain the life of the compressors. In this module we will discuss not only the easy of using ultrasound for air surveys but also the ROI of doing so.

How A Leak Generates Ultrasound

A leak creates a source of ultrasound as the higher-pressure rush through an orifice. The higher the pressure the greater the energy lose is associated with the leak. Many companies have enough wasted air loss to shut down 2 full compressors but, instead of finding and fixing them they just add another compressor to the systems to keep up with the leaks.

Pressure Leaks vs. Vacuum Leaks

Pressure leaks will generate a louder sound than vacuum leaks because the turbulence is exiting the vessel instead of entering it. This makes vacuum leaks a little harder to find especially in the presence of a pressure leak nearby. It is always useful to bring some shop rags to place over the large leaks as a temporary tourniquet to reduce the antagonistic ultrasound present in that area. This allows the CBM Analyst to locate smaller leaks more effectively.
In the case of vacuum leaks the CBM Analyst can also use a contact module to test for the source of a leak.
If a surfactant can be applied to the line the CBM Analyst will listen for the sound of the water splatting against the wall of the vessel being tested when the use a contact module.

Measurement Precautions

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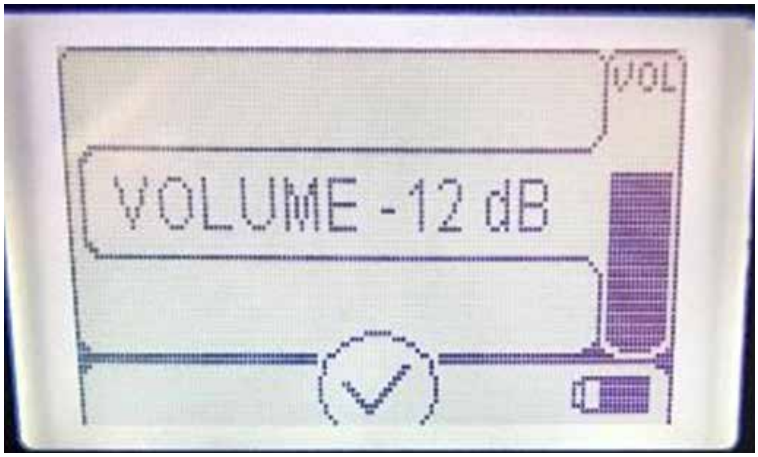
Some of the things to consider prior to running a leak survey are;

- What type of leak is it? IE Pressure, Vacuum, Gas, Nitrogen, Natural Gas, etc.
- Do you need an intrinsically safe device or a hot work permit?
- Are there atmospheric conditions that need to be dealt with while operating in that area?
- What equipment will you need to operate in that area. IE Scissor Lift, Flashlights, Tags, Camera, etc.
- How to overcome any Antagonistic Ultrasound in that area.
- What Is the distance from the leak and what module or accessories to use?
- Capture the reading from the leak 1 foot / .3048 meters away from the source.



It's very important the CBM Analyst adjust the volume on the unit to so they can increase or decrease the detectable distance. This helps to eliminate antagonistic ultrasound, isolate the location since the unit is very directional, and confirm the location of the leak. If the CBM Analyst fails to do so they can miss or mistake site of the leak.

When the volume is a set to 40 it is taking in the full intensity of its surroundings and the leak will appear to be coming from everywhere if it's a large pressure leak. In the case of a vacuum leak it may be set at 40 since the turbulence is inside the piping. By reducing the volume, the CBM Analyst can help to eliminate most of the antagonistic ultrasound in that area.

To confirm the location the inspection can using several techniques including the use of the Focusing Probe to seal up on the suspected leak. One of the other reasons to adjust the volume is avoid overwhelming the CBM Analyst 's ears. If the volume isn't adjusted, they will hear the maximum volume of sound in the headphones which is 85 decibels. Once the CBM Analyst has the found the source of the leak, they will then need to use the principals taught in the Inverse Distance Law of Sound and move to 1 foot away from the source to document the decibel value.

Accessibility to Leaks

1. Accessibility to leaks is a key part to any survey.
2. The CBM Analyst must take into account their distance first and foremost as that will help to decide which accessory to use or module.
3. Pressure will affect the effective range of detection.
4. The Airborne Modules are good for detecting the leaks at the source out to 30 feet / 9.144 meters.
5. The Focusing Probe is great for confirming a pressure or vacuum leak up close but is of no use for a leak over 5 feet / 1.524 meters away.
6. The Long-Range Horn is great to add onto the scanning module for up to 100 feet away but not for more than 150 feet / 45.72 meters away.
7. At a distance further than 150 feet / 30.48 meters away, the Parabolic Dish would be the best option and it would be limited in distance based off the pressure of the leak.

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It is important to start every inspection by performing a sensitivity validation test on the ultrasound equipment to ensure that the unit, modules and headphones are in working order to perform the inspection. As a minimum recommendation, calibration should be performed annual on the equipment to ensure that it meets all manufacture standards.

Before the inspection to ensure that equipment is working properly and at the end of the inspection to ensure that equipment has not malfunctioned. Below is the Scope of what is covered in the standard and like so many others the full standard can be purchase for $40.00 from ASTM online. https://www.astm.org/Standards/E1002.htm

***ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories.

ISO standard used by testing and calibration laboratories. In most major countries, ISO/IEC 17025 is the standard for which most labs must hold accreditation in order to be deemed technically competent. In many cases, suppliers and regulatory authorities will not accept test or calibration results from a lab that is not accredited. Originally known as ISO/IEC Guide 25, ISO/IEC 17025 was initially issued by the International Organization for Standardization in 1999. There are many commonalities with the ISO 9000 standard, but ISO/IEC 17025 is more specific in requirements for competence and applies directly to those organizations that produce testing and calibration results and is based on somewhat more technical principles. Since its initial release, a second release was made in 2005 after it was agreed that it needed to have its quality system words more closely aligned with the 2000 version of ISO 9001.

The standard was first published in 1999 and on 12 May 2005 the alignment work of the ISO/CASCO committee responsible for it was completed with the issuance of the reviewed standard. The most significant changes introduced greater emphasis on the responsibilities of senior management, and explicit requirements for continual improvement of the management system itself, and particularly, communication with the customer.

The 2005 version of ISO/IEC 17025 comprises five elements that are Scope, Normative References, Terms and Definitions, Management Requirements and Technical Requirements. The two main sections in ISO/IEC 17025 are Management Requirements and Technical Requirements. Management requirements are primarily related to the operation and effectiveness of the quality management system within the laboratory. Technical requirements include factors which determines the correctness and reliability of the tests and calibrations performed in laboratory.

The 2017 version of ISO/IEC 17025 has modified this structure to be Scope, Normative References, Terms and Definitions, General Requirements, Structural Requirements, Resource Requirements, Process Requirements, and Management System Requirements. General Requirements and Structural Requirements are related to the organization of the laboratory itself. Structure Requirements cite those issues related to the people, plant and other organizations used by the laboratory to produce its technically valid results. Process Requirements are the heart of this version of the standard in describing the activities to ensure that results are based on accepted science and aimed at technical validity. Management System Requirements are those steps taken by the organization to give itself tools quality management system in supporting the work of its people in the production of technically valid results.

Laboratories use ISO/IEC 17025 to implement a quality system aimed at improving their ability to consistently produce valid results. It is also the basis for accreditation from an accreditation body. Since the standard is about competence, accreditation is simply formal recognition of a demonstration of that competence. A prerequisite for a laboratory to become accredited is to have a documented quality management system. The usual contents of the quality manual follow the outline of the ISO/IEC 17025 standard.

ASTM Standard E 1002-2016

Scope

1.1 Practice A, Pressurization—This practice covers procedures for calibration of ultrasonic instruments, location, and estimated measurements of gas leakage to atmosphere by the airborne ultrasonic technique.

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1.2 In general practice this should be limited to leaks detected by two classifications of instruments, Class I and Class II. Class I instruments should have a minimum detectable leak rate of 6.7 × 10−7 mol/s (1.5 × 10−2 std. cm3/s at 0°C) or more for the pressure method of gas leakage to atmosphere. Class II instruments should have a minimal detectable leak rate of 6.7 × 10−6 mol/s (1.5 × 10−1 std. cm3/s at 0°C) or more for the pressure method of gas leakage to atmosphere. Refer to Guide E432 for additional information.

1.3 Practice B, Ultrasonic Transmitter—For object under test not capable of being pressurized but capable of having ultrasonic tone placed/injected into the test area to act as an ultrasonic leak trace source.

1.3.1 This practice is limited to leaks producing leakage of 6.7 × 10−6 mol/s (1.5 × 10−1 std. cm3/s at 0°C) or greater.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Considerations for a Leak Survey

When preparing for a leak survey it is very important to consider what type of gases maybe in the area? Is it pressure or vacuum? Do I have approachable access to the leaks? And what modules or accessories will help insure the successful detection of the leak.

If there are several leaks in line the CBM Analyst will need to isolate those leaks from the others as a larger leak can mask one that has a lower level of leakage. One way to isolate a leak is to use the Focusing Probe to seal up on the suspected leak. If the level of dB's increases the CBM Analyst has confirmed the source of the leak. The CBM Analyst can also use a shop rag as a temporary tourniquet to isolate the lower level leaks from the large leaks in the area.

Hazards to Consider

One of the biggest things to keep in mind are what atmospheric conditions will the CBM Analyst be working in.
Some areas may be considered a confined space simply because of the air quality in that area. The CBM Analyst also must consider whether their unit is rated for a Class 1`Division 1 Groups A-D area.

If the unit is not intrinsically safe IRISS does not recommend using the equipment in these areas.
However, some plants have Hot Work Permits procedures for operating in these areas and it will be up to the CBM Analyst to ensure their safety and those around them when operating around flammable gases. **Again, IRISS does not recommend or recommend using any non-intrinsically safe units in any Class 1 Div. 1 Groups A-D areas.**

Other things to consider while preforming an Air Survey is the fact that the CBM Analyst can get tunnel vision while tracking down the source of the emission and lose sight of what's around them.

Fork Truck traffic in the area or palletizer robots that can start up in a moment's notice so, the CBM Analyst must follow LOTO procedures in these areas or while walking around keep their heads on a swivel to account for traffic.

Another key item to watch for are any electrical hazards or lighting that could get in the way while operating on a man lift. Never preform Ultrasound inspection while standing on a ladder. There is no way to maintain 3 points of contact. For this reason, it is much safer to operate from a scissor, or man lift than a ladder.

This however could require a second technician to be the ground guide during the survey.

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Why Check for Leaks

The reason leak detection testing is so important is it offers a plant with so many avenues of ROI. The first ROI is Safety. Toxic & Asphyxiate gases can quickly overcome workers and can cause serious or life-threatening events inside a plant. The loss of life and production can become very costly when your factory is facing the possibility of lawsuits from family members for wrong death or long-term disability for employees. In the same vain some of these gases are known greenhouse gases and the release of these can cause damage to the environment not to mention the potential of fines for their release.

An air survey can account for the cost avoidance of annual usage of electricity and the greenhouse gas emissions reduction. This give the CBM Analyst a powerful addition to just reporting there is a leak at 35 dBs on that regulator.

Where a company can really justify, the ROI is doing an Air Survey to show the annual cost avoidance that can be achieved by fixing identified leaks. Some air leaks can cost a plant as much as $1,000 annual whereas a Nitrogen leak can cost that daily. So, finding these leaks and totaling them up quickly pays back the money invested in the equipment used, the training the CBM Analyst should receive and the operational hours of the CBM Analyst /s. Not to mention the increased efficiency of the compressors and insuring they run to full operational life span.

Safety Tips

It is very important that the CBM Analyst /s always take into account any and all safety hazards that can be present on site. This can be simply overlooked because the CBM Analyst become complacent in the workplace. Take 5 minutes to huddle up and go over the risk factors prior to going out.

Ensure that all equipment is rated to operate in that area. If a scissor lift or man lift will be used, is the CBM Analyst properly trained and authorized to operate it. If asphyxiate gases are present will there be a multi gas meter present as well as SCBA or other respiratory protection.
Over pressurization can be catastrophic as well as a vacuum system that becomes plugged up.
NASA test satellites under pressure and vacuum with pressures exceeding 4500 psi.
In the case of leaks at this pressure the CBM Analyst will need to be cautious and not reach in too close to the source of the emission and should never place their hands on any pressured leak.

Quality Assurance

With so many applications for quality assurance testing the ultrasound device is truly the multitool of leak detection. From testing for hatch covers to the use by the US Navy under NAVSEA 9820-4025 9820-4029 for the testing of Bulkheads it is the quickest and safest way to avoid or confirm pressurization testing results.
If your vehicle has a whistle in it when you drive, there is an air ingress somewhere and is difficult to pinpoint the exact location of the sound.

Using ultrasound can quickly pinpoint the location when a tone generator is placed inside the vehicle and scanned from the outside. Have a draft in the winter use the same steps to confirm the exact spot where the air infiltration is coming from.

Environmental Conservation

Air Surveys help find leaks that waste energy and contribute to greenhouse gases. This can allow companies after repairs are made to show an annual cost avoidance & reduction in their electrical usage which can then be calculated to figure out over all carbon footprint reductions.

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This can then be sent off to the power companies, state, or federal government to apply for tax incentives for reducing their energy usage. It can also be used as a marketing strategy to the community for some great public relations ads and feel good stories. This really help in the case of some sites who use compressed gases that can harmful to the environment or people living nearby. Where the release of these gases can lead to fines and potential lawsuits in some cases when leaks effect the surrounding area.

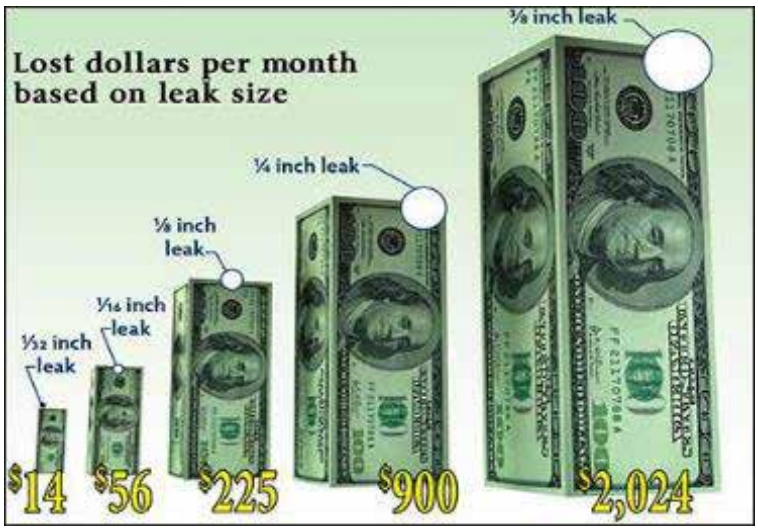
Energy Conservation

The Energy Conservation is the biggest ROI for an ultrasound program, because it can quickly identify annual cost avoidance for a site. One print mill was starting to consider getting a 6th compressor for their site. They were going to rent a diesel compressor to help with the demand the system needed. Prior to finally committing to this, a technician who had just attended an ASU CAT 1 course told the Maintenance manager what he had learned to do with his ultrasound equipment for finding and documenting leaks.

He was sent out to start an air survey and in a 2-week period he had found $150,000 in leaks. Over the next several months they started fixing these larger leaks since they were the low hanging fruit. During the first month, they shut down one compressor down completely. The next month they shut a second one down and eventually got to a point where they were running 1.5 compressors on site.

The Cost of Compressed Air

Compressed air has been used and abused for years and is often treated as something that is free. Some operators will even put small holes in the plastic pneumatic tubing near their operating station to cool off. Some will even clean themselves off or the shop with an air tool. This is another source of wasted air but also a safety hazard.



This chart above is a general guide to calculate the losses by estimating the orifice size. The 1/4” diameter leak can create a $900.00 annual loss, or a 3/32” diameter leak can create a $1,904.00 a day loss based on 100 psi, $0.25 /mcfm, 8760 hours / year.

Keys to a Successful Air Survey

The reasons sites should perform an air survey are all the same and it doesn’t matter if it’s a wastewater treatment facility or a major automotive manufacturer. Ever site uses electricity to manufacture compressed air and this has a direct effect of profitability for that company. It will also identify wasted air that drains on the system and also ensure that the compressor

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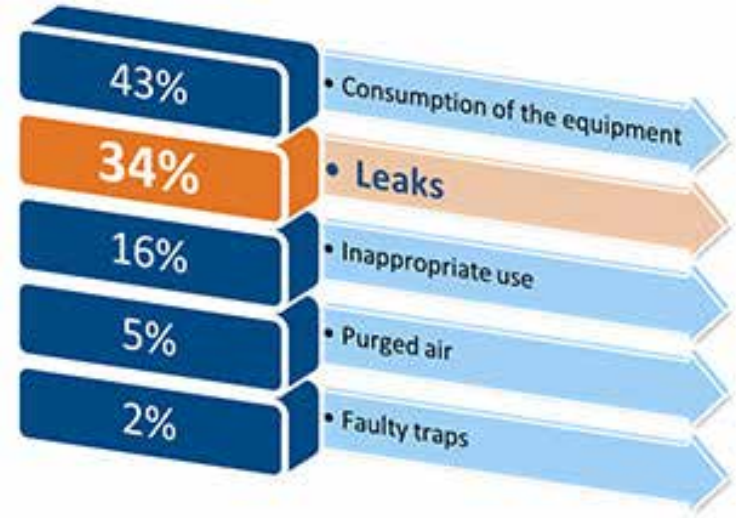
will last long enough to achieve its maximum life span. Prior to starting an Air Survey, a meeting should be set up with Plant Management, Engineering and Production to identify current estimations of energy consumption from the compressed air systems.



The ROI of an Air Leak Detection Survey

Sometime these leaks are manmade, like using air to blow packages without a photo sensor being installed so, its constantly blowing air when it could be turned off and on as the packages go by. It can even be caused by someone not placing thread tape on the threads of the gauge of the regulator, maybe it's a split hose in the middle of an air hose reel, or even the quick connect being used are a poor quality because the bean counters wouldn't spend the money on a higher quality quick connect that hold up better.

These poorer quality quick connects usually cost 1,000 times more in wasted air than the savings achieved by buy them vs the higher quality ones. All of these leaks being fixed will increase the effective usage of air in the system and reduce the electricity consumed by the site. The site could even see the benefit of shutting some compressors down once the leaks are repaired and the system is back in a healthy state.

How to Calculate the Cost

According to the Compressed Air Challenge of the U.S. Department of Energy's Office of Industrial Technologies, the total cost of 100 psig compressed air has been calculated to be in the general range of 18 to 32 cents per 1,000 manufactured cubic foot per minute. (Source: Best Practices for Compressed Air Systems by Compressed Air Challenge). This varies from state to state based off of the cost to the site. This formula will produce an estimate that is 85% accurate on the conservative side as to what the annual cost avoidance is for each leak as well as the total of the sum of all leaks.

The formula breaks down as follows:

CFM = Cubic Feet per Minute, this can be the value for one leak or the total sum of leaks.
60 = The number of minutes in an hour.
AHRS = The total number of hours the systems are operating annually.
1000 MCFM = Based off the cost off of Manufactured Cubic Feet per Minute.
kWh = The cost per Kilo Watt Hour.
Annual Cost Avoidance = The annual cost avoidance of a leak or the total sum of all leaks that can be negated.

The formula used to determine annual cost avoidance of a leak is
(CFM x 60) (8760 AHRS) x Cost kWh = Annual Cost Avoidance

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1000 MCFM

Using this formula let's figure out the cost of leaks totaling 58 CFM at a kWh cost of $.20 kWh

Step 1. (58 x 60) = 3480 Step2. (3480) (8760) = 30484800
Step 3. 30484800 = 30484.8 Step 4. 30484.8 x .20 = $6,096.96
1000 MCFM

Compressed Air Systems

In the Mid 19th Century the development of compressed air systems for industrial applications to power equipment and tools started to replace steam systems since they lost pressure due to the friction generated by the condensate.

The first major use of compressed air came in 1861 during the drilling of the Mont Cenis Tunnel in Switzerland, where a compressor was set up with a pressure of 87 psi to power the pneumatic drills, which greatly increase the effectiveness over the old manual drilling methods.

Even George Westinghouse was known for inventing an air braking system for trains that increased the safety of train operations around the World. A distribution system transports compressed air to the location where it is needed. A "prime mover" powers the compressor. Controls regulate the amount of compressed air that is produced. Contaminants are removed from the compressed air and accessories to keep the system operating properly.

CBM Analyst s who are familiar with the pneumatic system and proficient in scanning techniques are able to complete the Compressed Air Leak Survey without spending a lot of time aimlessly search for leaks. It is important that the CBM Analyst understands the lay-out and function of a pneumatic system before performing the inspection, interpreting inspection results, and avoid making unnecessary repairs. It is also important to always verify your diagnosis using techniques taught to you in this class.

Air Inlet Filters: An air inlet filter protects the compressor from atmospheric airborne particles.
Compressor Cooling: Air or gas compression generates heat. Compressor units are cooled with air, water, and/or lubricant oil.
Intercooling: Multi-stage compressors use intercoolers, which are heat exchangers that remove the heat of compression between the stages of compression.
Aftercoolers: As mechanical energy is applied to a gas for compression, the temperature of the gas increases. Aftercoolers reduces the air temperature after the final stage of compression. As the temperature is reduced, water vapor in the air is condensed, separated, collected, and drained from the system. Sometimes the aftercooler is an integral part of the compressor package.
Filters & Separators: Compressor filters and separators remove contamination from the air before it enters, and as it exits, the compressor.
Pressure Regulators: Deliver varying volumes of air in respond to the changing demand in addition to regulating pressure.
Air Receivers: Receivers are used to provide compressed air storage capacity to meet peak demand periods. Where peaks are intermittent, a large air receiver may allow a smaller air compressor to be used and can allow the capacity control system to operate more efficiently and improve system efficiency.
Traps and Drains: Are used to prevent the loss of air through open petcocks and valves. Drain valves should allow removal of condensate but not compressed air. There are mechanical and electrical traps.

Logistics of a Compressed Air Systems

For year companies have allowed their leaks to go unfixed. The sound of hissing becomes the norm, and everyone goes about their business as usual never taking into account how much money is actually wasted with the escaping gases around their plant. Several companies that I have visited over the years have sent guys out with soapy bubble solution such as snope or shaving cream to identify these leaks.

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Some companies even use smoke sticks to see where the leak is coming from. Other companies invest in gas sniffers which are great for detecting the parts per million in the area but can quickly become over saturated and cannot be efficiently used on windy days as the gas cloud gets pushed around and dissipates.

These methods are old and outdated with the development of ultrasound detection devices. During one site walk in the Philadelphia area we spent the better part of 2 days tracing nitrogen lines from the tank farm all over the site. During the initial size up it was stated they were losing $500,000 a month in nitrogen gas leaks.
So, the survey was started at the source which was a large tank farm of compressed gases. We walked the path of the underground piping out from the tank farm with the thought that if the leak was that large, we would surely pick something up.

As we approached the first T in the line going to a building, we followed the line and to the footprint of the building. I asked if we could enter the building, but it was locked up and we would need to get permission from the sites Safety Officer and the Security Supervisor before entering the building. So, we continued on our way and over the 2 days were only able to locate around $18,000 in leaks.

I kept asking if there was any way we could get into that first building, but the guy said it would be next to impossible in such short notice. A couple months later I received a call from the site saying they have found the source of the leak and it was located in the building that was locked up. Apparently, the header pipe in the basement had been damaged during the move out work and it wasn't reported. Had we continued to follow the flow into that building we would have located the leak early in the survey and easily saved them a million dollars.

Logistics of Compressor Testing

Due to the nature of the beast, the compressor rooms can sometimes be the toughest challenge for an CBM Analyst. This is because the inherit noise levels associated with compressors. As they can produce a lot of antagonistic ultrasound as well as the rare case of a strong acoustic pressure wave that can literally rattle the CBM Analyst 's brain from the reverberation in the room. This can cause severe stress to the CBM Analyst and cause health risk not worthy of continuing.

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This is similar to the use of a the LRAD (Long Range Acoustic Device) used by the military and police around the World as a non-lethal crowd control device. The sound wave it produces is not only deafening it literally rattles the brain and makes those that are exposed run in retreat.

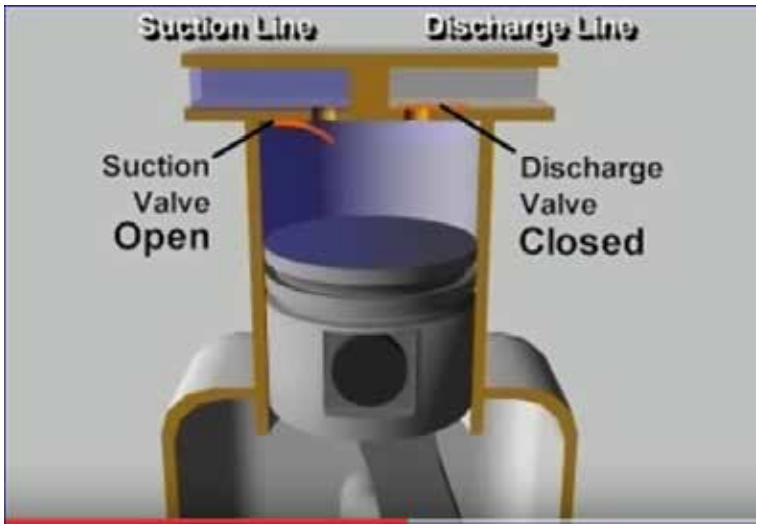
There many types of compressor so, the CBM Analyst will need to understand what type they are prior to testing them so, they know where to test for effective readings. There are several types of compressors that a site could use. From Rotary Screw to Centrifugal, Axial, Reciprocating and Scroll. Each of these are different and the CBM Analyst will need to know which type they will be testing in order to be successful.

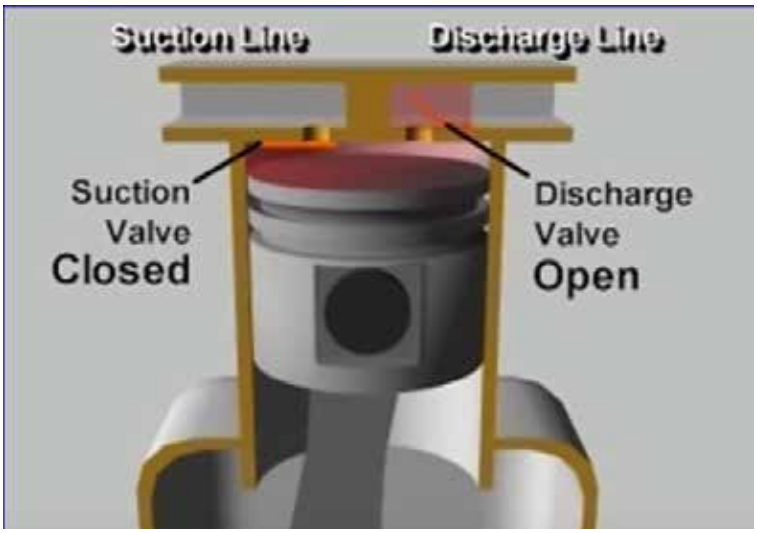
The use of ultrasound for the testing of compressors can be two-fold. First the CBM Analyst can perform an airborne detection for air ingress or egress around valve covers and other areas in and around the compressor.
The process would be the same as an air leak survey and all the methods that are used for a standard leak detection survey.

The second test would be a structure borne test using the contact module and placing it directly over the valves to listen and record the sound wave of the valves. This allows the CBM Analyst to use the Time Signal on the sound analysis software to compare and see the timing of the valves operation to determine if they are all functioning at the same rate. This method is called the comparison method and it can be used for all test application.

The comparison method is the easiest of methods for CBM Analyst s to use to determine if there is an issue with the equipment they are testing. Since there are several compressors valve it is easy to compare on of the inlets to each other and do the same with the outlets as well. The CBM Analyst can also use the contact module to test for issues with thrust bearing, crank shaft bearings, pistons, split pieced timing gears, and rotor issues.

Since the compressor produces turbulence the CBM Analyst can easily use the comparison method to listen in for the difference between all of suction lines and discharge lines opening & closing. This would be greatly aided by using a Time Signal Analysis software to see the duration of the discharge in the tenths of seconds it takes to open & close. A noticeable difference not only could be seen but calculated as well.





If the ultrasound device is capable of frequency tuning, they can set the unit to 40 kHz for airborne testing of air egress or ingress or for structure borne, they can tune the unit to 25 kHz for contact testing. The CBM Analyst will need to listen to the sounds to pick up the subtle difference in sound patterns and hints that the timing is different. The CBM Analyst would also be best suited to record the sound wave so it could be analyzed in a time signal format using the overlay 3D feature. Then produce a report to show the difference between its own compressor's valves or any other similar equipment for comparison analysis.

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Logistics of a Compressed Air Leak Survey

Every Air Survey should start at the compressor room and follow the flow of the headers out to the plant floor.
From there the CBM Analyst will need to determine if they are going to follow the header all the way around or stop and trace every down leg off of it to the end of the line and come back to the header.

This will help to ensure that a valve isn't shut off and potential causing the CBM Analyst who starts at the end and works their way back up stream hasn't wasted time and effort on a shut offline. It will also be important that the CBM Analyst knows how to use the proper techniques for locating, isolating and confirming the leak source.

Many techniques over the years have been proven to be over complicated and irrelevant since they contradicted themselves.
This chapter will train the CBM Analyst on the easiest ways to go about preforming an air survey based off of actually Real-World experiences.

Directionality

Antagonistic Ultrasound

Although the ultrasound devices do not pick up low frequency sound waves, they can encounter antagonistic ultrasound.
These antagonistic ultrasound waves can make it challenging at times for the CBM Analyst if they aren't properly trained on how to overcome them. This is why it's important to listen to the are prior so the CBM Analyst can identify potential sources of antagonistic ultrasound.

One of the other key pieces of the equitation are the headphones which attenuate 23 dBs of sound waves.
One thing every CBM Analyst should do is sweep around the room to try and visualize where the Antagonistic Ultrasound is coming from. This will help the CBM Analyst understand what they are hearing from the reflection of these nuisance sound waves.

Leak Inspection

Leak inspection can be either an airborne or structure borne event. This is why the CBM Analyst must take this into consideration when planning the leak survey. If a compressor valve is leaking by or a valve is by passing a Scanning Module will not pick up the sound because the first medium is the interior of the body and the housing is the second medium.

So, this would require that the CBM Analyst use a Contact Module to test for the source of the leakage.
Airborne inspection is the easiest to perform as the CBM Analyst is in the first medium and the Scanning Module is the second medium. The Long-Range Horn and Focusing Probe could also be used in this test procedure to help identify the source of the ultrasound emission versus the antagonistic ultrasound.

Follow the Flow

The First step to an Air Survey is to Follow the Flow. It's just as easy as it sounds. The CBM Analyst will start at the compressor room or the Header as it enters another room and follow the flow of the piping. As the CBM Analyst finds a down leg, they can continue to follow the header around or that down leg. Never start at the end of the flow and try and work back to the compressor. This can lead to wasted time if a valve is closed upstream.

Reducing the Distance

Once the CBM Analyst enters the area of air survey, they need to follow the flow and reduce the distance between the leak and the

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ultrasound device. If the CBM Analyst follows the flow of the system this helps to eliminate using over complicated procedures that companies were taught in the past and expedites the leak survey. Reducing the Distance can be used at any distance.

Positioning

No matter the CBM Analyst 's distance from the potential source of the leak, they need to consider the position they are at and try and move 360o around the target to confirm the Angle of the Incident. This can be done from 12 inches away to over 100 feet away depending on the pressure of the leak. By moving from one around the target or moving the device around and observing the ultrasound readings, the CBM Analyst is able to determine the actual area emitting the ultrasounds through a process of elimination.

How to Overcome Distances

If the CBM Analyst knows that they will be working at a distance further than 20 feet, they want to use the Long-Range Horn or Parabolic Dish to help narrow the field of listening. These help to minimize the field of listening and extend the distance of listening.

Since the sound was attenuate over a distance the use of the Long-Range Horn and Parabolic Dish help to increase the ability of the unit to focus on the source at these great distances. As the CBM Analyst reduces the distance, they will notice the display will show higher dB's levels as the approach the source.

Long Range Horn

The Long-Range Horn is a simple accessory designed to slide over the Scanning Module to help narrow its field of listening while extending its distance of detectability. Its effectiveness will be directly affected by the energy of the sound wave from the source. It is not effective beyond 60 feet or 18.28 meters.

Parabolic Dish

The Parabolic dish is the most effective module for detecting emissions over 100 feet or 30.48 meters. It will narrow the field of listening down to 10. This is perfect for those sites with the Headers more than 60 feet off the floor. With the Walther Red Dot Sight, it makes the identification of the source of the emission much easier for the CBM Analyst to visualize what they are targeting. Its two-piece design makes for easy storage in the same case as the Sonus XT is also a convenience.

Confirming The Location of a Leak

When performing a leak survey, the CBM Analyst will need to know how to confirm the location of the leak. There are several very simple and straight forward methods they can use to isolate and confirm the source of the leak.

- Using Focusing Probe.
- Sealing up the target.
- Blocking with the body.
- Blocking with a clipboard or some sort of barrier.
- Use a wipe rag.
- Use a gloved hand.
- Snoop or soapy water.

Blocking with The Body

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One of the fastest ways to shield against antagonistic ultrasound is for the CBM Analyst to block the sound with their bodies. Since the ultrasound waves are so weak, they will not penetrate through your body and into the ultrasound unit. By positioning your body between the target emission and the antagonistic ultrasound you can shield a lot of the interference. You may also consider placing the unit closer to the center of your chest to enhance the shadowing effect your body provides. This allows the CBM Analyst to continue on while minimalize interference.

Blocking with a Clipboard

Using a clipboard is another easy method to use to block against antagonistic ultrasound. Just like blocking with body the clipboard is thicker than the distance between the peaks of the sound waves, so they won't be able to pass through it. This method will also help minimalize interference from antagonistic ultrasound.

Wipe Rag & Gloved Hand Techniques

The hand has been used for years for finding leaks, but this can be an unsafe practice as materials can become embedded in the skin and in the case of higher pressures the loss of digits is possible. So, it is recommended that CBM Analyst never place a bare hand or fingers directly over the leak to seal it off. Instead a gloved hand is a safer option for less hazardous pressures. When the CBM Analyst places their gloved hand around or over the leak the sound & dB's will decrease if the leak is covered.

Likewise, a wipe rag can do the same if the CBM Analyst doesn't have a glove. The benefit of the wipe rag over the glove is the CBM Analyst can tie it off over the leak if it overwhelmingly loud and causing too much antagonistic ultrasound. This will allow the CBM Analyst to continue on down the line and find much smaller leaks in that area. This technique can be repeated several times over if need.

Sealing Method

The Focusing Probe is an accessory that can be used to seal up on the target to help confirm or deny the existence of the source of the leak. The Focusing Probe is also excellent for identifying vacuum leaks.
Once the leak site is thought to be found, seal up on the target and listen for a sucking sound.

Bubble Solution

For beginner and mature CBM Analyst s alike the bubble solution also known as a surfactant, is a **great** confirmation of the source of the leak after its been found with an ultrasound device. This is because the **CBM Analysts**, especially beginner still are not confident in what they are hearing and we as a society believe the human experience of sight over the hearing experience.

This is why the bubble solution has also been used for years as inexpensive leak detection method. It is however a limited test and can take up to 20 minutes (10-2 mbarl/s on an air system or 10-3 mbarl/s in Helium systems) for a bubble to develop on lower pressure leaks. This is a great secondary test to show nay-sayers the existence of a leak when they can't see it, feel it or hear it after it was found with the ultrasound device.

Mid-fine Leak Detectors

Mid fine leaks are easy for ultrasound devices to detect but there are other test methods and devices out there but, they are usually limited in their capabilities. Helium Gas Sniffer use a micro thermal conductivity sensor to detect the presence of leaks down to 10-7 mbarl/s. Multigas sniffer are designed to tell what the PPM are in the atmosphere and quickly become over saturated in higher levels of the gases they are trying to detect.

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Dye Penetrant Testing

Dye penetrant testing has been used for several different applications. From leak through on vacuum systems, phone lines, heat exchangers, pipe leaks and even at the famous Oak Island Money Pit. It comes in many colors and even a fluorescent dye that require the use of a black light. It can be very time consuming, but effective.

Vacuum Leak Detection

Vacuum leaks are usually tougher to locate than pressure leaks, since the turbulence is inside the vessel, making them much quieter than a pressure leak and as such harder to find. If the CBM Analyst can introduce a surfactant to the vacuum line this can be used to help aid the testing and confirm the leak site.

When the CBM Analyst isolates the area suspected of being the source of the leak the surfactant can be applied to the surface which will cause the sound to disappear temporarily as the surfactant is pulled through the orifice.
The CBM Analyst would then apply again over the source of the leak and use their close focusing probe to seal up over the source.

When the sealing method is used the CBM Analyst will notice little to no sound at first but, once the surfactant exits the orifice into the vessel the turbulent sound will start up again. A vacuum leak will have more of a sucking sound rather than a hissing sound of a pressure leak. The CBM Analyst could also follow the same procedure when using a contact module as the surfactant will make a sound as it smacks against the wall of the vessel. This process can also be used on vacuum valve stems test as well.

Airborne Ultrasound Tone Testing

Tone testing is a procedure that utilizes high frequency sound as an artificial pressure to find small leaks. These leaks can cause bulkheads to fail when needed or cause a whistle while driving your car. For the building envelope testing it is a great aid ad at finding where leaks of water and air are coming into a building. Building envelope testing is best suited to be performed with IR Cameras as well as Ultrasound to help pinpoint the area of air ingress & egress.

One test that IRISS took part in was with a company that manufactures the panel windows for skyscrapers. Their concern was to find where the wind, noise, and water leak issues in panels after they assembly and installation.
They had been using the bubble test method as well as pressure decay testing in the manufacturing site and were looking at other options for testing pre and post install.

They used a chamber to apply water to one side of the panel and look on the other side for bubbles to develop and, was in effective once it reached levels leaks ranging in size from 1-5 SCC/min (standard cubic centimeters per minute) and as high as 10 SCC/min. The reason for this is the bubble solution clog the orifice and the air flow will actual change from a vicious flow to a molecular flow. This makes testing using bubble solution under these low pressures impossible since the solution's molecules will clog the path of the leak making bubble testing impossible to do.

The Sonus XT was however able to detect at a much lower level and was successful down detecting leaks down to reaching below $1X[\![10]\!]\text{^ }(-2\ mBAR)\ X\ Liter\ Per\ Second$. However, once the pressures started getting below $1X[\![10]\!]\text{^ }(-3\ mBAR)\ X\ Liter\ Per\ Second$ the ultrasound was ineffective.
There are some draw backs with bubble testing and ultrasound pressure testing and therefore Tone Testing could be used as an artificial pressure and the sound will penetrate the smallest of openings because nothing is blocking the orifice. In one case a client was looking to use ultrasound for micro-porosity evaluations in a fuel cell component.

They had been using Nitrogen Gas and an IR Camera to try and look for these micro-porosity leaks in the fuel cell components with little to no success. When they looked into ultrasound as a choice it was decided that the best way to test these components

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was to design a housing that was 2 inches thick and place a tone generator in the bottom at 1 foot from the bottom of the component.

The shape was that of a four-sided funnel to direct an even field to the underside of the component and a seal at the top insured no sound would exit in an undesirable way. As the benchmarking testing proceeded the CBM Analyst would swap back and forth across the plate looking for a rise in decibels. It was determined that 23 dBs was the norm a leak free component and anything above that was an issue.

Bulkhead & Compartment Testing

Years ago, the US Navy approved the use of the Ultrasound to asset with bulkhead and hatch cover testing.
The Navy regulation that covers Water Tightness Integrity Testing is NAVSEA 9880.4025 - **9880.4029**. This test procedure came about to replace the old soapy bubble test that a 5-man crew would perform on large naval vessels like an aircraft carrier.

The normal operation is to pressurize that compartment with only 3 PSI and have the crew members on the opposite sides of the hatch covers, doors and walls that needed to be checked. This proves extremely difficult to do in areas like the hanger bays on an aircraft carrier not to mention very time consuming to boot.

During the initial trails of the validity of Ultrasound Tone Testing two teams were used to do the standard bubble test method and the other team using the ultrasound tone test in a controlled environment.
During this testing the teams found that in under 30 minutes the ultrasound team identified the same likes the bubble test team took over and hour to find.

Satisfied with their findings they tried this same comparison testing on an aircraft carrier and when the results came back with similar results, they rewrote the standard to include the use of Ultrasound Tone Testing.
One jet mechanic used a tone generator and pressured the cockpit of a fighter jet while it was inside.
He used a grease pencil to mark the areas he heard the tone generators sound and in about an hour he had identified several leaks that he then used his bubble solution and it took him 7 hours to find all the same leaks he had found in an hour with his ultrasound device.

Heat Exchangers, Condensers & Chillers

Heat Exchangers have evolved over the years and testing them has always been labor intensive. Some CBM Analyst s have gotten creative with their test procedures and determined how to test while the units are still operating. Some sites are limping theirs along till they can pull the funds together to install newer plate heat exchangers and, as such ultrasound wouldn't be the best test method for plate heat exchangers. The best option for plate heat exchangers is Infrared. So, for those still using Tube or Bundle systems these next methods will be the best at determining the condition quickly and easily when the system is offline.

Often the heat exchangers that are still in use are in the basements tucked away in areas that make it impossible to remove and replace. This has led to many sites going to smaller plate heat exchangers strategically positioned through the manufacturing floor. These smaller heat exchangers are easier to maintain, and replacement of plates make it more efficient then plugging tubes in the bundle.

So, the testing of Heat Exchangers becomes very import for sites that do not have the capital funds to replace them in the near future. The use of Ultrasound can help with the inspection of Heat Exchangers, Chillers and Condensers with one of 4 test methods.

These four test methods involve three of which are offline testing and the fourth is an online test. The CBM Analyst can even check fittings, headers, boiler casings, condenser tubes, inlet end erosion, stress corrosion cracking, crevice corrosion, tube OD damage and valve stems with the scanning modules as the pressure exiting the orifice will produce ultrasonic emission.

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Condensers can be tested the exact same way as Heat Exchangers and Chillers. So, this means we can use pressurized air to scan smaller areas of the face of the tubes. We want to compare similar tubes around the possible leak. When putting the system under vacuum we can heighten the flow of air in the smaller area of inspection by placing plastic over the tubes that are not being inspected. This will help to increase the amplitude of the decibels by minimizing the effects of tubes that are leaking in the areas that are not being tested. I will even act as a visual confirmation as the plastic wrap dimples from the force of the vacuum effect on tubes that have a leak. The use of a Tone Generator can also help find which tubes are leaking. Some companies are still using the old school method of using foam on the face plate to watch for bubbles to develop but the use of foam can actually block smaller leaks from being detected since it has such a thick constancy.

Pressure Testing

Pressure testing is always recommended as the first test method for heat exchangers, condensers & chillers offline testing. Pressure Testing is an offline test that is done by isolating the unit from all potential downstream or upstream source so, air pressure can be introduced into the shell side. The CBM Analyst s will open up the heat exchanger to gain access to the tubes. Then by scanning across the face of the bundle they will listen for the sound of air leaking. Then start sweeping the around the area of the sound and reducing the volume down on the until they barely hear the leak. They will then move in to isolate the tube that's generating the sound of the leak. Next slip the Focusing Probe over the Scanning Module and place the tip at the opening of the tube. If the sound gets louder insert the focusing probe deeper into the tube and listen for an increase of sound and decibel display on the unit. Back out and place a glove hand or wipe rag in the opening of the tube and see if the sound goes away. If it has? The source has been found and the tube can be plugged.

Vacuum Testing

In some cases where a systems cannot be placed under pressure; vacuum testing could be used. It follows the same steps as pressure however, the CBM Analyst will place the shell under vacuum instead of pressure and proceed as above. The problem with vacuum testing, however, is that the holes can become blocked and restrict the air flow being pulled into the shell, which also reduces the sound level. This test requires the added steps of cleaning out all the tubes prior to the inspection which can add significant time to the test procedure. It's for reason that vacuum is not the preferred method.

Tone Testing

Tone Testing also follows the same rules as vacuuming testing. It is dependent on the sound level it can generate inside the shell. This can be a problem with the baffles inside of the heat exchanger or chiller. For this test procedure the CBM Analyst s may need to place tone generators on the inlet and outlet of the heat exchanger. This will ensure the shell side has an even level of ultrasound present in the unit.

The Battleship Method

The Battleship Method is a contact test done while the unit is online. This involves setting up zones to test. Once the zones are established (Recommend using geographical reference points IE; North, East, South, and West) the CBM Analyst will start in that zone and make contact and move the contact module every six inches.
As the CBM Analyst moves, they will watch and listen for a jump in sound.
When the sound hits a high level, the CBM Analyst will change direction up or down 6 inches from the highest reading to see the readings drops again above or below that point. If the sound level goes down as the CBM Analyst moves away from the highest level, then they have isolated the source of the emission. This test however doesn't not tell the CBM Analyst how many or which tubes are actually leaking. A leaking tube will make a popping or crackling sound. If there any insulation on the outside of the vessel, test holes will need to be made for future testing. Do not use the Contact module to make these holes.

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Confirmations Methods

To confirm the source of the leaking tubes, scan the zone from about 6 inches away from the face of the tube bundle. When a smaller area is identified, reduce the volume to a lower level till the emission can just barely be heard. Be sure to properly position the airborne module over the tubes opening and seal up against it. If the sound increases, turn down the volume of the unit till the sound can just barely be heard. Then move to the surrounding tubes and confirm that sound diminishes when sealing up against the surrounding tubes.

Condensers

Condenser can be tested the same way as Heat Exchangers and Chillers.

- Air pressure test
- General area to a smaller area
- Comparing similar tubes
- Heighten flow of air with plastic wrap
- Increase amplitude of the turbulent flow
- Tone generator
- Foam
- Surfactant

How Ultrasound Could've Helped Prevent a Fatality

From www.EHSToday.com
Written by Sandy Smith

On the morning of June 13, 2013, a massive explosion rocked Geismar, La. As many as 600 workers were at the Williams Geismar Olefins chemical facility when an explosion occurred just after 8:30 a.m. Two employees died and another 167 reported injuries, many of them serious. The explosion started a large fire, and people as far away as 2 miles were ordered to shelter in place.

A jury in Iberville Parish, La, on Nov. 15 found that plant owners and operators "were negligent with respect to the cause of the June 13, 2013 incident." The jury decided in favor of four workers injured in the explosion, reaching a combined $16.1 million verdict for the workers. Saudi-based Sabic Petrochemicals, which owns a 1/6th stake in the facility, was added as a co-defendant in the case and was assigned 16 percent of the liability. Other defendants included Williams Olefins and its parent company – which was assigned 83.6 percent of the fault – as well as plant official Parker Tucker and plant supervisor Larry Bayer, who each were assigned .2 percent of the fault.
The case is the second of many. In the first case, four workers were awarded a total of $13.6 million in damages by an Iberville Parish jury on Sept. 26. The jury determined that Williams' Oklahoma-based parent company was 95 percent responsible for the explosion and Williams Olefins was 3 percent to blame. The jury also determined that Tucker and Bayer each were responsible for 1 percent of the blame.

"Williams Companies Inc. cannot accept fault for the Geismar plant explosion without taking full responsibility for it, and that means providing full compensation to the workers they hurt," said plaintiffs' attorney Kurt Arnold. "Williams has made too many reckless choices that led to this explosion. They don't get to decide our client's futures. Twice they've left it up to a jury to decide what is reasonable, and juries have awarded a combined $30 million for the first eight workers who have taken their case to trial."

Plaintiff Brian Cotton was awarded a total of $3,790,789, $2.5 million of it for "past and future" physical pain and suffering and mental anguish and emotional distress. Plaintiff Paul Thompson was awarded $5,799,907, with $3 million earmarked for physical pain and suffering and mental anguish and $1.3 million for diminished earning capacity. Veronica Sowell was awarded $4,596,281 total, with $2.7 million for physical and mental pain and anguish and $800,000 for future medical expenses. Dakota Kelley was

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awarded $1,930,000 total, with $60,000 for physical suffering and $1 million for past and future mental anguish and emotional distress.

The Chemical Safety Board (CSB) in October released its final report into explosion, concluding that process safety management program deficiencies at the Williams Geismar facility during the 12 years leading to the incident allowed a type of heat exchanger called a “reboiler” to be unprotected from overpressure, and ultimately rupture, causing the explosion.

The Williams Geismar facility produces ethylene and propylene for the petrochemical industry and employs approximately 110 people. At the time of the incident, approximately 800 contractors worked at the plant on an expansion project aimed at increasing the production of ethylene.

“The tragic accident at Williams was preventable and therefore unacceptable,” said CSB Chairperson Vanessa Allen Sutherland, when the agency released its report.

Williams Olefins was cited by OSHA in December 2013 for six process safety management standard violations, including one willful. Process safety management encompasses a detailed set of requirements and procedures employers must follow to address hazards proactively that are associated with processes and equipment that use large amounts of hazardous chemicals. In this case, it was the use of propylene.

“Williams Olefins violated safety and health standards which, when followed, can protect workers from hazardous chemicals,” said Dorinda Folse, OSHA’s area director in Baton Rouge at the time “It is the employer’s responsibility to find and fix workplace safety violations and to ensure the safety of its workers. Failing to do so cost two workers their lives. “

A willful violation was cited for failing to develop clear, written procedures for how to change and put idle pressure vessels into service. A willful violation is one committed with intentional, knowing or voluntary disregard for the law’s requirements, or with plain indifference to worker safety and health.

The five serious violations include inadvertently mixing hot quench water with propylene; failing to provide appropriate pressure protection for a pressure vessel; complete a process hazard analysis to address the opening of hot quench water flow into a pressure vessel; properly document workplace training; and promptly correct deficiencies related to process safety management discovered by an internal compliance audit team. A serious violation occurs when there is substantial probability that death or serious physical harm could result from a hazard about which the employer knew or should have known.

Proposed penalties were $99,000. The company reached a formal settlement with OSHA in December 2013 and agreed to pay total penalties of $36,000.

Additional trials are scheduled for January 2017 and April 2017

So how could ultrasound been used to help prevent this accident? First off, the isolation valves leading to the heat exchange that was offline could have been tested using the 4 Point Test Method (covered in the next module) would have be able to detect the liquid propane that was leaking by and accumulating in the heat exchanger.

Next a test on the newer installed manual valves where working properly after opening up the valve to ensure that they were not plugged or blocked isolating them from the pressure relief valves on the stack. Offline testing could also be done using ultrasound as mentioned in this lesson but, there is another test method available and that in the use of an Infrared Camera as that would have shown that there was some in the heat exchanger prior to opening the valve.

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ASU CAT 2 Module 2-6 B Valve & Steam Trap Inspection

When it comes to testing Valves and Steam Traps the use of a contact module will be the module of choice. In Structure Borne Ultrasound Valve & Steam Trap testing the CBM Analyst & Technician need to remember that the turbulence will be produced in the first medium which occurs inside the piping. This means the inspectors module must be placed on the second medium. The contact module then becomes a continuation of the second medium and will pick up the energy from the Shear and Plate Waves that is being produced by the turbulence on the inside of the piping and valve body.

Types of Valves

One of the keys to Valve testing is to understand the type of Valve that is being tested and the and how it operates. Even though there are many different body types the primary function is to close and hold back material. If the valve isn't seating properly because of sediment or wear, it will allow an orifice to be present and it's this orifice that will produce a source of turbulence as the higher-pressure side pushes through the orifice in an attempt to equalize pressure.

Turbulence Produces Ultrasound

One major factor to consider is the viscosity of the materials in the system. Next the CBM Analyst will need to take into account the actual pressure of the system and what the potential differential would be on both sides of the valve seat. Other consideration could be caused by defects, poor systems health such as a valve not seating from wear, obstructions, Intersections and elbows producing antagonistic ultrasound, a Stem that is broken off or maybe the valve isn't fully open.

Contact Testing

Since the source of the turbulence is inside the valve and piping the Contact Method must be used to test for leaks. There are 3 methods that can be used for testing valves for leaks. The CBM Analyst will also need to ensure that contact is made directly on the piping and never on the thread fittings. Contact should be at 90 degrees to the surface of the body being tested.

The Comparison Method

The first one is the comparison method. The CBM Analyst can compare similar valves in a closed position to listen and observe the decibels received on the downstream side of the valve. The CBM Analyst will need to ensure that the test points are exactly the same distance away from the valve body to compare the reading. If one of the valves is louder the CBM Analyst will need to, pressure is the same and the pipe size is the same.

Upstream vs Downstream Method

The second test procedure is also a comparison method known as the Upstream vs Downstream Method.
This time the CBM Analyst will compare the upstream side to the downstream side rather than like valves.
A valve in the open position should have decibels levels that are very similar to each other when comparing the upstream and downstream side.
If the valve is closed and the downstream side is louder there could be a leak. The way to confirm this is to continue with the Battleship Method to move away from the downstream test point and look for a rise in decibels and intensity of the sound present. This will help confirm whether or not there is downstream interference from an elbow or intersection of piping.

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4 Point Test Method

The third method is the **4 Point Test Method**. As the CBM Analyst sets up the 4 Test Points, they should ensure that test point 1 is on the upstream side of the valve. From there the CBM Analyst will ensure that its placement is 3 times the pipe diameter away from the valve body and test point 2 will be 1 times the pipe diameter away from the valve body.

These steps will be mirrored for test points 3 and 4. As the CBM Analyst begins the test, they must verify the that the valve is in the desired position for testing. The Contact Module should make direct contact on the pipe as this will ensure the module becomes a continuation of the second medium the sound wave interacts with.

If the valve is open the decibel readings should be fairly similar compared to their equal on the opposite side of the valve body. For example, if the test results showed a 20-decibel value for 1 & 4 and then a 22 decibel for 2 & 3 the **valve** would be considered to be open and flowing normally.

Valve Open and Working

When testing a closed valve, the CBM Analyst will take the same steps but now will be able to determine 3 conditions that could be present. The first condition is a properly closed valve. The CBM Analyst would experience a decrease in decibels as they move through the 4 Test Points. For example, if test point 1 received a reading of 24 decibels and each test point declines in decibels the valve is properly closed.

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Valve Closed and Working

The next condition that can be identified is antagonistic downstream ultrasound interference. The decibel indications for this event would be the polar opposite of a properly closed valve. The CBM Analyst would experience a rise in decibels across the 4 Test Points. To locate the source of antagonistic downstream ultrasound the CBM Analyst would then use the Battleship Method at an interval of 2 times the pipe diameter to verify the decibels increase as they move downstream of the valve. These antagonistic downstream ultrasound can usually be attributed to the elbows or intersecting piping.

Valve Closed and Experiencing Downstream Interference

The last condition that can be determined is a leaking valve and its indication is that test point 3 is higher than all others. This is because its closest to the source of the turbulence being generated as the higher-pressure material attempts to equalize with the lower pressure downstream of the valve seating.

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Valve failed and Leaking By

Always Take into Account

When testing valves, the CBM Analyst must always take into account the volume and placement of the module on the surface they are testing. The Contact Module will slip off if too much pressure is applied to the module. So, it's usually best to place the module on the top or hold it against the bottom of the pipe.

In some cases, a magnetic mount could be used and since the dB's are only being compared across the 4 test points the loss of signal will not matter since trending isn't being performed. Similar valves can be used to also perform a comparison method test to see if there are any noticeable differences between similar valves.
In the case where the insulation is covering the piping and it can be removed an upstream vs downstream test method is the next best thing to determine the condition of the valve. The Battleship Method can even be used to help rule out antagonistic ultrasound.

Steam Traps

Steam is derived from one of the world's most abundant re-cyclable elements, WATER. That is unless you live in the middle of the Sahara desert or similar location, then water is not so readily available, for the majority of us water is very readily available.

While most people think that steam is the white clouds they see coming out of a tea kettle. This is not so, what is commonly thought to be steam is water vapor, or steam giving up it energy. Steam gives up it heat very quickly and a boiling kettle of water is a great way to see this heat transfer taking place.

If you look very closely at the kettle spout you can observe **maybe up to 5mm** from the mouth of the spout of the kettle you can't see anything, this is steam, but as we stated it's invisible, immediately after this invisible section the steam starts to give up its stored energy then turn to water vapour, then totally back to the water it was made from.

If we are talking about superheated steam, then this would be a different story. Superheated steam leaks tend to stay in the atmosphere for a lot longer as an invisible gas. On ships that I have worked on superheated steam leaks would not condense until they were outside the engine room. This makes them very dangerous, because you can only hear them not see them.

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What Is Steam?

Understanding that one of the keys to a steam systems efficiency is the pressure of the system. The increased pressure raises the boiling point of the water and as such the temperature in the systems. Steam can be used for so many things like, power generation, heating, sanitation and food grade applications. The process of generating steam involves ensuring the quality of the water added to the systems.

If it's not balanced properly it can build up sludge in the systems. The PH & Alkalinity need to be monitored and adjusted on a regular basis. If left unchecked they can trigger many different types of faults in a steam system. So, there are many source of waste that can occur, but this section is going to concentrate on the use of ultrasound to test the efficiency of the steam traps and help determine the exact condition of the trap.

When Inspecting Steam Traps

When inspecting steam traps, it's very important to research what types of traps will be tested, systems pressure & temperature, and the discharge location. The CBM Analyst must also adjust the volume on the unit to ensure the antagonistic ultrasound is isolated as well as ensuring that it's not so loud that it causes the CBM Analyst to have to rip the headphones off when the trap discharges. When capturing a sound wave the CBM Analyst will need to ensure they listen for a complete cycle of the trap and capture a couple of cycles so the Discharges Per Minute can be calculated to see if the trap is working efficiently.

Pressure	Temp in F	Temp in C
0 PSIG	212	100
1 PSIG	215	102
3 PSIG	219	104
5 PSIG	227	108
8 PSIG	235	113
10 PSIG	239	115
15 PSIG	250	121
20 PSIG	259	126
25 PSIG	267	130
30 PSIG	274	134
35 PSIG	281	138
40 PSIG	287	142
45 PSIG	292	145

Pressure	Temp in F	Temp in C	Pressure	Temp in F	Temp in C	Pressure	Temp in F	Temp in C
0 PSIG	212	100	85 PSIG	328	164	290 PSIG	419	215
1 PSIG	215	102	90 PSIG	331	166	300 PSIG	422	217
3 PSIG	219	104	95 PSIG	335	168	320 PSIG	428	220
5 PSIG	227	108	100 PSIG	338	170	340 PSIG	433	223
8 PSIG	235	113	110 PSIG	344	173	360 PSIG	438	226
10 PSIG	239	115	120 PSIG	350	177	380 PSIG	443	229
15 PSIG	250	121	130 PSIG	356	180	400 PSIG	448	231
20 PSIG	259	126	140 PSIG	361	183	420 PSIG	453	234
25 PSIG	267	130	150 PSIG	366	186	440 PSIG	457	236
30 PSIG	274	134	160 PSIG	371	188	460 PSIG	462	239
35 PSIG	281	138	170 PSIG	375	191	480 PSIG	466	241
40 PSIG	287	142	180 PSIG	380	193	500 PSIG	470	243
45 PSIG	292	145	190 PSIG	384	195	520 PSIG	474	246
50 PSIG	298	148	200 PSIG	388	198	540 PSIG	478	248
55 PSIG	303	150	215 PSIG	394	201	560 PSIG	482	250
60 PSIG	307	153	230 PSIG	399	204	580 PSIG	485	252
65 PSIG	312	155	245 PSIG	404	207	600 PSIG	489	254
70 PSIG	316	158	250 PSIG	406	208	620 PSIG	492	256
75 PSIG	320	160	260 PSIG	409	210	640 PSIG	496	258
80 PSIG	324	162	275 PSIG	414	212	660 PSIG	499	259

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What Does a Steam Trap Do?

The design of a steam trap is to hold back steam and discharge condensate back to the boiler and some traps can even bleed off air. When these traps are under sized, they will cycle more frequently that indicating that the trap could be grossly undersized. The opposite is true if the trap doesn't cycle frequently enough and this would indicate that is oversized.

Types of Steam Traps

With so many different types of trap on the market it is critical that the CBM Analyst know what the traps look like, is there a numbered tagging system in place, how they operate, what pressure the system and what is the corresponding temperature that the trap should be operating at. These factor will help the CBM Analyst to quickly identify they have the correct trap and know what they should expect so see in their readings. There are many ways to tag the traps and the most common is the standard brass tag hung on the piping.

There are more modern options available that not can identify the asset but can store data about that trap and the CBM Analyst can update the tag and trend the results. An increase in downstream decibels and temperature can be in indication that the trap is becoming inefficient and nearing its end of life.

Inverted Bucket Trap

An inverted bucket trap works by using buoyance as a mechanism for lifting the bell housing inside as the steam rise to the top. As it fills the bell housing the condensate sinks to the bottom and allows it to raise to the top because the steam is more buoyant. The steam then cools down and returns to a state of condensate which causes the bell housing loses its buoyance and sink back down toward the bottom of the traps housing.
As it sinks down the arm of the trap also moves downward and opens up the opening to the valve allowing the discharge of the condensate back to the boiler.

Float & Thermostatic

This mechanical trap uses a closed float to determine the condensate level within the trap body. As the level increases, with incoming condensate, the float rises and pulls the valve away from the orifice by means of pivoting linkage. The function of condensate removal is achieved. Discharge of condensate causes the level to decrease. As the float lowers, the valve is sucked into the orifice by pressure differential. Flow is stopped before steam reaches the orifice, because the orifice is located below the minimum water level. The function of steam loss prevention is positive. This cycle repeats to provide the functions of condensate removal, and the prevention of steam loss.

Thermodynamic (Disc) Trap

These kinds Thermostatic Trap that operates on the difference in temperature between steam and condensate.
When closed, they should have little to no sound during hold back and during the discharges you will hear an increase in sound. A slight "hissing" sound indicates leakage. Never test during start up, as they can take a long time to get up to temperature. This discharge would last for a long period of time and the CBM Analyst would make the wrong call.

Bi-Metallic Trap

Bi-Metallic Traps are traps that fall into the Thermostatic Trap category. They operate with the same needs of other Thermostatic Traps. There must be a temperature differentials between steam and condensate to allow the 2 opposing metal to flex away from each other when the steam is inside the trap. When condensate is present, they flex towards each and this opens the orifice to

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allow the discharge to occur.

Steam Blast Jolts Midtown, Killing One

Written by James Brown
The New York Times

A steam pipe explosion beneath a street near Grand Central Terminal yesterday propelled a giant scalding jet of brownish steam toward the sky, sending commuters who had been heading home stampeding to safety.
Officials said that one person died and more than 30 were hurt, two of them critically. The city said that three firefighters and one police officer were among the injured.

The blast, near 41st Street and Lexington Avenue, raised fears of terrorism, but officials were quick to dismiss that possibility. “There is no reason to believe this is anything other than a failure of our infrastructure,” Mayor Michael R. Bloomberg said.

Crews worked through the night in an effort to clean up after yesterday’s steam pipe explosion on Lexington Ave., but debris remained at the site this morning.

Credit Robert Stolarik for The New York Times

The explosion sent up a foul cloud of hot steam mixed with mud, rust-colored gunk and pieces of pavement just before 6 p.m. in one of the busiest parts of the city. The mayor said that some telephone lines had been knocked out, but that electric power had not been.

As people on the sidewalks scrambled to flee and office workers in the buildings above looked down in horror, debris from the geyser pelted nearby skyscrapers. Then it rained on the streets like a sudden hailstorm. Some witnesses said the jet of steam roared like Niagara Falls.

Some people ran so fast their shoes came off. Others dropped their briefcases and purses. Men in tailored suits were caught in a lapel-singeing cloud. At a health club high up in the Grand Hyatt hotel next to Grand Central Terminal, people working out on the treadmills said the explosion was so powerful they worried the building would collapse. The steam shot up from a crater that looked like that of a volcano, with orange flames and bubbling mud around the edges. The explosion packed enough force to flip over a tow truck that ended up in the crater, which was about 35 by 40 feet. Several hours after the blast, officials said the crater could grow even larger because pavement at the edges was in danger of collapse.

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Con Edison crews stopped to photograph the scene with their cell phones.

Credit Robert Stolarik for The New York Times

The cloud of steam — and the hail of debris that followed — lasted more than two hours and raised concerns about asbestos, which was used when the pipe was laid in the 1920s. Officials advised people who had been in the neighborhood to discard their clothes and bathe carefully.

The mayor said the explosion appeared to have been caused by cold water that reached the pipe, which measured more than a foot and half in diameter and dated to 1924. “Cold water apparently causes these to explode,” he said.

Con Edison, which maintains the steam pipes beneath the city’s streets, said the pipe ruptured at 5:56 p.m. Kevin Burke, the chairman of Con Edison, said crews had checked the pipe after the thunderstorm that soaked the city in the morning. He said a heavy rain can cause a “vapor condition” if rainwater seeps onto a steam pipe, causing the steam to condense. He said the inspection earlier in the day had given no indication that anything was amiss.

Michael S. Clendenin, a spokesman for the utility, said tests would be conducted for asbestos. “We always assume there’s asbestos in a steam pipe,” he said, “so we are treating these materials sent up by the rupture, including piping, as if asbestos were in them.”

There have been more than a dozen steam pipe explosions in the city in the last 20 years. One of the largest shook the neighborhood around Gramercy Park in 1989 and did millions of dollars in damage. Three people were killed, two of them Con Edison employees who had been working in the street before the explosion.

Within hours of the blast yesterday, Con Ed and the city’s Department of Environmental Protection began taking air samples to determine whether asbestos had been released. They were also checking the debris that littered the street. Mr. Bloomberg said subway entrances and exits would also be tested.

The mayor urged people who might have come into contact with mud or soot from the blast to wash carefully, and to have their clothes cleaned separately as soon as possible.

Jessica Leighton, a deputy commissioner at the Department of Health and Mental Hygiene, also cautioned people inside buildings near the blast to close windows and set air-conditioners to recirculate the air inside instead of drawing in air from outside.

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Asbestos is a known carcinogen. Most health officials say there is no safe level of exposure. But asbestos-related diseases generally are linked to sustained exposure in industrial settings over many years.

The explosion yesterday began with a deep, rumbling noise. “It was, like, surreal, man, this rumbling, like Old Faithful,” said Randy Rocha, a bus driver who was pulling away from a stop on 42nd Street with about 20 passengers aboard when the pipe ruptured.

He described plunging into the suddenly dark street. His uniform was splattered with mud the way a housepainter’s clothes are splattered with color. Mr. Rocha could not read his wristwatch — it too was covered with mud.

In the skyscrapers that surround Grand Central, office workers realized that what they were hearing were not the usual sounds of the evening rush, of buses hitting manhole covers or dump trucks changing gears.

“It sounded at first like thunder, but it just didn’t end,” said Andrew T. Frankel, a lawyer whose office is at Lexington Avenue and 43rd Street.

Tabi Freedman, an information technology specialist who was walking out of Grand Central, said, “The ground was moving, the windows were rattling, and me and everybody else, we all looked up.” She added, “I’ve been to Yellowstone, and that’s what I thought of — the pitch, the volume, the shrieking, the steam and the vibration.”

Ken Houghton, a consultant who works at 101 Park Avenue, between 40th and 41st Streets, said he first thought what was coming down was hail. “Then we saw rocks hitting the window on the seventh floor,” he said. Officials said later that six nearby buildings sustained minor damage, mainly to windows on the lower floors.

More than 250 firefighters and 300 police officers were sent to the area. The Fire Department treated the blast as if it were a five-alarm blaze, and firefighters who approached the geyser had breathing tanks on their backs. Before long, ambulances were slicing past the stalled cars and buses, and were taking people who had been caught in the shower from the geyser to hospitals.

A trauma worker at Bellevue Hospital Center estimated that a dozen patients suffering minor injuries were taken there. Most

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of the injuries appeared to have been caused by falling debris; one person sustained a broken ankle, he said. As a precaution, patients were stripped and showered when they arrived.

The one death reported from the explosion was apparently caused by a heart problem. The victim, a woman, had apparently been close to the explosion, he said.

Mr. Burke of Con Edison said a number of 13,000-volt feeder cables for the utility's electric system had been damaged in the explosion. He said crews would lay new cables under the streets to bypass the damaged ones. He said that 15 to 20 buildings that tap into the steam pipes had been taken out of service.

Five hours after the explosion, wisps of steam continued to rise from the crater. Lexington Avenue remained closed, with barricades keeping onlookers two to four blocks away and emergency vehicles lining the street — ambulances, fire trucks, tractors and forklifts. The Lexington Avenue subways were running but were not stopping at 42nd Street.

Reporting was contributed by Diane Cardwell, Sewell Chan, Glenn Collins, James Estrin, Cassi Feldman, Ashley Gilbertson, Thomas J. Lueck, Michael Luo, Dylan Loeb McClain, Colin Moynihan, Anthony Ramirez, William K. Rashbaum, John Schwartz, Nicholas W. Skyles, Dalton Walker, Mathew R. Warren and Ethan Wilensky-Lanford.

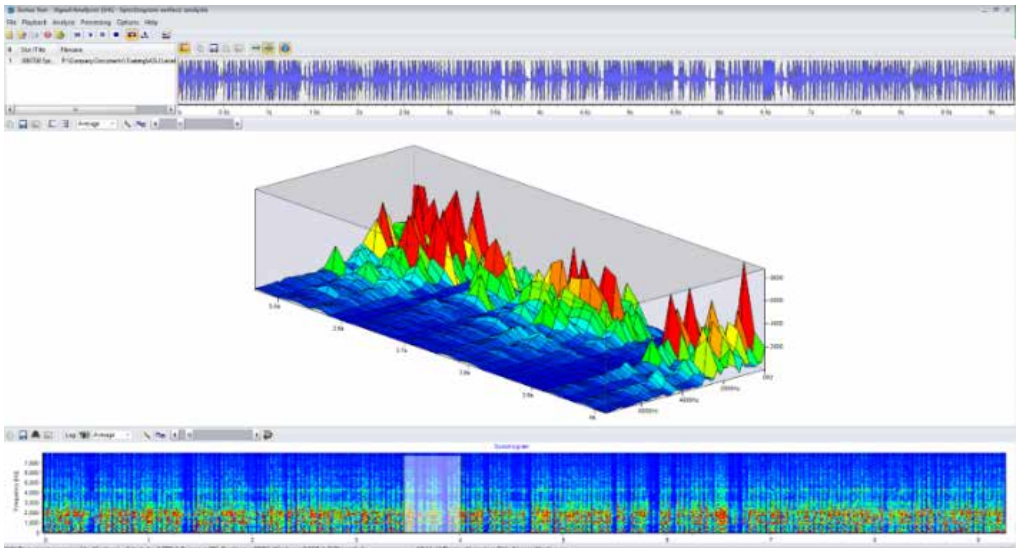
How Sound Analysis Helps

The use of Sound Analysis Software to help an CBM Analyst diagnosis the condition of Steam Traps is critical.
Temperature can let the CBM Analyst know if a steam trap is in range of working efficiently but, a sound wave can show the total number of discharges per minute which can then be used to determine how inefficient a steam trap is working.

This extra step can help to give the CBM Analyst the key piece of information in reporting the condition of the trap. Using Time Signal analysis is the easiest way for them to also show management how they were able to determine a good, bad or inefficient steam trap.

In addition to the Time Signal an CBM Analyst can also map out the intensity of the discharge by using a Spectrogram, Spectrogram Analysis of Spectrogram Surfacing to further highlight the condition of the steam traps. Frequency Spectrums are not that useful in analyzing the condition of a steam trap so, it always best to use Time Signal.

A comparison analysis can even be done by using the Time Signal over lay in a 2D or 3D format.
This will allow the CBM Analyst to conclusively show that one trap is not functioning properly when overlaid against like traps that are operating efficiently.



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ASU CAT 2 Module 2-6 C Part 1 The Theory of Electrical Inspection

Electrical systems for years have been put on an annual inspection cycle which has generally been mandated by insurance companies but beyond that these assets are usually just left alone. Sometimes it's simply because the plant doesn't have the personnel to do inspections and they get out sourced. Sometimes it's the mentality of the management and planners that these assets are as critical, or it takes too much time to inspect these assets.

With the use of ultrasound, it had always been a process of just scanning the seams and opening in equipment to determine if there was a condition that need to be looked into. With the invention of IR Windows and Ultrasound ports the time frame it took to perform Electrical inspections has dramatically been reduced also allows for a safer process of inspecting these critical assets. Now the site can have their assets inspected monthly if they wish because there is no need to wear an arc flash suit and remove the panels.

Ultrasound testing of electrical assets there isn't anything it can't be used for. Everything from transmission lines on down to breaker panels. It has always been relegated to scanning the seams and vent holes with some success. The problem with this however is the CBM Analyst can't always achieve the Critical Angle due to diffraction of the sound wave and makes it tough recording the truest sound of the anomaly. This can lead to limited harmonic indications when trying to analysis in the FFT format in sound analysis software. This topic will be cover more in depth in an upcoming module.

When it comes to electrical inspection Infrared, Ultrasound and TEV detection devices are the best tools to use to test electrical equipment. Ultrasound and TEV can be used to listen to what's occurring inside of equipment by making contact on the exterior of the cabinet or scanning and seam or opening. If the site has VPDS installed it becomes a lot more efficient and minimizes any loss of signal caused by Diffraction.

This causes a loss of clarity in the signal clarity that can interfere with the ability to analyze sound waves in an FFT format while the Time Wave Form can still show some Harmonic occurrences of the emission as it isn't as dependent on the Critical Angle since it is capturing the emission as it happens in Real Time and is a transformation of the signal.

Causes of Electrical Faults

Rodents, Insects and Reptiles love modern electrical equipment for seek shelter, building homes or even seeking out a meal. Why wouldn't they since they are usually always warm, dry and very infrequently accessed. By simply open a cabinet one can spook a mouse causing it to trigger an Arc Flash. Or provoke a Wasp or Hornets' Nest attack as they feel threatened by their nesting grounds being attacked. The use of clear IR Windows with Ultrasound ports can greatly increase the CBM Analyst 's safety and minimize the CBM Analyst 's risks.

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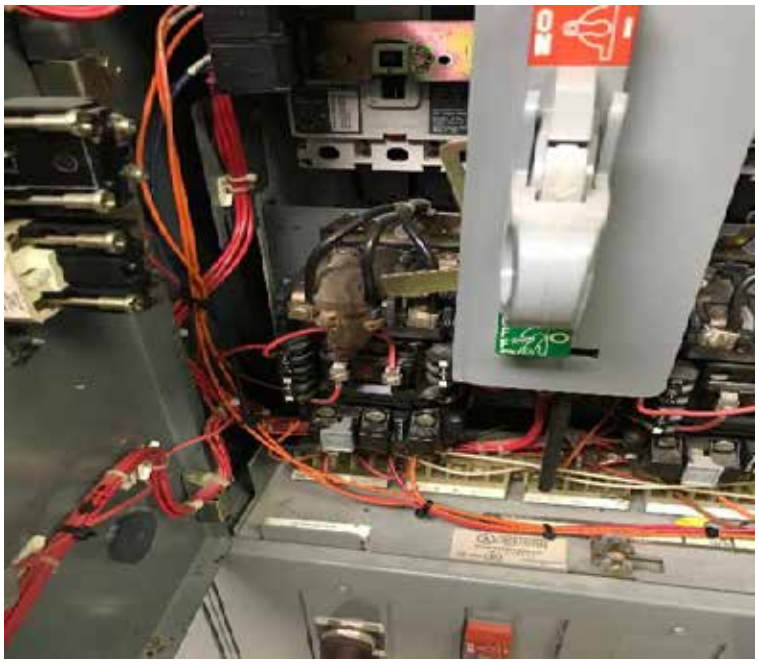

Weather has always been a big factor in disrupting the grid. In the case of Hurricane Irma in 2017 some 12 million people lost power due to the Hurricane. Parts of Puerto Rico as of December 2017 will still be without power for another year. In January of 1998 North America was hit with five smaller ice storms in close order. The accumulation was the most severe in Ottawa and Montreal but effected Ontario, Quebec, New Brunswick, Nova Scotia in Canada and in the USA New York, Vermont, New Hampshire and Maine were also affected as well. Some area the power was returned in a few days, but in the epicenter of the storm power was out for months. The ice is some area was as thick as 4 inches. This added weight even collapsed transmission lines towers.

The age of electrical equipment is one of the other contributing factors to failures that is known but just overlooked as part of doing business. Many facilities are running equipment beyond its designed life span and praying for the best. Others are at least using ultrasound to help determine the asset health so they can plan accordingly to repair or replace the asset.

Sometimes the equipment can fail due to animals interfacing with these assets. Recently at the Atlanta Airport a switchgear failed and took down the World Hub of Delta Airlines and caused a massive cancellation of flights.
Here is an Article from Fox News about the cost of this catastrophic failure.

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Delta estimates up to $50 million in losses after Atlanta airport outage - and wants somebody to pay up
Written by Emilie Ikeda 12/22/2017

Chaos caused by a nearly 11-hour power outage at the world's busiest airport Sunday is fizzling out, but consequences linger. Delta Airlines estimates losses between $25 million and $50 million – and the powerhouse airline wants somebody to pay up. The airline's CEO Ed Bastian announced they will be seeking reimbursement.

This comes after 1,400 flights were cancelled as a result of Sunday's power outage. "I don't know whose responsibility it is between the airport and Georgia Power, but we're going to have conversations with both of them," Bastian told the AJC Tuesday.

Bastian cited plans for conversations with Georgia Power and the Hartsfield-Jackson Atlanta International Airport, but the question of who should be held accountable remains unanswered. Georgia Power said that while it owns the electrical equipment in the underground facility that caught fire, the airport owns the tunnel itself.

According to a spokesperson from Mayor Kasim Reed's office, flames broke out when a piece of Georgia Power's switchgear failed in an underground electrical facility. This happened next to redundant circuit cables and switching mechanisms, which forced the loss of power from two separate back-up power substations – thus the delay in returning to full power. "Understand that we've never had a situation like this, and our redundant system had been working flawlessly for us for probably about three decades now," Airport General Manager Roosevelt Council Jr. told Fox News Monday.

A spokesperson for Georgia Power said in a statement that "we cannot and do not guarantee uninterrupted electric power service." Attorney Philip Holloway, a licensed commercial pilot, says it's too early to tell who Delta should take to court. The list of potential defendant's ranges from Georgia Power and Hartsfield-Jackson to contractors responsible for maintaining the equipment and the engineers behind its design. Though once blame is placed, we could see a settlement among the parties.

Holloway says it serves no one to disrupt the strong relationship Delta has with its hub city. "These are relationships that everybody has a vested interest in maintaining, and so the best way to ruin a great relationship is through litigation," Holloway said. Litigation, Holloway added, "could literally go on for years."

Human error is another cause of Electrical Faults and power outages. Everything from car accidents, to ladders against, antennas placed against power lines, to people digging up power lines and even some case of people strung out on drugs trying to steal the wiring to feed their habits. These interruptions are not something is preventable with testing equipment but just reinforces the fact that these things can and will happen.

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Wildfire can also be the cause of the fault. As a wildfire burns it produces heat and smoke which both lead to the breakdown of the insulation value of the air around the lines. This thins out the air as well as making it more conductive and allows the current to pass through the air that once kept it insulated.

In a report titled “California power company has resisted efforts to map risky power lines” written by Bill Gabbert and published in Wildfire News on 10/30/2017 some evidence was shown to the effect that the powerlines were seen exploding during the fire.

Following the Witch Creek, Guejito, and Rice Canyon fires that destroyed more than 1,300 homes and killed two people in Southern California in 2007, state officials began attempting to force the utility companies to produce maps designating areas where their power lines present the highest risk for starting wildfires.
The three large fires in 2007 were sparked by issues with lines operated by San Diego Gas and Electric.

CAL FIRE has not released the causes of the huge fires that started in Northern California October 8 during very strong winds, but at about the same time firefighters were first responding to numerous fires, they also received multiple calls about fallen power lines and electrical transformers exploding. In the next week, the stock price of the company that provides electrical service for large areas of Northern California, Pacific Gas and Electric, dropped 22 percent.

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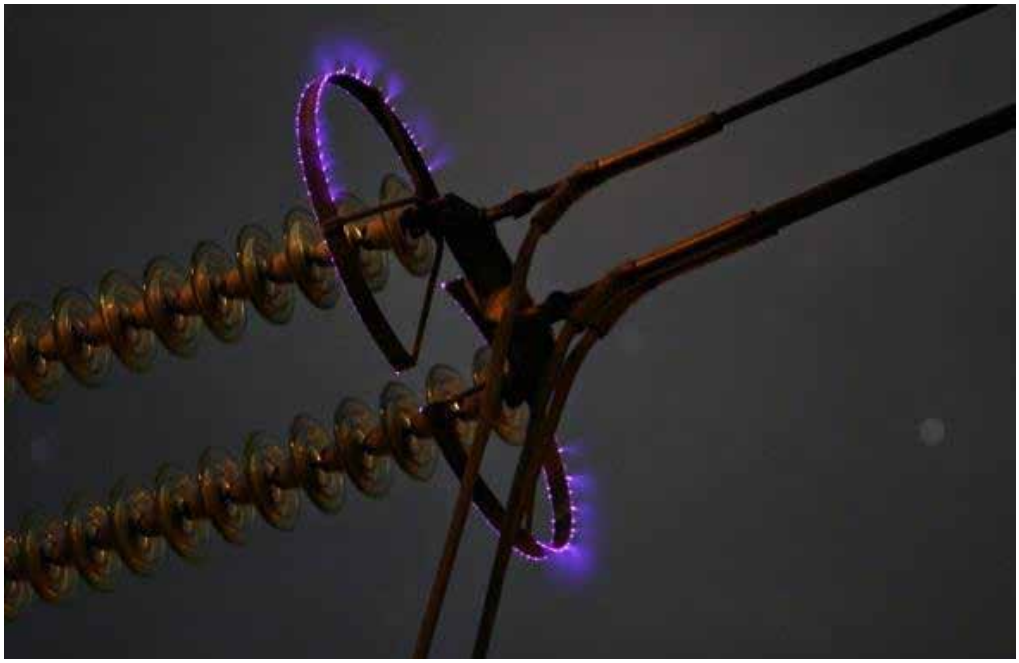
Ionization

Ionization is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes. Ionization can result from the loss of an electron after collisions with subatomic particles, collisions with other atoms, molecules and ions, or through the interaction with light.



Heterolytic bond cleavage can result in the formation of ion pairs. Ionization can occur through radioactive decay by the internal conversion process, in which an excited nucleus transfers its energy to one of the inner-shell electrons causing it to be ejected. As the occurrence of ionization builds it creates nitrogen oxide which is the white powdery substance we see on the wires. When this build up is exposed to moisture it turns into Nitric Acid which eats away at the surface leading to more detrition in that area.

Ionization and Corona

A **corona discharge** is an electrical discharge brought on by the ionization of a fluid such as air surrounding a conductor that is electrically charged. Spontaneous corona discharges can occur naturally in high-voltage systems unless **care is taken** to limit the electric field strength.

A corona will occur when the strength (potential gradient) of the electric field around a conductor is high enough to form a conductive region, but not high enough to cause electrical breakdown or arcing to nearby objects. It is often seen as a bluish (or other color) glow in the air adjacent to pointed metal conductors carrying high voltages and emits light by the same property as a gas discharge lamp.

In many high voltage applications corona is an unwanted side effect. Corona discharge from high voltage electric power transmission lines constitutes an economically significant waste of energy for utilities.
In high voltage equipment like televisions, radio transmitters, X-ray machines and particle accelerators the current leakage caused by coronas can constitute an unwanted load on the circuit.

In air, coronas generate gases such as ozone (O_3) and nitric oxide (NO), and in turn nitrogen dioxide (NO_2), and thus nitric acid (HNO_3) if water vapor is present. These gases are corrosive and can degrade and embrittle nearby materials and are also toxic to people. Corona discharges can often be suppressed by improved insulation, corona rings, and making high voltage electrodes in smooth rounded shapes. However, controlled corona discharges are used in a variety of processes such as air filtration, photocopiers and ozone generators.

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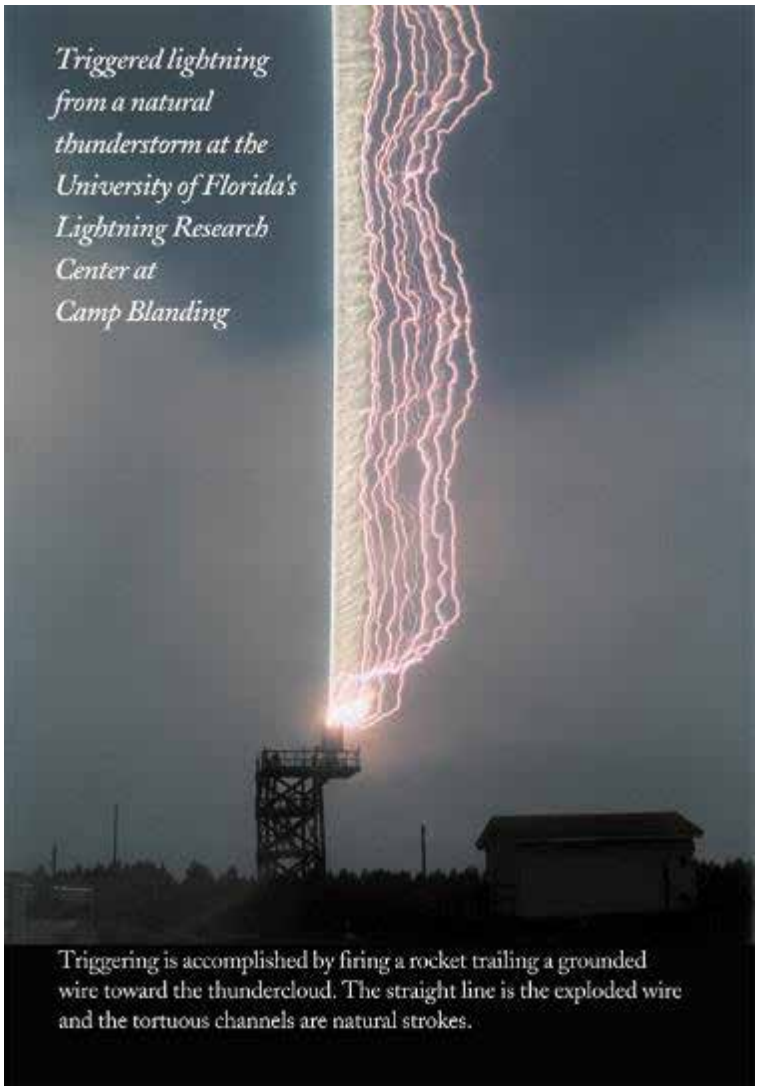

The conduction of electricity through air it been study at the University of Florida by the Lighting Research Group. They launch model rockets with a metal filament wire trailing behind to the launch pad give the lighting a path to ground.
This research is being used to test the ability to capture and store the energy from a lightning bolt which produces 1 million joules of Energy.

Some theorize this could power a house from 8 Days to 30 Days if someone could create a way to store this energy. Lighting will produce ultrasound prior to seeing the flash of lighting if close enough to a strike. Even before there is any human experience of sound ultrasound will be the first thing experienced.

Humidity

is defined as the amount of water contained in air.

In the human experience this experienced as mugginess but in the ultrasound realm it's how much partial discharge or corona is present. As the humidity levels increases the air becomes more conductive and these events can become more prominent which can in turn lead to a faster end of life for that asset. For years it had been stated that corona is not always destructive, but it is now better understood that the continuous occurrences of corona due to high humidity will lead shortened life cycle of these assets.

Tools Used to Measure Equipment Condition

For years maintenance departments where faced with the tough choose of which equipment to purchase to effectively test their assets. It didn't help that the salespeople walk into the plants didn't understand the importance of a complimentary approach to maintenance.

Over the last several decades have changed and so has the approach of the salespeople and maintenance personnel that these technologies all work together to confirm the existence of an anomaly and what that anomaly actual is. This leads to a stronger confidence from the CBM Analyst to be able to make the correct call as to the corrective action that should be taken.

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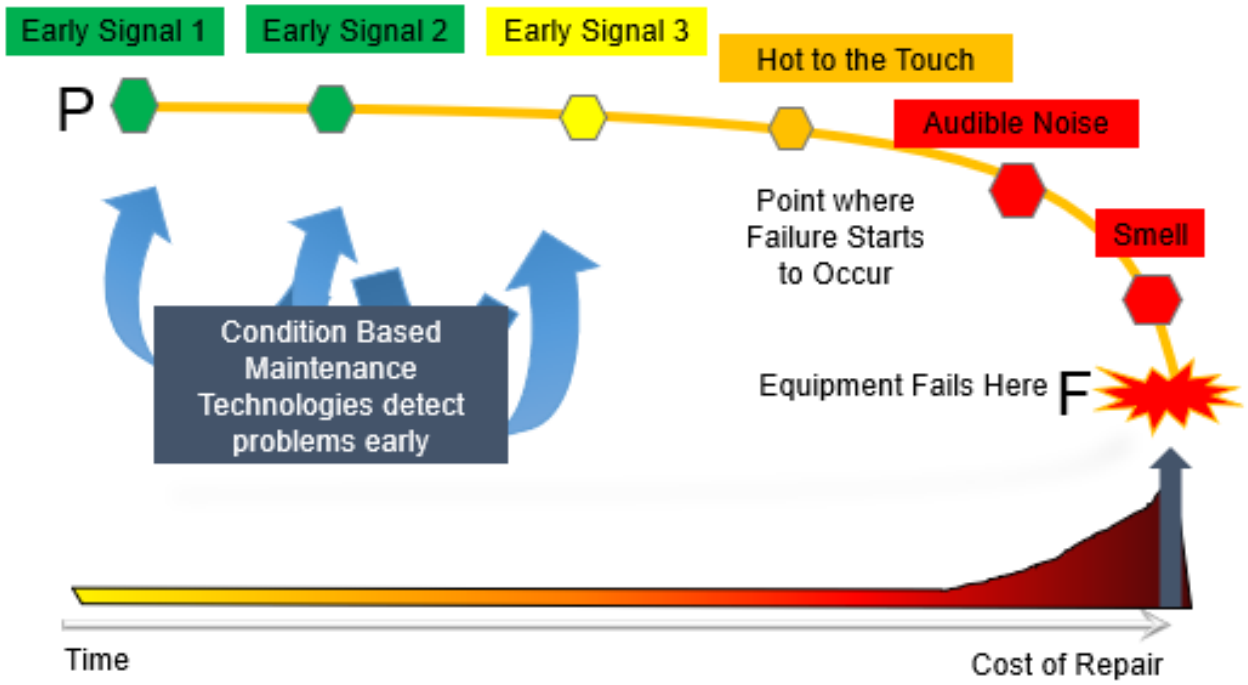
The P-F Curve of Electrical Assets



Multiple CBM technologies can catch early warning signals along the PF curve. This could be ultrasound, infrared, vibration analysis (motors), visual inspection, etc. The earlier you catch the problem, the simpler and cheaper it will be to institute repairs. Wait too long and functional failure will occur meaning an expensive repair and downtime.

Ultrasonic Testing

Ultrasonic emissions are caused by electric anomalies such as corona, treeing, tracking and arcing. All of these emissions produce ionization whereby neutral atoms and molecules gain or lose electrons becoming an ion.
Byproducts are Ozone (O3) and nitric acid which is destructive to most dielectric materials and corrosive to certain metals. Each anomaly has its own “sound characteristics”.

Ultrasound detectors work from 20-100KHz and use “heterodyning” to translate the Ultrasound into the audible range for the technician. Detectors also show the intensity of the signal in decibels (dB). Each has a level of severity as related to equipment. Most applications tend to be in medium and high voltage systems (>1000Vac).

Why You Should Use Sonus Vue Pro

When a clear pattern develops the CBM Analyst will need to determine at what intervals they are occurring. These occurrences can determine what part of a bearing is failing, discharge rate of a steam trap or what type of electrical failure is occurring. With the report feature the CBM Analyst can submit sound waves and images for their plant or client to review. Sonus VUE PRO is the most powerful Ultrasound Analysis software currently available. With higher functionality then the Sonus App the CBM Analyst can diagnosis the anomaly much more effectively.

What to Listen For

Many things can produce Ultrasound. Some of these sources are Frictional, Turbulent, or Electrical Anomalies. These are the anomalies we want to detect and diagnosis. Antagonistic Ultrasound anomalies can be produced by such things as a bad ballast,

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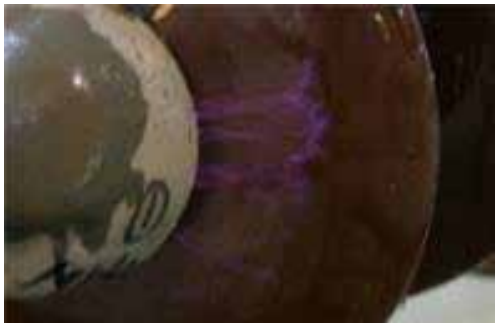
security & lighting motion detectors, bats, rodents, computers, PA systems and radios mounted to metal beams.

What is Partial Discharge

Partial Discharge (PD) is an electrical discharge that does not completely bridge the space between two conducting electrodes. The discharge can occur in a gas filled void, a solid insulating material, as a gas bubble in a liquid insulator, or around an electrode in a gaseous environment. When partial discharge occurs in a gaseous environment, it is usually known as corona.

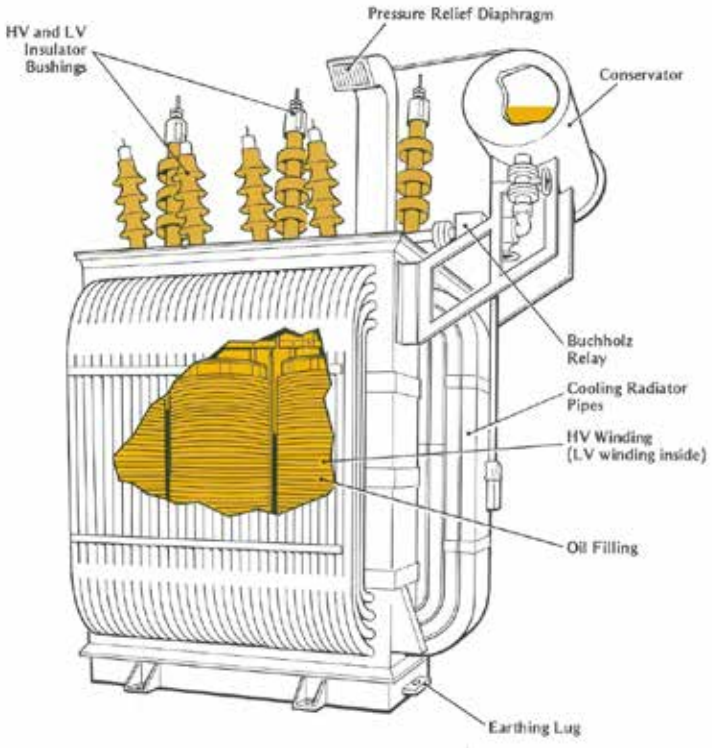
Partial Discharge can be broken down into 4 types of events.

Corona; Ionization of fluid (air) surrounding conductor.
Treeing; Electrical treeing over contaminated insulator.
Tracking; An established path across a surface that hasn't developed into a phase to phase event.
Arcing; Electrical breakdown of a gas that produces plasma discharge.



Partial discharge is generally accepted as the predominant cause of long-term degradation and eventual failure of electrical insulation. As a result, its detection has become an important part of testing on all types of electrical assets. In addition, partial discharge activity can be tested for or monitored on in-service equipment to warn against pending insulation failure.

Within gas bubbles in liquid insulation Voids within solid insulation Corona Around an electrode in gas Across the surface of insulated material



Partial Discharge can occur in gas filled voids in solid insulation which are bubbles in the jacketing of a cable which can lead to failure overtime. These voids can be caused by substandard cabling manufactures or environmental exposures.

Partial Discharge maybe found in liquid filled transformers where the paper insulation starts to degrade with exposure to high heat levels. This will lead to the oil losing its insulation value and the degradation of the cellulose paper more rampantly. This produces bubbles in the oil which allows the conduction of current inside the equipment which in turn will show TEV and AE indications.

Partial Discharge can even occur around the connections and insulators on transmission lines or in substations.
Chemically the discharged energy breaks down the chemical bonds of the oxygen atoms which turns it into nitrogen oxide. This will leave a white powdery substance around the anomaly that if exposed to moistures turns into Nitric Acid.

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Why does PD occur at normal working voltages? The defects or cavities in solid insulation are usually filled with a gas of significantly lower breakdown strength than the surrounding material. In addition to this, the permittivity of the gas is invariably lower than that of the solid insulation, causing the electric field intensity in the cavity to be higher than that in the surrounding dielectric. Therefore, under the normal working stress of the insulation, the voltage across the cavity may exceed the breakdown value and initiate electrical breakdown, or Partial Discharge in the void.

Electrical power is generally transmitted with a sinusoidal alternating current. The insulation undergoes varying electrical stress throughout the power cycle, with two peaks in stress per cycle. This creates a very distinctive distribution of discharge activity. The pattern, or distribution of the discharges in the power cycle, is key to recognizing PD and distinguishing it from other unrelated noise sources and identifying the source. The pattern is sometimes called a PRPD (Phase Resolved Partial Discharge or φ-q-n pattern).

Where can PD Occur?

The Sonus PD has the unique ability to synchronize with the phase of the power supply that is present in a substation room. This feature ensures that the unit is constantly looking for the most accurate phase from the power supply. the Sonus PD will consistently adjust to ensure that it has synchronized with the truest form of the phase occurring in that room. This helps the CBM Analyst to ensure that they are properly testing and always receiving the best quality of the signal strength from the transient earth voltage that is being discharged in the metal clad gear.

What are the Consequences of Partial Discharge?

Arc-flashes in the switchgear are the major cause of serious injuries.
Very high temperature (19,600 ºC) about 4 times the surface of the sun.
Force equivalent of being hit with a grenade.
Cause severe burns and hearing/memory loss.

If these events go undetected, they can progress into more significate failures that can cost a site a greater amount of repair cost and unscheduled downtime. If it was detected through a CBM program inspections and shutdown during a scheduled outage and repaired, it would have eliminated unscheduled downtime. The failure to detect these faults can and will have serious safety implications for the site as it could lead to an Arc Flash Event while the personnel are in or around the equipment. Not only will it take down the asset that had the failure it will cause collateral damage as well to neighboring gear and in some cases the entirety of the room its housed in. These failures cause major disruptions in the throughput of company and can be very costly to the profitability of the site.

Induvial discharges are low energy events that occur in a very localized area to start out. This is the case with insulation that has voids in it. The reduced insulation value of the jacketing allows for the seepage of current. Over time these event can start to not only produce ultrasonic emissions but heat as well. Over time the increased heat will not only show up thermal but visually as well as the chemical bonds start to be altered and the components start to discolor.

These event have gone undiagnosed by many ultrasound inspectors over the years, as it was taught that these sounds weren't anything other than normal sound of an electrical component. As such they have gone undiagnosed and maybe directly attributed to failures of electrical assets at sites that were using ASU devices to test their gear.

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Examples; Treeing

Treeing is the attempt to establish a conducting path across an insulator surface. Usually, the conduction path results from degradation of the insulation which will lead to a permanent conductive path that results in Tracking. Both of these events occur in carbon-based compounds.

Treeing as a phenomenon severely limits the use of organic insulators in outdoor environments. The rate of Treeing depends on the structure of the polymers and can be significantly reduced by adding appropriate fillers to the polymer, which inhibits carbonization.

High voltage plants are often very difficult to clean and are therefore susceptible to dirt and contaminant can build up. In the presence of moisture, these contaminating layers give rise to leakage current over the insulator surface. This heats the surface and through evaporation causes interruption in the moisture film. Large potential differences are generated over the gaps in the moisture film and small sparks can bridge the gaps. Heat from the sparks causes carbonization of the insulation and leads to the formation of permanent carbon tracks on the surface. Under such conditions, this process will develop over time and eventually lead to flashover and full breakdown of the insulation.

Partial Discharge Detection

The human visual experience or field of view is typically 135° vertically and 200° horizontally. The human hearing experience is known as omnidirectional, whereas ultrasound devices are very directional and with different transducer can get down to a 5° field of listening.

Case Study

This case study will detail how IRISS's Sonus PD detected a pending asset failure in a Middle East utility company.

A utility company in the Middle East was preforming CBM of their assets when they detected a partial discharge event on a medium voltage switchgear. Using both the TEV and AE mode of their Sonus PD they we able to find the treeing that was occurring on the fuse holder inside the fuse chamber. The Fuse and holder where replaced and brought back online and tested again and the indication of partial discharge were no longer present.

How the Sonus PD Detected Pending Asset Failure

Following routine tests using the Sonus PD, high levels of partial discharge activity was detected in the fuse chamber of a ring main unit by the inbuilt TEV (Transient Earth Voltage) and Ultrasonic Transducers.

As the Sonus PD is a dual transducer PD detector for switchgear, the instrument detects TEV signals generated by internal discharge, as well as acoustic discharge generated by surface tracking or corona.

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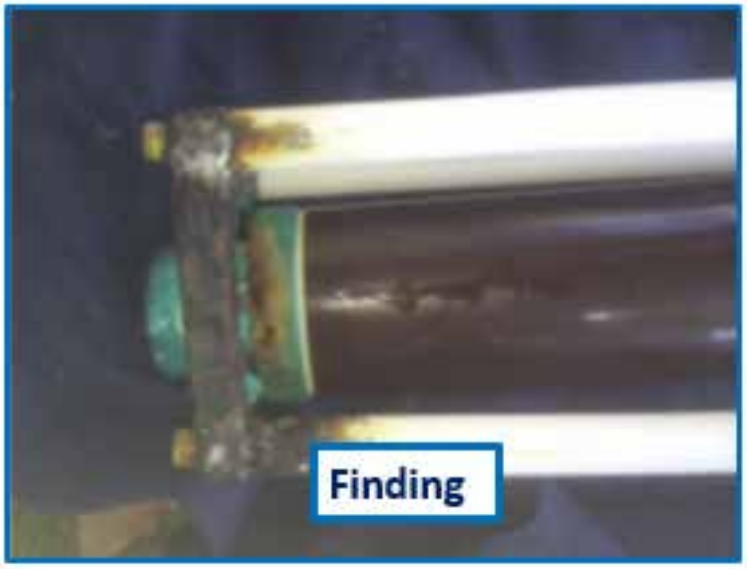

Partial Discharge Investigation

Following the detection of partial discharge activity through on-line testing, an off-line investigation was conducted on the asset to locate the discharging component. Clear evidence of extensive burning and carbonization was seen on the fuse holder within the fuse chamber.

The defective components were replaced, and following this, another on-line partial discharge test was performed to verify our findings. This test found that no partial discharge signals were detected, further supporting the theory that faulty assets are likely to release partial discharge signals before failure.

The Difference Between TEV & AE

TEV is a voltage induced spike that transfer to the cabinets housing as the partial discharge attempts to find a path to ground. TEV occurs as these spikes emit out from the source creating current spikes in the conductor and earthed metal surrounding the conductor.

This generates a wide range of Electromagnetic waves spanning from the kilohertz through the megahertz range. As the voltage spikes and incident wave strikes the earthed metals of the cabinet the produce a detectable ultrasound at 40 kHz and a TEV at 0 – 200 + MHz's.

Both of these electromagnetic waves fall in the radio spectrum of electromagnetic waves. They travel at different frequencies through the mediums and the TEV will potential travel a further distance than the ultrasound since the distance between its peaks can be much closer together than those in the ultrasonic range. This is why TEV can be heard in adjoining cabinets vs ultrasound which is easily impeded, diffracted, attenuated, or reflected away from the ultrasound testing device.

ASU CAT 2 Module 2-6 C Part 2 Analysis of Electrical Fault Conditions

Often, while performing Electrical Inspections, the CBM Analyst or Technician may find that they hear the sound characteristics change as they move around, as well see the decibels increase or decrease as they move around the target location. When the

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sounds from the anomalies are recorded from different angles, the CBM Analyst can see different signatures of the same event in the Frequency Spectrum as referred to as the FFT. While the Time Signal common referred to as Time Wave Form can still show similar harmonic indications without losing the harmonic occurrences. This is because there is only one Critical Angle of the anomaly and as such it has a limited field of reception.

Annual Inspections with Ultrasound

Historically, electrical systems have been scheduling for an annual inspection as mandated by insurance companies. Sometimes, it is simply because the facility does not have the personnel to perform inspections and the inspection is outsourced. Sometimes, it is the mentality of the management and planners that these assets are not as critical or that it takes too many man hours to inspect these assets.

Things to Consider

Safety is paramount when it comes to Electrical inspection and as such it's important to always inspect from a safe distance and wear your PPE. The use of a Parabolic dish can help close the gap on the distance related inspections. Whether it's due to a limited approach or an overhead power line the dish allows the CBM Analyst to easily pick up anomalies from a far. The CBM Analyst should always attempt to change their positioning and walk completely around the asset being tested. The CBM Analyst should always monitor their volume level to insure they are hearing the anomaly clearly with little to no antagonistic ultrasound. Once the anomaly is isolated the CBM Analyst can compare it to other like assets.

The Critical Angle of Ultrasonic Electrical Inspection

Electrical Ultrasound Inspection is one of the most unique applications as it is not dependent on decibel levels as much as the patterns the anomaly produces. However, limited approach restrictions can make it difficult to get the truest form of the Incident Sound Wave for pattern identification.

Why Does the Critical Angle Matter?

The Critical Angle is much riding in a car listening to the radio. The radio signal that it receives is strong when the car is in line with the transmission towers signal. However, when the car enters a valley or travels over the peak of the mountain and down its back side, the radio starts to lose signal clarity as the signal becomes blocked. Some of the signal can still be heard but some of it missing. As the car comes back in line of the radio signal, the Critical Angle is restored, and the occupants can enjoy the radio program.

Enclosed Cabinets

Statistics clearly show that exposure to electricity is still a major cause of deaths among construction workers.
Among non-electricians, failure to avoid live overhead power lines and an apparent lack of basic electrical safety knowledge are the major concerns.

Among electricians, the most serious concern is working "live" or near live wires, instead of de-energizing and using lockout/tagout procedures. The use of IR Windows has helped to reduce the risk and now the use of Ultrasound Ports is adding another tool to help determine if something is occurring inside the gear prior to doing any energized work.

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Enclosed Cabinets Can be Difficult to Test

1. Lack of opening to using an airborne module
2. Diffraction of Signal can affect your results
3. Some cabinets are hermetically sealed
4. No idea of what's happening on the other side of the panel
5. Energized work will one day be a thing of the past

When using ultrasound, the CBM Analyst scans the seams and openings in equipment to figure out if there is an anomalous condition that needs to be investigated further. With the invention of IR Windows and Ultrasound ports, the time it takes to perform electrical inspections has been dramatically reduced.

The IR Windows and Ultrasound Ports allow for a safer process of inspecting these critical assets while in their energized state. The facility can inspect their assets monthly if they wish because there is no need to wear an arc flash suit or remove the panels to perform these inspections.

Enclosed Cabinets Avoiding the Risk!

When it comes to ultrasound testing of enclosed electrical assets, there is no limit to what equipment class it can be used on. Ultrasound has always been relegated to scanning the seams and vent holes of switchgear with some success.

However, the CBM Analyst cannot always achieve the Critical Angle due to diffraction of the sound wave making it difficult to record the truest sound of the anomaly. This can lead to limited harmonic indications when trying to analyze the frequency spectrum (FFT) of the sound wave in a software like Sonus Vue Pro Desktop.

Enclosed Cabinets Defeating Diffraction

What is Diffraction? Diffraction is what happens to a sound wave when it encounters an obstruction or an opening as the sound wave bends and bounces off the material it is interfacing with which can vary its intensity.

Some electrical assets have hermetically sealed cabinets and the use of an Infrared Window with a built in Partial Discharge Sensor like the IRISS CAP-CT-PDS or CAP-ENV-PDS Series is the best choice.
These ports are significantly more effective than scanning the seam on enclosed systems.

With a transducer mounted inside of the cabinet, the CBM Analyst can eliminate antagonistic ultrasound from nearby defective lighting ballasts, ultrasonic motion sensors for lighting & security and from other sources generated by the everyday noises in production areas. This will improve the CBM Analyst s sound wave recording and get them in line with the Critical Angle of the incident wave.

When it comes to enclosed systems Diffraction of signal can also affect the ability of the CBM Analyst to achieve the Critical Angle of Electrical Inspection. The CBM Analyst is left to trace the seams around the panels of the assets and change their positioning of the airborne module when something is heard to try and see if they can a higher intensity of the emission.

Just like testing open air assets the CBM Analyst could see a harmonic appear in the Time Wave Form but because of the

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Diffraction of the signal as the signal exits the seam it will lose a significant portion of the emissions energy needed to receive a clear signal to be translated into an FFT.

When dealing with equipment with ventilation openings the CBM Analyst is afforded an opportunity to inspect through theses openings. By simply changing the positioning of the module the CBM Analyst can try and pinpoint the area the emission is originating from.

If the asset is completely enclosed and there are no ventilation openings the use of IRISS CAP or VP Series Ultrasound Ports will help to ensure the truest form of the emission can be record with minimal Diffraction.
These ports are more effective than scanning the seam on enclosed systems and for hermetically sealed cabinets the CAP-ENV-PDS Series is the best option as it ensures cabinet is still sealed.

With a transducer mounted inside of the cabinet the CBM Analyst can eliminate antagonistic ultrasound source from bad ballast, ultrasonic motion sensors for lighting & security and other sources generated by the everyday noises associated with production areas.

Environmental Factors & Pest Can Cause Failures

Whether its dust build up on transmission lines and substation assets or prairie dogs building a burrow inside electrical assets. Many things can cause premature faults and could quit possibly be picked up during monthly inspection, but few companies go beyond the annual inspection due to time constraints or just lack of commitment to an CBM program for electrical assets.

Do You Know What's Inside?

Here is an image that I took while performing a survey. The maintenance technician had opened the panel and not observed the rat laying across the electrical connections. The IR CBM Analyst scan the cabinet and also did not notice the rat laying across the connections.

When I approached with the ultrasound equipment I notice before I stood in front of the cabinet the rat slumped over the connections. The gear was de-energized, and this picture was taken prior to the rap being removed.

At this same site during our inspection I approached a cabinet that had the sound of an Electrical fault occurring. As I scanned the seams of the door, I could clearly hear the sound getting louder.

Once we de-energized gear we open the cabinet and were immediately on alert as several Hornets started flying in our direction.

After a few seconds the Hornets settled down in return to their nest that's when we notice in the bottom that cabinet the poor bat that had probably tangled with these Hornets and lost its life while in the gear.

As a former firefighter I can attest firsthand to the damage that squirrels and rodents can do to homes that cause fires. In this photo you can clearly see that our furry friend has gotten their self into trouble.

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From the NY Fire Investigator Webpage

Author Gordon Ivory

Insurance companies, adjusters and other real estate professionals need to be aware of the destruction that rodents can cause. Rats and mice start fires by chewing on electrical wires causing millions of dollars of structure damage each year.

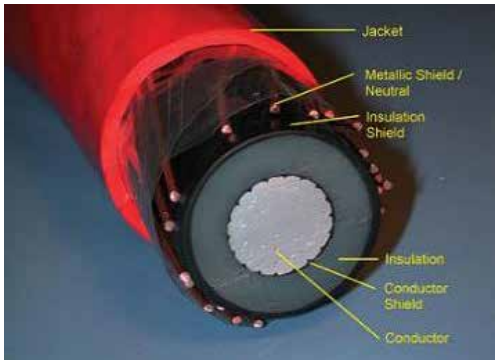
It has been estimated that rodents cause up to 20 percent of undetermined fires in the United States each year. As a professional fire investigator, I have investigated numerous fires over the years involving rodent infestation in everything from houses to cars to motorcycles and even lawn tractors. Mice and rats chew constantly because their teeth are always growing. They have incisor teeth that butt up against each other. They will chew through soft concrete, aluminum, wallboards, and plastic pipes. Field mice move undercover in the winter months and prefer to live near the warmth of electrical components.

To read the entire article go to https://www.nyfireinvestigator.com/articles/preventing-rodent-electrical-fires

Imagine opening this cabinet if this guy was still alive? Ultrasound can hear all of these All of these animals producing some form of ultrasound when alive.

Had the CBM Analyst s opened the panel while animals were alive. They could have jumped across connections causing an arc flash as the CBM Analyst opens the cabinet.

Can Be Tested; High Voltage Cable Tests



With high voltage cable there are many faults that can be detected. Voids in insulation is one of newer faults that has been heard over the years but gone undiagnosed. In the last few decades the science behind ultrasound anomalies has improved with the aid of sound analysis software.

The Harmonic patterns of each fault have unique characterizes that allow the CBM Analyst to identify the fault by seeing the pattern instead of trying to interrupt the sound they hear. With this knowledge the CBM Analyst can feel more confident in their diagnosis of the fault.

What Can Be Tested; Faults in Transformers

Transformer are electrical assets that transfers electricity between two or more circuits through electromagnetic induction. By alternating the current in one coil of the transformer it produces an alternating magnetic field, which in turn induces a voltage in a second coil. This magnetic field allows the power to be transferred between the two coils, without the need for a metallic connection between the two circuits.

Transformers are used to increase or decrease the alternating voltages in electric power applications. The invention of the first constant-potential transformer happened in 1885 and since that time transformers have become essential for the distribution, transmission, and utilization of alternating current electrical energy.

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When it comes to transformers there are several different types and styles that can be tested. There are a wide range of transformer designs and they range in size from 480 volts to 138 kV. Testing these assets should consist of airborne scan or a contact test on the exterior only. Never place your ultrasound device on our in energized equipment. Both have their limitations but always take into account all safety issue. Ensure a Size Up or Huddle Up is performed prior to starting the inspection process.

What Can Be Tested; Bushings Failures

Replacement of Damaged Substation Equipment Requires Town-Wide Outage

June 1, 2015 By Paul Loveless

Electricity supplied to the Town of Steilacoom is delivered to a single point of delivery (BPA/Steilacoom substation) where it is then distributed to Steilacoom electric customers via four substation feeder lines. At approximately 2:00 p.m. on November 27th (Thanksgiving Day) one of the four feeder reclosers in the Town's substation catastrophically failed, rendering the Town out of power for several hours.

Crews were able to restore power to the Town by reconfiguring the distribution system using the three remaining feeders. In order to put the system back to normal, the damaged recloser and conductors need to be replaced and all collateral damage repaired. Due to safety concerns and the nature of the work, a town-wide power outage was required to complete the necessary repairs and equipment installation.

It was estimated that it will take approximately 8 hours to make repairs and install the new feeder recloser.
In addition to the substation repairs, the crews took advantage of the outage to make additional improvements and repairs on other parts of the distribution system, avoiding the need for additional future outages. While there is never an optimal time for a power outage, the Town in consultation with others, had scheduled an 8-hour, town-wide power outage for Friday, July 17, 2015.

The plan is to shut off power at 8:00 a.m. and have it restored by 4:00 p.m. barring any unforeseen circumstances.

What Can Be Tested; Insulators

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There is no such thing as a perfect insulator, because even insulators will carry current. All insulators become electrically conductive when a sufficiently large voltage is applied. Some materials such as glass, paper and Teflon, which have a highly resistivity, are very good electrical insulators.

Since the insulators are exposed to the elements, they can build up dirt or bird scat which then lowers the resistivity of the insulator. This could lead to Corona, Treeing, Arcing and eventual premature failure.
These events do not have to start out as Corona and progress to Arcing, so any anomaly detected needs to be recorded and analyzed with sound analysis software. The CBM Analyst should always confirm the findings with an Infrared Camera.

What Can Be Tested; Switchgear

- Scan doors, seals, vents
- Listen to sound quality
- Compare to similar equipment
- Install CAP ENV PD or VPDS

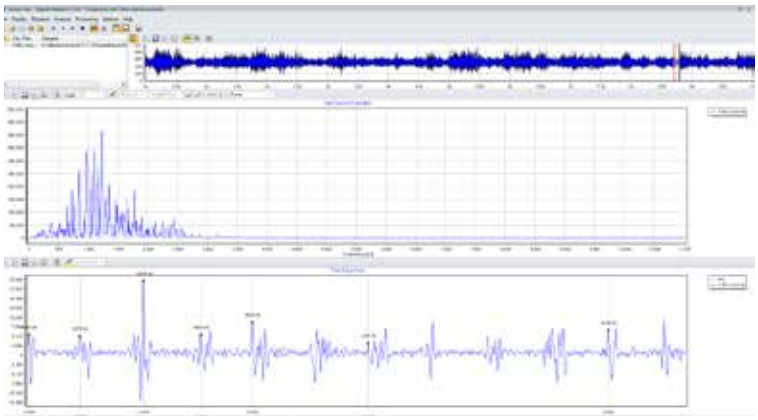
With so many seams, where does the CBM Analyst actually test? The answer is every seam if there are no Ultrasound ports. This leads to inconsistency in test location when testing seams. Especially when the sound could be coming from the cabinet above or below where the anomaly is heard. With the use of IR windows and ASU Ports the CBM Analyst s can assure consistency of the test location and cut the time it takes to do overall ultrasound inspections.

What Can Be Tested; Locating the Source of Radio & Television Interference

Everyone has driven by a powerline or transformer producing Ionization and experience a loss of radio signal temporally. This is caused by a Partial Discharge occurrences. This could be caused by Corona, Treeing or Arcing. This interference can sound similar to a sizzling, static, or a sparking sound quality to it. The intensity can increase and decrease due to the humidity in the air. The use of the Parabolic Dish is instrumental in the detection of these events since the distance is usually greater than 60 feet.

Preforming Electrical Sound Wave Analysis

It is a good practice when preforming an electrical inspection that it includes infrared and ultrasound equipment to detect fault conditions that could be occurring. When it comes to ultrasound it is critical that the anomalies are recorded so they can be analyzed in a sound analysis platform. These anomalies all have distinct characteristics when listening to them as well as distinct patterns when viewed in time wave form or FFT. In this module, we will briefly cover some examples of faults and the patterns that will traditional appear when being analyzed.



Ultrasonic signatures

- Corona
- Treeing (Tracking)
- Arcing
- Loose Connection
- Partial Discharge
- Dirty Power

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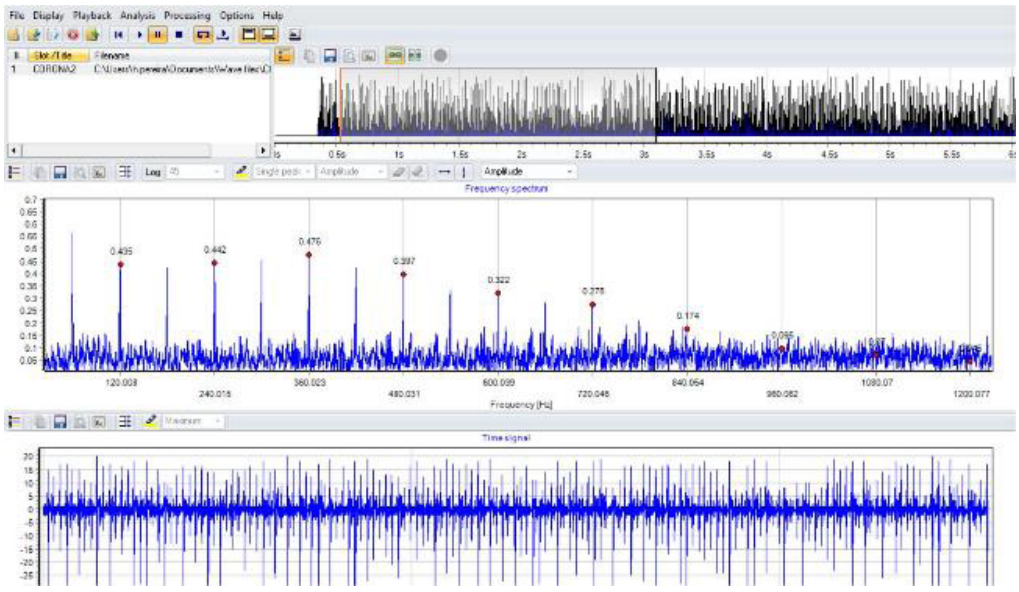
It is important in Electrical Inspection that the CBM Analyst take their time in locating the truest form of the ultrasonic emission. This will help to ensure that the sound wave can be diagnosed both in Time Wave Form, FFT and 3D Surfacing format. Since these events all have tell-tale signatures it is critical to take the time to ensure the event is recorded properly. Some CBM Analyst s can interpret the patterns with very little training and others still struggle with it. When chosen someone to use advance software for analysis it might be best to choose someone who isn't afraid of technology.

Many electrical issue generate ultrasonic emissions that can be determined by analyzing the sound wave pattern in a Time Signal, Frequency Spectrum or 3D Spectrogram Surfacing. These powerful platforms produce signatures that are very telling much like an EKG. The patterns will be distinct and show 50 or 60 Hz signatures depending on what part of the World the testing is being done in. Understanding these patterns is crucial to helping to determine the actual fault, as well as give the CBM Analyst a heads up prior to opening an asset that something is occurring, and all steps have been taken to ensure their safety. There is no set pattern to failure as an event could start off as Corona and slowly progress to Treeing and then on to Arcing, or it could start off as an Arcing event and then fail. So, it's important that the CBM Analyst captures the sound wave of the event for analysis in addition to using the Sonus Vue App on their phone.

Corona

Corona is generally characterized by a colored glow frequently visible in a darkened environment with audible sound usually described as a subtle sizzling sound. These events produce ozone which is an unstable form of oxygen is frequently generated during this process and will be malodorous. Since rubber is destroyed by ozone and produces nitrogen oxide which exposed to moisture turns into nitric acid. These items have detrimental effects on materials, inclusive of electrical insulators.

Corona can only occur above 1,000 volts and it will not produce any detectable heat, hence why IR won't see anything. If the CBM Analyst hears something Ultrasonic, they will need to record the sound and further investigate the harmonic indication in Time Signal. One of the unique factors with Corona is it will appear to have more amplitude in the Negative Portion than the positive portion. As the event generates its sound wave the compression of the air increases the airs density and prevents any spark of the corona event until the rarefaction portion of the wave moves through the area. Since the rarefaction actually thins out the molecules in the air the insulation of the air is negated and the current discharges into the air. These events will show a 60 Hz (50 Hz outside of the US) Harmonic throughout the Time Signal. These discharges will have more amplitude in the negative percent to scale. It is best to analyze the sound waves in only a 2/10th of a second interval for best analysis.



Corona: Corona is the glow and audible discharge that occurs when there is an excessive rise in localized electric fields surrounding an object that causes the ionization, which in turn can lead to possible electrical breakdown of the air around this point. When the sound recording is analyzed it will present with repetitive 50 or 60 Hz (Dependent on the line frequency of the

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country) richer harmonic indications in the negative portion to scale in will be seen in the Time Wave Form. This is due to the sound wave having a compression and rarefaction in the air around the anomaly. Rarefaction of the sound wave actually thins out the air on the negative side of the sound wave and reduces the insulation value of the air allow the partial discharge. If the inspector establishes the Critical Angle the Frequency Spectrum will also show repetitive harmonics at 50 or 60 Hz. It will not however produce a heat making it undetectable with Infrared.

One of the unique factors with Corona is it will appear to have more amplitude in the Negative Portion than the positive portion. As the event generates its sound wave the compression of the air increases the airs density and prevents any spark of the corona event until the rarefaction portion of the wave moves through the area. Since the rarefaction actually thins out the molecules in the air the insulation of the air is negated and the current discharges into the air. These events will show a 60 Hz (50 Hz outside of the US) Harmonic throughout the Time Signal. These discharges will have more amplitude in the negative percent to scale. It is best to analyze the sound waves in only a 2/10th of a second interval for best time analysis.

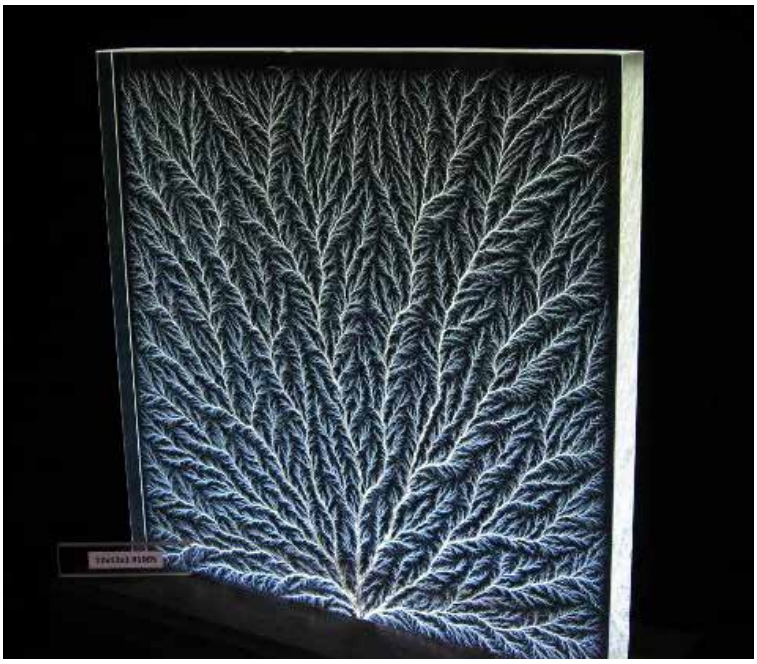
We will also notice we have convert the Hertz to Time will be .016667 so, we can either look for a .016 or a .017 interval. With Sonus Vue Pro we can actually extend out to a millionth of a second to see more definitively the actually harmonic occurring falling at the .016 to infinity value.

Treeing/Tracking

Electrical treeing occurs and begins to sprawl outwardly when a dielectric material is stressed over a period of time by highly divergent electrical fields. Electrical treeing is observed to originate at points where the sound source originates from which can be caused by impurities, gas voids, or mechanical defects. This can cause gases to ionize around the event creating small electrical discharges. A pollutant or defect may even result in a partial breakdown of the dielectric itself. This anomaly will produce ultraviolet light and ozone from these partial discharges (PD) and then react with the nearby dielectric, and further breakdown its insulating values. Gases are often discharged as the dielectric breaks down, creating more voids and cracks which leads to further weakening of the dielectric and accelerate the PD process.

Electrical Treeing can occur in High Voltage Equipment just prior to failing. During an RCA the treeing can be used to track down the source of the failure. There are 2 common types of treeing that can be produced when equipment starts to fail.

Bow-tie trees start to grow from within the dielectric insulation and grow outwards toward the electrodes. As it start inside the insulation it doesn't have a supply of air which would allow the continuous support of partial discharges. Hence these trees have limited growth and do not usually result in a failure in the insulation or ability to sprawl out to the nearest electrodes.



Vented trees initiate at an electrode insulation and sprawl out towards the opposite electrode. Being exposed to atmosphere is a key for its growth. These trees will continuously grow until they are able to bridge the electrodes which will result in the failure of the insulation.

Treeing has actually been used to create some amazing artwork where you can clearly see how this electrical event got its name. The use of this in artwork is known as Lichtenberg Figures and there are some pretty amazing images created when electricity is applied to the medium.

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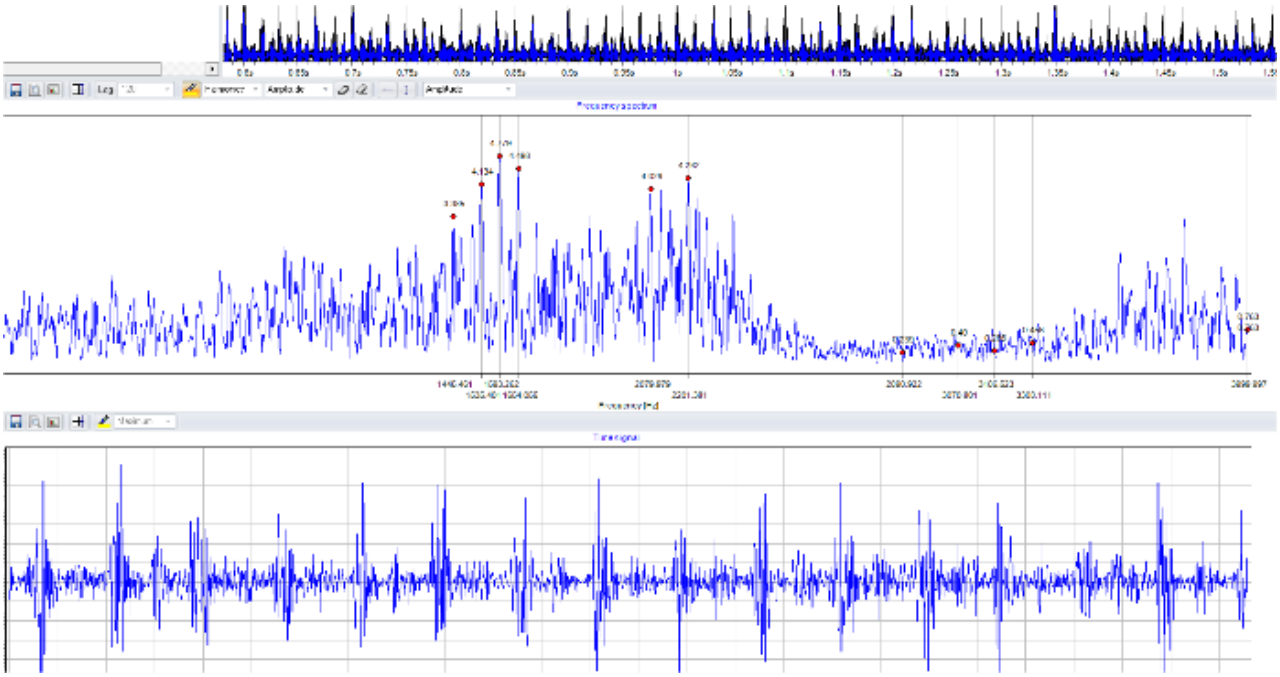

Tracking Is an electrical pre-breakdown in solid insulation that causes damage due to stressed insulation due to stressed dielectric insulation which allows partial discharges to travel through a medium in a path resembling the branches of a tree. Treeing of solid high-voltage cable insulation is a common breakdown mechanism and source of electrical faults in underground power cables. This event will produce Heat and Ultrasound emissions. The sound wave will have line frequency harmonics with the Time Wave Form showing almost equal amplitude in the positive and negative portion while the FFT will present with a few intervals and tamper off. The interval will present itself with a 50 or 60 Hz harmonics in the Time Wave Form will have a rich amplitude with the positive and negative overall peaks being nearly equal. In the FFT harmonics will also show up at line frequency if the Critical Angle has been achieved.

Arcing

Arcing is an electrical breakdown of air or gas insulating an electrical connection that allows for an ongoing electrical discharge. The current passing through this normally nonconductive medium in turn produces a visible & ultraviolet light as well as a source of ultrasound. Electrical arcing creates ultrasound & heat. Arcing will show very distinct burst over the entirety of the sound recording when viewed in Time Wave Form and the CBM Analyst will need to zoom in on the burst where the interval of the line frequency will be apparent. In the FFT the CBM Analyst will notice the 1-time occurrence and from there it will be very random indications which will usually tamper off by the 10th occurrence.

A total breakdown of the insulation value of a medium that allows for the current to pass through it.

It Produce ultrasound emissions.

It also produces a source of Ultraviolet light that will damage the retina if viewed without protective eye wear.

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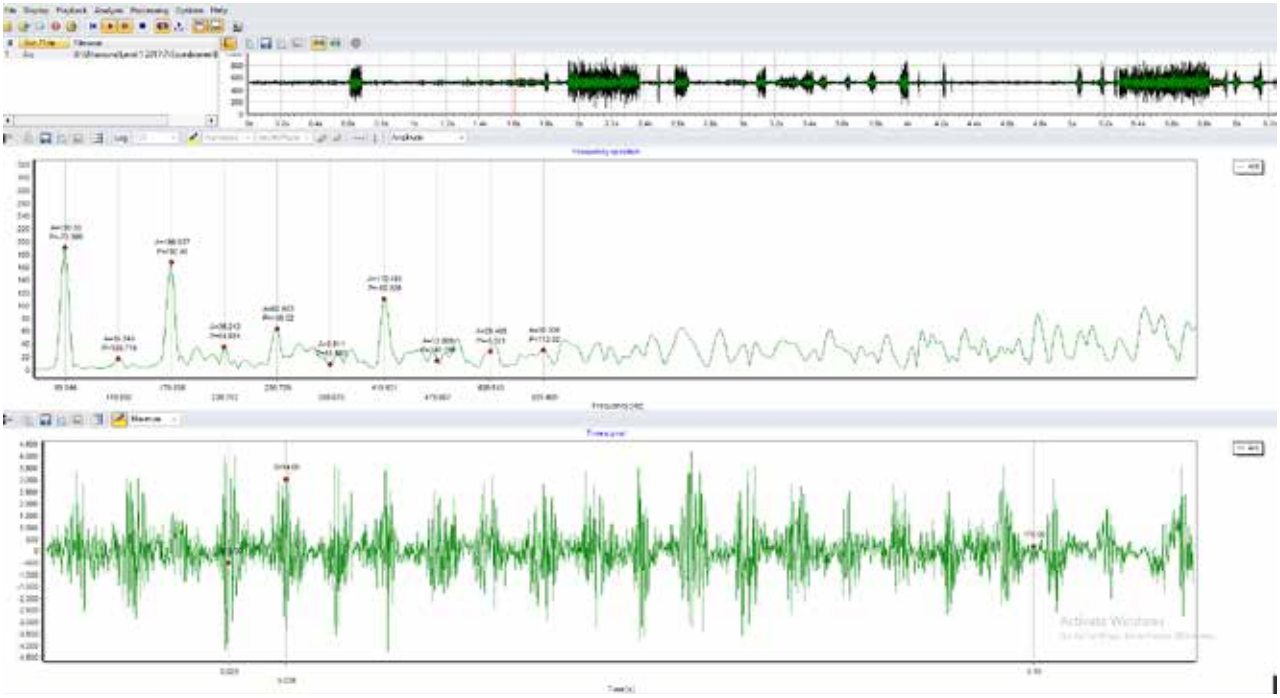
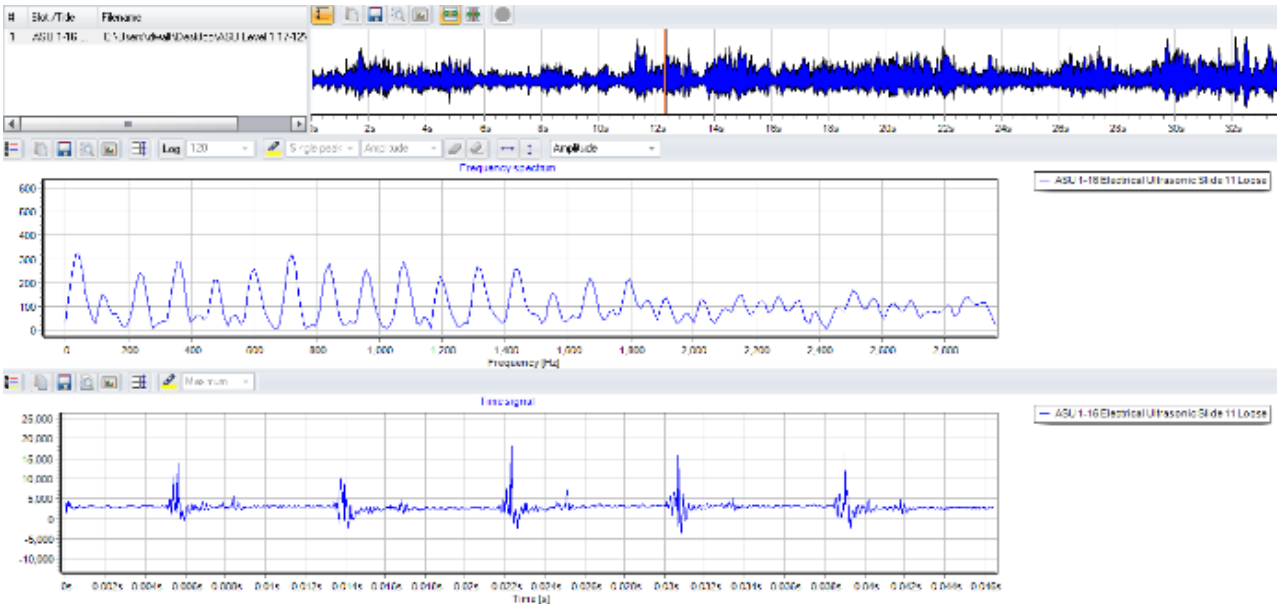


Arcing will show harmonics in burst when looking at the Time Wave Form and sporadic Line Frequency Faults in the FFT that tend to dissipate after the 10th occurrence. The key to analyzing the Time Wave Form is too zoom in on a burst of sound and isolate 2 tenths of a second of time of that burst. The CBM Analyst will then clearly see the line frequency faults.

Loose Connections

A Loose Connection is connection that becomes loose overtime from not being properly tightened at installation of the equipment which causes it to start to melt and oxidize from the excessive current its drawing. This will produce a source of ultrasound and heat. Loose connection will present with a 2-time line frequency harmonics in both the Time Signal and the FFT, but the Time signal will have a Fish Bone appearance that intensifies and wanes several times.



A loose connection will show up with Harmonics at 2 times the line frequency. In the Time Wave Form it will even show the characteristics of a fishbones from a cartoon. What does this mean? The CBM Analyst will notice the amplitude increasing and decreasing across the Time Wave Form. The FFT will also show indications of a 120 Hz Harmonics have a much higher amplitude

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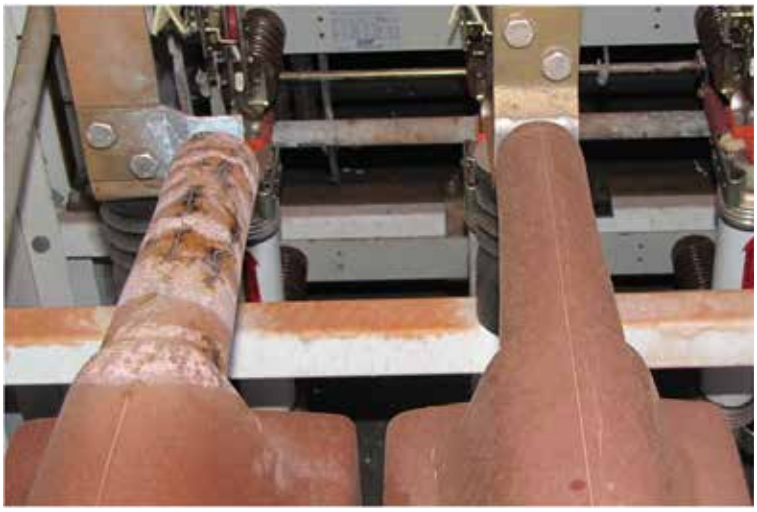
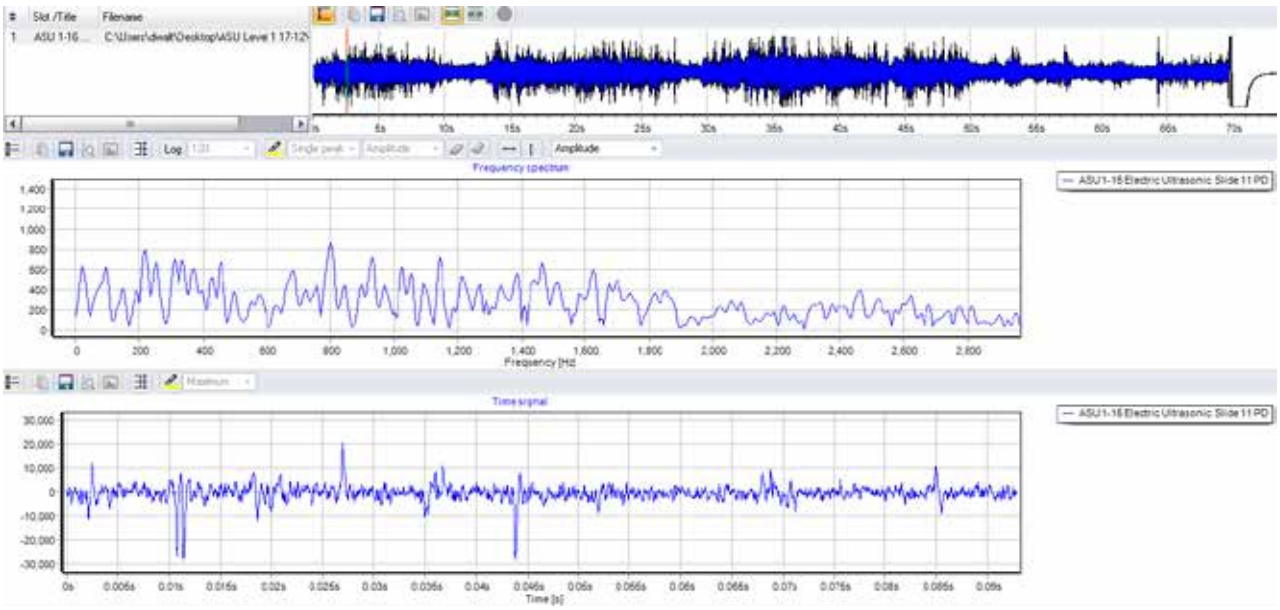
than the line frequency indication if any are even present.

Partial Discharge

Partial Discharge (PD) is a localized dielectric breakdown of a small portion of a solid or fluid electrical insulation system under high voltage stress, which does not bridge the space between two conductors. While a corona discharge is usually revealed by a relatively steady glow or brush discharge in air, partial discharges within solid insulation system are not visible. PD can occur in a gaseous, liquid or solid insulating medium. It often starts within gas voids, such as voids in solid epoxy insulation or bubbles in transformer oil. Protracted partial discharge can erode solid insulation and eventually lead to breakdown of insulation. This will not produce any detectable heat but will generate a source of ultrasound and Transient Earth Voltage (TEV).



Partial Discharge will sound like a slight bit of static and can be tough to capture due to its lack of amplitude. For years this sound was dismissed as inherit or unknown, but now with the confirmation with PD units Ultrasound devices have been able to pick up the same events. Harmonics will also vary due to the lack of amplitude and limitation of the Critical Angle.



Dirty Power

Dirty power is electromagnetic pollution called transients and harmonics. Dirty power creates erratic spikes and surges of electrical energy traveling along power lines and building wiring where only standard 50/60-Hertz AC electricity should be. Also called electrical noise, line noise, and power line EMI, it is one fast-growing source of electro-pollution in homes, schools, and businesses today. Dirty Power may show some signatures of heat but at the time of publishing there is no science to back this up, however it will produce signatures ultrasonically that can be traced all the way down to the motors. In the case of a waste water treatment plant in Ohio they had a known condition coming from their substation yard that had burnt up several assets over the years and during one test of the MCC's a line frequency fault was found at 121.5 Hz that repeatedly showed up in both the Time Wave Form and the FFT. Upon further testing of other MCC's the presence off a 121 Hz & 122 Hz were found and confirmed to be present in the motors they were driving.

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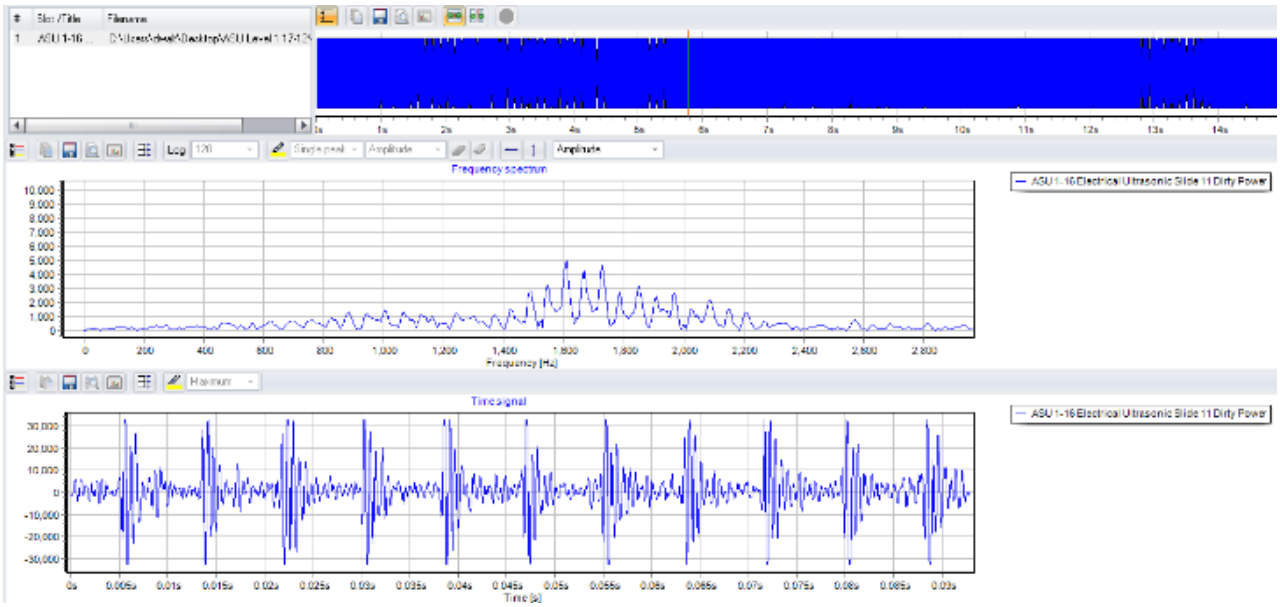
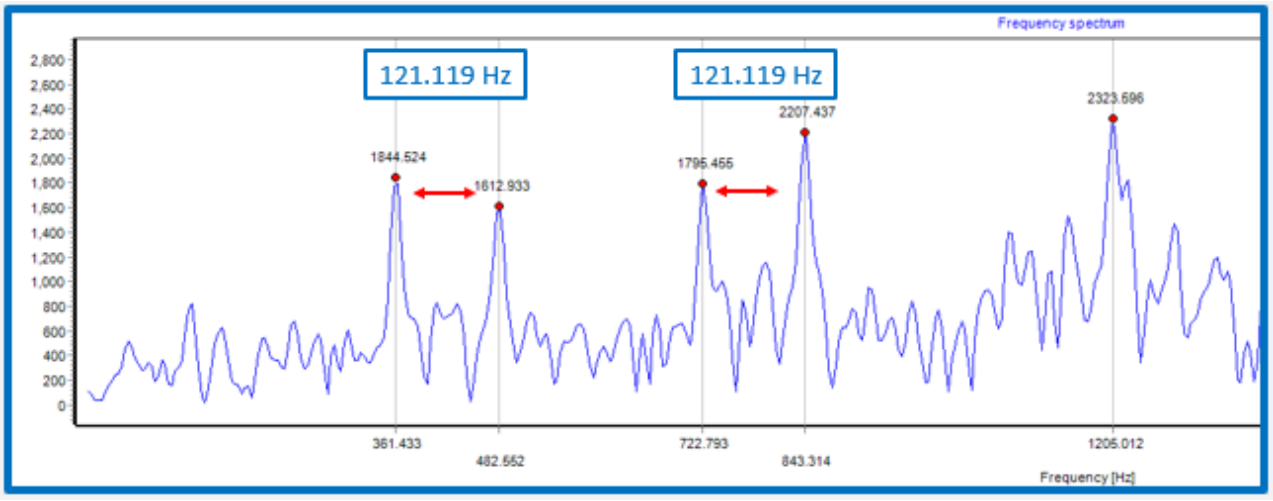


Dirty Power will produce a distinct buzzing noises with a lot of amplitude when viewed in the Time Wave Form. In the US the Harmonics will stack up at one of the following values 121, 121.5 or 122 Hz. No information has been established outside the US at the time of publishing this book. The FFT will show similar harmonics and in the case of this example there is too much amplitude in the recording so the translation of the signal from a Time Wave Form to an FFT isn't possible due to the distortion of the signal because the CBM Analyst had too much amplitude.



With the indication of a 121.119 Hz Harmonic in the Frequency Spectrum the CBM Analyst would be able to determine the existence of Dirty Power being present. With Dirty Power occurring between 121 Hz to 122 Hz the analyst can then transition to the Time Signal to look for its correlating time interval.

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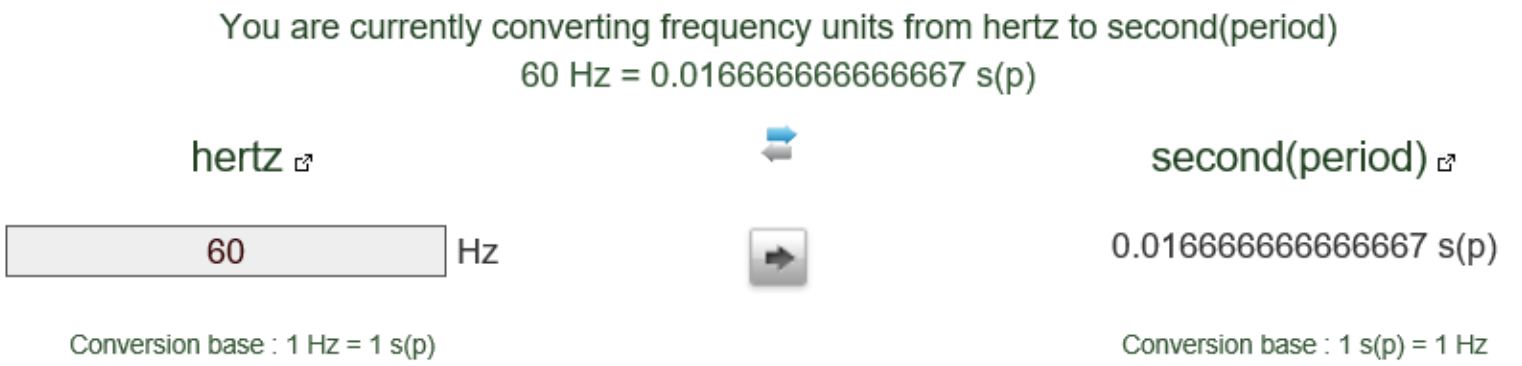
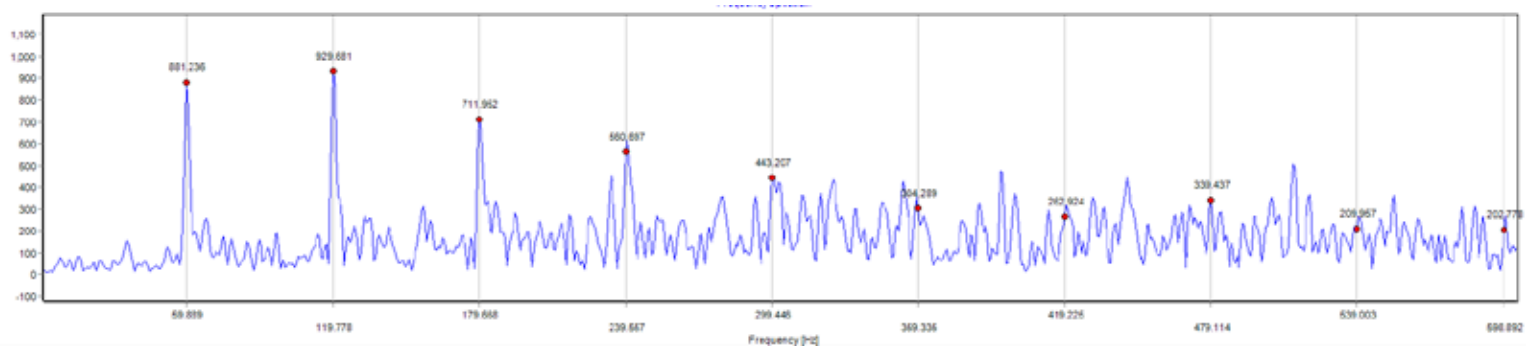
When looking in the sound wave using the Time Signal screen the analyst would be looking for a time interval of .00825 seconds to be occurring. These are just a few examples of the importance of how good data can be mined to determine fault condition not only through decibel trending but through the analysis of sound waves.

How to Convert Hertz to Seconds

We can calculate these occurrence by dividing 1 Hz by the harmonic occurrence found in the Frequency Spectrum to determine what the harmonic occurrence will be in the Time Signal. In the case of a 60 Hz Harmonic the value we would then look for is 0.016 or 0.017 seconds of time. If the Frequency Spectrum was showing up with a 120 Hz signature, we would use the same formula and divide 1 by 120 which would result in a value of 0.08333333333333333 harmonic. This same process can be used in the Mechanical Application for fault detection of Stray Voltage, Outer Race, Inner, Ball Pass and Cage Faults for example.



Marking Electrical Fault Conditions



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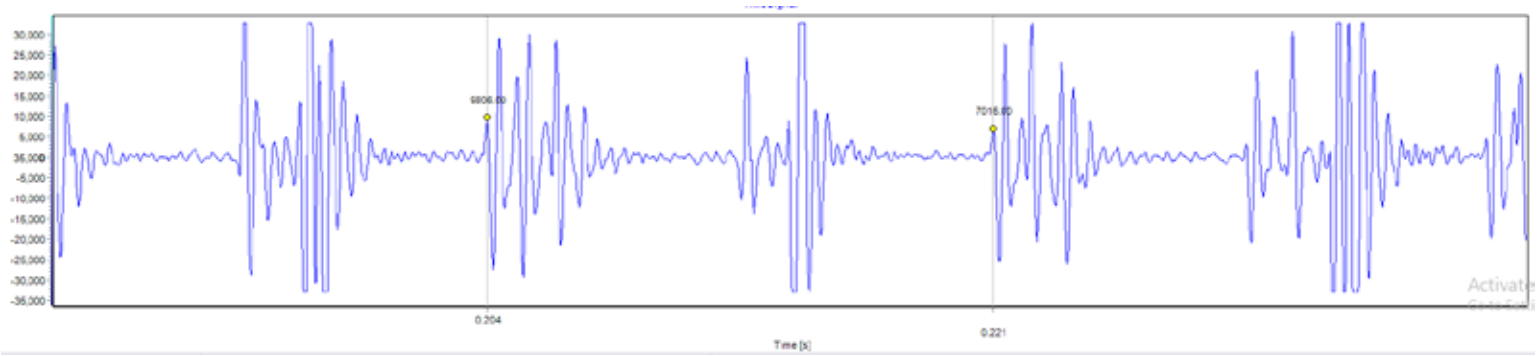
The Critical Angle of electrical inspections is the angle at which the CBM Analyst records the best sound characteristic and decibel level of the anomaly. Sound Analysis is critical in ultrasonic electrical inspections and the decibels can only be used to guide the CBM Analyst to best angle to capture the sound wave. Decibels are only to be used as a reference to find this angle and not a measurement of severity as decibels are not trend-able when it comes to electrical inspection application.

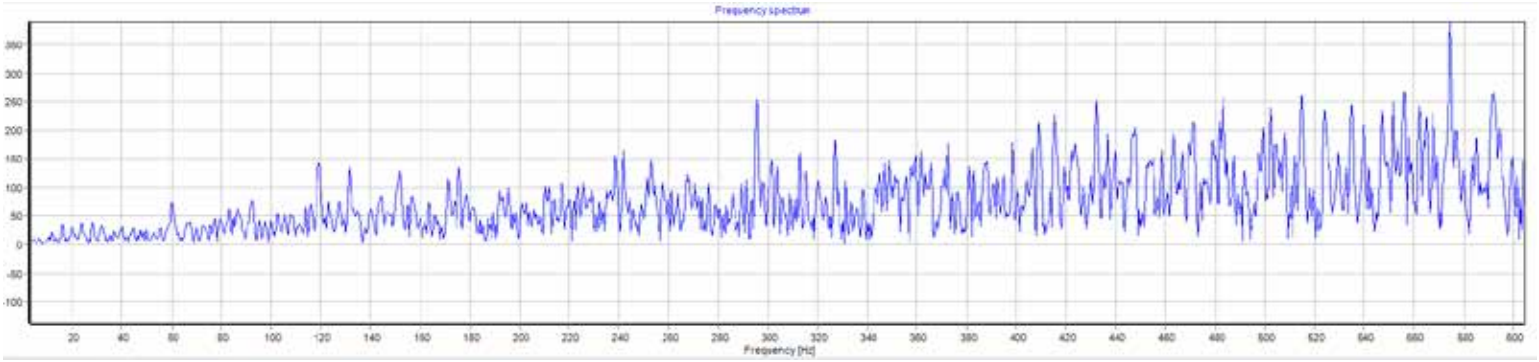
The decibel would only indicate that they have found the best angle they can achieve to record the sound wave of the ultrasonic anomaly. Sometime the Incident Wave is travel up and away from the CBM Analyst 's position and the Critical Angle cannot be achieved from their position since the CBM Analyst is at an obtuse angle to the Incident Wave.

The CBM Analyst can hear an electrical anomaly and record that anomaly for sound analysis. Analysis of that recording shows that the FFT does not always show a 60 Hz harmonic marking but the 60 Hz harmonic markings do show up in the Time Series visualization of the waveform.

This observation occurs when the captured sound waves are not at the Critical Angle. It is not the truest form of the incident wave because there is resolution loss due to distortion of the signal. The CBM Analyst will still be able to see some indications within the Time Signal as it is not dependent on any translation of the Time Signal into a Frequency Spectrum which allows us to see the harmonic occurrences.



In this first example the CBM Analyst was able to make the correct diagnosis of the ultrasound emission by confirming the existence of a .0167 seconds harmonic in the Time Signal and 60 Hz Harmonic in the Frequency Spectrum. With clear indications in both the Time Signal analysis and in the Frequency Spectrum, the CBM Analyst can confirm they have achieved the Critical Angle of the ultrasound emission and determined the existence of treeing (tracking).



The lack of rich 60 Hz harmonics in this treeing occurrence. There is a small indication at 60 Hz and another one at the 120 Hz Harmonic value, but it quickly disappears. The Critical Angle was not achieved in this recording and as such we do not have the signal strength to show rich 60 Hz harmonic intervals. These indicators show that this event is Treeing (Tracking).

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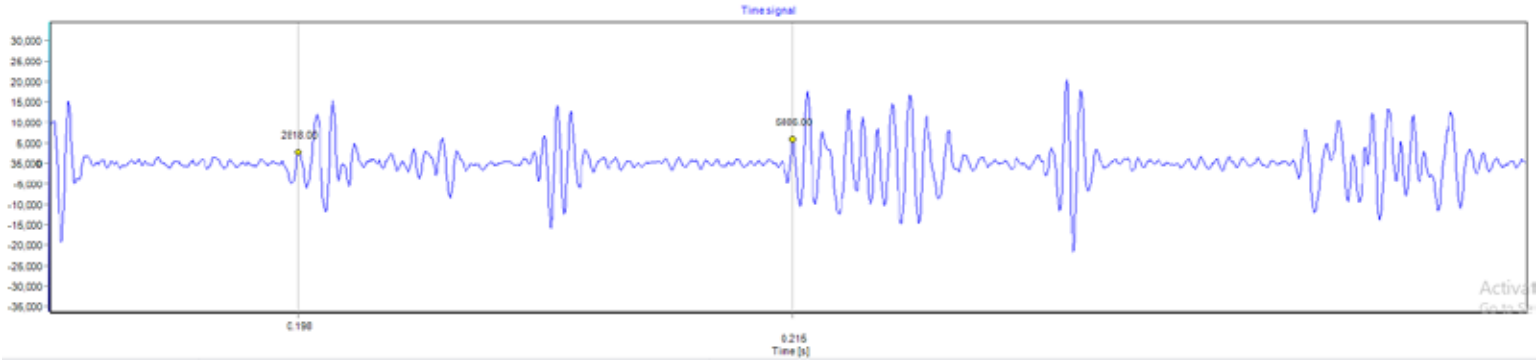
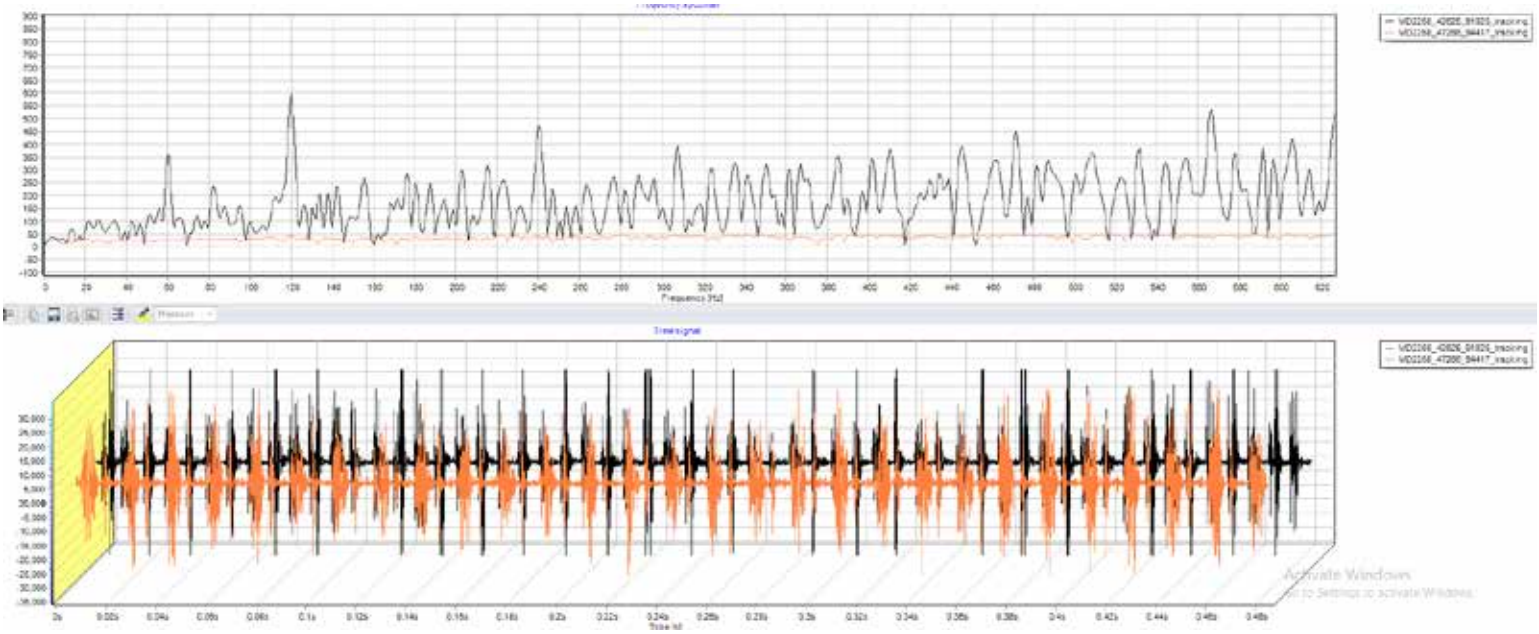


Even being outside of the Critical Angle of the Incident Wave the Time Signal will still show the occurrence of 0.016 seconds indicating the presence of and electrical anomaly occurring. Since Time Signal isn't a translation of this occurrence there is no loss of the 0.016 seconds indication as the current traveling across the surface as it happens. From there the CBM Analyst will notice that the amplitude in the positive and negative scaling is pretty even and constant which is the hallmark of a Treeing or even a Tracking event.

However, only when we run them through the sound analysis software can the CBM Analyst verify that they have achieved the Critical Angle of these electrical events. Therefore, it is very important to walk around and listen as you move to try to find the Critical Angle of these ultrasound anomalies.



The key is using your decibels only as an indication of increased strength of signal. Decibels should never be used for gauging severity of electrical anomalies. Decibel levels only indicate that the CBM Analyst is in line with the critical angle. This image is the overlay of both of these sound waves. The Frequency Spectrum shows the Critical Angle Sound Wave in Black and the Orange represents the sound wave that didn't achieve the Critical Angle.

ASU CAT 2 Module 2-6 C Part 3 Safely Preforming Electrical Inspection

The use of Ultrasound Inspection devices is one of the safest ways to determine the condition of an asset without having to open any equipment. This saves the CBM Analyst from having to wear an Arc Flash Suit with an open panel. Being able to inspect

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electrical equipment use to involve scanning the seams and openings of equipment and recording the sound wave to analysis what the condition inside is.

The one problem that the CBM Analyst runs into is the diffraction of the sound wave and the inability to establish the Critical Angle of the event. With the use of VP-12 US and VPDS the CBM Analyst can overcome the diffraction of signal. This will help to expedite the inspection process by eliminating the tracing of the seams of panels on equipment.

Why Risk Opening Electric Cabinets?

Traditional Maintenance and Testing of the electrical assets requires intrusive work practices that place the CBM Technician at risk of an Arc Flash Event. The use of Megger for stress testing does not cause damage to the system put places the CBM Technician at risk since the system must be energized to perform this type of testing.

These “Maintenance Tasks” are designed with one outcome in mind: “To confirm whether or not the circuits and connections are good, and that the system meets its “Operational Requirements”. Is there a better way?

The Challenge

Create the means for collecting on demand real-time condition status data of mission critical electrical distribution systems & components.
Mitigate the thousands of electrical worker injuries each year, some fatal, and billions in lost revenue from unplanned outages and equipment failures.
…Implement a comprehensive, safe and intelligent protocol for performing essential energized surveillance and inspection procedures on electrical distribution systems
…Remove the inherent dangers of Condition Based Maintenance procedures and still allow for efficient routine inspections on demand!

Safety and trade organizations around the globe are mandating that workers do not open electrical switchgear for maintenance activities unless they first put the equipment into a safe work condition, also we must ensure the appropriate level of safety and equipment training is given to everyone involved in the maintenance operation to ensure that the work is completed as safely and efficiently as possible.

Every site around the World has to open their electrical equipment for maintenance or annual inspection. The problem has always been that this is usually done when the equipment is still energized. Unfortunately, these actions expose us to electrical faults such as corona, treeing, tracking and arcing, which can cause very serious burns and even fatalities.

It is necessary to know when one of our assets is going to fail but doing so exposing the electrician to energized gear isn’t worth the life of our electricians and is not the best way to do it. This is why IRISS created Ultrasound Ports which allows a safer and more accurate way to detect ultrasound anomalies in electrical assets.

When using Ultrasound equipment, the benefits are huge as it can be used at any time without having to open electrical equipment. This would allow a program to safely inspect their electrical assets more frequently without having to risk opening any

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assets blindly and having to wear the arc flash suit.

Reducing Maintenance Induced Failures

Human Error is inevitable and using EMSD's allows us to design our systems and processes around this inevitability.

2005 – 2015 1400 insured fire losses from electrical failures cost $2.3 billion between Power disruption costs US businesses $145 billion/year. 50% of electrical deaths and severe injuries are associated with routine maintenance & repair.

- **Loose connections / parts 30.3%**
- **Moisture 17.4%**
- **Line disturbance (other than lightning) 10.4%**
- **Defective / inadequate insulation 9.9%**
- Lightning 8.1%
- **Foreign objects / short circuiting 7.3%**
- Collision 3.9%
- **Overloading / inadequate capacity 2.4%**
- **Accumulation of dust, dirt and oil 2.2%**
- **All other causes 8.1%**

88% of failures can be identified by utilizing more frequent CBM inspection models

Source: Failures Based on Hartford Steam Boiler Claims Data

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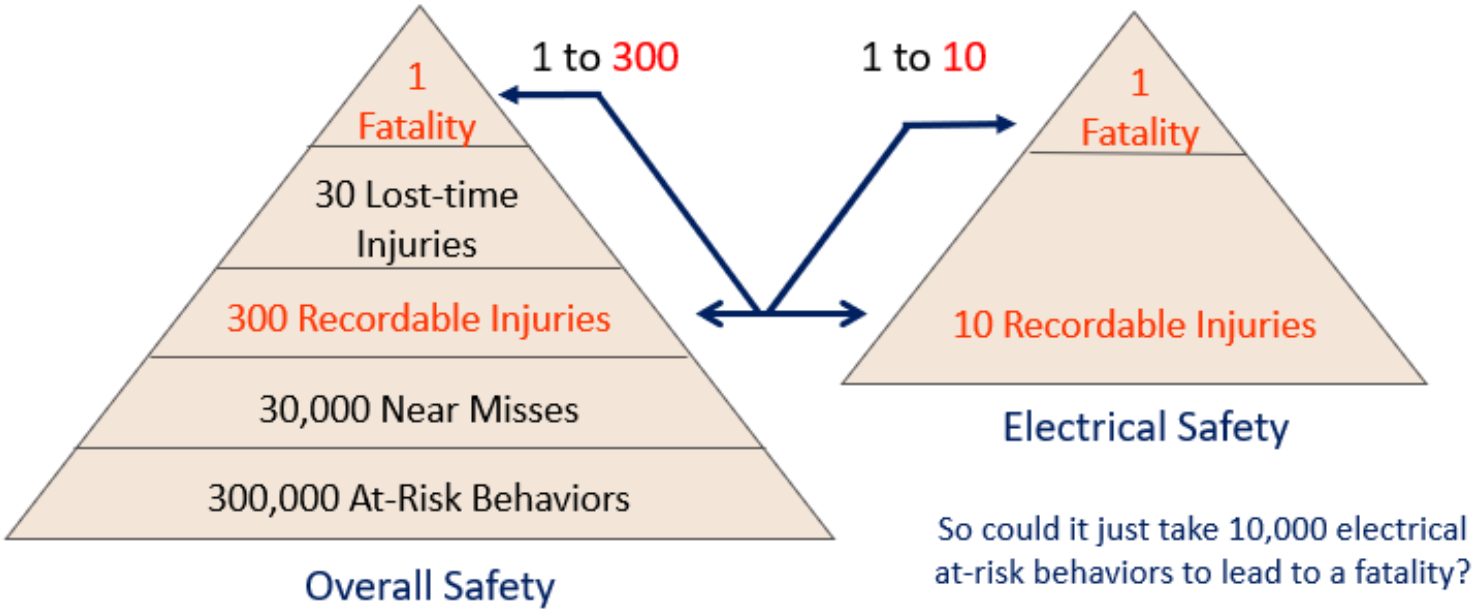
Importance of Electrical Safety



The larger pyramid is a standard workplace safety pyramid that shows the ratios between at risk behaviors and fatalities. The smaller pyramid is the electrical industry. What this shows is that the recordable injury to fatality rate goes from 300-1 to 10-1 in the electrical industry which equates to only 10000 electrical at-risk behaviors (opening panels, etc.) to lead to one fatality!! We remove the at-risk behaviors and therefore impact the fatality rate (getting to the root cause!).

Safely Testing the Grid

For years the Grid has been there delivering electricity, but it has been left under serviced and aging. As such there have been significant failure over the years that have called in to question the stability of the grid. With more and more demand we have seen the life cycle of the grid be tested. In some cases, the grid is taken down by human era. This usually comes from a lack of understanding of what can happen when working around electrical systems.

Here are some safety tips for electrical inspections.

- Wear appropriate clothing and safety gear
- Do not reach out towards electrical equipment when and anomaly is detected
- Use the Long-Range Horn or Parabolic Dish to keep a safe distance

A Breakdown of Electrocution Deaths

Every year, thousands of electricians are injured or even killed during work. Most of the organizations around the world are implementing regulations where workers are not allowed to open electrical panels for maintenance activities unless they are in a safe working condition.

They are also trying to ensure that the level of safety training and knowledge of the equipment being tested is at the highest of levels and it is given all those involved in the maintenance operation. Statistics clearly show that exposure to electricity is still a major cause of deaths among construction workers.
Among electricians, the most serious concern is working “live” or near live wires, instead of de-energizing and using lockout/tagout procedures. Among non-electricians, failure to avoid live overhead power lines and an apparent lack of basic electrical safety knowledge are the major concerns.

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Electrocutions are the fourth leading cause of death among construction workers in the United States. An average of 143 construction workers are killed each year by contact with electricity (based on government data for 12 years, 1992 through 2003).

Electrical workers had the most electrocutions per year, followed by construction laborers, carpenters, supervisors of non-electrical workers, and roofers (chart 1). (These numbers do not reflect the risk for each trade, because no corresponding information is available on hours worked for each trade.)

Trade	#Deaths	% of Total
Electrical Workers	586	34%
Construction Laborers	274	16%
Carpenters	97	6%
Non-Electrical Supervisor	86	5%
Roofers	72	4%
Other Trades	600	35%
Total	1,715	100%

Chart 1

Note: A total of 1,715 deaths in 12 years. Electrical workers includes electricians and their apprentices, electrical helpers, electrical power installers and repairers, and their supervisors. “Other trades” include apprentices and their helpers. Source: U.S. Bureau of Labor Statistics CFOI Research File

A study that ran over a 12-year period performed by the U.S. Bureau of Labor Statistics they determined that 1,715 workers were killed due to electrocution events. This isn’t just a problem in the United States as many of these events occur on a daily basis around of the World.

These events aren’t always fatal, and we hear on the news about an electrical fire that injured several workers a mill. The press doesn’t know that these events are caused by an Arc Flash event and this events can be reduced by using IR Windows and Ultrasound Ports as well as adhering to Safety Policies and Procedures.

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Senseless Accidents

Former Student Injured

- Don't be complacent
- Obey all safety procedures
- Wearing the appropriate FR Level clothing
- Never reach out with your Ultrasound device
- Never break the plain
- Keep a safe distance
- Stand on a rubber mat

The biggest factor in personnel getting hurt or killed in an Arc Flash Event is they are complacent. We have all heard or been that guy that says, "I done it a 1,000 times!" Well it on takes that one time for it to all go wrong and destroy lives. So, it's important that the first step in your program be to ensure that all personnel obey all safety procedures. This include wearing the appropriate FR Level Clothing for the task. Never reach out with your Ultrasound device. Never break the plain of the asset. Keep a safe distance and stand on a rubber mat when possible.

This accident only took seconds to occur and luckily for the former student he had his t shirt and long sleeve CAT 2 long sleeve shirt on, or this injury would have been far worse. He is no longer working as an electrician as he tried to go back to work but the thoughts of this near fatal accident, we too much him to overcome.

Painter Killed

By Mark Harrington
mark.harrington@newsday.com
Updated March 22, 2016 8:59 PM

A painting subcontractor sealing a LIPA substation in Glen Head for PSEG Long Island suffered a severe electrical shock and burns and is in "very serious condition,"

The man, 47, whose name was not released, was sealing the roof of the substation near the Long Island Railroad tracks on Glen Head Road when he "brushed up against roof bushings" and suffered a "severe electric shock,".

Substations convert higher-voltage energy from power plants to lower voltages distributed to homes and businesses. The worker encountered a 13,000-volt line.

Third Precinct officers, Emergency Service Unit officers, Ambulance Bureau AMTs and the Glenwood Fire Company responded to the scene.

Glenwood Fire Company responders used their ladder truck to assist emergency service officers to remove the victim from the roof and place him into a county ambulance.

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The man received severe electrical burns and remains at Nassau University Medical Center in East Meadow, according to the spokeswoman.

Power Line Kills Worker

Byline: By Lisa Hutchinson 12/15/2006

A Newcastle man died when he was electrocuted at a power substation which has 400,000 volts running through overhead lines. Steve Kirkup was working away from home in Cambridgeshire when tragedy struck. The 41-year-old was employed by contractors Siemens TD doing maintenance work from a cherry-picker in the middle of a National Grid substation on the edge of the village of Burwell when he received the fatal high-voltage electric shock.

He fell about 20ft although it is not yet clear whether he was electrocuted and then fell or fell from the crane and then received the shock. Emergency medical charity Magpas was called to the incident at 1.30pm on Monday and paramedic Andy Bates and Dr. James French rushed to the scene. Dr. French arrived in a police helicopter which had to circle the area three times before it was safe to land because of the hazards of the electric pylons.

A True Story of an Arc Flash Event

It's not too often we hear about an Arc Flash Event Survivor. The few I have meet over the years have often been left with more than physical scars. Some survivors actually have said they wished they had died that day because the and struggle they continue to have are overwhelming. PTSD, Depression and Divorce are some of the factor's survivors will face after their event. None of these are easy things to deal with and no one considers these things prior to going to work but, it should be reinforced every time electrical work is going to be conducted.

Drunk Man

As morbid as this may be, it is necessary to discuss the effects of electrical injury to emphasize the necessity of always thinking safety. Electrocution is one of the leading cause of workplace fatalities. As the current passes through the human body is burns skin and nerve ends, can split limbs wide open and blow pieces completely off the human body. Not to mention stop the heart or vaporize the induvial involved in the event.

The affects from the heat will cause catastrophic damage to the skin and will require the induvial to spend months in a burn center. The severity of a burn is largely dependent on the depth of tissue destruction and the total surface area that suffered burns. 3rd degree burns will no longer hurt the victim as the nerve endings are burned away.

Just 20 years ago someone with burns over more than 50% of their body stood a slim chance of survival, but today some victims are surviving with burns up to 80% of their body. The survival rate depends mainly on the age and health of the victim.

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ASU CAT 2 Module 2-6-D Hydraulic Systems Inspection

Hydraulics Systems have been used for thousands of years dating back to Mesopotamia and it was not until 1785 when Joseph Bramah and Sir William George Armstrong took inspiration from the common water wheel and designed a hydraulic piston engine to move a crane.
They applied the Pascal's Principle which state "that a pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere".

This advancement helped to aid the industrial revolution in its growth and is still used today for a wide array of equipment in use in everyday life. From Elevators to the brakes on your car Hydraulic Systems are still in use today.

Why Ultrasound Testing for Leaks is Safer

If we apply all of the same principles, we have learned in the previous modules to leaks in Hydraulic Systems, we will see that turbulence and friction will also be detectable in this system too. This make the use of an ultrasound device a quick and easy choice to use for the detection of leaks in valve, rams or even cavitation in the pump.

Since these systems operate at high rates of pressure the CBM Analyst will need to insure, they perform these tests safely at all times since hydraulic leaks can cause amputations or death. These types of injection injuries can go miss diagnosed and lead to amputation from the damage to the injected area caused by the inflammation and the chemical makeup of the fluid. Proper diagnosis is critical and will need several surgeries in order to try to ensure minimization of long-term damage to the affected are.

Hydraulic Valve Testing

Testing Hydraulic Valves, the CBM Analyst will need to listen upstream and downstream like a regular valve however, since these valves and piping usually so close together there is not enough room to use the 4-point method like a gated valve for example. So, the CBM Analyst will need to listen upstream and take note of the decibels and then do the same downstream as the valve are used. A distinct turbulent sound will be present when the valve is leaking by or in the case of a valve presenting with little to no sound downstream when operating the valve, it has failed closed.

Having used a mini excavator for years and experiencing the effect of these valves failing firsthand, I can attest that it is very noticeable when the valves fail. When I recently rented a mini excavator, it was very noticeable when making a turn of the tracks or the during the use of multiple actuations simultaneously.

When driving and operating the tracking steering valves the mini excavator bucked like a bucking bull when moving forward or in reverse while trying to turn. Using this method of testing I was able to detect the exact valve that was leaking by and let the rental company know. Several weeks later I received a call from the rental center's manager asking if I could test more of their equipment since my diagnosis was confirmed by their mechanic.

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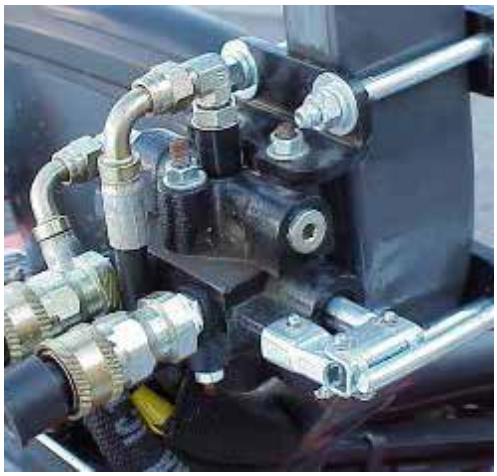

Comparative Method of Pumps

Pumps are a key piece of the hydraulic systems. If there is a presence of cavitation in the pump it will damage the pressure side of the impellers vanes and erode the surfaces making them rougher which, in turns adds to the volume of cavitation occurring in the pump. Not only can this damage the vanes in the pump, but it can lead to detrition of the piping and significant vibration of the pump and motor increasing the thrust load on the bearings.

Cavitation can be used to our advantage however with such application as ultrasonic cleaning equipment.
This process uses ultrasound to generate cavitation in a fluid and the item that needs cleaning is then dipped in this fluid. The implosion of the bubbles in the solution knocks the dirt of the dirty item.

Using the Comparisons Method is one of the quickest ways to determine if a pump is failing. When listening to a pump with the contact module the CBM Analyst should hear a smooth rushing sound with a steady decibel level compared to one with a large amount of popping sound. The CBM Analyst would also notice these ultrasonic indications accompanied by higher decibels, noticeable to significant vibration and higher temperatures when compared to like pumps. A pump with these indications would be considered as inefficient and should have action taken sooner than later.

Cylinder Leaks

Cylinder Leaks can be either classed as either a vacuum or pressure leak since the cylinder's changes direction of travel. This will cause the pressure to change as it extends and retracts in the housing causing either a vacuum or pressure effect dependent on where you are testing in reference the ram's path of travel. This can be a source of the cavitation heard in the cylinder and left in place long enough the hydraulic fluid will start to flow out and give a clear visual indication of a leak. The use of a contact module or airborne module can confirm this prior to any visible indications and help to ensure that more significant damage doesn't occur.

Excavator Testing in a Salt Mine

One example of the use of ultrasound to test hydraulics comes from a Salt Mine in NY where it was used on an excavator. The

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mine is located under Cayuga Lake has been active since 1915 and operates at depths up to 2800 feet below sea level. The elevator used to get there takes around 10 minutes to descend a half a mile.
It then can take up to 40 minutes to get to the work site.

The excavators cannot be lowered assembled, so they must lower them down in several parts and assemble them in the mine. Repairs of these units have to be made in the mine and since having a representative from the manufacture come in to look at this equipment is so expensive; they have come up with a clever way to trouble shot the excavators that are having issue with a sluggish response.

This test procedure involves a 3-man team consisting of an excavator operator, a spotter and the ultrasound CBM Analyst. The spotter is the key person in the safety of this procedure as he must ensure that the operator sees him at all times as well as watch where the CBM Analyst is and mimic his hand gestures to tell the operator what actuation the ultrasound CBM Analyst wants him to do next. The procedure allows the CBM Analyst to isolate and test the hydraulic cylinders, control valves, actuators, motors and reservoirs.

This allows the CBM Analyst to listen to the valves to hear if they are bleeding through when the valve is supposed to be closed or closing slowly. On the hydraulic cylinder the CBM Analyst can listen for cavitation or scraping of the cylinder in the housing. The CBM Analyst can also test the gear pump and listen for gear mesh issues and if they record the sound wave, they can calculate the exact gear that has the issue.

If the damage is significant enough that both gears are presenting harmonic indications, they can order both for replacement. Another test would be on the relief valve which normally will present with an intermittent sound as it opens and closes but, if it is stuck open it will have a constant flow and increased temperature that could also be seen with an IR Camera.

This in genesis use of ultrasound testing equipment saved this salt mine thousands of dollars in maintenance cost by not having to pay an outside contractor to come down and test the excavators as well as minimizing downtime and lost production due to equipment failure and poor operations. The ROI for this mine was huge when they considered all of the other applications that they could use their ultrasound equipment for in the mine.

Everything from conveyor bearings, crusher bearings, air leaks and electrical inspection. The unit was in such high demand they had to buy several more units for other crews as well as the topside operation for the bag house and other topside sites.

ASU CAT 2 Module 2-6 E Condition Based Lubrication

Introduction

Lubrication practices haven't changed much over the years, as most sites still relay on PM based Lubrication routes. This approach has led to the widespread over lubrication of bearings which in turn, results in more failures than intended. Simple things like mixing improper types of lubrication together to the bearing assembly will cause potential issues with the thickeners being incompatible which will have disastrous results.

These thickeners are so incompatible that it can cause the thickeners to harden trapping the oil and not releasing into the bearing assembly or it can soften the thickeners and release all of the oil at once. Both of these events would have the same results, ineffective lubrication which will cause a shorter MTBF to occur.

With the use of Ultrasound, a lubrication program can set action levels and only lubricate the bearings that are in need of lubrication rather than lubricating the bearing on a time-based event. Not only can the ultrasound be used to trend the bearing

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and determine when to lubricate, it can also be used to monitor the lubrication being added and determine when to stop adding lubrication to prevent over lubricating the bearing.

Setting Up Decibel Action Levels

The use of ultrasound for bearing trending has always been at the fore front of its use by CBM programs around the World. Trending, however, can only come with establishing a Base Line Value. The routes should be set up with like equipment referenced from ISO 20816 Severity Table. This will allow for the most efficient method of insuring similar equipment is tested together, allowing the program to quickly establishing true action levels. From there, the Action Levels can be set by using either averaging or selective averaging on the initial collection to establish the Action Levels.

Mature CBM Ultrasound Programs should have more than enough historical data to mine to establish their baseline value. This is just like using a selective averaging, only now the program will use months to years of data collected to determine the truest value for a baseline. Not only will they have the data to come up Action Levels they will have empirical data from actual failure events to confirm that their Action Levels are set to the truest values possible.

Establish a baseline value then add these decibel values to take appropriate action.

8 decibels = Diminished Lubrication of the bearing assembly surfaces.(add lubrication)

10-12 decibels = Incipient failure of bearing assembly surfaces. (continue to monitor.)

20 decibels = Substantial bearing assembly surface damage with vibrational indication. (Monitor Frequently)

35 decibels = Cataclysmic failure of the bearing assembly is near, now showing with indication of Infrared indications. (Plan for replacement sooner than later)

With this in place, the programs first action level when trending bearings should be at 8 decibels above the base line value. With 8 decibels being the known value set in place by NASA during their bearing study which established action levels apply to rotating equipment operating above 300 RPM. The value of 8 decibels is widely recognized as the rise in decibels that indicates the need for lubrication to be added. This article will cover how ultrasound can not only show this to be true but, conclusively show that this is the case by using sound analysis software to see these rises.

The first actionable value would be 8 decibels above the baseline value. This value indicates a bearing is in need of lubrication. The next established value that NASA was able to find during their study was between 10 to 12 decibels. At this value the presence of the incipient stage of failure of bearing assembly surfaces is occurring and it should be continued to be monitored. This action level, however, is meaningless since nobody is going to take a bearing out to look for microscopic faults just to put it back in since there's plenty of life left in this bearing. At 16 decibels NASA found that the visual damage would be present in the bearing assemblies

By establishing these above-mentioned action levels and using the value of 8 decibels above a baseline a program can switch from a PM based lubrication route to a CBM based lubrication route. This process will not only expedite the time it takes to perform lubrication routes, but it will also reduce the amount of lubrication utilized in the program. The biggest return on

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investment however for your lubrication program is maintaining the assets full lifecycle.

The next actionable level would be at 16 decibels above the baseline. At this value there would be visual faults present and the NASA study showed that when they removed the bearings at 16 decibels above the baseline value, they could physically see with the naked eye the imperfections in the race or balls in that bearing assembly. However, the use of 16 decibels as the high alarm value by many companies is way too low. Vibration analysts dispatched to test these motors would not find any indications of vibrational issues with the race, the bearings or cage at this value ultrasonically as there's not enough damage at this point to show vibrational indications of a fault since ultrasound is the first indication of surface wear and damage.

So, the use of 16 decibels is too low of a value for a high alarm. A truer value for indications of a low alarm setting instead of a high alarm should be at 20 decibels above the baseline. At this value the presence of substantial bearing assembly surface damage with vibrational indication and decibels, the vibration & ultrasound analyst would see indications of race, cage or ball issues inside that bearing assembly.

The last action level was found to be at 35 decibels above the baseline. This indicates the approach of cataclysmic failure and the end of useful life of that bearing. With the use of 35 decibels a program can quickly establish when to take an asset offline to avoid cataclysmic failure during peak season or peak operational timeframes. They can get a better idea of when exactly or how much longer this motor bearing will last. By using other technologies for confirmation such as vibration the program can confidently call a motor bearing as having reached its end of useful life.

During a 3-year period I worked with a major online sales company and we were able to confirm the values NASA had established years ago. Each site had over 3,000 test points per site that were collected on over 200 different routes. After collecting data from 42 different sites and sampling over 35,000 historical records we were able to establish that their Baldor Motors ran at an average of 35.4 decibels. The baseline value was set to 35 decibels across the entire companies' sites.

However, a few tweaks were made to the action levels based off of the historical data. The first change that was made was to drop the 8-decibel action level since they were running sealed bearing in their Baldor motors. The 10-12 decibel range was also dropped since it didn't serve as a functionable value for their sites. The First action level was set at 55 decibels which is 20 decibels above the baseline which would indicate actual surface damage to the race or bearings. At the decibel value of 55 decibels the analyst would report this as a low alarm to the planners. Their high alarm values were set to 70 decibels and once the bearing reach this level, they would then schedule the IR Camera to be taken out and check the temperature of the motor and gear box for a rise in temperature.

Once all the data was looked at, they would look at the time of year they were in and make the call to change out that motor based on whether or not they felt it was better to replace it before peak season kicked in when a shutdown of one of the conveyers could cost thousands of dollars a second while its down. This methodology helped them to migrate away from some of the time-based replacement of motors know as peak busting. It also meant they would no longer have to strategically place replacement motors

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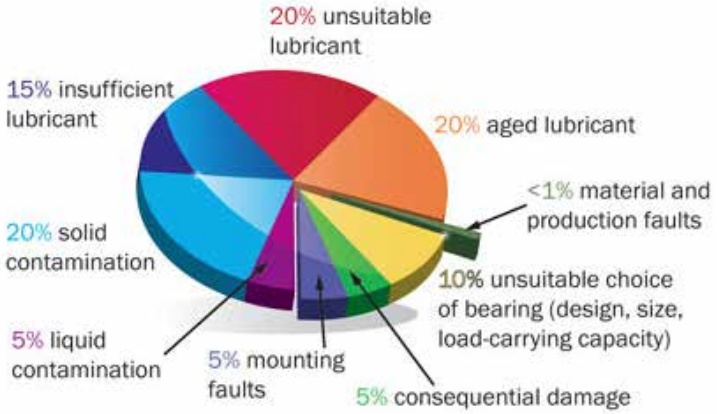
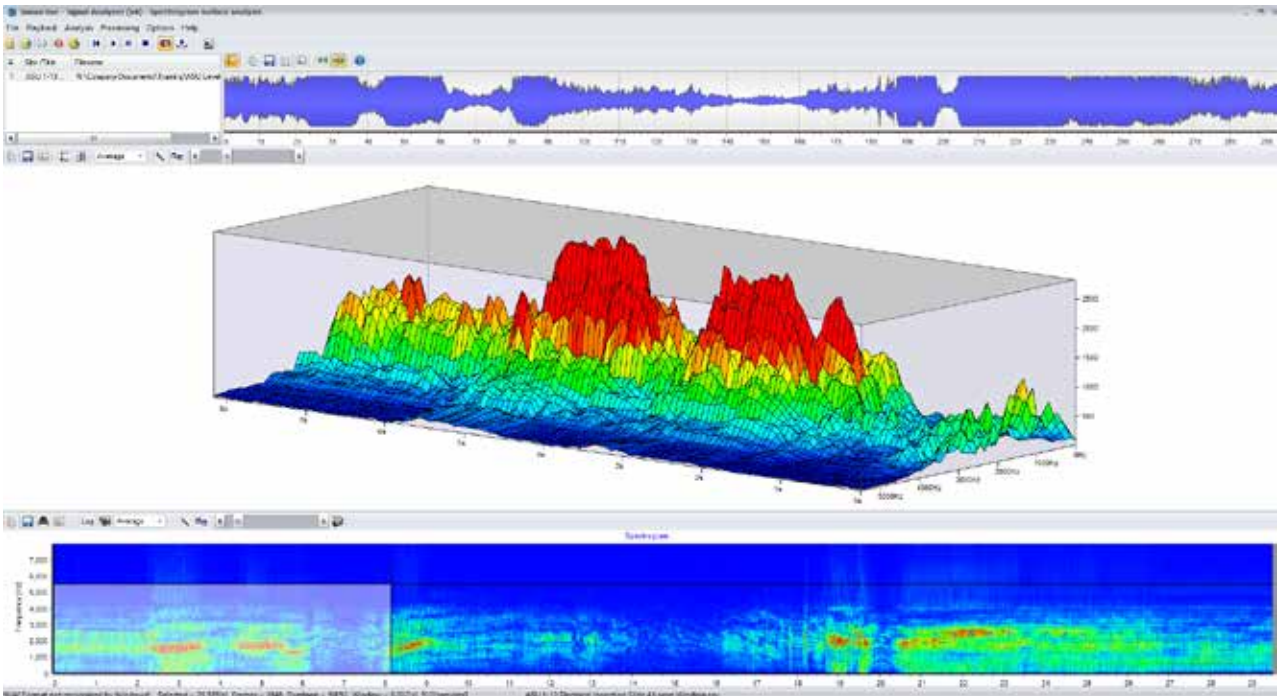
and gearboxes at known problem actors.

By reducing the risk of over lubrication of a bearing the asset lifecycle can reach its full potential without fear of over lubrication being the cause of the failure of the bearing. There are many other factors that can cause a bearing to fail that ultrasound will not pick up and this is where the implementation of the DIPF curve comes into play. By training the personnel on how to properly handle lubrication from beginning to end a CBM program can prevent such things as using aged lubrication or unsuitable lubrication.



In addition to using the action level of a decibels above the baseline to lubricate the analyst can record sound waves to use with sound analysis software. As they watch the screen and listens to the sound quality of the bearing, they can notice distinct popping snapping and cracking that's generally associated with lack of lubrication or damaged bearings. In these next few images you will see indications of a bearing that is in need of attention and we will outline a bearing that is in need of lubrication, a bearing beyond lubrications benefit, and a bearing that has been over lubricated.

Sound Analysis



Frequency Spectrum

The Frequency Spectrum screen takes into account the frequency of the occurrence harmonic value in Hertz along the X Axis while the Y Axis shows the measure of the amplitude of the sound wave at the frequency of occurrence. This allows the CBM Analyst to detect the harmonic occurrences of a fault condition. Then using a fault frequency calculator, the analyst can enter their turning speed and bearing count to see what harmonic values they would see with a race, cage or ball pass fault. It can even show indications of a stray voltage and rotor bar issues.

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Time Signal

The Time Signal screen is the one that uses a time interval for its X Axis and the Y Axis is in Negative & Positive Amplitude representation. This allows the CBM Analyst to see the beats or pulse they hear when testing in the field dance across the screen as they review the sound wave. They can even dive into marking the distance between the harmonics and calculate their interval in seconds to determine their corresponding harmonic value in Hertz.

Spectrogram

The Spectrogram screen is one that displays the X Axis in seconds and the Y Axis in in Hertz. It then takes the high and low amplitude and colorize it to giving a visual indication of where the banding is occurring with the most amplitude generally represented in red.

Spectrogram Surfacing

The Spectrogram Surfacing does the same thing as the Spectrogram screen does with coloring the amplitude, but it adds a third value with the Z Axis representing the Amplitude of the harmonics. This stunning imaging gives the CBM Analyst the ability to not only report on the decibels they received but also allows them to visual convey the severity of the anomalies.

Bearing Lubrication using Sound Waves Analysis.

Details of the Bearings being tested

Baldor 20 HP Motors
Line Frequency 60 Hz
8 Ball Bearings
1800 RPM

Before Lubrication Sound Waves

These sound waves are of different motors and the test point were taken on the Motor In Board end of these motors.

Adding Lubrication Sound Waves

These sound waves are of different motors and the test point were taken on the Motor In Board end of these motors. You can hear the changes in the sound quality and some popping is still present in a couple indicating damage to the bearings.

Over Lubrication Sound Wave

This sound wave you can clearly hear the sound level increase and clearly see it on the Sound Analysis Software Screen shots as the amplitude increases with too much volume of lubrication being added.

Before Lubrication 1

In this first example we will see a bearing prior to it being lubricated. We can see a rich amount of amplitude in all the screens whether it's in a frequency spectrum, time signal, spectrogram, or spectrogram surfacing. We can clearly hear the sound of the snapping, crackling and hissing sound that a bearing will make when it is in need of some lubrication.

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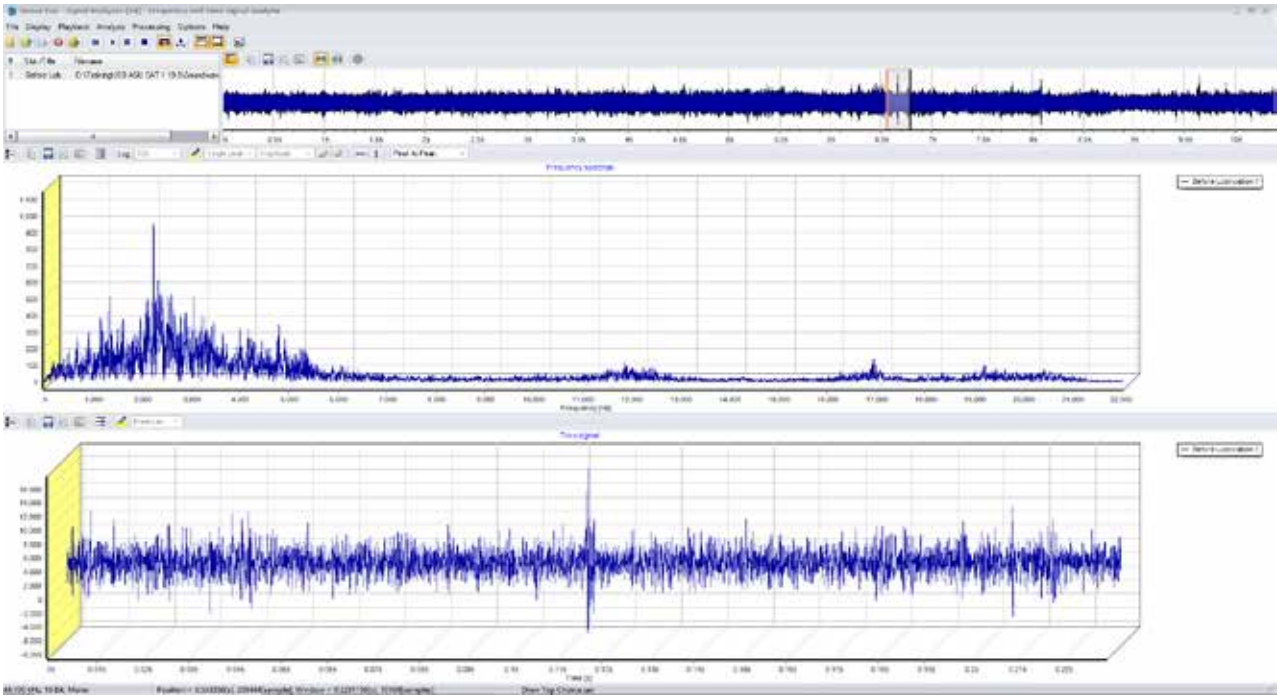
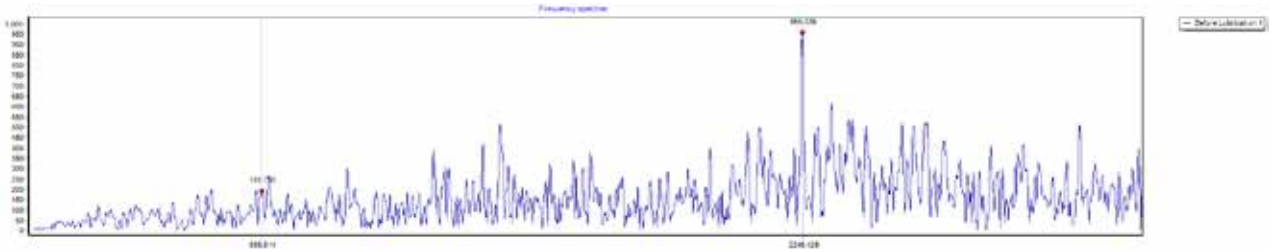
Before Lubrication 1 in a Frequency Spectrum and Time Signal 3D view.

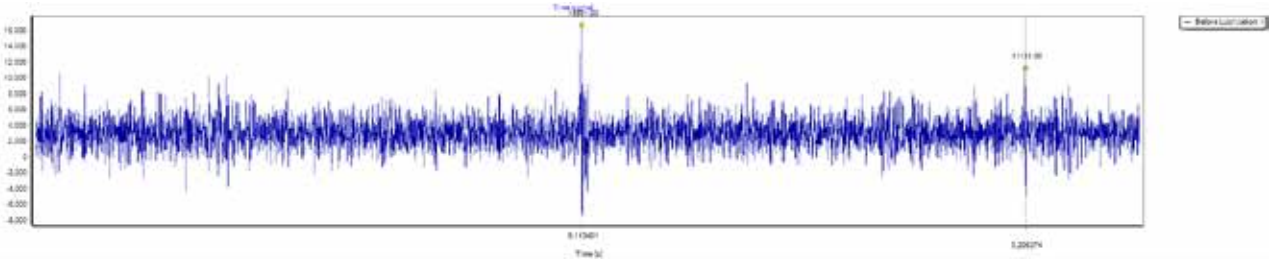


In the full-length Time Signal Spectrum at the top, we can see a constant base range of amplitude with an intermittent spikes of amplitude with varying intensity. When the sound wave is played it has a slight sputtering sound in the background and a constant static sound almost like water flowing.

In the Frequency Spectrum there is a significant amount of amplitude with the highest occurrence happening at 2246.425 Hz. When zooming in on 0 to 3,000 Hz range there are no repetitive harmonic occurrences that would indicate any bearing failures as seen below.



In the Time Signal we only see two distinct spikes when we look at 2/10th of a second of time that line up with a harmonic occurrence of .0108 which equals a 92 Hz harmonic value which could indicate the possibility of an early indication of an incipient stage of an outer race fault since this was an 1800 RPM 8 Ball 20 HP motor.



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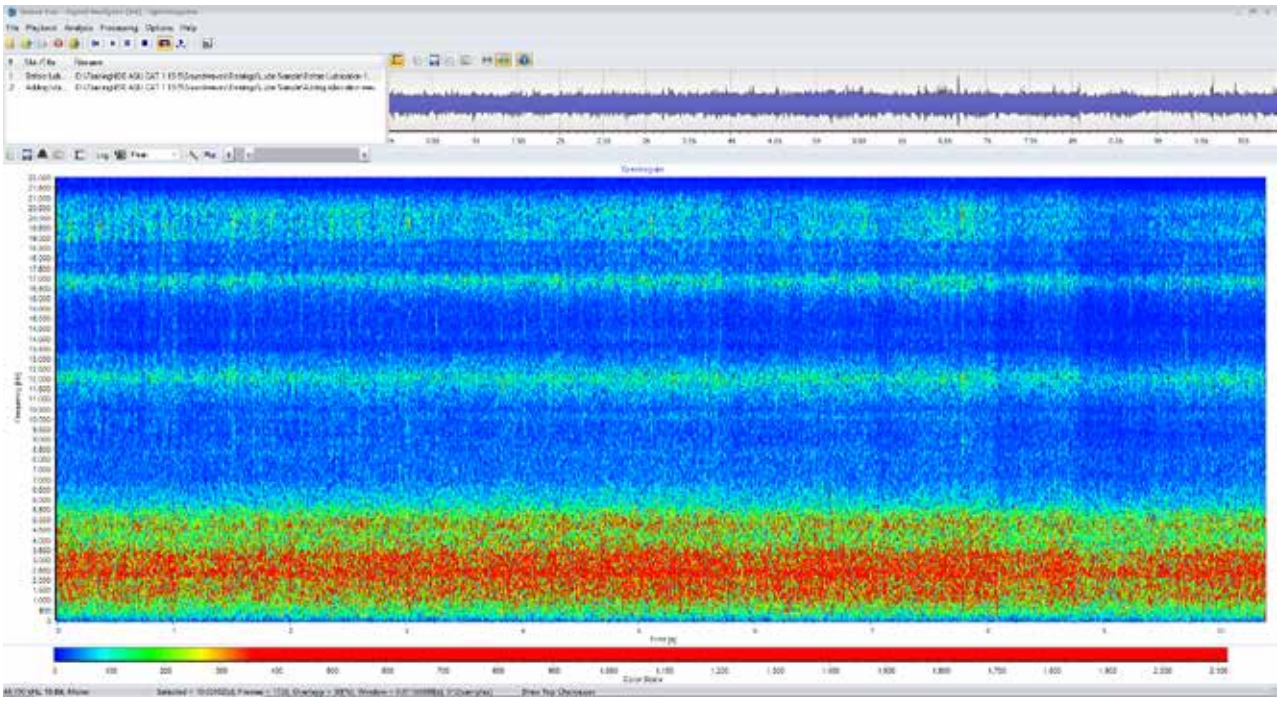
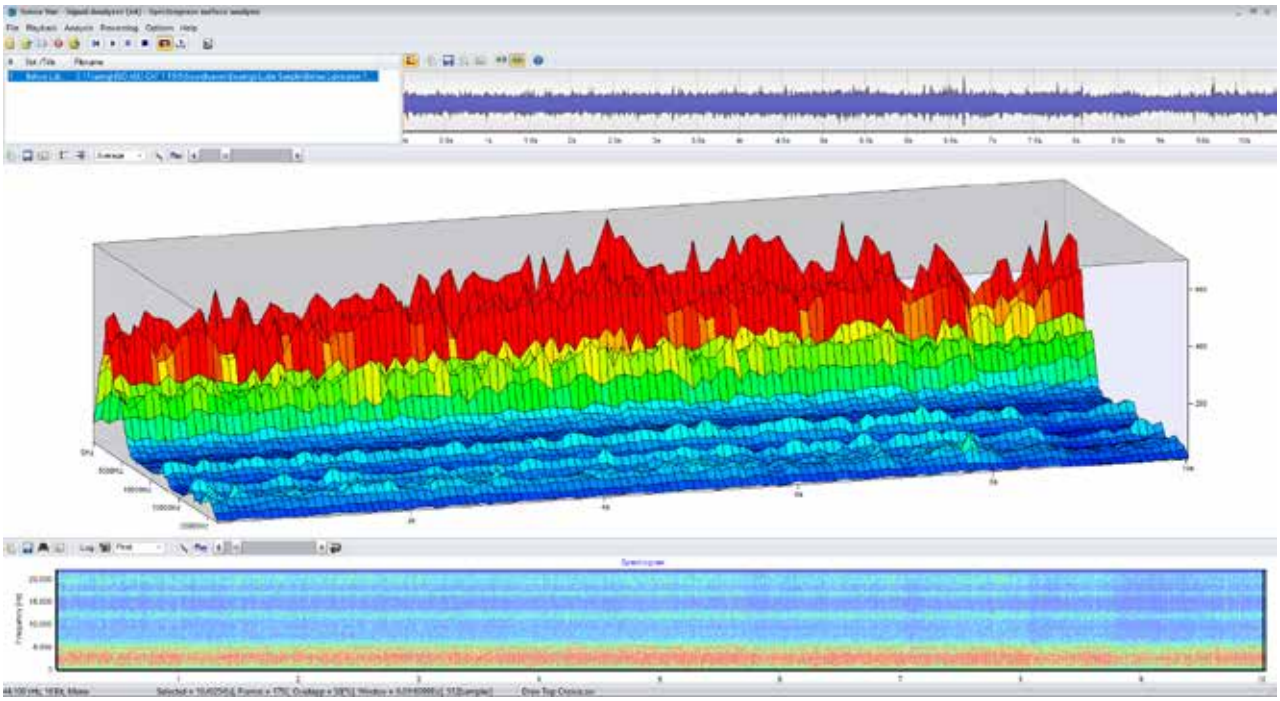
Before Lubrication 1 Spectrogram

When looking at the Spectrogram the highest amount of amplitude and wide banding in the range of 900 – 5,500 Hz. Then some more light banding at 12,000 Hz and 17,000 Hz. Then a narrow banding at 19,000 – 21,000 Hz.



Before Lubrication 1 Spectrogram Surfacing Left to Right

In the Spectrogram Surfacing view, the banding from 900 – 5,500 Hz shows up as a large ridge of amplitude and the smaller banding can be seen in the fore ground.



Before Lubrication 1 Spectrogram Surfacing Right to Left

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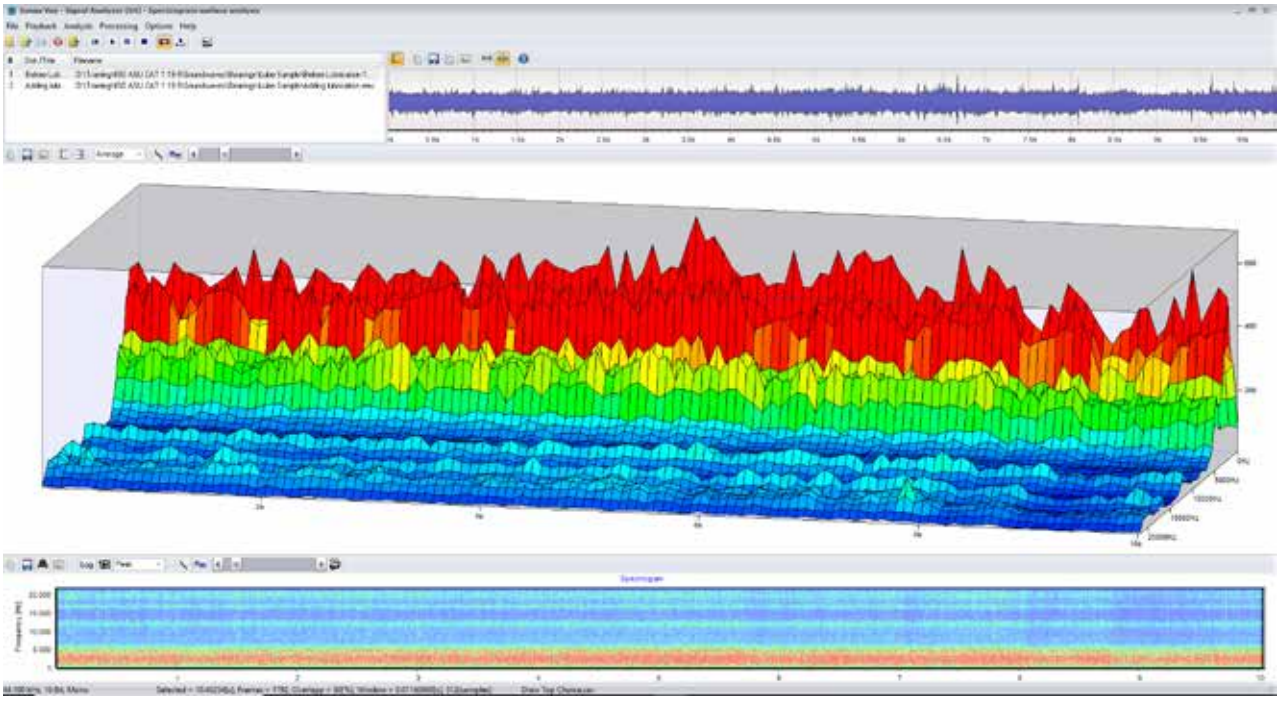

Adding Lubrication Frequency Spectrum and Time Signal View.

Just like the sound wave titled Before Lubrication the Adding Lubrication (different bearing) sound wave lets us see and hear the similar characteristic in the beginning with a slight sputtering sound in the background and a constant static sound almost like water flowing until the lubrication goes in. Once the lubrication enters the bearing assembly we can hear and see the static sound disappear and the sputtering comes to the fore front and can clearly be heard and seen.

In the image of the sound waves we see a blue line representing the Before Lubrication 1 Sound wave and the green line represents the Adding Lubrication sound wave that we know needs some lubrication but is not damaged enough to be called bad, just in need of a little lubrication.

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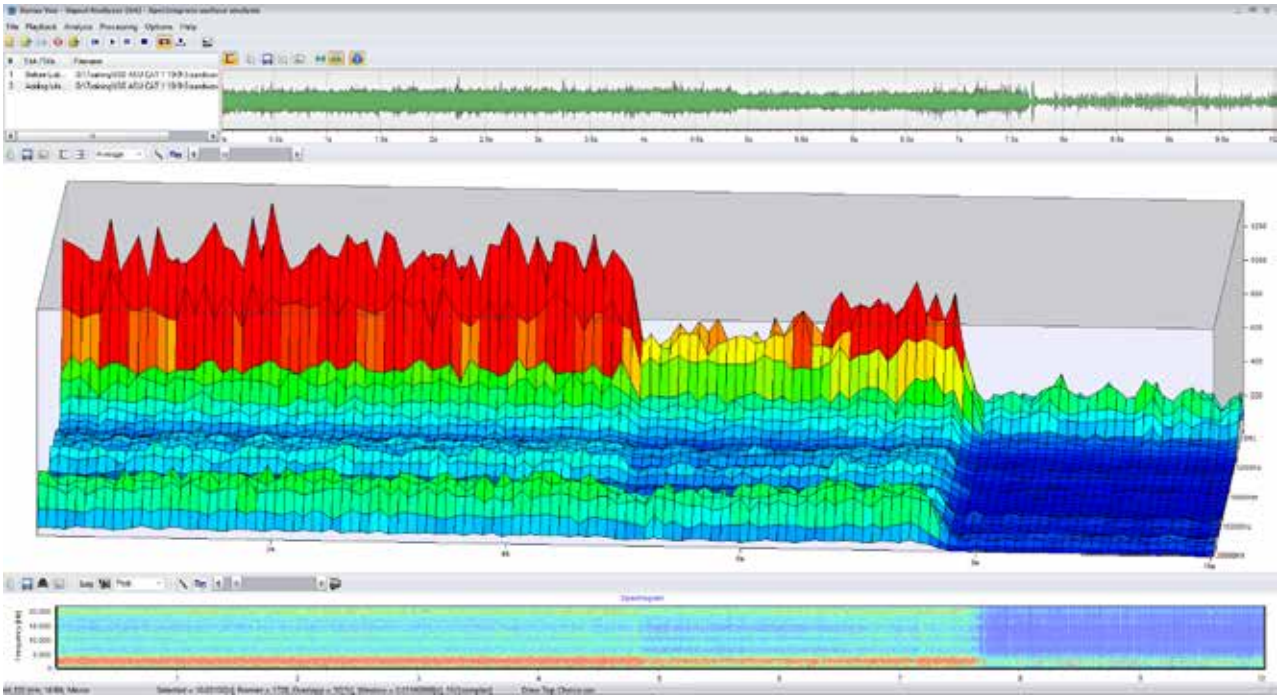
Adding Lubrication Spectrogram Surfacing Right to Left

In the full-length Time Signal at the top, 2/10th of a second of time was selected to view in the 3D Time Signal at the bottom. This area of the sound wave was selected since this is when the lubrication was added into the bearing assembly. During that time there are some harmonic indications that would indicate the very incipient stage of bearing failure.



We can also observe a dramatic drop in the amplitude as lubrication is added in around the Seven and a half second mark. looking at the spectrogram surfacing it's even more apparent where the lubrication is added slowly overtime and drops off dramatically.

Before Lubrication 2 Time Signal & Frequency Spectrum

Another example of a bearing in need of lubrication is the recording titled before lubrication 2. When playing this sound wave back there is a large amount of static sound and a slight sputtering sound which general indicates the bearing assembly's lubrication is diminished. At the 3.5 second mark we can visibly see a slight decrease in the amplitude of the sound wave and a slight change in the loudness heard by the ear.

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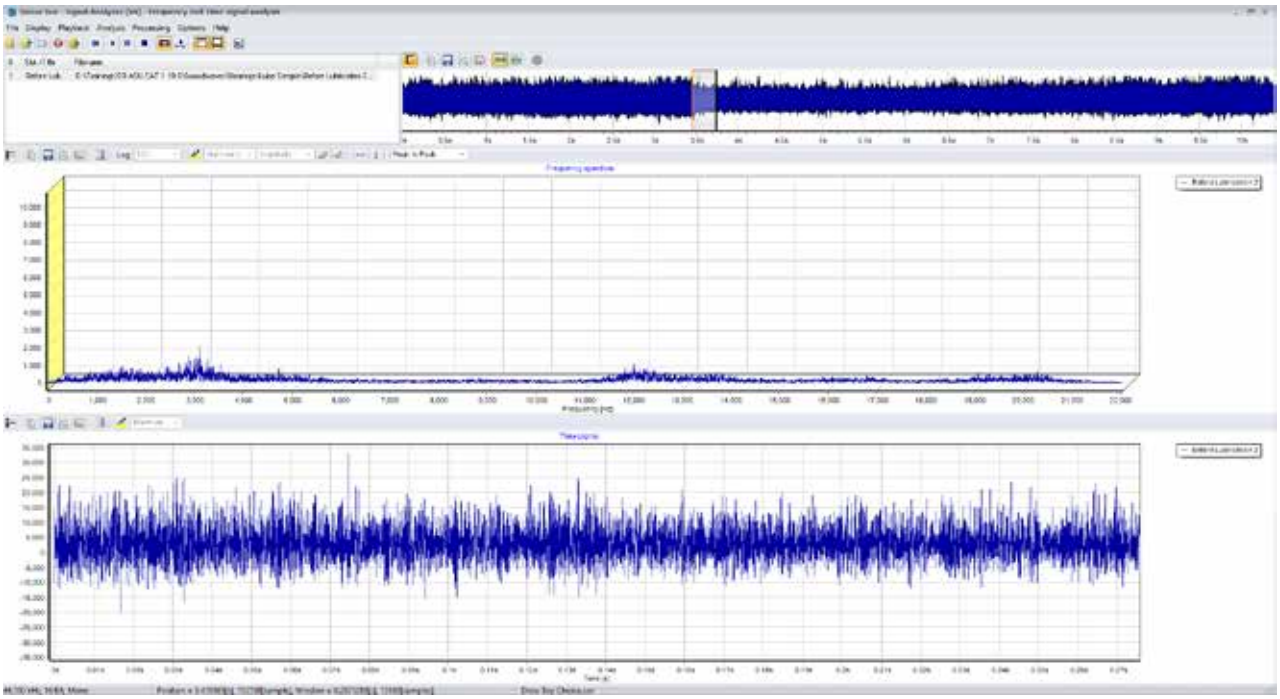
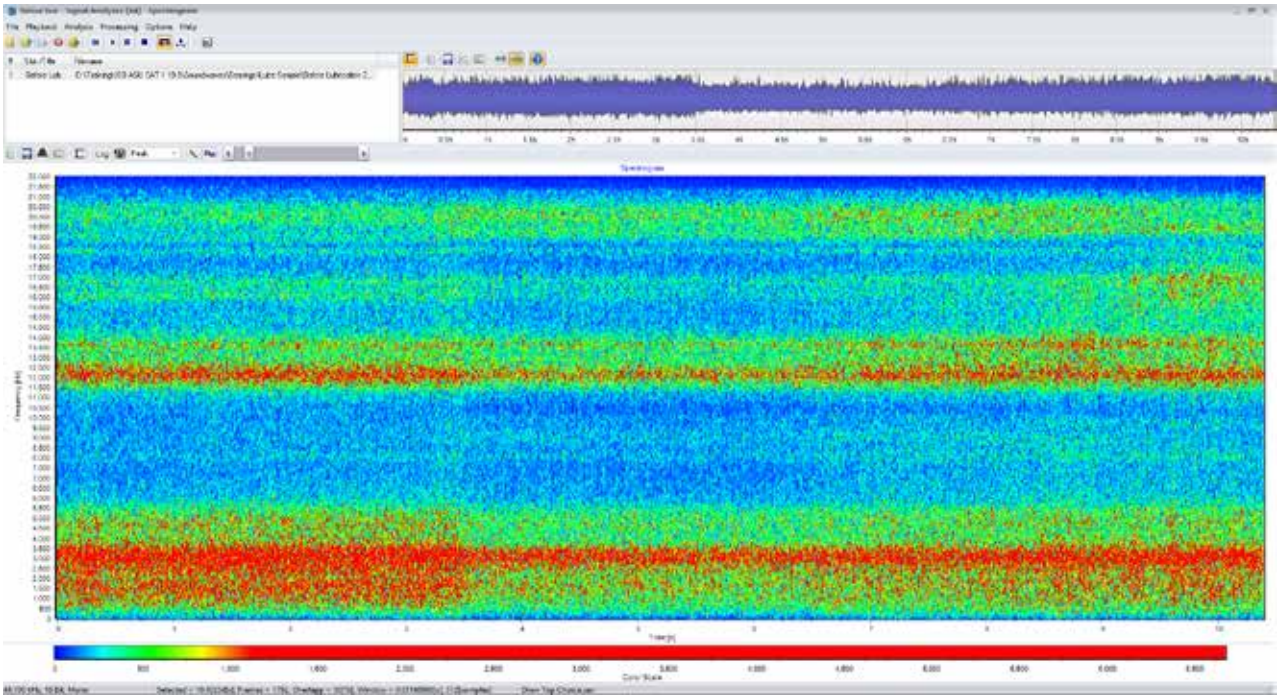


Before Lubrication 2 Spectrogram



This view of a shot of lubrications effect can easily be seen in the Spectrogram Screen. We can clearly see a reduction in amplitude in the banding occurring between the frequency range of 750 to 5,500 Hz at the 3.5 second mark.

Spectrogram Surfacing

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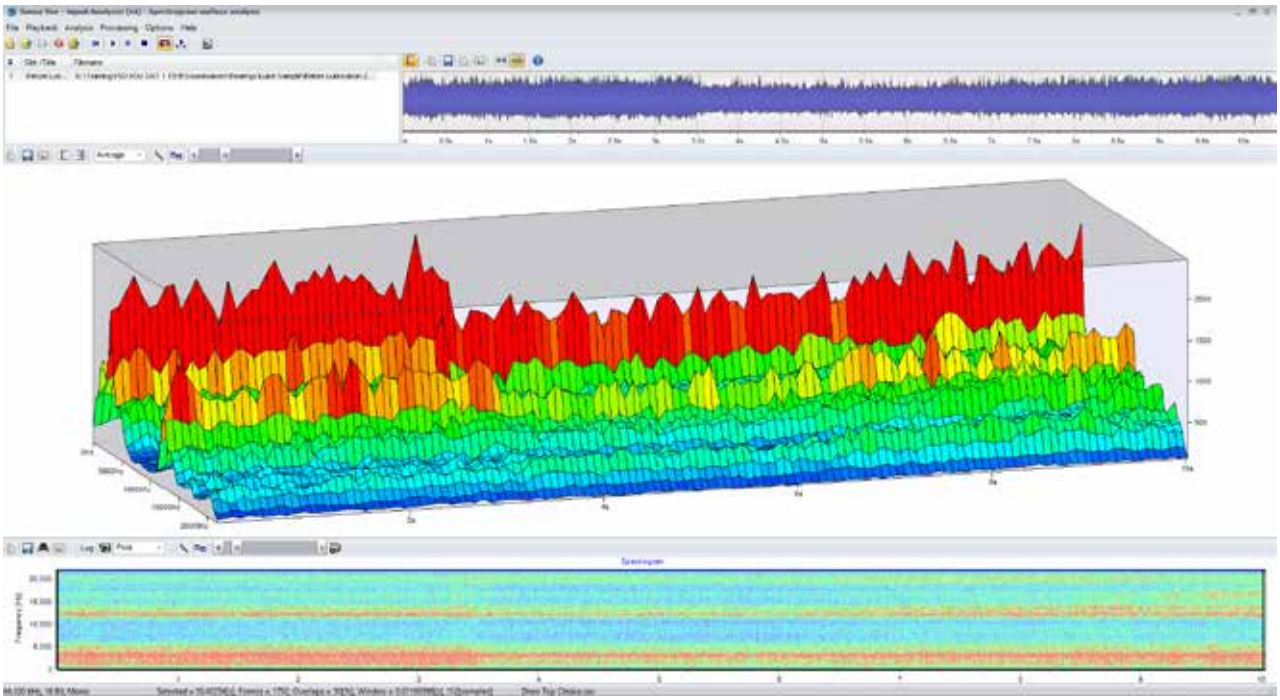
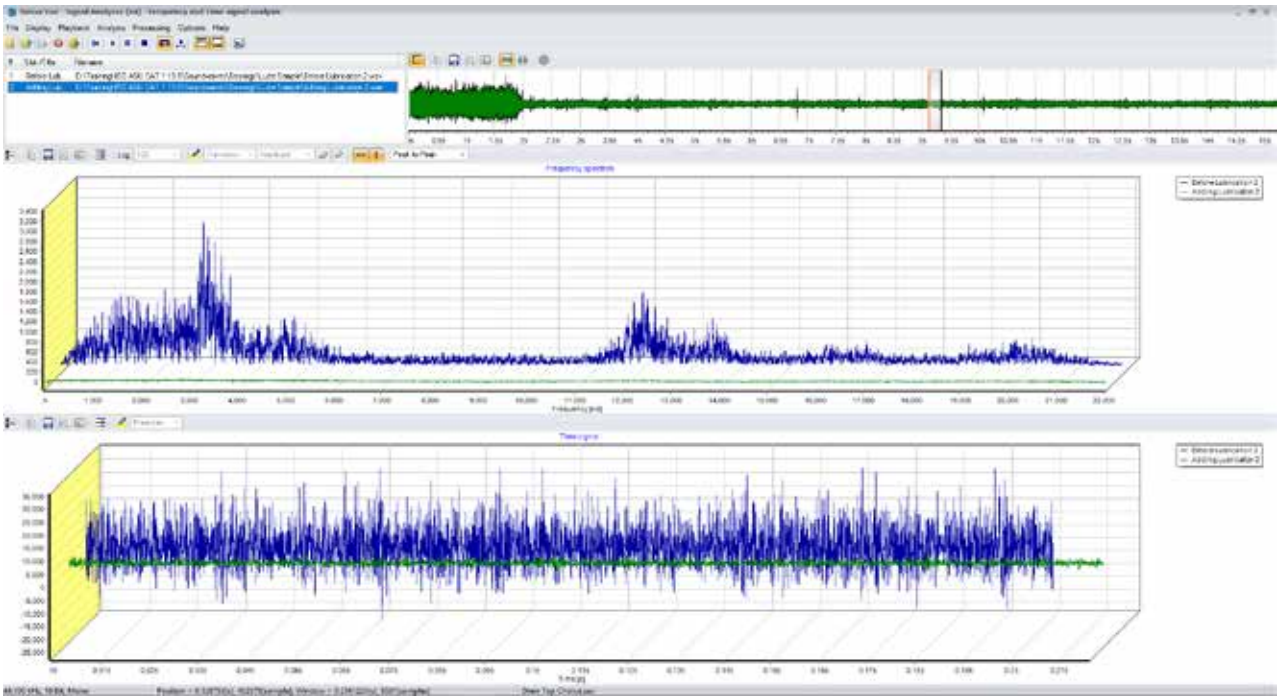


The decrease in amplitude can be seen even more clearly in the Spectrogram Surfacing. This view provide the best details when trying to show your lubrication program that CBM Lubrication works.

Adding Lubrication 2 3D Time Signal & Frequency Spectrum

Again, the green line represents the bearing getting lubricated and a clear dampening of amplitude at the 2 second mark. Not only can we see this occur we can clearly hear it as well. When compared to the itself prior to lubrication we can see and hear the difference.



Spectrogram

It becomes even more apparent when the lubrication is when viewing the sound wave in the Spectrogram view. The banding

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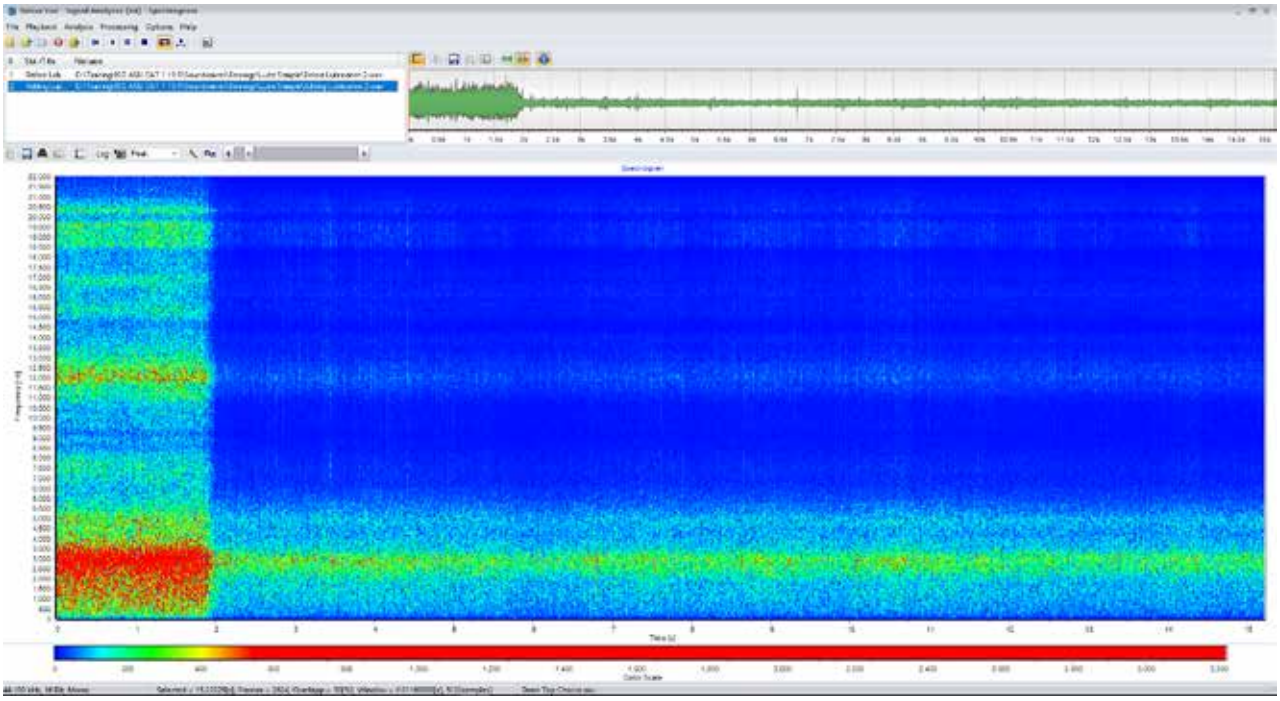
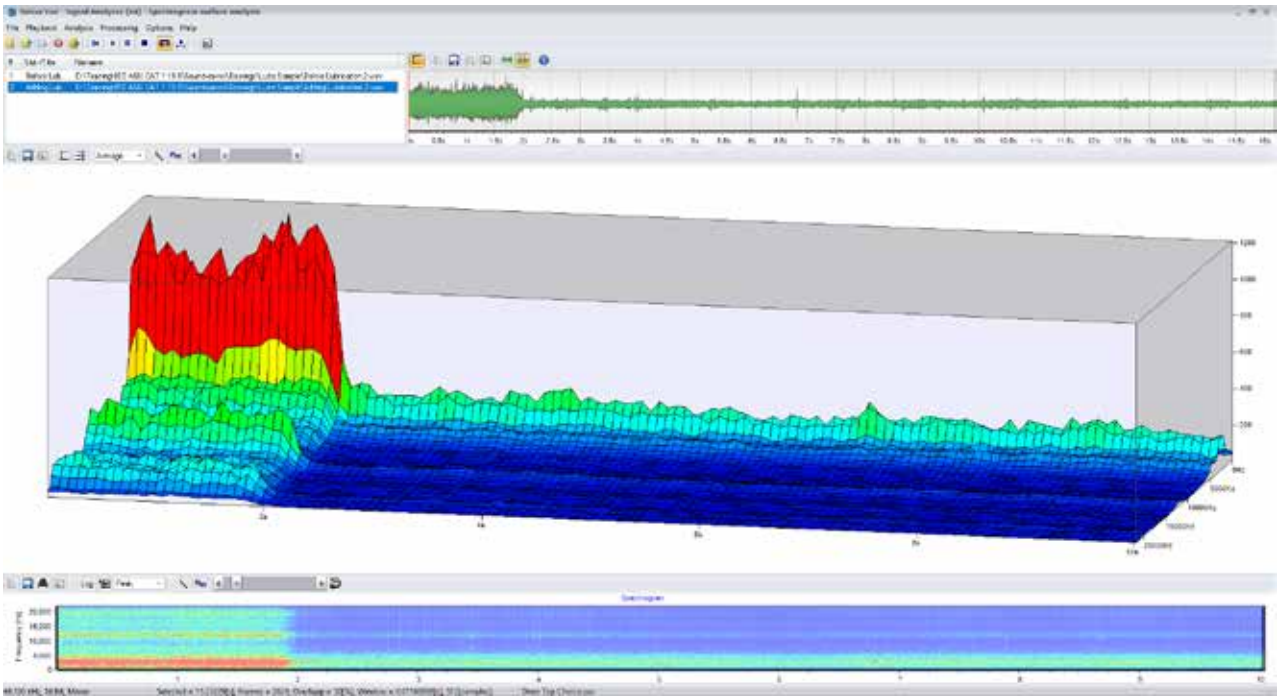
between 500 to 3,750 Hz is clearly evident during the first 2 seconds of the sound wave and it quickly decreases once the lubrication is added to the bearing.



Spectrogram 3D Surfacing



Spectrogram 3D Surfacing

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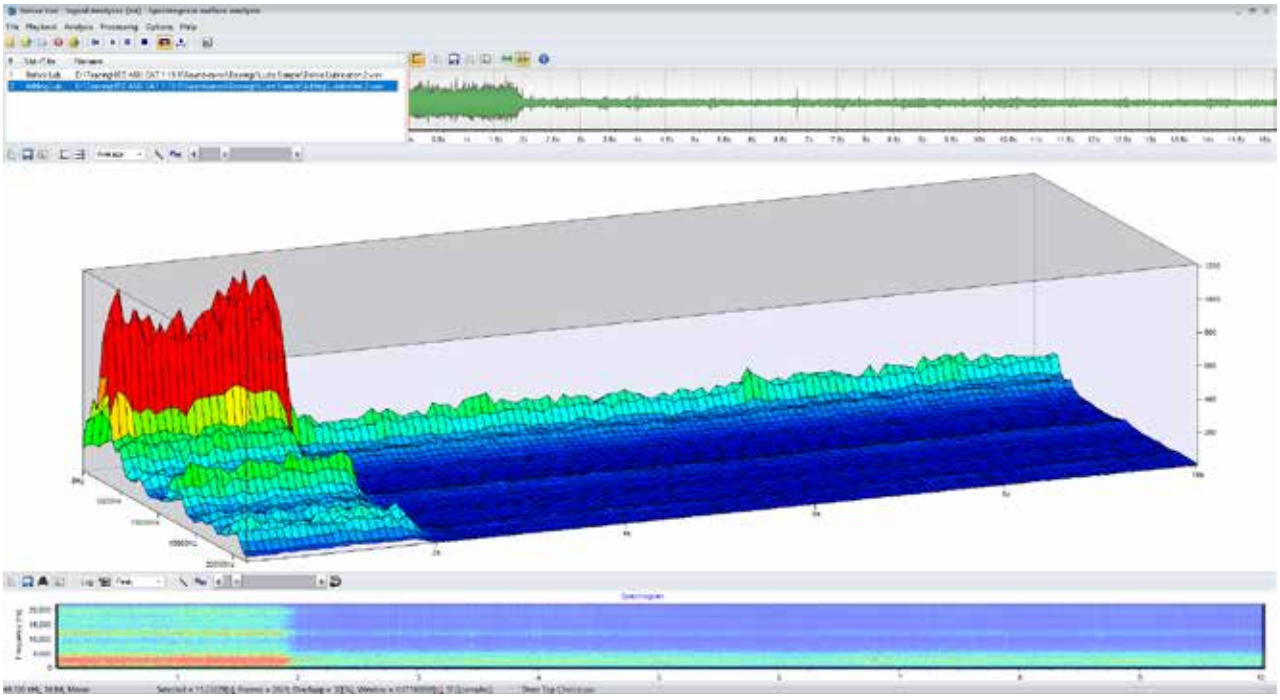
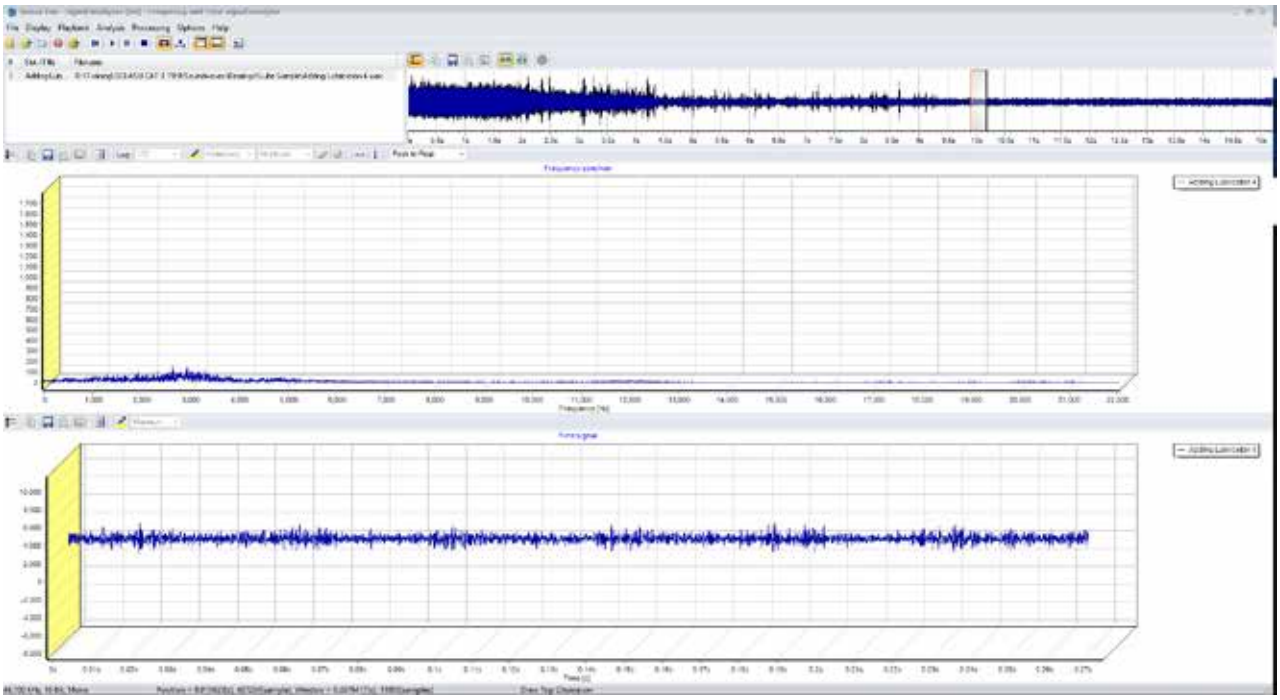


Adding Lubrication 4 Time Signal & Frequency Spectrum



Spectrogram

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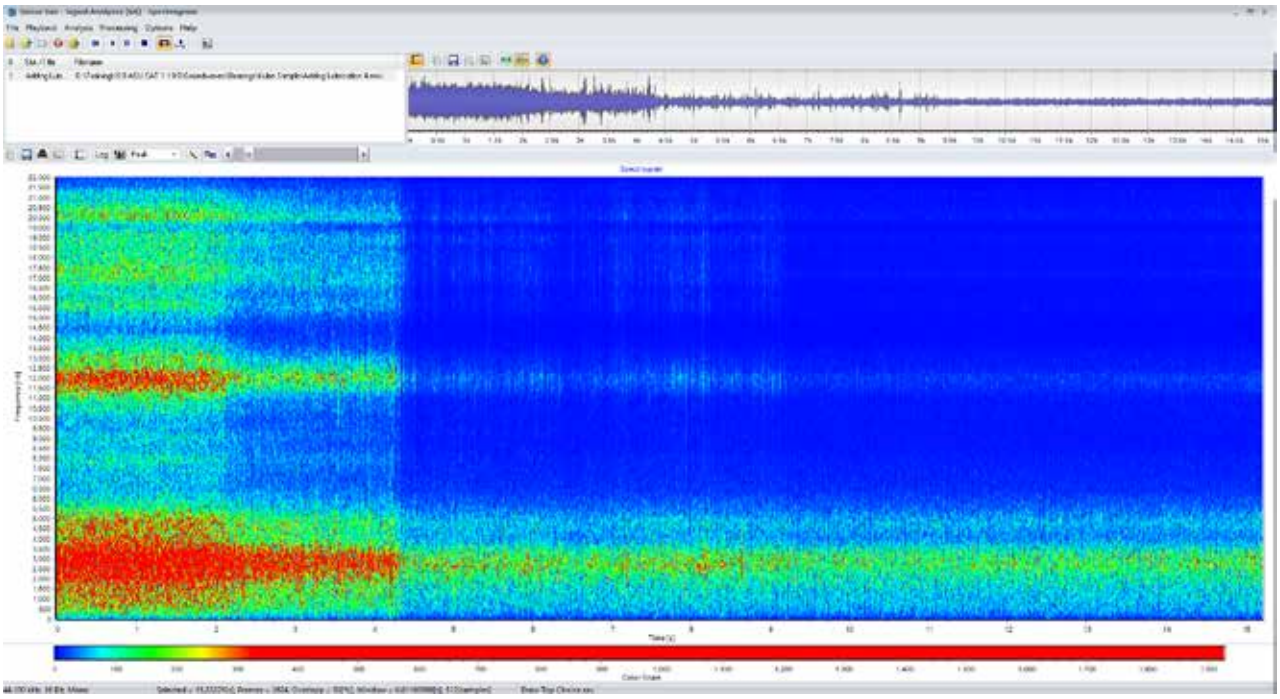
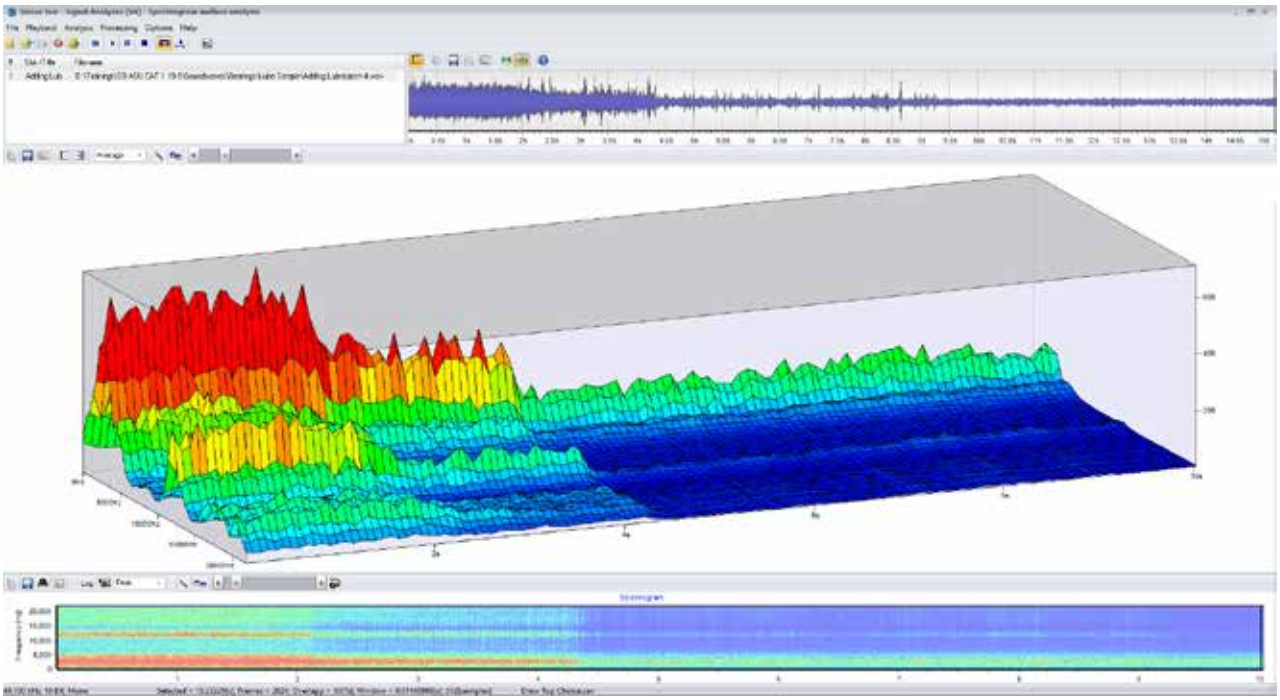


Spectrogram Surfacing



Over Lubrication Time Signal & Frequency Spectrum Before Lubrication

In the case of over lubrication not only can we hear the increase but, we can see the increase of amplitude as the bearing assembly struggles to handle the volume of lubrication added to its limited space. By listening to the lubrication going into the bearing assembly the lubrication specialist can ensure that they add the correct amount of lubrication and avoid the over lubrication of the bearing.

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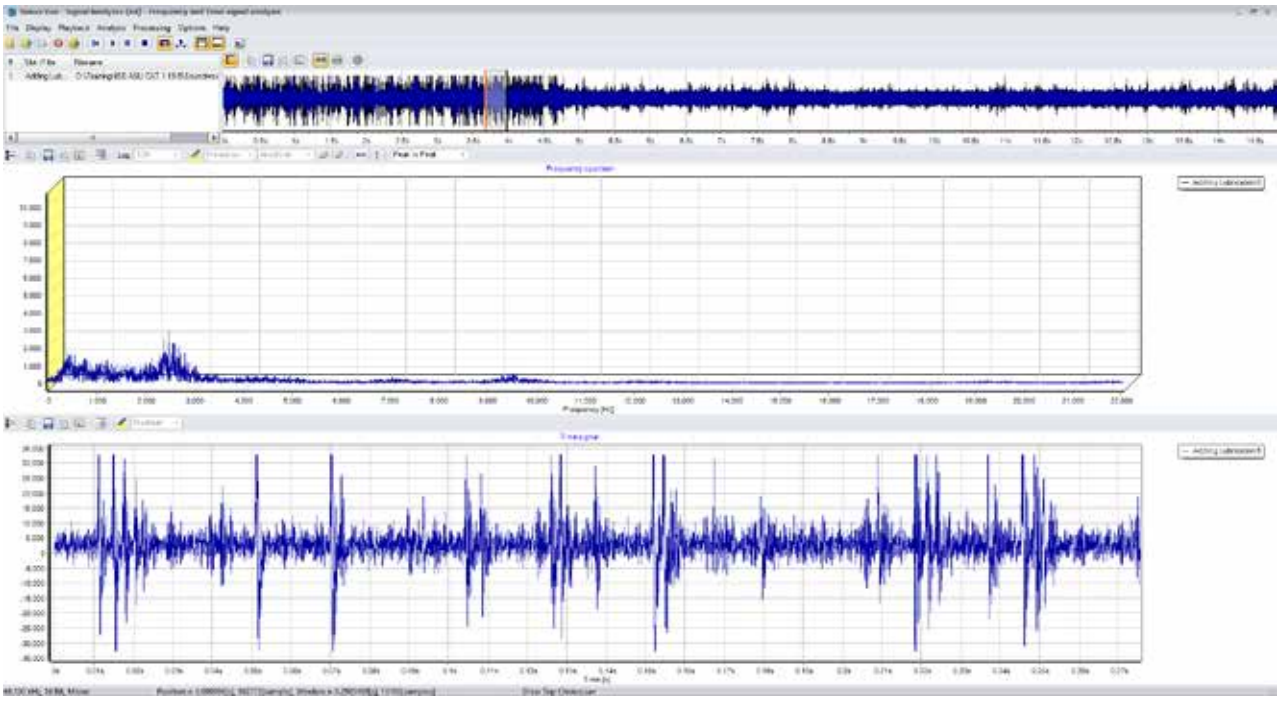
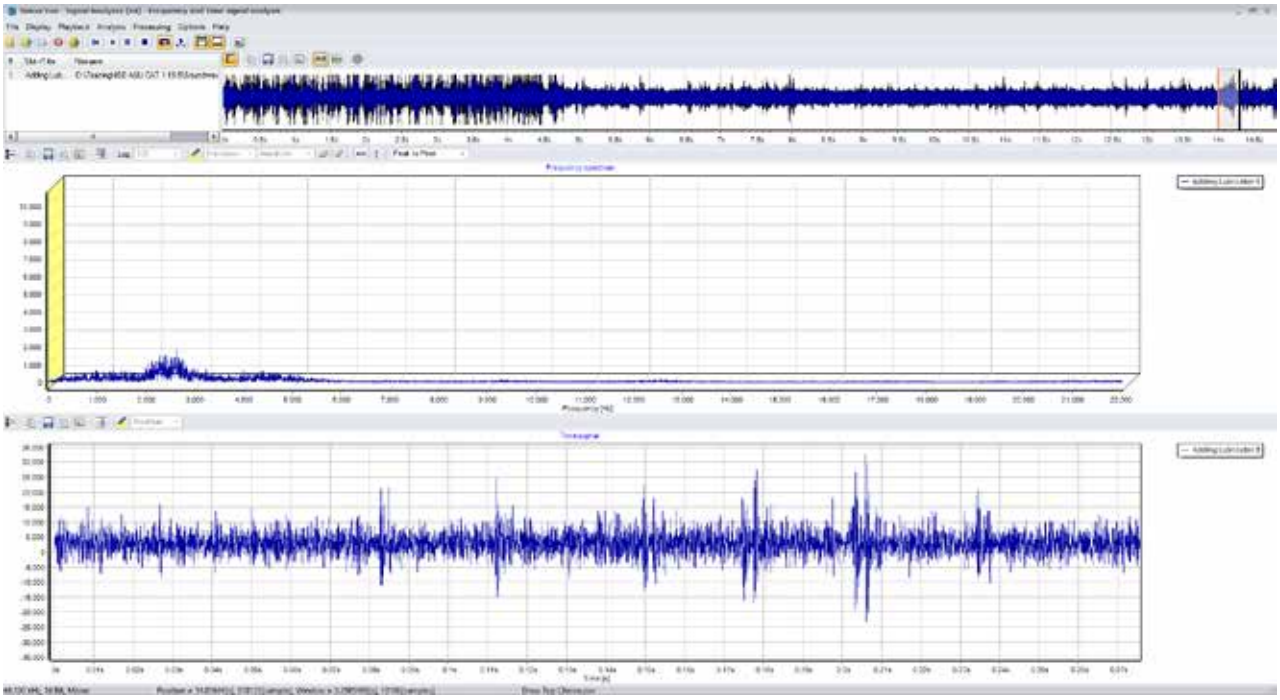


Over Lubrication Time Signal & Frequency Spectrum after too Much Lubrication is Added



Spectrogram

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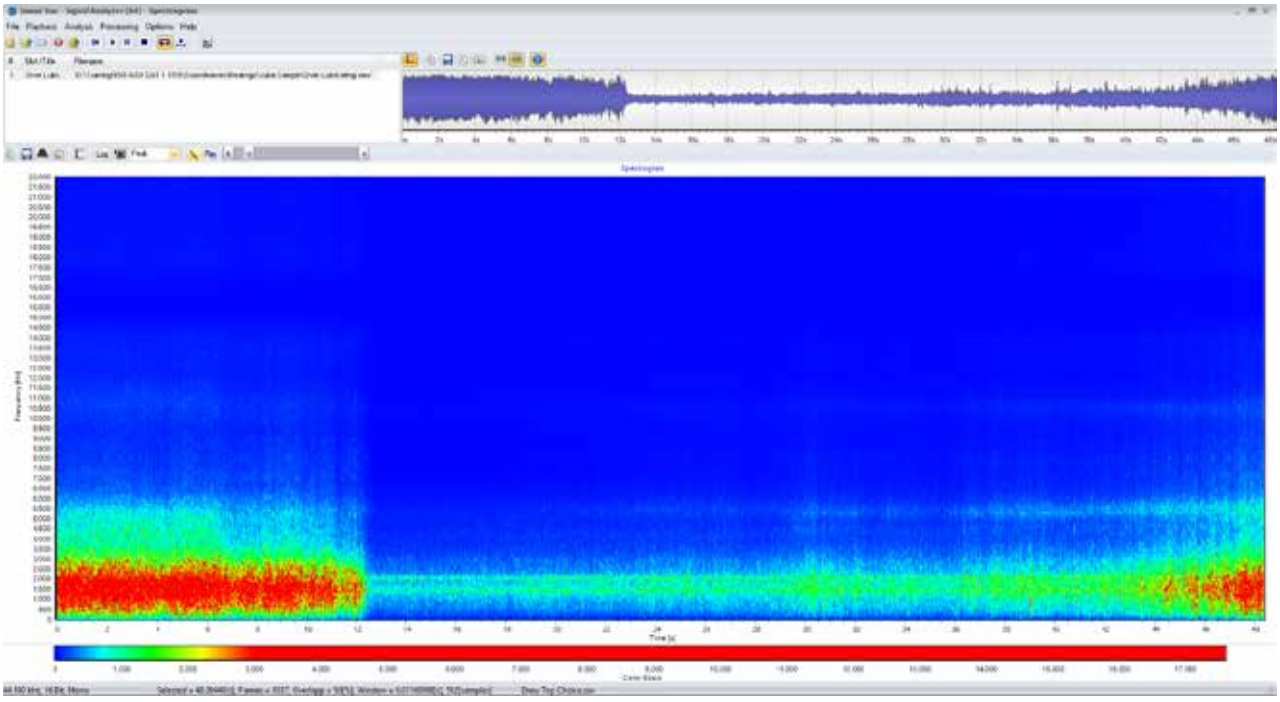
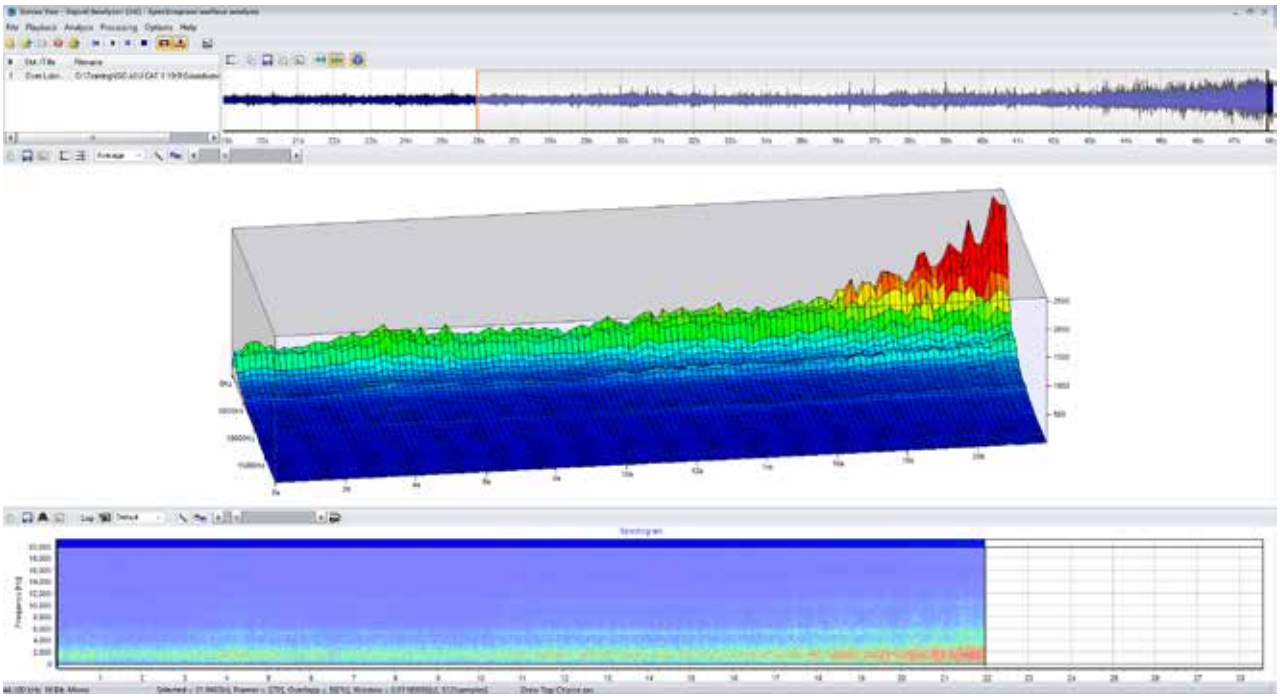


Spectrogram Surfacing



Conclusion

The use of ultrasound will help any maintenance program improve the asset life cycle of their motor bearings by setting an action level of 8 decibels above the average or historical values established through data mining. Then deploy the ultrasound to determine not only when to lubricate a bearing but also how much lubrication to put into the bearing. This advancement will help prevent the number one cause of motor failure. Improper Lubrication!

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ASU CAT 2 Module 2-6-F Theory of Mechanical Inspection

Mechanical inspection using ultrasound devices is one that has expanded of the years from just being a trouble shooting tool to a full-on diagnostic asset. By recording soundwaves, the CBM Analyst can determine the difference between inner, outer race, bearing, and cage faults as well as loose connection in the motor's junction box.

With the more frequent use of VFD's in plants, the determination of stray voltage indications has become another item that ultrasound is successful at determining and this is one of the top contributors to VFD failures. It will show up with the same harmonic value as the line frequency driving the motor.

Loose connection in a pecker head will also generate a distinct 2-time line frequency harmonic that can be seen in the Time Signal & Frequency Spectrum analysis. Add the ability to trend the bearings and the CBM Analyst can start setting up lubrication routes based off of actually data and not a time-based interval. This greatly reduces the chance of over lubrication of motors.

One key though to any lubrication route is to know the type of motor being tested. Some companies are actually shipping their motors to clients with the grease fittings attached even though the motor bearings are sealed. This has led to many motors receiving lubrication and shorting out once the lubrication starts entering into the windings.

How Structure Borne Ultrasound Travels

When it comes to Structure Borne Ultrasound the incident wave transfers it energy into the motor housing from the inside. By placing a contact module on the housing, the CBM Analyst 's ultrasound device becomes a continuation of the motor housing.

This is because the motor housing and the contact modules have similar characteristics so there is little to no acoustic impedance the incident wave to the transducer. This allows the CBM Analyst to successful hear what is going on inside of with the motor bearing and the presences of stray voltage.

What to do When Inspecting Bearings

The key to preforming dependable Ultrasound inspection of bearings it to ensure that the CBM Analyst test points are the same every time the asset is tested. The best spot to place the contact probe is directly on the zerk fitting.

The CBM Analyst should always clean the tip of the contact module and the zerk fitting prior to placing the contact probe on the zerk for the test. This position is the most direct path for the sound wave to travel through and give the unit the most energy. If the CBM Analyst placed the module on the Fan Shroud the sound of the turbulence from the fan will be a source of a huge amount of antagonistic ultrasound and the condition of the bearing will not be heard.

The same will hold true for the frame as we the CBM Analyst will again be affected by the air flow from the fan itself as well as the electrical field from the stator which can also produce antagonistic ultrasound. In the case of a motor with sealed bearing and no zerk fittings the bolt on the fan shroud would be the next best test point on the out-board side and on the inboard side the end bell would be the best point.

The CBM Analyst could even test the motor junction box to listen for loose connection which will present with a 120 Hz harmonic indication and will present a line frequency fault if their shaft voltage issues. The CBM Analyst also doesn't need to press down on the contact module when testing for structure borne issues. They should place the contact module at a 90° angle to the surface contact point and not their orientation.

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The test points should be documented and clearly marked on the asset when possible.

If due to environmental issues in the area that would eat away a paint pen marking the user could drill a small divot just deep for the contact probe to rest on. This isn't necessary for zerk fittings. I a photo can be taken and added to the training of the CBM Analyst or placed in the work orders job plan the program can help to ensure consistency in the data collected and minimize the human factors.

Over the years the trending of bearing has become more precious at determining at what decibel range a bearing could be considered bad. One of the first things a program should do is to ensure that the bearings being tested are similar Machine Classes per ISO 20816:2016. Horsepower range the best way to group together similar assets for trending.

It doesn't matter if a motor is 1 month old or 10 years old. If they are operating at similar horsepower, they should have a similar decibel values and similar action levels as well. The fastest way to establish this is too collect all of the decibels values for these and look for the out-laying readings and remove them from the equitation.

The remaining numbers would then be averaged to come up with an average value. This procedure is derived from the ISO standards of Broad Band Vibration Criteria for Specific Machine Groups Based on ISO 20816 which we will cover in the next module.

Accessibility to The Source

The key to any inspection program is to ensure that the collection of data and sound recording is done correctly. One of the keys is to ensure the correct amount of volume is set on the unit. If it's too low the CBM Analyst could potentially miss out on the subtle indication of a fault condition.

Likewise, it is important that the CBM Analyst ensures that the volume isn't too high since it will chop the peaks off of the sound wave when running it through the sound analysis software. This would lead to the loss of signal due to the amplitude being chopped off and negatively affect the ability to look for harmonic indications in both the Time Signal and Frequency Spectrum.

It is just as important to ensure that the contact module is placed at a 90° angle to the surface of the asset being tested and not the CBM Analysts orientation to the position. If the unit allows for Frequency Tuning the CBM Analyst can try other frequency ranges outside of the recommended values that have been used for years to see if they can get a better sound quality of what is actually going on but, they must insure that if there has been any previous data collection that they tune back to that same frequency so as not to corrupt any of the trending.

The CBM Analyst will also need to mark the test points and try to keep them standardized so anyone doing the data collection is trending at the same location every time. When unsure of the results the CBM Analyst can use the comparison method to test like equipment as they will have similar levels of decibels. In the next module we will explore classifying motors by HP and mountings.

They should never stick the contact module into any rotating equipment. The simplest rule to remember is "If you can't see into the hole don't stick it in the hole!" Often the outboard side may have a hole in the fan shroud for the grease fitting, but no extension is in place for lubrication purposes. This open may look and sound inviting but it will not end well if a contact module is stuck in there to listen for the sound of a bearing.

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Also, when testing bearings in some insistences a static discharge can occur. The CBM Analyst may notice a small blue flash when placing the contact module on the grease fitting. When this occurs if the unit you are using is on it could power down or experience a temporary readings issue.

It a good habit for the CBM Analyst to carry a tool to be used to dissipate a static charge in a known area of concern. In most case a grounding strap could help eliminate and risks created by the static build up. The CBM Analyst must also take into account any high-speed rotating equipment that could be operating around the test area.

These can't always be seen with the naked eye and the CBM Analyst must be aware of these hazards. Another area of concern is working around robots, just because the prohibited guarding only protects from the floor an CBM Analyst must be aware of this when operating overhead of the barriers and consider them extending to the ceiling. These are just some examples that have been encountered over the year in industry.

High Noise Environments

In an area with a high level of background noise the CBM Analyst will need to reduce their distance to the asset being tested. Another technique to help the CBM Analyst is to reduce the volume in the headset to the point that the sound is just barely heard from the source of the antagonistic ultrasound. This should only be done once the acoustic emission the CBM Analyst is targeting has been closed in on. This will prevent the CBM Analyst from potential missing the emission all together. The CBM Analyst can also try tuning their frequency to a different range to try and isolate the antagonistic ultrasound in that area.

Overcoming Antagonistic Ultrasounds

One of the hurdles new ultrasound CBM Analyst s must learn to overcome is Antagonistic Ultrasound. Antagonistic Ultrasound can be caused frictional rub, leaks, and ultrasonic motion sensors. The CBM Analyst will need to sweep the are to determine the location of the antagonistic ultrasound and try and mitigate the source.

This can be done by shutting down the equipment or testing in that area when the equipment isn't operating. In the case of airborne leaks, a wipe rag could be used as a sort of temporary tourniquet to help block out the sound being emitted by the leak.

This is not recommended on leaks with risk of injuries due to temperature differentials or chemical reactions. In the case of frictional rub there can be many sources that generate antagonistic ultrasound such as, belt rub from a miss tracked roller, finger guards that are misaligned and rubbing against the rollers, product traveling on the conveyors are just some examples of antagonistic ultrasound. If the CBM Analyst takes the time to listen to the sounds in that area, they may actually find a condition that wasn't previously known.

Gear Box Testing

Just like motors there are several sizes and types of gear boxes in use. Some are small enough to just require one test point to determine the condition of the gear box. To ensure that the inspector gets the best results they should set their unit to somewhere from 20 kHz to 25 kHz and capture the sound wave for further analysis.

The sound wave can be used to determine if the one gear is failing vs another based off of the harmonic indications displayed

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in the frequency spectrum or the time signal. Gear Boxes are historical quieter than the **motors driving** them, and this should be considered when building alarms levels.

Benefits of Ultrasound Testing of Rotating Equipment

Brinelling of a bearing surfaces will produce a similar increase in amplitude due to the flattening process as the balls get out of round. These flat spots also produce a repetitive ringing that is detected as an increase in amplitude of monitored frequencies.

The ultrasonic frequencies detected by the ultrasound device are reproduced as audible sounds. This “heterodyned” signal can greatly assist a user in determining bearing problems. When listening, it is recommended that a user become familiar with the sounds of a good bearing. A good bearing is heard as a rushing or hissing noise. Crackling or rough sounds indicate a bearing in the failure stage.

In certain cases, a damaged ball can be heard as a clicking sound whereas a high intensity, uniform rough sound may indicate a damaged race or ununiform ball damage. Loud rushing sounds similar to the rushing sound of a good bearing only slightly rougher, can indicate lack of lubrication. Short duration increases in the sound level with “rough” or “scratchy” components indicate a rolling element hitting a flat spot and sliding on the bearing surfaces rather than rotating. If this condition is detected, more frequent examinations should be scheduled.

Mechanical Inspection

The use of Ultrasound can quickly identify areas of concerns in a motor and there is even some new thoughts of testing in the higher frequency ranges when testing VFD’s to eliminate the inherit noise a VFD produces. Even with the antagonistic ultrasound being produced, the inspector will still be able to hear the sound of stray voltage over the antagonistic ultrasound as well as bearing, cage and race faults. There is even some theories about determining misalignment of a motor and its driven asset using ultrasound. The basis of this theory is that the side of the asset that is out of alignment will show a higher decibel value on the in-board side of the misaligned asset.

In addition, back pressure issue can be caused by clogged air socks in a bag house. The reduced air flow will cause the blower to work harder as the air pressure builds up and gives the motor a surging sound as it tries to compensate for the increased resistance of air flow.

As the use of sound analysis becomes more prevalent the information that will come from it will produce future technology that

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will actually be able to determine what the condition actually is just by taking a reading. There may even be a time in the near future where we could see an Ultrasound Table of Faults just like vibration. Vibration is also a great tool any Pd/M program to use since it picks up an array of things ultrasound hasn't shown it can do.

Improving Mechanical Efficiency

Improving Mechanical efficiency can be as easy as calculating the amount of energy a motor consumes, by dividing the output versus the input. Many companies try to compensate for the inefficiency of equipment by increasing the power to the equipment. This has especially been seen in sites that use VFD's and run them at a higher line frequency or too low of a line frequency.

This is like driving a sports car in 6th gear in the RPM's redline for too long or in 6th gear doing 15 MPH. The car can do it but, it will shorten the life of the motor. Several companies have found that out the hard way running the VFD's in these ranges as the motors tend to burn up and ultrasound indications have shown Stray Voltage to be the biggest cause of the early end of life. There are several formulas to calculate the efficiency of a motor these are just two examples.

Lever Solution

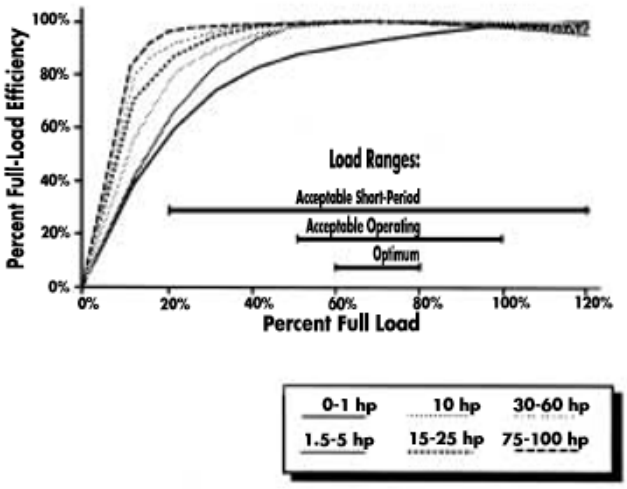
$$\text{Work Input} = \text{Force} \times \text{Distance}$$
$$= 80\ \text{N} \times 10\ \text{m}$$
$$= 800\ \text{J}$$
$$\text{Work Output} = \text{Force} \times \text{Distance}$$
$$= 100\ \text{N} \times 5\ \text{m}$$
$$= 500\ \text{J}$$
$$\text{Mechanical Efficiency} = \frac{\text{Work Output}}{\text{Work Input}} \times 100\%$$
$$= \frac{500\ \text{J}}{800\ \text{J}} \times 100\ \%$$
$$= 62.5\%$$

Ramp Solution

$$\text{Efficiency} = \frac{W_{out} \times 100\%}{W_{in}}$$
$$= \frac{(400\ \text{J}) \times 100\%}{(1000\ \text{J})}$$
$$= 40\%$$

From the U.S. Department of Energy's Motor Challenge

Most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load. Thus, a 10-horsepower (hp) motor has an acceptable load range of 5 to 10 hp, with a peak efficiency at 7.5 hp. A motor's efficiency tends to decrease dramatically below about 50% load. However, the range of good efficiency varies with individual motors and tends to extend over a broader range for larger motors, as shown. A motor is considered underloaded when it is in the range where efficiency drops significantly with decreasing load. shows that power factor tends to drop off sooner, but less steeply than efficiency, as load decreases.



Bearing Life Calculations

Over the last decade there has been a real change in the what ultrasound could detect and determine. It used to be said that bearing life was primarily determined by bearing, speed load and fatigue, but that is no longer the case as trended data has shown

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a better way to determine bearing life through the historical information collected in the field.

So, Bearing Life is now said to be defined as the number of revolutions or hours the bearing can run before showing signs of failures. The bearings life is dependent on the operating conditions as well as the proper mounting and maintenance practices used to maintain the bearing.

The International Organization for Standardization (ISO) published a revision ISO 281:2007 Standard for the calculation of bearing ratings and life to account for such factors as internal stresses from mounting, residual stresses from hardening and other manufacturing processes, and material cleanness.

Also included are the effects of solid contaminants with various lubricating systems, as well as bearing material fatigue stress limits. Before going into further detail, it's probably a good time to review the basics of bearing-life calculations, starting with the common definitions of life.

7. Calculate Life Hours

$$L_{10} = \left(\frac{10^6}{60 \times 3600}\right) \times \left(\frac{553}{18.08}\right)^3 = 132473h$$

Basic rating life =132473h

The basic static radial load rating and static equivalent radial load of a ball bearing are specified in JIS B 1519,"calculation method of static load rating of a ball bearing."

Basic life or L10 as defined in ISO and ABMA standards is the life that 90% of a sufficiently large group of apparently identical bearings can be expected to reach or exceed. The median or average life, sometimes called Mean Time Between Failure (MTBF), is about five times the calculated basic rating life. Service life is the life of a bearing under actual operating conditions before it fails or needs to be replaced for whatever reason. The so-called specification life is generally a requisite L10 basic rating life and reflects a manufacturer's requirement based on experience with similar applications.

Motor and Bearing Failures the Root Cause

There are many causes of motor and bearing that can be determined using CBM Technologies. Ultrasound can be used to pick up several things that are occurring in a motor such as electrical fault conditions, lubrication related issues, improper installation at start up, handling or storage related issues, operational issues, environmental issues, and even defects bearing assemblies. This can only be conclusively proven if a proper RCFA (Root Cause Failure Analysis) is performed on the asset. The use of the ultrasound devices will not only allow the CBM Program to trend the decibels but, also capture the sound waves of the progression of the asset as it approaches end of useful life.

By recording the sound waves the CBM Program can build their library of known fault condition sound waves to compare to future records to help determine the exact fault condition or stage of life the asset is in. The documentation of the HP, RPM, Line Frequency the motor is being driven at, internal temperature (if available), and external temperature are all keys to identifying what the fault condition is presenting when testing using any of the CBM Technologies.

Since many of the technologies detect things at different stage along the P-F Curve it is important to still testing using any and all technologies available to the CBM Program. Ultrasound will pick up somethings first but it's not the answer to every fault condition

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as it will only hear things where as a vibration analyzer will feel the presence of a fault condition that may not show any ultrasonic emissions, and an infrared camera may see a heat signature that can help confirm the findings of the ultrasound and vibration analyzer. This is why it is critical to use an integrated approach to testing motors and bearings as they will help to correlate what fault is occurring.

Here are some of the known RCFA of a motor or bearing failures that have been well established over the last several decades.

Power Quality

1. **Transient Voltage** can be generated by several events from either within the site or off-site issues. These event can be caused neighboring loads that are being turned off and on, power factor correction capacitor banks, or severe weather near the site or along the power transmission lines feeding the site. This can cause fluctuations in the frequency and amplitude of the current. This will lead to the erosion and breakdown in wiring at the site as well as the degradation of the windings in motors. These events can be very hard to determine the exact location of the source of the problem since they can occur randomly. A ranking of High on a Criticality Ranking.

One site in Ohio was having constant issues with motors that would randomly burning up on them. As we went through the electrical training in the field, we found several MCC's that were presenting with a very distinct sound characteristic that wasn't normal for an MCC. Sound waves were recorded of these MCC and later analyzed, and it was determined that they had harmonics indications in both the Time Signal and Frequency Spectrum ranging from 121-122 Hz.

The tech mentioned that they had an issue with one the motors it was driving burning up the month before so, we set out to test them. During the testing a distinct electrical surging could be heard over the top of the bearing noise. So again, sound waves were recorded and when they were analyzed, they too presented with the same harmonic occurrence's as the MCC's they were being driven by.

When this was brought to the attention of the Reliability Department during a meeting, one of the manager stated that they knew that the source was one of their transformers in their substation. The substation was installed by the site when the plant was built so, the ownership was all theirs and since they are part of the local municipality their budget couldn't afford to replace the 50-year components out in the yard.

2. **Voltage Imbalance** in a single-phase loads can be attributed to the load provided by the three-phase distribution systems that feed them. The imbalance in impedance or load distribution will cause an imbalance in all three phases which likely be the source of fault conditions in the motors cabling, terminations and the windings themselves. This imbalance causes increased stresses in the phase circuits. These events will cause the three voltage phases to have non-uniform magnitude which gives them a ranking of Medium on a Criticality Ranking.

A large internet commerce fulfillment center had a motor that during the routine Infrared inspection showed a distinct heat signature on the motor junction box. They asked me if I could take the students over to the motor in question and test it with the ultrasound device. Upon testing the motor in question, a distinct electrical sound could be heard in addition to some popping and cracking in the MOB (Motor Outboard Bearing), MIB (Motor Inboard Bearing) and the sound of an electrical issue was even more intense in the Motor Junction Box.

All three test points had the sound waves recorded of these anomaly for analysis and an interesting harmonic was found at 60 Hz in the Frequency Spectrum and in the Time Signal a .016667 second harmonic was showing. However, when they looked at the 120 Hz harmonics in the Frequency Spectrum, we could see more amplitude and it was even more intense at 180 with a twin peak at 190 Hz. We noticed that the harmonic occurrence shifted to start at 190 Hz and every interval of 120 Hz after that.

The motor was taken offline, and the mechanics where sent out to check the motor junction box out. When they were done with their repairs, they had reported that the wiring had come loose, and they tightened. We were sent back out with the IR Camera

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and the Ultrasound Device to do follow up testing. The IR Camera didn't see any heat signatures similar to what they had seen before, so we proceeded to test the same three points again. This time we could clearly hear an electrical sound in addition to the popping and cracking in the MOB & MIB. The Motor Junction Box had a clear sound of Tracking occurring.

So, three more sound waves were captured and reviewed of this event. In the frequency spectrum there were rich 60 Hz Harmonics and again in the Time Signal a constant .016667 seconds harmonics was seen. Both patterns were constant with a tracking event now occurring and voltage still passing through the bearings. This was reported and the mechanics were sent back out with us to look at the motor again. When the opened up the motor junction box this time we noticed that there was pitting and discoloration damage to the connections caused by the initial fault condition.

The connections were replaced, and the motor was retested, and no electrical sounds were present, but the bearings still had a distinct popping and cracking that indicated the beginning stages of failure. Since the bearings were sealed the decision was made pull the motor just prior to the business part of their season. The damage was later attributed to Voltage Imbalance.

3. **Harmonic Distortion** are a source of undesired supplementary high frequency AC Voltages or currents that affect the energy feeding the motors windings. This undesired supplementary energy serves no functional purpose as it only disperse into the windings which in turn attributes to energy losses in the motor. As they disperse into the motor, they produce additional heat which will lead to more rampant deterioration of the winding's insulation properties. These faults would be ranked as Medium on the Criticality Ranking Chart.

These Harmonic Distortions affects motor in five ways.

A. The reduced efficiency of a motor causing the copper and iron in the motor's stator and rotor to need more energy to keep its proper magnetization. This in turns produces higher amounts of eddy currents and a lag in the response of the stator. If harmonic frequencies exceed 300 Hertz, the surfaces of the stator and rotator can start to increase their resistance and produce what known as the **Skin Effect**.

B. Heat is the most damaging stress on a motor. The deterioration of the winding insulation which will affect the bearings lubrication to lose its effectiveness as it breaks down. This greatly reduces the asset life cycle of the motor and in turn relates to its **MTBF**. This heat may even build in such significance that it may start to trip the motors thermal protection system.

C. Bearing currents allow for the current to arc between the bearing raceway and journal or balls bearings as it seeks a path to ground. This current passing through the bearing race will start to etch bearing and flute the races. In turn creating a much rougher surfaces and contributing to more efficiency loss in the motor as the bearings take more energy to drive the bearings through the races. This increase amount of friction will also start to generate more heat in the race and between this and the arcing of the current across the race the further breakdown of the lubrication of the race shortening the life of the bear assemble and a more severe risk of seizure.

D. With this rampant change in voltage causing side effects like notching and ringing, the motor will cause partial discharge arcing in windings and will accelerating the deterioration in the winding insulation. The plot to the right shows the correlation between voltage rise time (dv/dt) of PWM square wave pulse overshoots,

E. This will also lower power factor causing your power bills to rise as the motor reduces in efficiency.

Variable Frequency Drives

4. **Reflections on Drive Output with PWM Signals** is the use of a pulse-width modulation to manipulate the output voltage and frequency of a motor to control the motors speed. The reflection occurs when there is an imbalance between the source and the load of the motor. This creates a mechanical impedance of the alternating current by electrical circuits and can be a direct result of the improper installation of the motor, improper component selection or the deterioration of the equipment over its

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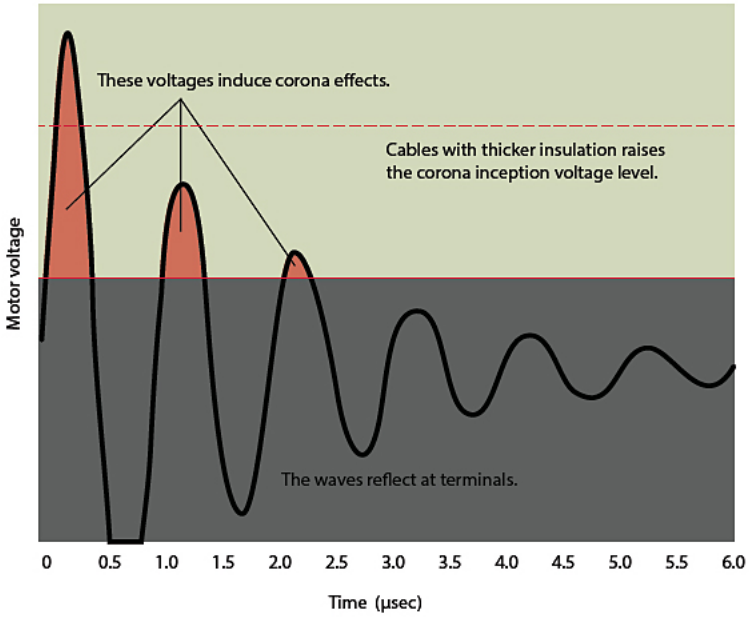
life. These fault conditions in the motor drive circuit could have reflection that could occur that are as high as the DC Voltage levels. These events rank **High** on the Criticality Ranking.



Another large food manufacture had hundreds of VFD Motors on their conveyance systems that were constant tripping out and noticeably hotter at 198° F that the like motors in the area which were showing at 155° F when looking at them with an IR Camera. It was later determined that during installation no ground straps were installed, and this was leading to the nuisance tripping caused by the Reflections on the Drive Output from the PWM Signals. They ended up working with the OEM to change the wiring on these motors and controllers to since the length of the wiring were having the same effects as a transmission line and surpassing the Corona Inception Voltage (CIV) Levels. Once the motor was replaced and the grounding strap was installed this problem went away.

5. **Sigma Current** are basically a spread of stray currents in a motor. This can be caused by the voltage levels, inductance in conductors, signal frequency and capacitance as they circulate through the motor in attempt to find a path to ground and cause the motor to trip out or create significant heat. Sigma current can be located in the cabling supplying the motor and its current equals the sum of all three phases which should equal 0. These events rank Low on the Criticality Ranking.

With these events ranking Low on the Criticality Chart many companies would just ignore this issue and carry on with their business. This may work for some companies but ones with different peak seasons for throughput may take this information and peak bust the motor, so they are caught off guard. This would usually require them to strategically place a new motor and gear box and VFD controller near the ones they were concerned about for faster replacement times when the motor or controller would fail.

6. **Motor Overload** occurs when a motor is run at an unreasonable load. A motor run in this state of operation will have issues with excessive current draw, insufficient torque and will overheat. Overheating is one of the biggest root cause of a motor not achieving optimal life span by 30% of during some studies. This leads to damage of the bearings as the expansion of the metal housing compresses the bearing assembly increasing the amount of friction generated in the race and in turn increasing the heat and ultrasound emissions form the bearings and races. These events rank **High** on the Criticality Ranking.

A Distribution Center Had an issue with one of their motors constantly burning up on their ship sorter at one site. I had inspected several of these same set ups and several of their other sites and it was noted that the VFD was set to 101 Hz. All of the other sites were running in the mid 60 Hz range and weren't experiencing this issue. When we tested the motor the IR Camera was indicating a 212°F external temperature and the ultrasound decibel levels were at 78 dB's a full 8 decibels above their Failure Action Level. There were significant harmonic indications of not only bearing damage but inner and outer race faults as well.

Mechanical Factors

7. **Misalignment** can occur with the motor and the load or the components the motor is coupled too. They can be one of the following, from parallel offset, symmetrical angular, non-symmetrical angular or combined angular-offset misalignments of the drive shaft. Some companies have attempted to defeat misalignment by installing flexible couplings, but this is only a band aid as the this only mask the many issue of the misalignment. The forces will still produce damaging cyclical forces

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to the shaft and motor. This force will increase the apparent load to the motor increasing its energy usage to overcome the misalignment. These events rank **High** on the Criticality Ranking.

One sugar plant actually had a misalignment issue that was so persistent that they installed a flexible coupling on several of their motors and pumps. During an air survey, several strange sounds were heard and traced back to the motors and pumps. The Scanning module was used with a close focusing probe to listen for the source of the strange sounds. One sounded like a flat tire on a car and another sounded like a helicopter making a hard bank. They were all tracked back to the coupling. These motors also showed signs of heat signatures of a motor with excessive heat and the Motor Inboard bears were higher than the normal 45 decibel range that they normally operated at.

So, a timing light was brought and used to test the coupling which appeared to be the source of these strange sounds. The one with the flat tire sound could be seen moving up and down when the timing light was on. The one with the helicopter sound actually had a crack in the coupling and a portion had flared up and was producing the sound that we heard.

8. **Shaft** Imbalance is a fault condition that is caused when the center of mass doesn't line up with the axis of rotation. These events can be caused by missing weights, manufactures defects, ununiform mass in the motor's windings, wear related issues, or dirt accumulation. These events will produce sources of ultrasound and heat signatures that a routine inspection would be able to pick up and schedule for repair before it fails cataclysmically. These events rank **High** on the Criticality Ranking.

One shingle mill had an issue with adhesive backing build up on some of their some of their drive shafts causing them the fail prematurely. This foreign debris caused the center of mass on the shafts to be off leading to increased decibels and heat signature in the motor. Eventual guards were placed over the shafts to reduce this this risk.

9. **Shaft Looseness** occurs when there is there is a disproportionate amount of clearance between either rotating or non-rotating components. The rotating looseness is related to the stationary and rotating elements of the motor bears. The non-rotating looseness occurs in the footings, foundation, or the bearing assemblies housing and the motors housing. These events rank **High** on the Criticality Ranking.

One bearing route was noted to have several bearings that sounded as if the bearings were bouncing up and down inside of the assemble so, the CBM Technician recorded the sound waves even though the decibels were not in an actionable range. During the analysis we noted that there was a distinct beat and pulse that could clearly be seen in the Time Signal analysis of the sound wave that was captured.

The Reliability Engineer sent the Vibration Analyst out to collect some data on the motor and when he returned, he said that he was seeing indications of harmonic occurrences of the RPM at the 1 time through 10 interval in the Frequency Spectrum and in the Time Signal the pattern was very truncated which are clear indications of a rotational looseness.

10. **Bearing Wear** is when the bearing starts to increase the amount of friction it produces as it drags through the bearing assembly. As this increase takes place it also increases the amount of heat it generates reduces the efficiency of the motor. This in turns reduces the MBTF and greatly shortens the life span of that motor. Regular bearing failures cause only 13% of motor failures while bearing wear accounts for 60% of mechanical failures at a site. These events rank **High** on the Criticality Ranking.

As the decibels increase the CBM program can trend them to determine if they have hit actionable levels based off their program's values. Generally, once the bearings starts reaching a range of 20 decibels over the baseline value the vibration analyzer will start to see the indication of bearing, race or cage faults. When the bearings start hitting the 35 decibels above the baseline the infrared camera would start to see a heat signature that is indicating failures approach. So, bearing wear cannot be stopped once it starts but it can easily be determined and managed to prevent unscheduled downtime.

11. **Fatigue** is related to the stress over time that causes the bearing to fail. This is different from bearing wear. Fatigue emanates

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from the sub-surface of the bearing and over time it will migrate to the surface and produce spalling. This can be directly attributed to the poor-quality bearings and in some cases counterfeit bearings. This is the incept stage of bearing failure and would rank **Low** on the Criticality Ranking.

These events will sound like a needle on a record when listening to a bearing. They will be very soft and not occur over the 8-decibel action level that would indicate the need for lubrication. The addition of lubrication will not fix the spalling once it starts to surface and should continue to be inspect at the regular interval till it exceeds the 20 decibel above the baseline action level.

12. **Improper Handling** of a motor and bearings can cause damage before it even starts to rotate. Storing a motor or bearings on a shelf might seem like a great use of the shelves, but vibrations from manufacturing and traffic will cause the bearings to rock back and forth in the races and start to cause false brinelling as this motion pushes the lubrication aside. Without the lubrication being in place, wear is expedited in the form of debris and oxidization of the surface. As the lubrication between the bearing intervals starts pooling, its abrasiveness is increased from the missing lubrication causing an acid etching to occur. These types of events rate as a **Medium** on the Criticality Rank Chart.

One plant identified that this was occurring when they would use their ultrasound to test a newly installed motor they ordered from their vendor. They requested a site visit and during the site tour it was observed that the motors were all storied on the shelve next to the rewind shop. They inquired about the vibrations they felt from the rewind shop floor and their effect on the motors being stored on shelves and floor. They were meet with a perplexed look by the shop foreman.

By storing these motors on shelves in the parts cage the vibrations from the rewind operation were resonating in the shelves and this was observed when one of the plant technicians placed his hand on the shelf and he felt the vibrations from next door. This is why it's important to know your vendors practices as well as yours as they might not even practice FIFO (First In First Out) with their inventory so you won't know how long the motor has sat on the shelf.

13. **Installation** might seem like the least concerning cause of failure, however, have some form of human interaction and the failure rate goes up. The improper installation of a motor or bearing cannot just kill a bearing it can murder it. If the installer uses a hammer, they can actually cause brinelling with force of each strike of the hammer. This can also occur when improper force is applied to the motor or bearing when it is installed. These events rank **High** on the Criticality Ranking.

At a food grade facility, I was teaching at, I noticed a motor that was still on the pad but had been gutted. So, naturally I walked over to check it out. I noticed several greasy shop rags laying around next to the motors housing. Then a guy came over with the rotator and the end caps for the motor on a cart. I asked him how he was doing, and he said he would be better when he put the motor back together. I asked, "what happened to it?" He said he had to pull it apart to replace the bearings since they were cooked, and he always pulled the rotator out to replace them as well as clean out any extra grease that might be in the windings.

I watched as he lined up the cart with the motors housing and pushed the cart towards the opening. He then began the reinserting the rotator and when it wasn't sliding in, he proceeded to hit the out-board side of the rotator with a hammer. I cringed with every strike. Once he was done reassembling the motor and reconnecting the pump, I asked him why he didn't just take the entire motor to the shop to work on it? His answer shocked me even more than him striking it with a hammer when he proceed to state that he wouldn't need to realign the motor if he left the housing attached to the pad.

14. **Soft Foot** is a fault condition in which the feet of the motor are uneven or loose. This allows for movement of the motor or driven assets as they flex from the forces inherent to the process. These events are broken down to 2 categories; Machine Based and Foundation Based. The Machine Based breakdown into 2 sub-categories of Parallel Soft Foot and Angular Soft Foot. Parallel Soft Foot occurs when one of the mountings feet is higher than the others. Angular Soft Foot occurs when there is a unparallel mounting of the feet to the foundation. The last category is Foundation Based which can occur from unlevel bases, erosion, wear, or damage to the foundation the motor is placed on. These events rank **High** on the Criticality Ranking.

An older salt mill I was teaching had been in operation since the 1800's and was in rough shape due to the brine run off and salt deposits. Much of the expanded metal grating was deteriorated or built up on the stairs. Concert had eroded away and several of

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the motor's pumps were squirting water from the housing and seals. One motor in particular was of interest as we could hear a chaffing sound as we approached it. When we placed the probe on the motor to test it, we could hear a very similar chaffing sound and we could feel the movement in the motor as we tried to hold the contact module on the zerk fitting to take our reading. When we looked closer at the foundation, we noticed it had worn away over time due to the brine solution and environmental conditions inside of the mill.

15. **Pipe Strain** can be caused by several of the issue discussed in this section. It is directly related to the resonances generated by the fault condition of the motor. It can cause the attached pipes to send a resonances back into the motor and then compounds the resonance in the asset. Some examples of the pipe strain sources are pipes that have been struck or bent, hangers that are broken, loose, or insufficient. These can cause a motor to become misaligned and continue to worsen over time as the resonance increases. These events rank **Low** on the Criticality Ranking.

One company in the Southeast had several motors and pumps that had pipe strain occurring at their site. So much so, that you could visually see the pipes moving when we went to test the motor and pump bearings. The initial test points that we were using on the frame of the motor and pumps, produced a large amount of antagonistic ultrasound as well as a lot of vibration in the contact module as it danced along the surface. When we used the zerk fittings to listen to the bearings we had a noticeable drop in the antagonistic ultrasound and decibel levels, giving us a much better sound quality of the bearings condition.

16. **Shaft Voltage** is a transfer of excessive voltages through the shaft which attempts to find a path to ground. As it passes through the lubrication into the bearings it begins to produce electrical fluting in the race and can cause pieces of the bearing to flak off. This fault condition will produce a noticeable ultrasonic emissions and heat signatures that can be seen in the IR Spectrum. Once the failure has progressed to an audible sound as well as an increase in heat felt in the Human Experience the asset is nearing its end of useful life. These events rank **High** on the Criticality Ranking.

At a brewery I was teaching at, one motor had a very distinct audible sound that could be heard by everyone. So, we walked over to the source and found a 20 HP motor attached to a pump on a concrete pad. We could feel the motor was hot to the touch, so we decide to take a listen to it. When the student started to place the contact module on the zerk fitting we saw a small blue arc for a split second and then it despaired. The student holding the unit instant jumped back as not only had he heard a little electrical sound in his headphones on approach, but the unit shut off of when the blue arc occurred.

Contributing Factors to Inefficiency

There are many factors contributing to inefficiency in rotating equipment which can lead to a shorter MTBF. Increased friction can be contributed to many things but, one of the biggest causes of increased friction is improper lubrication practices such as over lubrication, Lack of lubrication, Incorrect Lubrication or even adding lubrication to sealed bearing. Heat can also be the enemy of rotating equipment. Motors left out in direct sunlight can heat up and as they do the metal will expand and compress down on the bearing race causing increased friction. Slip is a term that refers to the difference between the magnetic field's synchronous speed and the shaft rotating speed, which is measured by referring to the RPM or frequency. A higher load also increases the slip and the amount of torque a motor produces. These will require the motor to use more energy to overcome these faults.

The Five Laws of Friction

1. When an object is moving, the friction is proportional and perpendicular to the normal force (N)
2. Friction is independent of the area of contact so long as there is an area of contact.
3. The coefficient of static friction is slightly greater than the coefficient of kinetic friction.
4. Within rather large limits, kinetic friction is independent of velocity.
5. Friction depends upon the nature of the surfaces in contact.

The Effects of Heat

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To help rid a motor bearing from problems, the temperature of the bearing should be a key concern when testing. If the bearing exceeds its pre-defined temperature limits, it has the potential to cause harm to the bearing. This can be due to ambient conditions or heat generated within the bearing itself. Improper lubrication is often the cause of an overheating in electric motor bearings. To help prevent harm to the bearings, the temperature should also be tested and documented when collect data for trending.

It has been observed that for every 10°C above rated insulation temperature [i.e. for a class F insulation system if a motor runs at 165°C (exceeding the 155°C)], then the thermal insulation life is cut to half. So, for every 10°C below the rated temperature, the insulation life is doubled.

GE - Power Conversion

Motor Temperature

A major consideration in both motor design and application is heat. Excessive heat will accelerate motor insulation deuteriation and cause premature insulation failure. Excessive heat may also cause a breakdown of bearing grease, thus damaging the bearing system of a motor. The total temperature a motor must withstand is the result of two factors: external, or ambient temperature; and internal, or motor temperature rise.

An understanding of how these components are measured and expressed is important for proper motor application. For a given application, the maximum sustained ambient temperature, measured in degrees Centigrade (Celsius), should be determined. The ambient temperature is the temperature that the motor sees. If the motor is in a housing or chamber, then the ambient temperature is the temperature inside the housing. Most motors are designed to operate in a maximum ambient temperature of 40°C. The temperature rise is the result of heat generated by motor losses during operation. At no-load, friction in the bearings, core losses (eddy current and hysteresis losses), and stat or I2R losses contribute to temperature rise; at full-load, additional losses which will cause heating are rotor I2R losses and stray load losses. (NOTE: I=current in amps and R=resistance of the stat or rotor in ohms). Motor current increases with an increase in load and under locked-rotor, temperature rise will be significantly higher under these conditions. Therefore, applications requiring frequent starting and/or frequent overloads may require special motors to compensate for the increase in total temperature.

Motor Cooling

The total temperature of a motor is greater than the surrounding environment; heat generated during motor operation will be transferred to the ambient air. The rate of heat transfer Effects the maximum load and/or the duty cycle of a specific motor design. Factors Effecting this rate of transfer are:

1. **Motor Enclosure** Different enclosures result in different airflow patterns which alter the amount of ambient air in contract with the motor.
2. **Frame Surface Area** Increasing the area of a motor enclosure in contact
3. **Airflow over motor** The velocity of air moving over the enclosure Effects the rate of heat transfer. Fans are provided on most totally enclosed and some open motors to increase the velocity of air over the external parts.
4. **Ambient air density** A reduction in the ambient air density will result in a reduction of the rate of heat transfer from the motor. Therefore, total operating temperature increases with altitude. Standard motors are suitable for operations up to 3300 feet; motors with service factor may be used at altitudes up to 9900 feet at 1.0 service factor.

Insulation Class vs. Temperature

NEMA has classified insulation systems by their ability to provide suitable thermal endurance. The total temperature is the sum of ambient temperature plus the motor's temperature rise. The following charts illustrate the maximum total motor temperature

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allowed for each of the standard classes of insulation. An additional 10°C measured temperature rise is permitted when temperatures are measured by detectors embedded in the winding. Figures 14-17 illustrate the temperature rise limits established for various insulation classes per NEMA MG-1, Part 12.

Slippage in Motors

Slip refers to the differential between the magnetic field's synchronous speed and the speed the shafts rotating at, which can be measured in frequency or RPM. Calculate the percentage of slip is a method that helps calculate an electric motor's speed performance and is linked to the motor performance.

$$\frac{100\ x\ (Synchronous\ Rotor\ Speed - Rotor\ Speed)}{Synchronous\ Speed}$$

Several factors can affect how slip is occurring, like the rotor resistance, voltage frequency of the stator, and the load torque. As the slip increases, this also Effects the motor's speed. When slip occurs, the voltage stays at its maximum level. This will in turn decrease the rotation of the rotor causing the voltage and the slip to decrease. It is worth noting that there is a direct correlation to the slip and the frequency. So, if there is a reduction in a slip, the frequency also decreases. These both effect the frequency and the slip of the induction motor's inductive reactance.

What To Do When Inspecting Bearings

Ultrasonic inspection and monitoring of bearings is the most reliable method for detecting incipient (beginning stages) bearing failure. Ultrasonic warnings appear before a temperature rise or an increase in driving torque.

Ultrasonic inspection of bearings is useful in recognizing the start of fatigue failure, brinelling of bearing surfaces, and lack or flooding of lubricant. As the ball or roller starts to begin to fatigue the small deformation begin to occur. These deformations cause an increase in ultrasound as the rolling elements impact against other surfaces.

Actions can be taken once a bearing reaches different action levels that the user will determine with trending.
The most important thing an inspector can do is to listen to the condition of a bearing. The inspector cannot rely on simply looking at the display as the most important aspect of these devices is the Human Interpretation of the sounds the asset is making. A good bearing will have a static or white noise sound. A bearing that has a need for lubrication will appear to have some small amount of popping or cracking to it.

As the decibels increase and the popping cracking sound increases the inspector will be able to see the decibels rise over time. When the inspector hears a severe amount of popping or a tonal quality the bearing is approach the end of useful life and plans can be made to change out this asset especially when indications are showing up with a vibration analyzer.

It is key to understand that they don't want to call out a bearing out too soon as there may be no indications when compared to a vibration analyzer and this is because ultrasound will pick up well before vibration will when it comes to these deformation.

This would be even more critical if infrared indications were seen in addition to ultrasound and vibration.
One of the easiest ways to get started trending or interpreting the condition is the comparison of like equipment.
This will quickly identify an asset that is out of range from the other ones.

This should only be used as a stop gap measure till historical information has been established to give a truer level for action to be taken. The inspector should also take the time to capture a sound recording so it can be run through sound analysis software to help determine harmonic indications that can give the inspector the confidence to make an educated hypothesis as to the condition of the asset in question.

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Keys Why Ultrasound Should Be Used

One of the biggest keys to successfully determining asset health in rotating equipment is to first establish what the average value of like assets is. This will allow the initial baseline to be set up and fine-tuned with more historical data mining over time. The trends that are established over time will give the inspector the true range for the action levels to be set at. These action levels can used to improve lubrication practices and strategical plan for replacement during scheduled down time. This help to insure the maximum effective life of an asset.

Comparative Bearing Method

Since most site have similar motors running at the similar RPM's and HP these classes should be the same used to group like equipment for test with Ultrasound. By doing so, comparison testing can be performed, and historical information can be established over time that can be used for alarming. It does not matter the age or brand of the motor for establishing alarm values, it's the HP that will affect the decibel level.

If we look to ISO 20816 1-8:2016 which provides guidance for vibrational testing of machines operating at 600 to 12,000 RPM and the four classes of motors. It gives an RCM program a great range of operating condition without the need for baseline data since this information was collected and data mined to determine these thresholds.

It is impractical to test a statistically significant number of bearings, so engineers rely on standardized bearing-life calculations to select and size bearings for a particular application. If we use these same 4 classes of machines, we should be able to establish a similar table for ultrasound emissions as well.

This will take time and historical data to prove this theory to be true. That data has shown that seemingly identical rolling bearing operating in the same class will have a standardized baseline value that could be used to start out at for the action levels.

Here are the 4 classes of machine that should be used when grouping equipment together for comparison and historical trending. These calculations will continue to evolve and become more accurate over time, reflecting the collective experience of the condition monitoring programs data, bearing industry, tribology, materials, and Historical data mining.

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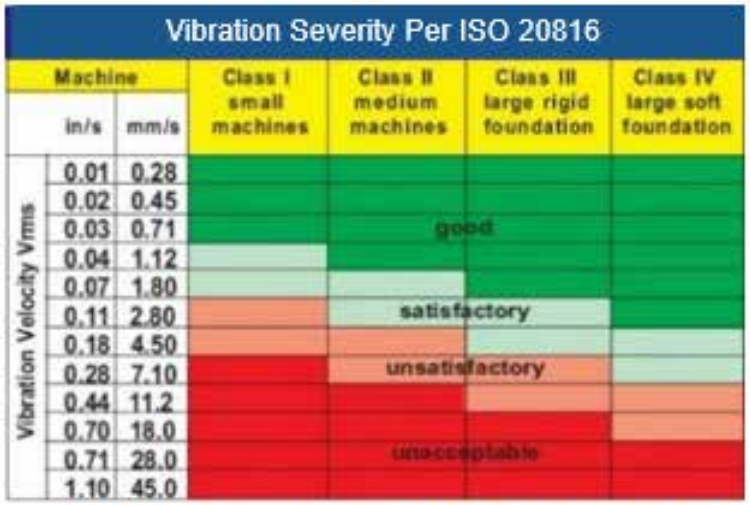
Machine Class:

Small	Medium	Large	
		Rigid supports	Flexible Supports
Class I	Class II	Class III	Class IV
<20 HP	20-100 HP	>100 HP	>100HP

Class I: Small size machines (up to 15 kW) are subassemblies of larger machines.
Class II: Medium size machines (15 kW to 75 kW) without special foundations, or machines up to 300 kW rigidly mounted on special foundations.
Class III: Large rotating machines rigidly mounted on foundations which are stiff in the direction of vibration measurements.
Class IV: Large rotating machines mounted on foundations which are flexible in the direction of vibration measurement.



ISO 20816-1-8:2016 Vibration Severity Ranges for 4 distinct classes

Causes of Bearings Failure by JAD Bearing Failure Analysis

Bearing;

Flaking and Surface Fatigue

Flaking due to rolling fatigue occurs when small pieces of bearing material are lifted and broken off the smooth surface of the raceway or the rolling elements. This flaking causes regions with a rough and coarse texture.

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Peeling

Dull or cloudy spots appear on the raceway surface along with light wearing. Tiny microscopic cracks are generated downward from these cloudy spots to a depth of 5-10 μm. Small particles of material then peel from the surface with areas of minor flaking starting to occur.

Scoring

Scoring is surface damage due to accumulated small seizures caused by sliding under improper lubrication or severe operating conditions. Linear damage appears circumferentially on the raceway and roller surfaces. Cycloidal shaped damage on the roller ends and scoring on the rib surface contacting roller ends also occur.

Smearing

Smearing is surface damage which occurs from a collection of small seizures between bearing components caused by oil film rupture and/or sliding. Surface roughening occurs along with melting.

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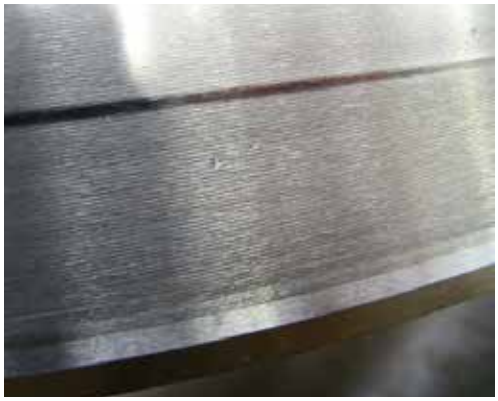
Denting and Pear Skin

Flaking due to rolling fatigue occurs when small pieces of bearing material are lifted and broken off the smooth surface of the raceway or the rolling elements. This flaking causes regions with a rough and coarse texture.



Bearing Wear

Wear is surface deterioration due to sliding friction at the surface of the raceway, rolling elements, roller end faces, rib face, cage pockets, etc.

Fretting

Wear occurs due to repeated sliding between the two surfaces. Fretting occurs at fitting surface between raceway rings and the shaft or housing. Fretting corrosion is another term used to describe the reddish brown or black wear patterns often seen on old shafts and worn housings.

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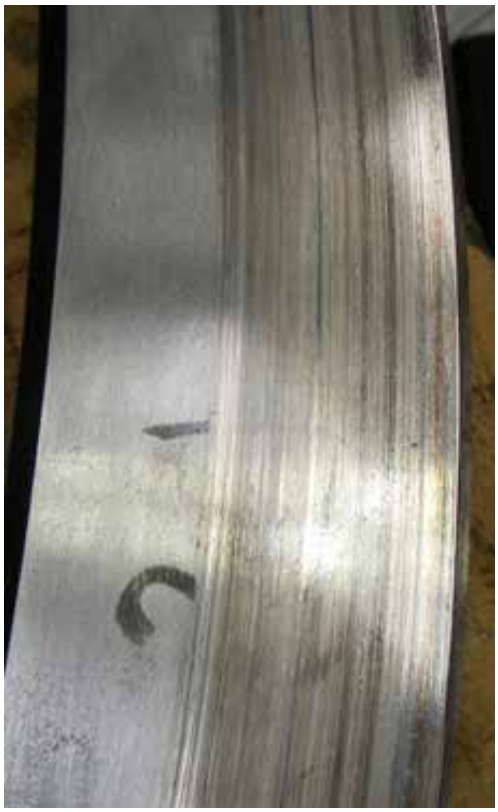

False Brinelling

Among the different types of fretting, false brinelling is the occurrence of hollow spots that resemble brinelled dents and are due to wear caused by vibration and swaying at the contact points between the rolling elements and raceway.

Creep

Creep is the phenomenon in bearings where relative slippage occurs between fitting surfaces and thereby creates a clearance between the surfaces. Creep causes a shiny appearance, occasionally with scoring or wear.

Seizure

When sudden overheating occurs during rotation, the bearing becomes discolored. Then, the raceway rings, rolling elements, and cage will soften, melt and deform as damage accumulates.

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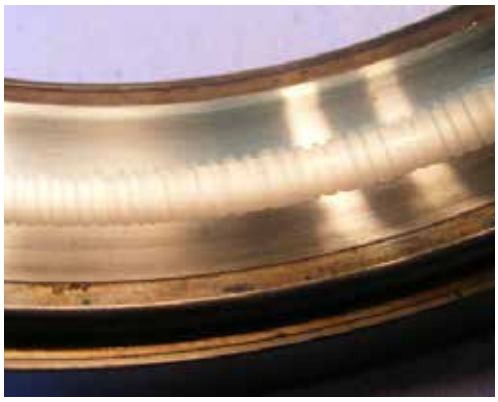
Corrosion

Electrical

When electric current passes through a bearing, arcing and burning occur through the thin oil film at points of contact between the raceway and rolling elements. The points of contact are melted locally to form “fluting” or groove-like corrugations which can be seen by the naked eye. Magnification of these grooves reveals crater-like depressions which indicate melting by arcing.



Rust

Bearing rust and corrosion are pits on the surface of rings and rolling elements and may occur at the rolling element pitch on the rings or over the entire bearing surfaces.

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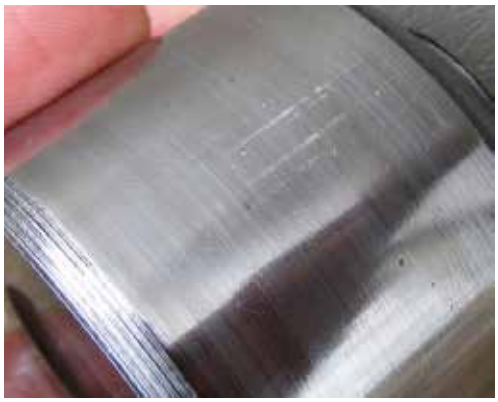
Mounting

Straight line scratches on surface of raceways or rolling elements caused during mounting or dismounting of bearing.



Cage

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Damage

Deformation

Cage damage includes: Cage deformation, Fracture and Wear Fracture of cage pillars.

Fracture:

Fracture refers to small or large metallic pieces which were broken off due to excessive load or shock load acting locally on a rolling element, rib or section of a raceway ring.

Wear

Rolling Elements and Raceways;

Cracks

Cracks in the raceway ring and rolling elements. Continued use under this condition leads to larger cracks or fractures.

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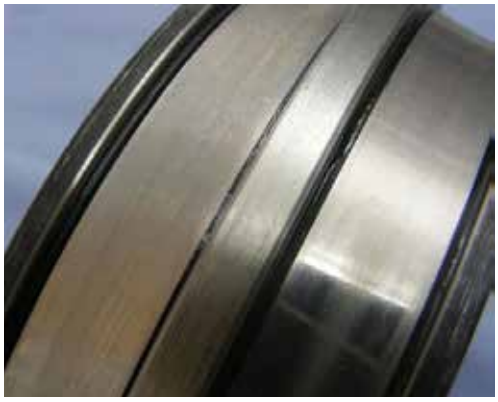
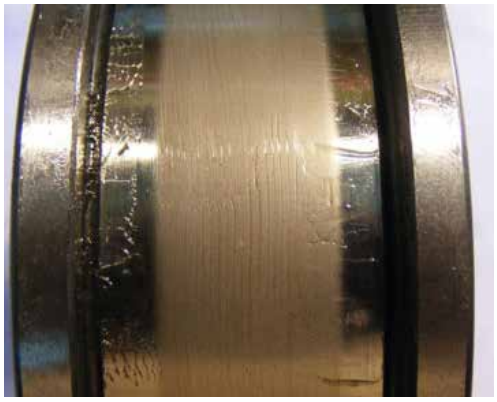
Pitting

Pitting has a dull luster and appears on the rolling element surface or raceway surface.

Housing or Shaft Damage

Wear, corrosion and burrs caused by repeated replacement of new bearings, a contaminated or moist environment or heavy handling during bearing removal.

Lubrication is The Biggest Cause of Failure

Over the years many studies have been conducted on the cause of early life bearing failure and one of the biggest causes of shortened life of a bearing is improper lubrication. There are 5 main categories of improper lubrication and they are lacking lubrication, improper type of lubrication, aged lubrication, over lubrication and contamination of lubrication.

These are all events that can be minimized to help insure the life of the bearing. The use of ultrasound can help to determine if there is a lack of lubrication by setting action levels and listen to the sound of the bearing.

If there is a slight static or needle on a record sound the inspector can look at the trended data to see if its slightly elevated. If they have a baseline sound recording it could then be used to compare to the current sound recording and compared in both Time Signal and Frequency Spectrum to look for harmonic indications of a change.

The inspector could then present a report to their lubrication crew that would show which assets actually need lubrication. This takes the PM based lubrication program and improves upon its Effects by only targeting the assets that are in need of lubrication.

The lubrication crew then could take the ultrasound device out to listen to asset while its being lubricated to ensure that the asset isn't over lubricated. This is achieved by listening as the lubrication is pumped in a little at a time.

Once the sound level quiets down the lubricator can stop pumping grease in and move on to the next asset.
If the they were to continue lubricating the sound level would increase letting them know they have added too much lubrication.

At the time of writing this material no one has shown what indication improper, aged or contaminated lubrication would present with as far as a sound indications but, it stands to reason that they would show an increase in the decibel's levels being emitted by the asset.

Sound Qualities to Watch Out For

As damage to the bearing, inner & outer races increase pitch & tone can start to be produced. This increase in sound will show

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up as a raise in decibels and well as a change in sound quality. These deformations will also produce significant Harmonic indications that can be calculated to determine if there is an inner or outer race issue, cage fault, bad bearing, lack of lubrication, loose condition, shaft voltage, dirty current and even a loose connection in the motor junction box. This is just like hitting a rumble strip at a higher speed.

Slow Speed Bearings

For the analysis of these sound recordings the inspector will need to use Time Signal Analysis as there is general not enough energy to produce an FFT of the event. Even vibration experts recommend that the vibration inspector should switch to Time Signal Analysis when testing slow speed bearings. Time Signal Analysis will so the deformations in time as the inspector hears them and can then be mapped out for their harmonic occurrence. By using a Fault Calculation Spreadsheet or long hand the inspector can determine if it's the Bearings, Cage, Inner or Outer Race issue quickly and easily.

ASU CAT 2 Module 2-7 Severity Determination

Severity Determination

Ultrasonic detection equipment has become a trusted source for trending and troubleshooting over the last few decades. The ability to run recorded sound waves through sound analysis software has opened a new realm of analysis for the CBM Analyst. No longer is Ultrasound simply a Go-No-Go test; it can be used for determining Stray Voltage in a motor, Inner & Outer Race faults conditions, Cage Faults, Ball Pass Faults, Corona, Treeing Tracking, Arcing, Looseness, Loose Connections and Delamination of Windings in a Transformer.

These issues can be determined by simply look at the representative images of the sound wave using a Frequency Spectrum view in an analysis software. Each one will have a distinct image that shows the Harmonic Marks that tell us what the Fault Frequency of those Harmonics are. In addition, the use of a Time Signal will show the harmonics and the Amplitude of the Sinusoidal Wave and can be calculated to determine their interval of occurrence not only in seconds but Hertz as well.

The Benefit of Time Signal vs Frequency Spectrum; Slow Speed Bearing Testing

Slow speed bearings have often been a source of frustration for facilities all over the world when trying to test with vibration analyzers. These slow speed bearings in mills can often be placed in hot wet places making it hazardous for the inspector to be exposed for an extended period of time not to mention the potential effects on the testing equipment. With vibration analyzer needing to test three points per end this can take a lot of time to get a proficient reading whereas the ultrasound only needs a as little as 15 seconds of sound recording to determine the condition of a slow speed bearing. When it comes to slow speed bearing it a lot like a rumble strip on a highway. If we hit a rumble strip at 55 mph it takes less time for the tire to traverse the depression and it gives us high pitch sound versus hitting it at 5 mph where the tire takes longer to traverse the depressions giving the inspector a deeper more distinguished thumbing sound. So too will the deformation of the surface will be more pronounced in slow speed bearings.

The Benefit of Time Signal vs Frequency Spectrum

Since Ultrasound has so many capabilities it is still a recommended must have for all Pd/M & RCM programs. The one drawback is the cost of the equipment & software. Some companies also phase out their older equipment and will no longer support the equipment after a decade or so. The learning curve to become a good vibration inspector takes a lot longer than that of an ultrasound inspector. This is due to the fact that it is the simplest of the two to use and become proficient at. One of the other keys to ultrasound is how Early it picks up bearing faults. It will literal hear everything from lack of lubrication, stress deformation

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on the surfaces of races and bearings, to stray voltage and even the catastrophic end of life of a bearing.

When Storing Data Beware of Errors

The inspector should always be aware of the amplitude the device is receiving especially when recording a sound wave. If the inspector has too much amplitude the recording will be distorted, and analysis will be next to impossible to determine harmonic indications in both Time Signal and FFT. The opposite is just as import, if the inspector doesn't have enough amplitude the sound wave will not have enough energy to clearly display harmonic indications of the fault. The inspector must also insure they are not moving the module around as any movement can cause frictional antagonistic ultrasound that could be misconstrued as mechanical noise.

Spectrum Analysis

The use of Time Signal Analysis is fast becoming the go to means for determining fault conditions in assets. Take for example a steam trap. It may have a set rate of recommended discharge from the manufacturer. With the use of the time signal inspector can determine the total number of discharges per minute. The inspector can then use this information to determine if a trap maybe cycling too frequently which could indicate an undersized trap. For valve testing the inspector could record the sound levels across the 4 test points and then over them against each other to show a rise in decibels against the other test points to help prove to the client or management that a valve has failed. These are just some of the application that an inspector could use sound analysis for.

Disposition of Anomalies

The establishment of Benchmarks and Baseline Values and Alarm value can be established if we look at the disposition (Tendency) of the assets being tested we can quickly establish a baseline value using the Comparison Method. This can even involve how the asset is installed or set up versus other similar assets.

Diagnosis and Prognosis

When it comes to understanding asset health, we need to think about how the data that is collected can be used to diagnosis a

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fault condition or to give a prognosis of that assets remaining life span. By establishing Benchmarks, Baselines, Alarm Levels, and Corrective Actions Steps a CBM program can quickly monitor what is occurring across the plant's assets. The definitions for Diagnosis and Prognosis have been intertwined in the medical field for years. In the CBM realm we are no different than the medical team overseeing our patient's life only we are over seeing asset life span.

Definitions

Diagnosis: refers to the process of analyzing information to understand or explain something. The plural of diagnosis is diagnoses. The adjective form is diagnostic.

Prognosis: means a forecast or prediction--a judgment about what is likely to occur in the future. The plural of prognosis is prognoses.

"The distinguishing difference between diagnosis and prognosis is that prognosis implies the prediction of a future state. Thus, to accomplish prognosis requires both diagnostic and predictive tools, the former to sense the current state of damage and the latter to predict the future state based on projected usage and applicable life-prediction routines." (Materials Damage Prognosis, ed. by James M. Larsen et al., 2005)

Case Studies; Unground Leak

Underground Leak Detection Survey Using Infrared and Ultrasound Technologies Saves Time and Repair Costs

by Drew Walts, SME and Training Manager at IRISS, Inc.

The Five Towns Complex in Clearwater Florida was experiencing an observable leak around one of their swimming pools in the complex. The maintenance manager, Chad Moises, hired a pool leak detection company that guaranteed they could find the source of the problem. The inspectors used various test methods such as dye testing, the bucket test method and a specialized leak detector in the 300-5000 Hz range, that is designed to amplify sound waves in this range to try to find the leak. After several days without finding the source of the leak, the company left and stopped responding to the maintenance manager's calls for help. However, they did, before giving up, shut off the pool's auto fill system and, oddly, the pool water level never dropped! This observation clearly highlighted that this was not actually a pool leak, but rather a water or irrigation line leak.

Specialized Water Leak Detector 300-5000Hz in Use

Chad then contacted Drew Walts of IRISS Inc. and asked if IRISS had any technology that could look at the area and locate the leak. The best approach was to observe the area in the evening when the solar heating ended so the concrete temperature would be cooler. Upon arrival, Drew saw a noticeable stream of water in the street coming from the base of the pool's patio area. There was a noticeable bubbling from a seam where the pad met the sidewalk. Drew's hypothesis for visiting in the evening was to first use an Infrared Camera to locate the target area and then zoom in on the location using

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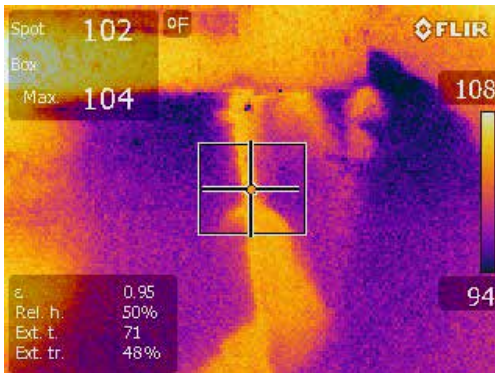
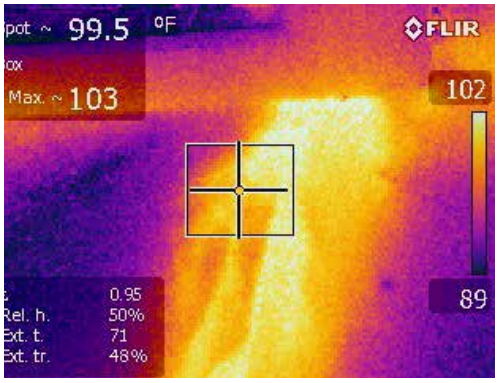
an ultrasound device to locate the leak.

Water Seepage Observed at the Site

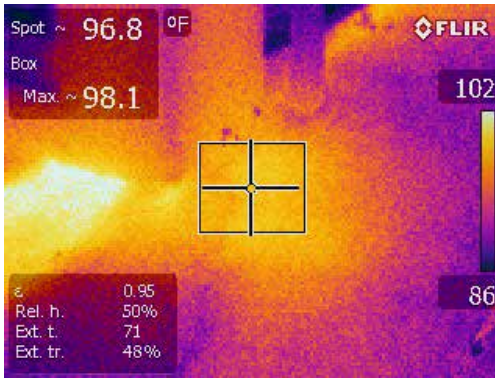
Step 1: Using Infrared Technology to Locate the General Area of the Leak

Using the IR Camera, the area around the south east corner was the coolest area and the moisture in the sidewalk was cooling further out than the visible stream of water. Recently, a new section of concrete sidewalk had been poured around this corner. After scanning the entire pool area, the only noticeable area of concern was at the pool entrance area where the stream of water was originating. The area where the first visible signs of a leak were coming from was visually warmer than the surrounding area. This just happened to be in the same area where the newest concrete had been poured. The general location of the leak had been found.





Infrared Images of the Sidewalk and Pool Deck



Step 2: Using Ultrasound Technology to Locate the Actual Leak

Five test points were drilled into the seams of the pavers and down into the concrete pad. Using the Sonaphone III, the BS20

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contact probe and a 15 mm contact rod was inserted into each hole listening for sound. No sounds were heard in these holes thereby eliminating the pool as the source of the leak. Two additional holes were drilled where the water was bubbling out of the ground. Again, no sounds were detected by the Sonaphone III.

Next, two holes were drilled at the base of the pad and the sidewalk. No noticeable sounds were observed; however, the dirt that came up with the drill was moist. Another hole was drilled to the right and the dirt was also moist and, a small amount of water started trickling from this new hole. When the Sonaphone III rod was placed into the hole, a slight decibel indication of 1-3 decibels was present as well as a small noise that sounded like little baby bird tweeting. Another hole was made at the base of the pillar and the new sidewalk where the dirt was moist, and, within a few seconds, a very noticeable flow of water started to appear. The flow of water through this new hole caused the water flowing from the other two locations to slow down. The Sonaphone III rod was inserted into this latest hole and the decibels immediately jumped up to 15-18 decibels and a distinct sound of bubbling was heard. The exact location of the leak had been found.

Using the Sonophone Ultrasound Tester to Pinpoint the Leak

The General Manager of the Five Towns Complex, Ken Chancey, came to observe the progress of the testing. Drew informed Ken that the leak was originating from under the new concrete sidewalk based on the results of the ultrasound test. Ken decided to order workers to dig up the new concrete to see what was going on.

Upon removing the new concrete, brown muddy water immediately started flowing. When Chad felt inside the pool of water, he found a split in a PVC irrigation line.

Brown Muddy Water Quickly Filled the Concrete Excavation

The photos below were taken during the full excavation and extraction of the water. The leak originated from the bottom of the PVC elbow. This leak could have been a result of over-pressurization, water hammer, defective pipe or human error during installation of the new concrete pad.

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Burst PVC Irrigation Pipe Elbow

Conclusion

The use of Infrared and Ultrasound technologies goes hand in hand when trying to locate faults and can be used in many applications. The Infrared Camera helped map out the area of concern to a ten-foot space. The Ultrasound device helped zoom in on the exact location of the leak. The source of the leak was within 6 inches of one of the test holes used for the Ultrasound testing. By using the combination of infrared and ultrasound technologies, a minimal amount of time was used to locate the problem and the repair cost was minimized since the entire pool patio area did not have to be excavated.

Case Study; Airborne Leaks

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A Dog's Sense of Hearing or Smell Teaches Man A Valuable Lesson

Overview

An established natural gas producer in the United States learned a valuable lesson from "man's best friend" – that canine ears can hear higher pitched sounds and can hear sounds within a much broader frequency range compared to the human ear. Because of this canine's behavior, the company researched ultrasound technology as a means of performing leak detection on various equipment at their multiple locations.

Background

A dog routinely visited the workers at one of this company's remote well pad locations. The workers would provide treats and play with this dog during the visit. One day, when the dog appeared, he ignored the workers and zeroed in on a pipe and began growling at it. After growling didn't do anything, the dog began to attack the pipe. Initially, the workers were laughing and joking that the dog had gone mad. However, one worker suggested that they should check the pipe to see if it was leaking.

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Discovery

The workers, using a Multigas detector, examined the exact location on the pipe that attracted the dog's attention. They discovered that they had a gas leak that couldn't be heard by their human ears. This incident was reviewed at a safety meeting with a recommendation to the company's corporate office that they keep dogs on the premise to help detect issues like this gas leak. Interestingly, there are a few businesses around the world that offer services using dogs that have been trained to "smell" gas leaks.

Research Options

One of the supervisors began researching a dog's sense of hearing and learned that a dog can hear higher pitched sounds and can hear sounds within a frequency range of 67Hz – 45 kHz whereas a human ear detects sounds within a range of 64Hz – 23 kHz. During his research, he discovered the term "ultrasound" and began searching for devices that can detect ultrasound which led him to reading about the SONAPHONE E.

Research Results

During the research the Supervisor found that raising dogs, having them trained, Kenneled, special outfitted trucks, feed and medical care could run into the range of $20,000 per animal. This then triggered her to mention in the next meeting that the dogs could possibly hear as well as smell the leaks that humans couldn't. One of her collages then looked into the frequency range of dogs and found that dogs could hear into the ultrasonic range. He then looked for ultrasonic leak detectors that were made for gas leak detection. This led him to the Sonaphone E webpage.

The SONAPHONE E Ultrasonic Testing Device is an intrinsically safe ATEX certified instrument that is suitable for use in the most hazardous areas and potentially explosive atmospheres such as a natural gas production site. In addition to the reliable location of compressed air and gas leaks, the multipurpose device is also suitable for tightness testing of various systems, wear control on

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rotating machinery and providing evidence of electrical partial discharge (PD) for power distribution equipment. Leak detection and rectification makes a significant contribution to energy saving and reduces operating costs. For routine inspections, the SONAPHONE E indicates where preventive maintenance work should be carried out to avoid greater damage, ensuring safety and machine availability, even in the most dangerous areas of the operation.

Current Procedure

When asked how they currently conduct leak inspections, the company representative stated that they have one inspector using one VOC (Volatile Organic Compound) camera to inspect approximately 400 pad sites and that their inspection routes were far behind schedule due to the cost of buying additional VOC cameras.

The Demonstration

The supervisor arranged for a site demonstration of the SONAPHONE E with IRISS Inc., the master distributor of this testing device in the Americas. An IRISS representative conducted the demonstration for a group of 9 employees at this remote location; many of the attendees hold upper management positions.

During the SONAPHONE E demonstration, several well heads, burners, tanks, valves, sand filters and compressors were inspected. The SONAPHONE E detected leaks on the top of the tanks, of which two of the leaks detected were not tagged as a problem by the VOC camera inspection that had been done a few weeks earlier. Several leaks were detected on the sand filters and one leak on the valve cover on a compressor.

The Future

Regardless if this company's canine visitor "heard" or "smelled" the leak, the company is planning on purchasing multiple SONAPHONE E devices to add to their inspection program. Because the SONAPHONE E costs about 1/10th the cost of a VOC Camera, the SONAPHONE E devices would be their primary device used to detect leaks, identify equipment that needs repaired and perform follow-up inspections to ensure that the repair fixed the leak. As a result of the demonstration, the company realized that the SONAPHONE E device quickly identifies problems and the price point was much less expensive than purchasing another VOC camera. They plan to deploy several E units and catch up on their leak backlog ASAP.

ASU CAT 2 Module 2-8 Program Management

Program Management is a key component to any CBM Program. If the data collected is generating key information on Action Levels and Fault Condition Severity Determination but it is not reacted upon then the program will become ineffective as the equipment is allowed to fail cataclysmically. Too often this is the case for a fledging program as the management has no confidence in the technology or personnel performing the task.

I was once teaching a class in Ohio for a company that was starting up their new CBM Program and 30 days prior to my arrival they had just completed MCA Testing on their new testing device. All of the sudden the guys on the ERT Team pagers were beeping and then the announcement came across that there was a fire on one of the lines in the mill. The guys scrambled out the door and training was put on hold.

When the guys from the ERT Team returned to the classroom they were all a buzz about the motor that had caught fire. As it turns out that very same motor had been identified during the MCA Training class as having a red flag indications of a fault condition and it was reported to management. Management had made the decision not to react to the indications of a fault since the technology and experience of their technicians was unproven at that point. This is only one of several examples I could go into about programs just starting out that the results were overlooked due to it being a new technology. Unfortunately, this isn't just

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limited to start up programs either. Too often CBM Analyst will report their findings only to have them ignored since management doesn't understand how the technology works, no confidence in the technology, or worse no confidence in the CBM Analyst.

This is why one of the keys to rolling out and of the CBM Technologies to your site should require an interactional overview of the capabilities of these technologies to everyone in the plant. This will help to ensure that everyone from the operator to management knows what your CBM technology can actual do to detect fault conditions and prevent unscheduled downtime. This is why it is so important for CBM Analyst to take certification training like this course so they have the knowledge of how the technology works so they can effectively explain it capabilities.

Route Inspection Consideration

Some things to consider when setting up an inspection routes might seem pretty obvious, but they still need to be mentioned. The first consideration should always be what module will be used to collect the data and soundwave of the asset. This will in turn will determine what frequency the unit should be set to for the collection of data and sound wave.

The next consideration that is a key to a successful test is the test points. On motors, pumps and bearings the zerk fitting should always be the first choice. This also make it easy to get repeatable results when different CBM Technician and Analyst are collecting the data and sound waves. On Electrical assets though this becomes difficult at best to repeat even with the same person doing the inspections as their position will not be exactly the same every time since they are using and airborne module instead of a contact module. This is another reason that Ultrasound Ports work best for repeatability when testing electrical assets as this establishes a fixed repeatable test point that eliminates any diffraction of signal.

Some additional considerations that should be taken into account during the inspection of a route are detailed notes are taken of what other conditions are occurring besides the decibels values the CBM Analyst is collecting on the route. These other factors can be such things as the setting of the VFD, humidity level during an electrical inspections or noticeable oil leaks from a gear box.

The CBM Analyst should take everything into consideration when going out to collect data from their routes. This will help to ensure that all relevant environmental data is noted as well. As this information can be key to helping to determine the cause or source of anomalies origination.

Likewise, the route should have set test points established as this will help to ensure the data is collected form the same test point constantly. This makes it easy for multiple personnel to collect the data properly. For electrical inspection the use of an ultrasound port will greatly increase the effectiveness and reduce the overall time it takes to test electrical gear since the old method requires the CBM Analyst to scan the seams which takes more time and the angle cannot always be repeated the next time the inspection is performed since there is no set test point to reference.

Route Management

Once a site has established their route for data collection they will need to see if they can improve the flow of the route as some assets may be easier to collect while operating in the same area vs the process flow that some sites use. This can help to make the data collection more effective and less tedious for the CBM Technician or Analyst. The capturing of Data is always important and baseline sound waves should be captured, then if something different is heard or a rise of decibels is noticed.

Remember to ensure that you are collect good data and sound waves as garbage in equals garbage out! From there the Data Mining can be begin. This is the second most important step that needs to be performed. Data Mining can be used to determine Baseline Values that can then be used to set Action Levels on equipment. It will also help the program to determine if a fault condition is present and what the fault is by performing sound analysis. The last step is to report the fault condition and schedule the asset for repair. Once the repair has been made the asset needs to be retested and new baseline data captured.

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Route Management; Asset Tags

Prior to Asset Tags companies would have to manually write down their findings with their ultrasound devices then, the invention of digital data capturing ultrasound devices made it a little easier to capture the decibels of the assets they were testing. This gave the programs the ability to trend bearing failures or determine the annual cost avoidance of an air leak. The next advancement was the ability to capture sound waves to be used in a sound analysis software platform. Now with the invention of Asset Tags the CBM program can quickly test assets using either and NFC, QRC, or RFID system to log the data from the inspection electronically.

Some sites use Asset Tagging platforms to capture and log the data collected in the field. These platforms allow for a faster and more convenient method of collecting and logging data. These tags allow the CBM Technician or Analyst to collect an asset in any order they want to collect. Some ultrasound device require you to load a route to the unit or a SD card to import the route into the unit. The route then requires the inspector to follow the exact order of the route that is loaded to the unit. Test points can be skipped but it is a little tedious in some devices to skip ahead.

Asset Tags allow the inspector the ability to walk up to an asset and scan the tag and log their data in any order they choose. This is also very beneficial when it comes to running out to test one asset that someone has reported and issue with since there is no need to clear the SD card, load the route to the SD Card, load the route to the unit from the SD Card, and then skip ahead to that signal asset that needs testing. Instead they simply scan the assets Asset Tag and log the dat and move on.

There are 3 operational platforms that these tags can use. The first is the most is the NFC system as it is used by all manufactures of smart phones for wireless payment. This makes the use of NFC Asset Tags less expensive deployment as a single smart phone like the CAT S60 can have the operational platform installed simply by going Google Play Store to download the APP. The Cloud based software platforms can be downloaded from the company's website. The ease of use of these platforms has really taken off in the last decade with the push for IoT Solutions.

Route Management; Online Monitoring

The addition of online monitoring can help bridge the gap between inspection periods or to keep an eye on critical equipment in between routine inspections. These new devices are meant to monitor equipment 24 hours a day and will give the CBM program insight into the operational status of the asset. When an action level is triggered, alerts can be sent out to the program manager instantaneously. Then a CBM Analyst can be dispatched to test the asset further for determination of the fault condition.

These devices can either be a contact or non-contact, wired or wireless, powered by batteries or directly wired, firewalled Data or Cloud based. With so many options available to choose from there is a solution for everyone.

These device can also be a completely stand-alone set up or integrated into a BMS or SCADA platforms. These devices can also produce reports as well which save the program time by not having to mine the data manually. This saves valuable time and can help to avoid human error in not determining the presence of a fault condition.

Route Management; Cloud Based Data Collection

Cloud Based Data Collection is a valuable option for sites that are running lean or are a World Leaders in the CBM Realm. These devices can constantly stream data and give insight into the operational condition of and asset without having to send personnel out to test the asset. The ROI can be significant when you calculate the man hours to inspect the assets, capture the data, download the data, analyze the data for ever asset. These Online Monitoring devices do it instantaneously without the need for hours of analysis by the CBM Analyst, freeing them up to only need to do follow up testing and analysis on alarmed assets instead of every asset.

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With the ability to set action levels these Online Monitoring Systems can quickly identify an issue and send personnel an alarm message. Personnel can then be dispatched to check on the asset with their Ultrasound Device or an IR Camera to perform more in-depth analysis of the asset and decrease the chances of experiencing a catastrophic failure.

Report Structuring

The key to any program is the database. How will you store your data you collect in the field? Does your equipment have software to use to store the data? Can you export the data to an excel spreadsheet so you can quickly identify out layers! Charting these values is a valuable visual aid for reporting issue to Plant Management and can help guide decisions that need to be made as well as forecast the future of that asset's life span. When using sound analysis software producing reports with the images from that platform can also give the CBM Team the added ammo they need to make their stand on why it's time to repair or replace and asset.

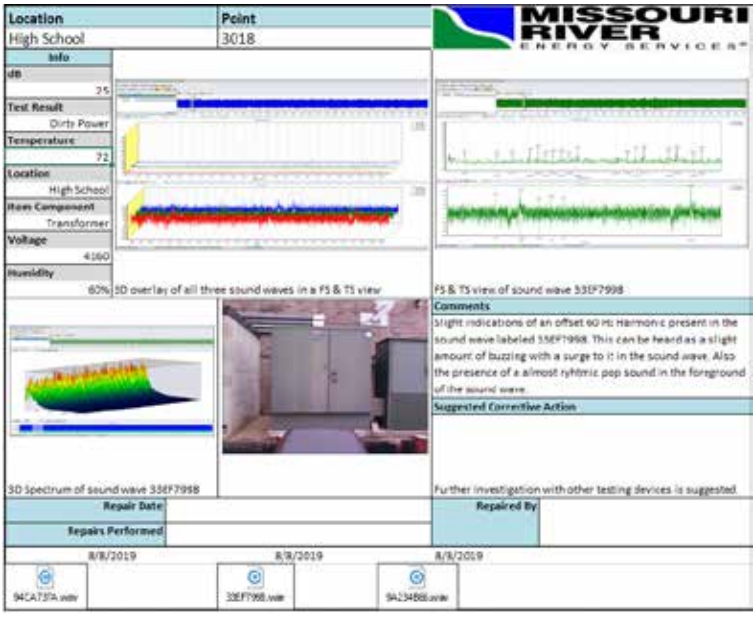
Report Structuring; Historical Data Plots

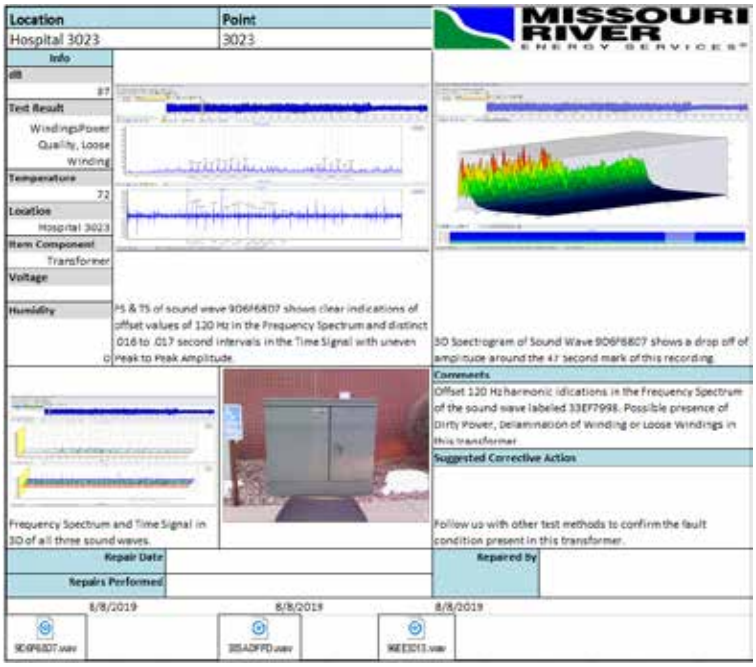
With the ability to set action levels these Online Monitoring Systems can quickly identify an issue and send personnel an alarm message. Personnel can then be dispatched to check on the asset with their Ultrasound Device or and IR Camera to perform more in-depth analysis of the asset and increase the chances of experiencing a catastrophic failure.

Report Structuring; Generating Custom Reports

Most software platforms comes with standard report fields but, some actually have the ability to generate a custom report which allows the program manager to export only the information they are interested in seeing. Maybe they only want to look at the history of one asset instead of the entirety of their assets. Or, maybe they want to see if a particular brand is having issues, It really allows for endless possibilities of Data Mining.

Report Structuring; Example Reports





Corrective Actions for Alarms

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It is important to set alarms values that prevent catastrophic failures. Alarms should be used to determine when to lubricate a bearing, when bearing are damaged and when they are approaching catastrophic failure. For Air Leaks value can be established to determine the urgency for repair. Electrical inspection is one that actually alarms cannot be set up initially so if something is heard a sound wave should be recorded for analysis. The key to this is collecting good Data to use for setting these values and what Criteria is involved in setting those values.

ASU CAT 2 Module 2-9 Reporting and Corrective Actions

Once the Data Mining is complete, the information gathered must be assembled into a report that is clear and concise in stating what the fault condition is present in the asset. By analyzing all of the data and the images of the sound waves that were analyzed, the CBM Analyst can highlight the harmonic indications that are present in that asset that points to the exact fault condition they determined. The CBM Analyst must be present the findings in such a way, that this information is clear to understand for those that know nothing about the technology and in most case don't know how the asset actually works.

The last step to any program is reporting the findings to the maintenance manager who will then take the data and analysis to the site's operations, production and site management personnel to report what the asset health is and what recommendations for repair or replacement of the asset are. Once the repair or replacement of the asset has taken place the CBM Technician or Analyst need to go back out to take a new baseline data and sound wave recordings of the asset as part of a commission process. This will help to determine that there are no fault conditions from improper installation or storage of the asset by the vendor, storeroom or manufacturer.

When it comes to assembling a report the CBM Analyst will need to ensure that the following information is in the report.

Date & Time are a key part of any report as they can then be referenced to determine if outside influences or load requirements were affecting the asset being tested. It can even track that the work is being done in an effective amount of time. Or it could be used to compare the data collection by one employee vs another to try and improve time management. The Date & Time is also critical piece of documentation for service providers as it will serve as proof of the service work being performed and may serve as legal evidence in a court case should there be a catastrophic failure, as insurances companies will investigate all angles of maintenance and service work performed on the doomed asset.

Decibels are also another key aspect of a report. If Baseline values are set up on motors, then the Action Levels can be set up and used to determine what action should be taken next. In the case of an electrical asset, an increase or decrease in decibels will correlate with changes in the sound wave pattern seen in the sound analysis software. In the case of compressed gas leaks, the level or severity of the leak can be assigned based off of the decibels value. Valve testing can use the decibels to pinpoint to the exact location the turbulences, to determine whether the vale is working properly or not.

Module Selection is another aspect of the testing that should be documented as this shows the test were repeatable. To maintain repeatable results, the same type of module should be used when collecting the data and sound waves. Structure borne Modules and Airborne Modules will have a majorly noticeable difference in sound characteristics at different frequencies settings.

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Frequency Selection is also another factor that needs to be reported, as it shows that the test was performed constantly. A change in the frequency setting will have a direct effect on the decibels and sound waves that are captured. If the frequency is not set to the same value, it will dramatically change the decibel values and sound characteristics of the sound wave. Making it impossible for this information to be compared to like equipment or historical information from one asset.

Recommended Frequency Tuning Table		
Application	Test Conditions	
Rotating Equipment	Under 300 RPM	Over 300 RPM
	20-25 kHz	28-32 kHz
Conveyor bearings	In Atmosphere	On the housing
	40 kHz	20-25 kHz
Electrical Gear	Scanning Seams	In Atmosphere
	40 kHz	40 kHz
	Enclosed (Exterior Contact Only)	Hermetically Sealed (Exterior Contact Only)
	20-25 kHz	20-25 kHz
Vacuum & Compressed Gases	In Atmosphere	Internal
	40 kHz	20-25 kHz
Steam Traps & Valves	Internal	In Atmosphere
	20-25 kHz	40 kHz
Heat Exchangers, Condensers & Chillers	In Atmosphere	Internal
	40 kHz	20-25 kHz

Historical Data is also important in a report as it can show the increase in decibels as the asset starts to reach the different Action Levels established and its eventual end of useful life. The decibels can also be used to show the historical progression of the assets to its end of useful life. This historical data can also be used to build historical information on the normal operational range of decibels on an asset over its life span.

Temperature can indicate many different things across the test applications, so it is an important value to document in the report as well. In the case of Steam Traps, it will directly affect the efficiency of the steam traps operations and in electrical systems a rise in temperature in addition to decibels is a clear indication of a fault condition. Bearing as well will be affected by an increase in temperature as the lubrication begins to breakdown form the excessive heat.

Description of the faults sound is another item that should be described in the report, as this will help those that are not use to this sound waves, to try and hear what you are hearing as the indication when they play it back. Being able to relate the sound to something in everyday life is helpful, for example a transformer with loose widening may sound like an electric razor to some. The sound of tracking is often described as a sound similar to bacon frying. These are some of the descriptions I've heard students use to describe these fault conditions over the years.

It will also help the program as it advances with more personnel using the ultrasound device to listen in the field and start to make their determination of what is occurring. They should never make their call in the field as they will need to review the sound wave patterns and look for the known sound signatures and harmonic indications to conclusively prove what is occurring.

Sound Wave Recordings are by far the single most crucial part of any analysis or reporting. Decibels are great for trending, but sound pattern identification is of the utmost importance as it can clearly identify the fault condition occurring as each fault condition will have distinct patterns to them much like an EKG a doctor uses. Each known fault has a similar characteristic to it, when comparing to like events. The patterns can be measured by looking at the amplitude of patterns positive and negative energy overall or each individual spike can be measure Base to Peak or Peak to Peak. Some patterns will show up with more amplitude in the negative portion vs their corresponding positive portion.

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There are also application specific information that should be included in the report as well.

RPM (Rotations Per Minute) is a rotating equipment specific value to be added to the report and it is one of the key values that needs to be collected in the field, as it is part of the information that is critical for calculation of fault frequencies events. It is also important in helping to determine which frequency to test at since the higher speed RPM assets are tested at a different frequency than their slowed speed counterparts.

# of Bearings is also a rotating equipment specific key value that needs to be added to the report as it will be another critical value that help to conclusively prove the existence of Ball Pass, Inner & Outer Race, and Cage Fault in rotating equipment. The use of a Bearing Coefficient Calculator will give you both the indication in Hertz for Frequency Spectrum Analysis and Seconds for Time Signal Analysis.

Bearing Coefficient Calculator

NTN Bearings

Outer Race Coefficient	Inner Race Coefficient	Fundamental Train Freq. Coefficient	Ball Spin Freq. Coefficient	RPM	Outer Race Fault	Inner Race Fault	Cage Fault (FTF)	Ball Pass Fault (BSF)	
3.58000	5.42	0.40	2.34	1170	69.81	105.69	7.80	45.63	in Hz
					4188.6	6341	468	2738	in CPM
					0.014325	0.009462	0.128205	0.021915	Time Series Equivilent

TO USE:
Look up bearing coefficients in NTN PDF table. Enter numbers from table under corresponding fault type. Enter the RPM in column "F". Fault frequencies will show in columns "G" through "J"

Line Frequency is another critical piece of information that should be captured in the field especially when dealing with VFD's. This value can clearly be detected in motors that have the occurrence of Stray Voltage in them. This is why its import to have this information on the report to prove that Stray Voltage is occurring as this fault is all too often ignored or disbelieved as an event that cannot be detected. Stray Voltage can occur in both VFD's and other types of motors. VFD's controls usually have a menu setting that lets you see what the line frequency in and out are set too, the RPM, Internal Temperature, and Torque maybe some other items you can locate in the VFD's menu.

Pressure is directly related to the volume of a compressed gas leak or the temperature of a steam system. The documentation of this can also indicate that there could be issue further upstream from the test site if the pressure isn't at the correct level. If a Steam system isn't operating at the correct pressure it could directly be related back to the temperature which will cause the trap to either work inefficiently or not work at all.

Distance is another factor that must be taken into account when testing using the Airborne Modules and, in some case, even the contact module. This should be noted in the report to show that the decibel value may actually be higher if the inspector was able to actually be able to approach the asset being tested. This directly relates to the Inverse Distance Law.

Corrective Actions; Recommendations

It is important to set alarms values that prevent catastrophic failures, lost through put, downtime and personal injuries. Alarms should be used to determine when to lubricate, when bearing are damaged and when they are approaching catastrophic failure. For Air Leaks value can be established to determine the urgency for repair. Electrical inspection is one that actually alarms cannot be set up initially so if something is heard a sound wave should be recorded for analysis. ISO 9001:2015 10.2 Covers Corrective Actions

10.2 Nonconformity and corrective action.

The 2015 update requires that when a nonconformity occurs, including any arising from customer complaints, organizations to take the following steps:

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1. Immediate containment actions. IE: React to the nonconformity and as appropriate, take action to control and correct it and deal with the consequences.
2. Identify Root Cause / Similar products or processes consideration. IE: Evaluate the need for action to eliminate the cause(s) of the nonconformity, so that it does not recur or occur elsewhere, by: Reviewing and analyzing the nonconformity, Establishing the cause(s), Determining if any similar nonconformities exist, or could potentially occur elsewhere.
3. Implement Corrective Action to address root cause(s) and review effectiveness.
4. Update Risks and Opportunities planning and any changes to the management system as appropriate. It is also noted that corrective actions must be appropriate to the effects of the nonconformities under review and that documented information (records) must be retained as evidence of: The nature of the nonconformities, Any subsequent actions taken, and the results of corrective actions taken.

Corrective Actions; Tracking the Outcome

Tracking Corrective Action is the final step to ensuring that repairs have been made. Some CMMS software platforms can keep track of the repairs and generate reports. Manually logging them can work too but is a tedious process for reporting the results. Results can only be measured when personnel are held accountable for the corrective actions. We have all worked in or seen a plant where there are no checks and balances after finding are brought to the attention of everyone. I once performed and Air Survey for a flour mill in early 2000's and when the Maintenance Manager moved on the program died off and the equipment sat on the shelf for 7 years.

When suddenly I received a phone call from that mill asking me to come down and help their new staff out with their unit they had just found. I ran them through the equipment and took them out to the field where I noticed some air leak tags that were placed there by me seven years earlier. None of the leaks had been fixed and the values on the tags weren't lower than what we were detecting now.

If Corrective actions are not taken after documentation of a fault condition the site could experience a cataclysmic failure that cost the site increased lost production time and even loss of life. Too often site don't take credence in the information they are presented by their CBM Program and it comes back to haunt them. This is why it's not only important to set up a CBM Program but to educate everyone one at the site of the benefits and abilities of these types of technologies.

It very beneficial to educate Production, Operations and Management on the capabilities these CBM Technologies and what why they can do what they do. Whether it's a power point presentation put on by the CBM Analyst or by the vendor, or maybe a Certification Course that they sit in on to educate them on why they should believe in these technologies.

One Site I was teaching at had a guest pop into the class. I spoke about the benefits of training the Operations. Management and Production staff on the use of the technologies. The guest got up abruptly and left the room without saying a thing. I asked the students from that site who that was, and they told me it was their VP of Global Operations. Moments later the sites Maintenance Manager knocked on the window and asked me to step out really quick to talk to him.

My gut was churning like crazy thinking back on whether I had said something discouraging about management and couldn't think of anything. When I stepped out, he apologized for interrupting and asked me who my supervisor was! I gave him his contact information and asked him if I was in trouble or had done something wrong. He respond "Not at all! In Fact, you just opened his eyes to what Ultrasound can do and he wants to roll it out to all of our sites Worldwide!"

This was due to the fact this site had not only been trending their bearings but also documenting and calculating their loss of compressed air. They had made so many corrective actions that they went from running 5 compressor and looking into installing a 6th one to operating just 1 ¼ compressors. This was achieved by fixing the hundreds of leaks they had and installing manual shut off valves to their stitchers which use to constantly be left blowing air from the thousands of nozzle when nothing was being produced.

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ASU CAT 2 Module 2-10 Personal Safety

When it comes to safety there are many different sayings, Safety First, Safety Always, Everyone Goes Home, Safety is No Accident, Take 5 and Stay Alive and Safety is our No 1 Priority are some of the most popular. They all lead back to key aspect, you! You have the final say on what you are doing when using ultrasound to inspect equipment. If you take 5 minutes to huddle up and size up the scope of work, you are about to perform it can help you to get into the mindset of what steps you need to take to ensure that you perform the inspection safely!

Just Because You Can, Doesn't Mean You Should!

Be safe—never make contact on energized equipment with an ultrasound device.

By Drew Walts
Training Manager, IRISS Inc.

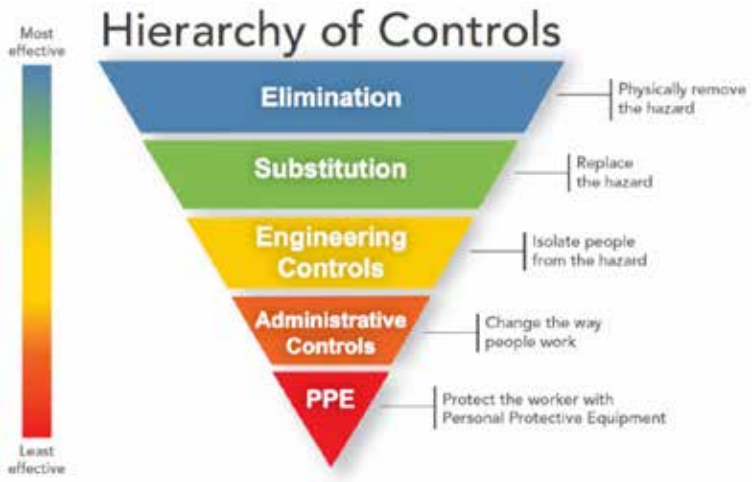
This blog post was contributed by IRISS Inc., a global provider of electrical and mechanical asset management solutions that increase safety and reliability, decrease costs, eliminate human error, and prevent injuries and fatalities in the inspection and maintenance process.

Growing up working for my father's construction company, I'd often hear him say that "just because you can, doesn't mean you should!"

This was usually dad's go-to statement when talking to one of his guys on the jobsite when they did something unsafe or risky. Today, this adage seems even more relevant when it comes to electrical inspections with ultrasound devices. Just because you have a contact module in your kit, doesn't mean you should use it to contact energized gear when you hear something with your airborne module from the seam, vented opening, or ultrasound port!

Hierarchy of Controls

If we look to the Hierarchy of Controls from NFPA 70E, the first step is the **Elimination** of the hazard by de-energization of the equipment. However, Condition Based Maintenance (CBM) inspections like ultrasound require the equipment to be energized, so elimination isn't possible.



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Safety by Design

The second stage is **Substitution**, or what we at IRISS refer to as "Safety by Design." Can we redesign the work task and/or the equipment in such a way as to eliminate the hazard without introducing any other new hazards? The use of infrared windows and ultrasound ports is the best method for Substitution of the hazard since infrared and ultrasound have become a go-to test method for the detection of electrical fault conditions of closed panel energized assets.

Without the substitution—Safety by Design—devices in place, it can be next to impossible to test using infrared cameras or ultrasound devices. With the enclosure panels in place the inspector may still be able to use an airborne module and trace the seams or air vents to listen for ultrasound anomalies. Remember that most electrical equipment should have no discernible noise emanating in the ultrasound spectrum. In addition, the challenge with this "scanning the seam" method is that diffraction of the signal can cause issues with the signal's amplitude being increased as it bounces out of the seam and increases the decibels. Decibels should never be used as a trendable value for determining required intervention action on electrical assets. The CBM Analyst should capture a sound wave of the anomaly so it can be analyzed in a Spectrum Analysis Software Platform. Sound wave analysis of the anomaly is the only way to truly determine what fault condition is present in the equipment.

When an ultrasound anomaly is detected around the seams or vent of the asset, it should be tested further. However, without having IR windows or ultrasound ports there is no way to safely perform these tests while energized. So, the gear will need to be de-energized and then opened to look for visual indications of corona, treeing or tracking or arcing. Once these visual indications are found, corrective action can be determined which may include cleaning, component replacement, tightening or re-cabling.

The "Last Resort" Requires More Training, More Planning, More Knowledge

The inspector should almost never perform an open panel energized inspection using ultrasound devices or infrared cameras, as this would be deemed a last resort per the Hierarchy of Controls. If this is deemed the ONLY way to perform the work, then there are several requirements that must be in place first:

- Personnel must have the appropriate training
- A job safety plan must have been created (including planning for human error)
- Proper PPE should be worn
- Proper boundaries should be put up to isolate the test area of non-essential personnel

If the equipment's arc flash rating has been gauged to be one that PPE can be worn to perform energized open inspections, there are still a few things that will need to be heeded:

- The CBM Analyst should never wear the headphones for their ultrasound device under the hood of the Arc Flash Suit. The analyst must hold the headphones of to the side by their ear on the exterior of the suit.
- Even when wearing PPE, they should also never break the plane of the opening of the gear. Restricted approach boundaries as defined in the NFPA 70E tables [130.4(D)] should always be maintained.
- They should **never** use the contact module or even rubber / plastic focusing probes or long-range horns to touch energized equipment to locate or listen to the anomaly. It only takes one time for it to be your last time ever.

So, a CBM Analyst should only very rarely open gear while it is still energized to perform an airborne ultrasound inspection. It has been brought to our attention that there are instances where a CBM Technician has swapped out their airborne module and used their contact module to make physical contact with open energized gear. To reiterate: **this is unsafe and should never happen under any circumstances**.

We at IRISS cannot stress the importance of safety for electrical personnel enough. We created IR windows and ultrasound ports to help protect those doing electrical inspection by minimizing the risk of this CBM data collection task. Being able to see the equipment with your eyes and with an IR camera affords you a safer view of what's occurring inside. Ultrasound ports give you

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the best sound quality of any possible electrical anomaly without the effects of antagonistic ultrasound, diffraction of signal or inability to achieve the critical angle of the anomaly.

Things to Never do With Your Ultrasound Device

Never make contact with energized equipment!
Never Break the Plain of the cabinet!
Never get inside the range of the current potential to jump!
Never make contact with rotating equipment!
Never a contact probe into a hole!
Never reach out to find external steam leaks!
Never wear the headphones if wearing an arc flash suit!
Never step over rotating equipment!
Never use an ultrasound device while on a ladder!

It's sad that we have to list these things as what not to do but, these things have happened in the past by people not stopping to think about what they were about to do. Complacency Kills!

The use of a contact module for ultrasound is a great tool for finding fault conditions in all types of assets. Sometimes it may be difficult to pinpoint the exact location of the sound with and the temptation to try testing an asset while ignoring the rules of safety my push some to try it anyways. This complacency can be fatal! The CBM Analyst should again never break the plain of energized electrical gear or make contact on energized equipment with a contact module. The Analyst should also avoid sticking the contact module into any hole that looks big enough to slide the contact probe into as you never know what's on the other side. The Analyst should also never operate an ultrasound device while working on a ladder. It becomes impossible to capture data or adjust the unit while standing on a ladder since you can no longer maintain 3 points of contact.

When it comes to ultrasound testing of rotating equipment, the inspector will need to very cautious not to stick the contact probe into any rotating equipment. The adage I like to use is "If you can't see in the hole, Don't stick it into the hole!". This applies to the fan shroud of a motor, the shaft guard, fan housing and even electrical gear. It might seem pretty ridiculous, but these things have happened.

I was working out in the field with one group of students, when from 30 feet away I heard a loud banging sound and turned around to see a student standing on the concert pedestal that had a large motor affixed to it. He was lean over looking at something in the fan shroud that was dancing around. As I went over, I watched as the student pulled the contact module from the fan shroud. He held it up and the module was now bent. I asked the student why he stuck the contact module in the hole where the zerk fitting would normally go? His response is one that still goes down in my book of what were you thinking.

He said," Well the sound was loudest nearest to the hole so, I moved the contact module to the edge of the hole, and it got even louder. So, I thought I would stick the contact module into the hole to get a bead on where the sound was coming from. Then all of the sudden the module was ripped out of the front of the unit and I reached down to pull it out. I don't know what I was thinking, and you warned us not to stick it in the hole if we couldn't see in the hole. I'm sorry!"

We have all seen this firsthand or through fail videos online. Sometimes we as human being simply forget what we are doing or worse we are complacent with our surroundings and this can lead to serious injuries, unscheduled downtime and worse death.

Safety is a Top Priority

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Most organizations say safety is top priority with catchy phrases. These phrase are meant to instill the mindset of safety into their staff with an easy to remember catchy phrase. Some companies are better at ensuring that these catchy phrase are adhered too and its part of the everyday policies and procedures, while other just give lip service.

These later sites usually do not see the benefit of safety on their site as it could interfere with throughput efficiency of the sites production. Other times its sear complacency that safety policies and procedures are not followed. One site that I was working with had sat through my training and we were stepping out into the field for some hands-on training. We had just completed the section on electrical inspection and discussed in-depth PPE and the benefit of ultrasound electrical assets while the gear was closed.

As we were walking out to an electrical room of interest, we noticed 2 workers up on the flood wall where the 4160 gear was installed. The workers were wearing short sleeve polo shirts jeans and sunglasses and we were aghast when we watched them open the door while standing directly in front of the opening. The Supervisor in my class immediately yelled up to them asking what in the heck they were doing, and the response was that they were just looking inside and wouldn't be performing any work on the 4160. He then proceed to yell at them to close the door and read the Arc Flash sticker out loud and tell him what was being done wrong. Now this event just shows that even with specific training, phrases and training. Complacency is still a threat to any program.

Reliability is Safety

Reliability can be engineered into electrical assets for personnel safety, repeatable test locations, and more frequent inspection with Ultrasound Ports and Infrared Windows but, that can't take the Human Factor out of the equitation. We can only look to eliminate the Physical Hazard of doing electrical inspection. The use of these Electrical Maintenance Safety Devices serves as a substitution of the current methods for ultrasound and infrared inspections.

This will also serve as an Engineering Control which isolates the personnel from the physical hazard of performing open panel electrical inspections. With this in place it will then add another layer of the Hierarchy of Controls as an administrative control which changes the way personnel work. The last layer to be addressed is to readdress the level of PPE needed when using these EMSD's. Since the personnel will no longer need to open the assets to inspect them, they could wear a minimal level of PPE similar to that of just walking through that area. This is the best safety method when it comes to electrical inspection.

The facts don't lie! A study by Andrew Fraser of Reliable Manufacturing on behalf of DuPont found that the most likely personnel to be injured were likely to be a Maintenance Technician with less than 2 years' experience doing reactive work. Joel Levitt wrote an article in Uptime Magazine that was based off information gathered from Exxon-Mobil in which they found that personnel were 5 times more likely to be involved in an accident during breakdown maintenance versus that of performing scheduled maintenance activities.

A plant in Baytown Texas just had a catastrophic failure that at the time of writing this material was still under investigation. It was widely reported that there were 19 reportable events in 2019 with 2 unexpected shutdowns.

In an article in the Houston Chronicle written by Julian Gill on 08/01/2019 about an explosion at a plant one of the employees injured lawyer was quoted as saying. "All refinery accidents are preventable, and it's important for the workers and the community to find out what could have prevented this disaster. "Attorney Kyle Findley

- Rohm & Haas reported you're 7-17 times more likely to introduce **defects during startup** than normal operation
- BP reported that **incidents** are 10 times more likely **during startup**
- The chemical industry reported process **safety incidents** are 5 times more likely **during startup**
- 56% of forced outages in power stations occur < 1 week **after a maintenance shutdown**
- 92% of rotating machinery has **defects at startup** that result in premature failure

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Foundation - When it comes to safety, Reliability is the cornerstone of the foundation of Safety! The foundation needs to be completed by providing training in the CBM Technologies, Skills, Safety and other important company specific orientations. Training will help to introduce the company's values and mission. This helps to ensure that Safety and Reliability go hand in hand.

Preparation - Should involve training from the vendor on the technologies they will use for their CBM Program and it should be done at their site so the personnel are trained on their own assets that they will be monitoring. This can also help them to establish baseline values of their assets. It will also let them see what hazards they may have to overcome when trying to collect their data. This will also highlight what PPE maybe required while operating in different areas of the site.

Execution - When it comes to execution of the data collection the CBM Technician and Analyst should take 5 minutes for a safety huddle as they go about their route collection. They will also need to keep their heads on a swivel to ensure they are watching out for moving equipment and atmospheric conditions as well as other safety related issue that can cause an accident while operating with headphones on. They should also never operate an ultrasound device without maintaining 3 points of contact at all times.

Results – The Drive to Zero is achievable with the building of the foundation of the company's values. By taking time to then look over all of the risk factors of each task the site can ensure they are properly prepared to perform the work safely! This will help to ensure that all preplanning for the requirements of the task at hand are made and will be utilized for the safe collection of data. This will also ensure that the risk of cataclysmic failure is all but eliminated from the site's operations.

Just like Safety, Reliability is everyone's responsibility and the facts show this. It's time to change the mindset site wide and get everyone spun up on its benefits to everyone. Since Reliability is Safety!

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Avoid Opening Electrical Cabinets

It is also important to understand that the test procedures defined in IEEE C37.20.7 are performed with the ultrasound ports and IR windows in a closed position. When the switchgear “passes the test,” it does not matter if the optic material was damaged or even disintegrated, as long as the heated gas from inside the cabinet does not ignite a flag placed outside the cabinet.

Therefore, any implied protection for a thermographer while using the window in an open position is not only questionable; it is a total misrepresentation of the test. Why Use IR Windows? IR windows are intended to remove the risk of triggering an arc flash incident during a thermographic inspection.

That being said, the windows should also offer the same level of structural integrity that UL746 requires of other common meters and controls, and the same integrity that IEEE C37.20.2 requires for impact and load of “viewing panes.” However, any claims by any manufacturer to have an arc resistant IR window are misleading and negligent since there simply is no test which offers a component level rating.

NFPA 70E lists removal of panels on electrical equipment as one of the riskiest activities that a worker can perform on that piece of equipment. The risk is elevated because the most common arc triggers occur either because the panel covers are open or as a result of removing the panel covers.

Closed-panel inspection using ultrasound ports & infrared windows will eliminate 99.9% of arc flash triggers during inspection. Therefore, the core benefit of IR windows is that they comply with the OSHA and NFPA 70E focus on removing the risk of an accident - protection with PPE is only used as a last resort, and the implementation of engineered controls is only used where risk elimination and substitution are not feasible.

Ultrasound Ports and Infrared windows are intended to allow safer, more efficient access to the ultrasound readings & thermographic data which recommended in NFPA 70B: They even state “Dependability can be engineered and built into equipment, but effective maintenance is required to keep it dependable.”
Experience shows that equipment lasts longer and performs better when covered by an EPM (Electrical Preventative Maintenance) program.

Ultrasound & Infrared inspections of electrical systems are beneficial to reduce the number of costly and catastrophic equipment failures and unscheduled plant shutdowns. Routine ultrasound & infrared inspections of energized electrical systems should be performed annually prior to shut down.

More frequent ultrasound & infrared inspections could be done quarterly or semiannually, They should be performed where warranted by loss experience, installation of new electrical equipment, or changes in environmental, operational, or load conditions. Ultrasound and Infrared surveys should be performed during periods of maximum possible loading but not less than 40 percent of rated load of the electrical equipment being inspected.

The Anatomy of an Arc Flash An arc flash occurs when a phase-to-phase or phase-to-ground fault causes a short circuit through the air. The core of the arc flash can reach temperatures of up to 38,000°F (21093°C); at this high temperature copper turns to a plasma state instantaneously and expands 67,000 times its original volume in a fraction of a second. The heat and resulting

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expansion cause a pressure wave that carries thousands of pounds of force, a blinding flash of light and molten shrapnel.

Ultrasound ports and Infrared windows are not intended to protect a user from an arc flash - they are intended to eliminate additional triggers of an arc flash during an inspection and replace a high-risk activity with a risk reduction/elimination strategy during inspection.

Ultrasound Ports and IR windows maintain the closed-panel inspections which helps companies to comply with the OSHA and NFPA mandates to eliminate risk wherever possible. Conversely, a protection strategy is acceptable only after other methods of risk elimination or reduction have been exhausted.

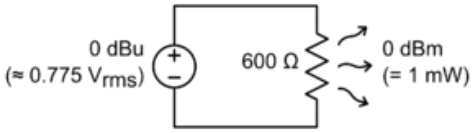
Arc rated switchgear and MCCs enlist a variety of safety mechanisms such as additional barriers and pressure relief mechanisms. These safety features redirect the forces and heat of an arc flash away from the panel doors and up through a series of **plenums** that **systematically** reduce the forces of the blast and minimize any damage that might have otherwise occurred had the blast escaped the confines of the system.

Any IR window, visual viewing pane, or panel meter that happened to be in place during this test would not have been responsible for the arc-resistance of the system but would merely be shown to not interfere with any safety mechanisms which were in place to redirect the blast. Just as the bolts holding the panel in place are not universally arc-resistant, they were simply the proper strength to hold the panel in place on that specific model of switchgear.

Appendix A

Voltage

Since the decibel is defined with respect to power, not amplitude, conversions of voltage ratios to decibels must square the amplitude, or use the factor of 20 instead of 10, as discussed above.



A schematic showing the relationship between dBu (the voltage source) and dBm (the power dissipated as heat by the 600 Ω resistor)

dBV = dB(V_{RMS}) – voltage relative to 1 volt, regardless of impedance.[1] This is used to measure microphone sensitivity, and also to specify the consumer line-level of −10 dBV, in order to reduce manufacturing costs relative to equipment using a +4 dBu line-level signal.
dBu or dBv = In professional audio, equipment may be calibrated to indicate a “0” on the VU meters some finite time after a signal has been applied at an amplitude of +4 dBu. Consumer equipment typically uses a lower “nominal” signal level of −10 dBV.[43] Therefore, many devices offer dual voltage operation (with different gain or “trim” settings) for interoperability reasons. A switch or adjustment that covers at least the range between +4 dBu and −10 dBV is common in professional equipment.
dBu0s = Defined by Recommendation ITU-R V.574. (See Appendix B)
dBm0s = Defined by Recommendation ITU-R V.574.; dBmV: dB(mV_{RMS}) – voltage relative to 1 millivolt across 75 Ω.[44] Widely used in cable television networks, where the nominal strength of a single TV signal at the receiver terminals is about 0 dBmV. Cable TV uses 75 Ω coaxial cable, so 0 dBmV corresponds to −78.75 dBW (−48.75 dBm) or approximately 13 nW.
dBμV or dBuV = dB(μV_{RMS}) – voltage relative to 1 microvolt. Widely used in television and aerial amplifier specifications. 60 dBμV = 0 dBmV.

Acoustics

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Probably the most common usage of “decibels” in reference to sound level is dB SPL, sound pressure level referenced to the nominal threshold of human hearing: The measures of pressure (a field quantity) use the factor of 20, and the measures of power (e.g. dB SIL and dB SWL) use the factor of 10.

dB SPL = dB SPL (sound pressure level) – for sound in air and other gases, relative to 20 micropascals (μPa) = 2×10^{-5} Pa, approximately the quietest sound a human can hear. For sound in water and other liquids, a reference pressure of 1 μPa is used. An RMS sound pressure of one pascal corresponds to a level of 94 dB SPL.
dB SIL = dB sound intensity level – relative to 10^{-12} W/m^2, which is roughly the threshold of human hearing in air.
dB SWL = dB sound power level – relative to 10^{-12} W.
dBA, dBB, and dBC = These symbols are often used to denote the use of different weighting filters, used to approximate the human ear’s response to sound, although the measurement is still in dB (SPL). These measurements usually refer to noise and its effects on humans and other animals, and they are widely used in industry while discussing noise control issues, regulations and environmental standards. Other variations that may be seen are dBA or dB(A). According to ANSI standards, the preferred usage is to write L_A = x dB. Nevertheless, the unit’s dBA and dB(A) are still commonly used as a shorthand for A-weighted measurements. Compare dBc, used in telecommunications.
dB HL = dB hearing level is used in audiograms as a measure of hearing loss. The reference level varies with frequency according to a minimum audibility curve as defined in ANSI and other standards, such that the resulting audiogram shows deviation from what is regarded as ‘normal’ hearing.
dB Q = sometimes used to denote weighted noise level, commonly using the ITU-R 468 noise weighting.
dBpp = relative to the peak to peak sound pressure.
dBG = G-weighted spectrum.

Audio Electronics

See also **dBV** and **dBu** above.

dBm = dB(mW) – power relative to 1 milliwatt. In audio and telephony, dBm is typically referenced relative to a 600-ohm impedance, which corresponds to a voltage level of 0.775 volts or 775 millivolts.
dBFS = dB(full scale) – the amplitude of a signal compared with the maximum which a device can handle before clipping occurs. Full-scale may be defined as the power level of a full-scale sinusoid or alternatively a full-scale square wave. A signal measured with reference to a full-scale sine-wave appears 3 dB weaker when referenced to a full-scale square wave, thus: 0 dBFS (fullscale sine wave) = −3 dBFS (fullscale square wave).
dBVU = dB volume unit.
dBTP = dB(true peak) – peak amplitude of a signal compared with the maximum which a device can handle before clipping occurs. In digital systems, 0 dBTP would equal the highest level (number) the processor is capable of representing. Measured values are always negative or zero, since they are less than or equal to full-scale.
dBm0 = Power in dBm measured at a zero-transmission level point.

Radar

dBZ = dB(Z) – decibel relative to Z = 1 mm^6·m^{-3}: energy of reflectivity (weather radar), related to the amount of transmitted power returned to the radar receiver. Values above 15–20 dBZ usually indicate falling precipitation.
dBsm = dB(m^2) – decibel relative to one square meter: measure of the radar cross section (RCS) of a target. The power reflected by the target is proportional to its RCS. “Stealth” aircraft and insects have negative RCS measured in dBsm, large flat plates or non-stealthy aircraft have positive values.[55]

Radio Power, Energy, and Field Strength

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dBc = relative to carrier – in telecommunications, this indicates the relative levels of noise or sideband power, compared with the carrier power. Compare dBC, used in acoustics.
dBpp = relative to the maximum value of the peak power.
dBJ = energy relative to 1 joule. 1 joule = 1 watt second = 1 watt per hertz, so power spectral density can be expressed in dBJ.
dBm = dB(mW) – power relative to 1 milliwatt. In the radio field, dBm is usually referenced to a 50-ohm load, with the resultant voltage being 0.224 volts.
dBμV/m, dBuV/m, or dBμ = dB(μV/m) – electric field strength relative to 1 microvolt per meter. The unit is often used to specify the signal strength of a television broadcast at a receiving site (the signal measured at the antenna output is reported in dBμV).
dBf = dB(fW) – power relative to 1 femtowatt.
dBW = dB(W) – power relative to 1 watt.
dBk = dB(kW) – power relative to 1 kilowatt.
dBe = dB electrical.
dBo = dB optical. A change of 1 dBo in optical power can result in a change of up to 2 dBe in electrical signal power in system that is thermal noise limited.

Antenna Measurements

dBi = dB(isotropic) – the forward gain of an antenna compared with the hypothetical isotropic antenna, which uniformly distributes energy in all directions. Linear polarization of the EM field is assumed unless noted otherwise.
dBd = dB(dipole) – the forward gain of an antenna compared with a half-wave dipole antenna. 0 dBd = 2.15 dBi.
dBiC = dB(isotropic circular) – the forward gain of an antenna compared to a circularly polarized isotropic antenna. There is no fixed conversion rule between dBiC and dBi, as it depends on the receiving antenna and the field polarization.
dBq = dB(quarterwave) – the forward gain of an antenna compared to a quarter wavelength whip. Rarely used, except in some marketing material. 0 dBq = −0.85 dBi
dBsm = dB(m^2) – decibel relative to one square meter: measure of the antenna effective area.
dBm−1 = dB(m^{-1}) – decibel relative to reciprocal of meter: measure of the antenna factor.

Other Measurements

dB-Hz = dB (Hz) – bandwidth relative to one hertz. E.g., 20 dB-Hz corresponds to a bandwidth of 100 Hz. Commonly used in link budget calculations. Also used in carrier-to-noise-density ratio (not to be confused with carrier-to-noise ratio, in dB).
dBov or dBO = dB (overload) – the amplitude of a signal (usually audio) compared with the maximum which a device can handle before clipping occurs. Similar to dBFS, but also applicable to analog systems. According to ITU-T Rec. G.100.1 the Level in dBov of a digital system is defined as:

$$L_{\mathrm{ov}} = 10 \log_{10} \left(\frac{P}{P_0} \right) \ [\mathrm{dBov}],$$

with the maximum signal P_0 owner, for a rectangular signal with the maximum amplitude x_{over}. The level of a tone with a digital amplitude (peak value) of x_{over} is therefore $L = -3.01\ \mathrm{dBov}$.

dBr = dB(relative) – simply a relative difference from something else, which is made apparent in context. The difference of a filter's response to nominal levels, for instance.
dBrn = dB above reference noise. See also **dBrnC**
dBrnC = **dBrnC** represents an audio level measurement, typically in a telephone circuit, relative to the circuit noise level, with the measurement of this level frequency-weighted by a standard C-message weighting filter. The C-message weighting filter was chiefly used in North America. The Psophometric filter is used for this purpose on international circuits. See Psophometric weighting to see a comparison of frequency response curves for the C-message weighting and Psophometric weighting filters.

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dBK = dB(K) – decibels relative to 1 K: Used to express noise temperature.
dB/K = dB(K^{-1}) – decibels relative to 1 K^{-1}.—not decibels per kelvin: Used for the G/T factor, a figure of merit utilized in satellite communications, relating the antenna gain G to the receiver system noise equivalent temperature T.

List of Suffixes in Alphabetical Order

Unpunctuated Suffixes

dBA = see dB(A).
dBB = see dB(B).
dBc = relative to carrier – in telecommunications, this indicates the relative levels of noise or sideband power, compared with the carrier power.
dBC = see dB(C).
dBd = dB(dipole) – the forward gain of an antenna compared with a half-wave dipole antenna. 0 dBd = 2.15 dBi.
dBe = dB electrical.
dBf = dB(fW) – power relative to 1 femtowatt.
dBFS = dB(full scale) – the amplitude of a signal compared with the maximum which a device can handle before clipping occurs. Full-scale may be defined as the power level of a full-scale sinusoid or alternatively a full-scale square wave. A signal measured with reference to a full-scale sine-wave appears 3 dB weaker when referenced to a full-scale square wave, thus: 0 dBFS (fullscale sine wave) = −3 dBFS (fullscale square wave).
dBG = G-weighted spectrum.
dBi = dB(isotropic) – the forward gain of an antenna compared with the hypothetical isotropic antenna, which uniformly distributes energy in all directions. Linear polarization of the EM field is assumed unless noted otherwise.
dBiC = dB(isotropic circular) – the forward gain of an antenna compared to a circularly polarized isotropic antenna. There is no fixed conversion rule between dBiC and dBi, as it depends on the receiving antenna and the field polarization.
dBJ = energy relative to 1 joule. 1 joule = 1 watt second = 1 watt per hertz, so power spectral density can be expressed in dBJ.
dBk = dB(kW) – power relative to 1 kilowatt.
dBK = dB(K) – decibels relative to kelvin: Used to express noise temperature.
dBm = dB(mW) – power relative to 1 milliwatt.
dBm0 = Power in dBm measured at a zero-transmission level point.
dBm0s = Defined by Recommendation ITU-R V.574.
dBmV = dB(mV_{RMS}) – voltage relative to 1 millivolt across 75 Ω.
dBo = dB optical. A change of 1 dBo in optical power can result in a change of up to 2 dBe in electrical signal power in system that is thermal noise limited.
dBO = see dBov
dBov or dBO = dB(overload) – the amplitude of a signal (usually audio) compared with the maximum which a device can handle before clipping occurs.
dBpp = relative to the peak to peak sound pressure.
dBpp = relative to the maximum value of the peak power.
dBq = dB(quarterwave) – the forward gain of an antenna compared to a quarter wavelength whip. Rarely used, except in some marketing material. 0 dBq = −0.85 dBi.
dBr = dB(relative) – simply a relative difference from something else, which is made apparent in context. The difference of a filter's response to nominal levels, for instance.
dBrn = dB above reference noise. See also **dBrnC**.
dBrnC = **dBrnC** represents an audio level measurement, typically in a telephone circuit, relative to the circuit noise level, with the measurement of this level frequency-weighted by a standard C-message weighting filter. The C-message weighting filter was chiefly used in North America.
dBsm = dB(m^2) – decibel relative to one square meter.
dBTP = dB(true peak) – peak amplitude of a signal compared with the maximum which a device can handle before clipping occurs.

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dBu or dBv = RMS voltage relative to.
dBuV = see dBµV.
dBuV/m = see dBµV/m.
dBv = see dBu.
dBV = dB(V_{RMS}) – voltage relative to 1 volt, regardless of impedance.
dBVU = dB volume unit.
dBW = dB(W) – power relative to 1 watt.
dBZ = dB(Z) – decibel relative to Z = 1 $mm^6 \cdot m^{-3}$
dBµ = see dBµV/m.
dBµV or dBuV = dB(μV_{RMS}) – voltage relative to 1 microvolt.
dBµV/m, dBuV/m, or dBµ = dB(µV/m) – electric field strength relative to 1 microvolt per meter.

Suffixes Preceded by a Space

dB HL = dB hearing level is used in audiograms as a measure of hearing loss.
dB Q = sometimes used to denote weighted noise level.
dB SIL = dB sound intensity level – relative to 10^{-12} W/m^2
dB SPL = dB SPL (sound pressure level) – for sound in air and other gases, relative to 20 µPa in air or 1 µPa in water
dB SWL = dB sound power level – relative to 10^{-12} W.

Suffixes Within Parentheses

dB(A), dB(B), and dB(C) = These symbols are often used to denote the use of different weighting filters, used to approximate the human ear's response to sound, although the measurement is still in dB (SPL). These measurements usually refer to noise and its effects on humans and other animals, and they are widely used in industry while discussing noise control issues, regulations and environmental standards. Other variations that may be seen are dB_A or dBA.

Other Suffixes

dB-Hz = dB (Hz) – bandwidth relative to one hertz.
dB/K = dB (K^{-1}) – decibels relative to reciprocal of kelvin.
dBm^{-1} = dB (m^{-1}) – decibel relative to reciprocal of meter: measure of the antenna factor.

Appendix B

Rec. ITU-R V.574-4 1
RECOMMENDATION ITU-R V.574-4
USE OF THE DECIBEL AND THE NEPER IN TELECOMMUNICATIONS*, **, ***

(1978-1982-1986-1990-2000)
Rec. ITU-R V.574-4

Scope

This text recommends the symbols to be used for the logarithmic expression of quantities referring to power and provides examples of the use as well as the relationship between the decibel and the neper.

The ITU Radiocommunication Assembly,

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considering

a. the frequent use by the ITU of the decibel and the neper for expressing quantities;
b. the International Standard IEC 60027-3 of the International Electrotechnical Committee; 1989 on “logarithmic quantities and units”;
c. International Standard ISO 31 of the International Standards Organization on quantities and units;
d. the convenience of using only one unit to express in logarithmic form the numerical values of international specifications and the results of measurements in exchanges at international level;
e. the use in radiocommunications of the decibel alone to express the results of measurements in logarithmic form,

recommends

1 that symbols used for the logarithmic expression of quantities that directly or indirectly refer to power should be chosen with the guidance of Annex 1.

Annex 1

Use of the decibel and the neper

1 Definition of The Decibel

1.1 The bel (symbol B) expresses the ratio of two powers by the decimal logarithm of this ratio. This unit is not often used, having been replaced by the decibel (symbol dB) which is one-tenth of a bel.
1.2 The decibel also may be used to express the ratio of two field quantities, such as voltage, current, sound pressure, electric field, charge velocity or density, the square of which in linear systems is proportional to power. To obtain the same numerical value as a power ratio, the logarithm of the field quantity ratio is multiplied by the factor 20, assuming that the impedances are equal.

The relationship between a current or voltage ratio and that of the corresponding power ratio is impedance dependent. Use of the decibel when the impedances are not equal is not appropriate unless adequate information is given concerning the impedances involved.

For example, if P1 and P2 are two powers, their ratio expressed in decibels is:

10 lg (P1 / P2)

_____

* The Director, BR, is requested to bring this Recommendation to the attention of the ITU-T.
** In this Recommendation, the notation lg is used for the decimal logarithm in accordance with International Standards ISO 31-11 and IEC 60027-3. The notation log10 is also used. The notation log can be used if there is no ambiguity.
*** This Recommendation was updated in 2005 for editorial reasons only.

2
If P1 and P2 represent the powers dissipated by currents I1 and I2 in resistances R1 and R2:

$$10 \lg \frac{P_1}{P_2} = 10 \lg \frac{I_1^2 R_1}{I_2^2 R_2} = 20 \lg \frac{I_1}{I_2} + 10 \lg \frac{R_1}{R_2}$$

1.3 The decibel may be used to express the ratio of two values of a quantity connected with power by a well-defined relationship.

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In this case, the logarithm of this ratio must be multiplied by a factor representing the relationship which connects the quantity with a power, and a term representing a multiplying factor may be added to it.

If the ratio of two powers P1 and P2 depends on the ratio of values X1 and X2 of another quantity X by a relationship of the form P1/P2 = (X1/X2) α, α being any real number, we can express it in decibels as:

$$10 \lg (P_1/P_2) = 10 \alpha \lg (X_1/X_2) \quad \text{dB}$$

2 Definition of the neper

The neper (symbol Np) expresses the ratio of two field quantities such as voltage or current, the square of which is proportional to power by the natural logarithm of this ratio. The value of a power ratio in nepers is one-half of the natural logarithm of the power ratio. The values in nepers of the ratio of two field quantities and of the corresponding powers are equal only if the impedances are equal.

One neper corresponds to the value of e of a field quantity ratio and to the value e2 of a power quantity ratio.

Sub-multiples such as the decineper (dNp) are also used.

In some disciplines, nepers may be used to express the logarithm of a power ratio without the factor 1/2. An example is optical depth or attenuation in radiometry. Such usage is prohibited in telecommunications in order to prevent ambiguity. Under this definition, the neper would in fact be equal to 4.34 dB, instead of 8.68 dB as is traditionally the case.

3 Use of The Decibel and Neper

Countries can continue to use either the neper or the decibel for measurement purposes within their own territory and, to avoid conversion of values, countries which prefer to do so may continue to use the neper between themselves by bilateral agreement.

For the international exchange of information concerning transmission measurement and related values and for the international specification of limits for such values, the only logarithmic expression to be used is the decibel. However, it is possible to use the neper for bilateral agreements.

For theoretical or scientific calculations, where ratios are expressed in terms of Napierian logarithms, the neper will always be used, implicitly or explicitly.

As a result of some calculations on complex quantities, a real part in nepers and an imaginary part in radians are obtained. Factors may be applied for converting to decibels or degrees.

The conversion values between the neper and the decibel are as follows:
1 Np = (20 lg e) dB ≈ 8.686 dB
1 dB = (0.05 ln 10) Np ≈ 0.1151 Np
4 Rules for the use of the symbols where dB is included

Concerning the symbols that include the symbol dB, the following rules should be used as far as possible:

4.1 The Symbol dB Without Additional Indication

The symbol dB without additional indication should be used to indicate a ratio of two powers, two power densities, two other quantities clearly connected with power or the difference between two power levels (see § 6).

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The symbol dB followed by additional information within parenthesis

The symbol dB followed by additional information within parenthesis should be used to express an absolute level of power, power flux-density or any other quantity clearly connected with power, in relation to a reference value within the parenthesis. In some cases, however, common use may give rise to simplified symbols, such as dBm instead of dB(mW).

4.3 The Symbol dB Followed by Additional Information Without Parenthesis

The symbol dB followed by additional information without parenthesis should be used to express by convention, special conditions such as measurements through specified filters or at a specified point of a circuit (see § 8).

5 Loss and Gain

The attenuation or loss is a decrease between two points of an electric, electromagnetic or acoustic power. The attenuation is also the quantitative expression of a power decrease expressed by the ratio of the values at two points of a power or of a quantity related to power in a well-defined manner. This ratio is generally expressed in decibels.

The gain is the increase between two points of an electric, electromagnetic or acoustic power. The gain is also the quantitative expression of a power increase expressed by the ratio of the values at two points of a power or of a quantity related to power in a well-defined manner. This ratio is generally expressed in decibels.

The exact designation of the loss or gain in question must be given (e.g. image-attenuation coefficient, insertion loss, antenna gain) which in fact refers to the precise definitions of the ratio in question (terminal impedances, reference conditions, etc.).

5.1 Transmission Loss

The ratio, expressed in decibels, of the transmitted power (Pt) to the received power (Pr):
L = 10 lg (Pt/Pr) dB

5.2 Antenna Gain

The ratio, usually expressed in decibels of the power required at the input of a loss free reference antenna (P0) to the power supplied to the input of the given antenna (Pa) to produce, in a given direction, the same field strength or the same power flux-density at the same distance in a given direction (when not specified otherwise in the direction of maximum radiation).

G = 10 lg (P0 / Pa) dB

The reference antenna is usually an isotropic antenna, a half-wave dipole, or, in certain cases, a short vertical antenna.

6 Levels

In many cases, the comparison of a quantity, here called x, with a specified reference quantity of the same kind (and dimension), xref is expressed by the logarithm of the ratio x/xref. This logarithmic expression is often called “the level of x (with respect to xref)” or “the x-level (with respect to xref)”. With the general letter symbol for level L, the level of the quantity x may be written Lx.

Other names and other symbols exist and can be used. x may in itself be a single quantity, e.g. power P, or a ratio, e.g. P / A, where A is area, xref is here supposed to have a fixed value, e.g. 1 mW, 1 W, 1 µW/m2, 20 µPa, 1 µV/m.

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The level representing the quantity x with reference quantity xref may be indicated by the quantity symbol: Lx (with respect to xref), and may be expressed in decibels, when the reference quantity is a power, or a quantity linked to power, in a well-defined way.

Example:

The statement that the level of a certain power, P, is 15 dB above the level corresponding to 1 W can be written:

LP (with respect to 1 W) = 15 dB, which means 10 lg (P / P0) = 15, with P0 = 1 W, or 10 lg P (W) = 15 In

many cases it is found practical to use a condensed notation based only on the unit, which in this case would be:

L P = 15 dB (1 W)

The number “1” in the expression of the reference quantity can be omitted, but this is not recommended in cases where confusion may occur. In other words, where no number is shown, the number 1 is to be understood.

There exist condensed notations for special cases, such as dBW for dB (1 W) (see § 8 below).

6.1 Absolute Power Level

The absolute power level is the ratio, generally expressed in decibels, between the power of a signal at a point in a transmission channel and a specified reference power.

It should be specified in every case whether the power is real or apparent.

It is necessary for the reference power to be indicated by a symbol:

- when the reference power is one watt, the absolute power level is expressed in “decibels relative to one watt” and the symbol “dBW” is used;
- when the reference power is one milliwatt, the absolute power level is expressed in “decibels relative to one milliwatt” and the symbol “dBm” is used.

6.2 Relative Power Level and Related Concepts

6.2.1 Definition

The relative power level is the ratio, generally expressed in decibels, between the power of a signal at a point in a transmission channel and the same power at another point in the channel chosen as a reference point, generally at the origin of the channel.

It should be specified in every case whether the power is real or apparent.

Unless otherwise specified, the relative power level is the ratio of the power of a sinusoidal test signal (at 800 or 1 000 Hz) at a point in the channel to the power of that reference signal at the transmission reference point.

6.2.2 Transmission Reference Point (see ITU-T Recommendation G.101)

In the old transmission plan, the ITU-T had defined “the zero relative-level point” as being the two-wire origin of a long-distance

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circuit (point O of Fig. 1).

In the presently recommended transmission plan the relative level should be – 3.5 dBr at the virtual switching point on the sending side of a four-wire international circuit (point V of Fig. 2). The “transmission reference point” or “zero relative level point” (point T of Fig. 2) is a virtual two-wire point which would be connected to V through a hybrid transformer having a loss of 3.5 dB. The conventional load used for the computation of noise on multi-channel carrier systems corresponds to an absolute mean power level of –15 dBm at point T.

6.2.3 Meaning of “dBm0”

If a measuring signal with an absolute power level LM (dBm) is applied at point T, the absolute power level of signal appearing at a point X, where the relative level is LXR (dBr), will be LM + LXR (dBm).

Conversely, if a signal at X has an absolute power level LXA (dBm), it is often convenient to “refer it to a zero relative level point” by computing L0 (dBm0) by the formula:

$$L_0 = L_{XA} - L_{XR}$$

This formula may be used, not only for signals, but also for noise (weighted or unweighted), which helps in the computation of a signal-to-noise ratio.

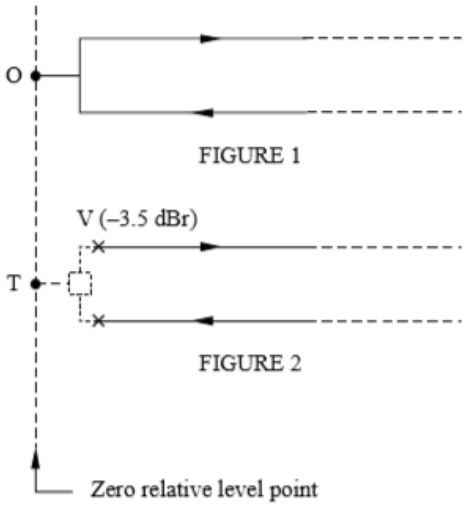

FIGURE 1

FIGURE 2

6.3 Power Density

Definition: Quotient of a power by another quantity, for example, an area, a bandwidth, a temperature.

Note 1 – The quotient of a power by an area is called “power flux-density” (“puissance surfacique”) and is commonly expressed in “watts per square meter” (symbol: W · m–2 or W/m2).

The quotient of a power by a frequency bandwidth is called “power spectral density” and can be expressed in “watts per hertz” (symbol: W · Hz–1 or W/Hz). It can also be expressed with a unit involving a bandwidth characteristic of the technique concerned, for example, 1 kHz or 4 kHz in analogue telephony, 1 MHz in digital transmission or in television; the power spectral density is then expressed in “watts per kilohertz” (W/kHz) or in “watts per 4 kHz” (W/4 kHz) or even in “watts per megahertz” (W/MHz).

The quotient of a power by a temperature, used particularly in the case of noise powers, has no specific name. It is usually

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expressed as “watts per kelvin” (symbol: W · K–1 or W/K).

Note 2 – In some cases a combination of several types of power densities can be used, for example a “spectral power flux-density” which is expressed as “watts per square meter and per hertz” (symbol: W · m–2 · Hz–1 or W/ (m2 · Hz)).

6.4 Absolute Power Density Level

Definition: Expression in logarithmic form, usually in decibels, of the ratio between the power density at a given point and a reference power density.

Note 1 – For example, if one watt per square meter is chosen as the reference power flux-density, the absolute power flux-density levels are expressed as “decibels with respect to one watt per square meter” (symbol: dB(W/m2)).

Similarly, if one watt per hertz is chosen as the spectral reference power density, the absolute spectral power density levels are expressed as “decibels with respect to one watt per hertz” (symbol: dB(W/Hz)).

If one watt per kelvin is chosen as the reference for power density per unit temperature, the absolute power density levels per temperature unit are expressed as “decibels with respect to one watt per kelvin” (symbol: dB(W/K)).

This notation can easily be extended to combined densities. For example, the absolute spectral density levels of the flux density are expressed as “decibels with respect to one watt per square meter and per hertz” for which the symbol is: dB (W/ (m2 · Hz)). Some examples are dB (W/ (m2 · MHz)) and dB (W/ (m2 · 4 kHz)).

6.5 Absolute Voltage Level

The absolute voltage level is the ratio, generally expressed in decibels, of the voltage of a signal at a point in a transmission channel to a specified reference voltage.

The nature of the voltage in question, e.g. r.m.s. value, should be specified in every case. A reference voltage with an r.m.s. of 0.775 volt is generally adopted which corresponds to a 1-milliwatt power dissipated in a resistance of 600 ohms, since 600 ohms represents a rough approximation to the characteristic impedance of certain balanced telephone lines. The absolute voltage level is then expressed in dBu.

If the impedance at the terminals of which the voltage U1 is measured, is in fact 600 ohms, the absolute voltage level thus defined, corresponds to the absolute power level with respect to 1 milliwatt, and so the number N exactly represents the level in decibels with respect to 1 milliwatt (dBm).

L u = 20 lg (U1 / U2) dBu
L p = 10 lg (P1 / P2) dBm

If the impedance at the terminals of which the voltage U1 is measured, is R ohms, N equals the number of dBm increased by the quantity 10 lg (R/600).

Lu = Lp + 10 lg (R / 600)

6.6 Audio Frequencies

6.6.1 Absolute Audio-Frequency Noise Level

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Measurement of audio-frequency noise in broadcasting, sound recording, or sound-program transmission is made, normally through a weighting network and by following the quasi-peak value method of Recommendation ITU-R BS.468 using a reference voltage of 0.775 volt at 1 kHz and a nominal impedance of 600 ohms and expressing the results normally in dBqp (in dBqps if a weighting network is used). NOTE 1 – The two notations in “dBq” and “dBm” should not be used interchangeably. In sound-program transmission the notation “dBq” is restricted to level measurements of noise with single or multiple tone bursts whereas the notation “dBm” only applies to sinusoidal signals used for lining up the circuit.

6.6.2 Relative Voltage Levels

The relative voltage level at a point in a sound-program transmission chain is the ratio, expressed in dB, of the voltage level of a signal at that point relative to the voltage level of the same signal at the reference point. This ratio is expressed in “dBrs”, the “r” indicating “relative level” and “s” indicating that the ratio refers to levels in a “sound-program” (sound signals) system. At the reference point (the point of zero relative level, 0 dBrs) a test signal at the alignment level has a level of 0 dBu. Note that in some broadcasting chains, there may be no point of zero relative level. However, points of measurements and interconnection may still be given a level (in dBrs) relative to a hypothetical reference point.

6.6.3 Use of The Decibel, by Extension, for Ratios of Quantities not Connected with Power

6.6.3.1 Voltage Ratios

In the audio frequency domain, the concept of voltage is sometimes more important than that of power. This is the case, for example, when low output- and high input-impedance two-port networks are associated in tandem. In this way a deliberate departure is made from the impedance matching conditions in order to simplify the formation of these networks. When this is done, only the voltage ratios at different points in the link need to be taken into consideration. It is then convenient to express these voltage ratios in a logarithmic scale, e.g. to the base 10, by defining the number N of corresponding units by means of the equation:

$$N = K \lg (U1 / U2)$$

In this equation the coefficient K is a priori arbitrary. However, by analogy with the operation:

$$N = 20 \lg (U1 / U2)$$

which expresses in decibels the ratio of the power loss as in two equal resistances at the terminals of which the voltages U1 and U2 respectively, are applied, one is led to adopt the value 20 for the coefficient K. The number N then expresses in decibels the power ratios which would correspond to the voltage ratios, if the latter were applied to equal resistances, although in practice this is not generally the case.

6.6.3.2 Absolute Voltage Level

If the impedance at the terminals of which the voltage is measured is not specified, the corresponding power level cannot be calculated. However, a number N can be defined conventionally in accordance with § 6.6.3.1 with respect to a reference voltage and can be expressed in decibels. To avoid any confusion, it is essential to specify that an absolute voltage level is concerned and the symbol dBu must be used. The symbol dBu appears to create no confusion with the use defined in § 6.7 as the absolute level of the electromagnetic field referred to 1 microvolt per meter. If, however, there is any risk of confusion, the expression dB (775 mV) must be written, at least the first time.

6.7 Absolute Level of an Electromagnetic Field

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The strength of an electromagnetic field can be expressed by a power flux-density (P / A), by an electric field-strength E or by a magnetic field-strength H. The absolute field-strength level LE is the logarithm of the ratio of E and a reference field-strength, usually 1 µV/m. It is usually expressed in decibels.

LE = 20 lg (E / E0) dB(µV/m)

6.8 Sound Pressure Level

This is the logarithm, generally expressed in decibels, of the ratio of sound pressure and a reference pressure, often 20 µPa.

Lp = 20 lg (p / p0) dB (20 µPa)

7 Ratios Expressing Transmission Quality

7.1 Signal-to-Noise Ratio

This is either the ratio of the signal power (Ps) to the noise power (Pn), or the ratio of the signal voltage (Us) to the noise voltage (Un) measured at a given point with specified conditions. It is expressed in decibels:

R = 10 lg (Ps / Pn) dB or R = 20 lg (Us / Un) dB

The ratio of the wanted signal to the unwanted signal is expressed in the same way.

7.2 Protection Ratio

This is either the ratio of the wanted signal power (Pw) to the maximum permissible interfering signal power (Pi), or the ratio of the wanted signal field-strength (Ew) to the maximum permissible interfering signal field-strength (Ei). It is expressed in decibels:

A = 10 lg (Pw / Pi) dB or A = 20 lg (Ew / Ei) dB

7.3 Carrier to Spectral Noise Density Ratio (C / N0)

This is the ratio Pc / (Pn / Δ f) where P c is the carrier power, P n the noise power, Δ f the corresponding frequency bandwidth. This ratio has a dimension of frequency, it cannot be expressed without caution in terms of decibels, for power is not linked with frequency on a well-defined basis.

This ratio could be expressed in relation with a reference quantity such as 1 W/(W/Hz) which clearly indicates the origin of the result.

For example, with Pc = 2 W, Pn = 20 mW and Δ f = 1 MHz, for the logarithmic expression corresponding to C / N0 we have:

$$10 \lg \frac{P_c}{P_n / \Delta f} = 50 \qquad \text{dB(W/(W/kHz))}$$

This expression can be abbreviated to read 50 dB(kHz) if it is not liable to give rise to any misunderstanding.

7.4 Energy to Spectral Noise Density Ratio

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In the case of the ratio “energy per bit to spectral noise density”, E / N0, which is used in digital transmission, the ratio is made between two quantities homogeneous with spectral power density, and this ratio may normally be expressed in decibels, like power ratios (see § 7.1). However, it is necessary to ensure that the units used for the expression of both terms in the ratio are equivalent; for example, joule (J) for energy and watts per hertz (W/Hz) for spectral noise density.

7.5 Figure of Merit (M)

The figure of merit (M) characterizing a receiving radio station is a logarithmic expression which is related to the antenna gain G (in decibels) and the overall noise temperature T (in kelvins) in the following way:

M = [G – 10 lg (T / 1 K)] dB (W/ (W · K))

The decibel notation may be abbreviated to read dB(K–1) which should however be avoided if it is liable to give rise to misunderstanding.

8 Special Notations

Examples of special notations, the use of which may be continued, are given below. These notations are often made in addition to other notations.

For absolute power level (see § 6.1, 6.2 and 6.6)

dBW: absolute power level with respect to 1 watt, expressed in decibels;
dBm: absolute power level with respect to 1 milliwatt, expressed in decibels;
dBm0: absolute power level with respect to 1 milliwatt, expressed in decibels, referred to a point of zero relative level;
dBm0p: absolute Psophometric power level (weighted for telephony) with respect to 1 milliwatt, expressed in decibels, referred to a point of zero relative level;
dBm0s: absolute power level with respect to 1 milliwatt, expressed in decibels, referred to a point of zero relative level in sound program transmission;
dBm0ps: absolute Psophometric power level (weighted for sound-program transmission) with respect to 1 milliwatt, expressed in decibels, referred to a point of zero relative level in sound program transmission.
For absolute level of an electromagnetic field (see § 6.7)
dBμ or dBu: absolute level of the electromagnetic field with respect to 1 μV/m, expressed in decibels.
For absolute voltage level including the audio-frequency noise level (see § 6.6)
dBu: absolute voltage level with respect to 0.775 V;
dBu0: absolute voltage level with respect to 0.775 V, referred to a point of zero relative level;
dBu0s: absolute voltage level with respect to 0.775 V, referred to a point of zero relative level in sound program transmission;
dBq: absolute noise voltage level with respect to 0.775 V;
dBqps: absolute weighted voltage level in sound-program transmission;
dBq0ps: absolute weighted voltage level with respect to 0.775 V referred to a point of zero relative level in sound-program transmission;
dBq0s: absolute unweighted voltage level in sound-program transmission with respect to 0.775 V referred to a point of zero relative level.
For relative power level (see § 6.2)
dBr. For relative audio frequency voltage level (see § 6.6)
dBrs: relative voltage level expressed in decibels, referred to another point in sound-program transmission.
For absolute acoustic pressure level (see § 6.8)
dBA, dBB or dBC: weighted acoustic pressure level with respect to 20 μPa, mentioning the weighting curve used (curves A, B or C, see IEC Publication 651).
For antenna gain (see § 5.2)

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dBi: in relation to an isotropic antenna;
dBd: in relation to a half-wave dipole.

In Appendix 1 is given the principle of the notation recommended by the IEC for expressing the level of a quantity with respect to a specified reference. The notations used in the present Recommendation are applications of this principle.

Appendix 1

Notation for expressing the reference of a level

(Part 5 of IEC Publication 27-3)
A level representing the quantity x with the reference quantity xref may be indicated by:

L x (with respect to xref) or by Lx / xref.

Examples:
The statement that a certain sound pressure level is 15 dB above the level corresponding to a reference pressure of 20 μPa can be written as:

Lp (re 20 μPa) = 15 dB or as Lp / 20 μPa = 15 dB

The statement that the level of a current is 10 Np below 1 ampere can be written as:

L I (with respect to 1 A) = −10 Np.

The statement that a certain power level is 7 dB above 1 milliwatt can be written as: L p (with respect to 1 mW) = 7 dB. The statement that a certain electric field-strength is 50 dB above 1 microvolt per meter can be written as:

L E (with respect to 1 μV/m) = 50 dB.

In presenting data, particularly in tabular form or in graphical symbols, a condensed notation is often needed for identifying the reference value. Then, the following condensed form, illustrated by application to the above examples, may be used:

15 dB (20 μPa)
− 10 Np (1 A)
7 dB (1 mW)
50 dB (1 μV/m)

The number 1 in the expression of a reference quantity is sometimes omitted. This is not recommended in cases when confusion may occur.

When a constant level reference is used repeatedly in a given context and explained in the context, it may be omitted. *

* The omission of the reference level, permitted by the IEC, is not permitted in ITU-R and ITU-T texts.

Glossary

Action Levels = numerical decibel values used above a baseline value for sites to take action to lubricate, plan or replace assets.

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Angle of Incidence= is the angle between an incident wave interfacing on the surface of a secondary medium and the line perpendicular to the secondary surface at the point of incidence, called the normal. The ray incident can be formed by any type of X-ray, optical, microwave, acoustic etc.

Baseline Value = numerical decibel value used to establish the normal operation value an asset should be operating at.

Benchmarking: noun;

1 a : something that serves as a standard by which others may be measured or judged a stock whose performance is a benchmark against which other stocks can be measured
b : a point of reference from which measurements may be made
c : a standardized problem or test that serves as a basis for evaluation or comparison (as of computer system performance)
2 usually **bench mark** : a mark on a permanent object (such as a concrete post set into the ground) indicating elevation and serving as a reference in topographic surveys and tidal observations

Critical angle; noun

1. Optics. (Sound will interact the same way.) the minimum angle of incidence beyond which total internal reflection occurs for light traveling from a medium of higher to one of lower index of refraction; the angle of incidence for which refracted rays emerge tangent to the surface separating two media, the light traveling from the medium of higher to the medium of lower index of refraction. Sound will interact the same way.
2. Also called **angle of stall, critical angle of attack, stalling angle**. Aeronautics. the angle of attack, greater than or equal to the angle of attack for maximum lift, at which there is a sudden change in the airflow around an airfoil with a subsequent decrease in lift and increase in drag.

Decibels; noun

1. a: a unit for expressing the ratio of two amounts of electric or acoustic signal power equal to 10 times the common logarithm of this ratio.
b: a unit for expressing the ratio of the magnitudes of two electric voltages or currents or analogous acoustic quantities equal to 20 times the common logarithm of the voltage or current ratio.
2. a unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average pain level.
3. degree of loudness; also: extremely loud sound —usually used in plural.

Diagnosis: noun;

refers to the process of analyzing information to understand or explain something. The plural of diagnosis is diagnoses. The adjective form is diagnostic.

Disposition noun;

1. a person's inherent qualities of mind and character. "your sunny disposition has a way of rubbing off on those around you"
   synonyms: temperament · nature · character · constitution · makeup · grain ·humor · temper · mentality · turn of mind · kidney
2. an inclination or tendency.
   "the judge's disposition toward clemency" · "the cattle showed a decided disposition to run"
   synonyms: inclination · tendency · proneness · propensity · proclivity · leaning · orientation · bias · bent · predilection
   antonyms: disinclination
3. the way in which something is placed or arranged, especially in relation to other things. "the plan need not be accurate so long as it shows the disposition of the rooms"
   synonyms: arrangement · arranging · disposal · ordering · positioning · placement · lining up · setting up · organization ·

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configuration · setup · lineup · layout · array · marshalling · mustering · grouping · gathering · dressing

4. the action of arranging or ordering people or things in a particular way. “the prerogative gives the state widespread powers regarding the disposition and control of the armed forces “(dispositions) military preparations, in particular the stationing of troops ready for attack or defense. “the new strategic dispositions of our forces “

   Legal definition the action of distributing or transferring property or money to someone, in particular by bequest. “this is a tax that effects the disposition of assets on death”
   synonyms: distribution · disposal · allocation · transfer · transference · conveyance · making over · bestowal · bequest · sale · auction

5. the power to deal with something as one pleases. “if Napoleon had had railroads at his disposition, he would have been invincible”
   synonyms: at the disposal of · for use by · in reserve for · in the hands of · [more]
   in the possession of · within the reach of · within easy reach of · at someone’s fingertips

Dielectric: noun;
1. a nonconducting substance; insulator.
2. a substance in which an electric field can be maintained with a minimum loss of power.

Electromagnetic wave = impingements upon the atoms in the medium, the atoms absorb the energy of that wave. This causes the electrons in the atoms to vibrate in what is known as a Vibrational Motion. The absorption of this energy by the atoms which creates a new electromagnetic wave that is emitted with the same frequency as the first electromagnetic wave. This process keeps repeating till the wave loses it energy or encounters a new medium.

Heterodyning = is the process of combining two or more frequencies to create a new and different one.

Incident Wave = reacts with the second medium the Incident Wave will change its characteristic through the process known as Mode Conversion. This is caused by the difference between the two mediums elasticity and density. These slight differences is what allows for Mode Conversion to occur.

Incipient = adjective;
1. Beginning to exist or appear; in initial stage.

Mode Conversion = takes place when a sound wave interfaces with a different medium other than its incipient medium.

MTBF = Mean Time Between Failure

Obtuse = adjective

1. not quick or alert in perception, feeling, or intellect; not sensitive or observant; dull.
2. not sharp, acute, or pointed; blunt in form.
3. (of a leaf, petal, etc.) rounded at the extremity.
4. indistinctly felt or perceived, as pain or sound.

Pd/M = Predictive Maintenance is a program that uses technology to trend an assets health and recommends when to lubricate based, set action criteria and order replacement off decibels values.

Permittivity noun; = Electricity. the ratio of the flux density produced by an electric field in a given dielectric to the flux density produced by that field in a vacuum.

Plate Wave = This type of wave can occur in three mediums if the material is thinner than that of the second medium. This wave is

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more useful for those doing Non-Destructive Testing for flaw detection. These waves are very indistinguishable from the shear or surface waves.

PM = Preventative Maintenance a time-based program that dictates when to do everything from lubrication to tightening.

Prognosis: noun;

means a forecast or prediction--a judgment about what is likely to occur in the future. The plural of prognosis is prognoses.

Reactive Maintenance = The act of waiting to fix assets after they fail.

Reflection = When a sound wave is produced, it will travel through its incipient medium until it encounters the secondary medium and depending on its characteristics a couple of things can occur. In the case of a smooth surfaces the sound wave will reflect off the secondary medium with little to no acoustic impedance.

Refraction = is what happens to a sound wave as it passes through the second medium and changes it path and exits into the third medium. The second medium can either speed up or slow down the sound wave as it passes through the second medium. This is due to the elasticity and density of the second medium.

ROI = Return On Investment

Shear wave = When the Incident Wave changes from a longitudinal wave to a Shear Wave. This wave also has an oscillatory nature to it, but it travels in a perpendicular direction to the Incident Waves motion. This occurs at the interface with the secondary medium.

Skin Effect: The tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor, and decreases with greater depths in the conductor. The electric current flows mainly at the “skin” of the conductor, between the outer surface and a level called the **skin depth**. The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor. The skin effect is due to opposing eddy currents induced by the changing magnetic field resulting from the alternating current. At 60 Hz in copper, the skin depth is about 8.5 mm. At high frequencies the skin depth becomes much smaller. Increased AC resistance due to the skin effect can be mitigated by using specially woven litz wire. Because the interior of a large conductor carries so little of the current, tubular conductors such as pipe can be used to save weight and cost.

Surface Waves = These waves are a combination of the Incident Wave and the Shear Wave it produces. This wave travels along the interface of the incipient medium & the secondary medium at a perpendicular angle to the impact of the incident wave.

Ultrasound = a frequency range that starts at 20 kHz and goes up to 200 MHz

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