Technology Overview: Ultrasonic Detection

One of the more useful technologies is airborne ultrasound. These instruments cover a broad range of plant operation, yet are simple enough so that almost anyone involved with equipment performance can use them with relatively little training. Lightweight and portable, these instruments may be used to inspect potential problems in all types of plant equipment and systems.

Some of the most common plant applications are: leak detection in pressure and vacuum systems (i.e., boilers, heat exchangers, condensers, chillers, distillation columns, vacuum furnaces, specialty gas systems), bearing inspection, steam trap inspection, valve blow-by, pump cavitations, detection of corona in switch gear, compressor valve analysis, integrity of seals and gaskets in tanks, pipe systems and large walk-in boxes.

All operating equipment and most leakage problems produce a broad range of sound. The high frequency ultrasonic components of these sounds are extremely short wave in nature, and a short wave signal tends to be fairly directional. It is therefore to isolate these signals from background noises and detect their exact location. In addition, as subtle changes begin to occur in mechanical equipment, the nature of ultrasound allows these potential warning signals to be detected early, before actual failure.

Airborne ultrasound instruments, often referred to as "ultrasonic translators", provide information two ways: qualitatively, due to the ability to "hear' ultrasounds through a noise isolating headphone, and quantitatively, via incremental readings on a meter. This is accomplished in most ultrasonic translators by an electronic process called "heterodyning", which accurately converts the ultrasounds sensed by the instrument into the audible range where users can hear and recognize them through headphones.

Although the ability to gauge intensity and view sonic patterns is important, it is equally important to be able to "hear" the ultrasounds produced by various equipment. That is precisely what makes these instruments so useful; they allow inspectors to confirm a diagnosis on the spot by being able to discriminate among various equipment sounds.

The reason users can accurately pinpoint the location of a particular ultrasonic signal in a machine or from a leak is due to its high frequency short wave. Most of the sounds sensed by humans range between 20 Hz and 20 kHz (20 cycles per second to 20,000 cycles per second). They tend to be relatively gross when compared with the sound waves sensed by ultrasonic translators. Low frequency sounds in the audible range are approximately 1.9 cm. to 17 meters in length, whereas ultrasounds sensed by ultrasonic translators are only 0.3 - 1.6 cm long. Since ultrasound wave lengths are magnitudes smaller, the ultrasonic environment is much more conducive to locating and isolating the source of problems in loud plant environments.

Instrumentation

Airborne ultrasound translators are relatively simple to use. They consist of a basic hand held unit with headphones, a meter, a sensitivity adjustment, and (most often) interchangeable modules that are used in either a scanning mode or a contact mode. Some instruments have the ability to adjust the frequency response from between 20 to 100 kHz. An ultrasonic transmitter called a tone generator is often included.

Many of these features are useful in helping a user adapt to a specific test situation. For example, if an ultrasound source is too difficult to locate due to an intense signal, a user can focus on the exact site by adjusting the sensitivity downward. In another instance, if a low level leak occurs in a water valve, the frequency tuning can be adjusted to help a user hear the trickle of the water leak.

The interchangeable modules allow users to adjust for different types of inspection problems. The scanning mode is used to detect ultrasounds that travel in the atmosphere such as a pressure leak or a corona discharge, while the contact mode is used to detect ultrasounds generated within a casing such as in a bearing, pump, valve or steam trap housing.

<u>Leak Detection</u>

This category covers a wide area of plant operations. It can be viewed as a way of keeping a system running more efficiently. Some plants include it as part of an energy conservation program, while others refer to it as fugitive emissions. Regardless, leaks cost money, affect product quality and can reek havoc with the environment. Ultrasonic detection can often locate the problem, whether the leakage occurred in a liquid or a gas system.

The reason ultrasound is so versatile is that it detects the sound of a leak. When a fluid (liquid or gas) leaks, it moves from the high pressure side through the leak site to the low pressure side, where it expands rapidly and produces a turbulent flow. This turbulence has strong ultrasonic components. The intensity of the ultrasonic signal falls off rapidly from the source, allowing the exact spot of a leak to be located.

Generalized gas leak detection is also very easy. An area should be scanned while listening for a distinct rushing sound. With continued sensitivity adjustments, the leak area is scanned until the loudest point is heard.

Some instruments include a rubber focusing probe which narrows the area of reception so that a small emission can be pinpointed. The rubber focusing probe is also an excellent tool for confining the location of a leak. This is done by pressing it against the surface of the suspected area to determine if the sound of the leak remains consistent. If it decreases in volume, the leak is elsewhere.

Vacuum leaks may be located in the same manner; the only difference being that the turbulence will occur within the vacuum chamber. For this reason, the intensity of the sound will be less than that of a pressurized leak. Though it is most effective with low-mid to gross leaks, the ease of ultrasound detection makes it useful for most vacuum leak problems.

Liquid leaks are usually determined through valves and steam traps, although some successes have been reported in locating water leaks from pressurized pipes buried underground. A product can be checked for leakage if it produces some turbulence as it leaks.

Valves are usually checked for leakage with the contact probe on the downstream side. This is accomplished by first touching the upstream side and adjusting the sensitivity to read about 50% of scale. The downstream side is then touched and the sound intensity is compared. If the signal is lower than upstream, the valve is considered closed; if it is louder than upstream and is accompanied by a typical rushing sound, it is considered to be leaking.

Steam traps are also inspected easily with ultrasonic translators. During examination, the steam trap is touched with the contact probe. By listening to the trap operation and observing the meter, trap condition can be interpreted. The speed and simplicity of this type of test allow every trap in a plant to be routinely inspected.

Leaking tubes in heat exchangers and condensers as well as boiler casing leaks are detectable with ultrasonic translators. In most power plants, the problem of condenser in-leakage is a major concern. Condenser fittings are often routinely inspected utilizing the leak detection method previously described. If a leak is suspected in a condenser tube bundle, it is possible to locate the leak by putting a condenser at partial load and opening up a water box of a suspected tube bundle. After the tube sheet is cleared of debris, the tube sheet is scanned.

How to Locate Leaks

Select the Log setting on the meter selection dial. Use "fixed band" position on the Frequency selection dial. If too much background noise is present, try some of the shielding methods. Start off with the sensitivity selection a 10 (maximum). Begin to scan by pointing the module towards the test area. The procedure is to go from the "gross" to the "fine"... with more subtle adjustments made as the leak is approached.

If there is too much ultrasound in the area, reduce the sensitivity setting and continue to scan. If it is difficult to isolate the leak due to competing ultrasound, place the rubber focusing probe over the scanning module and scan the test area. Listen for a rushing sound while observing the meter. Follow the sound to the loudest point. The meter will show a higher reading as the leak is approached. In order to focus in on the leak, keep reducing the sensitivity setting and move the instrument closer to the suspected leak site until you are able to confirm a leak.

To confirm a leak, position the rubber focusing probe (if it is on the scanning module) close to the suspect leak site and move it slightly back and forth in all directions. If the leak is at this location, the sound will increase and decrease in intensity as you sweep over it. In some instances, it is useful to position the rubber focusing probe directly over the suspect leak site and push down to seal it from surrounding sounds. If it is the leak, the rushing sound will continue. If it is not the leak site, the sound will drop off.

Overcoming Competing Ultrasounds

If competing ultrasounds make it difficult to isolate a leak, there are two options:

?? Manipulate the environment, i.e., when possible, turn off the equipment that is producing the competing ultrasound or isolate the area by closing a door or window.
?? Manipulate the instrument and use shielding techniques.

If environmental manipulation is not possible, try to get as close to the test site as possible, and manipulate the instrument so that it is pointing away from the competing ultrasound, and isolate the leak area by reducing the sensitivity of the unit and by pushing the tip of the focusing probe up to the test area, checking a small section at a time.

In some extreme instances, when the leak check is difficult in the fixed band mode of the frequency selection dial, try to tune in to the leak sound by tuning out the problem sound. In this instance, adjust the frequency selection dial until the background sound is minimized and then proceed to listen for the leak.

Since ultrasound is a high frequency, short wave signal, it can usually be blocked or shielded. Note: when using any method, be sure to follow your plant or company safety guidelines. Some common techniques are:

1. Place your body between the test area and the competing sounds to act as a barrier.
2. Position a clip board close to the leak area and angle it so that it acts as a barrier between the test area and the competing sounds.
3. Using a gloved hand, wrap the hand around the rubber focusing probe tip so that the index finger and the thumb are close to the very end and place the rest of the hand on the test site so that there is a complete barrier of the hand between the test area and the background noise. Move the hand and instrument together over the various test zones.
4. In addition to a glove, use a wipe rag to wrap around the rubber focusing probe tip (be sure not to block the open end of the tip). This is usually the most effective method since it uses three barriers; the rubber focusing probe, the gloved hand, and the rag.
5. When covering a large area, it is sometimes helpful to use some reflective material, such as a welders curtain or a drop cloth, to act as a barrier. Place the material so that it acts as a wall between the test area and the competing sounds. Sometimes the barrier is draped from ceiling to floor, at other times it is hung over the railings.

In ultrasonic inspection of leakage, the amplitude of sound often depends upon the amount of turbulence generated at the leak site. The greater the turbulence, the louder the signal; the less the turbulence, the lower the intensity of the signal. When a leak rate is so low that it produces little, if any, turbulence that is detectable, it is considered "below threshold". If a leak appears to be of this nature build up the pressure (if possible) to create greater turbulence, or utilize a liquid leak amplifier.

The Liquid Leak Amplifier (LLA) is a specially formulated liquid that produces a thin film through which the escaping gas will pass. When it comes in contact with a low flow of gas, it quickly forms a large number of small soda-like bubbles that burst as soon as they form. This bursting effect produces an ultrasonic shock wave that is heard as a crackling sound in the headphones. In many instances the bubbles will not be seen, but they will be heard. This method is capable of obtaining successful leak checks in systems with leaks as low as 1x10-6 standard cc/sec.

If there are situations where a signal may be difficult to isolate, it may be helpful to utilize the Frequency Tuning Dial. Point the system toward the test area and gradually adjust the frequency tune dial until the weak signal appears to be clearer and then follow the basic detection methods previously outlined.

Heat exchangers may be tested in a similar fashion. The header is removed and the shell side is either placed under vacuum or is pressurized. There will be some instances where it is difficult or too time consuming to inspect under pressure or vacuum. In this case, a test unique to ultrasound is incorporated.

This method uses an ultrasonic transmitter called a "tone generator". The tone generators are placed in the various access ports or fittings to produce an intense, uniform ultrasound within the shell side.

Since the sound waves are high frequency, they will tend to deflect off the surface of solid, intact tubes, but will penetrate through the leak site of a tube. By scanning the tube sheet, an operator listens for a distinct high frequency signal indicating the leaking tube.

The preferred method is pressure or vacuum, but the tone generator method is a good backup for difficult situations.

Electrical Applications

There are three basic electrical problems that can be detected:

1. Arcing: An arc occurs when electricity flows through space. Lightning is a good example.
2. Corona: When voltage on an electrical conductor, such as an antenna or high voltage transmission line exceeds threshold value, the air around it begins to ionize to form a blue or purple glow.
3. Tracking: Often referred to as "baby arcing", follows the path of damaged insulation.

Although theoretically ultrasonic detection can be used in low, medium, and high voltage systems, most of the applications tend to be in medium and high voltage systems.

When electricity escapes in high voltage lines or when it jumps across a gap in an electrical connection, it disturbs the air molecules around it and generates ultrasound. Often this sound will be perceived as a crackling or frying sound; in other situations it will be heard as a buzzing sound. Applications include: insulators, cable, switchgear, buss bars, relays, contactors, junction boxes. In substations, components such as insulators, transformers and bushings may be tested.

Ultrasonic testing is often used for evaluation at voltages exceeding 2,000 volts, especially in enclosed switchgear. This is especially useful in identifying tracking problems. In enclosed switchgear, the frequency of tracking greatly exceeds the frequency of serious faults identified by infrared. It is recommended that both tests be used with enclosed switchgear. Note: When testing electric equipment, follow all your plant or company safety procedures. When in doubt, ask your supervisor. Never touch live electrical apparatus with the system.

The method for detecting electric arc and corona leakage is similar to the procedure outlined in leak detection. Instead of listening for a rushing sound, a user will listen for a crackling or buzzing sound. In some instances, as in trying to locate the source of radio/TV interference or in substations, the general area of disturbance may be located with a gross detector such as a transistor radio or a wide-band interference locator. Once the general area has been located, the scanning module is utilized with a general scan of the area. The sensitivity is reduced if the signal is too strong to follow on the meter until the loudest point is located.

Determining whether a problem exists or not is relatively simple. By comparing sound quality and sound levels among similar equipment, the problem sound will tend to be quite different.

On lower voltage systems, a quick scan of bus bars often will pick up a loose connection. Checking junction boxes can reveal arcing. As with leak detection, the closer one gets to the leak site, the louder the signal. If power lines are to be inspected and the signal does not appear to be intense enough to be detectable from the ground, you can use an ultrasonic waveform concentrator (a parabolic reflector), which will double the detection distance of the system and provide pinpoint detection.

Mechanical Inspection

Ultrasonic inspection and monitoring of bearings is a reliable method for detecting incipient bearing failure. The ultrasonic warning appears prior to a rise in temperature or an increase in driving torque. Ultrasonic inspection of bearings is useful in recognizing the beginning of fatigue failure, brinelling of bearing surfaces, flooding of or lack of lubricant.

In ball bearings, as the metal in the raceway, roller, or bearing balls begins to fatigue, a subtle deformation begins to occur. This deforming of the metal will produce an increase in the emission of ultrasonic sound waves. When testing, changes in amplitude of from 12 to 50 times the original reading is indication of incipient bearing failure. When a reading exceeds any previous reading by 12 dB, it can be assumed that the bearing has entered the beginning of the failure mode.

This information was originally discovered through experimentation performed by NASA on ball bearings. In tests performed while monitoring bearings at frequencies ranging from 24 through 50 kHz, the changes in amplitude indicated the onset of, or incipient, bearing failure before other indicators; including heat and vibration changes. (An ultrasonic system based on detection and analysis of modulations of bearing resonance frequencies can provide subtle detection capability, whereas conventional methods have difficulty detecting very slight faults.) As a ball passes over a pit or fault in the race surface, it produces an impact. A structural resonance of one of the bearing components vibrates or rings by this repetitive impact. The sound produced is observed as an increase in amplitude in the monitored ultrasonic frequencies of the bearing.

Brinelling of 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 system are reproduced as audible sounds. This 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; often 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 uniform ball damage. Loud rushing sounds similar to the rushing sound of a good bearing only slightly rougher can indicate lack of lubrication.

There are two basic procedures of testing for bearing problems: comparative and historical. The comparative method involves testing two or more similar bearings and comparing potential differences. Historical testing requires monitoring a specific bearing over a period of time to establish its history. By analyzing bearing history, wear patterns at particular ultrasonic frequencies become obvious which allows for early detection and correction of bearing problems.

Comparative Test - Use the contact (stethoscope) module. (Analog users select LIN on the meter selection dial. Select the desired frequency on the frequency selection dial (try 30kHz). Select a test spot on the bearing housing and mark it for future reference. Touch that spot with the contact module. In ultrasonic sensing, the more mediums or materials ultrasound has to travel through, the less accurate the reading will be. Therefore, be sure the contact probe is actually touching the bearing housing. If this is difficult, touch a grease fitting or touch as close to the bearing as possible. For consistency, always approach the test spot at the same angle. Reduce sensitivity to help improve signal clarity (analog users - bring the sensitivity down until the meter reads 20. Listen to the bearing sound through headphones to hem the quality of the signal for proper interpretation. Select same type bearings under similar load conditions and same rotational speed. Approach the bearings at the same angle, touching approximately the same area on the bearing housing. Compare differences of meter reading and sound quality.

Historical Bearing Test - There are three methods to historically trend a bearing . . . the "Simple" method, the "Attenuator Curve" method and the "Ultratrend" method.

Simple Method - Use the basic procedure as outlined above in the comparative test. Note frequency, meter reading, and sensitivity selection on your bearing history chart. Compare this reading with previous or future readings. On all future readings, adjust frequency (and for analog users, the sensitivity level) to the original level recorded in the bearing history chart. Digital users can compare the previous dB reading with the current reading. For analog users, if the meter reading has moved from the original 20 mark up to or past 100, there has been a 12 dB increase. (Increments of 20 on the meter in the linear mode is about 3 decibels; e.g., 20-40=3 dB, 40-60=3 dB, etc.) Note: Increase of 12 dB or greater indicates the bearing has entered a failure mode. Lack of lubrication is usually indicated by an 8 dB increase over baseline. It is usually heard as a loud rushing sound. If lack of lubrication is suspected, after lubricating, re-test. If readings do not go back to original levels and remain high, consider that the bearing is on the way to the failure mode and recheck frequently.

Attenuator Transfer Curve Method - This method refers to a sensitivity/decibel reference chart that comes with the Ultraprobe 550 and 2000 models. In this instance, the meter is set to read 50. A quick glance at the chart using the sensitivity level used to produce a 50 meter reading will show a decibel reference level for trending purposes. This chart enables users to observe dB changes way beyond the set limitation of 12 dB as noted in the "Simple Method".

Ultratrend Method - Ultratrend is a "spread sheet" type of software that is on an open platform, meaning that the data are easily exported to most common software such as Excel and Access. The decibel readings are noted along with descriptive text, time and date. Digital Ultraprobe users can easily upload and download the readings from the instrument to the PC. Analog users can manually enter the data.

If a vibration program already exists for bearing analysis, an ultrasonic bearing monitoring program can be of assistance. Ultrasound translators can be used to aid a diagnosis. The high frequency short wave characteristic of ultrasound allows the signal to be isolated, so that a user can determine if a bearing has been correctly diagnosed as failing.

At times, there can be false signals generated by equipment connected to a particular bearing. By adjusting the sensitivity, the frequency, and listening to the sound, it can be determined whether it is the bearing, a rotor or something else that is the root of the problem. The ability to hear what is going on can prove very important. Ultrasound detectors work well on slow speed bearings. In some extreme cases, just being able to hear some movement of a bearing through a well greased casing could provide information about potential failure. The sound might not have enough energy to stimulate classic vibration accelerometers, but will be heard via ultrasonic translators, especially those with frequency tuning.

Sometimes there are so many bearings in a plant that not every piece of equipment can be checked routinely by a limited staff of trained technicians. Since ultrasound detectors require little training, a technician or the machine operator can determine potential bearing problems and notify the vibration technician for follow-up.

Lack of Lubrication - To avoid lack of lubrication, note the following: as the lubricant film reduces, the sound level will increase. A rise of about 8 dB over baseline accompanied by a uniform rushing sound will indicate lack of lubrication. When lubricating, add just enough to return the reading to baseline. Use caution. Some lubricants will need time to run to uniformly cover the bearing surfaces. Lubricate a little at a time. Do not over lubricate.

Over lubrication - One of the largest causes of bearing failure is over lubrication. The excess stress of lubricant often breaks bearing seals or causes a buildup of heat which can create stress and deformity.

To avoid over lubrication, don't lubricate if the baseline reading and baseline sound quality is maintained. When lubricating, use just enough lubricant to bring the ultrasonic reading to baseline. As mentioned above, use caution. Some lubricants will need time to uniformly cover the bearing surfaces.

Slow Speed Bearings

Monitoring slow speed bearings is possible. Due to the sensitivity range and the frequency tuning, it is quite possible to listen to the acoustic quality of bearings. In extremely slow bearings (less than 25 rpm), it is often necessary to disregard the meter and listen to the sound of the bearing. In these extreme situations, the bearings are usually large (1-2 inches and up) and greased with high viscosity lubricant.

Most often, no sound will be heard as the grease will absorb most of the acoustic energy. If a sound is heard, usually a crackling sound, there is some indication of deformity occurring. On most other slow speed bearings, it is possible to set a baseline and monitor. It is suggested that the attenuator transfer curve method be used, since the sensitivity will usually have to be higher than normal.

Steam Traps

Steam traps are also inspected easily with ultrasonic translators. It is important to determine exactly how a particular trap is supposed to operate. This can be accomplished by consulting with steam trap suppliers. In some instances, manufacturers of ultrasonic translators supply video cassette training tapes that show exactly how each type of trap can be inspected.

The method is quite simple. A steam trap is touched with the contact probe. By listening to the trap operation and by observing the meter, trap condition can be interpreted. The speed and simplicity of this type of test allow every trap in a plant to be routinely inspected.

Ultrasonic Translators

It is advisable to have instruments that are sensitive enough to detect the type of problems you will encounter in the plant. A wide dynamic range in an instrument will enable you to look for small leaks on one end and locate gross mechanical problems on the other.

Since sound quality is an important consideration, make sure the instrument heterodynes the ultrasonic signal. This will insure users that they are getting an accurate reproduction of the ultrasonic signal, for signal clarity and interpretation of the headphone sound. Noise attenuating headphones with good sound quality are essential. If the sound quality is not clear, it will be difficult to understand what is being sensed. It is advisable to get over-the-ear headphones that will block out ambient plant sounds during inspections. Without proper RF shielding, stray electronic signals will interfere with test results. In some instances, radio programs have been heard, which totally confused operators.

Since every plant is different, there might be special accessories needed to assist in some situations. For example, compressor valve analysis might be easier with a magnetically mounted probe and an oscilloscope interface. If you are going to inspect a variety of equipment or have fluids of different viscosities, it would be useful to have the ability to change. For leak detection of potentially explosive or flammable gases, it is advisable to use equipment rated intrinsically safe.

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