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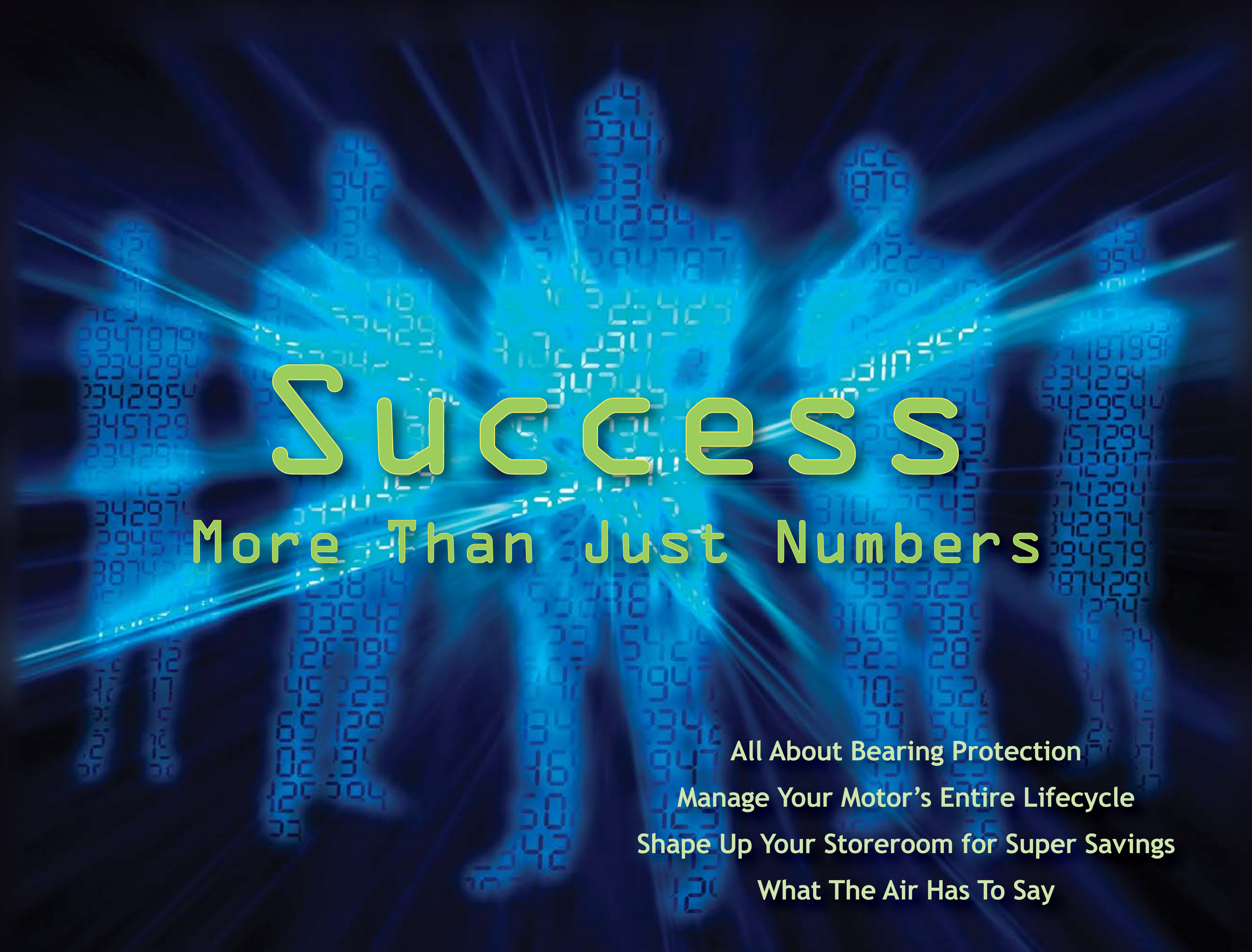

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There's Something in the Air

What Problems an Airborne Ultrasound Program Can Help Identify

by Thomas J Murphy, Eng

The use of ultrasound as a predictive tool has been with us for over 35 years. Despite this vintage, the use – and indeed, the understanding – of this technology is still not widespread. The purpose of this article is to explore the vast range of application of airborne technology from simple to sophisticated. A "Part 2" article in the November edition will explore contact ultrasound applications.

The Basics

Ultrasound can be very simply defined as any sound with a frequency above 20kHz, that is above the highest frequency a young adult can detect. This is a big, big frequency range. Medical ultrasound instruments can often be using ultrasound in the megahertz range. The typical frequency range used by predictive maintenance ultrasound systems is much lower – normally in the 30-40kHz region.

Ultrasound is inaudible. Traditionally, ultrasound systems use heterodyning or mixing techniques to present a signal to a headset, which would typically have an audible 2kHz frequency range. Once you get past the "cheap and cheerful" ultrasound system (which merely click or whirr to represent the presence of an ultrasound signal) to one which uses this mixer technology, you have an instrument which actually allows you to listen in on what is going on far beyond our human range of hearing. In fact, some instruments on the market allow you to change the mixer frequency so that you can listen to frequencies up to almost 200kHz. This is fascinating when you think about it – you can actually listen in on what is happening far beyond the capability of our ears. If there is a click, knock, rattle, whirr or hiss at 40kHz, that's just what you hear when you set your instrument to be within 2kHz of that frequency.

Measuring Ultrasound

Ultrasound is treated, quite rightly, as a sound, which means that when we quantify the level of ultrasound signal we are listening to, we use a decibel scale. Unfortunately, the arrival of the electronic calculator in the '70s meant that complex arithmetic could be performed without the aid of log tables. Because of that technology, very few people understand decibels anymore.

Log tables helped in all manner of engineering feats. Two key features of this relatively simple arithmetic are that:

1. Any number can be represented as a power of 10. For example, we all know that 10,000 = 10^4. The log of 10,000 is 4. The log of 20,000 would be 4.3.

2. When we want to multiply two numbers together, we add their logs. When we want to divide, we subtract their logs. This means that any multiplication or division of numbers could be reduced to simpler addition and subtraction just by using log tables.

The depth of the misunderstanding of the decibel scale has even spread to the pages of this and similar learned publications, so let's review a few points about dBs as they are known. For example, dBs are never multiplied or divided.

The dB is a logarithmic ratio scale and you cannot have a ratio without a reference value. In itself, it is not a unit of measurement. The measurement unit is the bit on the end: dB(A), dBm, dBV or dBμV could be termed units of measurement, but dB on its own is meaningless. For example, the equation which defines the dBμV used in SDT's ultrasound is:

$$20\log10\ (V1/V0)$$

Where V0 is the reference voltage of the ultrasound detector, namely 1μV. Simply quoting a dB and not quoting a reference is highly misleading since, without a reference value, you might be comparing apples with bananas.

Using this scale, an increase in ultrasound by a factor of 2 would increase the ultrasound level by 6dBμV. The increase from 20 to 26dBμV is the same as the increase from 50 to 56dBμV, since it is an increase of 6dBμV which corresponds to a doubling in the amplitude of the ultrasound measured.

Right. Well, now that the boring (but important) explanation is over, what can I do with ultrasound?

The Applications

Compressed Air Leak Detection – An ultrasound system allows me to hear in a different part of the audio spectrum from my normal hearing. If you turn that statement around, you understand that an ultrasound instrument does not hear what is in the audible range of human hearing. This means that I can take an ultrasound system into the loudest of factories, into the loudest of audible sound fields, and it doesn't make any difference in the ultrasound detector's ability to detect ultrasound sources.

There are many common applications for airborne ultrasound. Perhaps the most common is compressed gas leak detection. The gas is normally air, but in many cases it is also Nitrogen, Oxygen, Hydrogen, Carbon Dioxide, Argon and many others.

Skeptics often say that they can hear air leaks. Within a very small range of controls this is quite true. If there is no background noise, a relatively large leak will be audible. However, if you look at the frequency range of the noise generated by an air leak, only about 10% of the energy produced is in the audible range. The peak frequency range is 30-40kHz. So, those same skeptics wandering around a shut down factory will hear some, but far from all, of their air leaks.

There is a parallel between air leaks and the profile of machinery breakdowns – and both of these carry a passing resemblance to the ancient Japanese technique of death by a thousand cuts.

In the world of reliability, we know that it is not the big high profile, once in a lifetime, failures which ruin a business's reliability, it is rather the multiple high frequency, low impact, chronic failures.

So it is in the world of air leaks. Finding and fixing the few big air leaks is all well and good, but it is equally important to find and fix the dozens (or maybe hundreds) of small, inaudible, air leaks as well. These small, chronic leaks soon add up to being a major drain on your compressed air system. This statement, which I have often heard, "We saved our money and didn't buy an ultrasound system. We just listen for our leaks on the weekend." should now be seen for the absurdity that it is.

An air leak has quite a distinctive ultrasonic signature. You can hear a rushing or roaring noise similar to an aircraft engine. What we are effectively listening to is flow, we are also basically listening to friction. Finding air leaks is very simple. In fact, it is easy. Anybody can do it with only a nominal amount of training. Since it is not a specialist function, it is an inclusive technology. A comprehensive program of leak detection can turn a company around by increasing profitability and, therefore, competitiveness. Compressed air is expensive – frequently the most expensive energy resource used in the business. It is sometimes an interesting exercise to refer the cost of your air leaks to the input of your manufacturing process.

Consider a producer of potato chips making millions of packs per year which are sold for a profit of 5 cents per pack. Now consider that you have an annual cost of producing (and leaking) compressed air of $100,000. That means that you will have to sell, produce, package, ship, invoice and case the money for 2 million packs of chips just to pay for the air leaks!

If you reduce your air leaks to an annual cost of $10,000, you could use the savings to fund a promotion to give away 1,800,000 bags of chips and still have the same income! What's the value of that competitive edge?

Vacuum Leaks – If you have a vacuum system, you will know just how difficult it is to find a vacuum leak without ultrasonic assistance. The mechanism of sound generation is similar to that of a positive pressure leak, but in the case of a vacuum the sound is not travelling towards you but instead is being drawn back into the pipe.

The sound of a vacuum leak is similar to that of an air leak, but inherently, the vacuum leak is quieter. If you have to find a vacuum leak then, in the presence of air leaks, you could have a problem. Training helps out here and a Level 1 ultrasound certification would be a good investment if you may potentially run into this kind of problem.

To accurately identify a vacuum leak you must work hard to increase the sensitivity of your detector, block out competing ultrasound sources or both. For this reason many of the ultrasound equipment manufacturers produce an acoustic horn, which is a wonderfully useful device in the world of acoustics – and one which is still used extensively in the loudspeaker industry today. The beauty of an acoustic horn is that by controlling the relative dimensions of the throat, the mouth, and the length and profile of a horn, you can tune it to quite a narrow range of frequency – effectively it resonates.

The beauty of such a horn is that you could produce an amplification of more than 26dBμV which is a factor of 20x higher sensitivity. However, you do so at a price – the horn will have a very narrow frequency range over which this amplification will be present. Move outside this range and the horn could even reduce your sensitivity to a level below what you would have without the horn.

Vacuum systems are quite widespread – chemical and pharmaceutical processes frequently require vacuum to initiate a chemical reaction. No vacuum, no reaction, no production. This tends to sharpen the interest of these industries in ultrasonics. In this energy-poor environment we must now work in, it must surely be unacceptable to simply buy another vac pump if you don't have sufficient vacuum.

Steam Leaks – High pressure steam leaks are potentially deadly. If you are using superheaters, for example, you could be operating at a temperature over 300°C, perhaps up to nearly 600°F. A high pressure leak could, therefore, be generating an invisible lance which can easily cut through a human.

"Something so important must have an important detection system in operation," I hear you cry. Not so, it is still quite commonplace to find people using long poles or even broom handles with rags tied on the end to find such leaks – when the rag twitches you have a steam leak. A few years ago in the UK there were two near fatalities using this procedure, which finally resulted in it being banned and replaced with ultrasonic inspection.

As noisy as a compressed air leak is, the turbulence generated by a steam leak is even greater, which means that there is even more ultrasonic noise.

Electrical Inspection

Ultrasound can be used to find three common electrical problems: corona, tracking and arcing.

Corona is ionization of air molecules and a surface partial discharge. Ionization of the air is not likely to take place at voltages below 4kV. The presence of corona indicates that there is a problem and that this problem requires attention to prevent the problem from getting worse. Corona is particularly problematic in high voltage switchgear and transmission components. Sadly for thermographers, corona does not generate heat, so it is not detectable using an infrared camera.

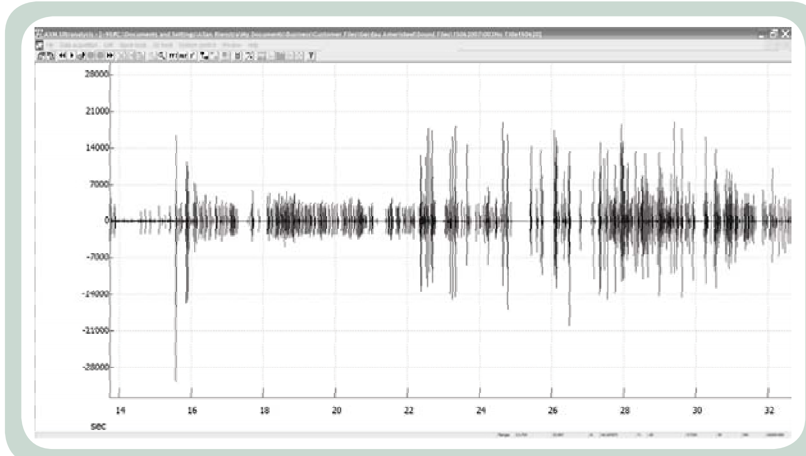


Figure 1- Insulator on 13.8kV step-down transformer before cleaning

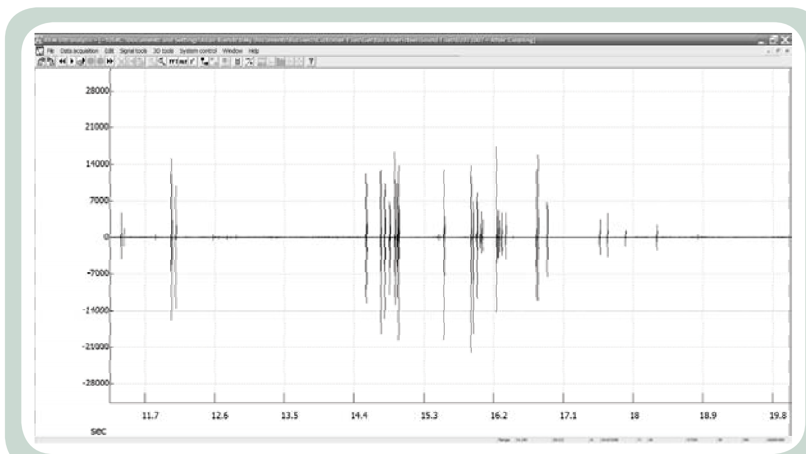


Figure 2 - The same insulator after cleaning still shows problems.

In recent years, arcing and tracking have become major topics in the world of infrared inspection of electrical cabinets. An ultrasonic inspection of a panel prior to opening it is now considered to be best practice - with good reason. Ultrasound is sound, and sound travels through gaps in doors and door frames and bounces around inside a cabinet. Using an airborne ultrasound sensor on a door which is not watertight would therefore identify any crackling sounds inside the cabinet which might be coming from arcing or tracking events.

Figure 1 is an example taken from a 13.8kV step-down transformer showing an insulator with a tracking problem before and after cleaning. As seen in Figure 2, the presence of activity after cleaning shows that there is a residual problem which will require more detailed repair action.

Tightness

Mentioning watertight electrical cabinets brings me to another major use for airborne ultrasound – tightness testing.

Now, instead of using a physical source of ultrasound like those discussed previously, we are going to generate ultrasound with a transmitter (loudspeaker) and listen to that sound. If I place a transmitter inside a sealed box, the sound of the transmitter will not be able to get past the seals of the box, so it can only be heard on the outside, like in the case of a car with a powerful sound system, by vibrating the panels of the box.

This simple idea opens up almost unlimited applications for airborne ultrasound. But, as with all simple ideas, there are some catches. The transmitter you rely upon to provide the source of your ultrasound must be stable and give a repeatable amplitude of signal source. Otherwise you could be in a situation where the combination of transmitter instability and poor detector sensitivity would make a leak inaudible.

This is actually the globally recognized and preferred method for inspecting hatch covers of cargo ships for tightness, an ultrasound transmitter and airborne detector.

Put a transmitter inside a car, close all the doors and windows and you can find where all the gaps are – in some cars you can find a pinhole gap and that gap will make an audible difference to the owner of that car.

This same test method is used to inspect heat exchangers, tractor cabs, buses, trains, trucks, vans, vacuum chambers, autoclaves, windows and roofs on buildings, watertight bulkhead doors and more applications are being added to the list every month.

Mechanical

Surely it is a contradiction in terms to contemplate using airborne ultrasound for mechanical applications. Not so. In fact, there are many mechanical applications where the ability to inspect without making physical contact can be highly beneficial.

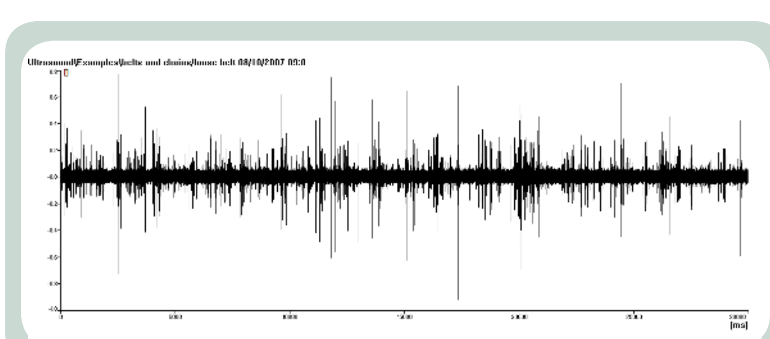


Figure 3- Time signal of slapping drive belts.

I mentioned before that we could listen to friction. I can perform an FMEA (Failure Modes and Effects Analysis) exercise to identify failure modes which are associated with friction. If I have instances where the ultrasound generated by that friction can become airborne then I can use airborne ultrasound detection to isolate the problem. The only thing that I need is an air path between the sound source and my sensor.

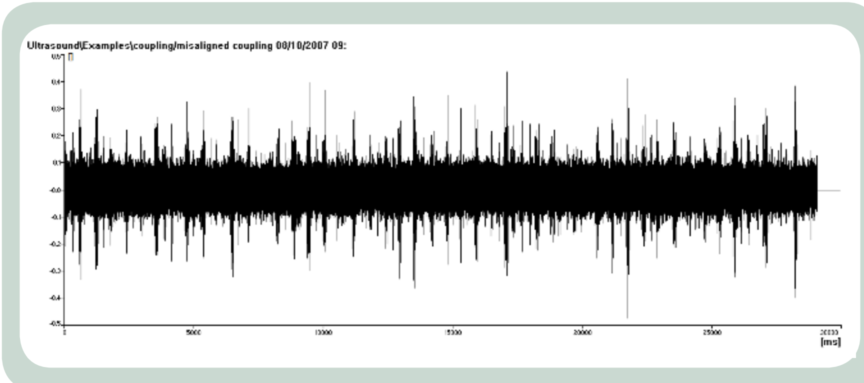


Figure 4 - Ultrasonic signal from a misaligned coupling.

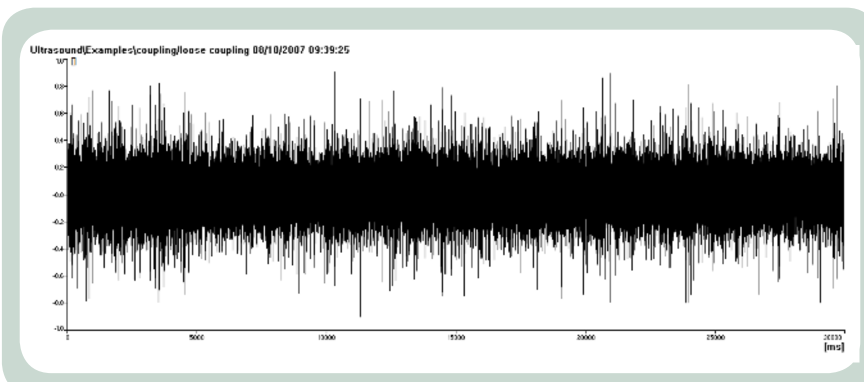


Figure 5 - Loose couplings generate a harsher and less periodic ultrasonic signature than misaligned couplings.

Some examples include:

Drive belts

Belts can be loose, belts can be tight, and belts can be running on misaligned pulleys. Loose belts will slap and produce a noise similar to a whiplash. Tight belts and misaligned belts will generate additional friction which will again be audible ultrasonically. Figure 3 is a sample time signal of some slapping belts.

Couplings

Couplings can be misaligned, and couplings can be loose. Infrared training tells us that a misaligned coupling generates heat. This heat is generated by the periodic friction caused by the coupling being squeezed with each revolution. Remember, friction we can hear. So, a misaligned coupling will generate periodic friction and, therefore, a periodic ultrasound signal like the one shown in Figure 4.

A loose coupling will generate an ultrasound signal caused by the fretting of the coupling halves rattling. This fretting will be more harsh and less periodic (see Figure 5) in nature than misalignment.

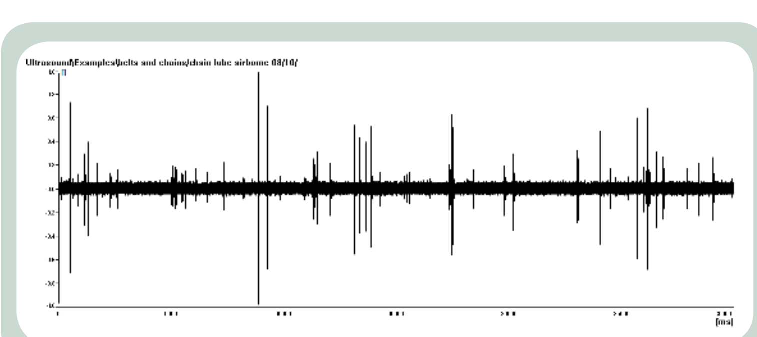
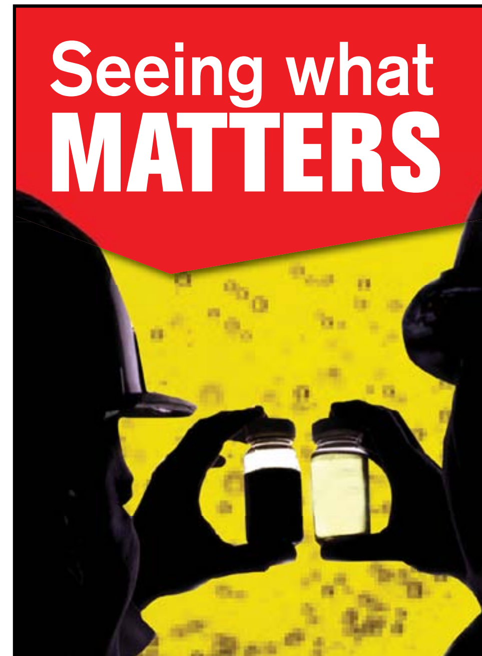


Figure 6 - Time signal of a chain drive.

Chains

Very few people with chain drives have any predictive or even non-intrusive inspection programs for chains. This is a shame since it is so easy to inspect a chain using ultrasound.



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As a chain link moves over a sprocket, two things happen. Firstly, the chain link bends and secondly a tooth of the sprocket must slip though the link and make contact with the pin. This is all going to introduce friction and, therefore, ultrasound, which will show impulses corresponding to each of these movements, with a degree of periodicity as the chain repeats its circuits (Figure 6, previous page).

Bearings

Certain bearing defects generate ultrasound. Bearings which are open to the environment will generate ultrasound which will be transmitted into the same environment. What sort of sounds can be expected? The most obvious one is, of course, friction. An incorrectly lubricated bearing will generate friction. The sound of poor lubrication is a constant crackling sound like something in a frying pan, and it looks like Figure 7.

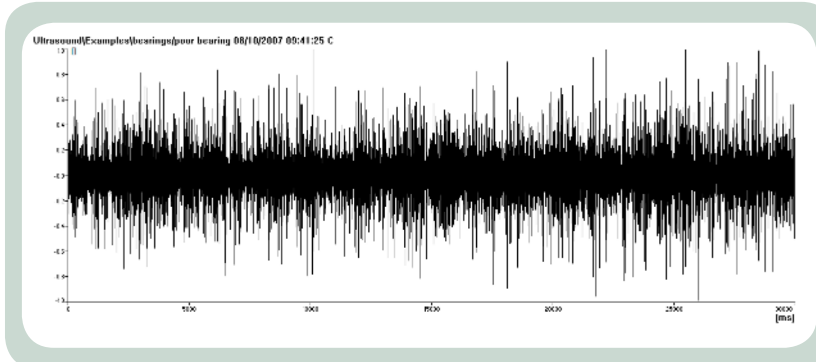

Figure 7 - Ultrasonic record of a poorly lubricated bearing.

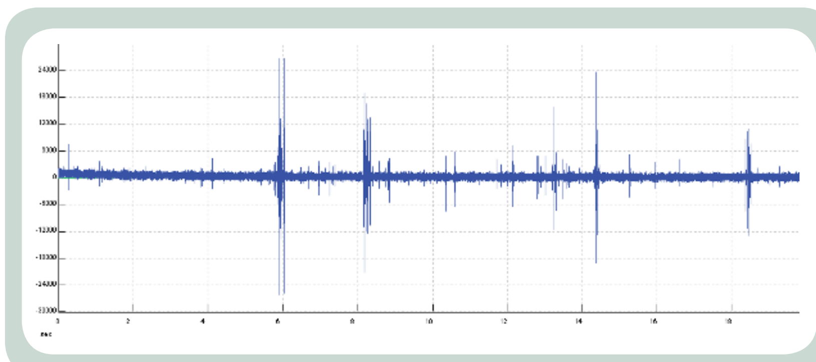

Figure 8 - Note the impacts of an object inside the bearing.

If a bearing has something worn or loose inside which is generating impacts internally, it is possible that these impacts will be audible in airborne ultrasound mode, and will look like Figure 8.

A loose bearing housing (or, similarly, soft foot on a motor) will generate a periodic impact as the foot lifts and falls. This impact will produce an audible airborne ultrasound signal. Figure 9 is an example where a loose bearing foot was identified by airborne ultrasound. The bearing was tightened up and an additional measurement was taken to prove the efficacy of the repair (Figure 10).

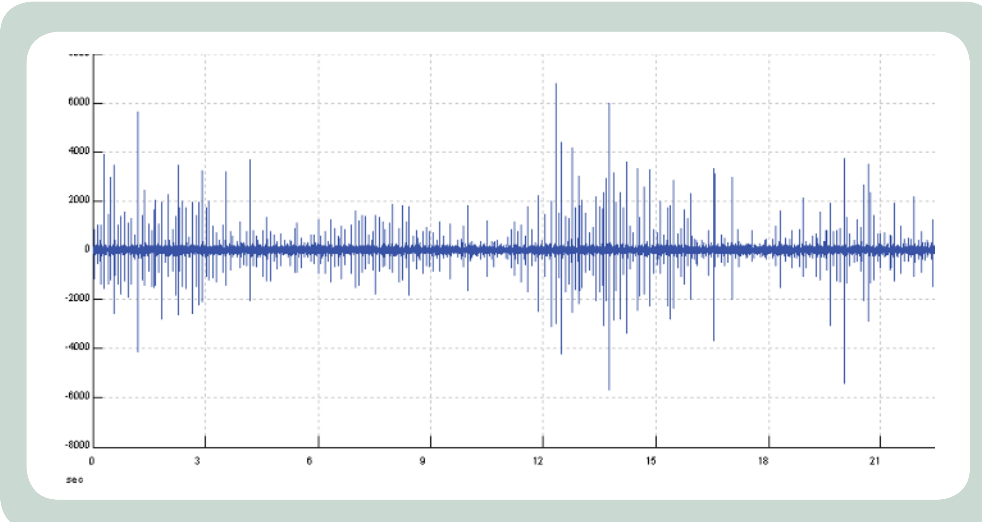

Figure 9 - Ultrasonic inspection confirmed a loose bearing foot.

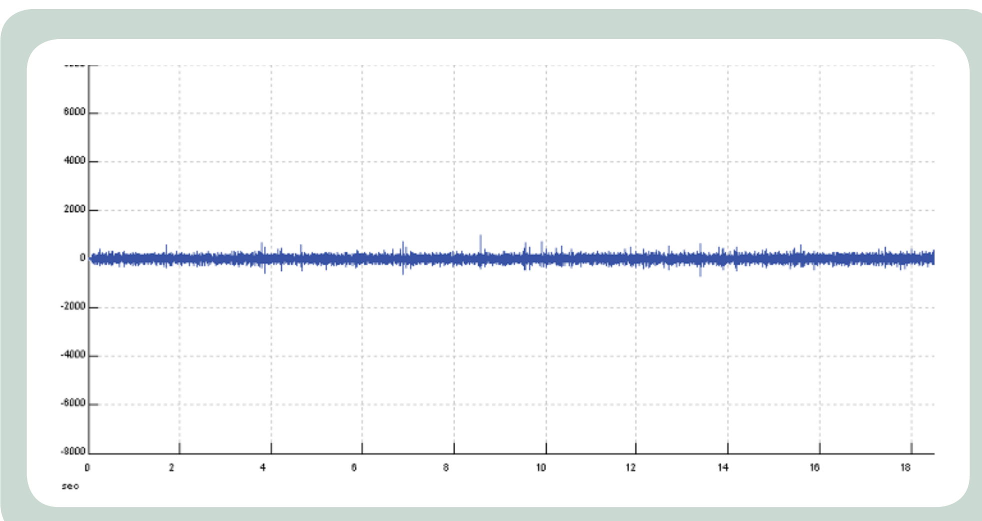

Figure 10 - Ultrasonic reading that validated the repair procedure.

The Future

One common misconception of ultrasound is that you need a 40kHz recording system – "normal vibration data collectors don't have the bandwidth" is a typical comment. Of course, this is incorrect because it a misunderstanding of the fact that the output to the headset of an ultrasound system is typically a signal of just 2kHz.

The last couple of years have seen a marked increase in the desire to record ultrasound signals for the purpose of more detailed, and advanced failure analysis. Previous articles in this publication have highlighted the need to capture a signal using a high quality device. For instance, one that captures high quality wave signals, not compressed MP3, and one that does not apply an autogain to the signal, thus corrupting the dynamics of the data for the purpose of analysis.

It is this ability to properly record and process the audio signals which has allowed me to show the time signal graphs in this article.

Great care must still be taken if comparative work is to be undertaken using recording methods. Apart from the obvious need to maintain the same distance from the test subject, it should also be clear that there is a need to control the output level from the ultrasound instrument and the input gain of the recorder in order to produce comparative data.

The future of ultrasound technology? Well, normally we would go with smaller, lighter, faster, or perhaps, more powerful, more sensitive. These are all, to some extent, useful – especially the more sensitive idea when dealing with ever smaller leaks. But what about more objective? Is there a need for systems which measure? Which measure more precisely, with traceability? Systems which capture dynamic data as well as the dBμV value and process that signal as a signal rather than as a sound? If ultrasound is to more fully deserve its rightful position as "the third technology" we must follow the lead of infrared and move from viewers, or hearers, to measurement devices.

Conclusions

The wide range of applications of airborne ultrasound reviewed above should have provoked some thoughts. Hopefully you will now realize that walking around any plant with an airborne ultrasound detector will uncover lots of problems.

Furthermore it should have raised the perhaps disturbing realization that it is not necessary to trend all defects. It is possible to find problems as part of an inspection, but not as part of a point-by-point measurement procedure.

Part 2 of this article will be in November's issue and will deal with contact ultrasound applications – and there are plenty of those too!

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