Technical paper: Heat exchanger tube inspection using APR

Heat exchanger tubes are a critical part of every nuclear power plant, and inspecting a condenser comprised of tens of thousands of these tubes can be a painstakingly long process. Acoustic Pulse Reflectometry offers a way to quickly inspect and detect faults in heat exchangers.

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Look under the hood of nearly every type of industrial plant, and you'll find heat exchangers of different shapes and sizes. Refineries typically have hundreds of them; power-plants have very large heat exchangers, often containing tens of thousands of tubes, used to condense steam after it has run through the turbine.

Heat exchangers run continuously for years, under adverse conditions. Condensers, for example, often use non-treated or partially-treated water from lakes, rivers or oceans which inevitably causes failure mechanisms to be set into motion. Various types of fouling mechanisms can be found: scale adhering to the inner part of the tubes, sedimentation, pitting, corrosion, erosion and even shellfish growing in the tubes. Fouling degrades the efficiency of heat exchangers, both by reducing flow and creating an insulating barrier. It can also create stress points and hotspots. Wall loss mechanisms can eventually cause leakages, which usually necessitate costly emergency steps such as partial or complete shutdown for repair.

Problems in heat exchanger maintenance

To avoid failure and increase condenser efficiency, it is widely acknowledged that periodic maintenance must be carried out. In the past, running condensers until they failed was sometimes preferred, though it has been shown that this approach is usually more costly. However, periodic maintenance requires plant shutdown, which also has its associated cost. Juggling the parameters of shutdown frequency and duration in the most cost-effective manner is therefore not a simple issue. Among all the other maintenance tasks in a typical power-plant, inspecting a condenser comprised of tens of thousands of tubes can be a painstakingly long process.

Several technologies are currently used for such tube inspection, based on electromagnetic or ultrasound principles. These technologies require physically traversing the entire tube with a probe. Ultrasound-based systems (IRIS – Internal Rotating Inspection System) require cleaning the tubes down to the bare metal, and filling the tubes with water during the inspection. Such requirements slow down the process considerably. Electromagnetic methods (Eddy Current) require less preparation and are faster in general, achieving inspection rates of up to about 50 tubes per hour. However, ferromagnetic tubes pose a problem for such methods, forcing the use of slower and less accurate variants (Remote Field Testing, Magnetic Flux Leakage). Generally, current methods can be said to suffer from one or a combination of several drawbacks:

- Low inspection speed
- Sensitivity to wall tube material
- Difficulties in inspecting bent tubes (such as U-tubes)
- High reliance on technician expertise

One of the consequences of low inspection rates is *sampling:* in order to fit into limited shutdown timetables, only a certain percentage of the tubes in a given heat exchanger are inspected, instead of all of them.

Enter APR

Methods that would enable non-invasive tube inspection hold great appeal for the industry for many reasons. In a sense, this is an extension of the idea behind NDT: NDT is based on probing the depth of the material without physically penetrating it. Extending this idea to tube inspection, an inspection method that enables scanning an entire tube from one access point has inherent advantages in many respects.

Acoustic Pulse Reflectometry (APR) is a relative new-comer to this field. The basic idea is not new, and is similar in some ways to ultrasound techniques: an acoustic pulse is sent into the tube along its axis, propagating through the air filling the tube (rather than perpendicularly into the tube wall itself, as in ultrasound). The frequencies that propagate best in this case are sonic, rather than ultrasonic, thus such a pulse can easily be heard. Again, similarly to ultrasound, if the tube is in pristine condition, the pulse will propagate all the way to the other side, where it will be reflected back. However, any changes in the tube's characteristic impedance will create additional reflections. Such changes in characteristic impedance are in turn caused by changes in cross section – obstructions, different types of wall loss, bulges, and holes: namely, defects.

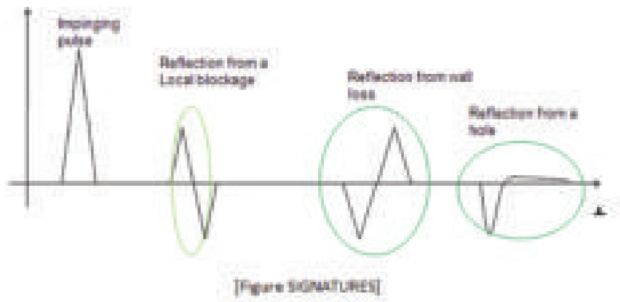

Figure 1. Different defects have their own particular acoustic signatures, enabling them to be distinguished from one another.

Typically, the different defects have their own particular acoustic signatures, which enable them to be distinguished from one another. This is demonstrated schematically in Figure 1. The signatures in this figure seem straightforward to analyze and classify, raising the question – why hasn't this method found widespread adoption before?

Challenges and solutions in applying APR

Implementing a technology, even one that has been proven in research labs, as a viable tool for use in the field, is far from a straightforward process. Many issues have to be addressed: interfering factors found in industrial environments – background noise, operator inconsistency, etc.; the need for recalibration in different environments and tube types; requirements of robustness and portability; and many more. Some of the main issues and their resolution are described below:

Noise (attenuation): Background noise is a phenomenon which accompanies every type of physical measurement, regardless of its specific nature. The main challenge in obtaining useful results from such a measurement is in characterizing this noise and maintaining an acceptable Signal to Noise Ratio (SNR). This is especially difficult in carrying out acoustic measurements in noisy industrial environments.

Several different approaches can be taken to improve SNR. The most obvious is to weaken the background noise, though this is rarely feasible. The signal itself can be strengthened, though there are practical limits, since driving transducers to their limits introduces undesirable nonlinear distortions. Another option is to repeat the measurement several times and average the results. Assuming the background noise is random in nature, such averaging gradually attenuates the noise, increasing SNR. However, this can be a lengthy process. If each measurement takes half a second, repeating it a thousand times for just one tube will result in unacceptably long measurement times. An alternative is to use advanced "pulse compression" methods: transmitting a carefully conceived pseudo-noise signal instead of a pulse, the equivalent of several thousand measurements can be taken in several seconds. One such pseudo-noise signal is the Maximum Length Sequence (MLS). Such a digital sequence is composed entirely of 1 and -1 values. For instance, transmitting an MLS signal of duration 0.34 seconds at a sampling rate of 48kHz is equivalent to repeating a measurement using a single pulse 16,383 times. This increases SNR by 42dB. Figure 2 demonstrates how increasing the length of the MLS sequence increases SNR.

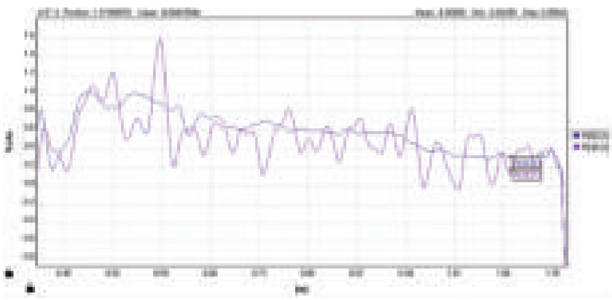

Figure 2. Two measurements of a noise; one taken with a short MLS signal, and a quiet one taken with a long MLS signal.

One of the drawbacks of remote measurement methods is that the acoustic signal is attenuated as it propagates down the tube and back. Thus, the desired SNR must be achieved with respect to the attenuated signal rather than the transmitted one. Using a combination of methods, at AcousticEye we have succeeded in achieving SNR's of approximately 100dB, which are necessary in order to detect the faint reflections from small wall loss defects. These are of great interest to the industry.

Calibration: Any expert in tube inspection is well acquainted with "reference standards." These are lengths of tubing with defects manufactured to close tolerances, on which test equipment can be calibrated. Using eddy current equipment requires a large, expensive inventory of such standards, for every combination

Pinholes

In this case, the ability of APR to detect small pinholes was evaluated. Hole diameters of 0.15, 0.3, 0.5 and 0.7 mm (6, 12, 20 and 28 mils) were drilled in 1" aluminum tubing with a wall thickness of 0.69mm (0.027"). The tubes were 2m in length, and the holes were between 1.4 to 1.5mm from the measurement point. APR measurements demonstrated detection of three out of the four holes, thus only the 0.15 mm hole was not detected. The signatures are apparent in Figure 6; a) measurement of 0.15mm holes – no signature found; b-d) measurements from 0.3, 0.5 and 0.7 mm holes – all demonstrate clear signatures of a hole.

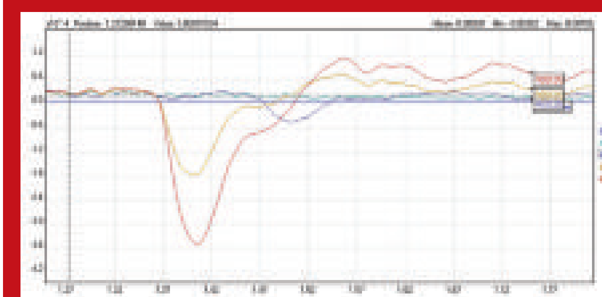

Figure 6. Hole signatures.

Nuclear application

In this case, APR was used to inspect coiled tubes at a Russian nuclear power-plant (Figure 3). Tubes were 18m long, with a diameter of 40mm, and wall thickness of 4.3mm. Obviously, such tubes are extremely difficult to inspect using invasive technologies. APR detected 10% wall loss at a distance of 4.3 meters, as shown by the signature in Figure 4. This was later verfied both using a high quality borescope (Figure 5) and later by cutting the tube at that point.

Figure 3. Coiled tubes in a Russian nuclear plant.

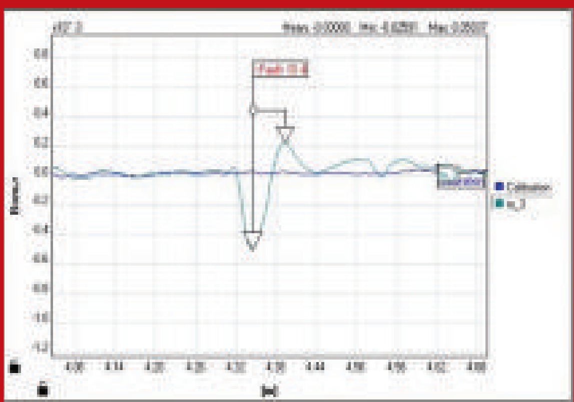

Figure 4. Coiled tube defect.

Figure 5. Borescope photo showing tube defect.

of tube material, diameter and wall thickness. Using APR, on the other hand, it is possible to calculate ad hoc the theoretical response of every type of defect and compare it to the measured one. Thus the use of calibration standards is unnecessary. Though a set of tubes with known defects can be used to verify that the system is operating correctly, one such set is sufficient.

Automatic classification: One of the main drawbacks of existing inspection methods is the need for an extremely experienced technician to interpret the acquired data correctly. For example, a joint study carried out by MTI and EPRI on heat exchanger mockups demonstrated that one technician found 87% of the defects, whereas a second technician found only 50%. In addition to being potentially inaccurate, this type of subjective interpretation is also slow. As implemented by AcousticEye, our APR equipment scans the measurements for reflections that indicate a potential flaw. An entire session consisting of hundreds of measurements can be scanned in several minutes, flagging all the suspected signals. If the technician so desires, he can rapidly scan them visually to verify the automatic diagnosis. This speeds up the process considerably, putting it also on a more objective basis.

A critical look at APR

Beyond the issues described above, APR has several inherent advantages that must be balanced with its drawbacks, on a case by case basis.

First, APR is extremely fast in comparison to other methods – about 9 seconds per tube. This can add up to an enormous time savings in comparison to other methods. In most cases, this can enable inspection of all tubes in a given heat exchanger, whereas other methods would force sample-based testing in order to comply with tight shutdown schedules. APR is also independent of tube material, be it ferromagnetic metal or not, or even graphite, plastic, composite or any other. In addition, APR can easily be used to inspect U-tubes, since the acoustic signal propagates through bends with no difficulty.

On the other hand, APR is purely an Internal Diameter (ID) tool, giving no indication of defects on the tubes' outer surfaces. It is also sensitive to fouling, to a certain degree: any defects covered by deposits will not present themselves to the inside of the tube, therefore they will not be detected. Of course, it is not the only inspection method to require cleaning, as IRIS requires much higher degrees of cleanliness. In fact, this can also be considered an advantage: there is currently no inspection method that can be used to verify the degree of internal cleanliness of a heat exchanger. APR has been used successfully in assessing tube cleanliness at various stages of the process, which is valuable information for operators, since cleanliness has a direct effect on heat exchanger efficiency.

Summary

APR is gaining acceptance rapidly as an ID inspection tool for heat exchanger tubes. Independence of tube wall material, the ability to go through bends, and the objective criteria for fault identification make this technique very useful. In addition, short inspection time per tube enables inspection of entire heat exchangers, without the need to resort to sampling.

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