White Paper

AcousticEye International

Condenser Tube Examination Using Acoustic Pulse Reflectometry

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CONDENSER TUBE EXAMINATION USING ACOUSTIC PULSE REFLECTOMETRY

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ABSTRACT

Acoustic Pulse Reflectometry (APR) has been applied extensively to tubular systems in research laboratories, for purposes of measuring input impedance, bore reconstruction, and fault detection. Industrial applications have been mentioned in the literature, though they have not been widely implemented. Academic APR systems are extremely bulky, often employing source tubes of six meters in length, which limits their industrial use severely. Furthermore, leak detection methods described in the literature are based on indirect methods, by carrying out bore reconstruction and finding discrepancies between the expected and reconstructed bore. In this paper we describe an APR system designed specifically for detecting faults commonly found in industrial tube systems: leaks, increases in internal diameter caused by wall thinning, and constrictions. The system employs extremely short source tubes, on the order of 20cm, making it extremely portable, but creating a large degree of overlap between forward and backward propagating waves in the system. A series of algorithmic innovations enable the system to perform the wave separation mathematically, and then identify the above faults automatically, with a measurement time on the order of 10 seconds per tube. We present several case studies of condenser tube inspection, showing how different faults are identified and reported.

INTRODUCTION

During the last several decades, Acoustic Pulse Reflectometry has been studied in several research laboratories for probing tubular systems. The principles of APR are simple to explain, though the theoretical and practical difficulties involved in implementation of this technology are numerous.

APR Basics

An acoustic pulse injected into a semi-infinite straight walled tube will propagate down the tube without generating any reflections. This pulse can be measured by mounting a small microphone with its front surface flush with the internal tube wall, through a hole in this wall. The microphone will measure the pulse once only, as it passes over the microphone diaphragm.

If however, the pulse encounters a discontinuity in cross section, a reflection is created. The amplitude and form of the reflection is determined by the characteristics of the discontinuity: a constriction will create a positive reflection, whereas a dilation (increase in cross section) will create a negative reflection. Neither of these discontinuities will change the shape of the pulse in their vicinity, but the reflection measured by the microphone will be an attenuated and smeared replica of the impinging pulse, due to propagation losses [4]. A hole in the tube wall, on the other hand, will create a reflection having a more complicated shape, affected by the size of the hole and the radiation of acoustic energy to the space outside the tube [3]. Schematic examples of these cases are presented in Figure 1.

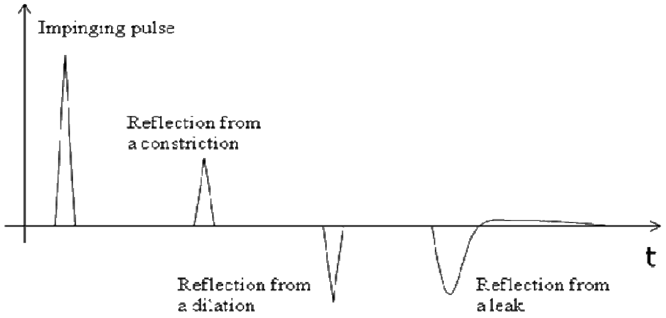

Figure 1: Schematic examples of reflections from discontinuities

Though some of the acoustic energy present in the original pulse is reflected at discontinuities, some of this energy continues to propagate down the tube. Any further discontinuities will once again create reflections. Therefore, diagnosing the internal condition of the tube is a matter of correctly interpreting the reflections as they arrive back to the microphone. One aspect of the interpretation is straightforward: the time of arrival of a reflection can be used to calculate the precise location of the discontinuity, since such reflections propagate at the speed of sound. The second aspect of interpretation is more complicated, as it involves inferring the exact nature of the discontinuity from the detailed shape of the reflection. In a practical system the pulse shape is constrained by the capabilities of the transducer, therefore it is more complicated than in the schematic example in Figure 1.

The conceptual system described above needs to be translated to an actual system that can be implemented in the laboratory before it can become a usable tool. This is described in the next section.

Components of a Practical APR System

A practical APR system requires a transducer to create the pulse, and a microphone that measures this pulse and the ensuing reflections. A schematic system is presented in Figure 2.

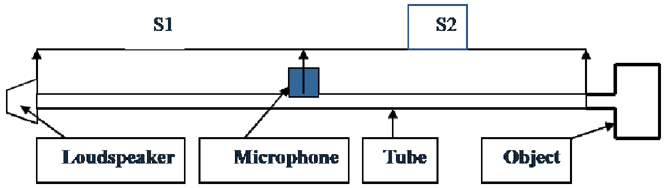

Figure 2: Schematic layout of an APR system

Several practical difficulties present themselves immediately when constructing such a system:

1. Pulse Shape: ideally, the pulse to be used would be a true impulse, of zero width and infinite amplitude, which is clearly not feasible. In practice the pulse should be made as narrow as possible in the time domain, with as little "ringing" as possible, which translates to a shape which is wide and flat as possible in the frequency domain.
2. False Reflections from the Transducer: as reflections from faults propagate back down the system, they impinge on the transducer after passing over the microphone. These could be mistakenly interpreted as reflections from further faults.
3. Signal Overlap: A major problem that occurs in an APR system is overlap between right- and left-propagating signals. The false reflections returning from the transducer can overlap over the microphone with reflections arriving from the pipe system, once again creating difficulties in interpreting them.
4. Signal Interpretation: collecting all the above signals and interpreting them correctly is a complex problem in itself.

Various solutions to the above problems exist, some of them appearing in the scientific literature. One of the main obstacles towards using APR systems in the field has been the most widespread solution to problems #2 and #3 (transducer reflections and ensuing signal overlap). Examining Figure 2, tubes S1 and S2, called "source tubes", located on either side of the microphone, are made as long as practically possible. This enables reflections from faults in the tube to propagate fully over the microphone before reflections from the transducer are created. Such tubes are often several meters in length, depending on the length of the object being examined. This causes the overall system to be extremely bulky and inconvenient for field tests.

Signal interpretation methods found in the literature depend mainly on a procedure termed "bore reconstruction" [1, 2, 3, and 5]. In this procedure, the reflections from the examined system are processed to obtain a full reconstruction of the internal bore of the measured tube. This might seem ideal, but unfortunately this method is associated with numerical instabilities which become more pronounced as the examined tube becomes longer.

Though APR has been used in various research labs [2, 3, 5] for several applications, the problems stated above have prevented this technology from being used widely as a diagnostic tool in the field. This is despite the fact that APR has several potential advantages over more established technologies such as eddy-current, amongst them: no need to traverse a probe along the pipe, no dependence on tube wall material, rapid test time, and the ability to test bent and coiled tubes.

The rest of this paper presents some of the steps taken in development of a portable test system based on APR, incorporating novel solutions to the problems presented above. We describe some characteristics of the system itself and present numerous results from using this equipment in the lab and in the field.

TAKING THE TECHNOLOGY FROM THE LAB TO THE FIELD

The first challenge towards creating a mobile APR was to reduce its size. This consisted mainly of reducing the source tubes to 20cm each. Thus the entire assemble of transducer, microphone and source tubes could be fitted into a hand-held probe, as shown in the photograph in Figure 3. All of the electronics related to synthesizing the pulse, amplifying, capturing and analyzing the results, were fitted into a separate unit.

Figure 3: The AcousticEye Dolphin G3™

Shortening of the source tubes creates overlap between right and left propagating waves, which are then separated using advanced signal processing methods, as detailed in a recently submitted patent application [6]. Some further attenuation of reflections from the transducer was achieved by inserting several layers of acoustically absorbent material at the connection between the transducer and source tube S1.

Once the signal containing the reflections actually due to faults in the tube is isolated from the repeated reflections due to the source, this signal must be scanned in order to determine if any faults actually exist, and if so – what kind of discontinuity caused them (constriction, dilation or hole). This must be carried out while taking into account that background noise is always present, potentially causing false identifications.

Since the focus of the present paper is on demonstrating test results rather than technology, we will not go into detailed descriptions of underlying the signal processing algorithms. The following sections will describe performance of the industrial APR in laboratory as well as field conditions.

APPLYING APR

Several factors determine whether the APR system identifies faults correctly: the level of background noise, the distance of the fault down the tube (since the pulses decay over distance, due to friction with the tube walls), and the accuracy of the detection algorithms. In order to isolate these factors as far as possible, extensive testing was carried out in the lab before venturing out into the field.

We first present results of several experiments conducted in laboratory conditions, where we could create known faults and then determine whether the APR system could identify them correctly.

Generic Examples from Laboratory Measurements

Initial tests were conducted on aluminum tubing with an internal diameter of 25.4 mm, and wall thickness of 1.04 mm. Though aluminum is not used for condenser tubes, APR is insensitive to the material the tubes are made of. Therefore aluminum was used as matter of convenience. The same results would be obtained whether they were made of brass, steel, titanium, or any other rigid material. Several generic faults were created: a hole of 0.7 mm diameter was drilled in one tube. Another tube was scored on the inside with a lathe, and a washer was inserted in a third tube to create a constriction. Figures 4, 5 and 6 show the resultant measurements registered by the APR system. All three types of faults show up clearly as compared to a reference measurement taken from a different tube. These tubes were of 3 meters in length, which is shorter than most condenser tubes, but the results were found extremely encouraging. Algorithms for automatic detection and classification of faults were also developed, though these will not be discussed here in detail.

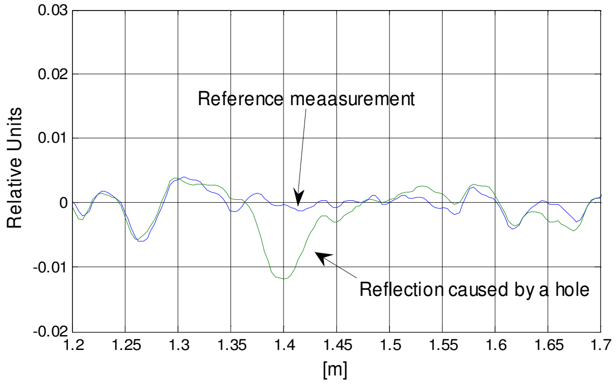

Figure 4: A segment of a measurement showing a reflection from a hole in the tube wall, vs. a reference measurement of tube without a hole.

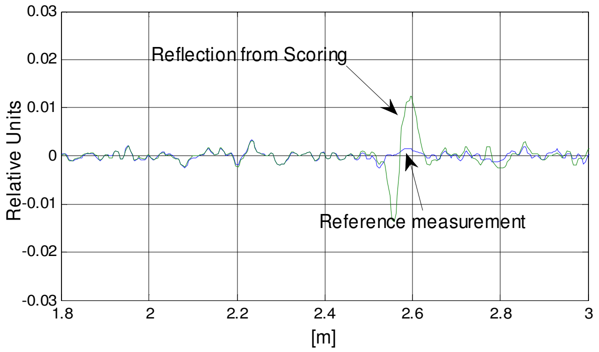

Figure 5: A segment of a measurement showing a reflection from scoring of the tube wall, vs. a reference measurement. Scoring creates a local enlargement of cross section, therefore the reflection is a negative pulse followed by a positive one.

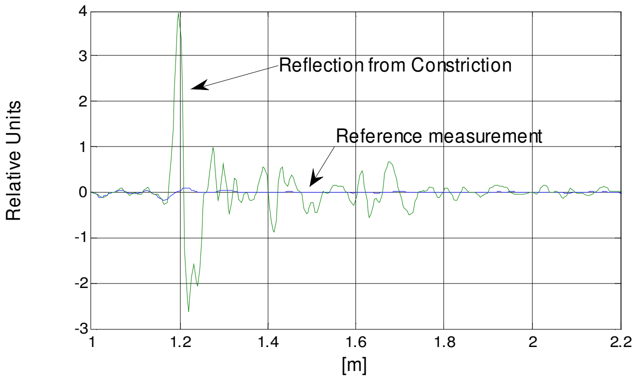

Figure 6: A segment of a measurement showing a reflection from a constriction created by a washer in the tube, vs. a reference measurement. The constriction is a local decrease in cross section, therefore the reflection is a positive pulse followed by a negative one.

Field Tests

Field tests of the APR system described here were next conducted on several condensers found in power plants in the USA, Europe. Such tests proved beneficial in refining the APR system's operation and of course to the operators of the power plants themselves. Results of two such tests are described below as typical test cases: one case of emergency maintenance, and one case of routine maintenance.

<u>Test Case I:</u> Emergency Maintenance

In February 2008, water chemistry sensors in one of the turbines in a power plant, indicated that cooling saltwater used in the condenser was leaking into the steam. Since this took place during a season of peak load, the turbine could not be stopped completely. Instead, emergency measures were taken by the maintenance staff. The condenser has four separate quadrants which can be emptied independently. Temporary plugs were inserted in a large number of pipes in a quadrant that was under suspicion. The following night this quadrant was emptied once more, several columns of plugged pipes were re-opened, and then examined using APR. It is noteworthy that the turbine was operative at the time, so that the levels of background noise were extremely high. As the results will show, this had no significant impact on the measurements.

Due to an extremely tight schedule, measurements were performed and then analyzed on the spot. The tubes were only partially cleaned prior to analysis. 6 tubes out of the 200 that were examined were found to have both large accumulations of deposits and suspected leaks. The measurement from one of these is presented in Figure 7.

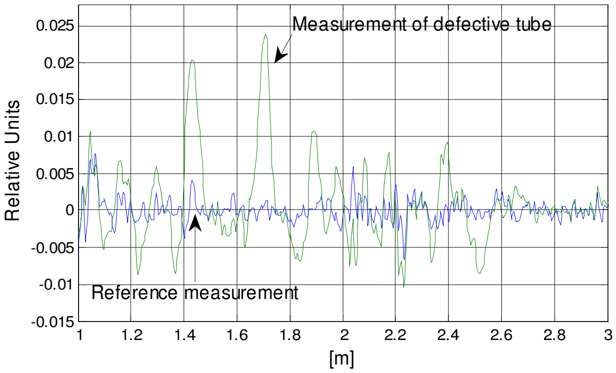

Figure 7: a segment of a measurement taken from the Reading condenser

These six tubes were plugged. Subsequently, the power plant maintenance team informed us that that the power-plant output increased by 15% the following day.

<u>Test Case II:</u> Routine Maintenance

In this case, APR was used to examine a condenser opened for routine maintenance, at Miami Dade Resource Recovery Facility. The face plates covering one side of the condenser were removed, exposing the tubes to inspection. One quadrant of the condenser, composed of 1140 pipes, was fully inspected in 190 minutes, giving an inspection time of 10 seconds per tube. The map of this quadrant is presented in Figure 8.

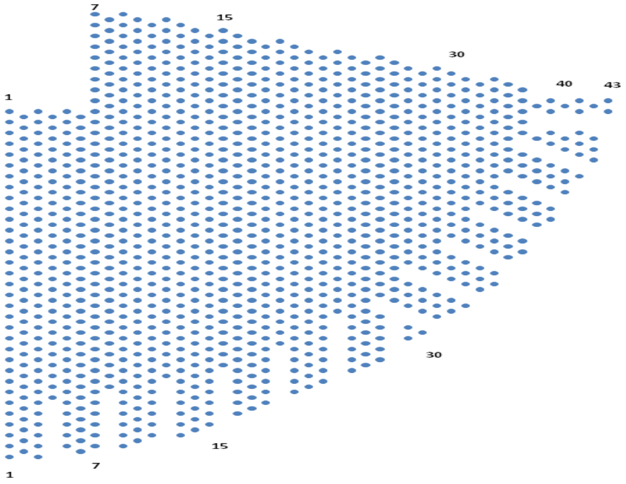

Figure 8: the inspected quadrant of the Miami condenser. Some of the column numbers are marked for reference.

Inspecting this condenser using APR revealed interesting information regarding the internal state of the tubes.

APR, similarly to other methods, requires that tubes be cleaned prior to inspection. This is necessary so that deposits do not cover any possible instances of holes or pitting. Since APR does not use a traversing probe, there is no danger that measuring uncleaned tubes will damage the equipment, but it can affect the integrity of the measurement. One of the interesting facts that came to light when inspecting this condenser was that the cleaning had not been carried out thoroughly. APR measurements give a clear indication in such cases, showing the presence of many slight constrictions due to deposit buildups which had not been cleaned off. One typical measurement of such a case is shown in Figure 9. In this condenser it was found, for instance, that the lower 2-3 tubes in each column had not been cleaned.

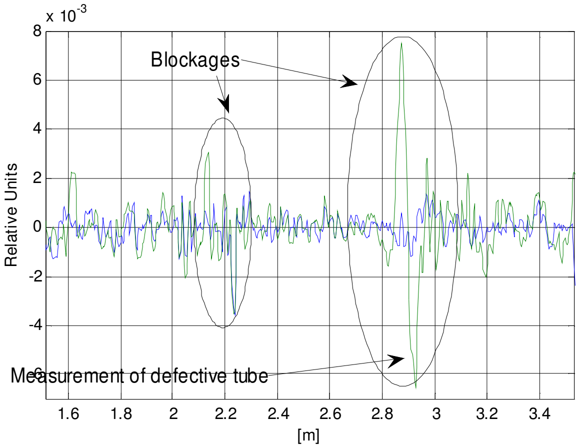

Figure 9: a segment of a measurement showing two local blockages, indicated by a constriction (positive spike) followed by a dilation indicating return to nominal cross section (negative spike).

The Miami condenser, using fresh water in a closed loop as a coolant, exhibited fewer deposits than the Tel-Aviv condenser. The latter uses filtered seawater, which can sometimes cause shellfish to grow in the condensers, blocking some of the tubes. Nevertheless, several full or nearly full blockages were found in the Miami condenser, which could easily have damaged other types of test equipment.

Finally, an interesting pattern of wall tube degradation appeared in one area of the condenser. A majority of the 80 pipes found in columns 35 to 43 exhibited one of two indications: either a local increase in cross section, indicating pitting, or an increase of cross section throughout approximately the last half meter of the tube, on average. Figures 10 and 11 show one measurement each, typifying the above faults.

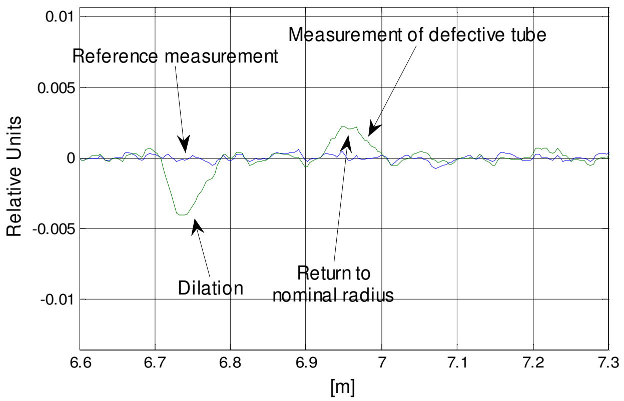

Figure 10: a measurement showing local increase in cross section – a dilation - followed by return to nominal cross section

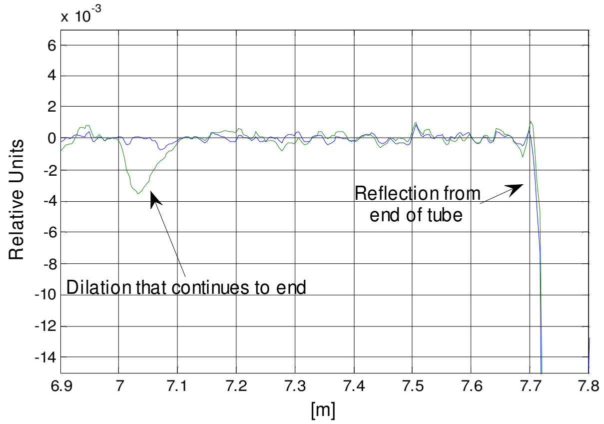

Figure 11: a measurement showing increase in cross section down to the end of the pipe – a dilation not followed by a return to nominal cross section

The fact that these faults were concentrated in one region of the condenser is probably due to some flow pattern in the condenser. In any case, these tubes were flagged for periodic surveillance or replacement.

SUMMARY

The examples shown above, taken from both laboratory and field tests, demonstrate the abilities of APR very well. The results presented here demonstrate a single aspect of the APR system, showing in detail how faults in the examined tube are manifested in the registered signals. Additional aspects of our instrument, crucial in making it a useful tool have been only touched upon. The usability of the Graphic User Interface (GUI), the ability of the incorporated software to scan an entire set of measurements and produce a report automatically, indicating all the faults found in a condenser along with detailed descriptions of each – these are important features in themselves, which aid in turning a promising technology into a productive tool.

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