NEW FAST NON-DESTRUCTIVE INSPECTION TECHNIQUE OF HEAT EXCHANGER TUBES APPLYING ACOUSTIC PULSE REFLECTOMETRY (APR)

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ABSTRACT - *The aim of this work is to introduce you new heat exchanger inspection technique, applying APR - Acoustic Pulse Reflectometry. This technique is not new. It has been used since decades for tube inspection, but in laboratory enviromental. Now APR is applicable in real industry for precise detection of every changes in cross sectional area in an inspection tube. The technique involves the injection of a sound pulse (one dimensional acoustic waves) into the tube under investigation and recording of the resultant reflections. Analysis of the reflections gives information about any changes in internal crossectional area of the inspection tube.*

1. INTRODUCTION

The next generation of tube inspection is using Acoustic Pulse Reflectometry (APR). Utilizing APR technology, the AcousticEye patented tool Dolphin G3 enables rapid and accurate inspections of every tube, regardless of size, shape or material. Dolphin G3 allows 10-20 times faster inspection than traditional invasive inspection technologies. It is accurate and sensitive tool for detecting Inside Diameter (ID) faults, like blockages (full or partial), pitting and erosion, and holes.

AcousticEye Ltd. was established in 2005 by Tal Pechter and Dr. Noam Amir to bring Acoustic Pulse Reflectometry to the NDT industry. Tal Pechter, after some years in the aeronautics industry, was coming out of a startup that had been developing solutions for Sleep Apnea. Dr. Noam Amir has been an academic, having carried out research on Acoustic Pulse Reflectometry (APR) at an earlier stage in his career. Tal Pecher had been searching for a noninvasive method to probe the human airway during sleep, and found Dr. Amir through an internet search to find solution to involve APR in Non-destructive testing.

Up until then, since decades, Acoustic Pulse Reflectometry (APR) has been applied in academic labs in many different fields.

For example from 1960-s was originally developed as a seismological technique for observation of stratifications in the earth's crust. Drilling deeply into the ground is a very expensive operation. The earth's crust is made up of layers of different types of rock. Information about them can be get from carrying out several explosions on the surface and measuring the waves reflected from changes in rock and ground density. From the boundary reflection coefficients and the impedance of the surface layer of rock, the impedances of deeper layer could be calculated.

From 1970s APR has used in medicine as a method for measuring human and animal airway dimensions. The medics have applied a sound pulse to the airway under investigation and have recorded the reflections at the lips, to have calculated the area profile of the airway [1].

From 1980-s APR has applied for measuring internal bore of tubular wind musical instruments by analyzing the reflections which occur when an acoustical pulse is directed into object. The leadpipes are designed to form the initial, or lead, part of a trumpet ***(Figure 1)*** *or cornet and their internal radii differ by less than 0,1mm between similar pipes.*

Figure 1 Trumpet

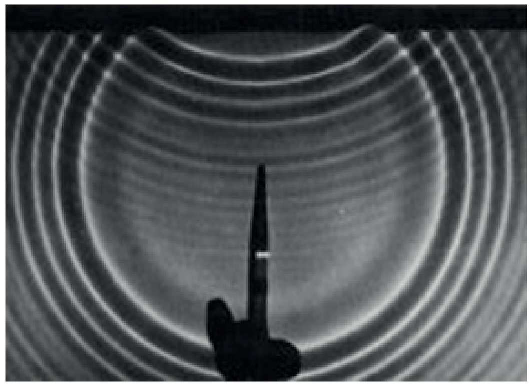
APR has been able to detect these small differences, which are considered by players to produce a noticeable difference in the sound of an instrument. It is able to distinguish between leadpipies with different nominal radii varying by as little as 0.03mm. This technique has used as a diagnostic tool by the instrument manufacturer to detect defects which are significant enough to acoustically alter performance. The absolute accuracy of the radius measurements is also considered at the end of the leadpipe, where the uncertainty is ±0,05mm [2]. In this paper is presented a short introduction to Acoustic Pulse Reflectometry (APR) and how it operate in heat exchanger tubes inspection.

2. BASICS OF ACOUSTIC PULSE REFLECTOMETRY (APR)

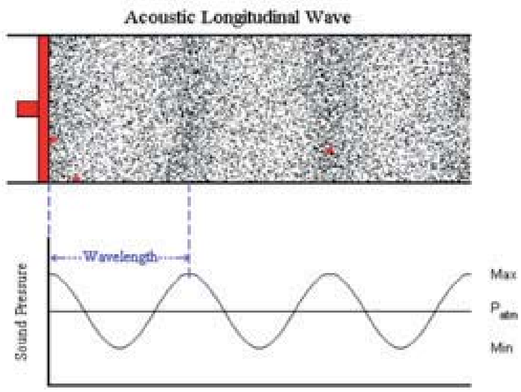
The acoustic waves mean transferring energy through some medium without transferring matter. For example when we talk, sound waves come out of our mouth, but the molecules of air near our mouth don't travel all the way to listener's ears. To be generated one acoustic wave it is necessary to have sound source and medium. Medium is something, where waves propagate through, in our case – air. The medium can be gas, liquid and solid. Acoustic waves can't propagate in vacuum. Important property for medium is to be elastic, because waves cause alternating compression and rarefaction, ***(Figure 2,b)****.*

Waves in free space (no walls) propagate in all directions. When they hit a wall or any other object during their propagation then will happen complicated things: reflection, scattering, etc. when waves ''hit" each other nothing's happens. Their local values sum up, but actually they continue to propagate independently of each other ***(Figure 2,a)****.*

In narrow space such as a tube they propagate along the tube in one direction. These waves are also called one-dimensional waves.



(a)



(b) isvr

Figure 2 Propagation of Acoustic waves in free space –a); creating compression and rarefaction-b)

The principle of APR tool is relatively simple ***(Figure 3)****. It involves sending an sound impulse in the media (air) inside the inspection tube and measuring all reflections caused by various defects. The impulse act essentialy „virtual probes", which differs in two significant ways: it cannot get stuck and it operates at the speed of sound. The impules will propagate in the medium and will undergo partial reflection and partial transmission at each change in cross-sectional area along the tube, creating a reflection sequence. This sequence returns from the defect and travels back up without further reflection. The reflections are recorded by a microphone and analyzed.*

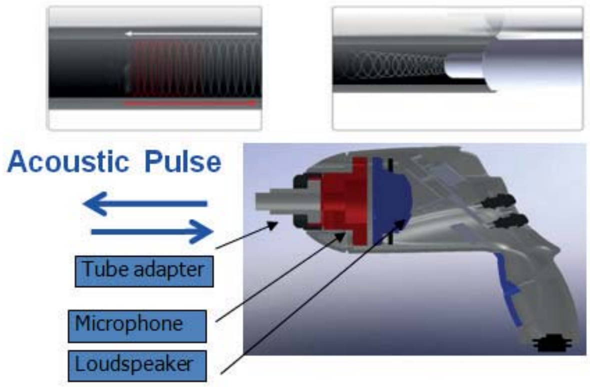


Figure 3 APR tool and propagation of acoustic pulse in tube

From the point of view of a pulse traveling down a tube, can occur three basic changes in cross section: a reduction in cross section caused, for example, by some kind of blockage; an increase in cross section, caused by wall loss or bulges; and a through hole. Importantly, the reflections caused by these three cross-section alterations are very different from each other. ***Figure 4*** *shows a schematic representation of the reflections caused by each kind of fault. The signatures in* ***Figure 4*** *are over simplified. Real-life signals are noisier and less uniform than theory might lead us to believe, although the main features are clearly visibul.*

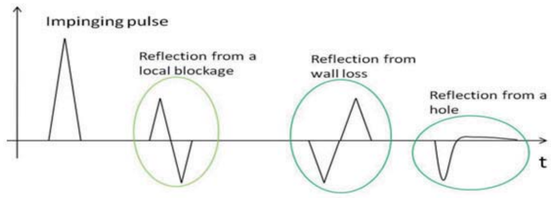


Figure 4 *Various types of faults cause different types of reflections[3]*

3. APR TUBE INSPECTION SYSTEM

Taking APR out of academic labs and turning it into a practical industrial tool involves several important challenges. The entire process of creating a pulse and measuring the reflections must be performed in the shortest time as possible, in a process that can be repeated reliably many thousands of times.

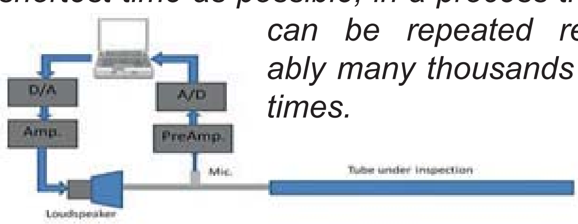


Figure 5 *Block diagram of the pulse creation and measurement system [3]*

The general block diagram of such system is outlined in ***Figure 5****.*

A controller, preferably a computer, creates a pulse in software and outputs it to a Digital/Analog card, which drives a power amplifier. The amplifier drives a loudspeaker, which creates an acoustic pulse in the inspected tube. The reflected waves are recorded by a microphone, after which they are digitized by an A/D card and stored in the computer. The digital signals must be processed by software to interpret and classify them into various types of faults as well as to quantify them.

The process of measuring a real signal (voltage signal from a microphone) and storing it in a digital computer involves three steps: 1. The probe creates acoustic waves in the inspection tubes; 2. Microphone translates reflection to electrical signals; 3.Transferring an electrical signal into the memory of a digital computer (analog to digital conversion-A/D).

Analog to Digital conversion (A/D) actually involves two steps: sampling- measuring the analog voltage signal at regular intervals and quantization- representing these voltages as numbers in the computer's memory. Sampling is a straightforward process. The analog signal is measured at regular intervals (sampling period-T), ***Figure 6****.*

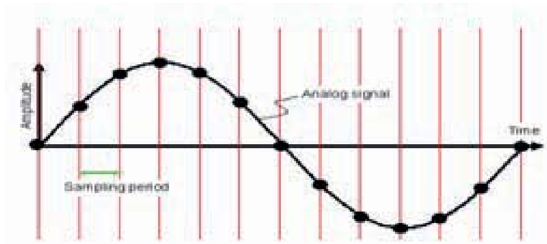


Figure 6 *Example of analog signal sampling*

If sampling period is small enough it is impossible to lose any signal. The number of samples per second (1/T) is called sampling rate. In the patented Acoustic Eye APR Tube Inspection System Dolphin C3 sampling rate is 48kHz throughout, which is 48000samples/second.

Sampling translates the voltage to numbers. Numbers are represented in the computer with ˝bits˝ (binary digits).

Patented system Acoustic Eye APR Tube Inspection System Use 16 bits per sample throughout, which gives 655 536 different values.

Each stage in this process presents unique challenges at the hardware and software levels. Addressing them correctly distinguishes a useful tool from just another nice idea.

Obtaining clean measurements is one part of the equation, but analyzing these measurements to find indications of faults is also important. Although in many NDT methods this is left to the technician, human interpretation is slow, error-prone, and highly dependent on the technician's proficiency. Applying APR correctly, the range of known possible faults can be simulated and compared to the actual measurements. With the proper on-screen presentation this can aid the human interpretation process as well as advance towards automatic interpretation, speeding up the analysis by an order of magnitude and turning it into an objective rather than subjective process.

APR Tube Inspection System operates without probes to drag through the tubes, no need for standards, it is easy to operate and made inspection with speed of sound. It is an accurate and sensitive tool for detecting ID faults in tube systems. It gives the location of faults and indicates their severity. This inspection method is not affected by bends in the tubes.

The tool has two parts **(Figure 7)** : a probe or a gauge and a main unit- computer. The probe contains mainly acoustic components: loudspeaker, which produced sound pulse and microphone, which record all reflections, created from any changes in ID (Internal Diameter). The computer has task: signal processing, data management and graphics.

Figure 7 Acoustic Eye's APR tool - Dolphin G3

4. TUBE INSPECTION PROCESS, USING THE NEWEST ACOUSTICEYE'S PATENTED APR TOOL - DOLPHINE G3

The tube inspection process comprises the following steps:
Step 1 - Mapping of site and generation of work plan:
In this stage, a photography or schematic diagram of the heat exchanger is uploaded to the system in order to create a map of the tube openings. Each of the tube openings is assigned a number. This enables the system to create a graphic representation of the heat exchanger and to keep track of which tubes have already been measured, allowing the technician to work in a systematic manner, (Figure 8).

Figure 8 2Dmap of inspection heat exchanger

Step 2 - Setup of Inspection Parameters:

Using Dolphin's intuitive user interface, the technician sets the inspection parameters related to the physical attributes of the tubes. These parameters include the tube's length, diameter, wall thickness, the probe adaptor's...

Step 3 - Taking the Measurements

Using Dolphin's compact handheld probe, the technician begins to inspect the tubes in accordance with the site map and work plan. The probe is applied to each tube opening for approximately 9 seconds. It emits an acoustic pulse and then measures the resulting reflections using APR technology. LEDs on the probe indicate when the measurement is complete and the software guides the technician to the next tube to be measured.

***Step 4** – Establish Reference Measurement and Set Inspection Thresholds*

Once all of the measurements have been taken, the system calculates a reference measurement based on an intelligent average of the measurements, taking into account statistical deviation and the presence of ambient noise. Any measurement beyond that deviation is a potential flaw. In addition, the system enables the heat exchanger owner to determine thresholds for each type of flaw depending on the sensitivity of the given application (e.g., percentage of wall loss, blockages, etc.). Only those measurements that exceed the defined threshold are reported as flaws.

***Step 5** – Generate Report and Analyze Results*

This is the stage in which the raw data (i.e., signals) collected by the system is interpreted and presented to the technician for analysis. This entire process is performed automatically by the system software.

Using breakthrough algorithms, software identifies the different signatures of each type of flaw, allowing the system to automatically identify every defect. It pinpoints the location and determines the severity of every problem in an objective and consistent manner. The precision and sophistication of detection algorithms are field-proven to ensure accurate identification of faults, regardless of the presence of background noise or the distance of the fault down the tube.

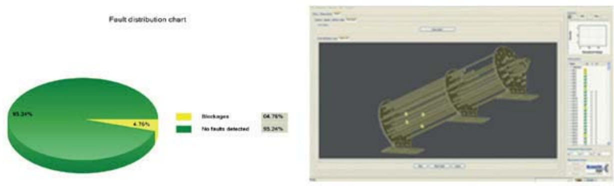


***Figure 9** Report and 3D model of heat exchanger, showing faults place*

The system flags all "suspicious" measurements which may indicate a fault and presents them in an easy-to-read online report for verification.

*The technician can drill down to obtain additional information on each measurement (including the signal graph) as needed before accepting or rejecting each flagged item, **(Figure 9)**.*

5. APPLYING APR

5.1 CHECK ID (INTERNAL DIAMETER) CONDITION

*APR technology allow from single point to check ID (Internal Diameter) tube condition, rapid and accurate in all tubes shapes and materials. The detected faults in tube are: blockages, partial blockages, pitting, corrosion, erosion, leaks **(Figure 10)**.*

***Figure 10** Tube defects causing failures. 1- partial blockage; 2- corrosion; 3-pitting; 4- hole*

5.2 CHECKING THE CLEANSINGS OF THE TUBES

Tube cleaning is a painful and somewhat controversial issue in heat exchangers inspection and maintenance. Depending on the operating environment, heat exchanger tubes can be fouled by a plethora of mechanisms, such as various forms of sludge, sediments and deposits, scale, and even shellfish. Cleaning out the tubes can be costly, time-consuming, and in some cases quite difficult. The approach to cleaning tubes during turnarounds varies greatly among operators.
On the one hand, deposits such as scale create a thermal and physical barrier in the tubes, reducing the overall efficiency of the

heat exchangers, and therefore it is often in the interest of the operator to clean the tubes. However, this process is often perceived as necessary to the inspection process, rather than for correct operation of the heat exchangers. Regardless, the cleaning process is very hard to control; up to now, no easy method existed for comparing tube condition before and after cleaning. APR, in contrast to the other technologies, does not require tubes to be cleaned before they are measured.

Before

After

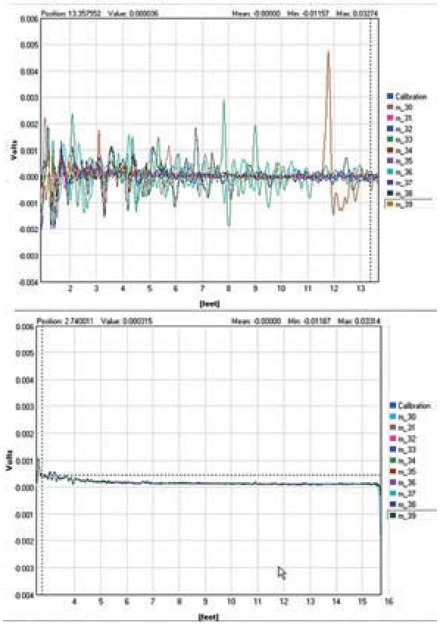


Figure 11 Comparison of measurement results for tube before cleaning (upper graph) and after cleaning (lower graph) [3]

Measuring a dirty tube will simply give strong indications of partial blockages along the tube, which then can be compared to measurements taken after cleaning. Figure 11 presents an example of such a comparison, showing the effectiveness of the cleaning. Thus, APR is a viable tool for quality control of tube cleaning in addition to detecting defects.

5.3 ACOUSTICEYE'S PATENTED APR TOOL WAS TESTED IN EMERGENCY MAINTENANCE [4]:

"In February 2008, water chemistry sensors in one of the turbines in the Reading power plant in Tel Aviv, Israel, 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 shown, 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. These six tubes were plugged. Subsequently, the power plant maintenance team informed us that the power-plant output increased by 15% the following day."

6. CONCLUSIONS

Acoustic Pulse Reflectometry (APR) method is based on sending an acoustic pulse (one-dimensional acoustic waves) into an internal tube medium (in our case air) and measuring any reflections created somewhere in this medium. Any change in the cross-sectional area in the tubular system creates a reflection, which is then recorded and analyzed in order to detect defects. The amplitude and form of the reflections is determined by the characteristics of the discountinuity.

Due to the bases of this inspection technique, this method reveals precisely any changes on the internal diameter (ID). It cannot detect defects on the Outer Diameter (OD). AcousticEye utilizes non-invasive APR technology to create a "virtual probe", which can navigate all shapes. Without difficulty eliminating the need from probes that can get stuck or damage the tube.

This technology allow test any tube from a single point outside the tube in less than 9 seconds, saving considerable time and resources.

This method has many advantages in comparison with other tube inspection methods. It is faster and cheaper, and allow testing every tube in contrary to sampling, significantly reduces risk and downtime; work with any tube configuration- bends, valves, bulges, fins; material independent- inspects all type of tubes, e.g. ferrous, non-ferous, carbon, brass, plastics, glas... APR guarante extremely accurate signal analysis- pinpoint detection of location, size and type of defect even in the presence of ambient noise. AcousticEye's APR tool Dolphin G3 detect crack 0,5mm in 40m length tube. APR can lead tube inspection in one emptied separate quadrants in independently heat exchenger, while other separate quadrants are in normal working mood.

7. REFERENCES:

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[4] Noam A, Barzelay O, Yefet A, Pechter T, Condenser Tube Examination using Acoustic Pulse Reflectometry- Proceedings of POWER2008, ASME Power 2008-60169, July 22-24, 2008, Orlando, Florida, USA (http://www.acousticeye.com/Assets/asme-power-2008.pdf)

POZIV

na Redovitu godišnju skupštinu HDKBR-a

koja će se održati 14.12.2012. (petak) od 14:00- sati u u prostorijama Hrvatskog inženjerskog saveza, Zagreb, sa sljedećim dnevnim redom:

Prijedlog dnevnog reda:

1. Prihvaćanje dnevnog reda
2. Prihvaćanje zapisnika predhodne sjednice
3. Izvještaj o radu za 2010 godinu i pregled o radu u 2011. godini
4. Članstvo i organizacija društva
5. Izbor novog člana UO-a
6. Program rada u 2011/2012. godini
7. Različito

Molimo članove HDKBR-a da sjednici prisustvuju i svojim učešćem doprinesu daljnjem razvoju HDKBR-a.

Nakon Skupštine slijedi Božični domjenak.