Detection of Internal OR External Pits from Inside OR Outside a tube with New Technology (EMIT)

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Abstract

The EMIT Technique is a new technique that allows corrosion examination of metallic tubing. EMIT allows corrosion exams and pit detection in areas and conditions where other techniques are less sensitive or totally unfeasible, including:

- Near baffle plates and in aluminum-finned tubing (in case of Conventional Exchangers)
- Dips, Crests and Mid Span (in case of Twisted Tube Exchanger).

The travel time and signal strength — phase and amplitude — of the received signal are plotted in strip chart and voltage plane format to identify and characterize defects. Metal loss causes the field to arrive at the detector coil with less travel time and less attenuation, resulting in a change in signal phase and amplitude.

This paper focuses on EMIT and its application on the Twisted Tube Heat Exchangers and presents some sample data from different conditions to highlight the sensitivity and utility of the new technique.

Introduction

Since 1985, hundreds of Twisted Tube exchangers have been installed world wide under various field conditions. As this installed base ages and the use of Twisted Tube exchangers becomes more widespread, the need for an optimized method of assessing the tube condition becomes vital.

This paper is dedicated to address this need Russell NDE Systems did some research and embarked on a set of preliminary tests to determine the applicability of the Electromagnetic Inspection Technique (EMIT) to inspect Twisted Tubes. The Electromagnetic Techniques are well-established for the inspection of tubular. The paper is focused on EMIT - equally sensitive to internal and external defects, and has a unique ability to ‘inspect at a distance’. This makes EMIT an ideal candidate for the inspection of Twisted Tubes. It is expected that alternative inspection techniques will have great trouble dealing with the regular diameter variations along the tube helix, while EMIT will be relatively insensitive to these variations. EMIT is capable of detecting defects on both the crests and dips - and any location in between. To verify the potential of this technique for the inspection of twisted tube bundles, Russell NDE Systems performed a feasibility study and it can be concluded that EMIT is a suitable technique for inspecting twisted tube exchangers. It has excellent sensitivity to dip defects, and an acceptable sensitivity to mid-span and crest defects.

Twisted Tube Design

An example of a Twisted Tube is shown in figure 1 below. As can be intuitively understood the unique helix shape promotes fluid mixing during operation of the heat exchanger and thus provides a higher heat transfer coefficient. Even though the surface of the tube has been changed to a helix shape, the actual annulus is still circular (see figure 1 and 2). This is an important consideration in the design of possible inspection probes.

Figure 1. Short section of Twisted Tube.

Figure 2. Circular Annulus

Twisted Tube Heat Exchangers provide a higher heat transfer coefficient than any other type of tubular heat exchanger. They also have complex swirl flow on the shell side to induce the maximum turbulence in order to improve heat transfer. The powerful tube side turbulence is achieved even at high viscosities and/or low velocities. Its uniform flow distribution gives more effective length and surface area than shell & tube exchangers.

The twisted design avoids the need for baffles. By arranging the tubes in a triangular pattern, each tube is firmly and frequently supported by six adjacent tubes. This is shown in the illustration below. The unique shape allows fluid to flow freely along its exterior length, while the individual support system eliminates tube vibration (which is a common problem in some heat exchanger services).

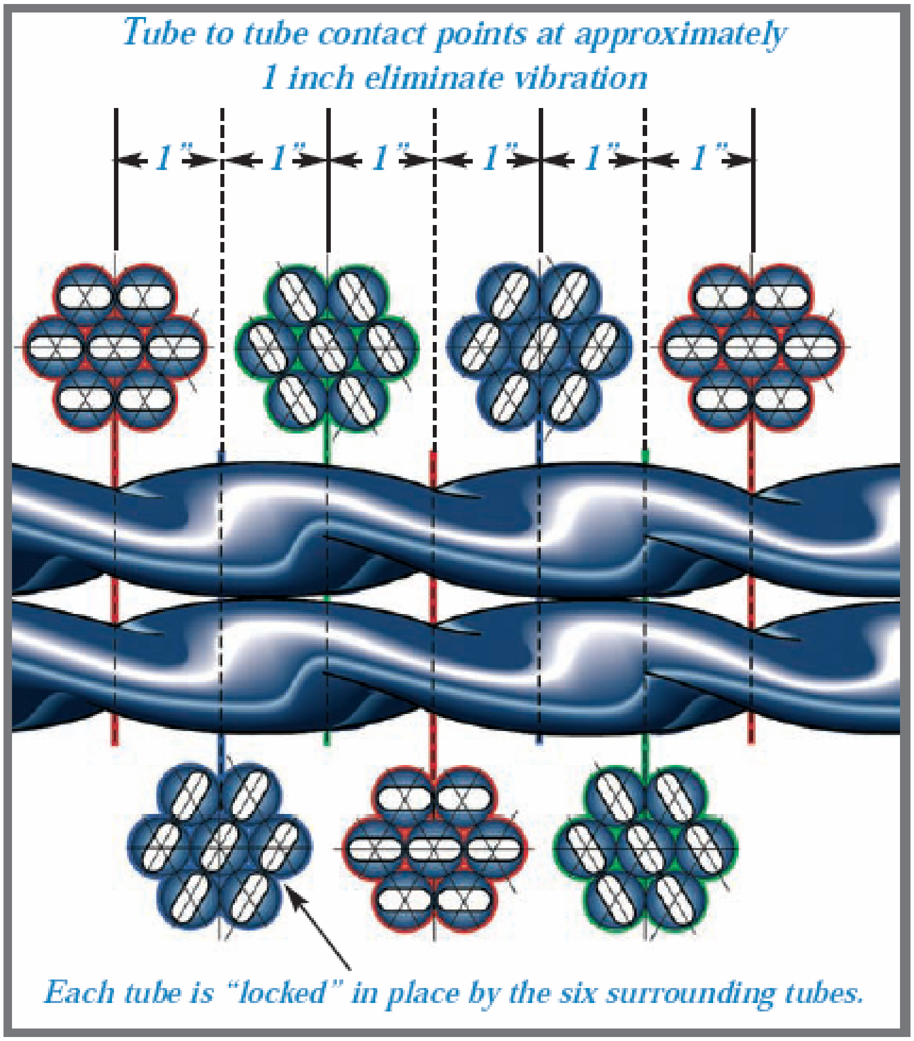


Figure 3. Twisted Tube placement inside the bundle.

To provide the regular individual support, the Twisted Tubes are oriented in the same clock position throughout the bundle so that the gaps between the tubes are aligned. Aligning of the gaps also improves fluid flow and easy access from the shell side for cleaning. At the ends, the Twisted Tubes themselves are round, allowing for conventional tube-to-tube sheet joints to be used. Based on the tube-shape and bundle-configuration explained above, two definitions for possible defect locations can be introduced:

1) Crest. The crest of the tube is defined as 'top' of the helix pattern. i.e. the point on the tube wall furthest away from the center. An individual tube is supported by neighboring tubes at regular points along the crest-line.

2) Dip. The dip is defined as the mid point (or 'valley') between two crests. i.e. the point on the tube wall closest to the tube center. For the purpose of this investigation we will be looking at defects on both the crests and the dips of the tubes.

Approach for Performing the Feasibility Study

The EMIT is equally sensitive to internal and external defects, and is based on the through-wall transmission of radially impinging EM-waves, as it relies on EM waves propagating through the pipe wall, intimate contact with the pipe wall is not required. In fact, as long as the EM waves are not hindered in their propagation, it will tolerate relatively large lift-off distances from the inside pipe wall. This means that EMIT can inspect through non-conducting liners like cement and epoxies. It is this unique ability to 'inspect at a distance', that makes EMIT an ideal candidate for the inspection of Twisted Tubes. As the tube diameter changes along the length of a Twisted Tube, any other inspection technique will have great trouble dealing with the regular lift-off variations. EMIT is expected to be relatively insensitive to these variations, and capable of detecting defects on both the crests and dips - and any location in between.

As a part of this feasibility study we had the following deliverables:

1) A twisted tube will be machined with FBH's (Flat Bottom Holes), 1-T in diameter
(T =wall thickness of tube), on the "crest". The flaws will vary in depth from 20% to 100%in 20% steps, and separated by one half twists. This tube will be tested before machining, after machining and after placement in the bundle.

2) The second tube will have the same flaws machined on the "dip", and the same three tests will be performed

3) Depending on these results, study will continue with stress-relieved tubes, with the same defects, or the defect sizes may be increased or decreased.

4) In all cases, when the tube is placed in the bundle, it will be positioned in the middle of the bundle, with care being taken to ensure that the tubes are oriented correctly.

5) A probe manufactured to fit down the middle of the tube, with a standard clearance no larger than 0.075". No special centralizing or other probe features was used for the first trial.

- **Apparatus**

The apparatus consists of 5 main components:
- Mock-up Twisted Tube bundle.
- Tubes with defects prepared by Russell NDE Systems Inc, positioned in the center of the bundle
- Data acquisition equipment.
- EMIT probe with an OD of 0.350" to just fit the borehole of the twisted tubes.
- Data analysis software.

Twisted Tube Mock-up bundle

The hexagon tube configuration in the Twisted Tubes bundle is illustrated in Figure 4 below. The center tube can be removed, and replaced with any of eight separately supplied tubes. The eight replacement tubes were labeled and are shown in Figure 5.

Figure 4. Small Tube sheet with 19 tubes.

Figure 5. Center tube replacements.

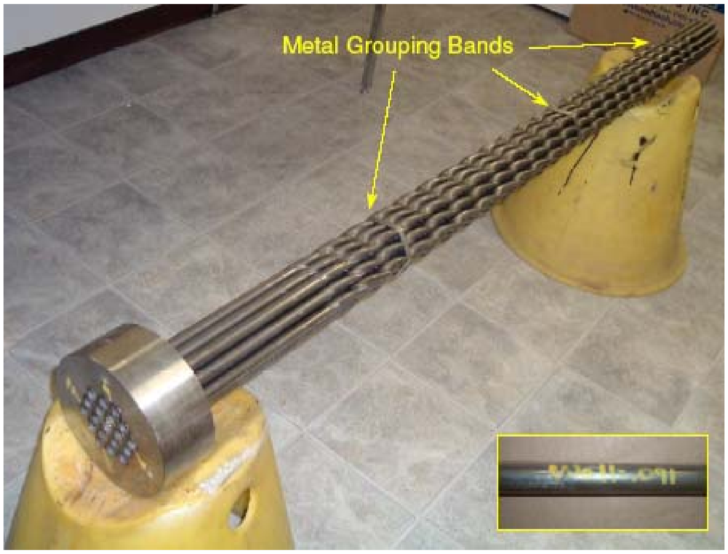
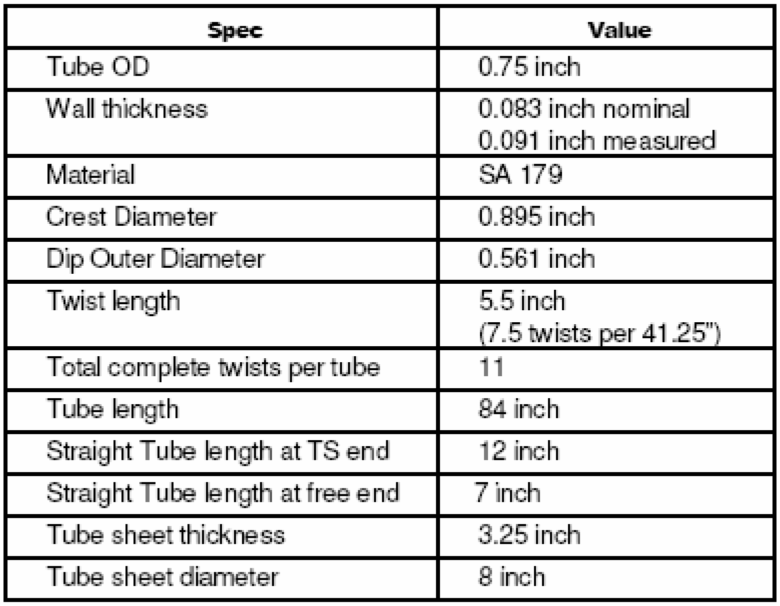


Figure 6. Metal grouping bands ensure tube support along the length of the bundle.

Table1 below gives a complete overview of the mock-up specifications. The twists start gradually at the tube sheet side, and reach their full dimensions in about 1-2 twists.



Spec	Value
Tube OD	0.75 inch
Wall thickness	0.083 inch nominal 0.091 inch measured
Material	SA 179
Crest Diameter	0.895 inch
Dip Outer Diameter	0.561 inch
Twist length	5.5 inch (7.5 twists per 41.25")
Total complete twists per tube	11
Tube length	84 inch
Straight Tube length at TS end	12 inch
Straight Tube length at free end	7 inch
Tube sheet thickness	3.25 inch
Tube sheet diameter	8 inch

Table 1. Properties of the twisted tube mock-up bundle.

- **Instrumentation**

The multi-purpose configurable instrument that allows a host of different probes to be connected was used. The probes are attached to the instrument through the connectors. The instrument used for this investigation was a multi channel, dual frequency system.
Display and Analysis Software was used to view and analyze the data acquired by the instrument. The software allows the user to display the data in several possible ways, and includes automatic sizing features. Four real-time Strip Charts are supported, each with its corresponding Voltage Plane display. The displays can be used to plot the raw data as-is, or perform additional mathematical functions like noise filtering or advanced signal processing operations (so called MIX, Q-Coil, and C-FLTR channels).

Procedure for the Feasibility Study

Initially the research focus was on characterizing EMIT responses in twisted tubes. Later the study included results using the EMIT probe.
The following general procedure was followed for this feasibility study.

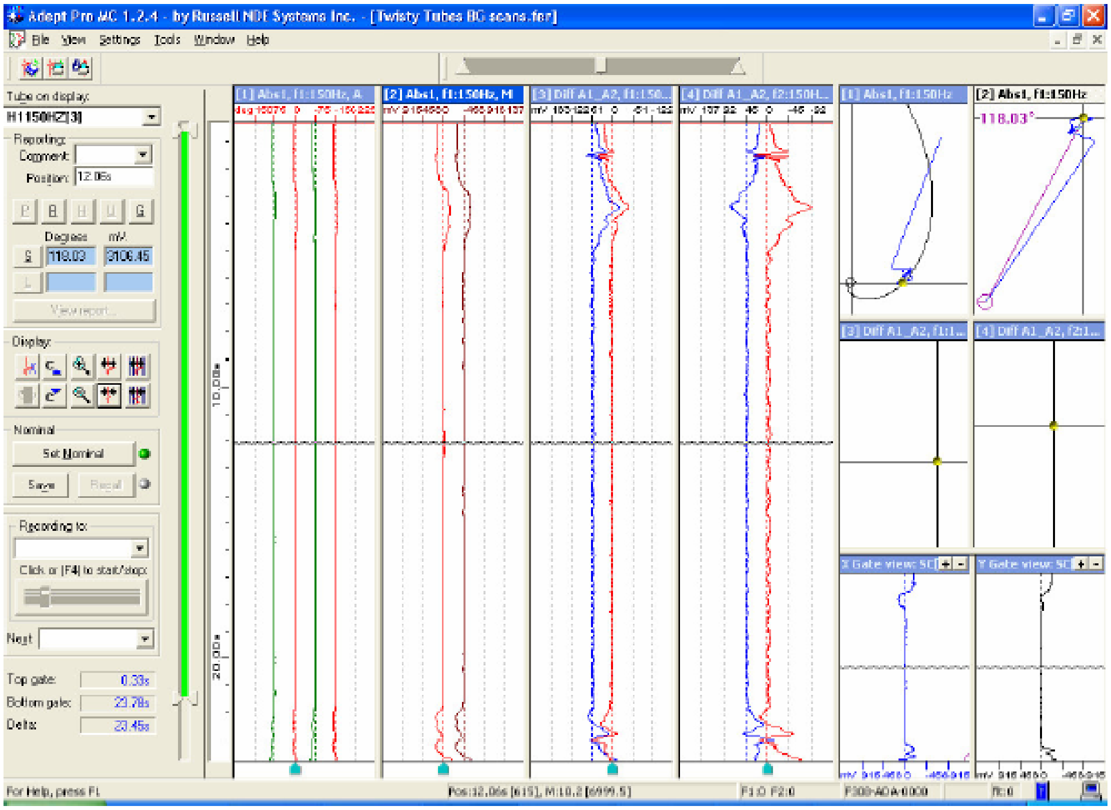
I. Inspect all the individual tubes using the EMIT probe.
II. Determine the optimal inspection frequency. Obtain background scans for all tubes.
III. Determine which tubes to be used for inclusion of defects. Machine the defects.
IV. Scan the machined tubes (with defects) outside the bundle in air. Determine sensitivity.

V. Scan the machined tubes (with defects) as the center tube inside the bundle. Determine sensitivity.
VI. Compare results inside and outside the bundle to determine bundle effect and summarize the results.

➢ Background scans and Characterization of the Twisted Tubes.

During the first stages of the investigation it was found that by varying the inspection frequency, the twists in the tubes can be accentuated (or suppressed). Compare for example the following two scans of tube. The first scan is performed at a low inspection frequency, while the second scan is performed at a significantly higher (4x) frequency. Pay special attention to the fourth strip chart (on the right).

Notice how the higher frequency brings out the twists in the tube. At 600Hz, the individual twists can actually be counted! This is quite unexpected, as the twists are continuous along the length of the tube. There is no discrete start (or stop) for each twist; there is only one start at the beginning of the tube and one stop at the end. The spacing between the twist indications appears to be variable on the data of figure 8, but in all likelyhood this is not the case. The spacing variations are an artifact caused by small fluctuations in the manual scanning speed which is difficult to maintain constant by hand. The fact that the data shows distinct starts and stops must be a result of the manufacturing process. The extrusion process possibly applies variable forces as it draws the twist. These varying forces will cause periodic stress variations along the length of the tube, thus producing corresponding changes in the magnetic properties. The magnetic variations are easily detected with a sensitive electromagnetic technique such as EMIT, and become visible as periodic alterations on the data. If the heat treatment (also called normalization) was performed properly, any manufacturing-related stress effects would be removed. Figures 7. and 8. display the data from one of the heat-treated tubes. As can be seen, the heat relieving shows roughly the same back ground variations at the lower frequency. At higher frequencies however, the heat relieving does appear to produce improvements: the twist indications appear considerably less spiky. This means that the stress variations have become less abrupt (although not totally removed). So the proper heat-treatment does seem to help, but should possibly be applied longer or at higher temperatures to completely remove the twist indications.



Tube on display: H1150HZ[3]

Position: 12.06s

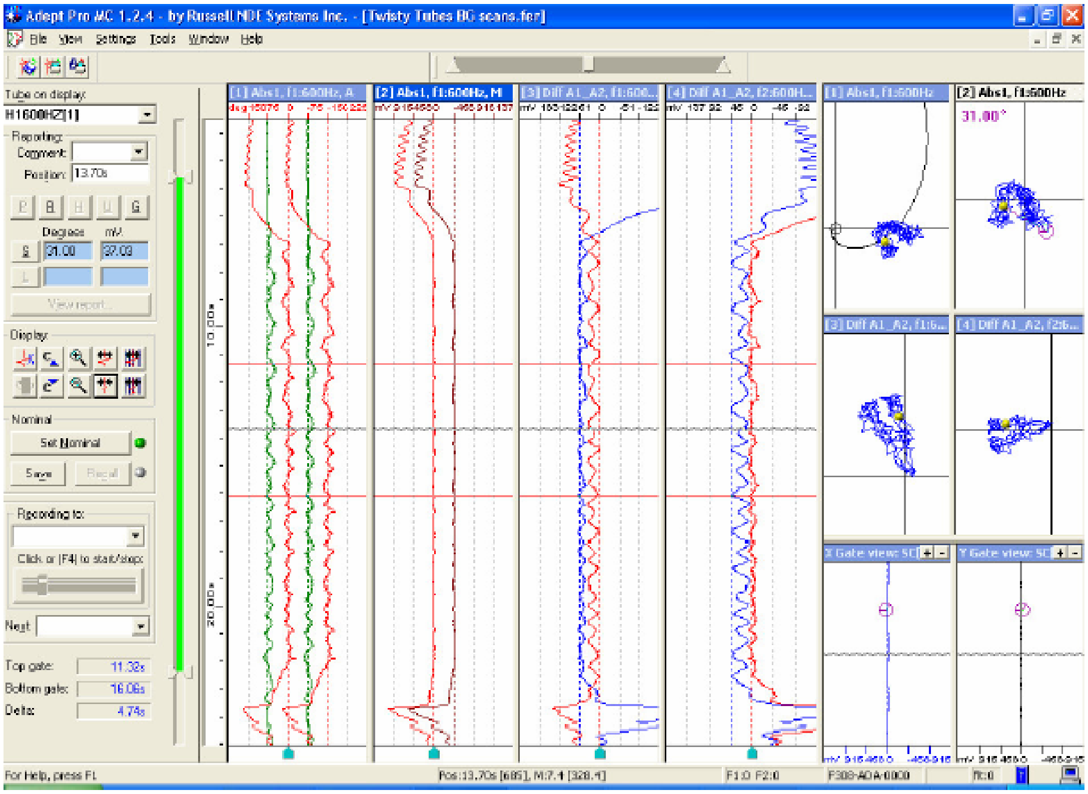
Degrees: 118.03 mV: 3106.45

Top gate: 0.33s

Bottom gate: 23.78s

Delta: 23.45s

Figure 7. Back ground scan of stress relieved tube at 150Hz



Tube on display: H1600HZ[1]

Position: 13.70s

Degrees: 31.00 mV: 37.03

Top gate: 11.32s

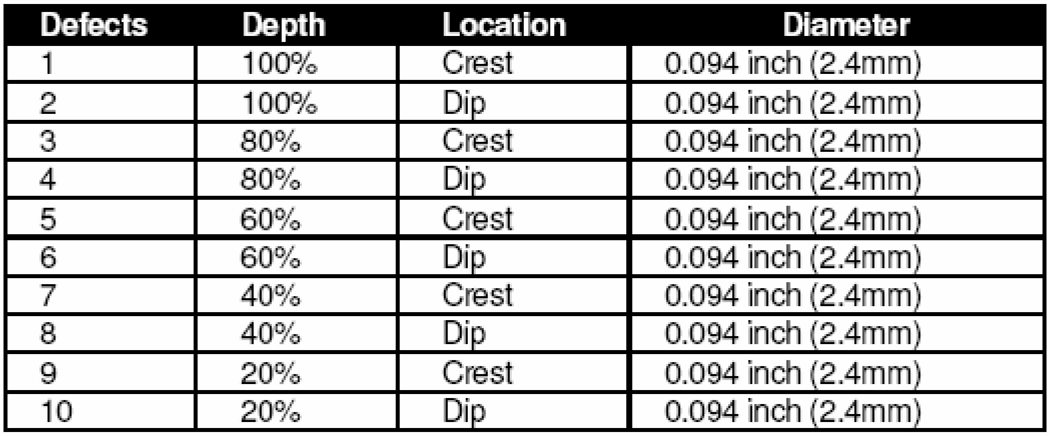
Bottom gate: 16.06s

Delta: 4.74s

Figure 8 Back ground scan of stress relieved tube at 600 Hz

➢ Artificial Flaws

The defects machined into the tube are listed in table 2 below. As specified the defects are circular in shape and have a flat bottom. The diameter of all the defects is 0.094 inch, which is as close as possible to the 1WT specification. Below table, Figure 9 shows a simplified sketch indicates the location of the defects along the length of the tube.



Defects	Depth	Location	Diameter
1	100%	Crest	0.094 inch (2.4mm)
2	100%	Dip	0.094 inch (2.4mm)
3	80%	Crest	0.094 inch (2.4mm)
4	80%	Dip	0.094 inch (2.4mm)
5	60%	Crest	0.094 inch (2.4mm)
6	60%	Dip	0.094 inch (2.4mm)
7	40%	Crest	0.094 inch (2.4mm)
8	40%	Dip	0.094 inch (2.4mm)
9	20%	Crest	0.094 inch (2.4mm)
10	20%	Dip	0.094 inch (2.4mm)

Table 2. Overview of defects machined into the tube.

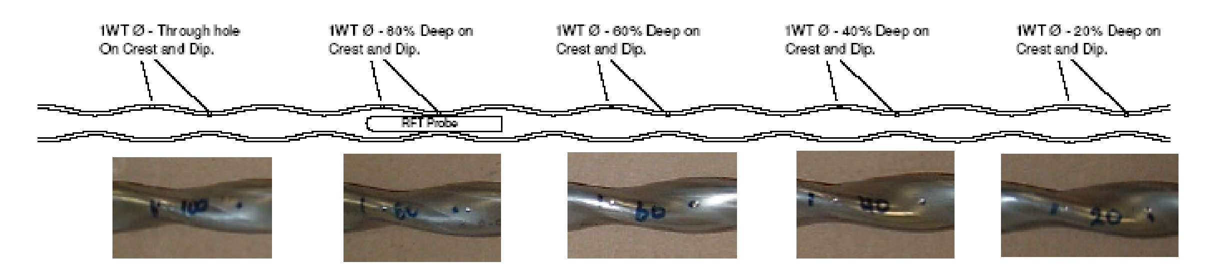


Figure 9. Crest and Dip defects machined into the Tube.

➢ Scans of Tube

EMIT scans were performed on the Tube. The figure 10 below shows the scan of the tube in free air (i.e. not in the bundle). It is obvious that the dip defects are significantly easier to detect than the crest defects. Even though EMIT is a relatively lift-off insensitive technique, there is a noticeable difference between the crest and dip responses. This difference makes that the dip defects are detectable down to 20% depth, while the crest defects become difficult to identify. The dip defect responses appear to be 4x larger than the crest responses (on average). Although the background variations are small at 150Hz and the defects stand out nicely, the phase rotation is limited. For the dip defects, the voltage plane signatures almost overlap. The traces for the crest defects are smaller, but seem to display more phase rotation. Selection of the inspection frequency is clearly a balancing act between background suppression of the twists and trace angle rotation for the defects.

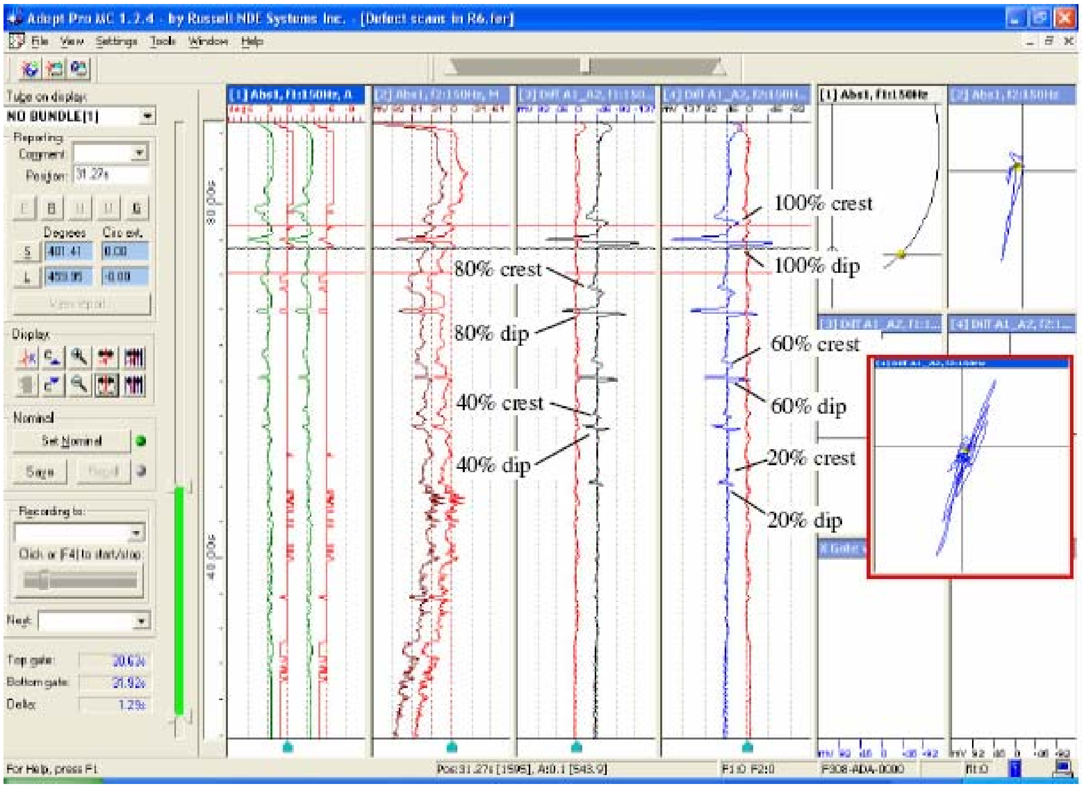
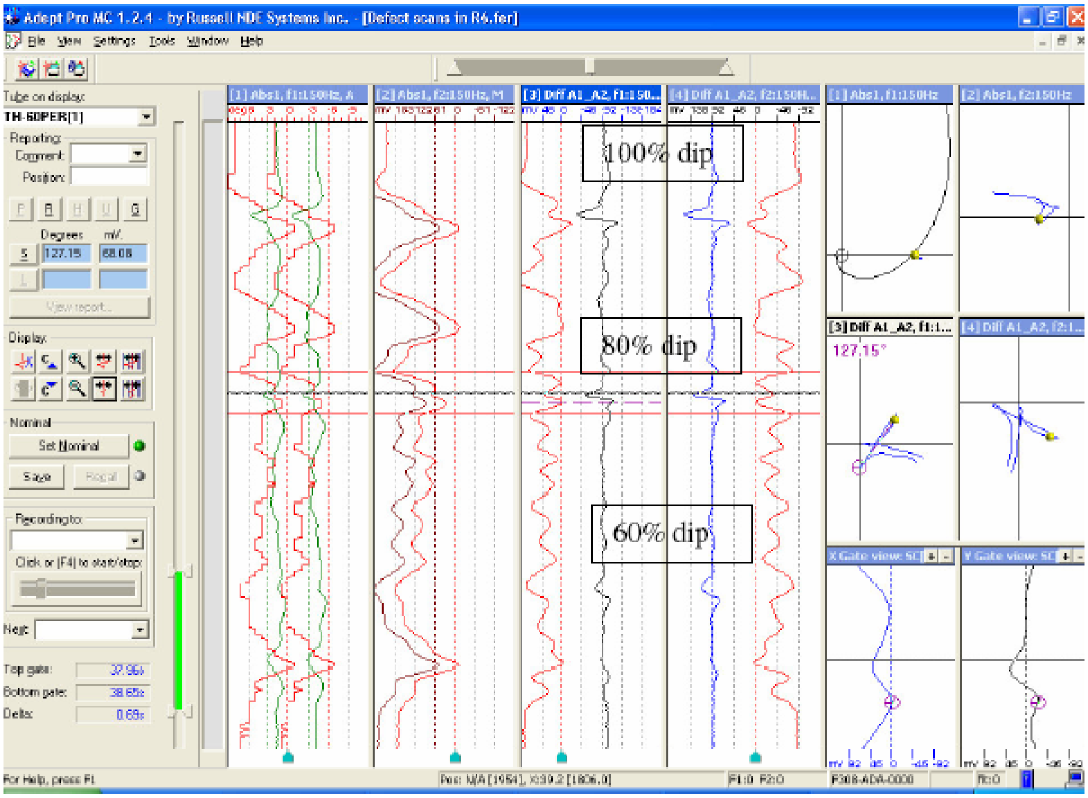


Figure 10. EMIT scan of the tube in free air.

- **EMIT scans of tubes inside the bundle**

The screen capture below shows initial EMIT scans obtained with tube placed in the middle of the test bundle (at 150Hz). The defects are aligned along the interface with the one o’clock tube. As can be seen from figure 11, 4 of the 10 defects in the tube are clearly identified. These are the 100%, 80%, 60% and 40% deep defects on the dips. Also notice the much larger background variations present on the data. The large background variations appear to be masking the shallower dip defects, and most of the crest defects.

So from the initial scans it looks as if basic EMIT signals are limited to about 40% deep defects, and that changing the frequency has little impact on defect sensitivity. The next step therefore was to attempt to mathematically enhance the defect signatures of the EMIT signals while at the same time suppressing the background variations of the twists. Figure12 below shows the results of a proprietary Q-coil algorithm. As can be seen, 40% and smaller dip defect is now starting to show as well as some of the crest defects.


Adept Pro MC 1.2.4 - by Russell NDE Systems Inc. - [Defect scans in R6.fer]

Tube on display: TH-60PER[1]

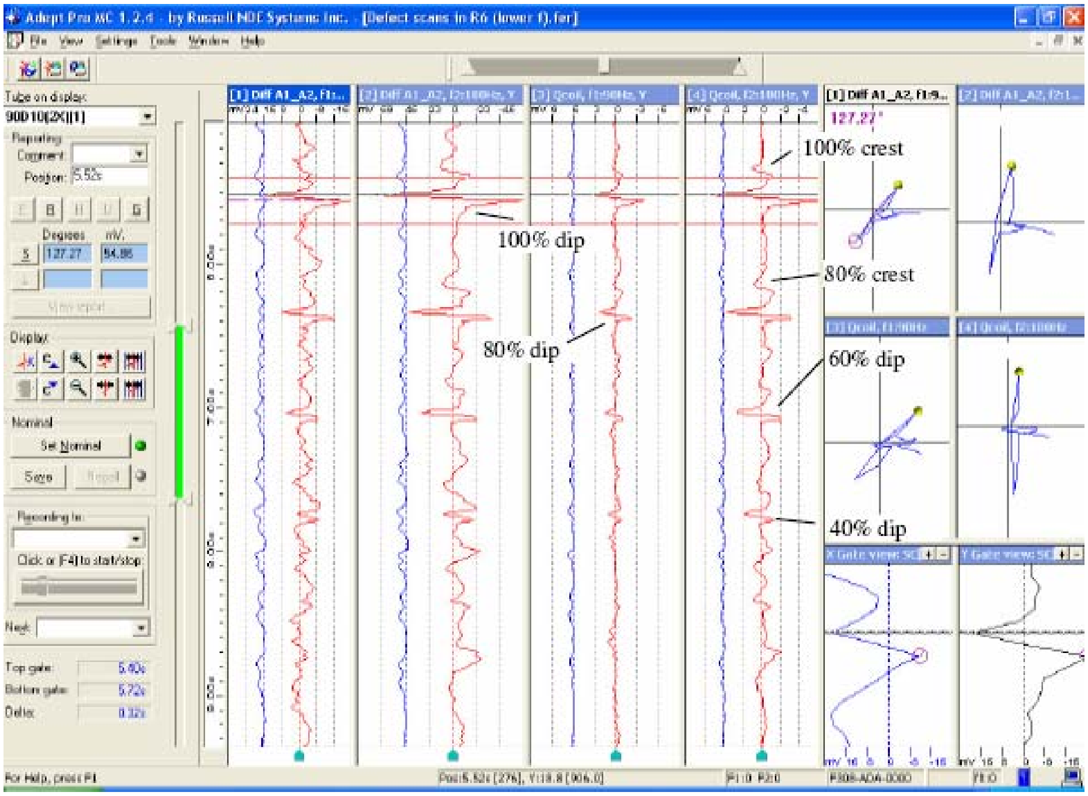
Degrees: 127.15 mV: 68.08

Top gate: 37.96s

Bottom gate: 38.65s

Delta: 0.69s

Figure 11. EMIT scan of the tube in the mock-up bundle at 150Hz.


Adept Pro MC 1.2.4 - by Russell NDE Systems Inc. - [Defect scans in R6 (lower f).fer]

Tube on display: 90D10[2X][1]

Position: 5.52s

Degrees: 127.27 mV: 54.86

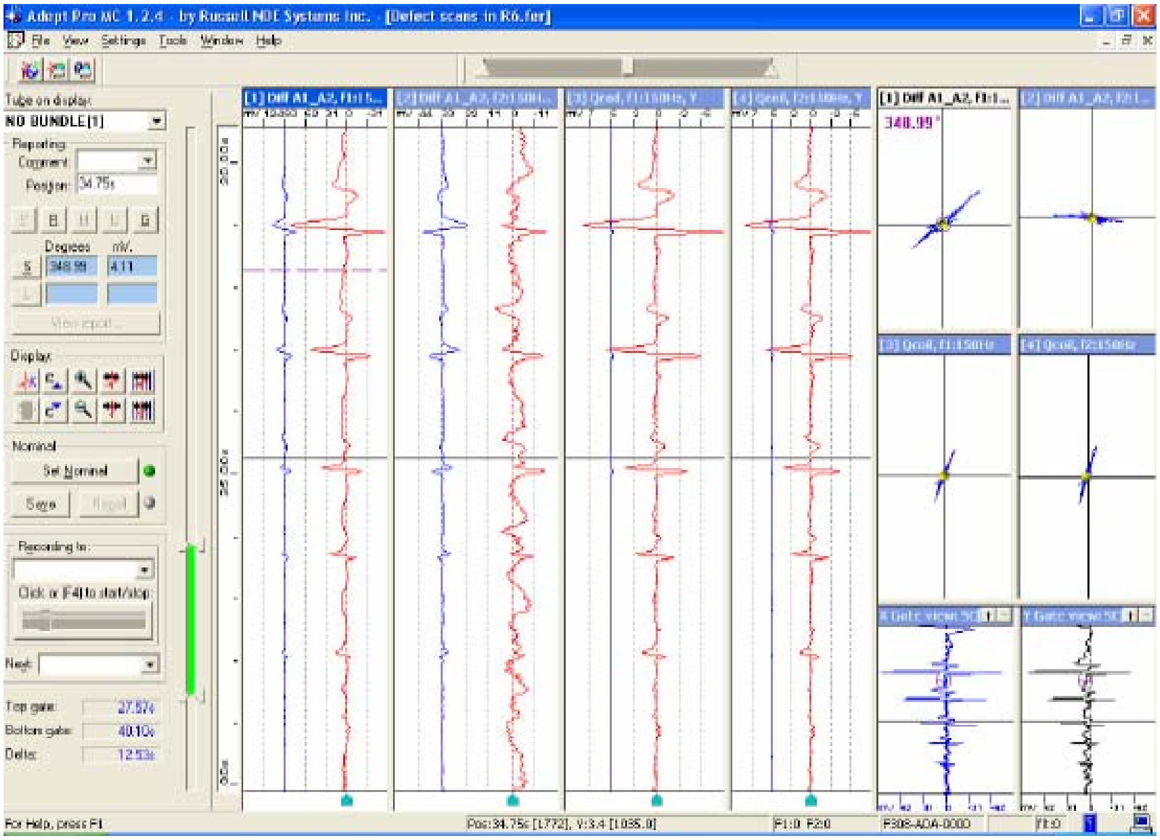
Top gate: 5.40s

Bottom gate: 5.72s

Delta: 0.32s

Figure 12. Q-coil results of dual frequency scan of the tube in the mock-up bundle (90 and 180Hz).

For completeness the Q-coil channel results for the tube in air is included.



Position: 34.75s

Degrees: 348.99 mV: 4.11

348.99°

Top gate: 27.57s

Bottom gate: 40.10s

Delta: 12.53s

Pos:34.75s [1772], V:3.4 [1035.0]

F1:0 F2:0

F308-ADA-0000

Figure 13. Q-coil results of the tube in free air.

Summary of EMIT for the inspection of twisted tube bundles

As can be seen the sensitivity depends greatly on the defect location. It should be kept in mind that the flaws used for this investigation are tiny small-diameter isolated flaws. EMIT is a volume-sensitive technique. This means that larger-area general corrosion will be much easier to detect and size. Clusters of pits will also result in easier identification and sizing. Still the results in table below give a good idea of the minimum detectable pit-size in twisted tube bundles using EMIT.

The results of the Q-coil algorithm are definitely encouraging, and a significant amount of effort was invested in tweaking the algorithm so the flaws could be accentuated even further.

Besides the ability to detect defects in twisted tubes, EMIT also has other advantages over competing methods, like UT, in that it is relatively fast and does not require cleaning to bare metal. EMIT will inspect through scale deposits and other debris (possibly accumulated on the inside of the crests), as long as there is enough clearance for the probe to pass.

Acknowledgements:

During this period of feasibility study Russell's instrumentation was used to inspect the tubes in a small-scale Twisted Tube bundle provided by Koch Heat Transfer. Koch Heat Transfer designs and fabricates heat exchangers for customers around the globe. Through its worldwide facilities it can fabricate bundles to all major design codes. Besides being an established manufacturer of standard straight-tube heat exchangers, Koch is also known as the only manufacturer of Twisted Tube heat exchangers. Upgrading to a Twisted-tube bundle can dramatically improve the capacity of an existing heat exchanger, while reducing the operating costs through lower working pressures.