Inspecting U-tube bundles using Acoustic Pulse Reflectometry

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Testing and maintenance of heat exchangers is common but **costly** and **difficult to perform** due to the following problems:

1. **Need for certified personnel to interpret inspection results**
2. **Technological limitations** of existing technologies:
   1. *existing equipment requires physical traversal of tubes*
   2. *does not work on composite materials*
   3. *Long measurement time*
   4. *Cannot traverse bends easily if at all*
Pipes and tubes ... 

...Are Everywhere ...
New – they look great …

Straight:

Or Bent:
... and they look far worse:
Many efforts have been made to facilitate tube inspection.

- **Common faults:**
  - Pitting – internal and external
  - Erosion
  - Wall perforations
  - Blockages
  - Creep/Bulging

- The most common **inspection technology:**
  - Eddy current
Limitations of eddy current inspection:

- Requires **traversal** of the entire length of the tube with a probe
  - Slow – about 1 minute per tube at best
  - Prone to getting stuck in the tubes
  - Doesn’t work on bent tubes (i.e. U-tubes)
  - Doesn’t work on bulges
- Dependent on **wall material**
  - Requires expensive standards and recalibration for different tubes
  - Sensitivity depends on wall thickness
  - Doesn’t work on composites
- Requires highly skilled **certified personnel** to interpret the results
We propose: Acoustic Pulse Reflectometry

- Not only is it Non-Destructive

- It goes one step further: Non-Invasive!

- ... let sound waves act as a "virtual probe" ...
The technology
Acoustic Pulse Reflectometry (APR) is based on one dimensional acoustic waves propagating in tubes:

Schematically:

- A wideband **acoustic pulse** is injected into a short tube
- As it passes over the microphone it is recorded
- It then propagates into the tubular system being examined
- Any discontinuities in the tubular system create **Reflections**
- All reflections propagate back to the microphone
- There they are recorded once more
- **In other words:** the pulse acts as a **VIRTUAL PROBE**
What can we learn from reflections?

Reflections are created whenever a change in cross section is encountered:

- **Constrictions**: a reduction in cross section due to a partial blockage (deposits, dents, welding material) or a connector to a narrower pipe

- **Expansions**: due to pitting, erosion, creep bulges or connection to a wider pipe

- **Effective changes** in cross section due to openings into the atmosphere - such as holes and cracks

Schematically:
Some measurements from the lab:

A hole:

- Relative Units
- Reference measurement
- Reflection caused by a hole

A constriction:

- Relative Units
- Reference measurement
- Reflection from Constriction
**Technological challenges in applying APR:**

- **Automatic classification** of reflections:
  - Faster than human interpretation
  - Replaces lengthy training and certification processes

- Many **technical difficulties** must be dealt with:
  - Attenuation in very long and narrow objects
  - Background noise, which reduces the accuracy of the measurements
  - Transducers are far from ideal
Taking a technology and actually making it into a useful tool in this field involves additional issues:

- **Usability** – creating convenient and useful user interfaces that streamline the operation

- **Report Generation** – automated report generation capabilities to automate the whole process as far as possible
U-tube inspection with APR
Invasive Technologies (eddy current, remote field, etc.) have a severe problem with sharp bends.

Alternatives:
- Used flexible probes where possible
- Measure each leg of the tube separately and give up on the bend itself

In any case – measurement is more tricky and time consuming than for straight tubes.
Since the acoustic pulse acts as a type of virtual probe, presumable it could work in a u-tube also.

Issues:
- Will the bend itself show up in any way?
- Will defects in the bend show up?
- Will defects in the leg beyond the bend show up?
The bend creates two faint reflections:

- A positive reflection from the beginning
- A negative reflection from the end
Theoretically it might be possible to manufacture u-tubes with uniform cross section throughout.

In practice:

- The **positive** reflection indicates a decrease in cross section in the bend, lasting till the **negative** reflection at the end which indicates a return to the nominal cross section.
- These are structural indications, not to be interpreted as faults.
- It remains to be seen whether these indications interfere with the detection of actual faults...
Example #1: a hole
- 1" U tube, length 5.2m
- Wall thickness 2mm
- Hole diameter: 1.5mm, drilled in the middle of the bend

Measurement:

Bottom line: the reflection from the hole is clearly visible
Example #2: a small dent

- 1” U tube, length 5.2m
- Wall thickness 2mm
- A dent was created in the leg beyond the bend

Measurement:

Bottom line: the reflection from the dent is clearly visible
Case Study 1
APR was used to examine a site used to store natural gas in underground caverns:

- 31 heat exchangers
- 2 bundles each
- 39 U-tubes per bundle
  arranged in 5 rows
- Total of 2418 tubes

The tube sheet was recessed, requiring an 80cm. extension to the probe:
Tube lengths:
- As often found in u-tube bundles, a systematic variation in tube length was found
- Tubes from each row were of the same nominal length
- Tubes from different rows were of different nominal length
- Difference between min and max nominal length – 30cm

This can be observed from the reflections from tube ends
- Measurements from 5 tubes taken from 5 different rows, zoomed to end of tube:
● Inspection took two days, which is longer than usual for this system:
  ○ Working with the extension tube slowed down the process
  ○ Many tube ends were corroded, making it difficult to obtain a good seal
● A full graphical and tabular report was generated:
Case Study 2
APR was demoed on 24 tubes in a U-tube bundle in a large refinery

- All tubes were in the same row
- As seen from measurements – all tubes were nearly identical in length – approx 6.4m.
Observing the reflection from the bends in all the tubes:

- The measurements group into 2 generic shapes.
  - Though the tubes are all the same length, the bends are not identical
  - Possibly the tubes come from two separate lots
U-bends do not prevent APR from detecting faults in the bends or on the far leg of the tube.

The presence of u tubes creates some variability in tube properties across a single bundle:
- Due to variation in u-tube length across rows
- Due to variation in specific u-bend structure

These variations must be taken into account when analyzing the measurements, to avoid false positives in reporting faults.
We would be happy to demonstrate

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