Material Compensation in Heat Exchanger Tubes

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Abstract

When testing heat exchanger tubes (ferrous and non-ferrous) there is a great potential for the calibration tube to be an imperfect match to the tubes in the bundle. Russell NDE Systems Inc. has developed software that will not only tell you the material of the tube but will alert you if the calibration tube material does not match the tubes in the bundle.

Mis-matches can occur due to de-alloying of the tubes while in service, or incorrect material specifications, or general erosion of the tube wall thickness over time. If the tubes’ electrical and magnetic properties (delta sigma or delta mu) are more than 5% different from the calibration tube, the software allows a correction to be made which makes the calibration curve valid.

1. Introduction

It is well known that the properties of carbon steel tubes change with such things as applied stresses, (which affects the magnetic permeability of the tube). Tubes that have become bent in service, (such as bent boiler tubes); tubes that have been bent during manufacturing (such as return bends) and tubes that have been bent during handling (such as the outer rows of exchanger tubes removed for cleaning every shutdown), can give signals that can be mistaken for wall loss.

Quite often, it is difficult to find a reference tube that is identical to the heat exchanger tube to be inspected in both material properties and geometry (thickness in particular). Material property variations could be due to manufacturing process or the installation tubes from different manufacturers or even different heats. Tube geometry variations could be due to manufacturing tolerances or deliberate use of thicker tubes (for instance the inner rows of U-Tube heat exchanger bundles). Differences in either material properties or tube wall thickness require the application of a Material Compensation Technique before defects can be properly quantified. It is a better solution to use the Material Compensation Technique than to prepare a variety of calibration tubes to calibrate the equipment for all possible tube types that may exist in a tube bundle. This
article shows the feasibility of using Material Compensation to take into account material and wall thickness difference between reference tube and H/E tube in the process of data analysis.

2. RFT theory and material compensation

RFT data is usually analysed through the voltage plane polar plot [1]. RFT data analysis can also be done in the same way as conventional eddy current analysis [2] on an X-Y voltage plane. Let’s assume that defect trace angle is \( \theta \), and the RFT defect depth in radians is \( \phi \). Then \( \theta \) and \( \phi \) are related to each other as follows:

\[
\tan \theta = e^\phi \sin \phi / (1 - e^\phi \cos \phi),
\]

where \( \theta \) and \( \phi \) are illustrated in Fig. 1. \( \phi \) is a linear function of defect depth while \( \theta \) is slightly non-linear with respect to defect depth, as shown in Fig. 2. It is a first order approximation to assume that \( \theta \) is a linear function of defect depth with an offset of 45 degrees at nominal wall area.

![Figure 1. Illustration of relationship between defect trace angle \( \theta \) and RFT defect depth \( \phi \).](image)
Figure 2. Typical plot of defect trace angle and RFT defect depth in degrees as a function of actual defect depth in percentage.

When actual tubes/pipes are different from calibration tubes, calibration curves such as those in Fig. 2 need adjustments through material compensation, which involves primarily calibration defect trace rotation and phase spread adjustment. The amount of trace rotation and phase spread is determined primarily by the difference of nominal phase reading between the calibration and actual samples. Free-air phase reading is also needed for the compensation.

3. Software program description

A software program called EasyLog was developed for both RFT and ECT inspection. EasyLog is a multi-functional software program. Both data acquisition and data analysis are in one single program. RFT material compensation is one of many features the program has. Fig. 3 is a screen capture of the main window of the program. User interface for material compensation is at lower left corner area of the screen, as shown in Fig. 3.

Two parameters are required by material compensation: RFT signal phase for probe in the free air and in the nominal tube wall area of the calibration tube. These values at given frequency can be obtained through EasyLog instrument settings wizard, which is part of instrument setup process.
4. Experimental verification of material compensation

Material compensation has been successfully applied to both tubes and pipes. The defect depth calls are improved after material compensation. Without material compensation, it is difficult and sometimes even not possible to size defects in tubes that are significantly different from cal tubes in wall thickness and material properties (magnetic permeability and electric conductivity). Case studies for tubes are presented below.

4.1 Short flat defects

Calibration defects are short flat defects of 30% and 60% deep in a φ0.75” x 0.083” SA179 tube. Test tube of φ0.75” x 0.085” SA214 has three short flat defects of 25%, 50% and 75% deep. At operating frequency of 250 Hz, the defects in the test tube were sized as 6%, 35% and 61% before material compensation was applied. Defect calls agree with each other within ±15%. After material compensation is applied to the test tube, the 25%, 50% and 75% deep defects are sized as 25%, 52% and 75%, respectively. Defect calls agree with each other within ±5% after material compensation.
Fig. 4 shows both strip chart and XY plane plot before and after material compensation. Two things are worth mentioning in Fig. 4: defect trace phase rotation and defect phase spread adjustment between 25% and 75% deep defects. All defect races rotate CCW after material compensation. This means that the test tube is either thicker than the calibration tube or its $\mu\sigma$ (magnetic permeability and electric conductivity) product is higher than calibration tube. Because of this, the phase spread between 25% and 75% flats increases after the compensation.

4.2 Short full circumferential grooves

Calibration defects are short full circumferential grooves of 20% and 40% deep in a SA214 tube of $\phi0.75'' \times 0.087''$. Test defects are short full circumferential grooves of 20% and 40% deep in a slightly thicker SA214 tube of $\phi0.75'' \times 0.109''$. Without material compensation, the 20% deep groove in the test tube can not be sized. The 40% deep groove was sized as 35%. After material compensation, the 20% and 40% deep grooves are sized as 9% and 47%, respectively. Defect calls agree with each other within ±12%.
after material compensation. The 40% deep groove seems to be off after material compensation. It is believed that other unknown factors may have played a role. Material compensation still improves defect sizing accuracy.

### 4.3 Flat bottom holes

Calibration tube of SA 214 $\phi 0.75" \times 0.087"$ has 53%, 75% and 100% flat bottom holes (FBHs). The test tube of SA214 $\phi 0.75" \times 0.115"$ is slightly thicker with 50%, 75% and 100% FBHs. Test data shows that at 250 Hz, material compensation is not needed probably because the thicker tube may have lower magnetic permeability in defect location possibly due to machining and consequently the test tube material property may have been self-compensated. The 50%, 75% and 100% FBHs are sized as 60%, 78% and 96% deep. Defect calls agree with each other within $\pm 10\%$ without material compensation.

### 5. Summary

RFT Material compensation has been successfully applied to test tubes which are different from calibration tubes in terms of tube material type and/or tube wall thickness. Defect types that have been material compensated include flats, full circumferential grooves and flat bottom holes. The EasyLog software program with material compensation feature has been developed.

### References