Inspection of Cup-Shaped Steel Parts from the I.D. Side using Eddy Current

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Abstract. An eddy current method was developed to inspect cup-shaped steel parts from the I.D. side. During the manufacturing process of these parts, a thin Al tape foil is applied to the I.D. side of the part. One of the critical process parameters is that only one foil layer can be applied. An eddy current inspection system was developed to reject parts with more than one foil layer. The Al tape foil is cut to length to fit the inner diameter, however, after application of the foil there is a gap created between the beginning and end of the foil. It was found that this gap interfered with the eddy current inspection causing a false positive indication. To solve this problem a sensor design and data analysis process were developed to overcome the effects of these gaps. The developed system incorporates simultaneous measurements from multiple eddy current sensors and signal processing to achieve a reliable inspection.

INTRODUCTION

Steel cups with a thin aluminum tape foil (ATF) applied to the inner diameter (I.D.) side of the cup are being made as part of a larger manufacturing process. (See fig. 1) During production, it is possible to have more than one ATF applied to the I.D. of the cup, which could lead to a product failure. Therefore, it is imperative that cups with more than one ATF be rejected during the manufacturing process.

Eddy current testing (ECT) is commonly used as a nondestructive testing (NDT) tool for crack detection, material thickness measurements, and coating thickness measurements[1], [2]. There are advantages for using ECT, including the ability to inspect complex shapes, minimal part preparation, no need for coupling medium, and immediate results[3].

Because the ATF is a conductive material, ECT was chosen as the NDT method for inspecting the cups to reject those with more than one ATF. The ATF are cut to length to fit the I.D. of the cup, however, after application of the foil there is often a gap created between the beginning and end of the ATF. While developing the inspection system it was determined that this gap interfered with the measurement causing a false positive indication.

The objective of this work was to develop a reliable inspection system that can inspect the cups from the I.D. side and determine if more than one ATF was applied to the cup and to overcome false positive readings from gap interference.

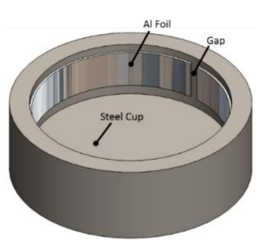


FIGURE 1. Steel cup with aluminum foil applied to the I.D. side of the part.

EXPERIMENTAL SET-UP

The major components that make up the ECT system, including the test station, eddy current probe, and user interface are described.

Test Station

The test station components shown in Fig. 2 include:

- Control and Data Acquisition
    - The user interface for the controls and data acquisition (DAQ) is described later in this paper. A PC-based control and DAQ system was used to engage the probe, take measurements, disengage the probe, save and plot the collected measurements.
- Function Generator
    - A function generator was used to generate an alternating current flow through the wire coils of the eddy current probe and generate an oscillating magnetic field. The function generator connects to the PC for data acquisition.
- Coil Interface Circuit
    - A coil interface circuit was designed to interface the coils with the function generator. The circuit allows the user to tune the coils to the same resonant frequency.
- Part Platform
    - A part platform was designed to set the cup shaped part on to line it up with the eddy current probe.

The test station was designed for the user to place the cup-shaped part onto the part platform over the eddy current probe (see Fig. 3) that is located on top of the test station. Once the cup is in position, a button is pressed and the eddy current probe is driven up against the wall of the cup via a linear actuator, a measurement is taken, and data is recorded and plotted.

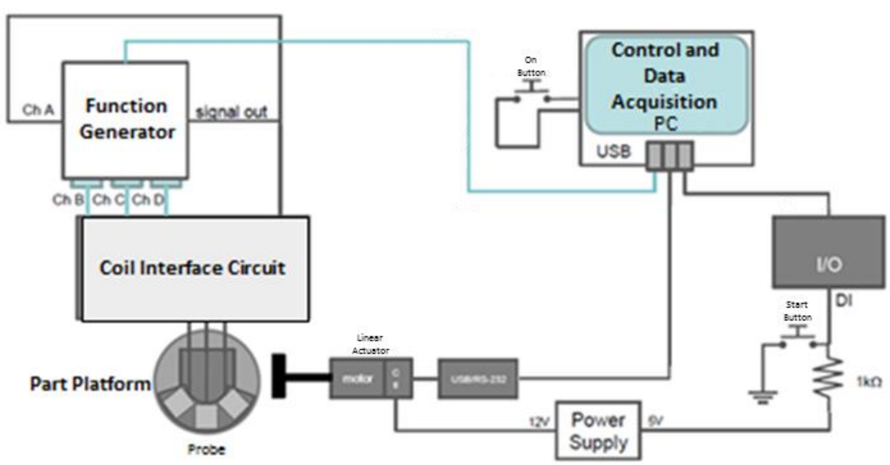


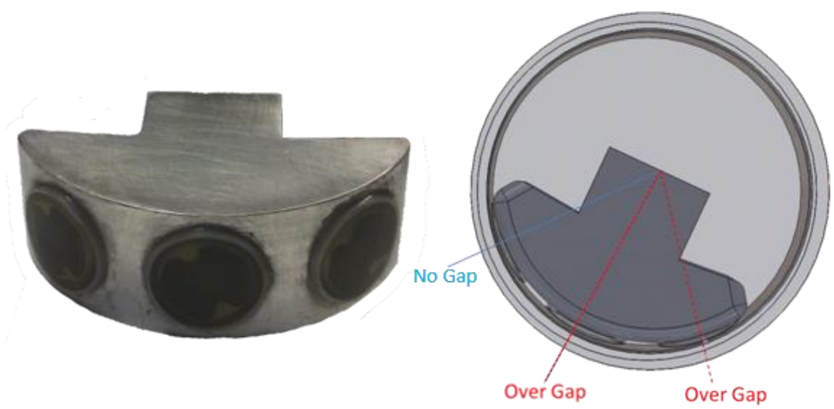
FIGURE 2. Schematic of the test station components.

FIGURE 3. Test station.

Eddy Current Probe

The coils in the eddy current probe (see Fig. 4(a)) were made with a winding machine and with the same number of windings so that each coil would have the same resonant frequency ~56 kHz. The coils were then potted into an Al housing.

Because it is possible to have more than one ATF applied to the I.D. of the cup it is possible to have more than one gap in the foil layers lined up with the eddy current coils as shown in Fig. 4 (b). This was taken into consideration in the design to of the three-sensor eddy current probe. To avoid the interference from the gaps, the three coils were spaced in the probe so that during any given measurement at least one coil would not lineup over a gap.



(a) (b)

FIGURE 4. (a) Picture of the eddy current probe. (b) Drawing of the eddy current probe lined up over a gap in the cup shaped part.

User Interface

The software for the ECT system is LabView-based with a user-friendly GUI. Controls (see fig. 5) include:

- Sensor setup
    - Allows the user to find the resonant frequency of the coils in the probe. A reference is taken during sensor setup with the probe in air. The reference is subtracted from the measurements taken.
- Program controls
    - Gives options to reset the graphs, abort a measurement, or end the program.
- Sample Type
    - Creates a file name to save the data to a text file.
    - Selects the material type. In this study, it was an aluminum tape foil.
    - Allows for the selection of more than one diameter cup.
- Raw Waveforms
    - Displays the raw waveforms from each sensor.
- Measurements
    - Takes a measurement and plots the data on the graphs. The user is also told to reject the part if more than one ATF is detected.

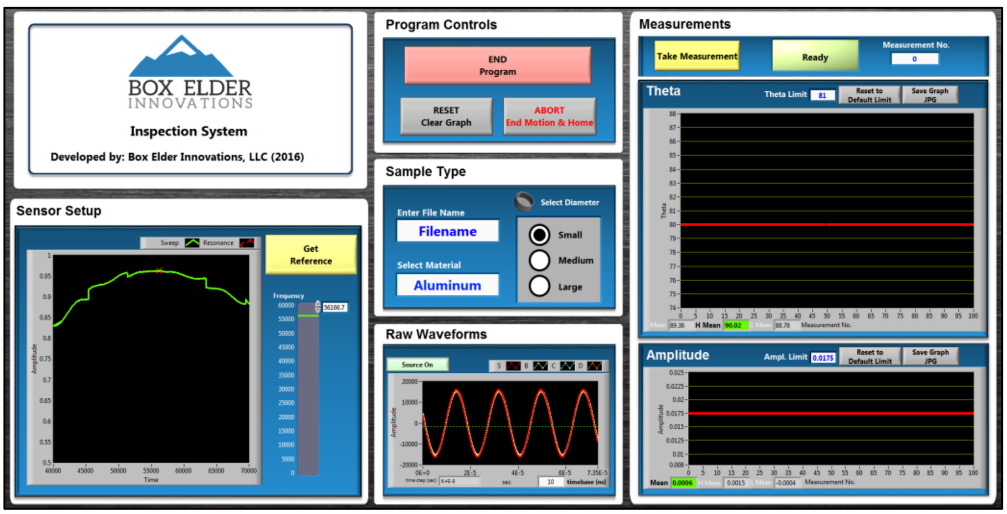


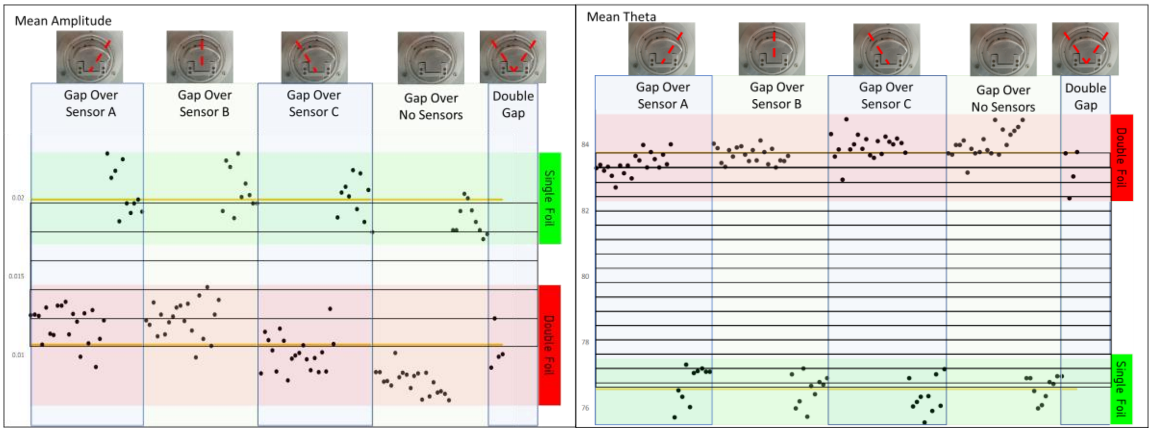
FIGURE 5. LabView based GUI.

EXPERIMENTAL RESULTS

To determine the effect of gaps on the 3-coil probe design, the gap in the applied ATF was lined up directly in front of each of the sensors, A, B, and C (see Fig. 6), and a measurement was taken. To simulate a double gap, the gaps were lined up over sensors A and C. Amplitude and phase of the eddy current were measured at the resonant frequency of the coils.

FIGURE 6. Sensor assignments on eddy current probe.

The amplitudes from all three coils were averaged and plotted in Fig. 7(a) for each condition. A notable difference in amplitude was observed between the single and double foil conditions. Phase measurements have a response that is the opposite of the amplitude. The phase measurements shown in Fig. 7(b) were taken from all three coils and the lowest value was dropped. The remaining two high values were then averaged and plotted. The phase difference observed between the single and double foils was more significant than was the amplitude difference.



(a) (b)

FIGURE 7. (a) Mean amplitude for each condition. (b) Mean phase (Theta) for each condition.

The following data analysis method gave the best results (see Fig. 8) including for the case of two gaps lining up with two sensors:

1. Calculate the standard deviation of phase measurements.
2. Drop the lowest value.
3. Average the remaining two high values.
4. If the standard deviation is above 2, keep only the highest value. This happens when gaps are lined up with two coils leaving one coil not over a gap. Otherwise keep the average of the two high values.

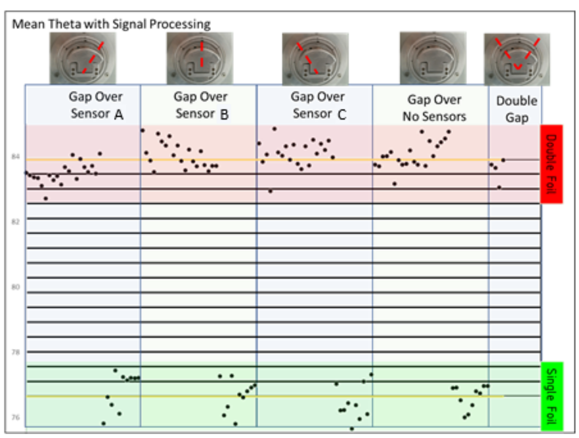


FIGURE 8. Result of only using the highest phase value if the standard deviation was above 2.

CONCLUSION

More than one ATF can be detected with confidence without interference from gaps using the developed ECT system. The eddy current phase is the best property to measure for this application using the data analysis method described in this paper.

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