DETECTION OF SURFACE CRACKS IN ALLOY 600 TUBING WITH AN AC MAGNETIC BRIDGE

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INTRODUCTION

Alloy 600 tubing is in widespread use in steam generations of nuclear power plants, due to its good high temperature corrosion resistance. It is, however, susceptible to a variety of corrosion damage mechanisms. One of these is tress corrosion cracking (SCC).

SCC of steam generation tubes can be very difficult to detect by nondestructive means. The cracks are typically very tight and frequently in an area of the tube surrounded by a structural member, such as a tube support plate or the tubesheet. These tight cracks do not produce large eddy current responses, even at substantial crack depths.

The magnetic bridge is an emerging NDE technology with applicability for crack detection. The magnetic bridge sensor utilizes an AC magnetic circuit. AC magnetic circuit theory has been discussed by Zinke and Schmidt. [1] The magnetic bridge is constructed of ferrite bars and equipped with a flux driver coil, two balance coils and a sensing coil. (See Figure 1). The bridge can be balanced by adjusting resistance and capacitance values in external circuits, which are connected to the balance coils. The sensing coil detects a nulled state.

The bridge interacts with a test material by means of an air gap with a conducting insert in one of the bridge legs. The insert produces a fringing field, which passes through a test material placed adjacent to the gap. (See Figure 2). Once the bridge has been nulled on a test material, the sensing coil can detect very small changes in test material

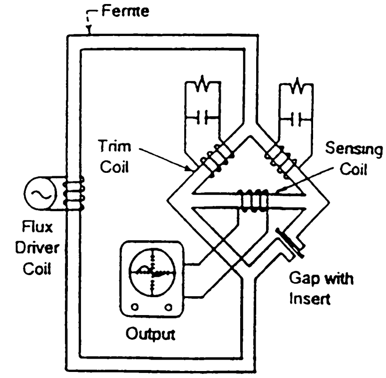

Figure 1. The magnetic bridge.

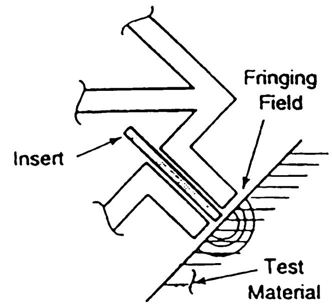

Figure 2. The fringing field produced by the insert.

reluctance. The resistance and capacitance of the balance coils can then be adjusted to renull the bridge and the changes in values used to compute the change in test material real and imaginary reluctance.

Research conducted by International Validators and Foster-Miller has shown that changes in many material conditions of interest are accompanied by changes in the magnetic reluctance of the material. These conditions include hardness, applied stress and torque and the presence of cracks and defects. [2, 3, 4, 5, 6]

THE EXPERIMENT

As a preliminary assessment of the ability of the magnetic bridge to locate cracks in alloy 600 (Inconel) tubing, a tubing specimen containing SCC was examined using a magnetic bridge. SCC was generated in the tubing specimen by exposure to a known aggressive, cracking environment for a prescribed period of time. This technique has been shown to produce representative SCC. The presence of OD initiated cracks was verified by dye penetrant testing (PT). The tubing specimen was provided by the Electric Power Research Institute. The tubing OD was about 22.6 mm, and the wall thickness was 1.27 mm.

The tubing specimen was inspected from the tube OD, as current bridge designs are too large for inspection from the tube ID. A cradle was fabricated to support the tube specimen in a horizontal position and control the position of the bridge during scanning of the tube specimen. The bridge was mounted inside an aluminum box with circular cut outs on the bottom to fit around the tube as shown in Figure. 3. The purpose of the circular cut outs was to provide centering and stable positioning of the bridge relative to the tubing.

The bridge used was of the usual design, with 20 input amp-turns and a copper insert of 2.46 mm thickness. The bridge was operated at 50 KHz for this experiment. The

typical operating range of the bridge is from 100 Hz to 100 Khz, with lower frequencies preferred for inspections requiring deeper penetration.

Magnetic bridge measurements of real and imaginary reluctance were made at 28 angular positions around the circumference of the tubing specimen. The "foot print" of

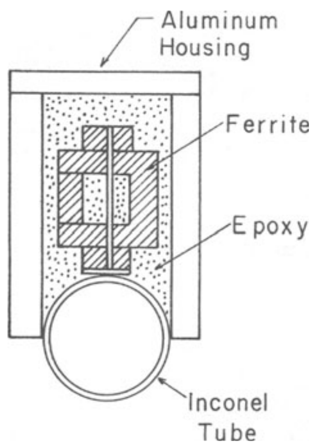

Figure 3. Drawing of the epoxy-encased AC magnetic bridge and the Inconel tube.

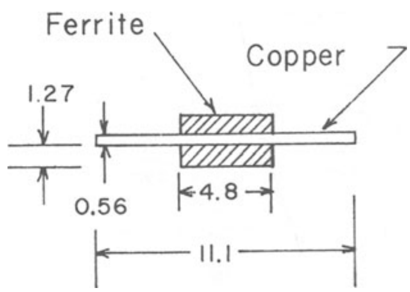

Figure 4. Drawing of the bridge-gap configuration facing the tubing. Dimensions are in mm.

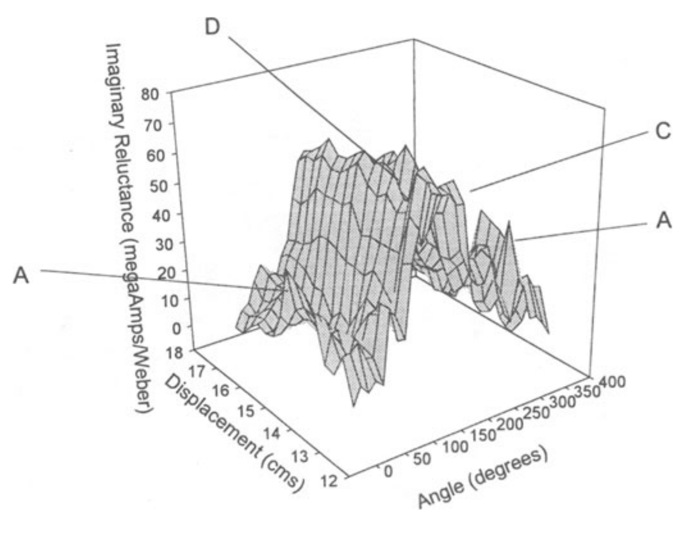

Figure 5. Imaginary reluctance variations on tubing specimen J-4, as seen from the left.

the bridge, i.e., the gap which faces the tubing is shown in Figure. 4. The longest dimension of the copper insert was parallel to the axis of the tubing. The 28 angular positions divided the circumference into 2.5-mm segments as opposed to the sensor width of 3.1 mm. Bridge axial position was then incremented 3 mm and the circumferential scan was repeated. Circumfenantial scans were obtained from 12.8 to 15.3 cm where SSC was known to have occured

As has been discussed in [1], real reluctance is proportional to magnetic permeability, and imaginary reluctance is proportional to electrical conductance. This suggests that imaginary reluctance should be a good indicator for cracks and other discontinuities, when in the induced current path, since they will affect conductance. Indications of SSC were seen in the imaginary reluctance as expected. Views are shown in Figures 5 and 6. Imaginary-reluctance scans of cracks as narrow as SSC should produce a single peak per crack [7] as compared to compound peaks produced in real-reluctance scans.

The imaginary reluctance maps do indeed contain areas of sharp divergence from background values. These areas are identified as A, C & D. The peak A seen in both figures occurs on the origin of the angular displacement. The data also contains a global variation that results in the large hump centered at about 120 degrees angular displacement. This hump is believed to be the result of a large variation in lift-off. Following inspection of the tubing specimen, the OD was measured in the inspection area and found to be significantly ovate. The maximum OD was 22.9 mm and the minimum was 22.4 mm. Since the bridge used in this experiment was mounted inside a saddle block, the tube ovality would have been manifest as a lift-off variation.

The areas of sharp divergence of the imaginary reluctance from background also physically correlate with position of known SCC on the tubing specimen, as determined by Penetrant Testing (PT). A developed view of the tubing specimen (J-4) with known crack locations is shown in Figure 7. From the measurements of AC magnetics, it appears that the SSC at D is more complicated than would be supposed from the PT test.

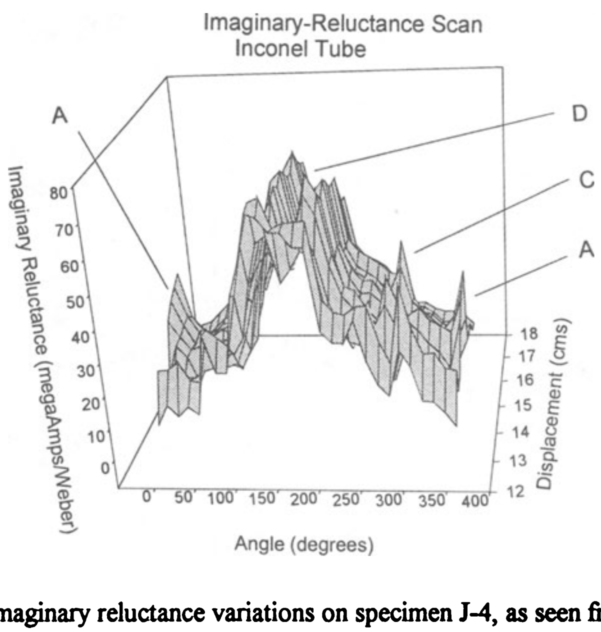

Figure 6. Imaginary reluctance variations on specimen J-4, as seen from the right.

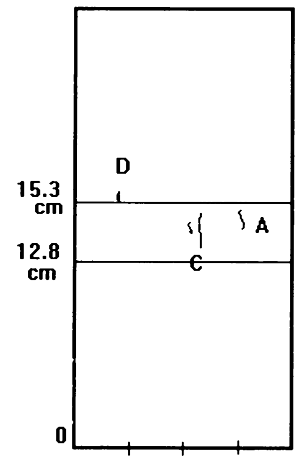

Figure 7. Developed view of specimen J-4 with locations of surface cracks identified by penetrant testing.

CONCLUSIONS

SCC in alloy tubing produces sharp discontinuities in imaginary reluctance of sufficient magnitude to be detectable by the magnetic bridge. Incorporation of a magnetic bridge into a tube probe should eliminate the development of a large lift-off variation, as was encountered in this experiment. Such a probe might take the form of a bridge whose pole faces are surface riding on the tube ID, with motorized rotation, similar to the Motorized Rotating Pancake Coil (MRPC) type of ECT probe, which is in widespread use for tubing inspection. A smaller bridge with smaller pole faces would improve spatial resolution and would be valuable for characterizing SCC in alloy 600 and for estimating its effect on tubing integrity and residual strength. Also, a differential bridge arrangement might prove to be valuable for suppressing global material variations and enhancing crack detection and characterization.

ACKNOWLEDGMENTS

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