TECHNOLOGY ASSESSMENT FOR
CONFORMABLE ARRAY FOR MAPPING CORROSION PROFILES

CONTRACT NO. DE-FC26-01NT41153

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November 13, 2001

DISCLAIMER

This Technical Assessment Report was prepared with the support of the U.S. Department of Energy, under Award No. DE-FC26-01NT41154. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author and do not necessarily reflect the views of the DOE.

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INTRODUCTION

The objective of the project is to determine the feasibility of using an eddy current testing (ECT) method with an array of sensors to measure the depth profile of a corroded area on the outside surface of a transmission pipeline. The purpose of this technology assessment is to identify related work that could be of help to the project and to determine if patents have been awarded for this application. Southwest Research Institute™ (SwRI™) has performed a significant amount of work with ECT, including the development of techniques and sensors to measure the spacing between sensor and the surface of a test piece (liftoff), as well as for measuring the depth of corrosion pits. The technology survey will include relevant information from this work, as well as results from computerized literature searches to find work performed by others.

Currently Used Corrosion Mapping Methods

One method is direct mechanical measurement. A device has been constructed for this purpose. A steel straight-edge about 18-inches long is equipped with a dial micrometer that can freely move along the straightedge. The indicator of the micrometer points downward and is in contact with the pipe. The bar is positioned over the defect and the micrometer is positioned at a location where there is no corrosion. The dial is set to 0.000-inches. The operator then slides the micrometer along the straightedge while applying light pressure to keep the indicator pin in contact with the pipe. Measurements are then read directly from the dial. Some error is induced because of the contact of the micrometer with the bar. The actual defect depth will be more like +0.010 –0.0-inches. The error, by design, will always be conservative. That is, the defect will always be measured slightly deeper than it actually is. The operator visually selects the area that appears to contain the deepest pit and focus on that area. If there are other interesting features or multiple clustered pits, the operator must measure each one and transpose that information to the inspection tool record of the defect or to a defect map. If multiple defects are present, then each will be measured in roughly the same manner as well as the distance between the defects. Interaction rules will be applied to determine the true defect length.

A laser-based corrosion mapping system is available [1]. This system is known as the Laser Pipeline Inspection Tool. It uses a fixture to position a laser-based displacement sensor on the pipe. The sensor is scanned over the pipe surface to map the corrosion depth. Thorough cleaning of the corroded area to bare metal is required because the depth is measured to the point where the laser reflects from the surface. This system appears to be very accurate but requires considerable time to set up.

ECT Background

ECT is based on the use of a wire coil probe which is used to introduce the flow of electrical currents into the test piece.[2,3] The wire coil is energized with alternating current at a given frequency, and when it is placed in proximity to the test piece, current flow (eddy currents) are produced in the test piece because of inductive coupling. Typically, flaws such as cracks are detected because they represent a variation in the local conductivity of the test piece and thus alter the local flow of eddy currents. This conductivity variation can be detected by a change in electrical impedance of the probe.

The impedance of the probe is also affected by the way in which the probe is coupled to the test piece; a strong factor in this coupling is the spacing between the coil and test piece surface. When the coil is close to the test piece, the coupling is strong and as the coil is moved farther away, the coupling is reduced. Thus, there is a significant effect of this spacing (or probe liftoff) on the probe impedance and the ECT response. When ECT is used for applications such as the detection of small cracks, this effect is usually undesirable because it creates "noise" as the probe liftoff varies. In other cases, the liftoff response is advantageous because it allows ECT to measure the distance between the probe and test piece. ECT probes operating in this mode are the basis for displacement sensors used in many applications.

For the current project, it is this liftoff or displacement mode that is of interest. Because the corrosion areas to be measured are generally large compared to the probe size, the corrosion pits appear more as a change in liftoff rather than a localized change in conductivity. The approach is to use ECT probes as liftoff sensors to measure the pit depth by measuring the "displacement" between the probe and bottom of the pit. By having an array of many probes, the corrosion profile can be measured.

Literature Search

Literature searches were performed using the following computerized databases: COMPENDEX (Engineering Index), INSPEC (Database for Physics, Electronics, and Computing), NTIS (Government Reports and Announcements), ENTEC (German Energy Database), and Aerospace Database. Internet searches were performed using the search engine Google. Information was also obtained from the knowledge and contacts of SwRI and Clockspring personnel.

Displacement Measurement

ECT has been widely used for displacement measurement, and probes and instruments are available commercially [4,5]. Operating ranges for this equipment are as small as 0.5 mm (0.02 inch) and as large as 61 mm (2.4 inches) with resolutions of 0.1 μm (4 μinch) and 6 μm (240 μinch) respectively.

SwRI™ has also developed specialized ECT probes for displacement measurement applications. One application involves the use of very small coils (e.g. 1.5 mm (0.06 inch) diameter) for the dynamic measurement of small gaps between automotive engine pistons and cylinder walls. A second application is a probe that measures the height and orientation of a second flaw detection probe above a surface. This was used to keep the proper probe orientation and position as the probe was scanned with a robotic device.

The displacement measurement technology can, in principle, be used for corrosion depth measurement; however, the systems are intended for flat test piece surfaces. The accuracy will be affected when the surface is irregular.

Applications to Corrosion

The work most relevant to the current project was performed by SwRI™ for the New York Gas Group (NYGAS) [6,7]. This work involved the use of ECT to measure the depth of graphitization in cast iron gas pipe in a similar manner to the approach in the current project. Graphitization results in metal loss with a rough and pitted surface, and ECT was used to measure the depth from the original surface to the bottom of the pitted region. In this project, a commercially-available device known as the Tokyo Gas Graphitic Corrosion Meter (which is no longer manufactured) was evaluated for this application. The instrument uses a single probe and must be moved over the surface to be tested to map the graphitization depth. Results from this project showed that the instrument was reasonably accurate when the damage was of sufficiently uniform depth, but the accuracy was affected by the aspect ratio (diameter : depth) of the pits. Tests showed that large improvements could be made by the use of different coils, instrumentation, and signal processing. It was also found that the graphitization by-products affected the accuracy and that special fixturing was needed to reference the probe position to the original height of the pipe surface.

In other work [8], an ECT technique was investigated to estimate the dimensions of crevice corrosion pits. As with the NYGAS work**,** this investigation showed that there can be a significant effect on the measurement results because of the shape of the corrosion pits. It was shown that when the width of a notch (rectangular notches were used instead of pits in the study) is smaller than the width of the probe's magnetic field, that the measurement of maximum ECT response is a poor indicator of depth. A model was developed to predict the ECT response while accounting for the notch width. The inverse problem, where the notch depth is predicted from the ECT response, was not tested, however. Literature searches specific to these authors were conducted in an attempt to find later publications for an inverse model, but none were found.

A variation of an eddy current technique was applied to detection and sizing of cracks and corrosion pits in waste storage tanks [9,10]. This method uses the patented Alternating Current Field Measurement (ACFM) approach to map corrosion. ACFM induces eddy currents using a magnetic field that is uniform in the area of interest and then detects changes in current flow using multiple sensors designed to detect separate components of the magnetic field associated with the current flow. This system uses an array of 96 coils to inspect a 3-inch by 3-inch area. The array can be scanned by a robotic manipulator to inspect large areas. These papers discuss the system in general and little specific data or design information is given.

PATENTS

No patent was found which covers the use of flexible array ECT probes for corrosion mapping. A patent was found that covers flexible array eddy current probes for inspecting components [11]. This patent appears to cover only ECT probes that have separate drive and sense elements. A reference was found to a paper pre-dating this patent that describes a flexible array of single-element sensors similar to that proposed in this project, but intended for flaw detection [12]. Another patent was found that covers a three-dimensional array of single-element eddy current elements on a flexible substrate; the elements are staggered on different layers to obtain more complete coverage of the inspection area [13].

CONCLUSIONS

Based on previous work, the approach to be taken in this project to map corrosion using ECT appears feasible and appears, from the limited investigation, to be work that has not previously been attempted. It has been shown that ECT can measure the displacement between the sensor and the bottom of corrosion pits; however, the ECT response can depend on the shape of the corrosion pit. It has also been shown that by using certain types of probes and signal processing, the effect of defect shape can be minimized and the accuracy of the measurement improved. Patents were found which may have some reference to sensor array design and should be examined further for potential conflicts.

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