DESIGN CONSIDERATIONS FOR THE REMOTE FIELD EDDY CURRENT PROBE FOR INSPECTING FERROMAGNETIC FLAT STRUCTURES

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INTRODUCTION

Traditionally the remote field eddy current (RFEC) phenomenon has been applied to the inspection of ferromagnetic tubes in heat exchangers, boilers etc. The RFEC probe has an exciter and sensor coil spaced such that most of the magnetic field received by the sensor is due to the field that has diffused through the pipe wall. The phase difference between the exciter and sensor signals is indicative of the defect dimensions. This same idea has been applied to the design of a new RFEC probe for inspecting flat ferromagnetic structures [1-3] and thick aluminum plates [4].

Above ground storage tanks (AST) are used in the petrochemical industries for storing variety of corrosive solutions. These tanks are typically single walled or double walled in structure. The bottom of these tanks begin to corrode over a period of time resulting in leakage. This leak can cause serious problems to the environment which could cost millions of dollars to clean up the area. Conventional nondestructive testing (NDT) methods used presently to inspect these bottoms are magnetic flux leakage and ultrasound [5]. Due to the ferromagnetic nature of these tank bottoms the surface conditions are not good with varying layers of scale on them. This makes the inspection very complicated especially interpreting the sensor signals.

The RFEC technique seems to overcome some of these limitation and is attractive as an alternative NDT method for the inspection of the AST. The key physical phenomenon needed for the RFEC techniques is the ability of the probe to focus the magnetic field and the electromagnetic energy into the specimen such that it interacts with the flaw to produce a signal, which is detected and analyzed. Thus, to fulfill this phenomenon, special considerations is given to the probe design.

PROBE DESIGN

The key physical phenomenon needed for the RFEC techniques is the ability of the probe to focus the magnetic field and the electromagnetic energy into the test piece such that it interacts with the defect to produce a signal, which is detected and analyzed as the defect signal. Thus, to fulfill this phenomenon, the RFEC prototype probe design is divided into the following:

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1. Specially designed magnetic circuit consisting of a pot-core and an excitation coil.
2. A magnetic circuit for the pick-up coil.
3. An auxiliary coil to help guide the signal path.
4. Shielding for the excitation and pick-up coils to minimize the direct coupling between them.

A schematic of the probe is given in Fig. 1. The probe has two excitation coils, the primary and auxiliary. The pot-core works as a magnetic circuit for the flux. Carefully chosen parameters of the excitation currents in both coils enables the electromagnetic energy released from the coils to penetrate downward into the plate. The aluminum cover works as an additional shield, minimizing the flux leakage above the plate and any direct linkage of the fields between the exciter and pick-up coil. The pick-up coil senses the electromagnetic field that has penetrated the plate from the bottom to the upper surface. Thus the magnitude and phase of the pickup coil are sensitive to the plate thickness, permeability and conductivity. Additionally there is an auxiliary coil present which is also used for aiding in focusing the magnetic field into the sample or ferromagnetic sample. This auxiliary coil is wound opposite to the primary coil such that the auxiliary magnetic field will cancel a portion of the primary magnetic field and the remaining field is then focused downwards into the sample. The design of the auxiliary coil is also critical depending on the dimensions and the number of turns of the primary coil.

Since the flux is focused into the material, the phase and the magnitude of the pickup coil signal is sensitive to defect anywhere in the sample or ferromagnetic plate. Thus one can not only detect defects or corrosion on the top of the plate, but also at the underside of the plate.

The next few sections will detail the finite element simulation and experimental data collected in the laboratory. A field usable prototype RFEC probe is currently being developed at Amtak, Inc. Previous publications [1-3] have demonstrated some of the FEM data and the feasibility of using the RFEC probe for inspecting ferromagnetic flat plates. Recently the same technique has also been extended to inspect thicker aluminum structures.

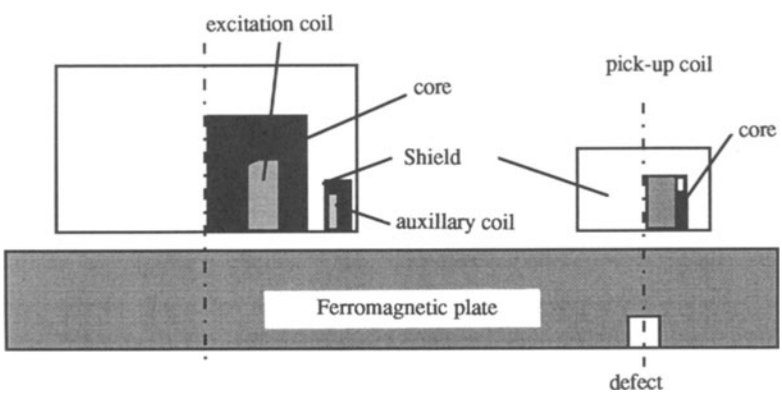

Fig. 1 Schematic of the RFEC probe for inspecting ferromagnetic flat plates

FINITE ELEMENT MODELING

An axisymmetric finite element model (FEM) is used to simulate the RFEC probe. The model was also instrumental in the design of the prototype probe. The model uses a pickup coil of dimensions 7.5 mm x 25 mm (.3" x 1") with an excitation current of 2 Amps and frequency of 10 Hz. A number of different frequency and excitation current are simulated but the results presented in this paper are based on the parameters mentioned above.

A slot of varying depth is modeled and the pickup coil voltage is calculated for different defect depth. The depth of the slot is a percentage of the thickness of the ferromagnetic plate. Fig. 2 and fig. 3 are the estimated magnitude and phase of the pickup coil voltage.

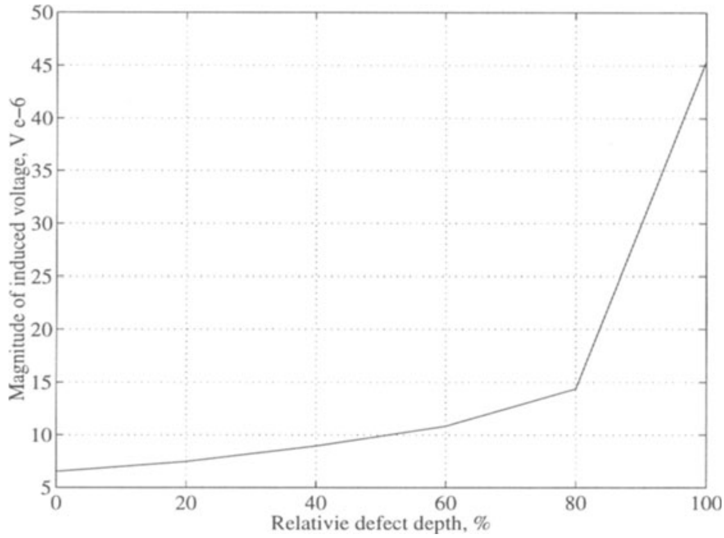

Fig. 2 Finite element simulation of the estimated magnitude of the induced voltage of the pickup coil as a function of the defect depth.

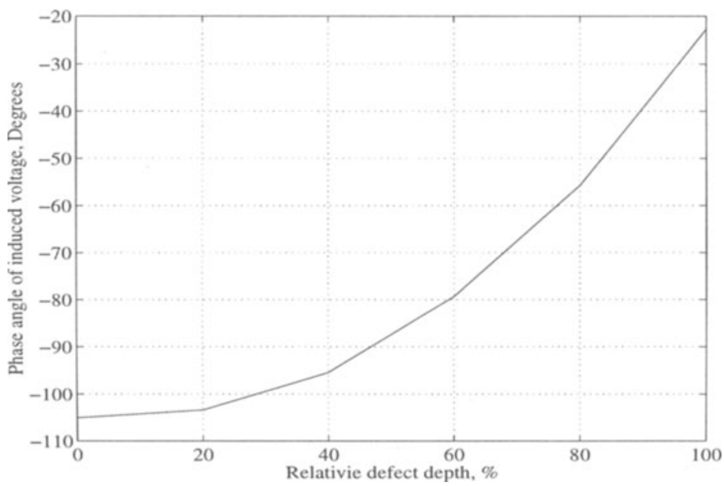

Fig. 3 Finite element simulation of the estimated phase angle of the induced voltage of the pickup coil as a function of the defect depth

The remote field region is where the pickup coil is present. The flux linking the pickup coil is the indirect flux that has traversed the plate thickness twice. Thus the magnitude of the voltage is small but measurable. The challenge is to have a large signal to noise ratio such that the defect signal is much larger than the background noise or any other system noise. On the other hand the phase as a function of the defect depth is very attractive. The finite element simulated curve of the phase angle definitely shows the detectability of the RFEC probe for the present circumstances.

PROTOTYPE PROBE

A prototype field usable RFEC probe is being developed for inspecting AST. The major limitations in the design is that the whole instrumentation needs to fit into an 18 " hole at the top of the AST. Also the probe needs to be on wheels to be able to scan a complete tank bottom and store all the data for off line processing. An advantage with the RFEC probe is that it has low power requirement since there is no necessity for magnetizing the tank bottom as in the case of the magnetic flux leakage methods. The major instrumentation needed is a current source for the exciter coil, phase lock-in amplifier for the measurement of the pick-up coil signal magnitude and phase and a computer to store all the data. Fig. 4 shows the overall view of the probe demonstrating its usage in the field. A close up showing specifically the exciter and sensor coils at the bottom of the probe is shown in fig. 5.

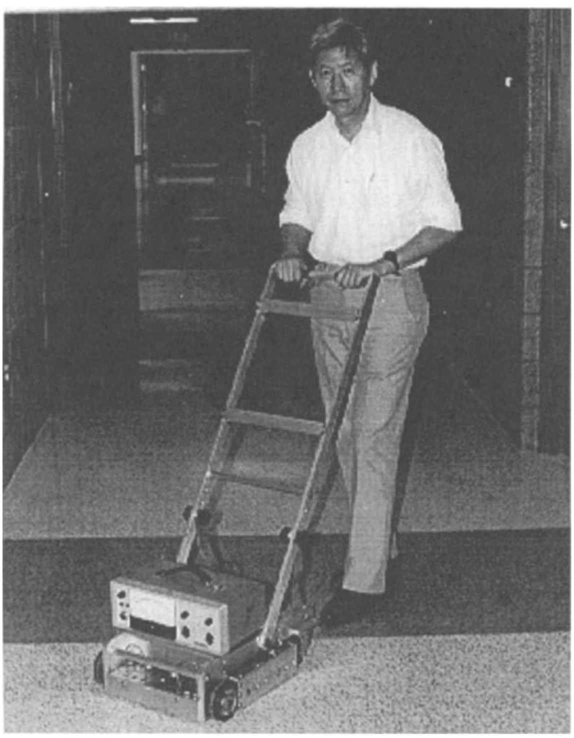

Fig. 4 A photograph of the RFEC probe with some of the instrumentation. Typically the system will be handled by the operator in the field.

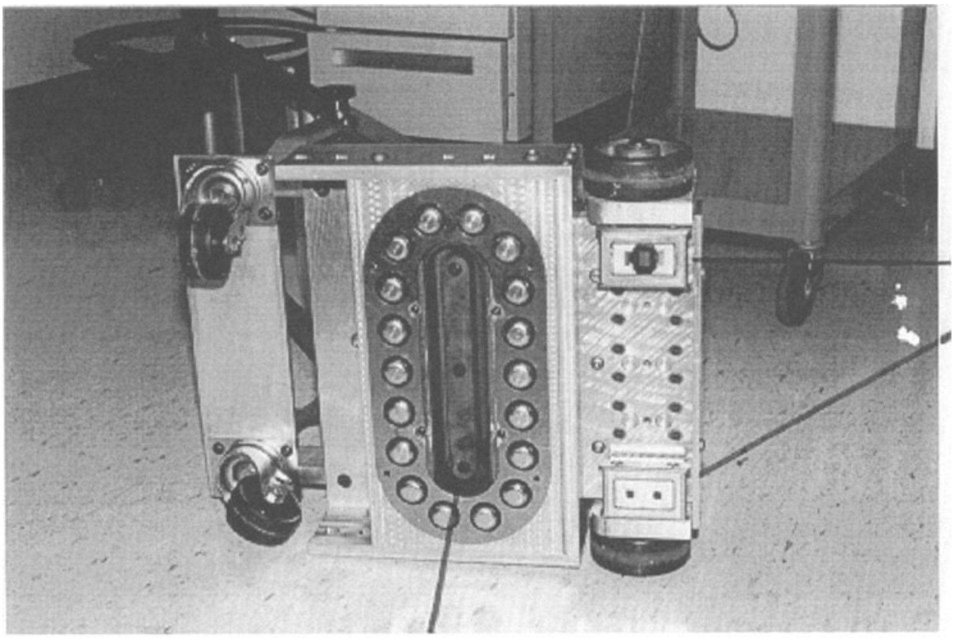

Fig. 5 Close up view of the RFEC probe showing the exciter, pick up coils and the magnetic circuit for shielding.

EXPERIMENTAL DATA

A probe developed in the laboratory is used to collect data on some ferromagnetic plates with machined defects. The distance between the exciter and sensor is fixed at 130 mm. Various excitation frequencies are evaluated with 10 Hz giving the best response to most of these defects. Since accurate phase measurements is critical, an ITHACO lock-in amplifier is used for the data collection. The probe scans the top of the block and so the defects are on the other side of the block. A 50 mm diameter, 75 % deep pit is machined in a 9.375 mm thick steel plate. Fig. 6 is the surface plot of the differential signal phase distribution for the given defect. Instead of using a single pickup coil, two pick up coils are used and the differential signal is used for defect detection. This plot clearly shows the capability of the probe for fairly thick ferromagnetic plates.

CONCLUSIONS

A new RFEC probe for inspecting ferromagnetic plates is designed, tested and now built into a commercial field usable system. The finite element and experimental data clearly shows the effectiveness of the probe for detecting defects in thick plates. Some of the advantages of this probe are:

- low power requirements
- minimum surface preparation
- detection capability for flaws anywhere in the plate thickness

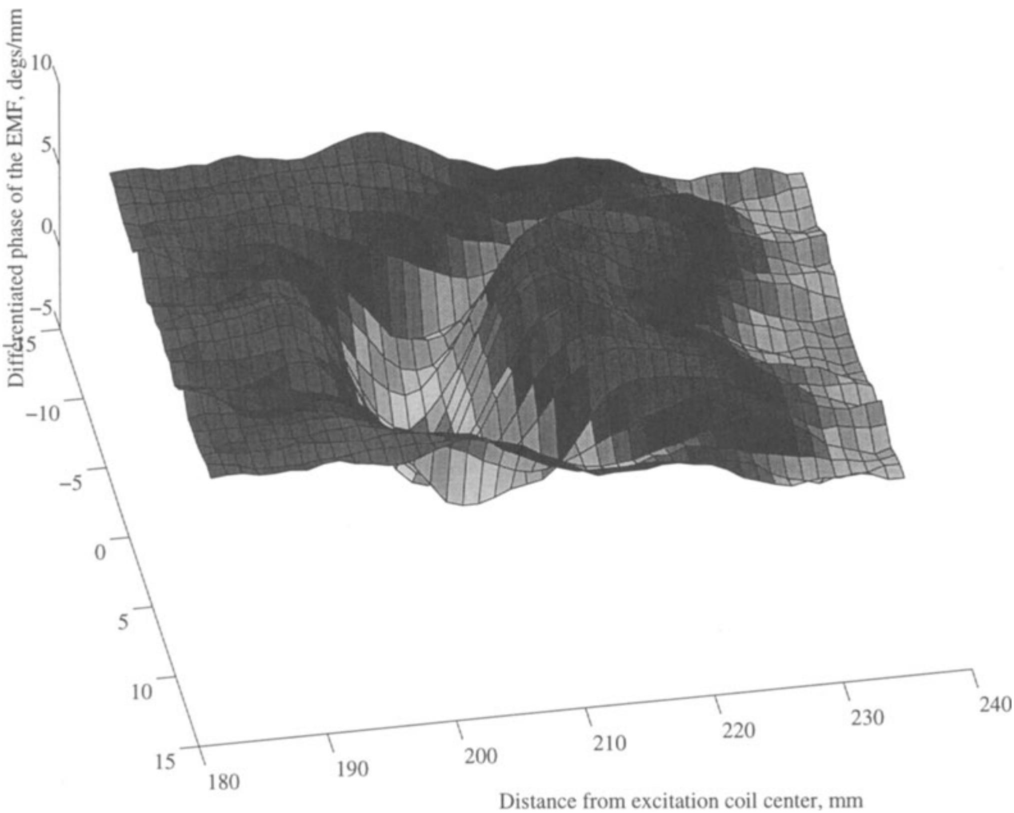

Fig. 6 Experimental data of for the slot machined in the 9.375 mm steel plate using a differential pickup coil sensor.

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