APPLICATION OF SELF NULLING EDDY CURRENT PROBE TECHNIQUE TO THE DETECTION OF FATIGUE CRACK INITIATION AND CONTROL OF TEST PROCEDURES

S. Nath†, M. Namkung, B. Wincheski† and J. P. Fulton†,

NASA Langley Research Center, MS 231
Hampton, VA 23681

† Analytical Services and Materials, Inc.
107 Research Dr., Hampton, VA 23666

INTRODUCTION

A major part of fracture mechanics is concerned with studying the initiation and propagation of fatigue cracks. This typically requires constant monitoring of crack growth during fatigue cycles and the knowledge of the precise location of the crack tip at any given time. One technique currently available for measuring fatigue crack length is the Potential Drop method[1]. The method, however, may be inaccurate if the direction of crack growth deviates considerably from what was assumed initially or the curvature of the crack becomes significant. Another popular approach is to optically view the crack using a high magnification microscope, but this entails a person constantly monitoring it. The present proposed technique uses an automated scheme, in order to eliminate the need for a person to constantly monitor the experiment. Another technique under development elsewhere is to digitize an optical image of the test specimen surface and then apply a pattern recognition algorithm to locate the crack tip.

A previous publication[2] showed that the self nulling eddy current probe successfully tracked a simulated crack in an aluminum sample. This was the impetus to develop an online real time crack monitoring system. An automated system has been developed which includes a two axis scanner mounted on the tensile testing machine, the probe and its instrumentation and a personal computer (PC) to communicate and control all the parameters. The system software controls the testing parameters as well as monitoring the fatigue crack as it propagates.

This paper will discuss the experimental setup in detail and demonstrate its capabilities. A three dimensional finite element model is utilized to model the magnetic field distribution due to the probe and how the probe voltage changes as it scans the crack. Experimental data of the probe for different samples under zero load, static load and high cycle fatigue load will be discussed. The final section summarizes the major accomplishments of the present work, the elements of the future R&D needs and the advantages and disadvantages of using this system in the laboratory and field.

EXPERIMENTAL SETUP

The experimental setup consists of a tensile testing machine, a two axis scanner and

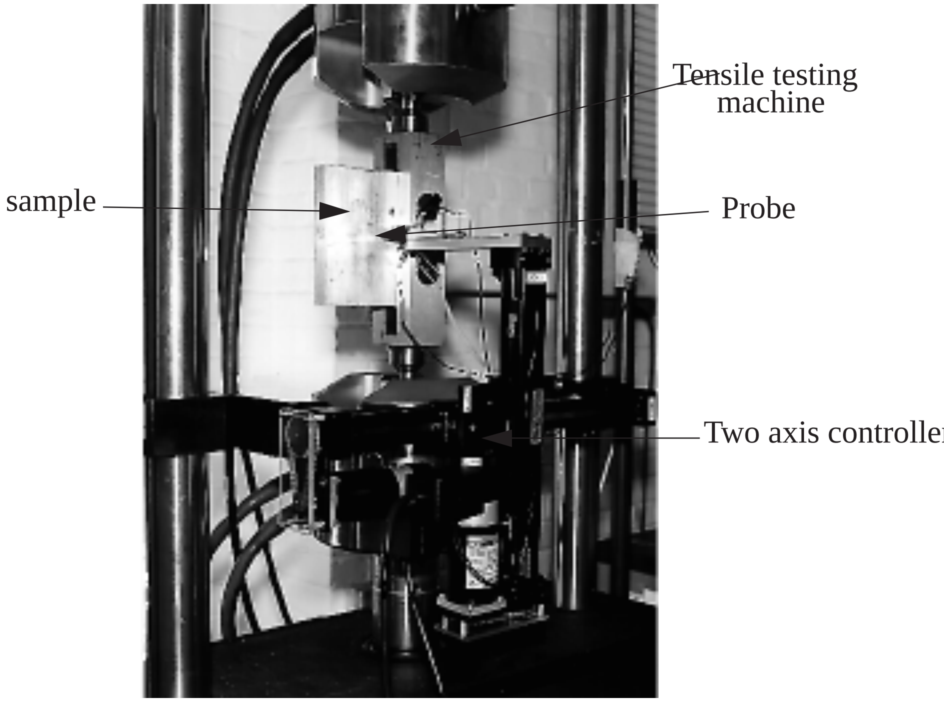

Fig.1 Experimental setup showing the tensile testing machine, two axis controller mounted on the machine, sample and the self nulling eddy current probe.

controller, the self nulling probe and its instrumentation and a PC to control all the instruments and for the storage of information. The scanner is attached to the load frame and has the flexibility to be placed anywhere vertically depending on the sample size and cross head location. Resolution of the motors in the controller is 10 microns in both directions. Figure 1 shows the specimen, probe and the controller mounted on the tensile testing machine. The self nulling probe has been discussed in detail in a number of publications [2] - [4].The most unique feature of this probe is the self-nulling capability that significantly simplifies the instrumentation for the probe. Also the probe provides a well defined local maximum voltage near the crack tip which is exploited in this application. Menu driven software controls the loading procedures and the controller movements during the test. The software keeps track of the crack trajectory, crack length, the number of fatigue cycles and the time elapsed during the test. All this information is archived for further analysis.

FINITE ELEMENT MODEL

A three dimensional finite element model is used to visualize the magnetic field distribution of the probe and the field interaction with the crack.The eddy current distribution in the sample near the crack tip dictates the induced voltage in the pick up coil. These eddy currents generate their own magnetic field and the normal component of these fields which link with the pick up coil will generate the output voltage. This information is useful to understand exactly where the peak voltage occurs with reference to the crack tip and the center of the pickup coil. Since the accuracy needed to identify the crack tip is about 0.1 mm, the model predictions are very useful.

The model uses a probe with a 6.25 mm outer diameter driver coil, 3.2 mm outer diameter ferromagnetic shield with a thickness of .75 mm, and pick up coil with outer diameter of 1.7 mm. The height of the shield and driver coil is 12.5 mm, while the pick up coil height is 6.25 mm. A 100 mA current was used as the excitation to simulate the experimental situation. The sample modeled is an Aluminum 2024 sheet with dimensions 25 mm x 25 mm x 6.25 mm having a 1 mm notch. Figure 2 shows the top view of the finite element model showing the v-notch and crack in the sample and the probe positioned on the crack. The lift-off for the probe modeled is .125 mm which corresponds to a layer of wear tape present under the probe. Another feature of this probe is that it is not very sensitive to lift-off for non-magnetic materials like aluminum [5].

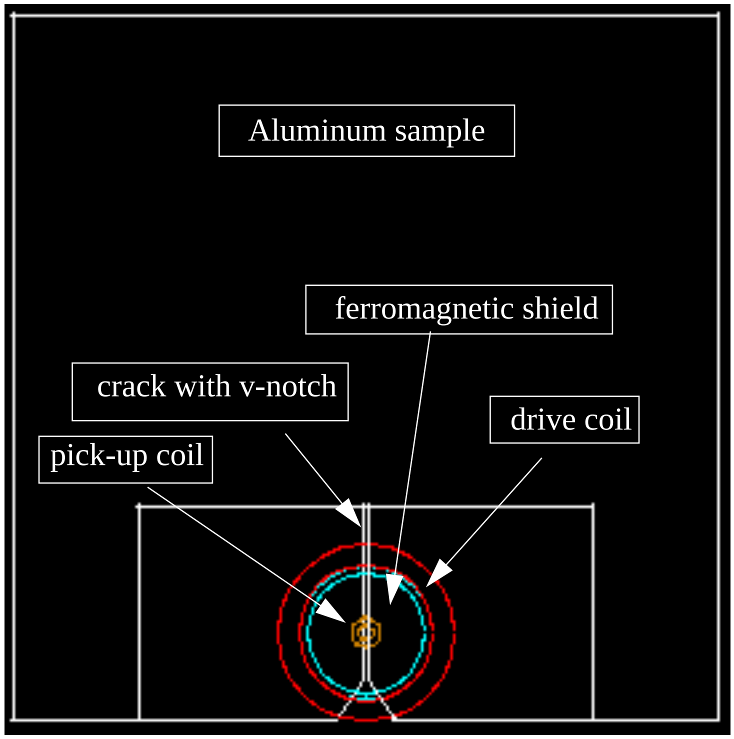

Fig.2 Top view of the three dimensional finite element model of an aluminum sample with a tight crack and the self nulling eddy current probe.

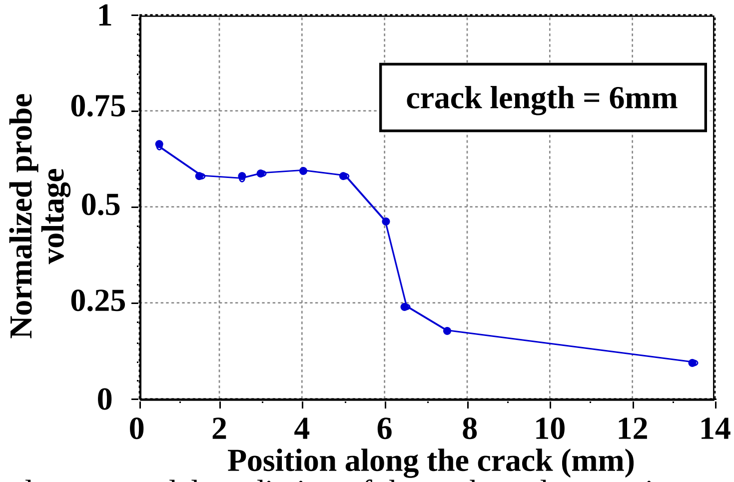

Fig. 3 Finite element model prediction of the probe voltage as it scans a crack 1mm thick and 6mm long. The voltage has been normalized to the voltage obtained in air.

Figure 3 shows the finite element prediction of the normalized probe voltage for a crack length of 6 mm as the probe scanned the sample along the crack. The voltage is normalized to the response of the probe in air. This result clearly indicates the local peak at the crack tip and the rapid decay in the probe response as it scans away from the crack tip. The next section discusses the experimental data.

RESULTS

The system software was tested extensively for different compact tension samples under different conditions. The results included are for a v-notch Al-2024 sample with an existing fatigue crack (unopened crack) and a thin Al-2024 plate with an EDM notch that was fatigued to failure.

Crack Chasing Algorithm

Once the sample is loaded, a peak finding algorithm is used to trace the starter notch and find the initial crack tip. This gives the reference position for the algorithm to keep

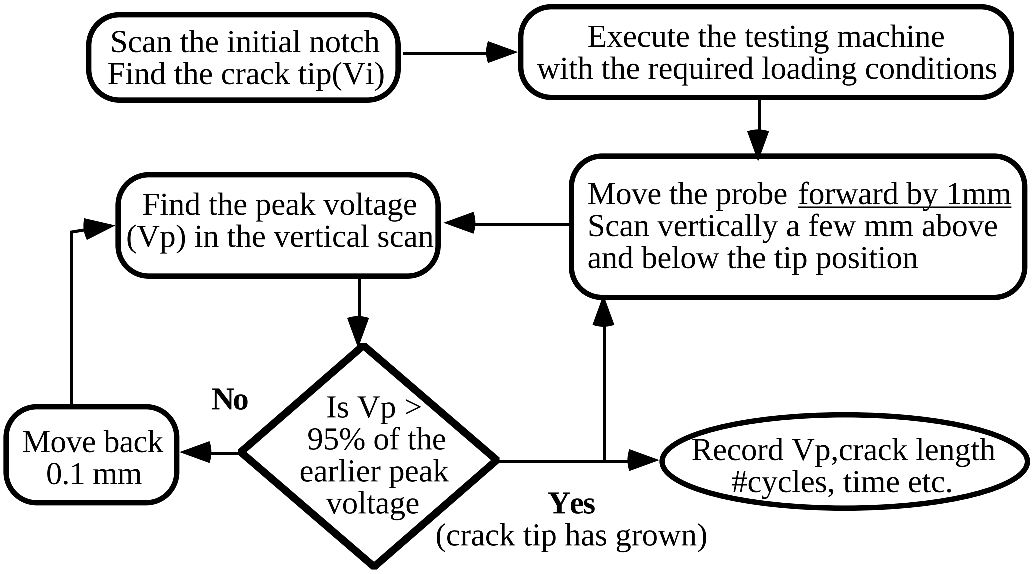

Fig. 4 Block diagram of the algorithm used to monitor the crack tip in real time.

track of the tip. A simple block diagram of the algorithm used for monitoring this crack tip in real time is shown in figure 4. After obtaining the reference position, the probe is moved forward by 1 mm. The probe is then allowed to scan vertically across the crack tip. For every vertical scan a peak voltage is obtained, which is compared to the earlier peak voltage. If this voltage is more than 95% of the earlier peak then the probe is moved forward another 1 mm, assuming the crack has grown. The peak voltage, its location (coordinates), the number of fatigue cycles and the time elapsed are all recorded for further analysis. If this condition is not satisfied then the probe is moved back by 0.1 mm and the process continues. Finally, on the onset of failure the hydraulics of the testing machine shut off and triggers the algorithm to quit and stop all activity.

From the finite element (fig.3) and experimental data (fig.5) for a fatigue crack or EDM notch, there is a localized peak at the crack tip and then the voltage drops off quickly to the base material value (null voltage).The algorithm always maintains the probe ahead of the crack tip somewhere along the steep part of the voltage slope.

Measurements

The v-notch sample is 25 mm thick with an existing fatigue crack. A C-scan (Fig 5b) of the sample using a 6.25 mm diameter probe was useful in designing the chasing algorithm. This sample is then loaded on the tensile testing machine and scanned with the same probe. Fig. 6 is the probe response for the sample under different static loads. As expected the probe output increases with increasing load. This is because the fatigue crack opens wider with increasing load, interrupting the induced current more and hence this induced current generates a larger magnetic field linking with the pickup coil to give a larger output. It is interesting that the voltage due to a tensile-tensile cyclic load at 10 Hz applied to the same fatigue crack generates a voltage comparable to the no load situation. Most of these

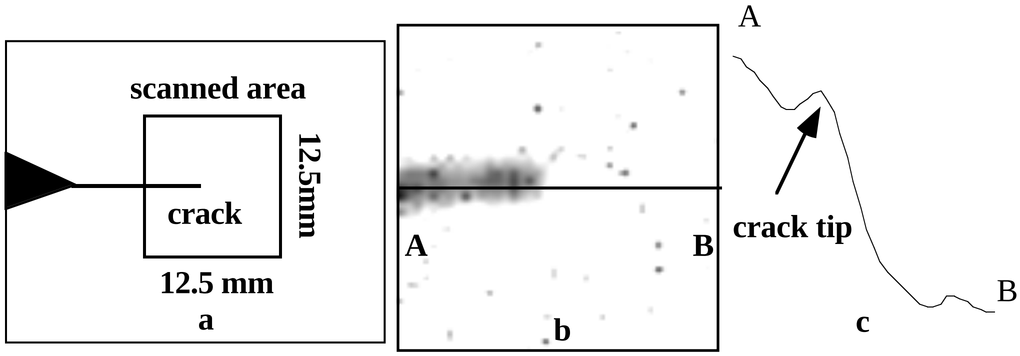

Fig. 5 Probe voltage from a 6.25 mm diameter probe operating at 750 kHz. a) geometry of the scanned area, b) C-scan of the fatigue crack and c) probe response along AB.

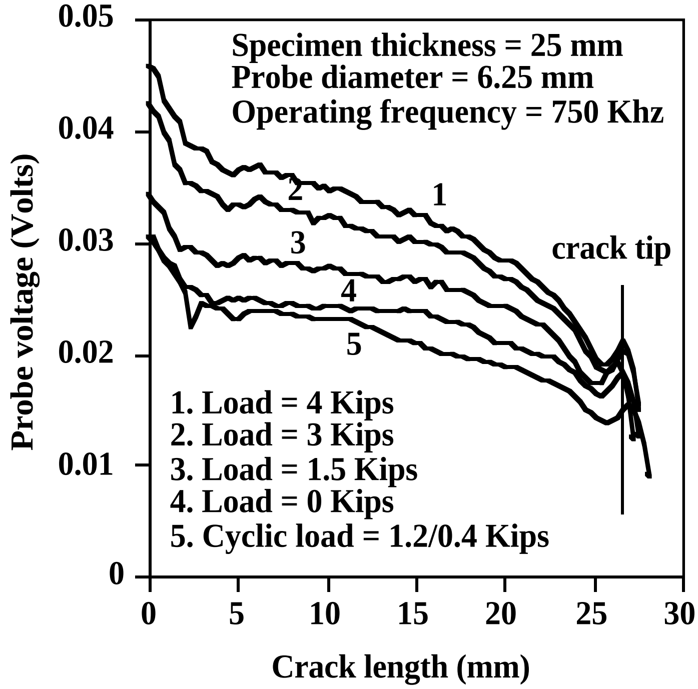

Fig. 6 Probe response to an unopened fatigue crack for varying static loads and cyclic load.

tests were done at least twice to confirm the reproducibility of the results.

A 1.5 mm sample with an EDM notch was then loaded on the machine and scanned. Fig. 7 shows the probe voltage for the EDM notch under no load conditions. As compared to the fatigue crack the local maximum voltage at the crack tip is less pronounced, but still sufficient to track the crack tip during fatigue.The curves in figure 7 are for two trials to confirm the reproducibility and accuracy of the probe.

Finally, a 10 Hz tensile-tensile load was applied to the 1.5 mm sample to monitor the fatigue crack growth. The tensile strength and yield strength for Al-2024 is 70 Ksi and 50 Ksi respectively. An initial load of 1.0/.35 Kips was applied. Fig. 8 is a plot of the crack growth as the probe tracked the tip and the fatigue time. Once the crack is initiated it grew rapidly for a few mm with the initial load. At this stage the load was reduced to slow down the crack propagation rate, so that sample would take a longer time to fail. The peak voltage at the crack tip is plotted with reference to the crack trajectory in Fig. 9. The bounds of the peak voltage are between 180 mV and 200 mV. The probe voltage is plotted only up to a

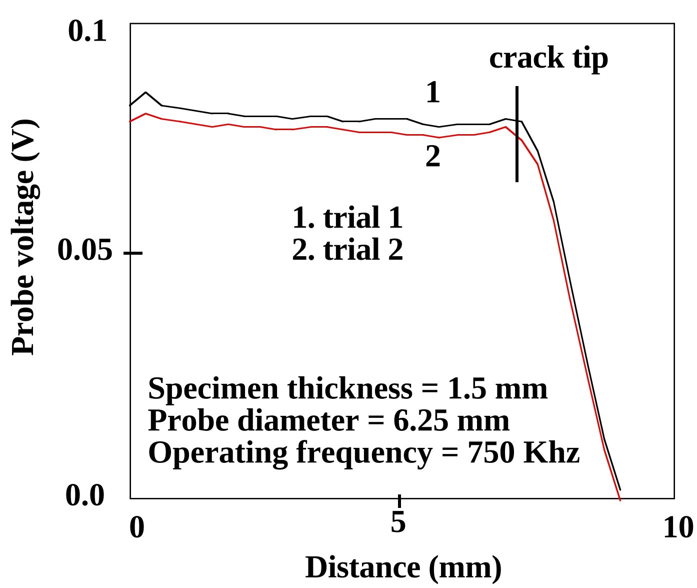

Fig. 7 Probe voltage for a thin sample with an EDM notch at no load.

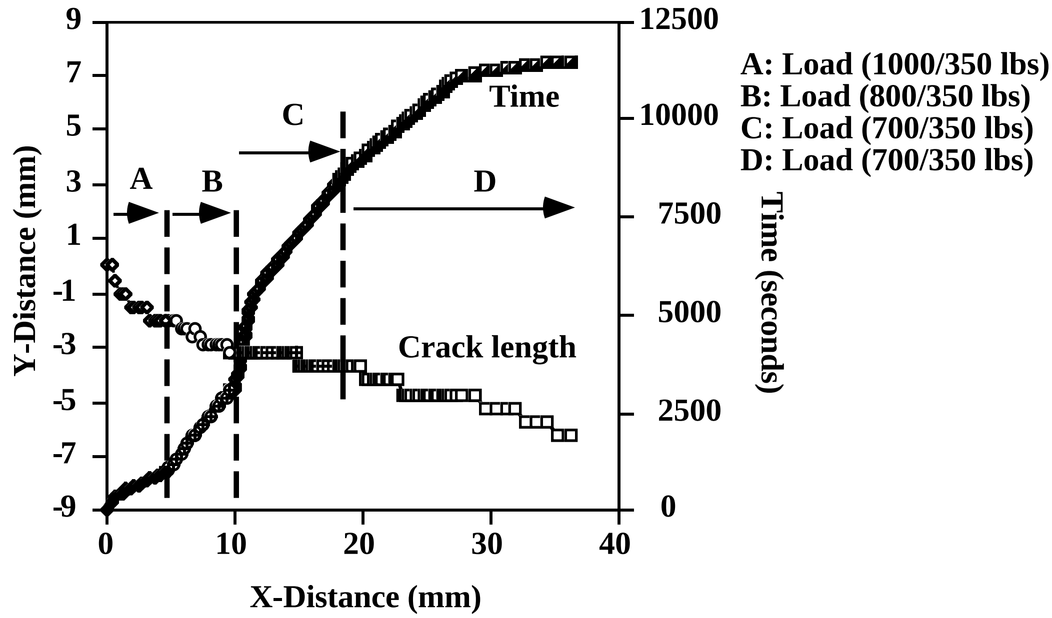

Fig. 8 Fatigue crack trajectory and the fatigue time for the 1.5 mm thick Al-2024 sample using a 6.25 mm diameter probe at 750 kHz.

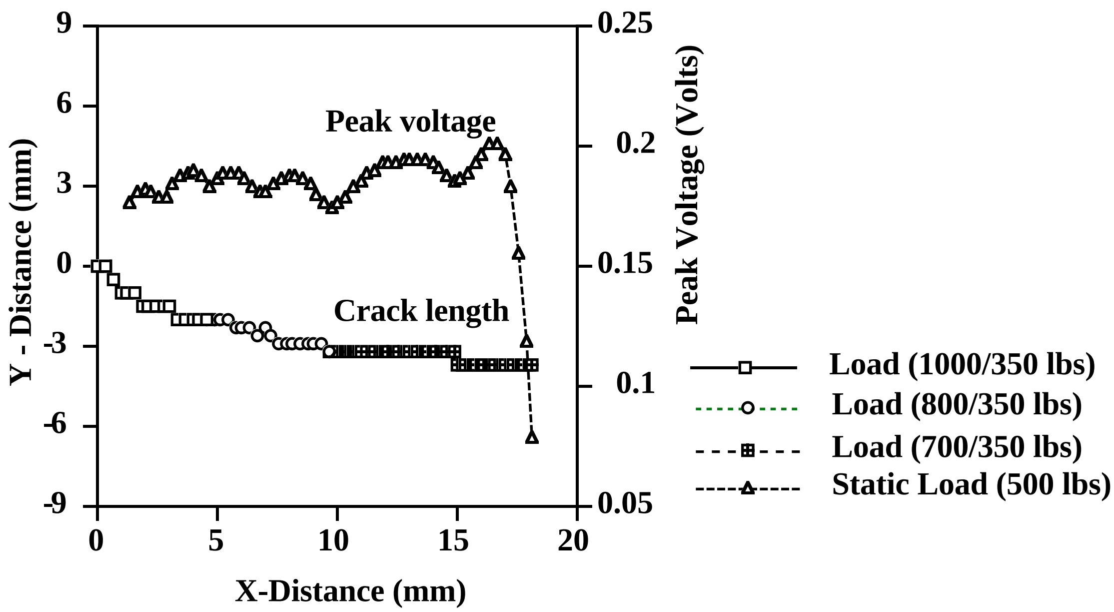

Fig. 9 Probe peak voltage and the crack trajectory for the 1.5 mm thick Al-2024 sample using a 6.25 mm diameter probe at 750 kHz.

crack length of 18 mm although the probe monitored the tip for an x-distance of 37 mm before the sample failed.

SUMMARY AND FUTURE WORK

The paper described one of the application areas of the NASA Langley Research Center developed self-nulling electromagnetic probe that requires very simple instrumentation and test procedures. An automated system has been designed and tested to monitor real time fatigue crack propagation. The system stores information regarding the crack trajectory, fatigue cycles, fatigue time etc. for future analysis. Tracing the tip of a fatigue crack in a thin aluminum plate, the self-nulling probe provides a very well defined probe output near the tip area. This feature has been exploited in this application. A three dimensional finite element model has been used to study the eddy current distribution near the crack tip and how it effects the probe voltage. The output voltage predicted by the model as the probe scanned a tight crack matched the experimental data qualitatively which confirmed the validity of the model. The output voltage from the model predicted the location of the peak voltage of the probe with reference to the crack tip. With the current system, one can predict the crack tip to occur within 0.2 mm of the actual tip.

Some of the future work entails building a smaller diameter probe to improve accuracy for predicting the crack tip. Optical measurements of the tip will be correlated to the probe measurements to confirm the accuracy. The system will be tested in the field to get feedback from the actual users and incorporate their suggestions. Additional finite element modeling will be done to study different sample types, materials etc. Though the software is tailor made to communicate with a particular type of MTS testing machine, modifying this software will be fairly simple. At present some more thin aluminum samples are being fatigued and tested in the laboratory with this setup.

REFERENCES

1. R.H. Vanstone and T.L. Richardson, “Potential Drop Monitoring of Cracks in Surface Flawed Specimens”, *Automated Test Methods for Fracture and Fatigue Crack Growth*, ASTM Special Technical Publication 877, 1985, pp. 148-166.
2. M. Namkung, J.P. Fulton, B. Wincheski and C.G. Clendenin, “An Application of a New Electromagnetic Sensor to Real-Time Monitoring of Fatigue Crack Growth in Thin Metal Plates”, *Review of Progress in Quantitative NDE*, Vol. 13B, edited by D. O. Thompson and D. E. Chimenti, (Plenum Press, New York, 1993), pp. 1633-1640.
3. B. Wincheski, J.P. Fulton, S. Nath, M. Namkung and J.W. Simpson, “Self Nulling Eddy Current Probe for Surface and Subsurface Flaw Detection”, *Materials Evaluation*, Vol. 52/No. 1, Jan. 1994, pp. 22 - 26.
4. B. Wincheski, M. Namkung, J. P. Fulton, J. Simpson and S. Nath, “Characteristics of Ferromagnetic Flux Focusing Lens in The Development of Surface/Subsurface Flaw Detector”, *Review of Progress in Quantitative NDE*, Vol. 13B, edited by D. O. Thompson and D. E. Chimenti (Plenum Press, New York, 1993), pp. 1785 1792.
5. S. Nath, R. Wincheski, J.P. Fulton and M. Namkung, “Study of the New Eddy Current Non-Destructive Testing Sensor on Ferromagnetic Materials”, To be published in the *IEEE Transactions on Magnetics*, November 1994.