EDDY CURRENT TESTING AND SIZING OF FATIGUE CRACKS

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Abstract

This study proposes an investment for the evaluation of fatigue cracks by eddy current testing (ECT). Fatigue cracks (FC) manufactured on SUS316 plates are detected using ECT. Inverse analysis is applied to the ECT signals and both crack depth and length are estimated. Two models are applied, one is the EDM model without conductivity, and the other is the SCC model with partial conductivity. The detection and sizing results are discussed in this paper.

1. Introduction

Numerical analysis methods are applied to predict the Eddy current testing (ECT) signals, to aid the design of ECT probes, and to reconstruct crack shapes from their ECT signals [1]. Up to now, sizing of artificial EDM cracks has been completely solved. To decrease the computational time of iteration computing, some fast forward analysis of ECT signals are introduced. Inverse analysis method based on these fast ECT simulators has been applied, and sizing of EDM cracks can be completed in a few minutes [2][3].

When detecting stress corrosion cracks (SCC) using ECT, a much smaller ECT signal is obtained comparing with the EDM cracks of same depth, because of the partial conductivity in the SCC. By introducing a conductivity parameter in the slit model for inverse analysis problem, better depth estimations can be performed, according to the results proposed by authors [4][5].

One the other hand, fatigue cracks (FC) have much more narrow width than EDM cracks. For this reason, the detection of FC is more difficult than the detection of EDM crack when using some nondestructive testing methods such as ultrasonic (UT). In this study, detection and sizing of FC will be discussed, form the viewpoint of experiment and numerical analysis method.

2. Detection and Sizing of FC

Three fatigue cracks are manufactured on SUS316 plates by four-point bending. The size of specimen is 200mm*100mm*10mmt. Initial notch is EDM slit which is 0.5mm depth, 10mm length and 0,3mm width. Fatigue cracks (FC1, FC2 and FC3) are induced after 100,000, 70,000, 80,000 cycles separately. Surface removal of 0.8mm is applied after fabrication finished.

2.1. Detection results

Two types of ECT probes are applied to the detection of fatigue cracks. One is the plus-point type ECT probe, which use two rectangular coils as exciter and pickup sensor. Another is the uniform type ECT probe, which use a large rectangular coil as exciter to induce uniform eddy current and a pancake coil as sensor. Both theses two types of probe can reduced lift-off noise significantly and have very good signal noise ratio (SNR) according to previous study. The shapes of these two probes are shown in Fig. 1 and Fig. 2.

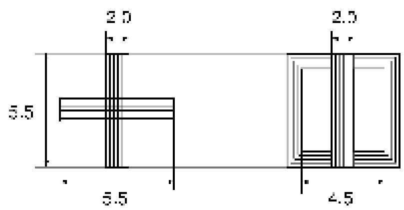


Figure 1*: Plus-point probe*

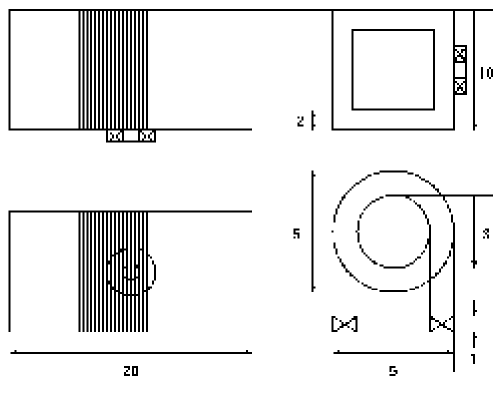
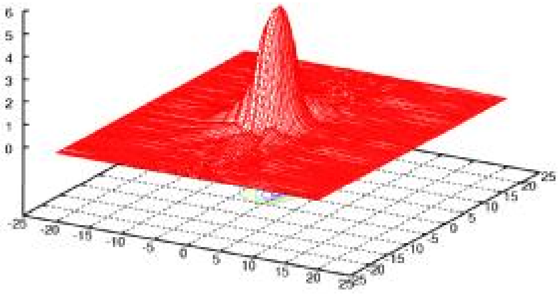
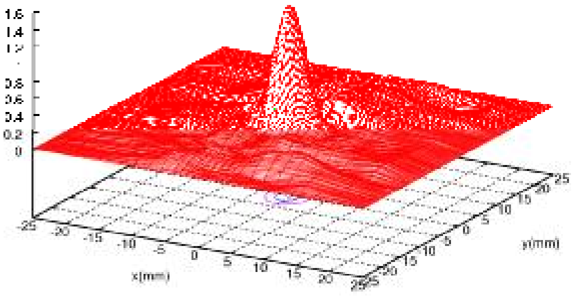


Figure 2*: Uniform probe*

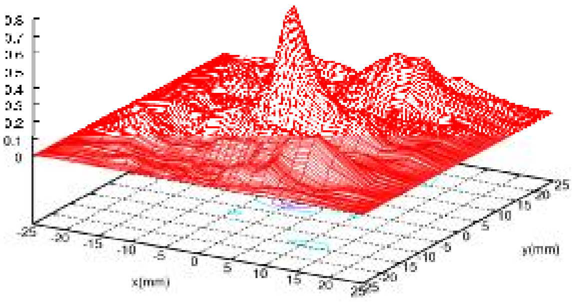
The life-off of ECT probe is 1.0mm and three frequencies of 50, 100 and 400kHz are used. A region of 40mm*50mm is scanned using two dimension scanner control by step motor. The amplitude of ECT signals (50kHz) of plus-point probe and uniform probe are shown in Fig. 3 and Fig.4. Calibration signal of a 5mm depth EDM crack is shown together.



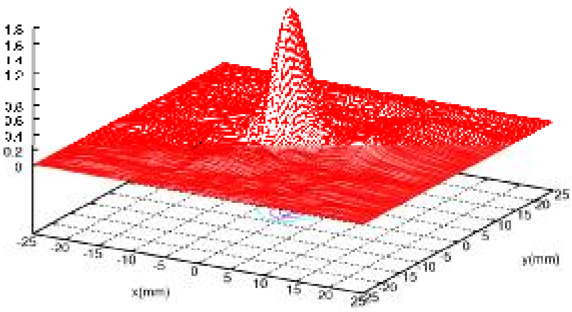
(a) ECT signal of 5mm depth EDM (calibration)



(b) ECT signal of FC1

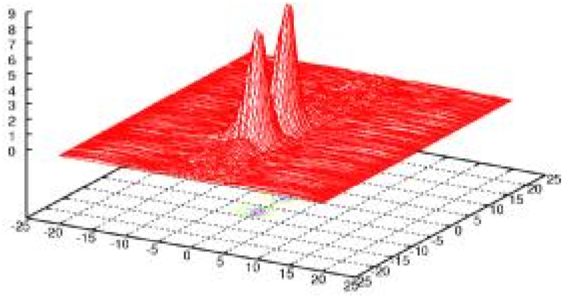


(c) ECT signal of FC2

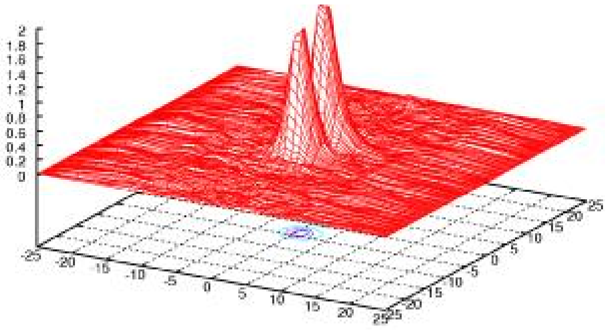


(d) ECT signal of FC3

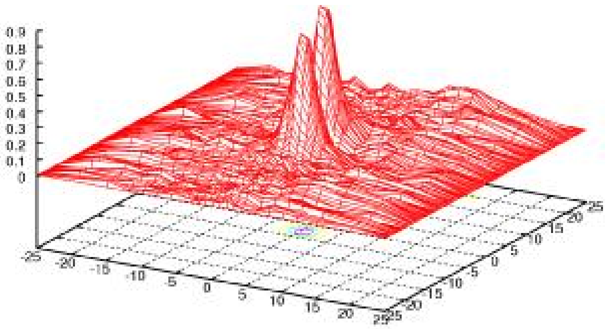
Figure 3*: ECT signal of a plus-point probe*



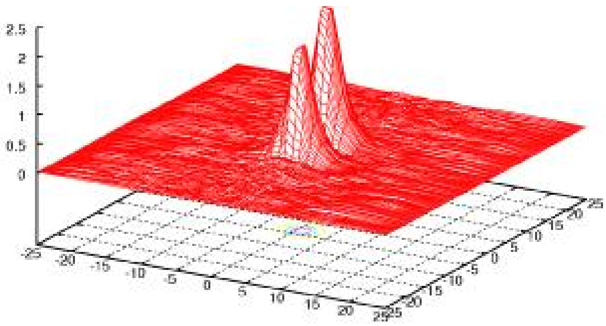
(a) ECT signal of 5mm depth EDM (calibration)



(b) ECT signal of FC1



(c) ECT signal of FC2



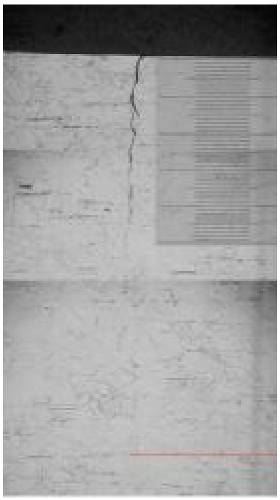
(d) ECT signal of FC3

Figure 4*: ECT signal of a uniform probe*

A peak signal can be found for plus-point probe, which shows the position of detected crack. One the other hand, two peaks occur at the edge of the crack because the self-differential characteristic of uniform probe. Comparing with the 5mm EDM crack, signals of fatigue cracks are much smaller.

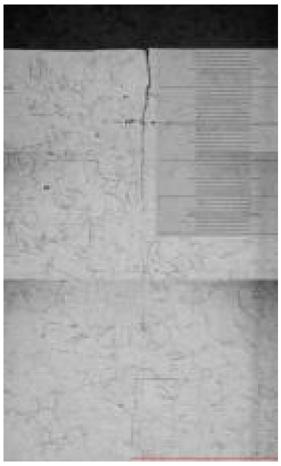
2.2. Destructive testing results

Destructive testing experiment is applied. For each fatigue crack, 3 cross-sections are photographed and the deepest depth is considered as the true depth of the fatigue crack. From the photo of cross-section of the FC, the width is very narrow (less than 5μm) and the opening is nearly closed. Different from SCC cracks, which always appear as a "group" of cracks and disperse in a large region, FC appears as a "single" crack similar to EDM crack. The cross-section of FC is shown in Fig. 5. A scale is also shown in the photo and the deepest parts of FC are about 1.1mm, 0.8mm and 1.2mm separately. This depth is almost proportional to the cycles of four-point bending experiment.

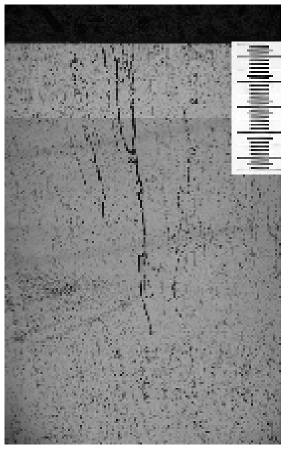


(a) FC1

(b) FC2



(C) FC3



(d) SCC sample

Figure 5*: Cross-sections of fatigue cracks*

2.3. Sizing results

The high accuracy of some numerical simulation techniques has been demonstrated and several fast computational methods are presented. The ECT signals can be achieved in a short amount of CPU time with high precision, which allows the inverse problems to be solved in a practical amount of time. In the normal approach to solving inverse problems, the least square error function between the estimated signals and the observed signals is minimized. The following evaluation function is used:

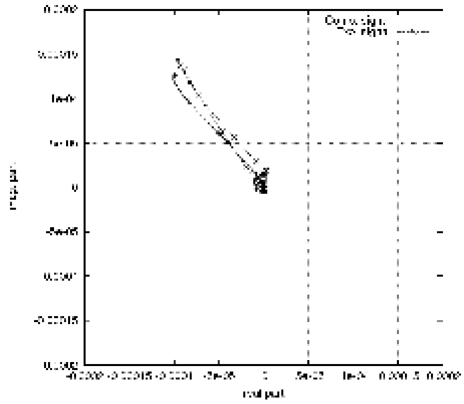
$$e(\boldsymbol{c}) = \sum_{m=1}^{M} w_m \left| Z_m(\boldsymbol{c}) - Z_m^{obs} \right|^2 \qquad (1)$$

Where $\boldsymbol{c}$ is the parameter of cracks, m is the measurement point, and *obs* is the experimental results. w is weight of each points using form inversion. The weight w is set to the same value 1 in this study.

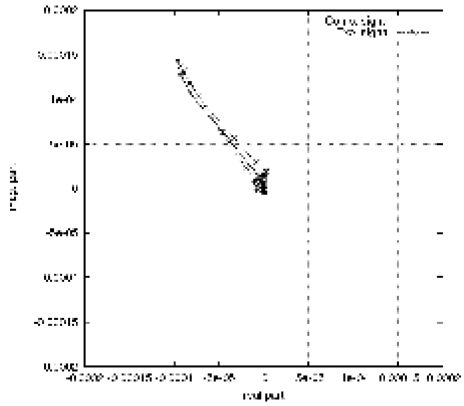
Two models are applied in this study, one is the EDM model without conductivity, and the other is the SCC model with partial conductivity. The parameters of the crack are really a 2 dimensional (a cross-section) type with the position, length and depth. Because the width of crack is unknown, all model using a fixed width of 0.2mm. Previous study shows that sizing of SCC using SCC model will obtain better sizing results.

All inverse computations stop after several iterations. Because of experimental noise, there are still some differences between numerical and experimental signals. However, good agreement can be acknowledged. The computational and experimental signals (FC1 only) are compared in Fig.6. As shown in (a) and (b), using the SCC model (with one more parameter conductivity), these signals fit each other better than using the EDM model. Anyway, these differences may be due to the difference of crack width, other than conductivity. For uniform probe, conductivity change is not so obviously and results of two models are nearly the same.

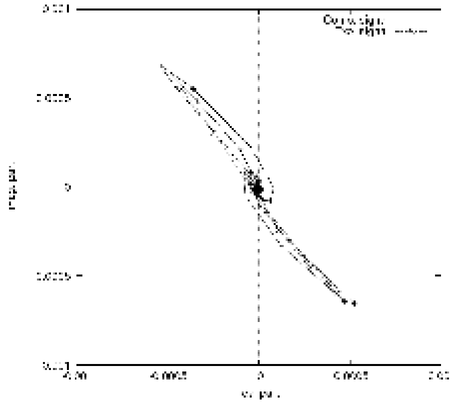
Sizing results using two models are compared with true results from destructive testing, as shown in table 1 and 2. All reconstructions show that the lengths of FC are about 10mm.



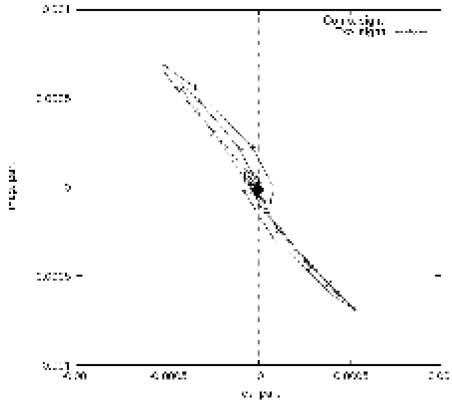
(a) EDM model, plus-point



(b) SCC model, plus-point



(c) EDM model, uniform



(d) SCC model, uniform

Figure 6*: Comparison of signals of FC1*

Table 1: Sizing results of plus-point probe

	Sizing Depth (EDM)	Sizing Depth (SCC)	True Depth
FC1	1.2 mm	1.4 mm	1.1 mm
FC2	0.8 mm	1.3 mm	0.8 mm
FC3	1.4 mm	1.7 mm	1.2 mm

Table 2: Sizing results of uniform probe

	Sizing Depth (EDM)	Sizing Depth (SCC)	True Depth
FC1	1.0 mm	1.0 mm	1.1 mm
FC2	0.7 mm	0.7 mm	0.8 mm
FC3	1.2 mm	1.3 mm	1.2 mm

Both methods obtain good sizing results of depth of FC. However, the depths of the fatigue cracks are estimated better using EDM model without conductivity. Although the width of fatigue cracks is much similar to the SCC, the conductivity characteristic of fatigue cracks is nearly the same as EDM cracks.

3. Conclusions

Fatigue cracks are detected and sizing using eddy current testing method. FC is able to detected using ECT with good SNR. Sizing of FC shows that the conductivity characteristic of fatigue cracks is nearly the same as EDM cracks.

4. References

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