FUNDAMENTAL STUDY OF FLAW ESTIMATION IN EDDY CURRENT TESTING USING GENETIC ALGORITHM

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Abstract : In recent years, not only flaw detection but also flaw estimation with a high degree of accuracy is needed for eddy current nondestructive testing. The eddy current flaw testing signal (ECT signal) varies depending on the depth, length, width and shape of flaw. We propose an optimization technique that optimizes flaw shape by minimizing the difference between ECT signal and flaw signal calculated by FEM. The genetic Algorithm (GA) method, which can efficiently use global retrieval as an optimization technique, is used. Due to improved computer performance it is now possible to do three-dimensional analyses and to research and develop various FEM techniques. In flaw shape estimation using a GA, it has up to now been necessary to calculate, using a very lengthy process, the flaw signal of each shape.

The authors propose a technique for calculating the flaw signal by superposing an ECT signal that does not use FEM to calculate the flaw signal of each flaw shape. Under these experimental conditions, the authors have found linearity between the signal for a short-length flaw than the surface coil diameter and the signal of long-length flaw than the coil diameter. That is, the ECT signal is calculated by superposing an ECT signal for a shorter flaw than the surface coil diameter. The authors have conducted a fundamental study of flaw shape estimation from ECT signal using GA. We also discuss our proposed technique for calculating the flaw signal by superposing the ECT signal.

Introduction : Eddy current nondestructive flaw testing, which utilizes electromagnetic induction, is a nondestructive test method for detecting flaws in the surfaces or subsurface of metal products. It is used for in-process inspections, product inspections and in-service inspections. The requirements of eddy current nondestructive flaw testing are broadening to include not only flaw detection, but also evaluation of the characterization of a flaw such as its depth, length, and width. The phase angle of a flaw signal obtained using eddy current nondestructive flaw testing using an inner eddy current probe, which is used for in-service inspection of piping, enables the estimation of flaw depth. However, this method cannot provide information on the characteristics of the flaw such as its length, width or shape. It has, however, been noted that an ECT signal varies with flaw depth, length and width. Using this information, optimization techniques have been proposed that optimize the flaw shape so as to reduce the difference between the ECT signal and the flaw signal derived from electromagnetic field analysis. A Genetic Algorithm[1)], which allows efficient global retrieval, has been used as one of these optimization techniques.[2-3)] Recently improved computer performance and R&D of various electromagnetic field analysis techniques have helped facilitate three-dimensional analysis. However, current flaw shape estimation using a GA requires the calculation of a flaw signal for each flaw shape, which is a very lengthy process.

The authors propose a method of calculating a flaw signal for each flaw shape not by means of electromagnetic field analysis but by simple superposition of ECT signals. Under the experimental conditions used in this study, the authors found linearity between the ECT signals of flaws both shorter and longer than the coil diameter of a pancake surface eddy current probe of a type in wide use in eddy current nondestructive flaw testing. Consequently, the ECT signal of a flaw longer than the coil diameter can be calculated by superposing the ECT signals of flaws shorter than the coil diameter. In this paper, we report that the results of a fundamental study on flaw shape estimation from ECT signals using a GA, and a method of calculating the flaw signal for each flaw shape by superposing ECT signals.

Principle of the Estimation of Flaw Shape Using a GA : In the evolution of living organisms, organisms that do not adapt to their environment disappear, while those that do, survive and leave offspring. Through continuous alternation of generations, organisms that adapt better to their environment are more likely to survive. GA, an optimization technique that mimics this evolutionary process, enables efficient global retrieval. The algorithm consists of the following steps: generation of initial population of organisms, calculation of fitness to the environment, selection and multiplication of individual organisms based on their fitness values, creation of new organisms through crossover and mutation, and evaluation of the population of organisms.[1)]

Figure 1 shows a flow chart for flaw shape estimation from ETC signals using a GA. First, any number of flaws of any shape are generated. As shown in Figure 2, coordinate values from "A" to "H" are randomly created for each flaw shape. Figure 2 represents a cross section of a flaw in the longitudinal direction. The flaw signal of each flaw shape generated is calculated by superposing pre-measured ECT signals corresponding to various flaw depths. The error between each signal derived from the superposition and the ETC signal obtained in eddy current nondestructive flaw testing is then calculated using the following equation.

$$E_m = \sum_{j=1}^{n} (ECT_j - CAL_{mj})$$

where m, j, ECT, and CAL represent individual number, scanning position, eddy current nondestructive flaw testing signal, and flaw signal calculated by superposition, respectively. The smallest error corresponds to the largest fitness value. Using Roulette Wheel Selection, individuals having flaws with small fitness values are eliminated, and individuals having flaws with large fitness values are bred. In the crossover step, any two individuals are chosen, some of their coordinate values are interchanged, and two new individuals having the characteristics of both the chosen individuals are created. In the mutation step, an individual is randomly chosen, its coordinate values are additionally recalculated, and an individual having an entirely new flaw shape is created. The fitness values of the next generation of flaw shapes created in this way are calculated and the population of organisms is evaluated. If the population of organisms satisfies the termination conditions, the algorithm is completed. If it does not satisfy the termination conditions, it is returned to the selection and multiplication steps, and subsequent generations of the population of organisms are newly created.

Superposition of ECT Signals : We propose a method for calculating a flaw signal for each flaw shape, not by electromagnetic field analysis but by simple superposition of ECT signals. As exemplified in Figure 3, a flaw with a length of 15 mm and a depth profile of 40-60-40% is regarded as a composite of "two flaw components with a length of 5 mm and a depth of 40%" and "a flaw component with a length of 5 mm and a depth of 60%". In the proposed ECT signal superposition process, the ECT signals of the three flaw components with a length of 5 mm and depths of 40% and 60% are measured in advance, and the flaw signal is calculated by summing these ECT signals while sequentially shifting the scanning position by 5 mm.

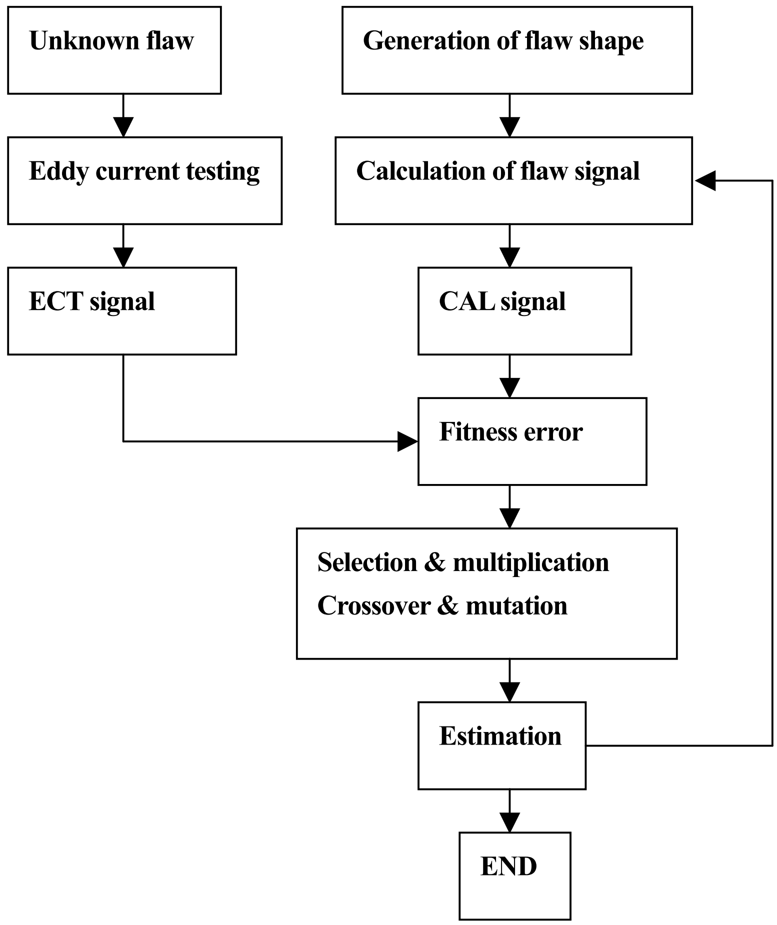


Figure 1. Flow chart of estimation of flaw shape using a GA

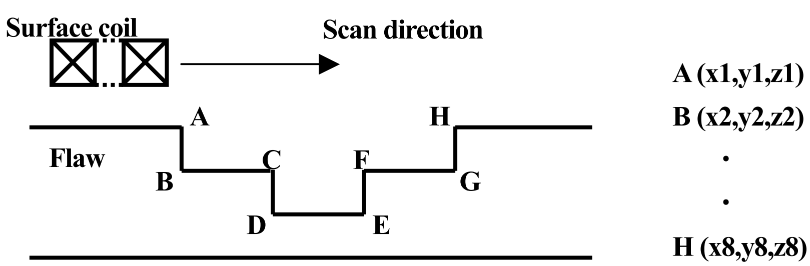
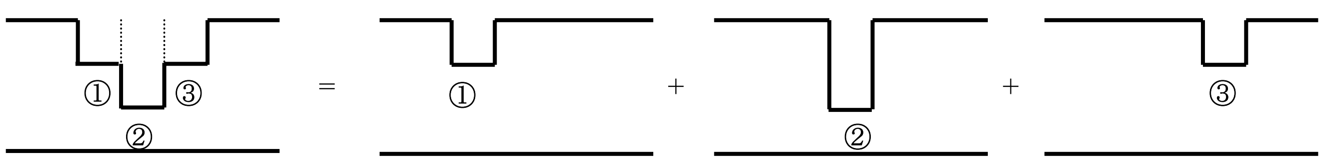


Figure 2. Coordinate values of created flaw



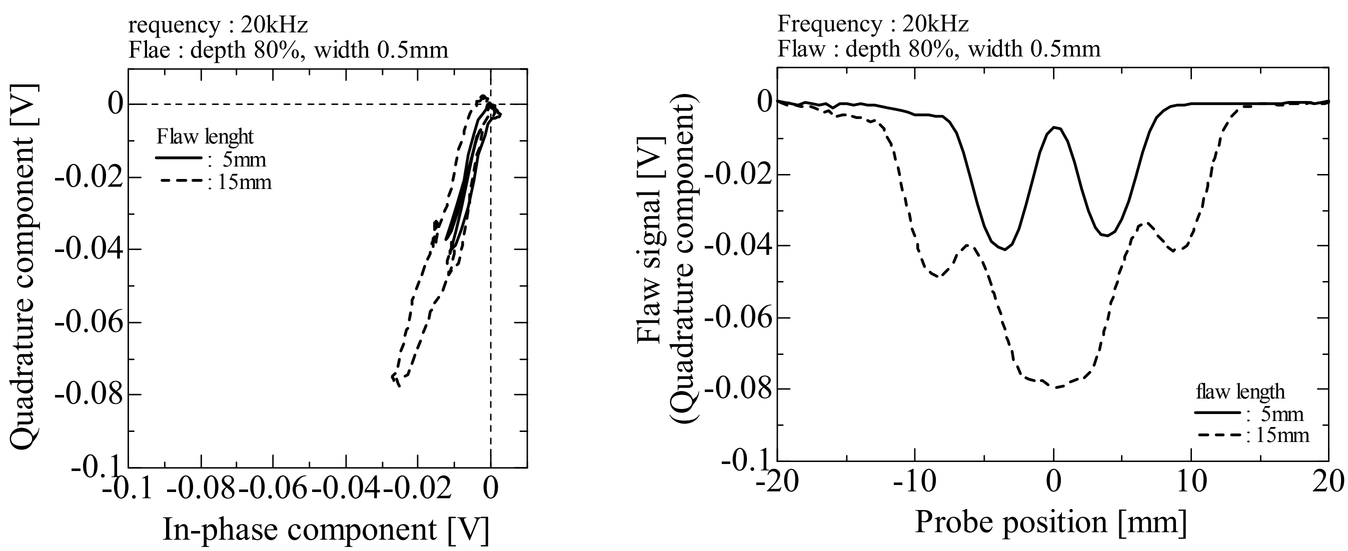
(a) length 15mm, depth 40-60-40% (b) length 5mm, depth 40% (c) length 5mm, depth 60% (d) length 5mm,depth40%

Figure 3. Proposed technique for superposition of ECT signals

Experimental Condition : A surface coil with an outer diameter of 9 mm and a cross section of windings of area 1 mm^2 was used as a test coil to perform eddy current nondestructive flaw testing. A non-magnetic brass plate with a side length of 160 mm and a thickness of 1.5 mm was used as the test specimen. Various slits (length: 5 mm and 15 mm; depth: 20%, 40%, 60%, and 80%; width: 0.5 mm) were made by electric discharge machining and used as flaws. ECT signals were obtained by two-dimensional scanning of the test coil at a constant test frequency of 20 kHz, with the distance between the test specimen and the coil (lift-off) held at 0.5 mm. In an experiment for flaw shape estimation using a GA, the number of individuals expressing various flaw shapes, crossover rates, and mutation rates were set at 128, 25%, and 2%, respectively. In this experiment, scanning of the test coil was performed directly above each flaw and flaw width was set at 0.5 mm.

Experimental Results :

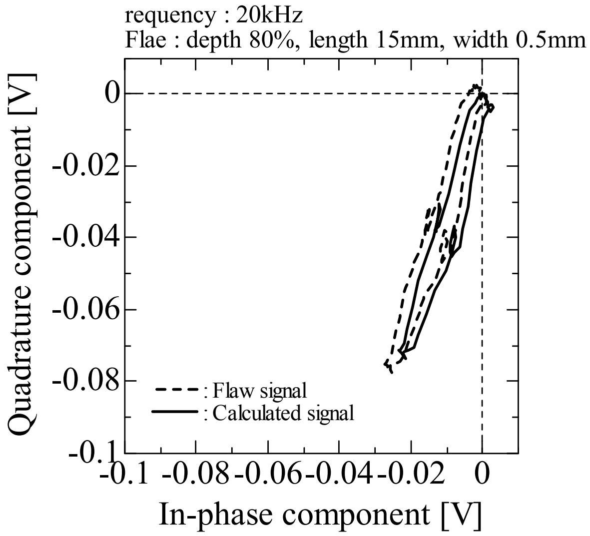
Superposition of flaw signals : Figure 4 shows the 8-figure patterns and waveforms of ECT signals for 5- and 15- mm long flaws with a depth of 80%. Figure 5 represents a flaw signal calculated by superposing the ECT signals of the 5 mm-long flaw shorter than the coil diameter (shown in Figure 4) three times while sequentially shifting the scanning position by 5 mm and the ECT signal of the 15 mm-long flaw longer than the coil diameter. The Figure indicates that almost the same signal as the ECT signal of the 15 mm-long flaw is obtained by superposing the three ECT signals of 5 mm-long flaws. Experiments on other flaws produced similar results. The results in this study suggest that there is linearity between ECT signals of 5- and 15 mm-long flaws created in a nonmagnetic material. Based on this information, ECT signals of 5 mm-long flaws shorter than the coil diameter were superposed to calculate a flaw signal for each flaw shape using a GA.



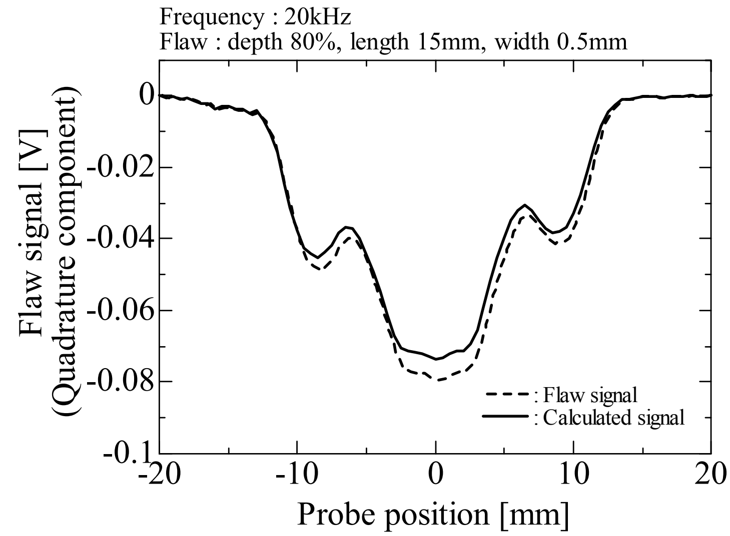
(a) ECT signal patterns

(b) ECT signal versus probe position

Figure 4. ECT signals of two flaws with different lengths



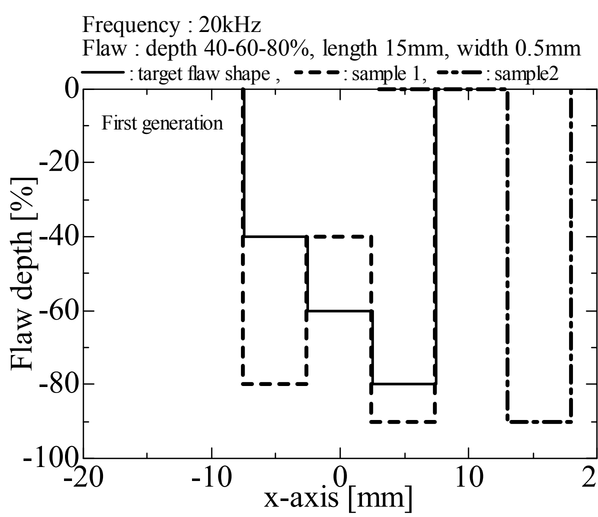
(a) ECT signal patterns



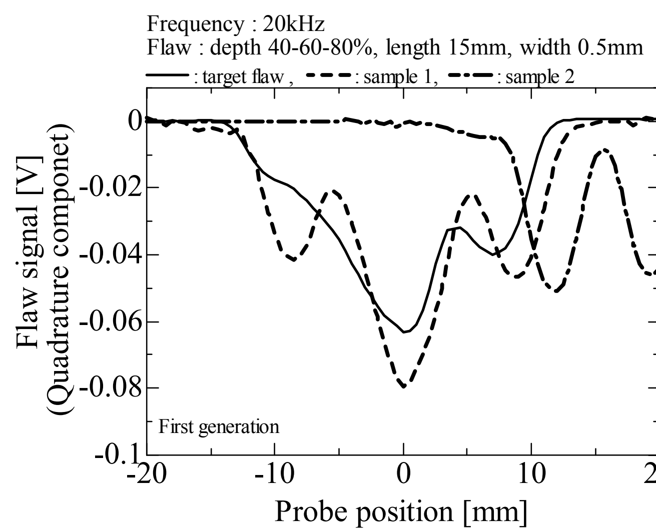
(b) ECT signal versus probe position

Figure 5. Flaw signals calculated by superposing ECT signals of 5 mm-long flaws

Results of Flaw Shape Estimation Using a GA : Figure 6 shows the results of a flaw shape estimation using a GA. A step flaw with a depth profile of 40-60-80% was used as a target flaw, i.e., an unknown flaw in Figure 1. Figures 6 (a) and



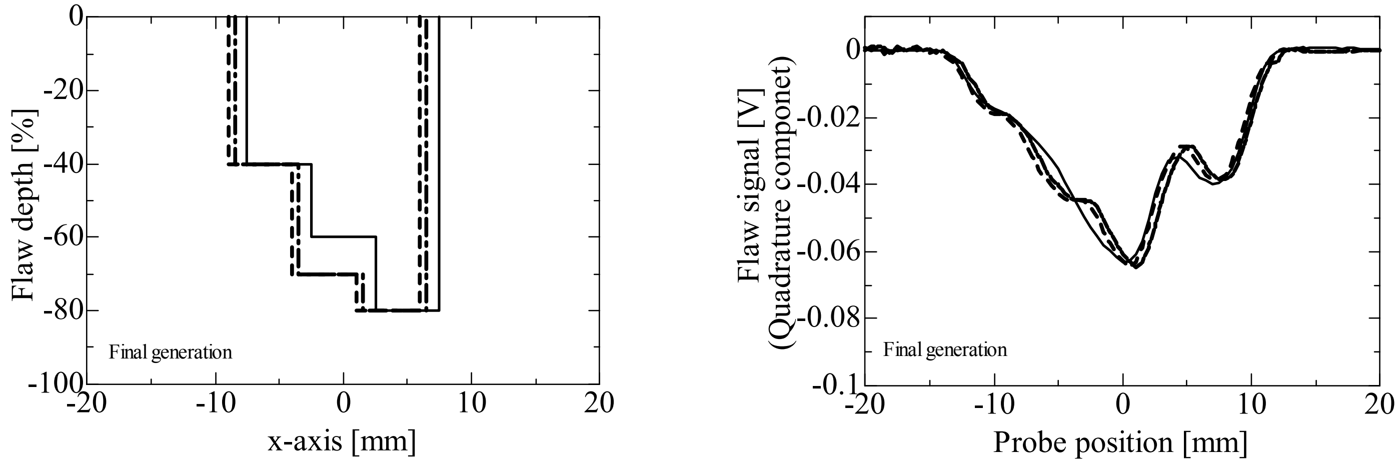
(a-1) Flaw shape



(a-2) Flaw signal

(a) Estimation results for the first generation

Figure 6. Results of flaw shape estimation from an ECT signal using a GA



(b-1) Flaw shape (b-2) Flaw signal

(b) Estimation results for the 150th (final) generation

Figure 6. Results of flaw shape estimation from an ECT signal using a GA

(b) show the estimation results of the first and 150th (final) generations, respectively. As shown in the Figure, the final generation of flaw shape is almost the same as the target flaw shape, in spite of an error of about 10% being recognized in one of the depth components. The results indicate that GA is successfully able to estimate flaw shapes. Other flaw shapes were also estimated using a GA.

Conclusions : We attempted to estimate a flaw shape from an ECT signal using a GA and obtained the following information.

1) Under the experimental conditions in this study, it is confirmed that GA is successfully able to estimate slit flaw shapes.

2) Linearity between the ECT signals of flaws shorter and longer than the coil diameter was found. It was confirmed that the signal of a flaw longer than the coil diameter can be obtained by superposing ECT signals of flaws shorter than the coil diameter.

Further investigations will be conducted in detail under varying conditions.

References : 1) F.Glover : Future Paths for Integer Programming and Links to Artificial Intelligence, Computer and Operations Research, 13, pp.533-549 (1986)

2) K.Rasheed and B.D. Davision : Effect of Global Parallelism on the Behavior of a Steady Genetic Algorithm for Design Optimization, Proceedings of Congress on Evolutionary Computation, pp.534-541 (1999)

3) N.Yusa et. al. : Comparision of Efficiencies of Metaheuristics in ECT Inversion Problems, Journal of JSNDI, Vol.52, No.9, pp.504-510 (2003) in Japanese