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Eddy Current Testing for Radiator Tubes Surrounded by Cooling Fins

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This paper presents a non-destructive evaluation study on a radiator with cooling fins as a complex shaped specimen. Radiator structures are used in various heat exchangers, such as automobiles, air conditioners and refrigerators. An eddy current testing method, namely multi-frequency excitation and spectrogram method (MFES), was employed to detect a defect on the radiator tube surrounded by cooling fins. Overall, experimental results suggested that the influence of cooling fin is not as noticeable as that of the defect signals.

Keywords: multi-frequency excitation and spectrogram method, MFES, eddy current testing, radiator tube

1. Introduction

Non-destructive evaluation (NDE) techniques that evaluate the properties of an object can save the consumption of both energies and resources. In theory, NDE is suitable for any system, even for structures with complicated shapes. However, so far NDE has only been adapted to structures with simple shapes. In reality, ordinary manufactured products are often constructed with parts that have complicated shapes. Therefore, it would be very interesting to investigate the validity of NDE for these complicated systems.

Radiator structures, fallen in the catalogue of complicated structures, are commonly used in various equipments including refrigerators and air conditioners, and hence they play very important roles in numerous industrial situations. These structures have many dense cooling fins surrounding the tubes where coolant gas or fluid flows inside. These radiators often contain chemical coolant, and therefore can easily suffer from corrosion. Once these structures have developed defects such as cracks or holes, it is very difficult to replace the damaged parts. It is not certain whether such defects on the radiator tube can be detected by means of conventional eddy current testing, considering the influence of the cooling fins on defect signals is still uncertain.

In this study, an actual radiator with a cooling fin is employed as the specimen with a complicated shape. As the first step, we tried to detect a defect on this radiator specimen by employing the multi-frequency excitation and spectrogram method (MFES) [1, 2]. Overall, the cooling fins are expected to have some influence when excited at a specific frequency. However, the frequency characteristics of the signal are generally unknown, and furthermore, it is very difficult to obtain the specific frequencies when the radiator specimen is excited with a conventional single frequency sinusoidal waveform. In order to cover broad frequency responses in a time, MFES therefore is much more suitable.

Our final goal of this study was to develop an NDE system, which can detect the microscopic erosion on a radiator tube. However, as a fundamental study, this paper only concentrates on the following; (1) to clarify how a large signal appears to affect the cooling fins, and (2) to clarify the ability to detect a defect. Before performing any experiment, an artificial hole (diameter of 1 mm) was generated on a tube as a defect, since it was sufficient in size to confirm the validity of the NDE method.

2. Measurement System

Fig. 1 shows the structure of an actual radiator specimen. The radiator consists of tubes made from copper and cooling fins made from aluminum. The cooling fins are arranged so that they are placed 2.0 mm away from each

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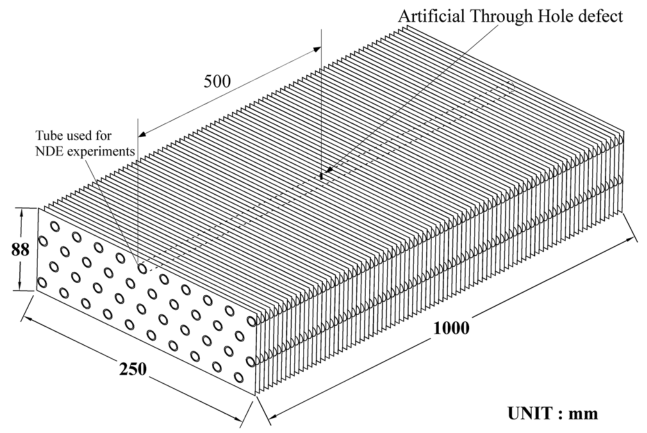


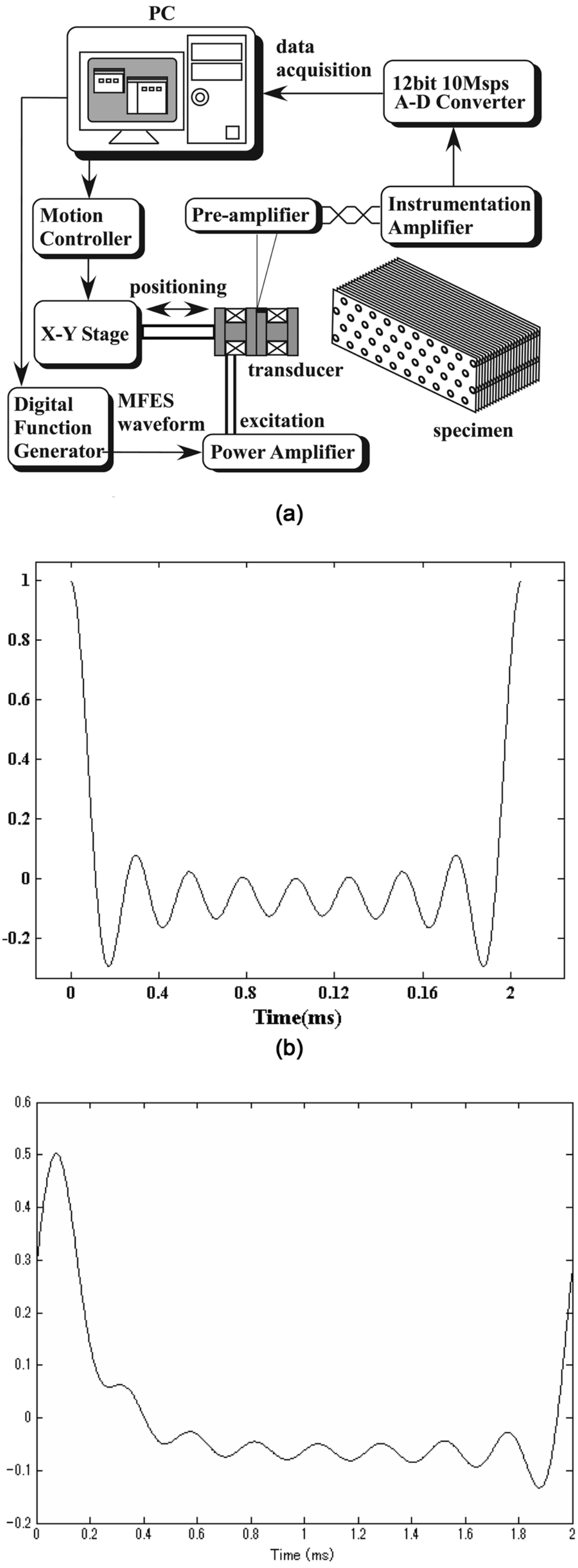
Fig. 1. The structure of an actual radiator contained the tubes used for NDE measurement.

other.

Fig. 2(a), (b) and (c) are block diagrams of the NDE measurement system (Fig. 2(a)), the MFES exciting voltage waveform (Fig. 2(b)), and the exciting current waveform (Fig. 2(c)). An optimal excitation frequency range is resolved by the MFES method and the exciting voltage waveform is shown in Fig. 2(b), which includes eight frequency components with the amplitudes of all components equal to 0.125 (V). Fig. 2(c) is a plot of the exciting current waveform obtained when the transducer was driven at the voltage waveform shown in Fig. 2(b). With the MFES method, the magnetic characteristics of the transducer and the specimen are assumed to be linear. Non-linearity such as that characterized by B-H hysteresis is not utilized due to the increasing in the distortion of the harmonic components. Furthermore, the exciting current waveform shown in Fig. 2(c) is small enough so that it will not induce a non-linear distortion to the signal.

Fig. 3 indicates the transducer construction that will successfully excite the specimen and detect the defect signals. Two excitation coils (0.3 mm UEW wire, 50 Turns) are wound around the central yoke, and a search coil (0.05 mm UEW wire, 10 Turns) is wound at the outer yoke edge. Additionally, the search coil size is 1.2 × 1.7 mm. Importantly, two excitation windings supply the phase reverse voltage so that the magnetic flux density only concentrates around the search coil.

Fig. 4 illustrates the dimensions of the actual radiator specimen. The cooling fins are 0.2 mm thick, and are arranged in the manner so that they can surround the tube at the positions that are 2 mm away from each other. One of the forty tubes was chosen as shown in Fig. 4 for NDE study. An artificial hole defect (1.0 mm diameter) was made at the top of the tube and at the center of the longitudinal direction as shown in Fig. 1. Fig. 5 reveals



(a)

(b)

(c)

Fig. 2. (a) Block diagram of the MFES measurement system. (b) Exciting voltage waveform of MFES. (c) Excitation current waveform of MFES.

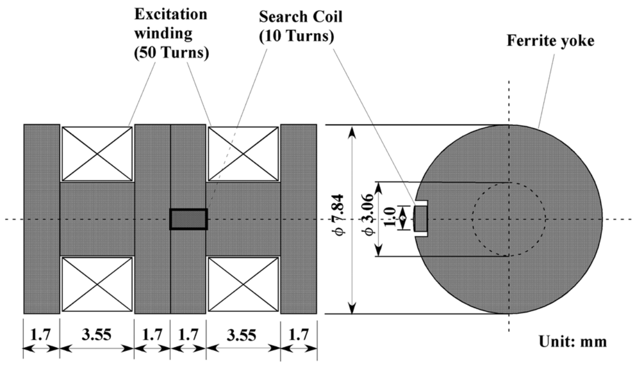


Fig. 3. Constructions of the transducer.

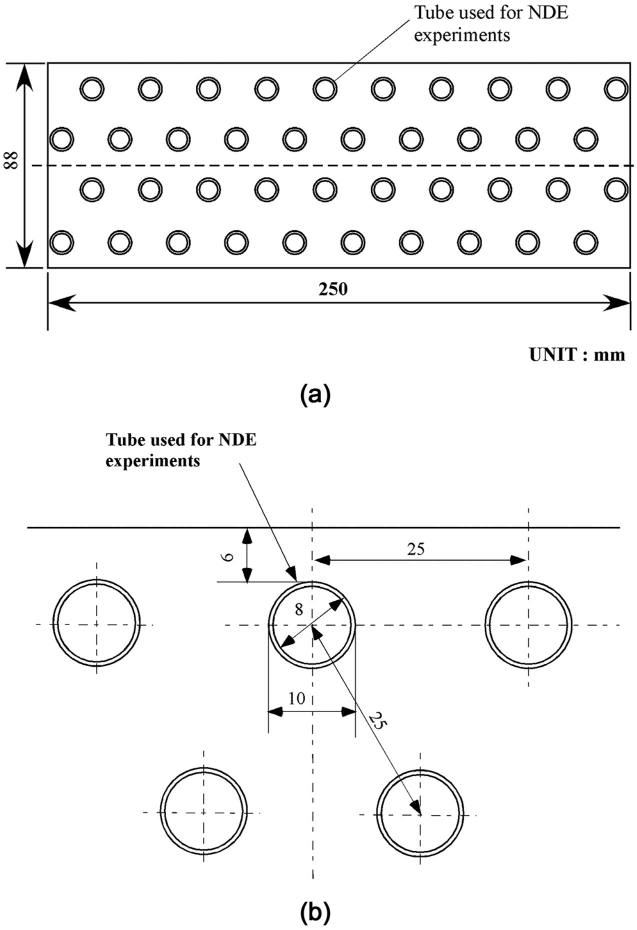


Fig. 4. Constructions of the specimen under measurement.

the relation of the tube, defect and transducer, where θ indicates an angle between the defect and the search coil. This transducer is suitable for the detection of a small local defect near the search coil. However, it is difficult to detect one at a remote position. Therefore, in practical use, the transducer must be rotated according to the angle q at every measurement point, which was varied from 0 to 60° at 5° degree interval.

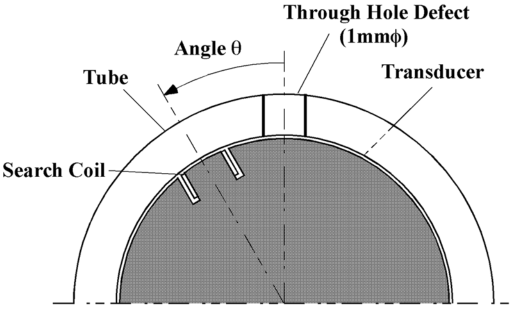


Fig. 5. Constructions between the tube, defect and transducer when measuring.

3. Results and Discussion

Fig. 6 presents the measurement results of a specimen without a defect by means of MFES. The prime frequency of MFES was set to 500 Hz and 8 frequency components at every 500 Hz interval were applied to the excitation waveform. The MFES system can subsequently be measured within a widespread excitation frequency. Fig. 6 indicates a MFES spectrogram of an extracted specimen without any defect. In this figure, signals from the surrounding cooling fins are not observed. Despite that the distance between the cooling fins on the outer side of the tube are 2 mm, the transducer moved and was measured within 0.2 mm intervals. Therefore, it was observed that the fins do not produce a remarkable amount of noise. The lowest frequency component was 500 Hz, so the skin depth of the copper tube was estimated to be approximately 3 mm. The thickness of the tube was 1 mm, therefore, eddy currents could be induced to the cooling fins. Then our hypothesis is that the ferrite core of the

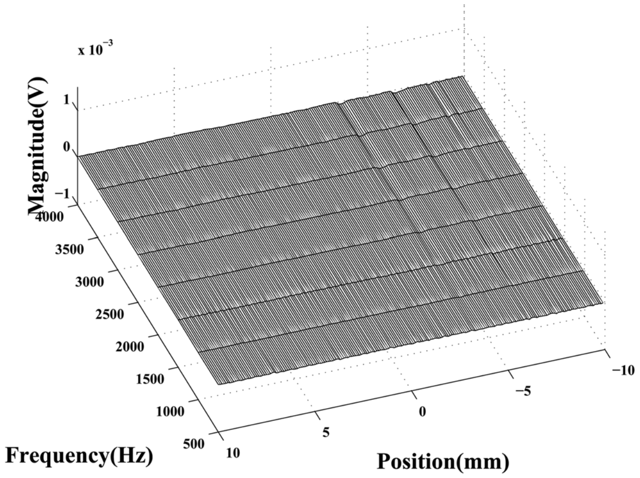


Fig. 6. Measured spectrogram result without any defect by means of MFES.

transducer was not sensitive in the lower frequency range, and therefore, noise disappeared. In order to seek the effect of a fin on outer side of the tube, lower frequency excitation should be utilized with another transducer core and sensing device.

Figs. 7 and 8 illustrate an MFES power spectrogram and phase spectrogram with the hole defect when θ equal 0º. Noticeably, two remarkable signal peaks appear at a higher frequency. Therefore, it is suggested that a specific frequency depends on the size and the position of the defect. In the case of the hole defect, a specific frequency can be defined as the higher frequency. However this is not always true for other types of defects. Additionally, too large frequency excitation brings a serious skin effect, therefore, when seeking a defect on the outer side of the tube, lower frequency excitation can be much helpful. In this case, the defect was found to be located at the center of the two peaks. In contrast, the signal peaks were not symmetrical, because the search coil was not located at the center of the transducer yoke as shown in Fig. 3. If the search coil is located at the center of the transducer yoke, symmetrical signal distribution in an M shape will occur. Anyway, in these measurements, the influence of the cooling fins was not observed. This result indicates that it is easy to distinguish a hole defect on the tube. Compared with Fig. 7 and Fig. 8, the phase spectrogram shows small but clear defect signals even at a lower frequency.

Figs. 9, 10 and 11 are the power spectrogram plots when the angle θ is equal to 5º, 10º and 15º, respectively. As the distance between the search coil and the defect increases, the peak value of the power spectrogram de-

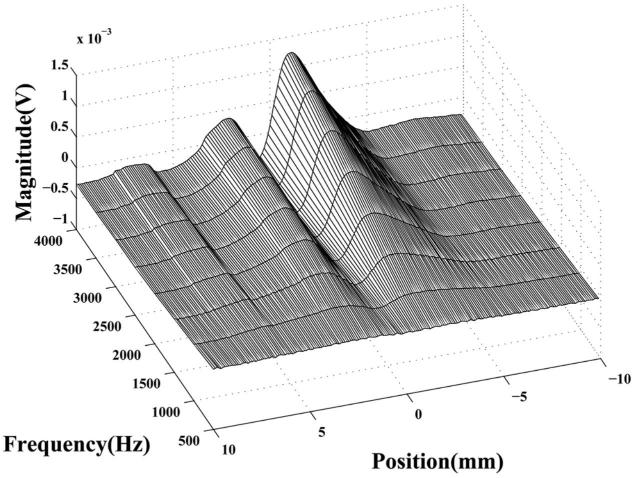


Fig. 7. Measured power spectrogram with hole defect specimen, angle $\theta = 0$ (deg).

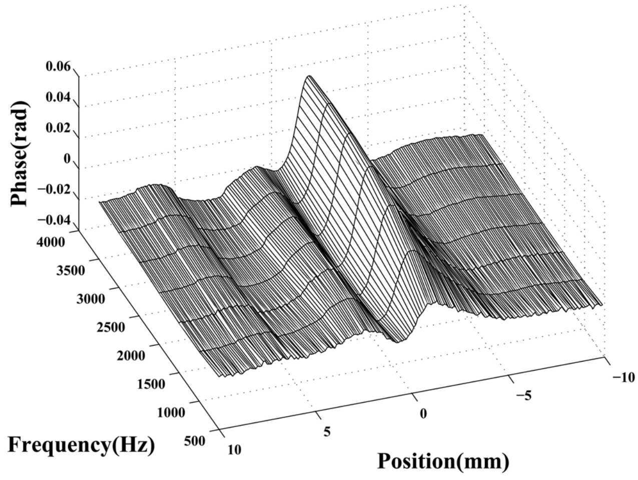


Fig. 8. Measured phase spectrogram with hole defect specimen, angle $\theta = 0$ (deg).

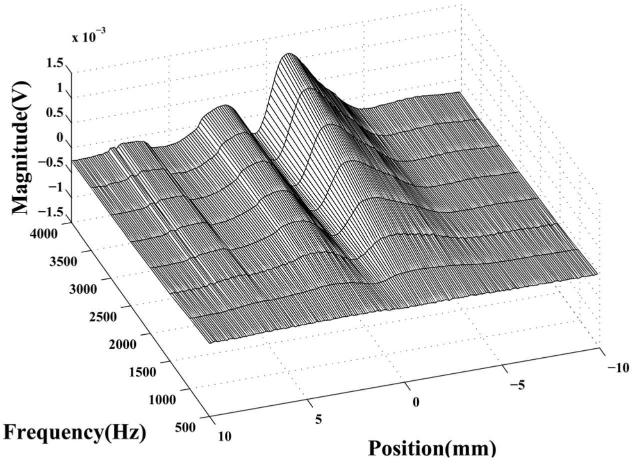


Fig. 9. Measured power spectrogram with hole defect specimen, angle $\theta = 5$ (deg).

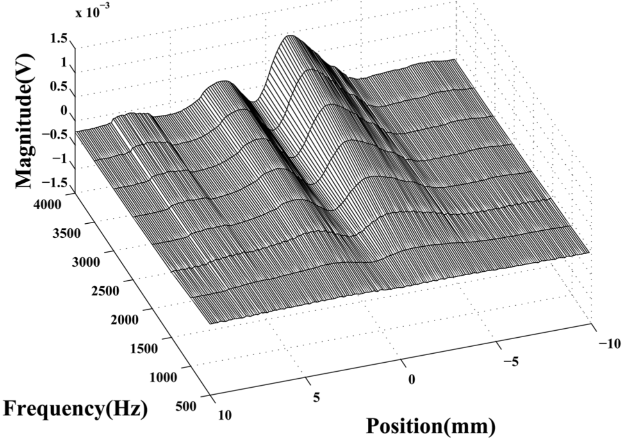


Fig. 10. Measured power spectrogram with hole defect specimen, angle $\theta = 10$ (deg).

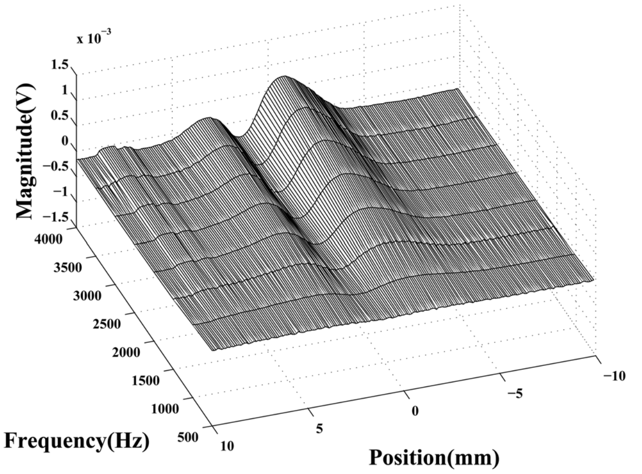


Fig. 11. Measured power spectrogram with hole defect specimen, angle $\theta = 15$ (deg).

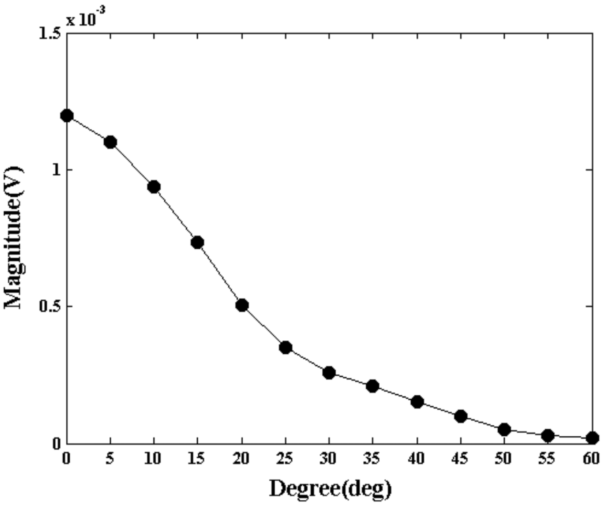


Figure 12. Peak value of MFES power spectrogram dependencies on angle θ.

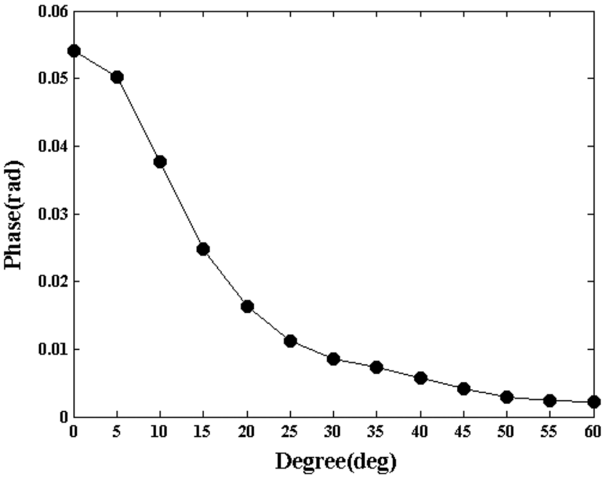


Figure 13. Peak value of MFES phase dependencies on angle θ.

creases. To summarize these data, Figs. 12 and 13 combine the information and illustrate the dependencies between the peak values of MFES power and the phase spectrograms at 4000 Hz, respectively. These figures indicate that a sufficient sensing region is provided by means of the proposed transducer. These characteristics are also obtained with the conventional single frequency eddy current test, however, it is difficult to determine the exciting frequency. Another advantage of utilizing MFES is to derive the specific frequency from the spectrograms at 4000 Hz.

4. Conclusions

We have attempted to apply the MFES method to the non-destructive evaluation of a radiator tube with fins. In this paper, we have evaluated the influence of fins on NDE signals. The fin signals are not that significant and do not seem to interfere with the defect signal detection. However, the interaction between the fins and the defect are unknown. In order to obtain a stronger signal from the fins, further investigations are needed to develop additional transducer structures or excitation frequencies.

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