Simulation and Design of Applied Electromagnetic Systems
T. Honma (Editor)

An application of DC magnetic fields to eddy current sensor

Y.Hirama[a], Y.Oohira[a], N.Sahoda[a], S.Hayano[b] and Y.Saito[b]
[a]R & D Hitachi Building Systems Engineering and Service, 16-23 Nakagawa, Adachi-ku, Tokyo 120, Japan
[b]Coll. of Engng., Hosei Univ., Koganei, Tokyo 184, Japan

Abstract

In the present paper, a pure experimental work concerns with the eddy current sensor utilizing the DC magnetic fields. The operation principle of the eddy current testing (ECT) is based on the input impedance deflection caused by the defect or crack. Therefore it is essential to taking into account the magnetization characteristics of the objects. In order to overcome this difficulty, we have applied the DC magnetic fields superposing to the alternating magnetic fields. The DC magnetic field makes the magnetic materials possible to saturate. This means that the magnetic materials may be regarded as the nonmagnetic materials. Thus, we have succeeded in increasing the sensibility of ECT up to the three times.

1. INTRODUCTION

Crack or defect searching is of paramount importance for the safety check of the elevator and escalator in modern buildings, because the defect and crack of these objects possibly cause the serious accidents. Thereby, various nondestructive testing methods, e.g. eddy current testing, electric potential method, ultrasonic wave imaging, and X-ray tomography, are currently utilized [1-3]. Among these methods, the eddy current testing method does not require the direct contact to object and the complex electronic circuits. Further, the defect or crack in the objects whose major frame parts are composed of the conductive metallic materials can be selectively inspected by the eddy current sensor.

In the present paper, a pure experimental work concerns with the eddy current sensor utilizing the DC magnetic fields [4]. Most of the main frame parts of the elevator and escalator consist of iron or its compounds so that the objects are in essence the magnetic materials. The operation principle of the eddy current testing is based on the input impedance deflection caused by the defect or crack. Therefore it is essential to taking into account the magnetization characteristics of the objects. In order to remove this problem, we have applied the DC magnetic fields superposing to the alternating magnetic fields. The reason why is applied the DC magnetic fields is quite simple. The applied DC magnetic field makes the magnetic materials possible to saturate. This means that the magnetic materials may be regarded as the nonmagnetic materials. Our experimental work suggests that the sensibility of our eddy current sensor can be enhanced up to the three times higher than the conventional eddy current sensor. The sensibility of this DC biased ECT is not lineally related to the biasing DC magnetic fields but nonlinear saturation curve similar to those of B-H curve of the magnetic materials.

Thus, we have succeeded in increasing the sensibility of ECT up to the three times.

2. THE DC BIASED EDDY CURRENT SENSOR

2.1. Basic Equations

As is well known that the magnetic materials are composed of the magnetic domains. This leads to a following constitutive relationship:

$$B = \mu_0 H + M, \tag{1}$$

where B, H, M and μ_0 are the magnetic flux density, magnetic field intensity, magnetization vector and permeability of air, respectively. Because of the existence of magnetic domains, the anomalous eddy currents flow between the domain walls when the alternating magnetic field is applied to the ferromagnetic materials. Thereby, it is difficult to apply the conventional eddy current testing (ECT) method to the ferromagnetic materials, because the input impedance of the ECT device is dominated by the domain structure of the materials.

2.2. Operation Principle

In order to carry out the nondestructive testing for the ferromagnetic materials, two representative methods may be considered. One is the DC magnetic field superposition in addition to the alternating magnetic fields in order to saturate the material, i.e. reducing the magnetic materials into nonmagnetic materials [1,4]. The other is the DC magnetic field application to the materials in order to align the magnetization vector in a direction of the applied DC field. If there is a defect in the material, then the magnetization vector could not align at the defect position. This magnetic field distortion can be picked up by moving the search coils in a parallel direction to the applied DC magnetic field [5].

When we introduce the permeabilty μ, (1) is modified to

$$B = \mu_0 \{1+[M/(\mu_0 H)]\} H = \mu H, \tag{2}$$

where the permeability μ is defined by

$$\mu = \mu_0 \{1+[M/(\mu_0 H)]\}. \tag{3}$$

Mathematically, former method is based on the following fact:

$$\lim_{H\to\infty} \langle\mu\rangle = \lim_{H\to\infty} \langle\mu_0 \{1+[M/(\mu_0 H)]\}\rangle = \mu_0. \tag{4}$$

Equation (4) means that the application of strong magnetic field H makes the magnetic materials possible to saturate. This means that the magnetic materials may be regarded as one of the nonmagnetic materials. Thus, the ECT sensibility can be enhanced. On the other side, latter one has to measure the permeability discontinuity due to the defect. Even though latter method is based on the quite simple principle and requires the relatively simple electronic circuits but the target is limited to the objects having flat surface. Also, its determinative weak point is that the error operation is caused by the residual magnetic flux in the magnetic materials.

2.3. Exploited DC biased ECT Device

We have exploited a DC biased eddy current testing device for the defect or crack inspection in the thin iron plate. This is because we have an urgent need of the iron plate inspection used for the modern escalator steps. If the iron plate is broken, then the escalator becomes one of the slow speed guillotines.

Figure 1 show a schematic diagram of the device. The left and right electromagnets make the magnetic materials having plate shape to saturate. The head of eddy current sensor is located at the center, and alternating current is fed to the coils enclosing the head. The difference of input impedance of this coils caused by the defect or crack indicates the existence of defect or crack in the iron plate.

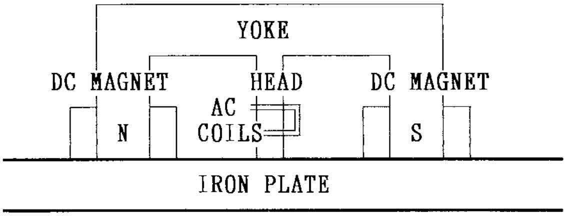

Figure 1. Schematic diagram of a DC biased ECT.

2.4. Experimental

We have carried out the experiments changing the size of defect. Figure 2 shows a sample iron plate used in the experiment. The length, thickness and width of this iron plate are 30, 2.5 and 10cm, respectively. Also, the details of defects in this sample are shown in Fig. 2.

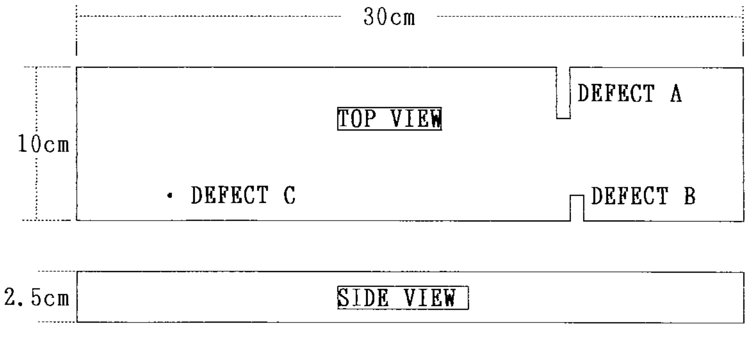

Figure 2. A sample iron plate used in the experiment.
DEFECT A:length=30mm, width=0.5mm, thickness=25mm.
DEFECT B:length=6mm, width=2mm, thickness=25mm.
DEFECT C:hole shape crack, diameter=1.5mm, depth=25mm.

Using the 50kHz exciting frequency, we have checked up the sensibility of our DC biased eddy current sensor. As shown in Fig.3, the sensibility for the relatively large defects A and B were not so enhanced. However, the sensibility for the small defect C was increased up to the three times. The results of our experiments reveal that the large defects, e.g. defect A and B in Fig.2, dominate the input impedance of the exciting coils but the effect of small defect C in Fig. 2 may be lost by the ferromagnetic property of the sample plate. The sensibility for the small defect such as C in Fig.2 is not lineally related to the biassing DC magnetic fields but nonlinear saturation curve similar to those of B-H curve of the magnetic materials. This fact verifies our theoretical consideration.

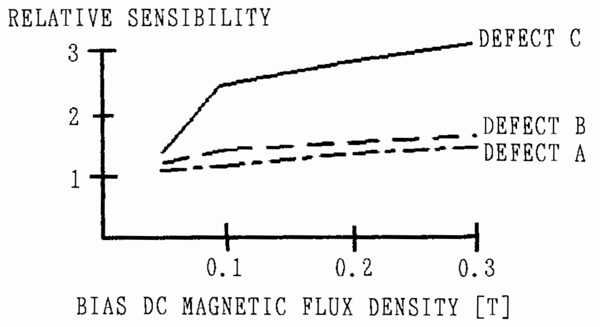

Figure 3. Sensibility vs. DC bias flux density.

3. CONCLUSION

As shown above, a pure experimental work has been carried out to the eddy current sensor utilizing the DC magnetic fields. In order to enhance the ECT sensibility for the ferromagnetic materials, we have applied the DC magnetic fields superposing to the alternating magnetic fields. The DC magnetic field successfully has made the magnetic materials to saturate. Thus, we have succeeded in increasing the sensibility of ECT up to the three times.

4. REFERENCES

1 Y.Hirama et al, The method for Eddy Current Sensor added to Magnetic Bias, Paper on Technical Meeting of Magnetics in IEEJ, MAG-92-73, Feb.(1992)pp.143-148.
2 T.Doi et al, Inverse Analysis of Defect Identification based on the Electric Potential Method, Proc. of 2nd Japan-Hungary Joint Seminar, Published by Hokkaido University, (1992).
3 H.Saotome et al, Crack Identification in Metallic Materials, IEEE Trans. Magn. to be published.
4 G.Cecco et al., Eddy Current Detection of Corrosion Damage in Heat Exchanger Tubes, At Energy Can Ltd., No.AECL-6965, pp.33, (1980).
5 Y.Oohira et al, Defect Searching in the Ferromagnetic Materials, Companion paper of the ISEM-Sapporo, Jan. (1993).