Polyphase eddy current testing

I. Marinova, S. Hayano, N. Ishida, and Y. Saito
College of Engineering, Hosei University, Kajino Koganei, Tokyo 184 Japan

Y. Hirama and M. Yamamoto
R&D Hitachi Building Systems Engineering and Service, 16-23 Nakagawa Adachi-ku, Tokyo 120 Japan

Polyphase eddy current testing is proposed. The operating principle of this system is as follows. The polyphase eddy current testing system may be regarded as one of the polyphase transformers. Primary balanced polyphase coils are star connected and secondary polyphase circuits are composed of the target. When balanced polyphase currents are fed into the primary coils, zero phase voltage is detected if the target has defects. No zero phase voltage is detected if the target has no defects. It is found that this method has a higher sensitivity compared with that of conventional eddy current testing.

I. INTRODUCTION

The search for cracks and defects is one of the most important elements of the nondestructive testing of many equipments, e.g., elevators, escalators, lifts, etc. Various testing methods, such as eddy current testing, electric potential method, ultrasonic wave imaging, and x-ray tomography, are currently utilized.[1–7] Among these methods, eddy current testing method does not require complex electronic circuits and direct contact to object. Further, objects of which major frame parts are composed of conductive metallic materials can be selectively inspected by eddy current sensors. In the present article, we propose a novel eddy current testing method utilizing polyphase alternating currents. The operating principle of this new method is as follows. First, the polyphase eddy current testing system may be regarded as a polyphase transformer. Primary balanced polyphase coils are star connected and secondary polyphase circuits are composed of the target. When balanced, polyphase currents are fed into the primary coils, zero phase voltage is detected if the target has defects, no zero phase voltage is detected if the target has no defects. Conventional eddy current testing method detects only the input impedance difference caused by the defects in the target. As an initial test, we measured a zero phase input impedance instead of zero phase voltage. It was found that our new method clarified a possibility to enhance the sensitivity of the eddy current testing compared with conventional eddy current testing.

II. POLYPHASE EDDY CURRENT TESTING

A. Conventional eddy current testing

As shown in Fig. 1 the conventional eddy current testing (ECT) system may be regarded as a single-phase transformer. The equivalent transformer is composed of the primary exciting coil having resistance R_1 and self-inductance L_1, and the secondary coil, being the metallic target having resistance R_2 and self-inductance L_2. Let us denote M as a mutual inductance between the primary and secondary circuits and k as a coupling factor defined by

$$k=\frac{M}{\sqrt{L_1 L_2}}, \quad 0<k<1. \tag{1}$$

If there are no defects in the target, this would correspond to the secondary circuit short ($R_2 \approx 0$) and input impedance Z becomes

$$Z=R_1+j\omega L_1(1-k^2). \tag{2}$$

If there are defects, then resistance of the secondary circuit becomes $R_2 \approx \infty$, and the input impedance Z changes,

$$Z=R_1+j\omega L_1. \tag{3}$$

Analyzing Eqs. (2) and (3) it is obvious that the sensitivity of conventional ECT depends on the parameters ω, L_1, and k. Therefore, it is desirable that the inductance L_1 as well as coupling factor k are as large as possible, but due to the skin effect, it is not desirable to increase the angular velocity ω. To detect defects in axial as well as circular directions from the interior of cylindrical pipe, a multicoil ECT system, shown in Fig. 2 may be used. However each of the coils in multicoils is scanned by complex electronic circuits; also, the scanning speed is limited by the relaxion time of eddy current.

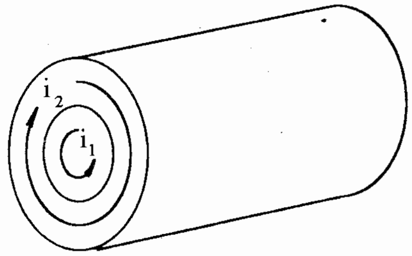

FIG. 1. Principle of conventional eddy current testing system.

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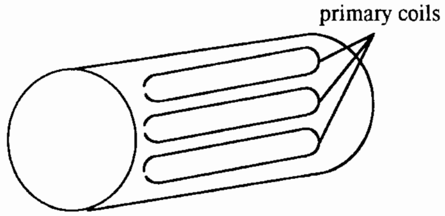

FIG. 2. Multicoil eddy current testing system.

B. Polyphase eddy current testing

In this article we propose a novel eddy current testing method utilizing polyphase alternating currents in order to increase the sensitivity of ECT system. The polyphase ECT system consists of polyphase coils and target. This system may be considered as a polyphase transformer. Primary balanced polyphase coils are star connected. Secondary polyphase circuits are composed of the target (see Fig. 3). For a star-connected system, with the time origin taken at the maximum positive point of the phase a voltage wave, the instantaneous voltages of the three phases are

$$\begin{aligned} V_a &= \sqrt{2}V\cos(\omega t) = \sqrt{2}V\,\mathrm{Re}(e^{j\omega t}),\\ V_b &= \sqrt{2}V\cos\left(\omega t - \frac{2\pi}{3}\right) = \sqrt{2}\,\mathrm{Re}(e^{j[\omega t-(2\pi/3)]}),\\ V_c &= \sqrt{2}V\cos\left(\omega t + \frac{2\pi}{3}\right) = \sqrt{2}V\,\mathrm{Re}(e^{j[\omega t+(2\pi/3)]}), \end{aligned} \tag{4}$$

where V is the rms value of the phase voltage. Considering a operator defined by

$$a = e^{-j(2\pi/3)}, \tag{5}$$

we can express

$$\begin{aligned} V_0 &= \tfrac{1}{3}(V_a + V_b + V_c),\\ V_P &= \tfrac{1}{3}(V_a + a^2V_b + aV_c),\\ V_N &= \tfrac{1}{3}(V_a + aV_b + a^2V_c), \end{aligned} \tag{6}$$

where V_0, V_P and V_N are the zero sequence, positive sequence, and negative sequence. For the balanced three phase voltages, they become

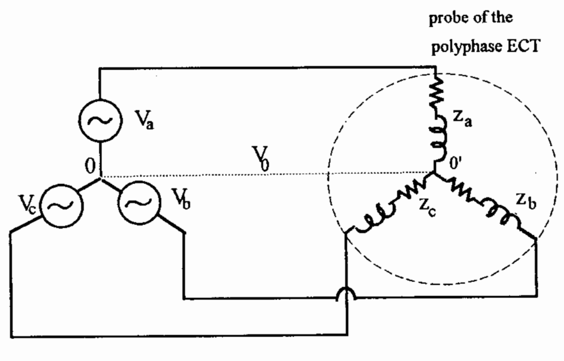

FIG. 3. Polyphase eddy current sensor.

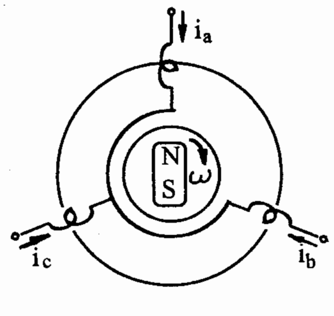

FIG. 4. The balanced polyphase current system used to scan the target.

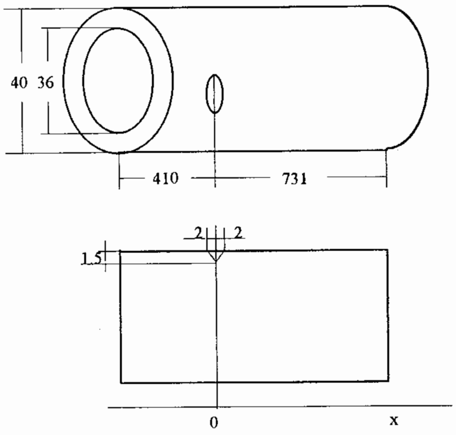

FIG. 5. Tested target tube with a defect (unit of mm).

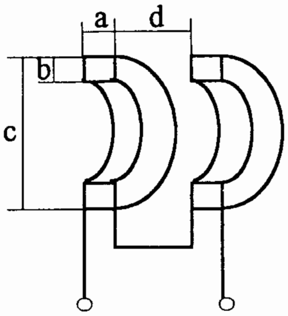

FIG. 6. Tested conventional eddy current sensor with a=5 mm, b=5 mm, c=35 mm, d=10 mm, and 50 turns.

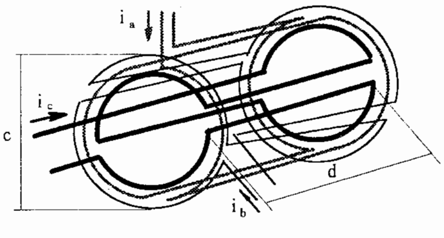

FIG. 7. Tested polyphase eddy current sensor with d=20 mm, c=35 mm. The number of turns is 50 or 80.

10p

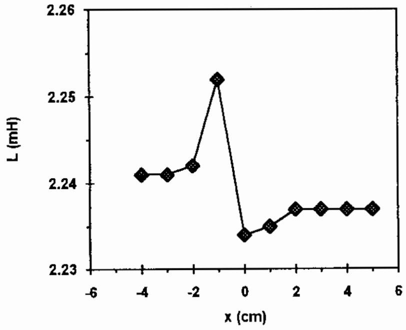

FIG. 8. The change of the inductance in x direction using conventional eddy current testing.

$$V_0=0,$$
$$V_P=\sqrt{2}V\ \mathrm{Re}(e^{j\omega t}), \qquad (7)$$
$$V_N=0.$$

Figure 4 shows that with balanced polyphase currents, the primary coils generate a revolving magnetic field and this is used to scan the target.

To detect defects in the target, balanced polyphase currents are fed into the primary coils and the zero phase voltage V_0 is measured. If the target has defects then zero phase voltage V_0 is detected. If the target has no defects then zero phase voltage V_0 is not detected. Conventional eddy current testing method detects only the input impedance difference caused by defects in the target.

III. EXPERIMENTAL MODEL AND RESULTS

In order to investigate the efficiency of the proposed novel ECT system, a tube target with defect shown in Fig. 5 was examined. First, conventional ECT was applied to detect the defect. Figure 6 shows that a conventional eddy current sensor with two serial connected coils was used. The input impedance was measured by a resistance bridge. The experimental frequency was 1 kHz. Second, the polyphase eddy current sensor, as shown in Fig. 7, was employed to examine the target. Polyphase coils were star connected and supplied with balanced polyphase currents. In order to compare the sensitivity of this method with conventional ECT, the zero-phase impedance was measured instead of the zero-phase voltage.

Results showing the change of inductance in the x direction around the defects applying both conventional and polyphase ECTs are presented in Figs. 8 and 9, respectively. The polyphase eddy current sensors with 50 and 80 turns are used in Figs. 9(a) and 9(b), correspondingly.

The results of Fig. 8 show the change of inductance corresponding to the change of the field distribution in the coil volumes during movement in x direction. The changes of the field distribution are produced by the defect, which changes the impedance of the target, and the coupling between target and primary coils, respectively. Figures 9(a) and 9(b) show that the defect, increasing the impedance of the target (secondary circuits) caused a change of the impedances of the primary coils. This lead to an unbalanced polyphase current system. Near the defect the zero-phase voltage appeared and zero-phase impedance changed with position of the probe coils during the x direction. The inductance, corresponding to zero-phase impedance, began to increase around the defect. It reached a maximum when the middle of the polyphase coils was under the defect. After that, moving the polyphase coils in the x direction, the inductance decreases depending on the impedance of the secondary circuits. Figures 9(a) and 9(b) show that changing the number of turns it is possible to increase the sensitivity using the polyphase ECT. Thus, we succeeded to obtain 0.78% relative measured difference applying polyphase ECT with 50 turns while using polyphase ECT with 80 turns or conventional ECT it is 0.37% or 0.49%, respectively. Instead of zero-phase impedance, we measured a zero-phase voltage. This increases the sensitivity of our new polyphase ECT.

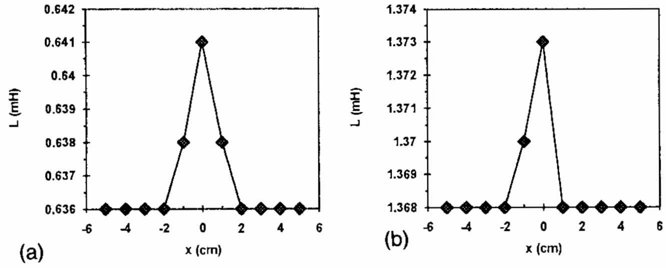

FIG. 9. The change of the inductance in x direction: (a) polyphase eddy current testing with 50 turns; (b) polyphase eddy current testing with 80 turns.

IV. CONCLUSION

We proposed a novel ECT to detect defects in targets. Experimental work concerning the ECT system utilizing polyphase alternating currents has been carried out. Star connection and balanced polyphase currents are used as primary coils. Examination of the zero phase voltage was proposed to detect the defects. Comparison with conventional ECT was made. It has been demonstrated that the new method enhances the sensitivity of the eddy current testing compared with conventional ECT.

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