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APPLICATION OF EDDY CURRENT TECHNIQUE FOR THE NON-CONTACT SENSING OF LOW CONCENTRATION OF ELECTROLYTIC SOLUTION

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Abstract Application of eddy current sensing principle for the non-contact estimation of very low concentration of electrolytic solution is presented in this paper . For this application, a new, simple, low-cost, low-power structure for the eddy current sensor is proposed. By measuring the eddy current produced in the conducting electrolytic solution, the concentration is estimated. Therefore, the unknown concentration can be estimated comparing with the database which is prepared as the relation between the change in inductance and various concentrations of electrolytic solution. The concentration, as low as 1 ppm of the solution can be detected by this sensor. It was tested on various low concentration solutions of NaCl. It shows distinct response for various concentrations.

Keywords Eddy current sensing, electrolytic solution, concentration

1. Introduction

Eddy current sensing technique has been deeply studied so far as the sensing tool of various physical parameters of samples having high electrical conductivity such as metal. On the other hand having nice feature of non contact sensing, very few works on eddy current sensor have been reported so far as a sensor for samples having very low conductivity such as that of electrolytic solution, which is considered to be of great importance in the industry and laboratory. But suitable design of the structure for the eddy current sensor can enable us to measure non-contactly the very low conductivity and hence the concentration of electrolytic solution. Under this background, we present a simple structure of an eddy current sensor for the non-contact sensing of low concentration of electrolytic solution. The concentration is determined by measuring the change in self inductance of the sensing coil of the sensor due to the eddy current produced in the solution. Since the conductivity and hence the amount of eddy current depends on the concentration of the solution, the inductance of the sensing coil becomes different for different concentration. The structure of the sensor and its response to various concentrations of NaCl solutions in its two modes of operation namely single coil mode i.e. using one coil and two coils in opposition mode, is presented in this paper.

2. Theory and structure

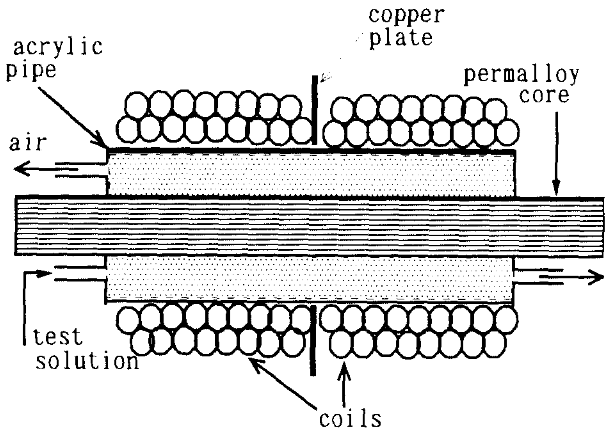

Fig. 1 Construction of the sensor

The construction of the sensor is shown in Fig. 1, where an acrylic pipe is used as the body of the sensor on which, copper wire having diameter of 0.12 *mm* is wound 1500 and 1600 turns to make two coils. The length of the coils is 24 *mm* with a 1 *mm* gap between them. In this gap a copper plate of thickness 0.13 *mm* with a radius of 40 *mm* is placed as a shield. To make a core, 56 pieces of permalloy wire having diameter of 0.3 *mm* and length of 80 *mm* are bundled inside a thin plastic tube and is placed along the axis of the pipe. For the temperature measurement a thermistor is mounted inside the pipe. The length, outer diameter and inner diameter are 50 *mm*, 20 *mm*, and 17 *mm*, respectively. The volume of the empty space between the inner wall of the pipe and the core is 9.80 *cc*. In this space the test solution is poured. For the measurement of inductance HP 4284A precision LCR meter is used. Unlike other inductive sensor it requires very small excitation current. As a result, self heating phenomenon which arises from the hysteresis and eddy current heating in the core and dc resistance of the copper wire, is thereby largely reduced. It also reduces the temperature effect on the sensitivity of the sensor. Fig. 2 shows the connection of sensing coil(s) in the two modes of operation.

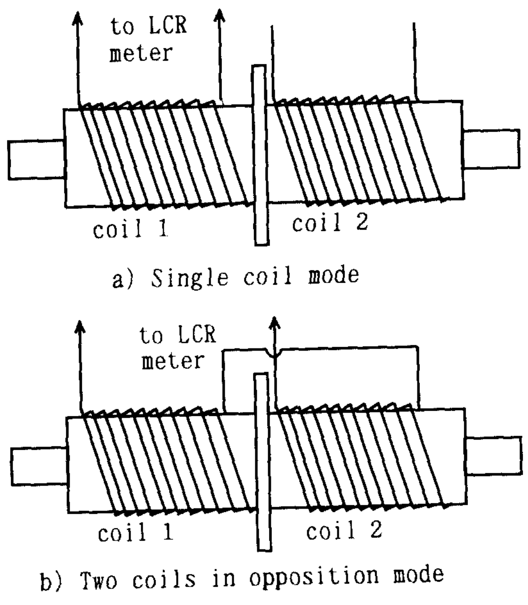

Fig. 2 Modes of operation of the sensor

The analysis of this type of structure can be efficiently done by calculating the total magnetic vector potential induced by the exciting current flowing in the coil(s) encircling the acrylic pipe. As shown in Fig. 3 our system can be considered as coil(s) encircling a coaxial two layer conductors. Here the central conductor is the high permeability ferromagnetic core of high conductivity and the second conductor is the electrically conducting electrolytic solution having magnetic permeability μ_0 and low conductivity.

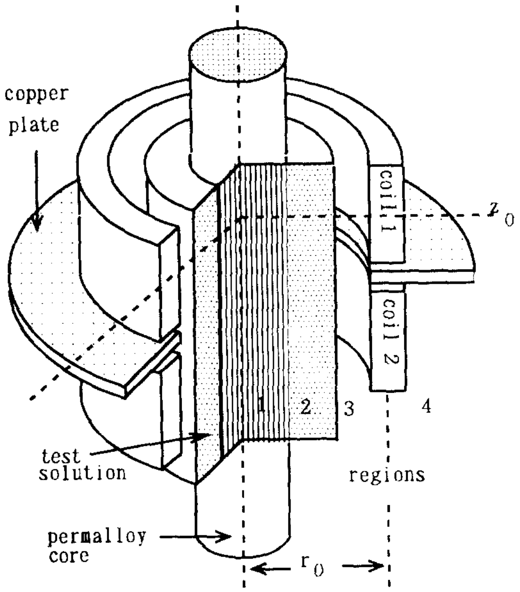

Fig. 3 Coil encircling two layer coaxial conductors

The conductivity of an electrolytic solution with single electrolyte is expressed as[1]

$$\kappa = Fc\sum_i |z_i| v_i u_i \tag{1}$$

where,

F = Faraday constant

c = concentration of the solution

z_i = charge number of i types of ion

v_i = partial specific volume of i types of ion

u_i = mobility of i types of ion

We can let z_i, v_i, u_i, to be constant as a rough assumption for a particular solution, and equation (1) can be written as

$$\kappa = pc \tag{2}$$

where constant p defined as

$$p = F\sum_i |z_i| v_i z_i \tag{3}$$

After finding the total magnetic vector potential considering the system as coil encircling a two layer conductor[2], the impedance of the sensing coil can be calculated from the following equations

$$z = 2\pi i\omega\mu_0 h\left(\frac{n_1}{N_1}\right)^2 \sum_{N_1} mA_{m,n} \qquad (4)$$

for single coil mode and

$$z = 2\pi i\omega\mu_0 h\frac{n_1}{N_1}\frac{n_2}{N_2}\left[\sum_{coil1} mA_{m,n} - \sum_{coil2} mA_{m,n}\right] \qquad (5)$$

for two coils in opposition mode. Where ω is angular frequency of the excitation current and $A_{m,n}$ is the total magnetic vector potential at a point $r=mh$ and $z=nh$ produced by coil having N lattice points and n number of turns. From the above equations of impedance the inductance can be calculated.

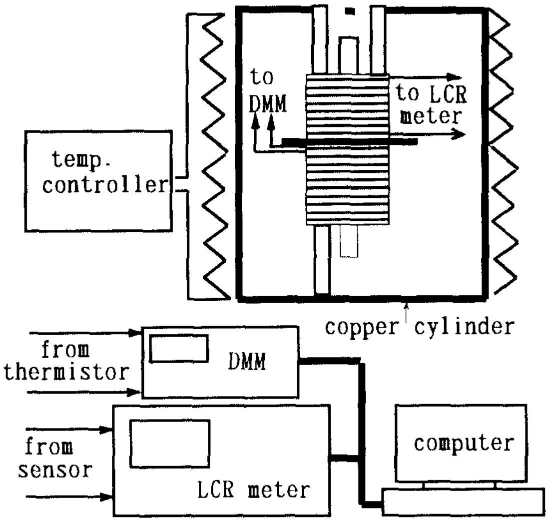

Fig. 4 Experimental setup

The frequency of the input excitation is chosen[3] to obtain the desired efficiency of the sensor. For the purpose of our study an excitation current of about 56 μA for single coil, and 39 μA for two coils combination at a voltage of 5 V and frequency of 80 kHz and is chosen as the most preferable. The experimental setup is shown in Fig. 4.

3. Experiments

Various investigations were carried out to characterize the sensor and know the response to various solutions of NaCl in its two modes of operation. First of all the nature of response was obtained. To do this the inductance is measured without the solution. When the solution is poured, the inductance changes instantaneously and reaches a constant value after few seconds. We refer this time as response time. These values of inductance are recorded and plotted against time as shown in Fig. 5, which show the typical response of the sensor.

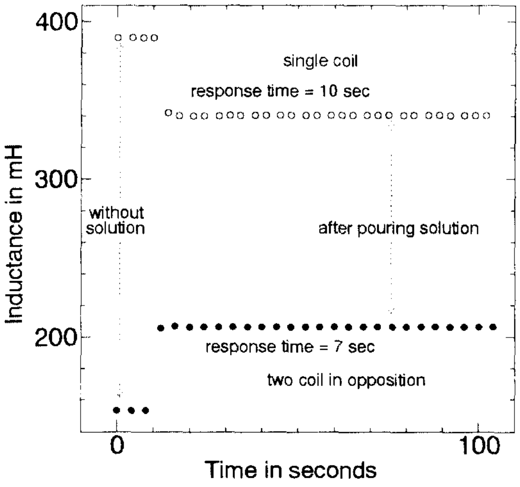

Fig. 5 Typical time response of the sensor

To see the effect of temperature of the solution on the response, the change in inductance of the sensor is recorded for various difference in temperature between the sensor and solution as shown in Fig. 6.

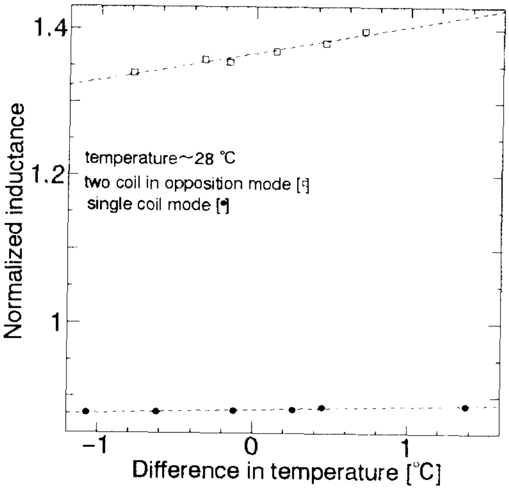

Fig. 6 Dependency of the sensor response on difference in temperature for water

In these experiments the sensor is kept at a constant temperature which is higher than the room temperature. The slope of the line representing the response of two coils in opposition shows greater dependency on the difference in temperature than the other mode. But it was found that they show very little dependency if operated at room temperature. Therefore, the test of the sensor on the various solution were performed at room temperature as shown in Fig. 7.

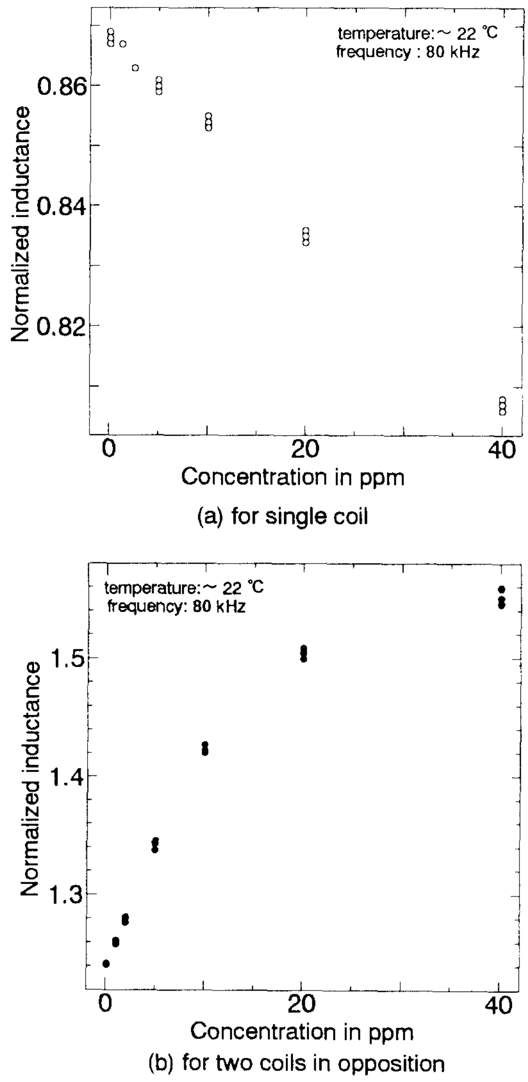

Fig. 7 Response of the sensor to NaCl splution

4. Result and discussion

The structure of the sensor based on eddy current principle for the sensing, was tested for estimating low concentration of an electrolytic solution, in its two modes of operation. The nature of response and response time of the sensor are different for this two modes of operation. From Fig. 7(a) we see that the response is not satisfactory at lower concentration up to 2 ppm. This may be due to the unstability of its initial inductance, which was found during the experiment and which has a great influence on the sensitivity of the sensor. For the second method, as can be seen in Fig. 7(b), the response is quite satisfactory with good reproducibility to each concentration particularly at the very low concentration. The main advantage of this connection is that any drift in the inductance is canceled out. In our experiment we used distilled water as the solvent of electrolyte. It is possible to measure the very low concentration of solution if ion exchanged water is used as the solvent. Therefore to use this sensor for the purpose of estimation of concentration of an electrolytic solution, a database is made with the inductance of the sensor offered to various solutions of known concentration of a particular electrolyte. Then, the unknown concentration can be estimated by comparing the inductance of the sensor for the unknown solution with the database.

5. Conclusion

A new approach for the non-contact measurement of low concentration of electrolytic solution applying eddy current sensing technique was investigated in this paper. Results of the various experiments presented in this paper reveal that the technique of eddy current sensing can be used efficiently for the non contact estimation of low concentration of electrolytic solution by simply designing an efficient structure of eddy current sensor. From the experimental data of our proposed structure, we can conclude that for very low concentration measurement, operation in the two coils in opposition mode is better than single coil mode.

6. References

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