

EDDY-CURRENT PROBE SENSITIVITY INHANCEMENT

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Abstract: Local Eddy-Current Probe (ECP) (ECP with shielded wire) model is developed. Though local ECP inductance decreases compared to ECP without shielded wire, local ECP sensitivity to gap variation behaves itself differently compared to classical ECP. Local ECP sensitivity to gap variation can be increased in some conditions, as the results of theoretical researches show, and it can improve the accuracy of mechanical amplitude oscillation measurement by Eddy-Current technique.

KEYWORDS: EDDY-CURRENT PROBE, SENSITIVITY INHANCEMENT, SHIELDED WIRE, MATHEMATICAL MODEL

1. Introduction

The actuality of ultrasonic sources (USS) parameters control is undeniable. The ultrasonic techniques are used not only in industry for intensification different physicochemical processes, hard and fragile stuff processing, nondestructive control, but it is successfully used in medicine, as for diagnostic of human health, as for human treatment [1].

2. Prepositions and means for resolving the problem

As the face of the USS tip is characterized by finite radial dimension, its minimum value is restricted by economical reasonability and is equal to 3 mm, the problem is to enhance the sensitivity of the eddy-current probe (ECP) to gap variation, that is, the oscillation of mechanical amplitude, when you use eddy-current technique [2].

The ECP sensitivity enhancement problem can be solved by restricting magnetic flux leakage. It also lets to enhance ECP noise immunity and selectivity. There are two ways to solve this problem. It's a structural design of ECP coil and the usage of local ECP.

Though, the usage of a structural design of ECP coil lets to enhance magnetic flux concentration, but results in technological difficulty of ECP realization. When you use local ECP, the problem is to calculate it accurately [3].

Because of the local ECP design accurate methodic absence; there is a need to develop the methodic of coil with shielded wire over CO design, to define its sensitivity function to mechanical ultrasonic oscillation.

3. Solution of the examined problem

3.1. Theoretical computation

Formulated in this article problem can be solved if we represent local ECP as a transformer. The equivalent scheme of the coil with shielded wire is depicted on fig. 1, where shielded wire is presented as a secondary winding.

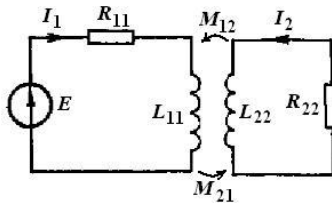


Fig. 1. Equivalent scheme of the coil with shielded wire

Parameters of the scheme, depicted on fig. 1, for a coil with shielded wire over CO can be presented as:

$$\begin{cases} L_{11} = L_{011} + \Delta L_{11}; & R_{11} = R_{011} + \Delta R_{11}; \\ L_{22} = L_{022} + \Delta L_{22}; & R_{22} = R_{022} + \Delta R_{22}; \\ M_{12} = M_{012} + \Delta M_{12}; & M_{21} = M_{021} + \Delta M_{21} \end{cases} \quad (1)$$

where L_{11} , R_{11} – inductance and resistance of the coil, L_{22} , R_{22} – inductance and resistance of the shielded wire, M_{21} , M_{12} – mutual inductances between shielded wire and coil and coil and shielded wire; subscript «0» – parameters meaning in free space; notation « Δ » – reflected parameters meaning due to CO.

Reflected parameters of the coil with shielded wire over cylindrical CO can be calculated with the help of the next expression:

$$\dot{A}_{\varphi \text{ref}} = -\frac{\mu_1 I_c \dot{k}(R_2, \omega, \mu_2, \sigma_2)}{2} \sum_{n=1}^{\infty} \left[\frac{F_{nm}(h_g) K_n(R_c)}{\lambda_n \|J_1(\lambda_n r)\|^2} \times \right. \\ \left. \times \dot{\phi}_n(\omega, \mu_2, \sigma_2) e^{-\lambda_n z} J_1(\lambda_n r) \right] \quad (2)$$

where I_c – current of the coil; $\dot{k}(R_2, \omega, \mu_2, \sigma_2)$ – complex function, which takes into account the CO edge effect; $\dot{\phi}_n(\omega, \mu_2, \sigma_2)$ – complex function of the CO stuff electrophysical parameters; R_2 – CO radius; ω – frequency of AC current; μ_1 – absolute permeability in free space; μ_2 – absolute permeability in CO stuff; σ_2 – conductivity in CO stuff; $F_{nm}(h_g)$, $K_n(R_c)$ – function of coil wire parameters; h_g – gap between CO and ECP; R_c – wire coil radius; λ_n – eigenvalue of the system; $J_1(\lambda_n r)$ – Bessel function of the 1st kind, 1st order.

Reflected electric field can be calculated with the usage of (2) by the next expression, [4]:

$$\dot{E}_{\varphi \text{ref}} = -j\omega \dot{A}_{\varphi \text{ref}} \quad (3)$$

Integrating (3) over volume of coil wire and dividing to coil wire current I_c , it can determine reflected inductance ΔL_{11} and reflected resistance ΔR_{11} of the coil, definite in (1). And when integrating (3) over volume of shielded wire and dividing to coil wire current I_c , it can determine reflected mutual inductance ΔM_{12} of the system, definite in (1).

Reflected mutual inductance ΔM_{21} from (1), can be determined by exchange in (2) h_c to $h_{s.w.}$ and R_c to $R_{s.w.}$ and then integrating (3) over volume of coil wire and dividing to shielded wire current, where $h_{s.w.}$ – gap between CO and shielded wire; $R_{s.w.}$ – shielded wire radius.

The impedance of the coil with shielded wire over CO can be written as [5]:

$$\dot{Z}_1 = R_{11} + \frac{\omega^2 M_{12} M_{21} R_{22}}{R_{22}^2 + (\omega L_{22})^2} + j\omega \left(L_{11} - \frac{\omega^2 M_{12} M_{21} L_{22}}{R_{22}^2 + (\omega L_{22})^2} \right)$$

ECP reflected impedance sensitivity to gap variation can be written as:

$$\begin{aligned} \frac{\partial \dot{Z}_1}{\partial h_a} &= \frac{\partial \Delta R_{11}}{\partial h_a} + \\ &+ \frac{\partial}{\partial h_a} \left(\frac{\omega^2 (M_{012} + \Delta M_{12})(M_{021} + \Delta M_{21})(R_{021} + \Delta R_{22})}{(R_{022} + \Delta R_{22})^2 + (\omega(L_{022} + \Delta L_{22}))^2} \right) + \\ &+ j\omega \frac{\partial \Delta L_{11}}{\partial h_a} - \\ &- j\omega \frac{\partial}{\partial h_a} \left(\frac{\omega^2 (M_{012} + \Delta M_{12})(M_{021} + \Delta M_{21})(L_{022} + \Delta L_{22})}{(R_{022} + \Delta R_{22})^2 + (\omega(L_{022} + \Delta L_{22}))^2} \right) \end{aligned}$$

As a result, it was developed analytical method to calculate local ECP, presented as a coil with shielded wire over a cylindrical CO.

4. Results and discussion

Accordingly to theoretical calculations, presented above, let's carry out mathematical research of shielded wire influence on ECP inductance and sensitivity of ECP inductance on gap variation. Let us consider a cylindrical coil with geometrical parameters like these: radius of the coil 3.9 mm, pinch of the coil 100 μ m, number of coil turns 10. Shielded wire geometrical parameters: radius of the shielded wire 4.7 mm, displacement of the shielded wire relatively to the first wire of the coil 0 mm. CO parameters: radius of the CO 10 mm, conductivity 1 MS/m, relative permeability 1. The results of modeling are depicted on fig. 2 – 4.

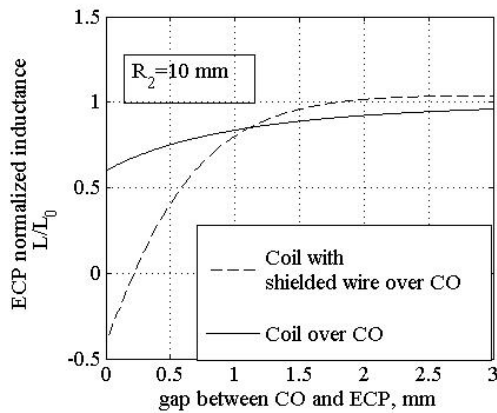


Fig. 2. ECP normalized inductance dependence on gap

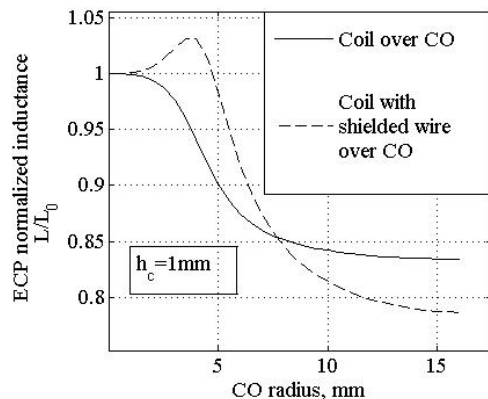


Fig. 3. ECP normalized inductance dependence on CO radius

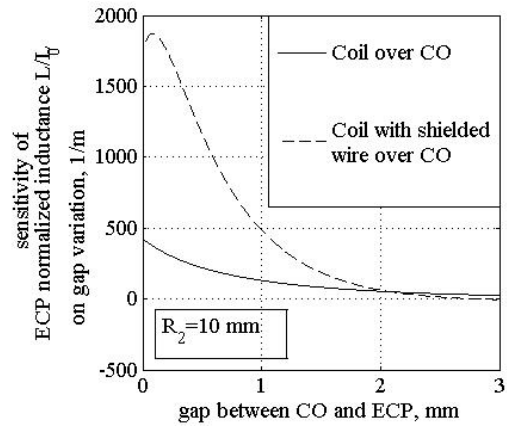


Fig. 4. ECP normalized inductance sensitivity to gap variation on gap

As a result, shielded wire influence on parameters of the coil over CO modeling was carried out. It can be noticed that sensitivity of ECP inductance on gap variation increases, though absolute value of the coil inductance with shielded wire decreases when compared with the coil without a shielded wire.

5. Conclusion

Analytical model of the coil with shielded wire over CO was developed. Modeling of the coil over CO with and without a shielded wire was carried out. It was shown that sensitivity of the coil inductance with shielded wire over CO is higher than sensitivity of the coil inductance without shielded wire over CO, though absolute value of the coil inductance with shielded wire is lower than absolute value of the coil inductance without shielded wire.

6. References

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