NUMERIC CALCULATION OF EMAT TRANSDUCER HARMONIC EDDY CURRENT

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ABSTRACT

EMAT transducer is equipment for noncontacting nondestructive diagnostics of metal materials. This text derives eddy current generated by transmitting part of EMAT. We suppose harmonic exciting signal and examine amplitude, phase and skin depth. As comparison we use analytical solution of distribution of eddy current of conducting thread with harmonic current near to conducting material described in [1]. For numerical solution was used finite element mothod Ansys programme.

1. INTRODUCTION

EMAT (Electro-Magneto-Acoustic Transducer) is known equipment for generating and sensing of acoustic waves difussive through metal material. Important condition is electric conductivity of tested specimen. Transmitting and recieving part of EMAT can be of same design, so that we talk about reciprocal equipment. Advantages of EMAT is smoother and wider frequency characteristics a possibility of noncontact measuring. This paper derives with transmitting EMAT typified in figure 1, in the concrete with meander line coil. This coil is supplied with high frequency harmonic current, which causes induction of eddy current in tested specimen. For us is important distribution of this eddy current, whereon process of generating of mechanical power is dependent. In this parer is described process of design of numerical model with using finite element method. Results are compared with analytical soulution.

2. ANALYSIS

In figure 1 are shown basic parts of EMAT transducer. The subject of our interest is meander line coil. The span between individual line wires is important for wave length of generated acoustic wave as well frequency of exciting signal. On this frequency sensitivity of transducer should be maximal. But frequency spectrum is much wider and resonance character is not desirable. For maximal effectivity is amplitude of exciting signal on maximal standardized value for copper conductor. Parameters of meander line coil coresponding with figure 1, material parameters of tested specimen and parameters of exciting signal used for this model are stated in table 1.

2.1. PARAMETERS OF EMAT AND SPECIMEN

Design of meander line coil depends on wave length of acoustic wave diffusive in elastic material. Modelling type of EMAT sensor is designed for generating Rayleigh's wave diffusing on the surface of tested specimen. Velocity of wave designates formula (1)

$$c_R \approx \frac{0{,}87 + 1{,}12\mu}{1+\mu} \cdot \sqrt{\frac{G}{\rho}} . \qquad (1)$$

where c_R [m.s^{-1}] is velocity of Raylegh wave, μ [-] is Poisson constant, G [Pa] is skid modulus of elasticity and ρ [kg.m^{-3}] is material density. Wave length of generated acoustic wave depends on wave velocity and frequency of meander line coil current.

$$\lambda_R \approx \frac{0{,}87 + 1{,}12\mu}{f(1+\mu)} \cdot \sqrt{\frac{G}{\rho}} . \qquad (2)$$

where λ_R [m] is length of acoustic wave ad f [Hz] is frequency of source current.

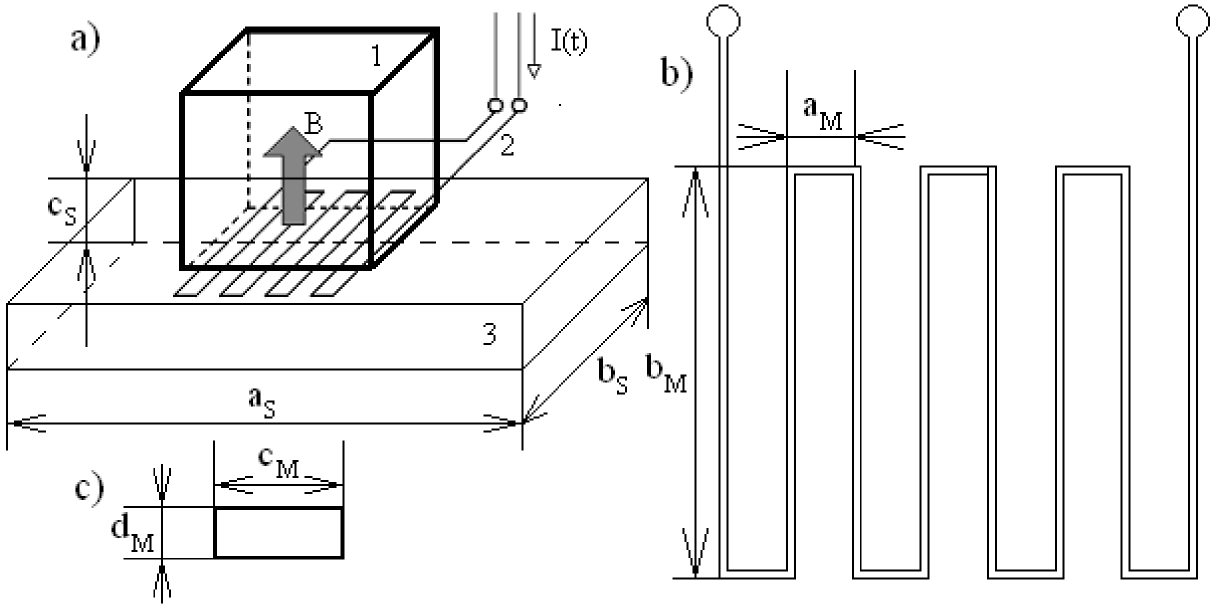

Fig.1: a) Transmitting EMAT, b) Meander line coil, c) Cross section of conductor

Meander	a_M[mm]	b_M[mm]	c_M [µm]	d_M [µm]	material	σ_M [MS.m^{-1}]
	6	30	1000	68	Copper	56
Specimen	a_S [mm]	b_S [mm]	c_S [µm]	material	σ_M [MS.m^{-1}]	
	300	250	100	dural	37	
Signal	J [A.mm^{-2}]		I [A]		f [MHz]	
	0,4		0,0312		1	

Tab.1: Parameter values

2.2. NUMERICAL MODEL - THEORY

On the basis of designed meander (c_M,d_M « b_M) line coil the conversion on 2D model is possible. Principial splitting of individual area is on figure 2.

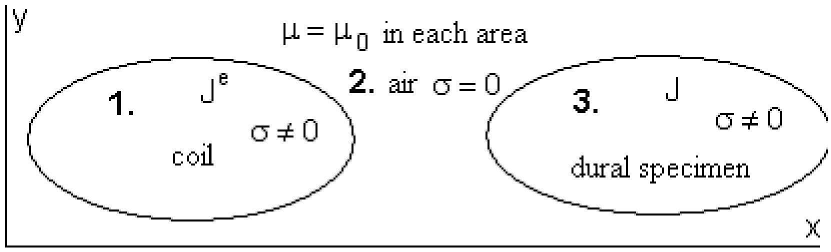

Fig.2: Individual areas in model

II. Maxwell equation in differential form (3) is initial point in creation of numerical model.

$$rot\vec{H} = \vec{J} + \vec{J}^e + \frac{\partial \vec{D}}{\partial t}. \qquad (3)$$

where H [A.m^{-1}] is intensity of magnetic field, J [A.m^{-2}] is inducted current density, J^e [A.m^{-2}] is source current density, D [C.m^{-2}] and t [s] is time. Third item in equation (3) can be neglected in our case. Using material relations equation (3) converts on (4)

$$rot\frac{1}{\mu}\vec{B} = \sigma \cdot \vec{E} + \vec{J}^e. \qquad (4)$$

where B [T] is magnetic induction , μ [H.m^{-1}] is magnetic permeability, σ [S.m^{-1}] is electric conductivity and E [V.m^{-1}] is intensity of electric field. For simplification of calculation we boot auxiliary quantity magnetic vector potential. Potential A is in 2D model one-dimensional vector normal to plane xy, which is scalar quantity. Equation , where A is vector is in form (5)

$$rot\frac{1}{\mu}rot\vec{A} = -\sigma \cdot \frac{\partial \vec{A}}{\partial t} + \vec{J}^e. \qquad (5)$$

Next we consider A as scalar quantityIn the following we use relations between differential operators, which suppose that *rot rotA=grad divA* - $\nabla^2 A$. Because in choosen Cartesian coordinates is valid relation $\nabla = \Delta =$ *div grad,* we acquire relation (6)

$$div\frac{1}{\mu}gradA_z(x,y) - \sigma \cdot \frac{\partial A_z(x,y)}{\partial t} = -J_z^e(x,y). \quad (6)$$

which is scalar parabolic equation for calculation of quasistationary magnetic fields. Next step should be time discretization. Because source signal is harmonic, than time differentiation can be displaced by relation jω an equation (6) change to final form (7).

$$div\frac{1}{\mu}gradA_z(x,y) + k^2 A_z(x,y) = -J_z^e(x,y). \quad (7)$$

where $k^2 = -j\omega\mu\sigma$. Table 2 shows forms of partial differential equations on individual areas from figure 2

oblast	PDE
1.	$div\, v\, gradA_z(x,y) = -J_z^e(x,y)$
2.	$div\, v\, gradA_z(x,y) = 0$
3.	$div\, v\, gradA_z(x,y) - \sigma \cdot \dot{A}_z(x,y) = -J_z^e(x,y)$

Tab.2: PDE types on individual areas

2.3. NUMERICAL MODEL – REALIZATION

First step during creation numerical finite element model is skin depth of quasistationary magnetic field calculation of accordance with relation (8).

$$\delta = (0{,}5 \cdot \omega\mu\sigma)^{-0{,}5}. \qquad (8)$$

where δ [m] is skin depth, ω [rad.s^{-1}] is cyclic frequency. On the basis of parameters of specimen and source signal stated in table 1 skin depth is δ = 827μm. Skin depth is main parameter affecting mesh density in area of tested specimen. As you see in figure 3, aprox-imately four elements are covering skin depth area, which is enough.

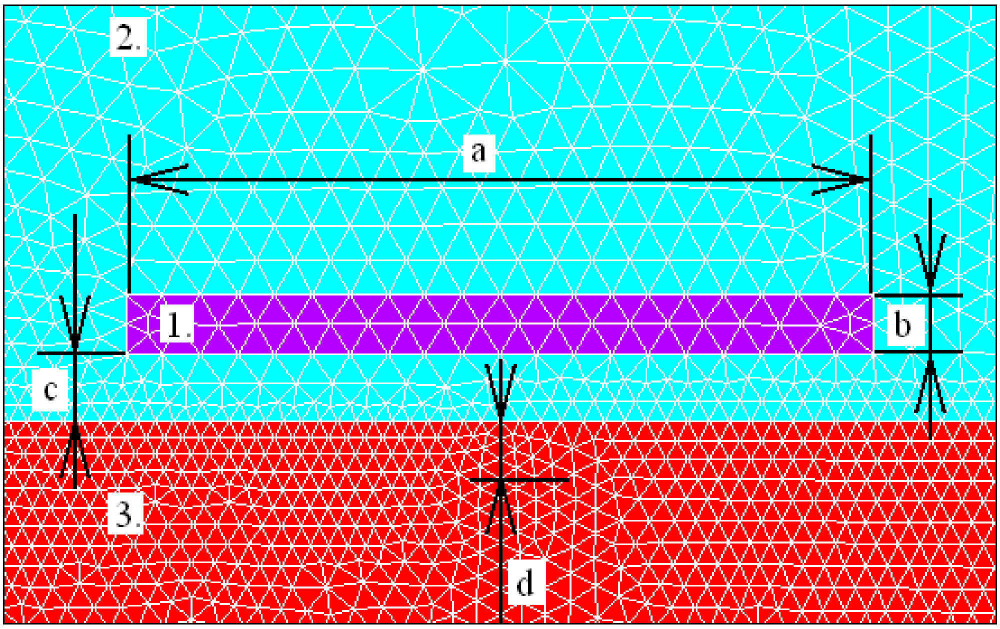

Fig.3: finite element model – detailed view of close conductor area

In figure 3 a is analogous with c_M, b with d_M, c = 90μm, d is calculated skin of depth. Numbers of areas is analogous with figure 2. Height of area 2 (air) is 5cm, width 10cm as well dural specimen. On the edges of model Dirichlet homogenous condition A = 0 is set.

2.4. RESULTS

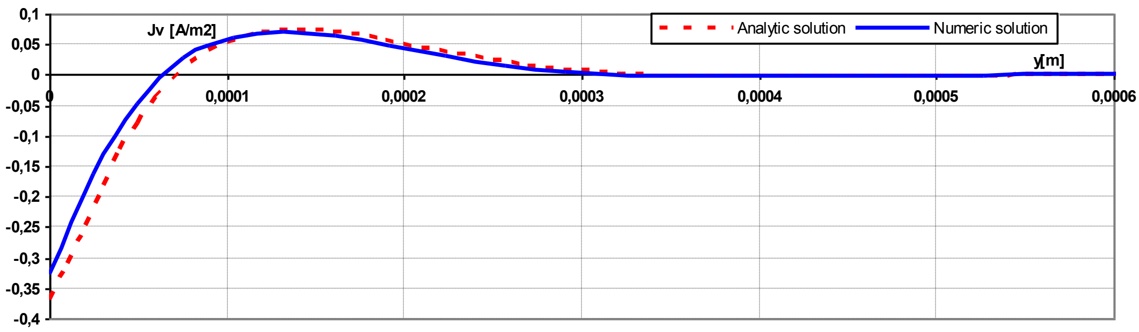

Fig.4: Amplitude of eddy current density depending on distance from surface

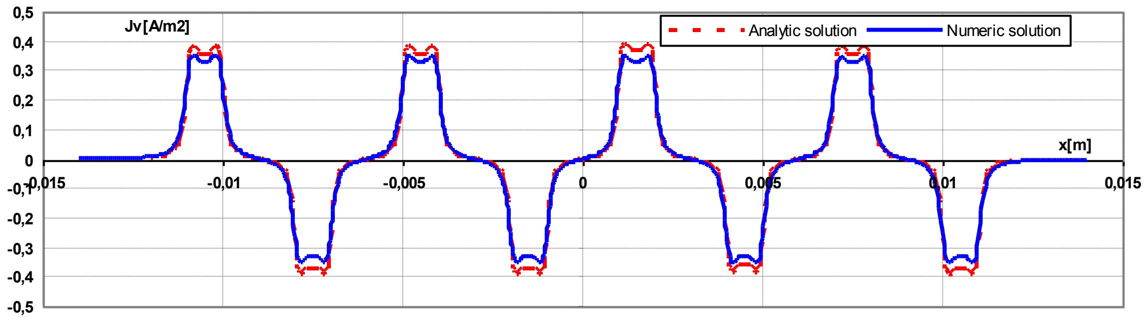

Fig.5: Amplitude of eddy current density depending distributed on surface

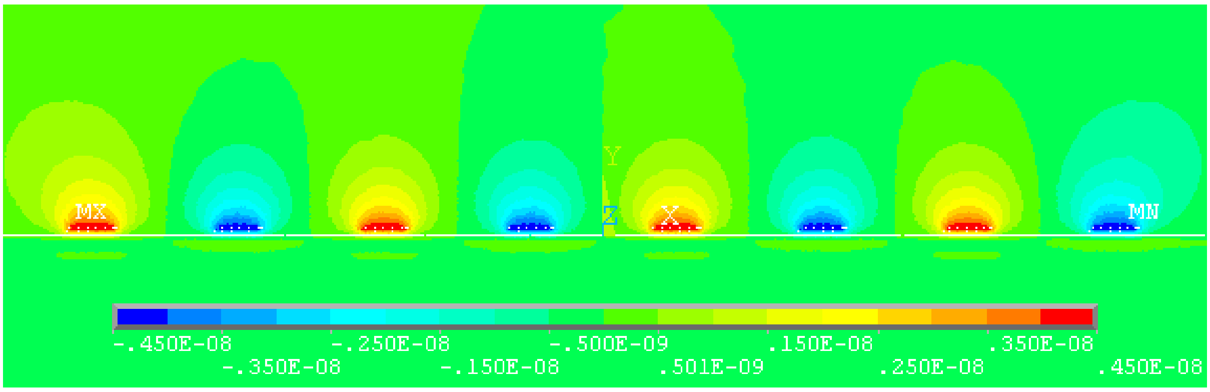

Fig.6: 2D distribution of magnetic vector potential

3. CONCLUSION

Results showed behaviour of eddy current inducted by EMAT transducer. Amplitude decrease on 50% aproximately 100μm under surface. According to presumption is quasi-stationary magnetic field absorbed in conducting material. Analytic solution is only aproximate and does not reason about proximity phenomenon of inducted eddy current. For practical realization of EMAT transducer is important maximal possible source current and maximal minimal proximity meander line coil from surface of tested specimen.

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