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Modelling of Ferrite-cored Multi-pancake Probe in Eddy Current Inspection of Tubes

MODELLING AND SIMULATION OF ELECTROMAGNETIC FIELD PROBLEMS

The safety of nuclear power plant is partially based on reliable work of steam generator. For effective operation, steam generator tubes must be free from defects like stress corrosion crack, pitting, wearing. But this heat exchanger tubes are continuously exposed to quite harsh environment which initiates many degradation mechanisms in metallic material of tubes. Eddy current (EC) testing is the conventional method for in-service inspection of heat exchanger tubes and has advanced significantly over the years in probe design and computer-aided signal analysis. Most of steam generators usually inspected after stopping and cooling procedures when their internal structures are available for testing equipment and repairing. Standard procedure of nondestructive testing uses bobbin coil probes and has some serious disadvantages. One of them is that this probe type does not provide information concerning a defect oriented in circumferential direction. So there are defects of different morphology and dangerous level which can give the same EC signal. In this case the problem of evaluating defect parameters becomes very difficult.
The problem can be solved by using rotating coil probe or multi-pancake probe. The advantage of both probe types is in increasing inspection accuracy and resolution. This allows to detect and estimate parameters of defects with complicated geometrical morphologies. We choose multi-pancake probe because it has obvious advantage over rotating coil probe due to rapid inspection productivity (more than 10 times faster) [1].

For successful detection, classification and parameterization of tube defects it is necessary to develop adequate mathematical model that allows us to predict EC signals for multi-pancake probe. It can be done by numerical modeling using finite element method. Modeling procedures were realized with the help of program MagNum3D. To accelerate process of calculation, two-step algorithm was used [2, 3].

Electromagnetic field for eddy current testing is described by equation

$$\nabla\times\left(\frac{1}{\mu}\nabla\times\mathbf{A}\right)+\sigma\frac{\partial\mathbf{A}}{\partial t}=\mathbf{J}, \qquad (1)$$

in which physical parameters μ, σ - are dependent in all space coordinates. Selecting such approximation coefficients μ^0, σ^0 for real parameters which are one- or two-dimensional functions in any (plane or cylindrical) coordinate system and differ from its only in those regions of solution domain where defects defined. The current density $\mathbf{J}^0$ is two-dimensional approximation for full currents $\mathbf{J}$, and $\mathbf{J}^{non}$ - three-dimensional part of external currents.

Present vector magnetic potential $\mathbf{A}$ as a sum of two vector potentials $\mathbf{A}=\mathbf{A}^0+\mathbf{A}^{def}$, where $\mathbf{A}^0$ and $\mathbf{A}^{def}$ satisfy to differential equations

$$\nabla\times\left(\frac{1}{\mu^0}\nabla\times\mathbf{A}^0\right)+\sigma^0\frac{\partial\mathbf{A}^0}{\partial t}=\mathbf{J}^0, \qquad (2)$$

$$\nabla\times\left(\frac{1}{\mu}\nabla\times\mathbf{A}^{def}\right)+\sigma\frac{\partial\mathbf{A}^{def}}{\partial t}=\mathbf{J}^{non}+\nabla\times\left(\left(\frac{1}{\mu^0}-\frac{1}{\mu}\right)\nabla\times\mathbf{A}^0\right)+\left(\sigma^0-\sigma\right)\frac{\partial\mathbf{A}^0}{\partial t}, \qquad (3)$$

On the first step the electromagnetic field distribution of one pancake-coil is calculated. The coil is situated above the inspected object (in our case steam generator pipe wall). And there are no defects in solution area for the first step. Besides, first step can be done once for all defect types.

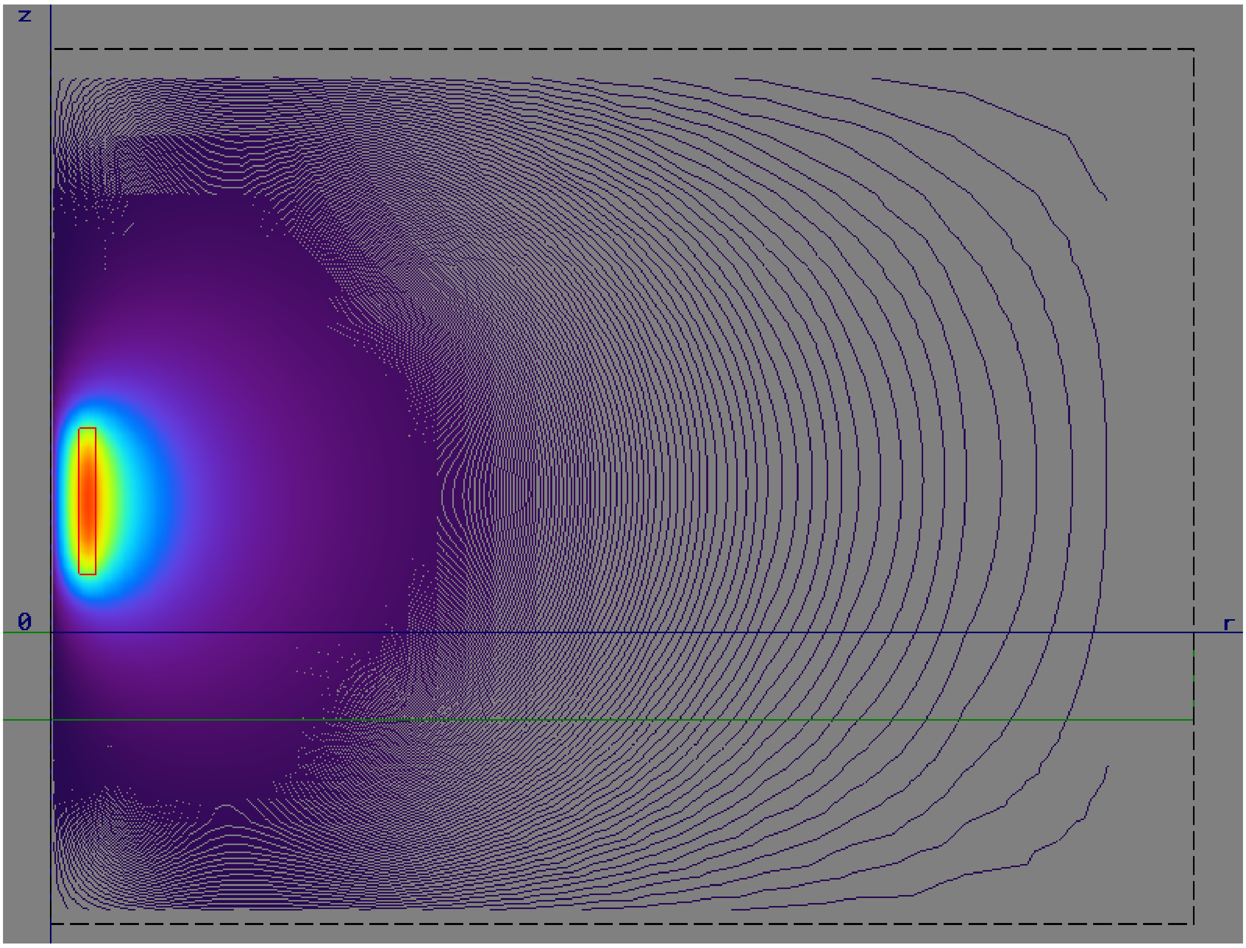

Fig.1 Vector potential (real part) distribution after 2D model calculation

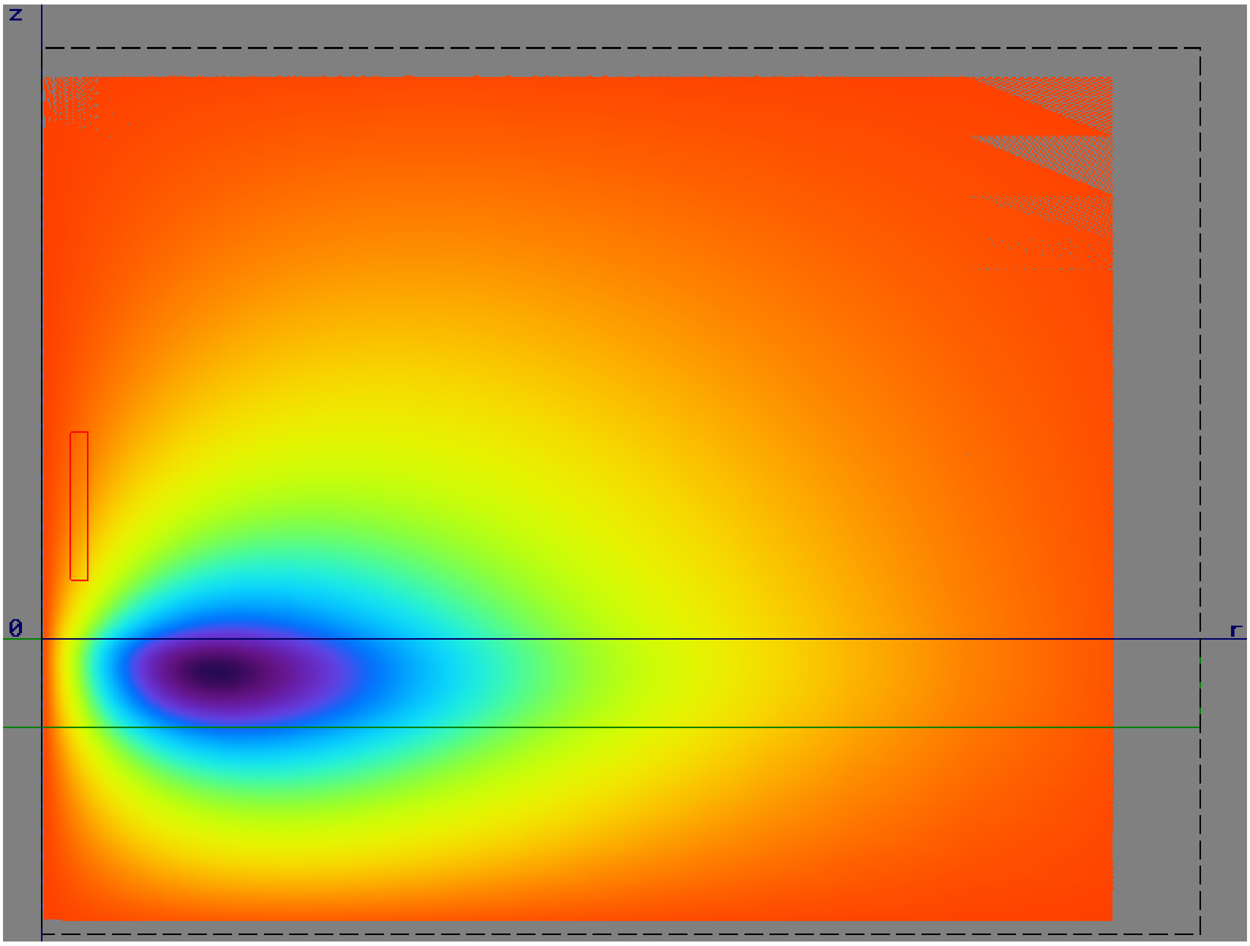

Fig.2 Vector potential (imaginary part) distribution after 2D model calculation

Then potential distribution from 2D area is transformed to 3D area, assuming the axial symmetry of 2D model.

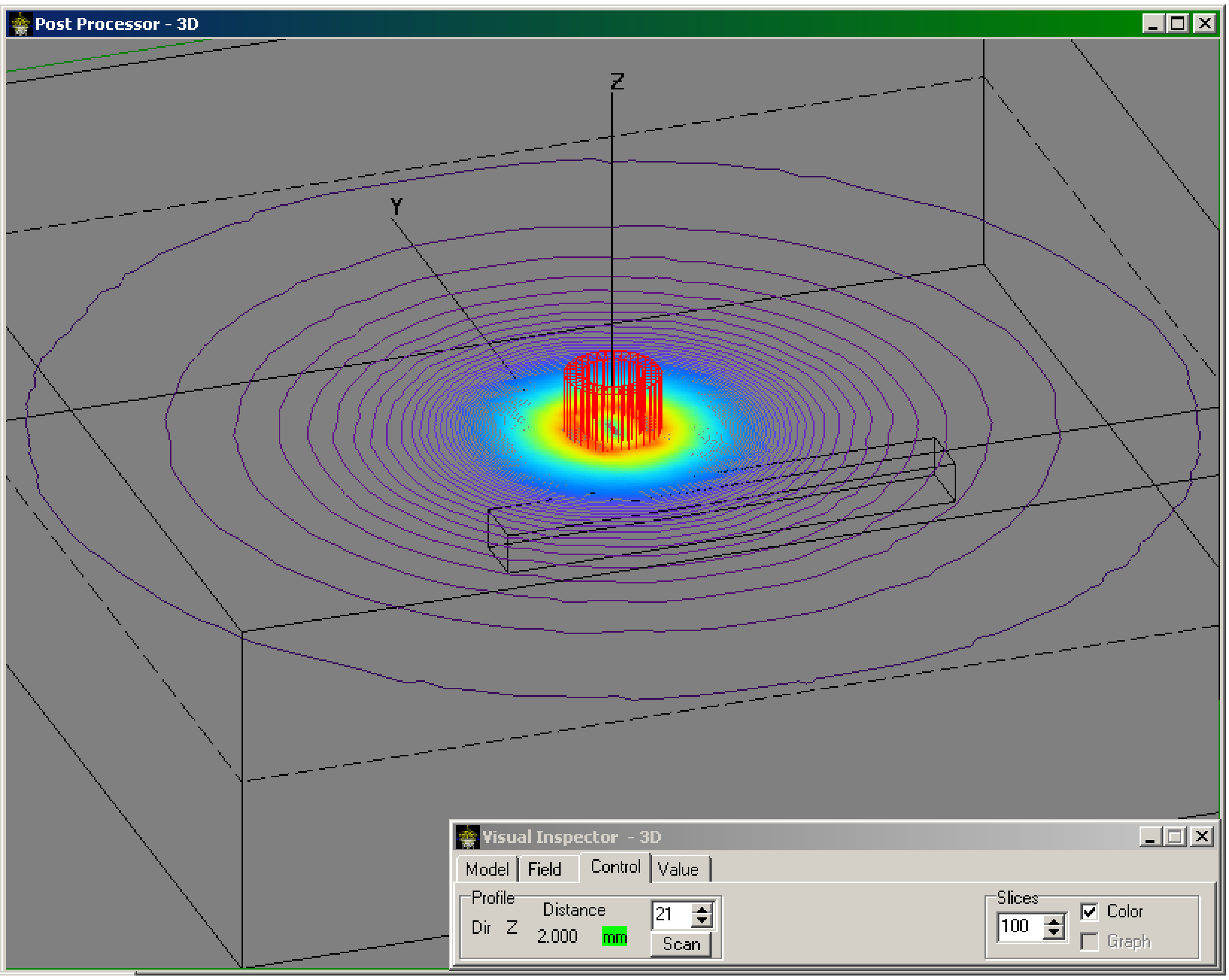

Fig.3 Vector potential distribution in 3D area from single-coil probe

Then using the superposition principle the sum of vector potential from each coil is calculated by formula (4).

$$\vec{A}(x, y, z) = \sum_{i=1}^{NCoils} \vec{A}_i(x - xc_i, y - yc_i, z) \quad (4)$$

where xc_i and yc_i – coil's centers coordinates at the inner surface of pipe; *NCoils* – total amount of coils; $\boldsymbol{A}_i$ – vector potential distribution from *i*-th coil.

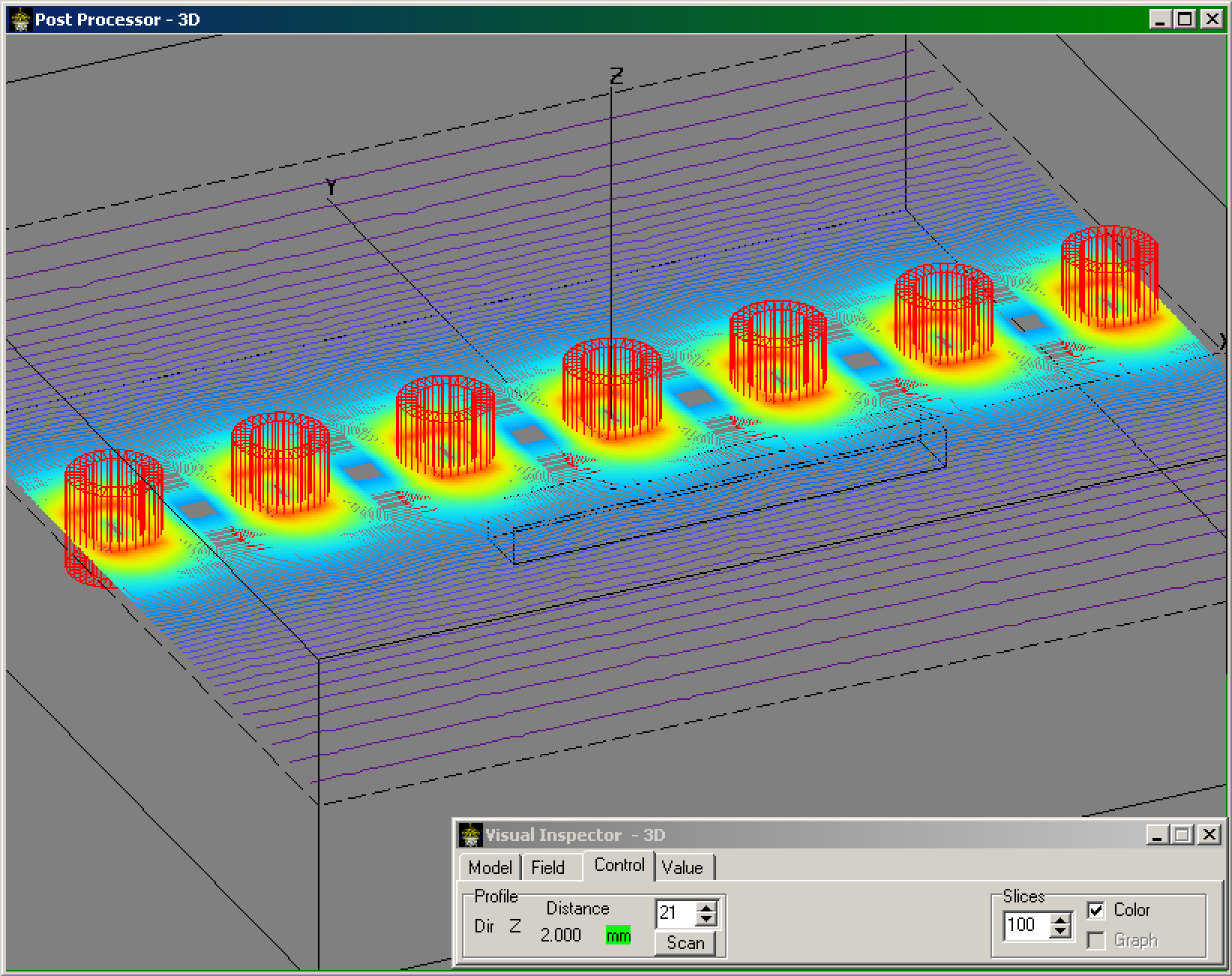

Fig.4 Vector potential distribution in 3D area from the multi-coil probe

The second step of algorithm provides calculation of electromagnetic field distribution due to defect.

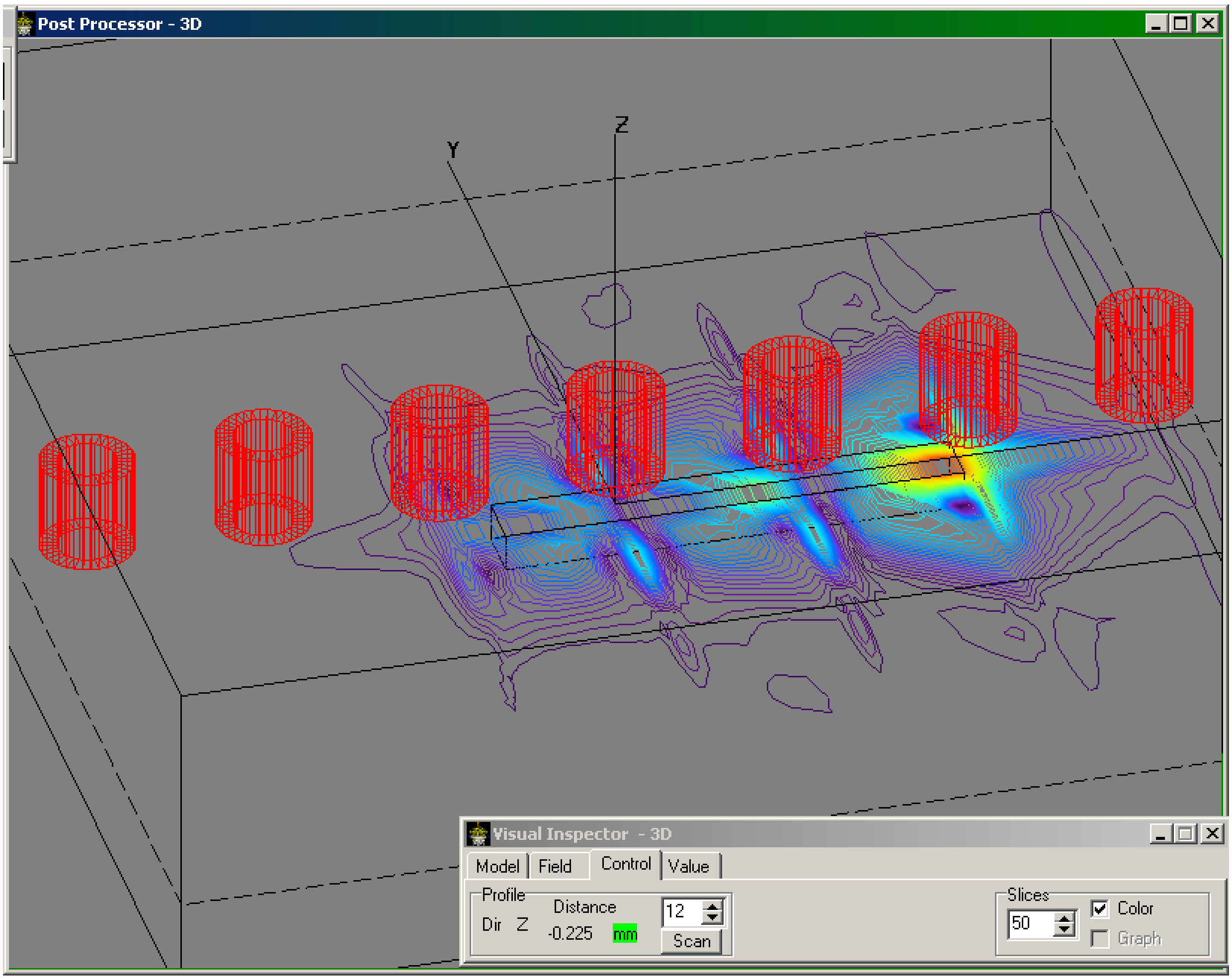

Fig.5 Field distribution due to defect presence in the area of defect

It is necessary to set moving step gage and then, using it, to move external electromagnetic field relatively to defect. At each step the complex-type induced voltage of every coil is calculated.

New special module was developed in which a model of multi-pancake probe can be created selecting some numerical and geometrical parameters. These parameters include amount of coils arranged around the circumference of the probe to facilitate full coverage of the tube, amount of rows, inner and outer diameter of each coil, existence (or not) of ferrite core.

The voltage induced due to defects of various orientation and morphologies was calculated using new module. Each result is two-dimensional signal in axial and circumferential coordinates.

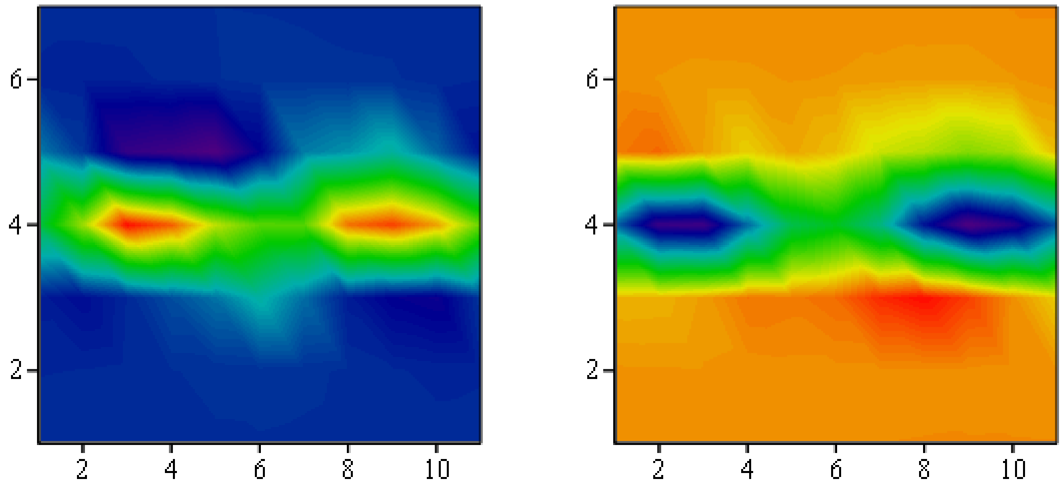

Fig.6 Multi-coil probe signal from longitudinal crack

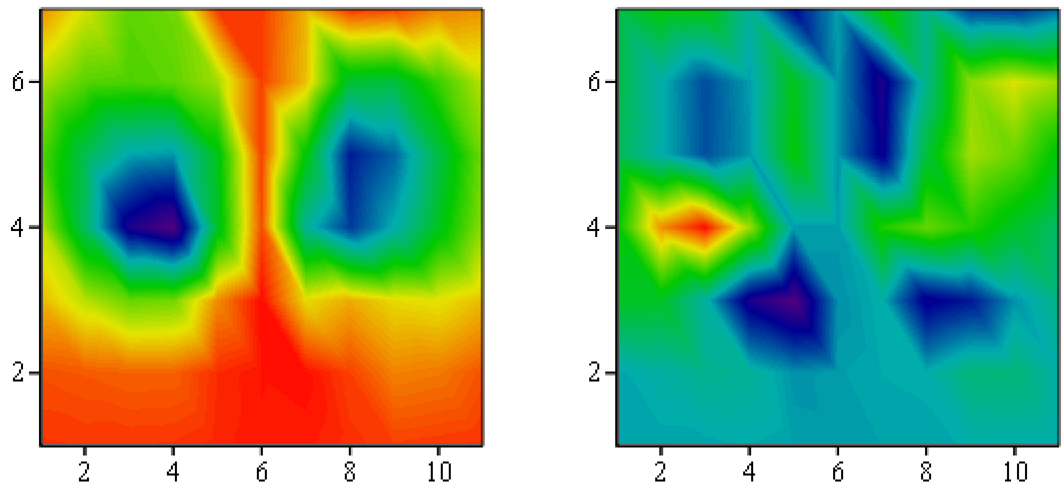

Fig.7 Multi-coil probe signal from transverse crack

The figures above show signals of multi-coil probe from various cracks. On the left part there is real component of induced voltage, on the right part – imaginary component. In the horizontal axis scanning position is shown (the scanning step is 1mm). In the vertical axis coil number is shown.

References:

[1] Mr. Huiping Cheng, "Verification of WWER steam generator tube integrity", NPES/NENP, CRP I2.10.14, IAEA,Vienna, Austria, 2005

[2] Z. Chen, K. Miya, "ECT Inversion Using a Knowledge-Based Forward Solver", Journal of Nondestructive Evaluation, Vol. 17, No. 3, 1998

[3] V. Lunin, A. Zhdanov, "Two-step Algorithm in Calculation of Defect Influenced Eddy Current Field", 48th International Scientific Colloquium: Proceedings Ilmenau, Germany, 2003, pp.345-346

[4] G. Pichenot, F. Buvat, V. Maillot, H. Voillaume, "EDDY CURRENT MODELLING FOR NONDESTRUCTIVE TESTING", in Review of Progress in QNDE Vol.23, 2004

[5] V. Lunin, D. Podobedov, "Modeling of Electromagnetic Problems Using the Finite Element Computer Code MagNum3D", 43rd International Colloquium, Technical University of Ilmenau Germany, 21-24 September 1998, pp.240-245

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