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Investigation of the HIP Joints of the First Wall using ECT

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Abstract. Effectiveness of conventional ECT method using pancake probe for detection of defect in the HIP joints of the first wall is investigated. SUS tubing to copper block HIP joint defects are proven to be detectable. Numerical results of simulation using a 3D FEM-BEM code are presented.

1. Introduction

Development of the International Thermonuclear Experimental Reactor (ITER) Project raised a broad palette of scientific, technological, design and economical problems. One of the key aspects, which involve both technological limits evaluation and political support through public acceptance of the project is related to the Nondestructive Testing (NDT) effectiveness in evaluating the potentials failures and flaws for structural integrity assurance. Between the critical points signaled by the early evaluations during Pre Service Inspection (PSI) was the possibility to detect flaws in the Hot Isostatic Pressing (HIP) joints of the First Wall. Figure 1 shows the structure of the Cu-SUS HIP joints. Due to the large dimensions of the structure, traditional Eddy Current testing (ECT) with 200 kHz frequency pancake is limited only to flaws placed close to the surface. Therefore, only two kinds of defects are investigated here. First, we investigate effectiveness of the method in detection of surface flaws on the border between SUS and HIP zone on the small diameter SUS tubing in the Cu zone. Second, we try to detect volumetric defects centered at 5 mm deep from the interior surface of SUS tubing. Simulations are conducted using a 3D FEM-BEM coupling, based on A-ϕ formulation code [1]. The mesh used for the first set of simulations is show in Fig. 2.

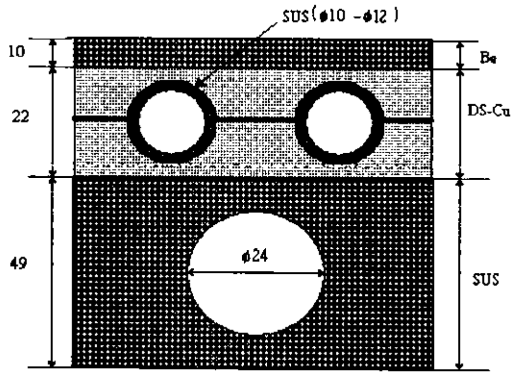

Fig. 1 HIP Joint structure description

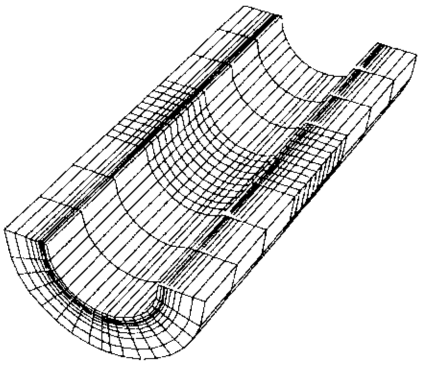

Fig. 2 Mesh of the ½ section SUS tube with HIP Joint and Cu mantle

2. FEM-BEM A-ϕ based code for harmonic eddy-current analysis

The code used for the simulations was extensively described elsewhere [1]. Starting from Maxwell laws in the quasistationary approximation and using the magnetic vector potential A, we obtain the following governing equations:

$$-\frac{1}{\mu_0}\Delta A-\sigma\left(\frac{\partial A}{\partial t}+\nabla\frac{\partial\phi}{\partial t}\right)=0 \quad in\,\Omega_c, \tag{1}$$

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$$\nabla\sigma\left(\frac{\partial A}{\partial t}+\nabla\frac{\partial\phi}{\partial t}\right)=0 \quad in\,\Omega_c \tag{2}$$

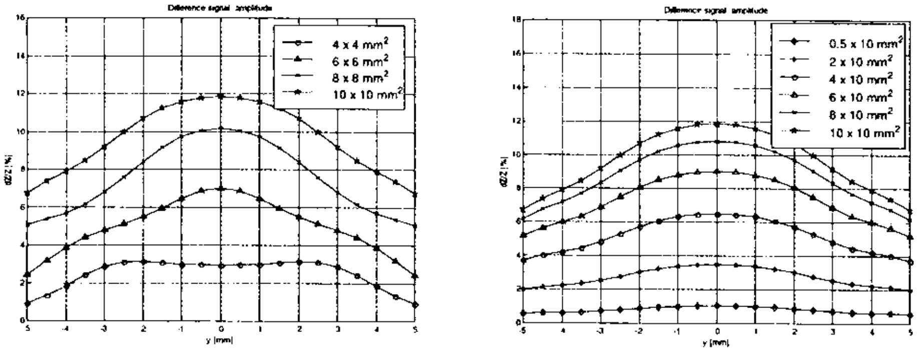
with $\phi = \int_{-\infty}^{t}\varphi(\tau)d\tau$.

$$-\frac{1}{\mu_0}\Delta A = J_0 \quad in\,\Omega_0, \tag{3}$$

where $\Omega = \Omega_c \cup \Omega_0$ is an unbounded domain, Ω_c being the conductive domain and Ω_0 the air. The sources of field are the impressed current sources J_0 in the air. Using Coulomb gouge, a Galerkin approach and coupling the FEM-BEM equations, we finally obtain an equation system in complex unknowns which is solved using a active column Gauss procedure for partially banded matrix. The system matrix is inverted only once and after solution of the system the impedance of the probe is computed for every scan step.

3. Sensitivity analysis

Using the code described above, we simulated the B-scan from the inner of the 10mm diameter SUS tube, with a conventional pancake probe energized with frequency 200 kHz. The liftoff was 0.5 mm and the scan line 10 mm length, with 21 equally distanced points. For Cu, the conductivity was assumed $\sigma_{Cu} = 58.14 \cdot 10^6$ S/m, for SUS 304, the conductivity is $\sigma_{SUS} = 1.0 \cdot 10^6$ S/m and therefore, $\sigma_{HIP} = 29 \cdot 10^6$ S/m. Figure 3 shows the amplitude of relative difference signals for circumferential square and non-square surface defects. The signal phase is not changing significantly with variation of length or surface of fracture. The defect is modeled as having 0.1 mm depth. Even for very small defect (0.5 mm circumferential, 10 mm axial and 0.1 depth) we can detect a noticeable difference signal. The preliminary tested that we performed for more deep fractures, modeled as volumetric defects, centered at a depth of 5 mm under the ID surface of SUS tube shows unsatisfactory results. The difference signal between case with and without defect, in the case of very deep fractures is too small to be experimentally measured (amplitude is less than 0.1% of the amplitude of signal). The solution for this case should be based on usage of lower frequency ECT, pulse EC or static field injected current, in order to achieve a penetration depth considerable improved.



a b

Fig. 3 Difference signal for a 0.1 mm depth fracture, circumferential, between the SUS tube and the HIP joint with Cu; a) variation with surface of a square surface fracture; b) linear, 0.5 to 10 mm circumferential width, 10 mm long in axial direction.

4. Conclusions

Preliminary simulated tests were performed for evaluation of possibility to detect HIP Joints fractures around the small diameter SUS tubing of the first wall of fusion reactor. Conventional ECT pancake probe energized with 200 kHz frequency, according to the simulations, is effective for detection of fractures 0.5 mm modeled with 0.1 mm thickness between SUS tube and joint. For deep volumetric defects (3 to 5 mm depth) other methods should be used to obtain measurable signals.

References

[1] Z. Chen and K. Miya, "ECT Inversion Using a Knowledge-Based Forward Solver", *J. Nondestr. Eval.*, Vol. 17, No. 3, 1998, pp. 167-175.