NONDESTRUCTIVE EVALUATION OF STEAM GENERATOR TUBES ANDPRESSURE TUBES FROM THE PHWR REACTORS, USING THE ROTATING MAGNETIC FIELD METHOD

D. Prémel*1, R. Grimberg2, Adriana Savin2 , D. Placko1
1LESIR, ENS Cachan, 61, Av. du Président Wilson 94235 Cachan Cedex, FRANCE
2National Institute of R&D for Technical Physics, 47 Mangeron Blvd, 6600, Iasi, ROMANIA

Introduction

The tube bundles of the steam generators from the nuclear power plants are almost exclusively controlled by using the eddy current method on single or multiple frequency.Besides the eddy current transducers currently used in the control operation, namely the absolute, the differential and the revolving transducers [1], a large range of transducers has been developed within the last years [2], [3]. The appearance of these new types of transducers responds to the need to detect with a good signal-to-noise ratio, as many types of defects as possible from those existing in the tube bundle of the steam generators. This work presents a new type of inner eddy current transducer utilizable for the control of steam generator tubes and pressure tubes of the PHWR. This transducer is of absolute send-receive type and is based on the rotating magnetic field principle.

Transducer description. Experimental set-up

The inner eddy current transducer with a rotating magnetic field is of absolute send-receive type. The emission part that generates the rotating magnetic field consists of three windings a, b, and c placed on an insulating casing A (Figure 1a). The reception part consists of a certain number of flat coils occupying the whole inner surface of the tube under test. The coils are wound on the insulating cylindrical casing B inside of which the emission part is inserted (Figure 1b).

Figure 1. The inside transducer with rotating magnetic field
a) Emission part
b) Reception part

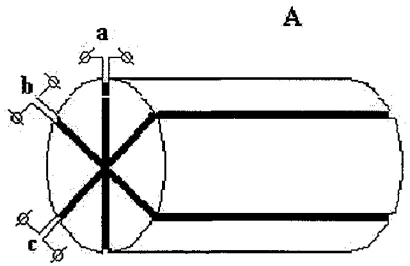

Figure 1a

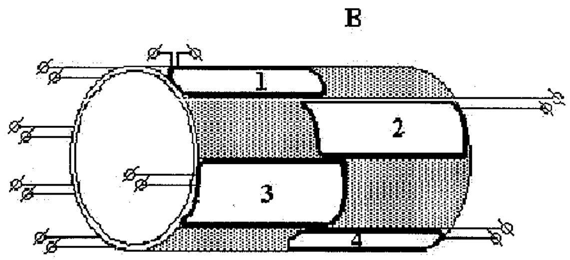

Figure 1b

The axes of the emission coils are set 1200 apart in angle, the coils being star-connected and supplied by a three-phase current system. The rotating frequency of the magnetic field generated by vectorially composing the fields generated by each coil apart equals the angular frequency of the supply alternating currents. The interaction between the eddy currents and the possible material discontinuities from the tube wall is revealed by the reception coil system. The signal processing method is classical; the reception coils being interrogated sequentially.
Figure 2a presents the basic diagram of the control equipment, while its specific embodiment is given in Figure 2b.

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International Atomic Energy Agency
INIS Section
P. O. Box 100
Wagramerstrasse 5
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Figure 2
a) Basic diagram of the equipment
b) Control installation picture

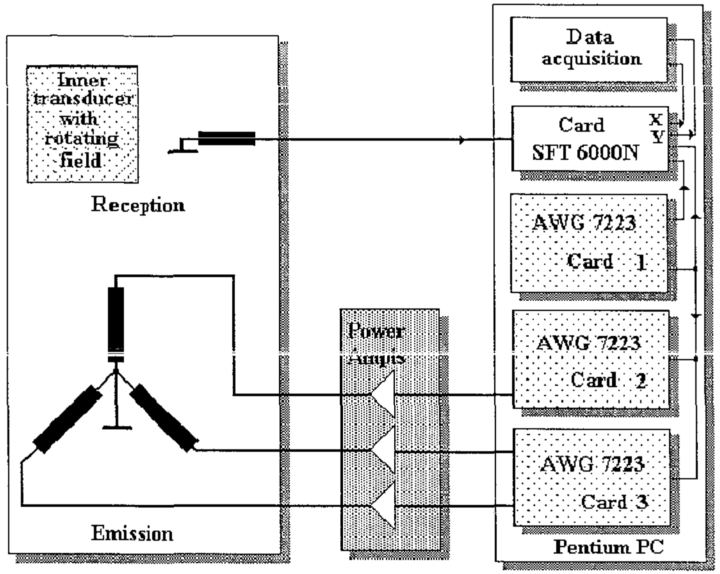

Figure 2a

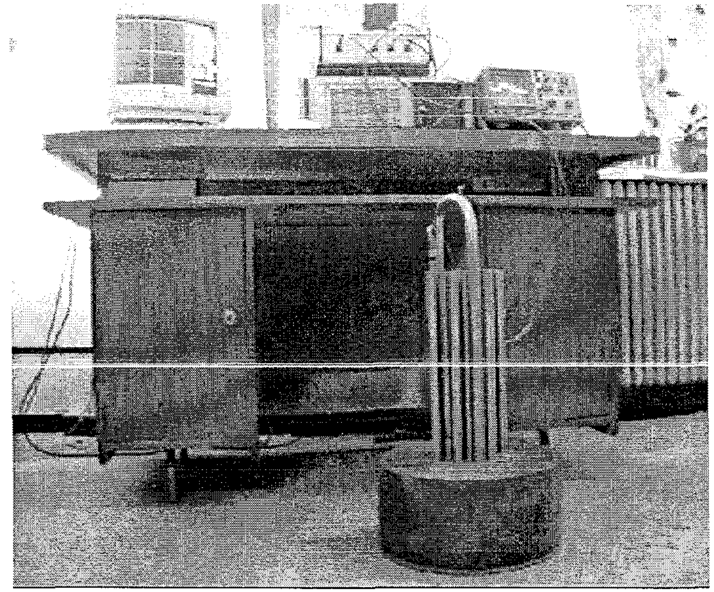

Figure 2b

Experimental results

In order to determine the capability of the eddy current transducer with rotating magnetic field to detect material discontinuities, Incolloy 800 tubes have been used with the inner diameter of 20mm and wall thickness of 1.8mm, of which the following test samples have been made: a standard sample according to the ASME Code Section V, having the discontinuities conforming to the tube size; a test sample with four outer circumferential channels of different depths and widths (Figure 3 a), and a test sample simulating corrosion (Figure 3 b).

Figure 3
a) sample with outer channels
b) sample simulating corrosion

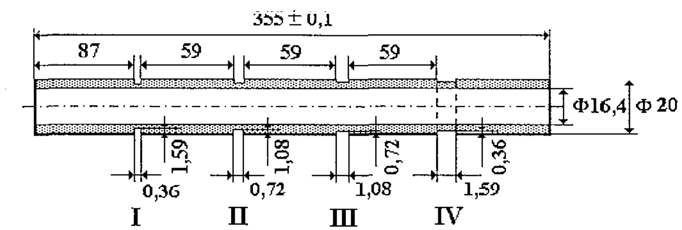

Figure 3a

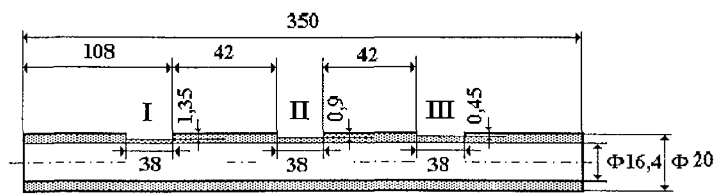

Figure 3b

The transducer's responses to the discontinuities from the three samples are presented in Figure 4 a, b and c.

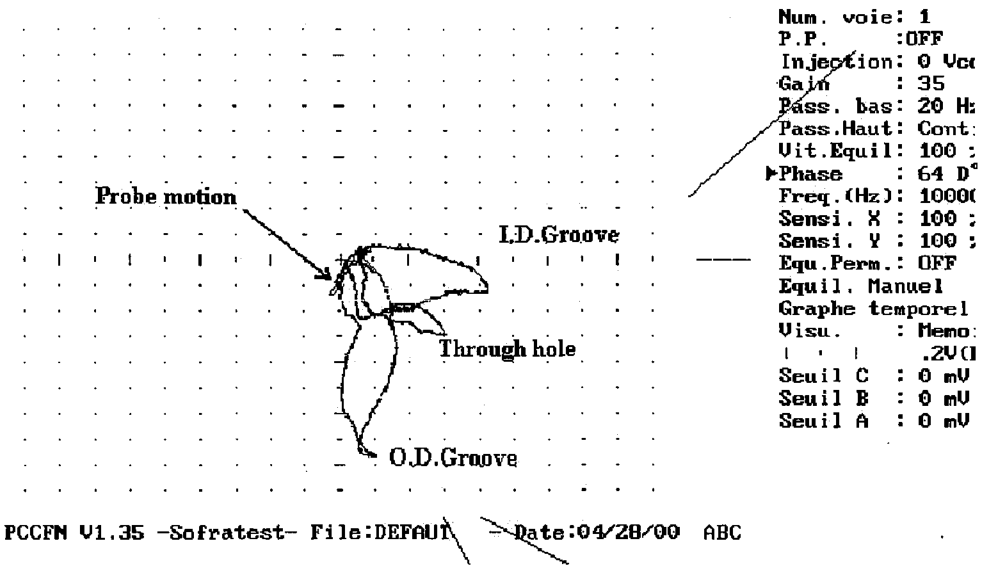

Figure 4a

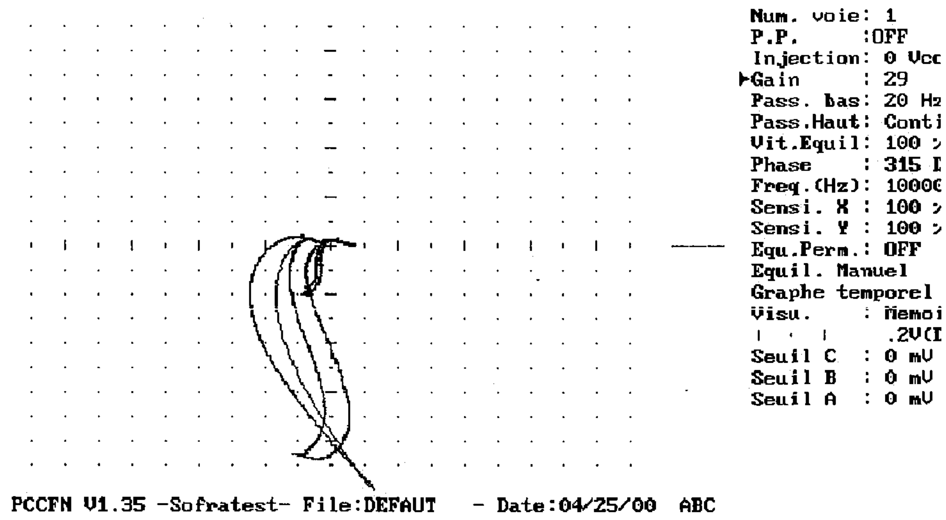

Figure 4b

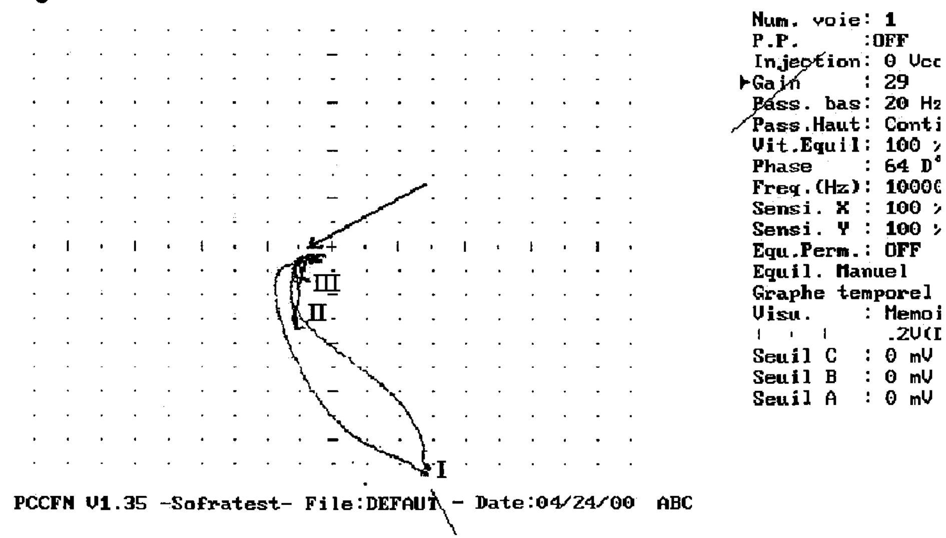

Figure 4c

Figure 4
a) transducer's response to the ASME standard sample
b) transducer's response to the test sample with outer channels
c) transducer's response to the sample simulating corrosion

Mathematical modeling of the transducer's operation

The symmetry of the problem imposes the utilisation of a cylindrical coordinate system with the OZ axis coinciding with the axes of the inspected tube and that of the transducer's emission part. Four regions can be discerned here : region Ω_1 representing the tube interior with the transducer, the region Ω_2 consisting of the tube wall, the region Ω_3 consisting of the copper or magnetite layer, and the region Ω_4 outside the tube.
Within the region Ω_1 the following relations are valid :

$$\begin{aligned} \overline{E}_1 &= \overline{E}_0 + \overline{E}^{EC} \\ \overline{H}_1 &= \overline{H}_0 + \overline{H}^{EC} \end{aligned} \qquad (1)$$

where $\overline{E}_0$ and $\overline{H}_0$ represents the electric and magnetic fields created by the transducer's emission part in the free space and are given by the relations :

$$\overline{E}_0(\overline{r}) = j\omega\mu_0 \int_{Vsource} \vec{G}_0(\overline{r},\overline{r}')\overline{J}(\overline{r}')d\overline{r}' \qquad (2)$$

with $\vec{G}_0(\overline{r},\overline{r}')$ the dyadic Green's function for the free space, $\overline{J}(\overline{r}')$ the current density, ω the angular frequency of the three - phase current system, $\mu_0 = 4\pi 10^{-7} H/m$;

$$\overline{H}_0(\overline{r}) = \frac{1}{j\omega\mu_0}\nabla \times \overline{E}_0(\overline{r}) \qquad (3)$$

$\overline{E}^{EC}$ and $\overline{H}^{EC}$ are the fields created by the eddy currents induced in the tube wall, solutions of the differential equations

$$\begin{aligned} \nabla^2\overline{E}^{EC} + j\omega_0\sigma_0\overline{E}^{EC} = 0 \\ \nabla^2\overline{H}^{EC} + j\omega_0\sigma_0\overline{H}^{EC} = 0 \end{aligned} \qquad (4)$$

where σ_0 is the electrical conductivity of air.
For the regions $\Omega_2, \Omega_3, \Omega_4$ the field are solution of the equations :

$$\begin{aligned} \nabla^2\overline{E}_i + j\omega\mu_i\sigma_i\overline{E}_i = 0 \\ \nabla^2\overline{H}_i + j\omega\mu_i\sigma_i\overline{H}_i = 0 \end{aligned} \qquad (5)$$

where i=2, 3, 4.
The system of equations have been solved by taking into account the continuity of the tangential components of the electric and magnetic fields in the four regions.
A numerical code has been written using Matlab 5.3.1 permitting to compute the induced e.m.f. at the terminals of the pick-up coils of the eddy current transducers with rotating magnetic field. The code permit to introduce additional layers on the tube outer surface, with different thickness, conductivity and magnetic permiability, making use at the above theoretical presentation.
The induced e.m.f. is

$$e = \oint_{\Gamma} \overline{E}_1 d\overline{l} \qquad (6)$$

where $\overline{E}_1$ is the electric field inside the tube and Γ is the contour of the pick-up coil.

Conclusion

The described transducer permits to detect certain material discontinuities and to discern the information resulting from the presence of copper and magnetite coating on the outer surface of the steam generator tubes. In the case of testing the pressure tubes of PHWR, the position of gartner springs is clearly visible.

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References

[1]. V.S.Cecco,G.van Drunen,F.L.Sharp, Manual on eddy current method, Chalk River, Ontario, KOJ 1JO, 1981
[2]. K.Miya, H.Komatsu, A.Kurokawa, K.Tachibana, Progress of Tube Inspection Technology in Nuclear Power Plant of Japan, Nondestructive Testing of Materials,R.Collins et al.(Eds) IOS Press (1995), 211-222
[3]. D.Prémel, A.Savin, R.Grimberg, Nadia Madaoui, "Modeling the operations of a new type of eddy, current transducer for non-destructive evaluation of tubes of steam generators", Studies in Applied Electromagnetics and Mechanics, vol. 17, Electromagnetic Nondestructive Evaluation (IV), S.S. Udpa et al.(Eds) IOS Press 2000, pp.42-49.