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EDDY CURRENT NON-DESTRUCTIVE TESTING OF MAGNETIC TUBES

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The paper focuses on eddy current non-destructive testing of magnetic tubes. Remote field eddy current testing is concerned here. Basic principle of the method is explained and standard configurations of probes are listed. A new probe dedicated for the remote field inspection of a magnetic tube from its outer surface is designed. Simple arrangement composed from two outer encircling coils is chosen. Both the coils, ie the exciting coil and the pick-up one, are shielded with a magnetic material to gain the remote field effect in the considered configuration. The finite element method is used for numerical investigations. Presented results prove the effectiveness of the probe in the remote field inspection of the magnetic tube performed from its outer circumference.

Keywords: eddy currents, remote field, non-destructive testing, magnetic materials, probe, shield

1 INTRODUCTION

Eddy current non-destructive testing (ECT) is a non-invasive inspection method applied to evaluation of structural integrity of conductive materials. Numerous advantages such as high sensitivity, rapid scanning, contact-less inspection, and versatility contribute to wide utilization of the ECT [1].

Principle of the method underlies in the interaction of induced eddy currents with the structure of an examined body. A primary alternating electromagnetic field generated by a suitable impedance coil penetrates into a surface layer of a contiguous conductive object being tested. The eddy currents flow there according to the electromotive force. The resulting electromagnetic field given by interaction of the primary field and a secondary one generated by the eddy currents influences the impedance of the coil. Therefore, when a path of the eddy currents is altered by presence of any discontinuity in the tested volume, the impedance of the coil varies [2].

In spite of the very useful advantages, the ECT has a particular drawback that indeed originates from its principle. The secondary field produced by the eddy currents is opposite to the primary exciting field and thus attenuates it. Therefore, the eddy currents gain maximum density at the surface and decay exponentially with depth in the material being tested. This is the well known skin-effect. Thickness of a surface layer that can be inspected depends mainly on the exciting current frequency and on the electromagnetic parameters of a tested material, ie conductivity and permeability [3]. Therefore, the ECT of magnetic materials is quite difficult especially for detection of cracks which are located at opposite side of a specimen concerning position of an ECT probe, ie far-side defects.

Remote field eddy current testing (RFECT) is widely used for inspection of magnetic tubes from their inner surfaces [4]. However, not all tubes can be accessed from their inside; they must be inspected from their outside. It is reported that it is quite difficult to gain the remote field effect in such configuration using conventional arrangements of the RFECT probes. Several studies have proposed to use magnetic shields to obtain the effect when probes are situated outside a tube. Whereas successful results were reported [5], only nonmagnetic tubes with thin wall have been considered.

The paper presents design of a new RFECT probe dedicated for inspection of a magnetic tube from its outer surface. Configuration of the probe is proposed and its dimensions are set. Numerical results reveal the effectiveness of the probe in the outer inspection of the magnetic tube.

2 REMOTE FIELD EDDY CURRENT TESTING

The RFECT is primarily used to inspect ferromagnetic tubing since conventional eddy current techniques have difficulty inspecting the full thickness of the tube wall due to the strong skin effect in ferromagnetic materials. The RFECT assures almost equal sensitivity to the near-side and to the far-side defects, because it detects magnetic flux penetrating a tube wall.

Principle of the method is shown in Fig. 1 [6]. An inner encircling coil, so called bobbin coil, is utilized to drive the eddy currents along a tube circumference. Three field zones can be recognized along the tube axis: the near zone, the transient zone and the remote zone. The region where the magnetic field from the exciter coil is interacting with the tube wall to produce a concentrated field of the eddy currents is called the near field zone. This zone is used in the conventional ECT; the pick-up coil is positioned in proximity of the exciting coil or even exciting coil can take both the roles. The region just outside the near field zone is known as the transition zone. In this zone there is a great deal of interaction between the magnetic flux from the exciter coil and the flux induced by the eddy currents. Since the secondary field is more spread out than the primary one, the magnetic field from the eddy currents extends farther along the tube axis. It becomes dominant at some distance away from the exciter coil in so called remote field zone.

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The remote field zone is the region in which direct coupling between the exciting coil and a pick-up coil is negligible. Coupling takes place indirectly through the generation of the eddy currents and their resulting magnetic field. The remote field zone starts to occur at approximately 2 tube diameters away from the exciter coil.

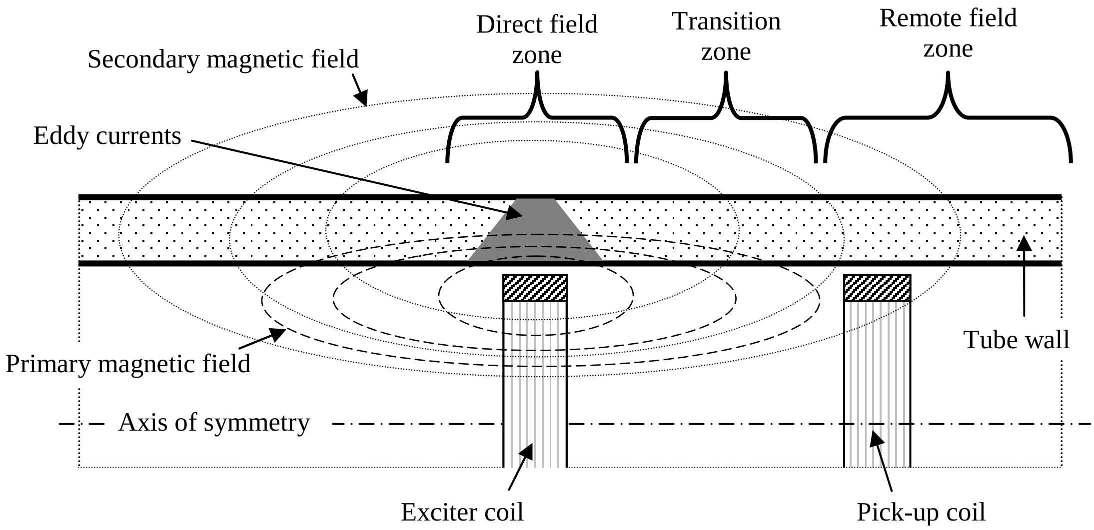

Fig. 1. Principle of the RFECT

Figure 2 displays typical dependence of the pick-up signal amplitude as well as its phase on the distance between the exciting coil and the pick-up coil. Numbers in the figure are just informative. When the pick-up coil is close to the exciting coil the signal is strongly influenced by the direct field. Amplitude of the signal rapidly drops with increasing the distance. The signal starts to rotate of almost 180° in the transient zone. It means that the eddy current field, which is opposite to the exciting field, starts to be dominant. Also the slope of the dependence of the signal amplitude on the pick-up coil position changes as the secondary field becomes leading.

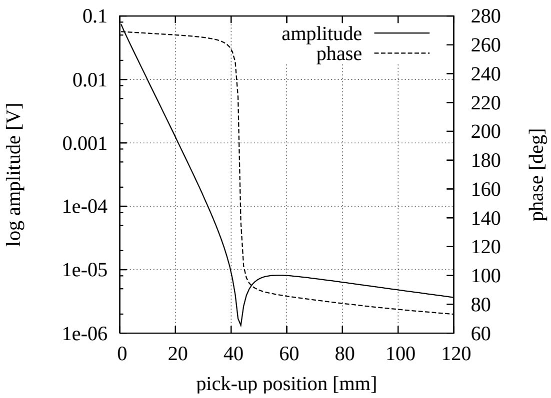

Fig. 2. Dependence of the signal amplitude and its phase on the distance between the exciting coil and the pick-up coil

The RFECT probes are usually made of the bobbin coils positioned coaxially inside the tube. The distance between the exciting and the pick-up coil is approximately 2-3 times a tube diameter. Figure 1 shows the simplest configuration of the probe. Two exciting coils positioned on both sides of the pick-up coil are used in same cases to increase the signal level. Differential connection of two closely positioned pick-up coils is frequently employed for reduction of the wobbling noise.

The RFECT reliably works when the probe is positioned inside the tube. However, not all the tubes are accessible from their inside. When the exciting coil encircles the outer surface of a tube it is not possible to gain the remote field effect with conventional configurations of the RFECT probe even the distance between the exciting and the pick-up coils is quite large. Design of a new probe dedicated for the remote field eddy current testing of a magnetic tube from its outer surface is presented in the next section.

3 NEW OUTER RFECT PROBE

The paper considers the inspection of a magnetic tube with an outer diameter of 500 mm and a wall thickness of 10 mm [7]. The electromagnetic parameters of the tube include a conductivity of $\sigma = 1$ MSm^{-1} and a relative permeability of $\mu_r = 100$. The tube is accessible only from its outer surface. It has been reported that the standard configurations of the RFECT probe do not allow remote field inspection from outside a tube. Thus, the main goal is to design a new probe able to work properly in the given configuration.

There are many variable parameters concerning the design of a probe, ie arrangement of coils and their dimensions, distance between the coils, inspection frequency, etc. Numerical simulations were carried out to find out proper arrangement and dimensions of the new probe. Two-dimensional finite element code was used for the purpose.

Preliminary results clearly indicated that complex arrangement of coils, eg double excitation, does not bring any advantage in reaching the remote field effect from outside the tube. Thus, simple configuration with one exciting coil and one pick-up coil has been chosen. Both the coils are of the bobbin type and encircle the tube from the outside.

A proper shield must be used for gaining the remote field effect from outside the tube. Several configurations and materials of the shield have been studied. Preliminary numerical results illustrated that complex shield does not bring reasonable results for sake of the remote field effect. Therefore, one monolithic shield covering both the coils has been chosen for further investigations.

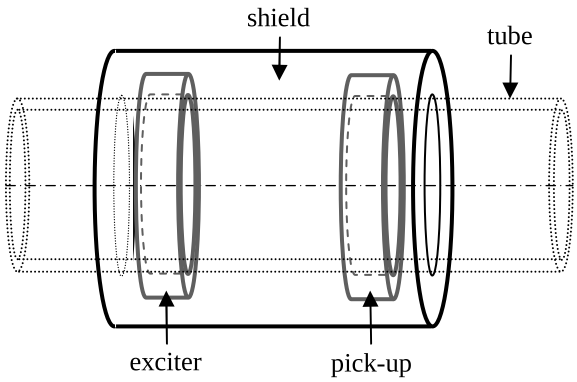

Fig. 3. Layout of the new RFECT probe

Layout of the new RFECT probe is shown in Fig. 3. It should be noted that the dimensions of the coils (width, height) have been set in advance as they do not influence the required behavior of the probe. The increasing distance between the coils as well as the increasing exciting frequency reduce the amplitude of the pick-up signal. Thus, it is preferable to adjust both the parameters as low as possible to obtain a higher level of the detected signal. However, certain limitations have to be taken into account. Dimensions and material of the shield are adjusted along with the other parameters. Preliminary simulations showed that good properties are gained when a material of the shield has approximately a conductivity of 10 MSm^{-1} and a relative permeability of 50.

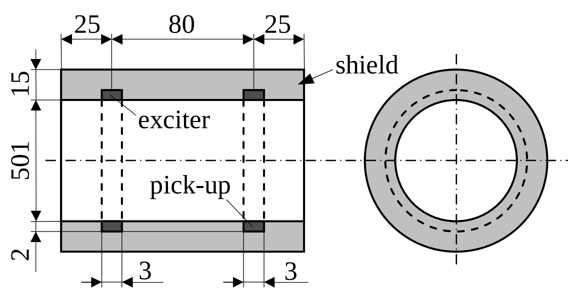

Fig. 4. Configuration and dimensions of the new RFECT probe

Configuration and dimensions of the new RFECT probe are given in Fig. 4. Note that the drawing is not proportional. The shield is made of the Cobalt. Its electromagnetic properties are: conductivity of σ = 16 MS/m and relative permeability of μ_r = 68. Exciting frequency is set to a value of 300 Hz.

Whole circumferential wall thinning of variable depth and of variable width is used to model the inner (ID) and the outer defects (OD) in the tube. The tube is numerically inspected with the proposed probe. Figure 5 displays Lissajous plot of the crack signals for the ID and the OD cracks with a depth of 20% of the tube wall thickness and a width of 5 mm.

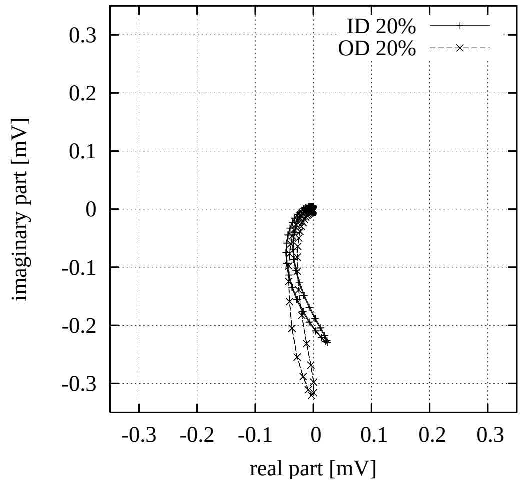

Fig. 5. Lissajous plot of the crack signals for the ID and the OD cracks with a depth of 20% of the wall thickness and a width of 5 mm

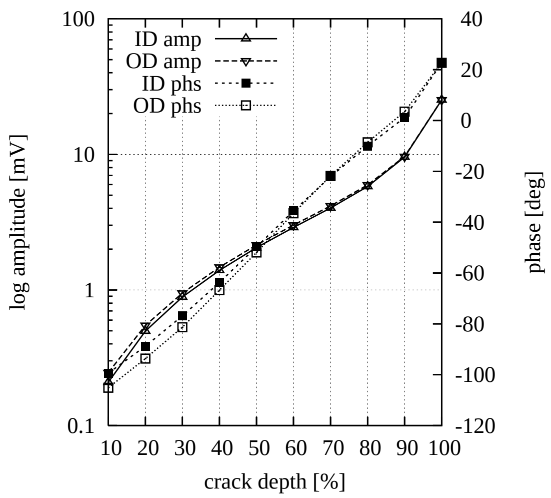

Fig. 6. Dependence of the crack signal amplitude and its phase on the crack depth, crack width is 20 mm

It can be seen that the signals of ID and OD cracks are close to each other. The depth of the ID and the OD cracks is varied from 0 to 100% of the tube wall thickness. The width of the crack is set to 20 mm in this case. Figure 6 shows the crack signal amplitude as well as its phase as a dependence on the crack depth. It can be observed that the ID signals are as clear as the OD ones that confirm correctness of the proposal.

The shield is the key point of the new probe. The remote field effect is gained despite the tube is inspected from its outside. Moreover, shorter distance between the coils can be adjusted. Although, the tube has outer diameter of 500 mm, the distance between the coils is only 80 mm.

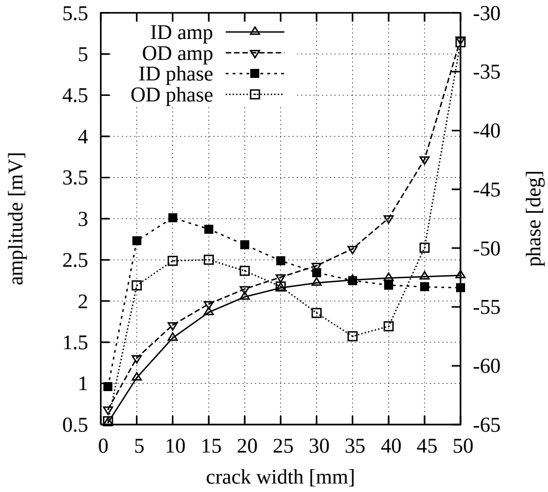

Fig. 7. Dependence of the signal on the crack width for the ID and the OD cracks of 50% in depth

Figure 7 displays how the signal depends on the crack width. The ID and the OD cracks of 50% in depth are considered. Since the distance between the coils is quite short, it can be observed that when the crack is wider than 40 mm, the difference between the signals of the ID and the OD cracks starts to become significant.

4 CONCLUSIONS

The paper dealt with the remote field eddy current non-destructive testing of magnetic tubes. The principle of the method was described. It was explained that conventional configurations of the remote field eddy current probe allow only the inspection from the inner surface of a tube. Design of a new eddy current probe dedicated for the remote field inspection of a magnetic tube from its outer surface was presented in the paper. The probe consists of two bobbin coils shielded with the magnetic material. It was presented that the magnetic shield helps to achieve the remote field effect when the coils are located outside the tube. Moreover, the shield allows shortening the distance between the exciting coil and the pick-up coil and thus to increase level of the pick-up signal.

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