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MAGNETIC LEAKAGE FIELDS AS INDICATORS OF EDDY CURRENT TESTING

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ABSTRACT

With eddy current testing in homogenous fields it is often spoken about hindrances that are represented by cracks to eddy currents that cannot flow so as in non-defective material. Such homogenous condition can be met with the magnetizing in a very long coil. If however the coil is short the fields are not homogenous any more and especially with testing of ferromagnetic materials the magnetic leakage field may not be neglected. The demagnetizing effect of eddy currents can be seen also in magnetic leakage field. By proper arrangement of primary and secondary coil it is possible to get more information. It is given in the article what cracks can be detected in the proposed arrangement of primary and secondary coils.

***Keywords**:* Differential coils, Magnetic leakage fields, Surface cracks, Ferromagnetic material

1. Introduction

With the electromagnetic non-destructive testing there are usually two main methods used. The basis of detecting surface cracks with eddy currents is in the fact that cracks are preventing eddy currents from flowing across the crack and causing changes in skin effect. In this case cracks being oriented along the magnetic field can be detected. The second is the method of magnetic leakage fields that is mostly used to show surface changes of magnetic field of a ferromagnetic part by spreading ferromagnetic fluorescent powder over the surface of the part. In this case cracks being oriented perpendicularly to the field in ferromagnetic material can be detected.
At the Faculty of Mechanical Engineering in Ljubljana a special arrangement of coils has been developed where both principles are combined. So it is possible to detect surface cracks in a ferromagnetic bar that can be oriented along or perpendicular to the axis of the bar.

2. Eddy currents

2.1 Primary and secondary coil

The basis of the eddy current method is often explained by a simple example of detecting surface cracks in a metal bar.

A long metal bar of circular cross-section is supposed to be put in a homogenous magnetic field oriented along the bar. Because of the demagnetizing effect of eddy currents flowing in circular direction in the cross-section (skin effect) the magnetic field in the cross-section is not uniform. It is much stronger close to the surface than in the middle and there are also phase differences in the induced field among different parts of the cross-section. This effect depends on frequency and on physical properties of the material.
In a secondary coil wound around the bar the induced voltage is directly proportional to the magnetic flux in the cross-section of the bar. There is a phase difference between the primary magnetization and the voltage induced in the secondary coil which depends on frequency and on physical properties of the bar.

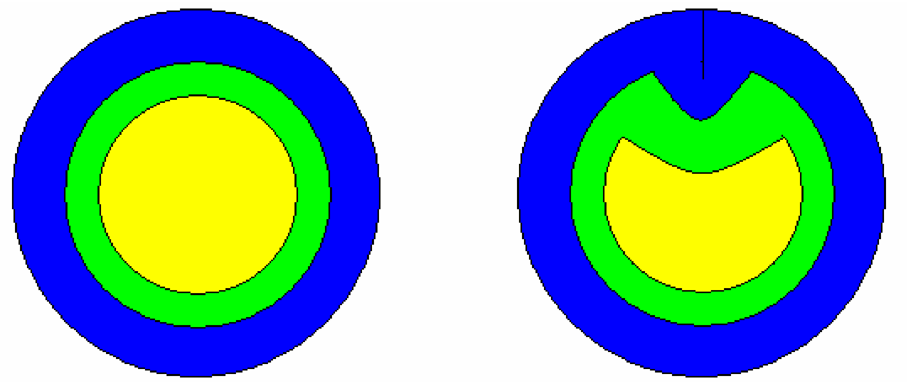

Fig. 1: Cross-section of a metal bar with a radial crack and without a crack.

The situation in the secondary coil changes if there is a surface radial crack being oriented along the length of the bar. The demagnetizing influence of eddy currents in the cross-section is diminished because eddy currents cannot flow across the crack. The net magnetic flux in the cross-section is increased in the vicinity of the crack and so is the induced voltage increased in the secondary coil. The difference between two induced voltages is the indicator of the crack in a metal bar. Fig. 1.schematically shows the magnetic field in the cross-section of a metal bar with a radial crack and without a crack. The dimensions of two outer regions of the cross-section are increased and indicate the increase of the field caused by the crack. The darker regions belong to smaller phase difference and to stronger magnetic field.
There are several explanations given in the literature how to distinguish among voltage differences caused by different position and forms of cracks [1].
According to these explanations it would not be possible to detect difference in the induced voltage if the surface crack is not hindering the flow of eddy currents. It would not be possible to detect very thin surface cracks in the direction perpendicular to the axis of the bar. In the case mentioned above the eddy currents namely would not be forced to change their direction at all.

2.2 Differential arrangement of secondary coils

Changes of voltage induced in a secondary coil (according to Fig. 2) are normally very small and the so called differential arrangement of two secondary coils is used very often.
Two differential coils are wound around the bar and their contacts are connected so that the induced voltages are subtracted. If there is no difference in the induced voltages the bar is supposed to be without a defect. A sudden start of a defect or a sudden end of a defect would cause a signal from the pair of coils. This arrangement is a very sensitive means for detecting longitudinal surface cracks in a metal bar.
This very promising method has some drawbacks. If the crack is uniform along all the length of the bar the magnetic flux would increase uniformly and the differential arrangement of coils could not detect it since the induced voltage in both secondary coils would be the same.

Even if the crack has a good defined start and good defined end it is also not possible to tell its position on the circumference of the bar.

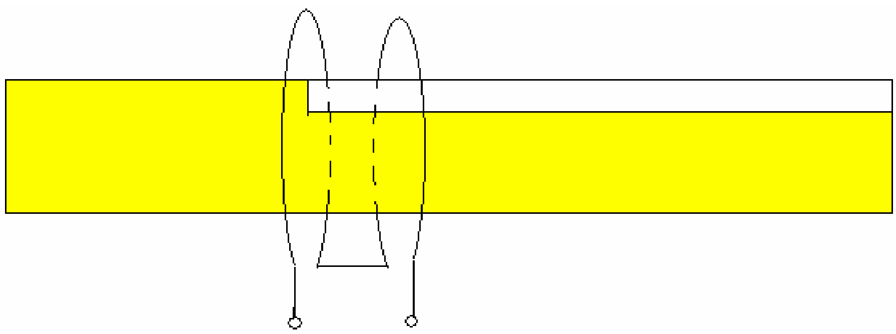

Fig. 2: Two differentially connected loops of pair of secondary coils.

2.3 Radial magnetic flux

There are however some other effects observed in the case of a metal bar with a uniform crack which starts at a certain point and which ends at a certain point. A differential arrangement of secondary coils can detect both points. According to the electromagnetic theory the increase in the magnetic flux in the cross-section that is caused by smaller demagnetizing effect of eddy currents, can be seen also in a different way. If the magnetic flux is increased due to a sudden surface crack the magnetic flow lines must enter the bar somewhere from outside. The theory and the practice showed that there is a strong radial magnetic flux flowing from outside of the bar into the bar localized just at the beginning of the crack. This fact was theoretically and practically verified 23 years ago [3]. The measured radial flux would be namely equal to the signal from the pair of secondary coils being connected differentially. The measurement of radial magnetic flux as indicated in Fig. 3 is giving an additional information. Not only the position of the start and the end of the crack but also the circumferential position of a crack could be detected. I do not know if this idea has been used in any practical NDT instrumentation up to now.

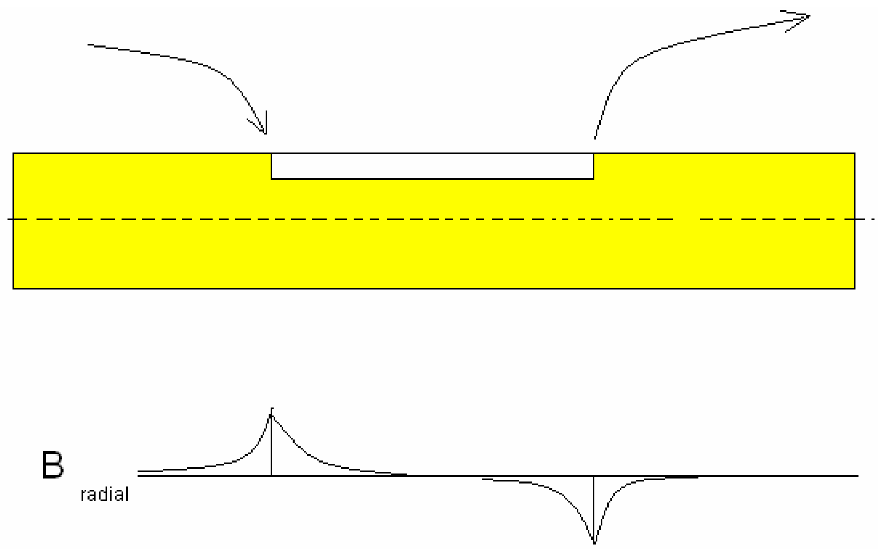

Fig. 3: Radial flux entering the bar at the beginning and leaving it at the end of the crack.

3. Magnetic leakage flux

As mentioned above there is another effect of the flow of magnetic flux used in non destructive testing although it is more often mentioned with the d.c. magnetic fields. It is so called magnetic leakage flux used for indicating surface cracks in magnetized ferromagnetic parts.
The explanation of the principle is very often given for two dimensional case of detecting surface crack when the homogenous or not homogenous filed is crossing a surface crack in a ferromagnetic plate (Fig. 4).

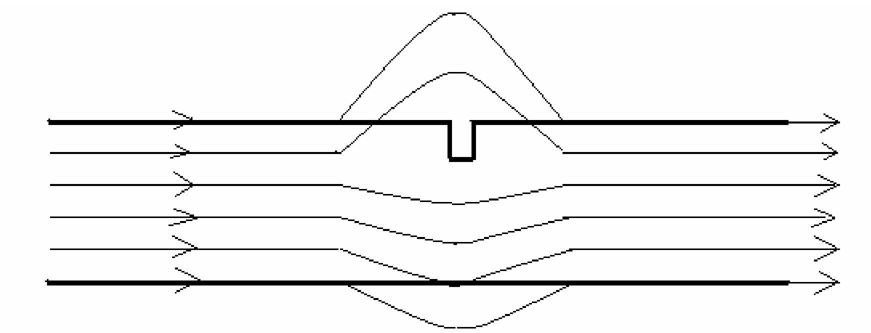

Fig. 4: Magnetic leakage field in two dimensions.

Suppose the homogenous magnetic field flows from the left to the right. Near the crack the flux is divided to two parts. One part tries to avoid the crack by flowing under the bottom of it and another part flows out of the material up into the air and then it again enters the plate on the right side of the crack. This effect is observed in ferromagnetic materials and if the surface of the plate is covered by ferromagnetic powder it is possible to view the emerging field around the defect outside by naked eye. If some fluorescent color is added, the method of detecting surface defects can be very effective.
There were some attempts made to measure the emerging field and to connect it with the depth of the crack [4].

4. Two parts of a primary coil and one radial secondary coil

In the Faculty for Mechanical Engineering in Ljubljana a special arrangement of coils for the NDT control of ferromagnetic bars of circular cross-section was developed where both methods were joined together.

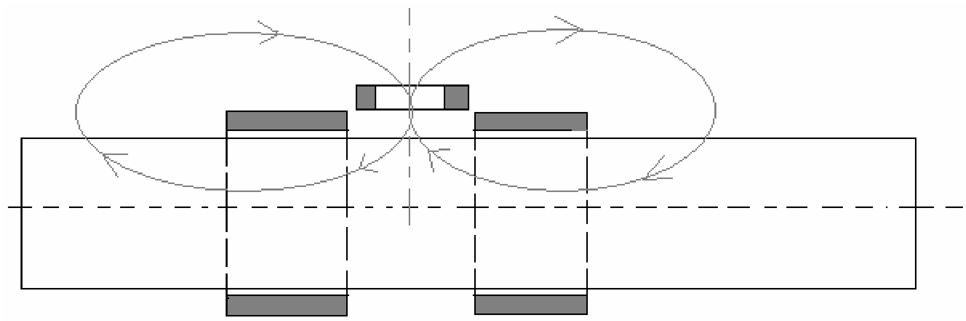

Fig. 5: Two parts of a magnetizing coil with one secondary coil in the middle.

The magnetizing primary coil is made of two equal parts being separated by so called critical distance. In the place between them there is one secondary coil oriented so that the induced

voltage is caused only by the radial magnetic flux flowing through it. In this way both types of surface cracks can be detected.
In the secondary coil the magnetic fluxes emerging from the two parts of the primary coil are subtracted and if the bar is homogenous there is no net radial magnetic flux and no induced voltage in the secondary coil. If however there is some crack in one part of primary coils present, the both parts of magnetic flux flowing through the secondary coil are not equal any more, and a net voltage indicates the presence of the defect.
The phase of the signal gives the information about the direction of the net magnetic flux through the secondary coil and the amplitude is somehow proportional to its magnitude. The dimension of the critical distance must be properly chosen to assure the most sensitive registration of the defect. There can be several secondary coils placed around the circumference of the bar and also the position of the crack could be defined correspondingly.

4.1 Advantages of the arrangement

There are two very important facts observed with practical work:

- It is possible to detect a thin surface crack in a ferromagnetic material in longitudinal or in perpendicular direction.
- It is possible to detect cracks lying in the opposite side of the detecting secondary coil.

Using the arrangement of coils, shown in Fig. 5, the two effects are combined. However it is very important to define the critical distance properly. If the difference between the two parts of the primary coil is too small, the stray magnetic flux is also small and so are all the changes in the radial magnetic flux. If it is too large there is no direct impact on magnetic radial fluxes in the secondary coil.
The critical distance must be chosen so that the information in the longitudinal magnetic field in the bar can be transferred optimally to the radial sensing coil.
The optimal dimension of the region can be evaluated taking into account practical limitations of coil construction and the electric parameters being used [5].

5. Conclusions

Using the arrangement of two equal parts of a primary coil and one secondary coil for detecting radial net flux it is possible to construct a device for detecting all kinds of surface cracks in ferromagnetic material. It is possible to detect defects also from the opposite side of the secondary crack and to define the precise position of defect along the circumference if there are more secondary coils placed around the bar .
The idea of using method of two part primary coil and a secondary coil in the middle is very promising especially for the development of NDT devices for controlling ferromagnetic tubes.

6. References

[1] Brudar B.: How to Distinguish Surface and Subsurface Cracks Using Electromagnetic NDT Methods, NDT International, Vol. 17, August 1984, p 221-223.
[2] Brudar B.: The electromagnetic Field in the Neighborhood of a Defect in a Material, Research Techniques in NDT, Vol. V, Academic Press, London, 1982, 169-238.
[3] Brudar B.: Proceedings of 10th WCNDT, Paper I-C6, Moscow, 1982.
[4] Brudar B.: Magnetic Leakage Fields Calculated by the Method of Finite Differences, NDT International, Vol. 18, No.6, December 1985, p 353-357.
[5] Brudar B.: Magnetic Field Around Two Separated Magnetizing Coils. The 8th International Conference of the Slovenian Society for Non-Destructive Testing, September 1-3, 2005, Portorož, Slovenia.