USE OF EDDY CURRENT TESTING FOR CRACK CHARACTERIZATION IN STRUCTURES

Silvério Ferreira da Silva Júnior
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
silvasf@cdtn.br

Donizete Anderson de Alencar
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
daa@cdtn.br

José Marcos Messias
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
jmm@cdtn.br

Geraldo Antônio Scoralick Martins
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
gasm@cdtn.br

Paulo Villani Marques
Universidade Federal de Minas Gerais - UFMG
pvillani@ufmg.br

Abstract. *Eddy Current Testing is a nondestructive test method used for detecting surface discontinuities and for materials characterization. It consists in to induce electrical currents into the tested material and monitoring their behavior. Eddy currents are affected by materials characteristics such as geometry, microstructure and electrical and magnetic properties. These aspects allow the use of Eddy Current Testing as a nondestructive tool for materials evaluation. This paper presents a study about the use of eddy currents for cracks detecting and sizing, involving probes development and the experimental methodology used. The results obtained during experimental measurements showed a good correlation between crack depth and measurements using eddy current testing.*

Keywords*. Eddy current, nondestructive testing*

1. Introduction

Cracks can occur in structural components during manufacturing stages as well as during its operational life, due to the inservice conditions. During structural integrity evaluation programs, as well as life extension programs (Cruz, 2002), structural components should be evaluated using different nondestructive techniques, in order to determine the presence of hazardous discontinuities, such as cracks, that can promote the equipment failure. From information about the crack length and depth and the stress state present at the crack region it is possible to evaluate the structural integrity of the component, using a numeric modeling method.

Cracks can be detected and sizing by nondestructive testing methods, like ultrasound or eddy current. However, there are situations where the part geometry or the crack profile could make impracticable or very expensive the ultrasonic inspection. In these cases eddy current testing is the best option to be used for crack characterization.

Probes used in eddy current testing of materials must be designed based on the characteristics of the materials to be examined and the nature of the discontinuities to be detected and characterized (Stegmann, 1987). In this context, the availability of the technology of probes design and manufacturing presents great advantage, mainly due to their high acquisition cost. The experiments and results presented were carried out using a probe designed and manufactured at CDTN facilities.

2. Principles of eddy current testing

Eddy current testing of materials consists in to induce electrical currents in a electrical conductive material and to monitor their behavior (ASNT, 1986). A coil called test coil, with specific characteristics, is placed at the materials surface. An electrical current flowing through the coil at the test frequency produces an alternate magnetic field, that promotes eddy current generation in the superficial layers of the tested material. The eddy currents, in turn, produce an ac-magnetic field opposite to the coil magnetic field. The interaction of these two magnetic fields results in a specific value of the complex impedance Z of the test coil, that can be measured. This value depends on the material conductivity σ and the material magnetic permeability μ at the regions close to the coil, because they affect the behavior of the eddy currents in the material and, consequently, affect the magnetic field created by these eddy currents. The presence of structural discontinuities such as cracks, voids and inclusions changes the local value of the material conductivity and permeability and hence, the value of the test coil complex impedance Z. This feature allows to investigate materials characteristics such as structural discontinuities, chemical composition, mechanical processing, presence of residual stresses and depth of heat treatments using eddy current testing (Kröning, 1997). The application of the eddy current test is comparative and depends on the use of calibration and reference standards.

3. Experimental methodology

3.1. Materials

A plate of ASTM A 36 steel, Fig. (1a), the same material of the calibration standard, was used in the experimental measurements. A slot with irregular geometry, it means different depths along its length, was machined in this plate, using an electrical discharge machine, in order to simulate a crack. A posterior scanning in the plate surface was carried out, in order to detect the crack and to determine its length and depth.

A second test specimen Fig. (1b), an AISI 1045 sample extracted from a round bar of this material was also used in this study. The purpose was to verify the test system capability to detect and sizing natural cracks, that present a non-regular geometry when compared to the machined slots. This sample was submitted to a quenching in water, in order to generate cracks in its surface.

(a) (b)

Figure 1. Test samples of ASTM A 36 steel plate (a) and AISI 1045 steel round bar (b).

3.2. Instrumentation

The experiments were performed using an ECT MAD8D (ECT, 2000) eddy current testing equipment with two frequency channels and data acquisition and analysis software. Signals from the slots in the calibration standard, as well as from the tested samples were acquired using a differential surface eddy current probe, designed and manufactured at CDTN nondestructive testing laboratory facilities as shown in Fig. (2).

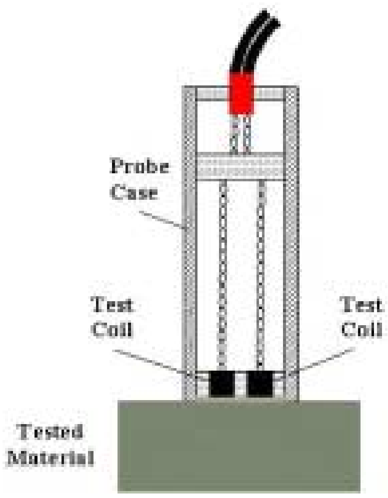


Figure 2. Eddy current surface probe for crack detection and sizing.

3.3. Calibration standard

A common reference standard, generally used to the test system calibration, consists of a plate containing slots with different depths (ASNT, 1986). For this study, a plate of ASTM A 36 steel containing three slots with depths of 0.2

mm, 0.5 mm and 1 mm was used as a calibration standard, as shown in Fig. (3). The slots in the reference standard were machined using an electrical discharge machine.

3.4. Test System Calibration

During the calibration step, a scanning of the calibration standard surface was performed. The peak to peak amplitudes of the signals referent to the three slots present in the calibration standard were registered Fig. (4). These amplitude data were plotted as function of the slots depth and a calibration curve Fig. (5) was obtained. No phase changes were observed in the signals acquired.

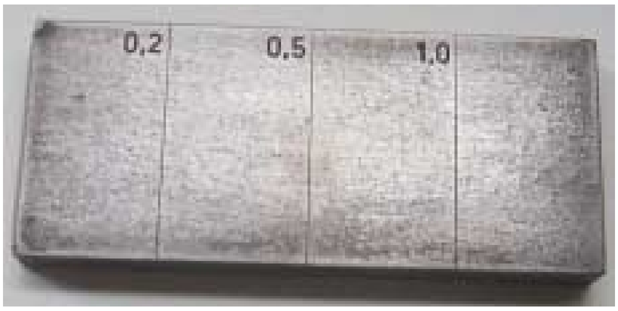
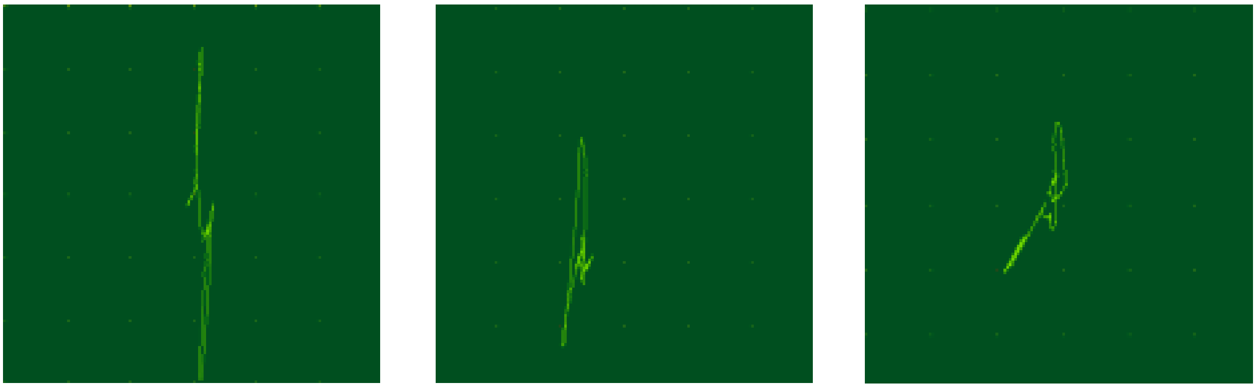


Figure 3. Standard for testing system calibration.



(a) (b) (c)

Figure 4. Signals referent to the slots of 1 mm depth (a), 0.4 mm depth (b) and 0.2 mm depth (c).

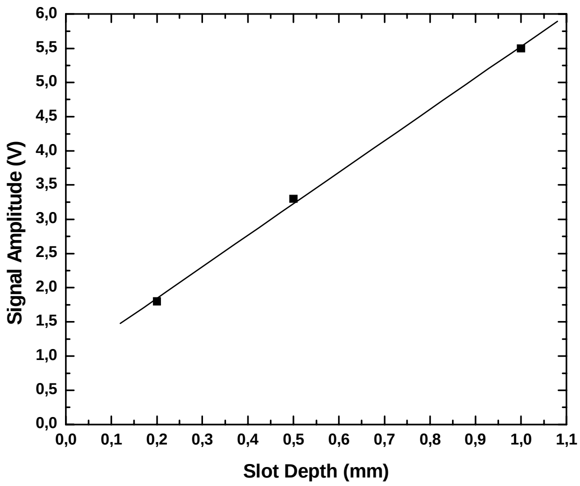


Figure 5. Calibration curve.

3.5. Measurements

A scanning in the ASTM A 36 carbon steel plate surface, using the eddy current probe was carried out, in order to determine the length and depth of the machined crack, as shown in Fig. (6). The measurements indicate the presence of the crack. After this, measurements of the crack depth along its length were performed using an optical microscope. From these measurements, the crack profile was obtained, Fig. (7).

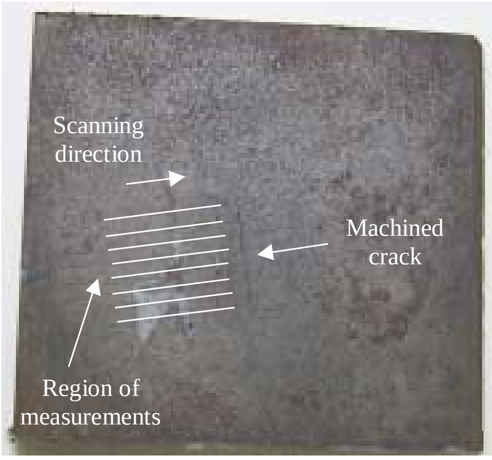
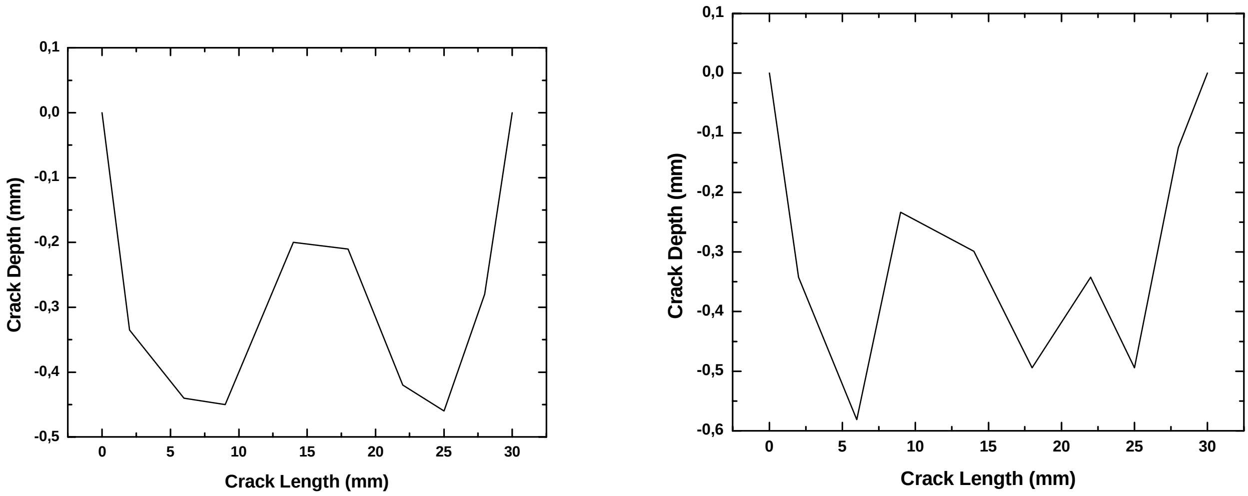


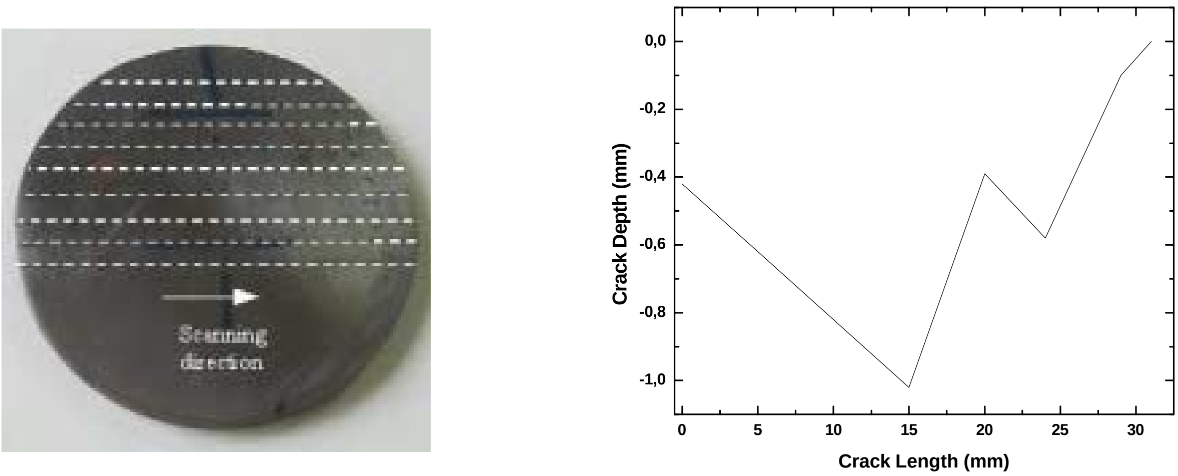
Figure 6. Measurements in the ASTM A 36 steel plate.



(a) (b)

Figure 7. Crack profiles obtained from optical microscope measurements (a) and eddy current measurements (b).

A scanning performed in the AISI 1045 sample surface revealed the presence of the crack, Fig. (8a). From the analysis of the eddy current signals, a profile of the crack depth along its length was obtained, as shown in Fig. (8b).



(a) (b)

Figure 8. Scanning directions (a) and crack profile in AISI 1045 sample (b).

A posterior examination of the crack surface using another nondestructive testing method, Liquid Penetrant Testing, revealed the presence, shape and length of the crack, as shown in Fig. (9).

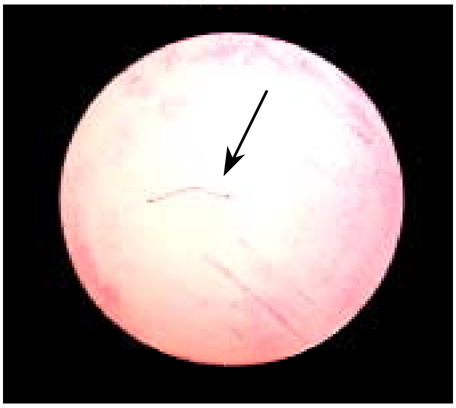


Figure 9. Crack detected by liquid penetrant testing.

4. Discussion of the results

The profile of the irregular slot in the ASTM A 36 carbon steel plate, plotted from eddy current measurements and optical microscope measurements presented differences. It can be due to the test coil diameter, in this case, 4 mm. The measurements performed with the eddy current probe were influenced by the slot profile in the region under the test coil, it means, they represent a medium value of the slot depths under the coil test. The measurements performed using the optical microscope were punctual. To minimize this difference, the use of probes of a smaller size than the used in this study can be effective.

The crack length measured by the liquid penetrant testing Fig. (9) indicated about 19 mm. Crack depth can not be find out by this test method. Eddy current testing indicated a crack length of about 30 mm. The reason for this difference is due to the different characteristics of these two test methods. Liquid penetrant testing allows the detection of discontinuities open to the surface. In this case, only part of the crack was open to the sample surface and could be detected by this test method. Eddy current testing is sensitive to the presence of discontinuities in the regions near to the surface of the material inspected and was capable to detect the presence of the crack under the sample surface.

5. Conclusions

The probe developed to conduct this study was able to detect the presence of cracks in the materials studied. However, it was observed the necessity to use test coils of smaller dimensions, in order to increase the probe resolution to sizing the discontinuities in a more accurate way. Eddy current testing was capable of detect a crack under the material surface, allowing a correct evaluation of the crack length in the sample of AISI 1045 carbon steel. However, a more accurate study can be performed, in order to compare the differences occurring in the depth measurements using calibration standards containing machined slots and natural cracks.

Additionally, the use of absolute probes and send-receiver probes should be investigated, in order to establish the more adequate probe for crack detection and sizing.

6. References

ASNT-American Society for Nondestructive Testing, 1986, "Nondestructive Testing Handbook - Electromagnetic testing", V.4, Columbus, 187p.

CRUZ, J.R.B, et al. – *Gerenciamento de Envelhecimento e Extensão de Vida de Centrais Nucleares"*, In: Anais do IV Seminário Latino-Americano de Energia, Rio de Janeiro, 2002, v.1, pp. 87-94.

ECT Inc. – Eddy Current Technology Incorporated, 2000, "MAD - 8D Operating Manual", Virginia Beach, 90p.

Kröning, M., Häubler, F., Arnold, W., 1997, "Surface Analysis by Nondestrucive Testing Techniques", Fresenius J Anal Chem, Springer-Verlag, pp. 3-9.

Stegmann, D. – "*Curso de Correntes Parasitas"*, São Paulo: ABENDE, 1987.

7. Copyright Notice