NDT.net - The e-Journal of Nondestructive Testing (October 2008)
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Using Eddy Current NDT to Check Integrity of TRIGA MARK I Fuel Rods Cladding

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Abstract
A methodology to perform the integrity assessment of research reactors nuclear fuels cladding, such as those installed in the IPR-R1 (TRIGA) using eddy current nondestructive electromagnetic inspection method is presented. This methodology is constituted by the development of calibration reference standards, specific for this type of fuel; the development of customised test probes; the recommendations for the inspection equipment calibration; the construction of voltage based evaluation curves and the inspection procedures developed for the characterisation of the detected flaws. The operational performances of the developed resources, as well as the special operating characteristics of the test probes, such as underwater operation, were experimentally demonstrated. The practical applicability and the efficacy of the developed methodology were verified experimentally in non radioactive environment.
Keywords: Eddy Current, Nuclear Reactor

1. Introduction

The integrity of cylindrical type nuclear fuel cladding has been evaluated worldwide by means of classical non destructive examination, such as visual inspection [1]. The application of that practice is important but is restricted to the external and visible surfaces of the fuel elements. Some examples of the possible occurrences are corrosion pits, external cracks and external holes. Due to the technical limitations of that method, many other flaws can not be investigated, such as small external holes or sub-surface volumetric flaws. Additionally, in many other cases, the detection of a flaw is feasible, but its characterisation can not be easily done. Eddy current is an important nondestructive test, widely applied to perform integrity assessment of equipment and components [2]. Classically, the method has been used to examine metal sheet properties in aeronautics equipment, and tubes, mainly those installed in heat exchangers. The resources necessary for its application are: a suitable testing equipment, adequate testing probes, calibration reference standards and a valid analysis methodology. The development of a methodology useful to evaluate the integrity of fuel cladding in nuclear research reactors, including sub-surface flaws, using eddy current nondestructive test was proposed in November 2001 [3] and was conducted at CDTN, in 2003, by the IAEA support. Some goals achieved in that research were the design and development of inspection probes and calibration standards to be applied in the examination of cylindrical fuels, such as TRIGA – IPR-R1 reactor, installed at CDTN – Brazil. Additionally, performance demonstrations of the test applicability, in non radioactive environmental conditions, were also conducted. For IPR-R1 reactor, the fuel cladding is a 0.76 mm in thickness aluminium 1100F alloy. This paper shows the main aspects and results of the research.

2. Development of Calibration Standards and Probes

The proposed development required a lot of planning, machining, assembling and testing tasks. The infrastructure and facilities demanded for such jobs were found at CDTN and can be listed as follows:

- A mechanics workshop for precision machining for probes and standards manufacturing;
- A metrology laboratory, equipped with the necessary instrumentation for the dimensional control of probes and calibration standards;
- A nondestructive testing laboratory, equipped with the necessary instrumentation, for the construction of probes and calibration standards such as: electric discharge machine, impedance bridges, signal generators, DC source supplies and a computer assisted eddy current inspection system [4].

Since eddy current is a comparative evaluation NDT method, the development of calibration reference standards is mandatory. IPEN supplied some plates of Al-1050 alloy, whose composition is very close to Al-1100 alloy, in terms of electrical resistivity. To plan the calibration standards and design the test probes, it is necessary to have the following information, directly related to the inspection conditions:

- Electrical conductivity or resistivity of the material under testing (cladding). In this case, it can be found $2.90\ 10^{-8}\ \Omega.m$ [5];
- Thickness and other relevant geometric and dimensional characteristic of the cladding. The nominal thickness for TRIGA MK I cladding is 0.76 mm and its internal diameter (fuel core) is 35.6 mm [6];
- The expected discontinuities that can occur and should be detected by the inspection system. In this case, were considered the occurrence of corrosion pitting, surface and sub-surface cracks and located or generalized losses of thickness.

Based on that scenario, 22 reference calibration standards were planned and effectively machined. The aluminium plates were laminated until achieving the nominal thickness of the fuel cladding (± 0.02 mm). So, they were cut in 50 mm x 50 mm rectangles. By means of electric discharge machining, several artificial discontinuities, such as: through wall holes (TWH); flat bottom holes (FBH); through wall grooves (TWG); flat bottom grooves (FBG) and losses off thickness (LT) were built. All holes are circular 1.0 mm in diameter. All grooves are 0.22 mm in width and 11.6 mm in length. Once performed the dimensional characterization, all reference standards were bent, getting the same shape and curvature of the fuel core, as shown in Fig. 1. Finally, all plates were identified and bonded into a PVC rod (35.6 mm in diameter). The final aspect of the standards set can be seen in Fig. 2. A list for all of them is presented in Table 1.

Table 1. List of the obtained reference calibration standards

Identification	Description	Thickness (mm)	Depth (mm)
1	TL	0.78	-
2	TL	0.58	-
3	TL	0.41	-
4	TL	0.22	-
5	TWH	-	0.78
6	Sub-surface FBH	-	0.64
7	Sub-surface FBH	-	0.49
8	Sub-surface FBH	-	0.33
9	Sub-surface FBH	-	0.17
10	Surface FBH	-	0.61
11	Surface FBH	-	0.49
12	Surface FBH	-	0.33
13	Surface FBH	-	0.16
14	TWG	-	0.78
15	Sub-surface FBG	-	0.61
16	Sub-surface FBG	-	0.50
17	Sub-surface FBG	-	0.35
18	Sub-surface FBG	-	0.17
19	Surface FBG	-	0.62
20	Surface FBG	-	0.46
21	Surface FBG	-	0.33
22	Surface FBG	-	0.17

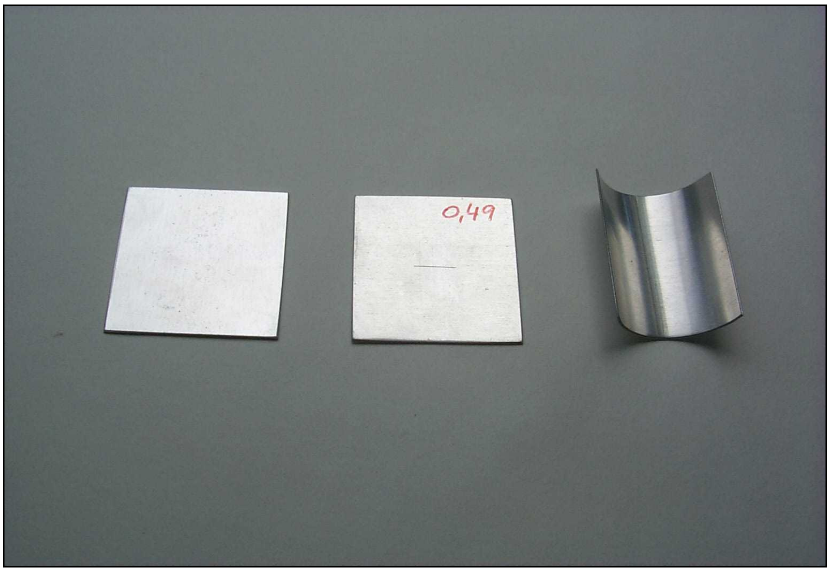

Figure1. Fabrication sequence for a standard.

Figure 2. Final aspect of the obtained standards set.

Two probes were specially developed for IPR-R1 reactor fuel cladding inspection. Once there is no access restriction to proceed the inspection, the probes have similarities to conventional surface-type ones, but they have some special characteristics. They can operate underwater and have the same curvature of the cladding surface in their sensitive contact area. This feature is very helpful to reduce lift-off effects. Fig. 3 shows of a developed test probe.

Figure 3. A developed test probe.

3. Experimental Results

All reference standards were individually scanned using the adequate developed testing probe, connected to a computer assisted eddy current inspection system (ECT, MAD 8D). After optimising the operating parameters (frequency, gain, sensitivity, etc.) particular response signals were recorded for each standard. Fig. 4 and Fig. 5 show typical screenshots taken from the inspection system screen. The signal to noise relationship is high and allows to observe clearly signals of interest. In Fig. 4, the signals recorded for calibration standards numbers 14, 19 and 20 (surface FBG), can be observed at the strip-chart window (left side). The operating frequency was set to 80 kHz. Each depth corresponds to a signal amplitude.

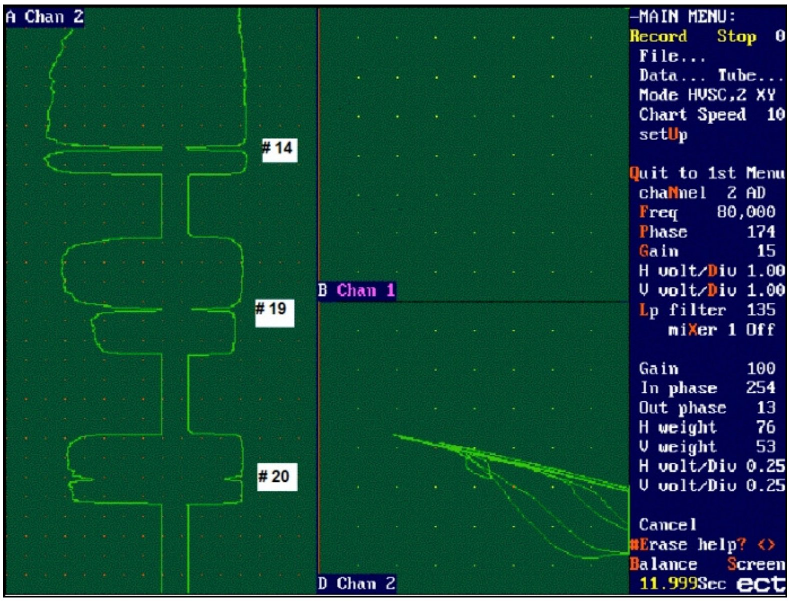

Figure 4. Different amplitude signals obtained for calibration standards numbers 14, 19 and 20.

Fig. 5 shows the signals recorded for calibration standards numbers 14, 15 and 16 (sub-surface FBG). The test frequency was set to 50 kHz, increasing the system sensitivity.

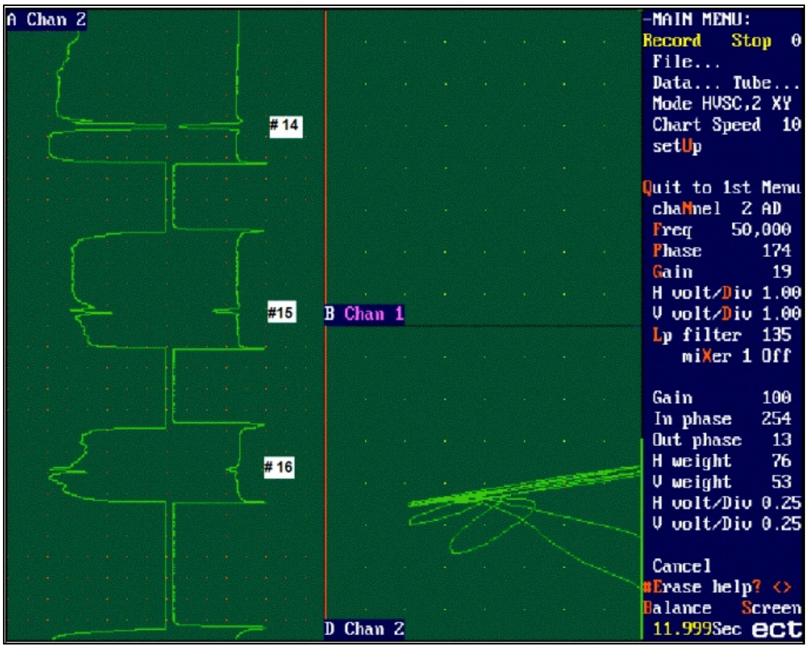

Figure 5. Signals for calibration standards numbers 14, 15 and 16.

In both cases, as a general rule, the deeper the flaw, the higher the signal amplitude. This ratio is not linear and should be fitted for each calibration condition. The evaluation of actual flaws in in-situ tests will depend on this.

The practical applicability of the developed methodology was verified, in non radioactive environment, using a dummy fuel element model similar to an IPR-R1 fuel element containing some artificial flaws. The detected discontinuities were located and directly characterized by simple correlation methods.

4. Conclusions

The expected goals for this research were achieved. Test probes and calibration reference standards were successfully developed. The operating performance of the inspecting system was demonstrated for laboratory conditions. Actual inspections (*in situ*) for research reactors, using the developed method could be performed in future, added to other NDT techniques, improving the reliability of that installations.

References

1. D. A. ALENCAR, S. F. SILVA JÚNIOR, *Acompanhamento do Ensaio de Inspeção Visual nos Combustíveis do Reator IPR-R1*, CDTN, Belo Horizonte, Brazil (2000).

2. ASNT, *Electromagnetic Testing v.4.*, ASNT, Columbus, USA (2004).

3. D. A. Alencar, S. F. Silva Júnior, “Eddy Current Testing: A New Possibility for Integrity Evaluation of Nuclear Fuels”, *Proceedings of IAEA-RLA Workshop on Research Reactor Spent Fuel,* 20-22 Nov. 2001, in CD-ROM, São Paulo, Brazil (2001).

4. EDDY CURRENT TECHNOLOGY INC., *Mad-8D Operating Manual,* ECT, Virginia Beach, USA (1999).

5. EDDY CURRENT TECHNOLOGY INC., *Electrical Resistivity of Materials,* ECT, Virginia Beach, USA (2000).

6. CDTN, *Relatório de Análise de Segurança do Reator TRIGA IPR-R1*, CDTN, Belo Horizonte (2000).