Eddy Current Testing for Detection of Cracks in Austenitic Cladded Pressure Vessel

Arbind Kumar, Manojit Shaw & PP Nanekar

Atomic Fuels Division, Bhabha Atomic Research Centre

Trombay, Mumbai (India) – 400 085

e-mail : arbindk@barc.gov.in

Abstract

Reactor Pressure Vessel (RPV) of Boiling Water Reactor (BWR) Tarapur is made of Low alloy steel with inside clad of Austenitic Stainless Steel weld deposit. RPV faces a hostile environment in the presence of oxygenated water at high temperature and radiation. There is a possibility of degradation of pressure vessel during service. Ultrasonic Testing is used for detection of crack inside the vessel. Detection of surface defect on inner surface is difficult by Ultrasonic Testing due to dead zone. Visual Testing is applied for detection of cracks on inner surface of the vessel. Due to presence of undulations on inner surface and limited lighting condition, visual examinations may not be effectively utilized for detection of surface crack. To overcome these limitations, an eddy current testing technique was standardized and utilized for detection of surface crack on inner surface of Reactor Pressure Vessel Clad at BWR, Tarapur.

1.0 Introduction

In India there are two boiling water reactors (BWRs) at Tarapur, which are in operation since early 1970s. The reactor pressure vessel (RPV) in these BWRs is made of low alloy steel and is cladded on inside surface by a 6-8 mm thick austenitic stainless steel to prevent the RPV base metal from uniform corrosion. The RPV operates under hostile conditions of temperature, pressure, neutron irradiation and corrosive environment in the form of oxygenated water. These conditions may lead to initiation of stress corrosion cracking on RPV inside surface. Another phenomenon of cracking, which is possible in the stainless steel clad on low alloy steel material, is the under clad cracking. These cracks originate at the base metal-clad interface and propagate deep in to the base metal and the clad. The ASME Boiler & Pressure Vessel Code required periodic in-service inspection of RPV weld joints to assure its structural integrity. The in-service inspection is carried out by visual examination and ultrasonic testing. Visual examination of the inside surface is carried out by the radiation resistant underwater camera to detect the presence of any crack-like indications in the weld or heat affected zone (HAZ). Ultrasonic examination is carried out to detect the presence of any manufacturing flaw or service induced flaw in the weld and HAZ. One major limitation of conventional ultrasonic test is the in-ability o detect flaw on the scanning surface or very close to it to 'dead zone'. This limitation can be overcome by carrying out examination using angle beam up to 1 V path (full skip). In the case of thick and cladded RPV, this option may not be feasible due to larger beam bath and the scattered noise signals from the austenitic clad. Both these factors lead to poor sensitivity for detection of crack-like defects on the ID surface or at the interface between the clad and base metal using ultrasonic test while doing inspection from the inside surface. Use of special underclad crack detection probes overcomes this limitation to some extent by detecting the cracks, which start at base metal-clad interface but they cannot reveal whether the crack has reached the ID surface or not.

Visual testing from inside surface can overcome the limitation of conventional ultrasonic test, but it requires good lighting conditions and good quality surface finish. In the case of RPV at Tarapur, the austenitic clad is deposited by welding. This clad is left unmachined due to which the ID surface has many undulations. As a result visual testing for crack detection on inside surface is not a reliable option.

Considering the limitations of visual and ultrasonic testing, an eddy current based technique was developed for detection of surface cracks on the inside cladded surface of RPV. The major challenges were: (i) the surface undulations on the cladded surface, (ii) variation in chemical composition (δ-ferrite) of the clad surface from one point to the other and (iii) detection of tight crack-like defect on the inside surface. A differential probe coil of100 KHz frequency was designed and fabricated for this purpose. A reference defect standard with fine EDM surface notches were made on the rough austenitic clad deposited by welding surface for standardization of testing parameters. The eddy current test parameters were standardized in such a manner that the signal from the clad undulations appear in the horizontal direction while the one from the crack appear in vertical. It was observed that it was possible to detect an EDM notch of 1 mm deep on the cladded RPV surface. It was possible to distinguish, whether an under clad crack, which has originated at the clad-base metal interface has reached the inside surface.

This paper deals with the design of eddy current test coil and standardization of eddy current test parameters for detection of crack-like defects in the austenitic clad pressure vessels. The details of reference defect standard and the analysis of eddy current test signals are described in this paper.

2.0 Eddy Current Testing

Eddy current testing is based on the principle of electromagnetic induction. When a coil carrying alternating current comes near a conducting material, the changing primary magnetic field associated with the alternating current flowing through the coil induces the eddy current in the material. The eddy current flows parallel to the coil winding but opposite in direction to that of primary current. The secondary magnetic field associated with the eddy current opposes the primary magnetic field and the impedance of the coil differs to that of the empty coil impedance. This change in impedance is visualized on the CRT screen in terms of voltage. Material conditions govern the flow path of eddy current and change the amplitude as well as the phase of the signal. There are many variables that affect the eddy current flow path but generally the signal responses from the different variables are different.

Eddy current density decreases exponentially from the surface to the inside of the tube. This limits the material thickness which can be tested by eddy current testing. Standard depth of penetration, the distance from the surface at which eddy current density is 37% of surface current density, depends on the test frequency as well as test object variables such as electrical conductivity and permeability. As the tube properties such as electrical conductivity and permeability are fixed,only variables left are frequency that can be varied to meet the desired depth of penetration as well as sensitivity. Depth of penetration decreases and sensitivity increases as the frequency increases.

3.0 Test Parameters Selection

Selection of the test parameters is extremely important in eddy current testing. Three parameters such as frequency, phase and gain are to be selected for testing of the test object by eddy current testing.

Frequency decides the depth of penetration of eddy current in the test object, the sensing volume of the material as well as the sensitivity of the flaw detection. Frequency 100 KHz is selected for the testing based on standard depth of penetration and optimum sensitivity. During frequency selection, it was also considered that the signal due to undulations in austenitic stainless steel clad is to be minimized. Phase was selected to set the probe-wobbling signal as well as undulation signals in horizontal direction so that the signal of interest could be visualized in vertical direction. Gain was selected to get the appreciable signal from the reference flaws.

4.0 Test Coil Design

The detection of flaws depends upon the test coil characteristics. Test coil carries alternating current and induces eddy current in test object with the help of changing magnetic field across it. Self-comparison type differential surface coil was designed, fabricated and used during testing. Differential coil compares nearby zone and hence it is the most suitable coil for detection of localized flaws.Transmitter Absolute Coil was used for generation and differential receiver coil was used for detection of eddy current signal. This probe was designed and fabricated for 100 kHz central frequency as shown in Fig 1. Number of turns and diameter of the copper wires, coil depth and coil length were selected to match the impedance of the equipment and coil Q-factor (ratio of inductive reactance to resistance) of 10.

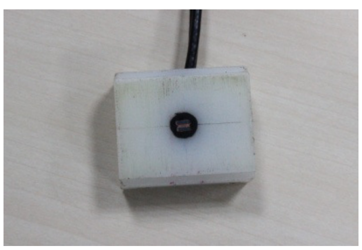
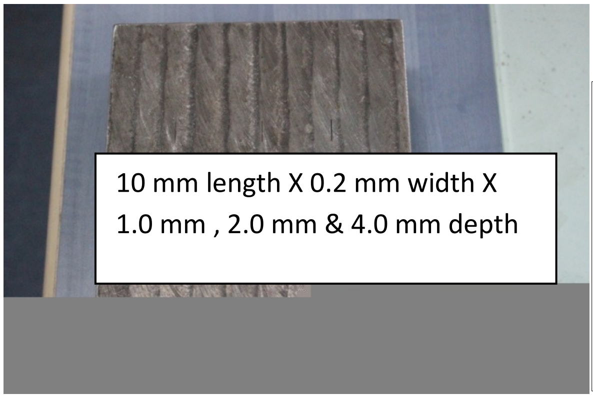


Fig 1 : Eddy Current Test Probe

5.0 Calibration of Eddy Current Test Equipment

The reference surface cracks of depth 1.0 mm, 2.0 mm and 4.0 mm were fabricated on the welded clad surface on low alloy steel plate as shown in fig 2. The width and length of the reference cracks are 0.2 mm and 10.0 mm. The frequency of 100 KHz was set in the equipment and the calibration standard was scanned using transmitter-receiver differential surface probe. The phase and gain was set to attain the optimum signal from the reference flaws without the interference of the unwanted signals. The signals from the reference flaws were recorded as shown in Fig 3.



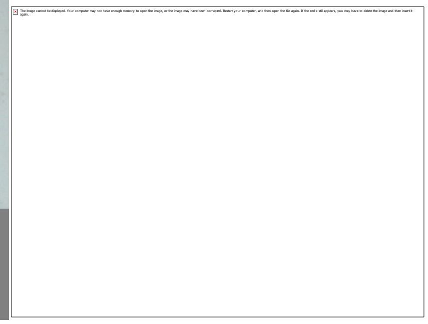


Fig 2 : Reference Plate containing axial and circ. Flaws Fig 3 : ECT Signal from Reference Flaws

6.0 Testing of RPV Inner Clad Surface

The inner surface of RPV clad was scanned in a raster fashion across the longitudinal weld using drive mechanism and the calibrated eddy current test equipment. The eddy current test signals recorded during the scan is shown below. The crack type defect signals were not observed during this inspection as shown in fig 4.

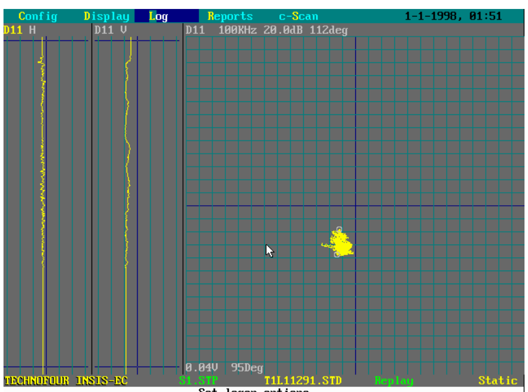


Fig 4 : ECT Signal from RPV Weld Clad

7.0 Analysis of Test Results

The eddy current test signals were analysed on the basis of phase and amplitude of eddy current test signals. Phase of the signal is used for flaw depth measurement and the signal amplitude is used for measurement of volume of the defect.

8.0 Conclusion

The defects in the low alloy steel plate are detected by ultrasonic testing but detection of surface flaws in the weld clad is difficult by UT. The surface opening flaws in the weld clad can be detected by eddy current testing by proper design of test probe, selection of test parameters and signal analysis. Eddy Current testing is utilised for detection of surface defect in RPV weld clad at TAPS 1&2 and no surface crack was observed during in-service inspection.