Development and Application of Eddy Current Testing for Quality Assurance of Nuclear Components

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Abstract

Eddy Current Testing (ECT) is based on electromagnetic induction. It is used for detection of surface and sub-surface flaws, in electrically conducting material. Eddy Current test results are affected by lift-off, test material properties viz. electrical conductivity and magnetic permeability and test parameter such as frequency. Some of the difficulties faced during eddy current testing are: the control of lift-off, selection of the proper frequency and test technique, design of a suitable test probe, reproduction of the calibration standard and standardization of the test methods. To overcome these limitations, various developments were carried out and these developments were applied for quality assurance of nuclear fuels and in-service inspection of nuclear reactor core components as well as heat exchanger tubes of heavy water plants. The design and fabrication of eddy current test coils and development of indigenous eddy current test system for fuel inspection, in-service inspection of PHWR coolant channels and heavy water plants, is described in this paper.

Development of Indigenous Eddy Current Test System for Testing of PRP Fuel Element

Dispersion fuel is used for PRP. The intermetallic fuel is vibro-compacted inside a Zr-1%Nb fuel tube, having diameter 5.8 mm and length 1000 mm and Al-Si alloy is infiltrated through the fuel tube. The continuity of the fuel, inside the fuel tube, needs to be confirmed using eddy current testing. The selection of test frequency was a challenging task, as the materials of the fuel tube and fuel are different. The test frequency was standardized and the ECT probe was designed and fabricated. An indigenous automated ECT system was developed, for checking the continuity of Dispersion Fuel in PRP Fuel Element as shown in Fig. 1. There are three channels in this equipment for detection of surface flaws, subsurface flaws and variation in electrical conductivity. The feeding of fuel element, testing, recording of test results and sorting of accepted and rejected fuel elements are carried out automatically.

Fig. 1: Automated Eddy Current Test System for Testing of PRP Fuel
Development of Indigenous Automated Inspection System for Metallic Fuel for Fast Breeder Reactor

Uranium oxide fuel is to be used in PFBR at Kalpakkam. This fuel has low breeding ratio, low thermal conductivity and linear heat rating, and low burn-up. The metallic fuel (U-Pu-Zr) can overcome these limitations of oxide fuel. Hence, it was proposed to develop the metallic fuel for PFBR. The metallic fuel (diameter -5 mm & length – 300 mm) is fabricated through melting and casting route. Being a cast product, the fuel rod may have physical discontinuities. The integrity of the fuel rod needs to be checked, using a non-destructive test method. An automated fuel inspection system, for checking the integrity of metallic fuel for fast breeder reactor was designed and fabricated as shown in Fig. 2. This system has facilities for weight measurement, length and diameter measurement using LVDT probe and flaw detection using eddy current testing. This system is installed under glove box and testing will be carried out remotely.

In-service Inspection of Coolant Channels of Pressurized Heavy Water Reactors (PHWRs)

The coolant channel of PHWR consists of a pressure Tube (Zr-2.5%Nb), a concentric calandria tube (Zircalo-2) and four tight-fit garter springs (Zr-2.5%Nb-0.5% Cu) rested on pressure tube, in the annular space between pressure tube and calandria tube. Heavy water coolant flows through the pressure tube, to remove the heat generated around the fuel bundles. The coolant channel components degrade during service, due to the hostile environment such as high temperature and high pressure of the coolant, fuel load, vibration and irradiation effects. Hence, periodic in-service inspection (ISI) is required, to monitor the integrity of these components. ECT is used to detect the location of garter springs and the gap between calandria tube and pressure tube. ECT coils for garter spring detection and CT-PT Gap measurement in coolant channels of PHWRs during pre-service as well as in-service inspection, were designed and fabricated as shown in Fig. 3. A few hundreds of coolant channels of PHWRs were inspected during pre-service and in-service inspection.

In-service inspection for Heat Exchanger Tubes of Heavy Water Plants

Heat Exchanger Tubes (AISI 316L) of heavy water plants degrade due to localized corrosion such as crevice corrosion, pitting corrosion and stress corrosion cracking at tube to tube sheet joints, support plate location, U-bend and tube internal surface during service. The integrity of these tubes needs to be monitored using non-destructive examination, to avoid the unplanned shutdown of the plants. Eddy current test coil was designed and fabricated.
and eddy current test procedure for testing of these tubes was standardised, using multi-frequency eddy current test methods. About 300 km of heat exchanger tubes of heavy water plants at Kota and Manuguru were inspected, during annual turn around.

**Design of Eddy Current Test Coil and Development of Eddy Current Techniques for Quality Control of Dhruva Fuel**

Eddy current test coils were designed and fabricated and an eddy current test technique was standardized, for quality control of Dhruva Fuel. Annually 1500 Natural Uranium Metallic Rods and Aluminum Finned Clad Tubes are tested, for surface and sub-surface flaw detection using these eddy current test coils and standardized test procedures.

**Design and Fabrication of Eddy Current Test Coil and Development of Eddy Current Techniques for Testing of Various other Nuclear Components**

Eddy Current test coils were designed and fabricated and ECT procedures were standardized for the many important applications as mention below.

- Electrical Conductivity Measurement of Rubber Strip containing Metallic Particle
- In-Service Inspection of Condenser Tubes at TAPS 1 & 2, Tarapur
- Detection of Discontinuity of Silumin in Fuel Rod Simulator
- Pre-Service Inspection of Condenser Tube of VVER, Kudankulam
- Detection of Discontinuity in Welded Austenitic Stainless Steel Pipes for Cable In Conduit Conductor for Superconductor wire
- In-Manufacturing Inspection of Titanium Tubes for LWRD Project

**Conclusions**

Eddy Current Testing is used for surface and sub-surface flaw detection in conductive metals. ECT results are affected by test coil variables as well as test material variables. Design of the ECT probe, selection of test parameters, standardization of ECT technique and signal analysis were carried out for non-conventional applications, such as testing of PRP B-core fuel element, uranium rod for Dhruva reactor and metallic fuel for PFBR, in-service inspection of PHWR coolant channels and heat exchanger tube testing of heavy water plants. ECT coils were designed, fabricated, utilized and ECT procedures were standardized, for various other applications too.