Duel Frequency Saturation Eddy Current Examination of Ferromagnetic Tubes

■ EXECUTIVE SUMMARY

For quality assurance of modified 9Cr-1Mo ferromagnetic steam generator (SG) tubes during manufacturing, eddy current and ultrasonic non-destructive evaluation (NDE) methods are employed. Eddy current examination of these tubes is difficult due to variations in magnetic permeability and hence, D.C. Saturation method is followed. During manufacturing of these tubes, extended wall thickness variations within acceptable limits of ultrasonic testing have produced disturbing signals during eddy current examination. In order to detect defects in these regions, a two-frequency approach has been developed based on the wall thickness measurements made by ultrasonic testing. The approach has shown identical detection performance in wall thickness variation regions as well as other regions for detection of standard reference 1.2 mm diameter hole. After establishing suitable thresholds for implementing the accept/reject criteria, this approach has been successfully implemented in production-line to test 600 SG tubes of PFBR. Apart from enhanced quality assurance of SG tubes, significant cost saving has been resulted in.

■ OUTLINE

Stringent quality control of modified 9Cr-1Mo steel tubes of SGs is ensured using eddy current (EC) and ultrasonic testing (UT) techniques during manufacture of tubes at Nuclear Fuel Complex (NFC), Hyderabad (Figure 1). Immersion ultrasonic testing is performed for detection of longitudinal and transverse defects and for measurement of wall thickness. Two 190 focussed angle beam transducers (5 MHz) and two 190 angle beam ultrasonic transducers are used in bidirectional scanning mode for detection of longitudinal and transverse defects, respectively. For eddy current testing, localized variations in magnetic permeability of the tube have predominant influence on the impedance of EC coil and do not allow full wall examination due to skin-effect. The permeability variations drastically reduce signal-to-noise ratio (SNR). To overcome this, DC saturation based EC testing procedure has been developed after systematic optimisation of saturation current, EC signal parameters, pulling speed, tube centering, and demagnetization enabling reliable detection of calibration defects. This optimised procedure is being routinely used at NFC for examination of SG tubes.

During ultrasonic examination of one lot of SG tubes, gross wall thickness variations extending 100 mm and in the depth range of 0.05 to 0.1 mm have been detected on the inner side surface thickness. These variations, attributed to improper pilgering of tubes, are within the acceptable limits. However, they produce large amplitude signals during saturation EC testing as typically shown in Figure 2. In order to detect defects, if any, present in those regions of the tubes, first of its kind, two-frequency EC technique has been developed. This approach involves

- Identification of defect-free tubes with known wall thickness variations based on ultrasonic data
- Introducing standard localised defects in wall thickness variation regions
- Optimisation of two-frequency mixing procedure for suppression of wall thickness variations
- Validation of mixing procedure to detect localised defects in wall variation region
- Determination of appropriate threshold for accept/reject criterion

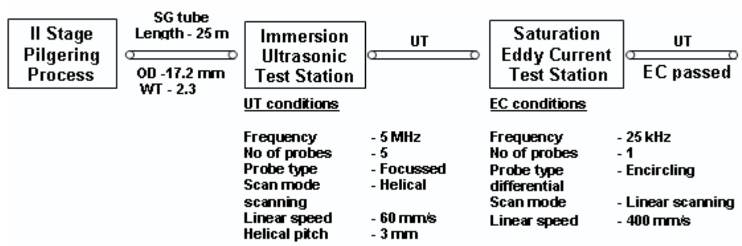

Fig. 1 : Non-destructive examination of steam generator

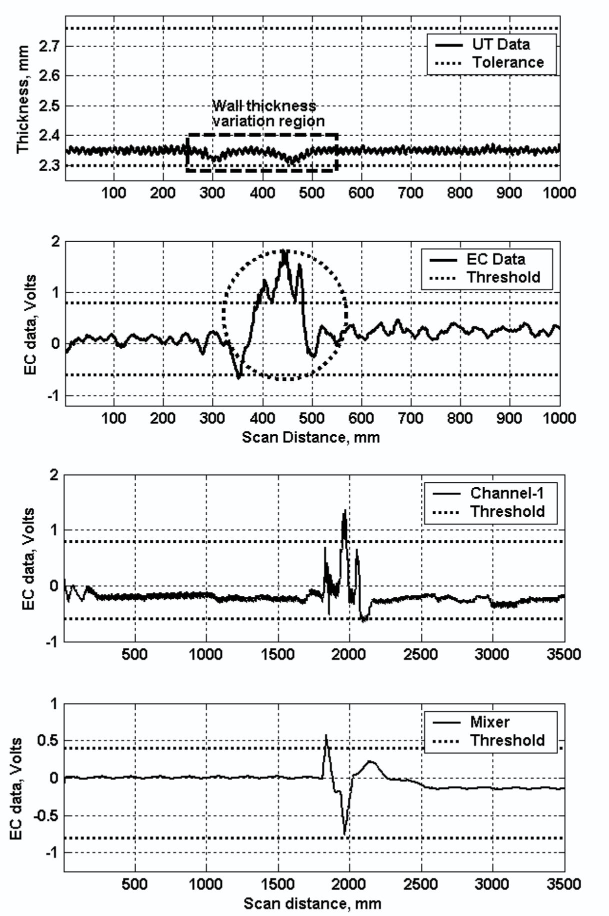

Fig. 2 : Ultrasonic wall thickness data using a 5 MHz normal beam probe and EC response for the thickness variation region (Top). Channel-1 and mixer channel EC data for a 1.2 mm diameter reference hole in wall thickness variation region (bottom)

ADDITIONAL INFORMATION

For validating this approach, the ultrasonic testing results of tubes are innovatively used to introduce reference defects. Six tubes which are ultrasonically defect-free and found to be having variations in wall thickness in the range of 0.012 to 0.130 mm are chosen for optimising the two-frequency mixing procedure. For recording and evaluation purpose, signals from channel-1 and mixer channel are oriented along the Y-axis of the strip chart recorder and the amplitude is measured. Using this procedure all recorded and rejected indications of channel-1 data from wall thickness variation regions are verified in the mixer channel.

GENERAL EXPLANATION RELATED TO THE DESCRIPTION

The channel-1 and mixer channel data for 1.2 mm diameter hole in the wall thickness variation region is shown in Figure 2. Through the use of a separate threshold, it is possible to reliably detect localised defects in the wall thickness variation regions.

The following criterion has been arrived at for acceptance and rejection of a tube based on the K_c value: ($K_c = A_d / A_r$, where A_d is the signal amplitude of a defect indication and A_r is signal amplitude of the 1.2 mm diameter reference hole)

$K_c < 0.5$ for accept

$0.5 > K_c < 1$ for Record and accept

$K_c > 1$ for Reject

BRIEF DESCRIPTION OF THEORETICAL BACKGROUND

As the tubes are ferromagnetic, D.C saturation based EC technique is employed. In this technique, the tube material is magnetised to near saturation region such that the variations due to magnetic permeability are minimized and the disturbing signals that reduce the signal-to-noise ratio (SNR) are not produced. In that situation, encircling differential EC probe embedded in the magnetising solenoid coil can detect localised defects. The observed disturbing signals during EC testing due to extended wall thickness variations are similar to that of the support plate signals from heat exchanger tubes using a bobbin type coil. In case of heat exchanger tubes, two-frequency mixing technique is adopted for eliminating the disturbing signal from support plate for detection of localised defects, if any, under it. In an analogous manner, a two-frequency approach is proposed to suppress the high-amplitude signals from the wall thickness variations which mask feeble indications of localised defects, if any. The challenge in implementing two-frequency mixing technique, in the present case, is the lack of proper reference standard replicating such extended wall thickness variations to tune the mixer settings for suppressing the disturbing signals. Further, fabrication of a reference standard replicating the wall thickness variations is difficult, essentially because, the variations are on the ID side. In view of this, this approach innovatively uses the ultrasonic thickness measurement data.

ACHIEVEMENT

This approach has been successfully implemented at NFC, Hyderabad to test more than 600 tubes having wall thickness variations. A total of 15 tubes have been rejected based on the conventional EC testing i.e. channel-1 threshold, due to localised defects in regions other than wall thickness variations. Four tubes have been rejected based on the mixer channel threshold, due to localised defects in wall thickness variation region. This effective procedure is routinely used at NFC for imparting stringent quality control of SG tubes. This approach can be applied to other similar situations in metallic tubes.

PUBLICATIONS ARISING OUT OF THIS STUDY AND RELATED WORK

1. B.P.C. Rao, S. Thirunavukkarasu, T. Jayakumar and Baldev Raj; INSIGHT-Non-Destructive Testing and Condition Monitoring (Journal of the British Institute of Non-Destructive Testing) **49** (2007) 698.
2. Internal Report No: IGCAR/NDED/EMSI/1/2005, July 2005.

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