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Development, optimization and validation of ultrasonic testing for NDE of ELM coils

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HIGHLIGHTS

- Non-Destructive Evaluation method based on ultrasonic technique has been developed for Inconel 625 weld joints in ELM control coils.
- Probe selection, beam parameters and procedure has been simulated using CIVA software and validated by experimental trials.
- Inspection procedure and parameters has been optimized and demonstrated on actual 1:1 demo ELM coil.

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ABSTRACT

Institute for Plasma Research (IPR) has been developing technologies appropriate towards realizing fusion relevant Edge Localized Mode (ELM) magnets in Tokamaks such as Joint European Torus (JET) and Steady State Superconducting Tokamak (SST-1). The winding pack of ELM coils have been encased inside the Inconel 625 casing using customized double groove and single bevel weld joints. It is critical to ensure soundness of these weld joints. With this motivation, Non-Destructive Evaluation (NDE) method using ultrasonic technique has been developed and established for inspection of weld joints in ELM control coils. The development of ultrasonic test procedure, test parameters, test validation and optimization using simulation as well as experimental approach has been discussed in this paper. The selection and locations probes along with beams parameters for weld joints have been optimized with commercially available software CIVA- versatile simulation tool developed by CEA (French Atomic Energy Commission), France. Further, the developed ultrasonic test method has been established and validated on mockup box sample of casing for ELM coils. It has been again successfully demonstrated for its performance on 1:1 demo coil equivalent to small ELM coil.

1. Introduction

The Edge Localized Mode Control Coil (ELM CC) for JET are designed as in-vessel coils in saddle configuration with array of 32 coils arranged in two toroidal belts around the plasma. The upper belt with 8 large coils and lower one with 24 small coils are arranged inside vacuum vessel. The winding pack for ELM CC consists of high temperature insulation and CuCrZr as the conductor encased in Inconel 625 casing. Each turn in the winding pack is capable of carrying 1.25 kA current resulting in total of 60 kA in coil. During the operation, ELM CC will be charged with the current of 1250 A in each turn (60 kA for 48 turns) for 8 s on and 30 min off for 8 cycles rising the temperature of conductor to maximum 350 °C [1,2]. The feasibility studies for the design and installation of the ELN CC in JET has already completed and presented [1,2]. Under India-EU collaboration, Institute for Plasma Research has undertaken an engineering feasibility initiative which is aimed at developing 1:1 prototype ELM coils of Joint European Torus (JET). It includes development of the characteristics winding topologies, developing an appropriate special purpose winding facility complying with the tolerance requirements of the ELM coils, developing the high temperature resin insulation impregnation system optimization, developing vacuum pressure impregnation of the high temperature resin systems in manufactured winding pack, developing profiled case manufacturing technologies and developing technologies at consolidating and encasing the impregnated winding packs. All the essential manufacturing technologies to realize an ELM coil has been developed and introduced [3]. Encasing of the winding pack was critical task involving welding of the Inconel 625 plates manufactured in the required shape as shown in Fig. 1. ELM CC is an in-vessel coil with initial temperature of 200° C inside the torus of JET. According to the operation scenario of the ELM CC, weld

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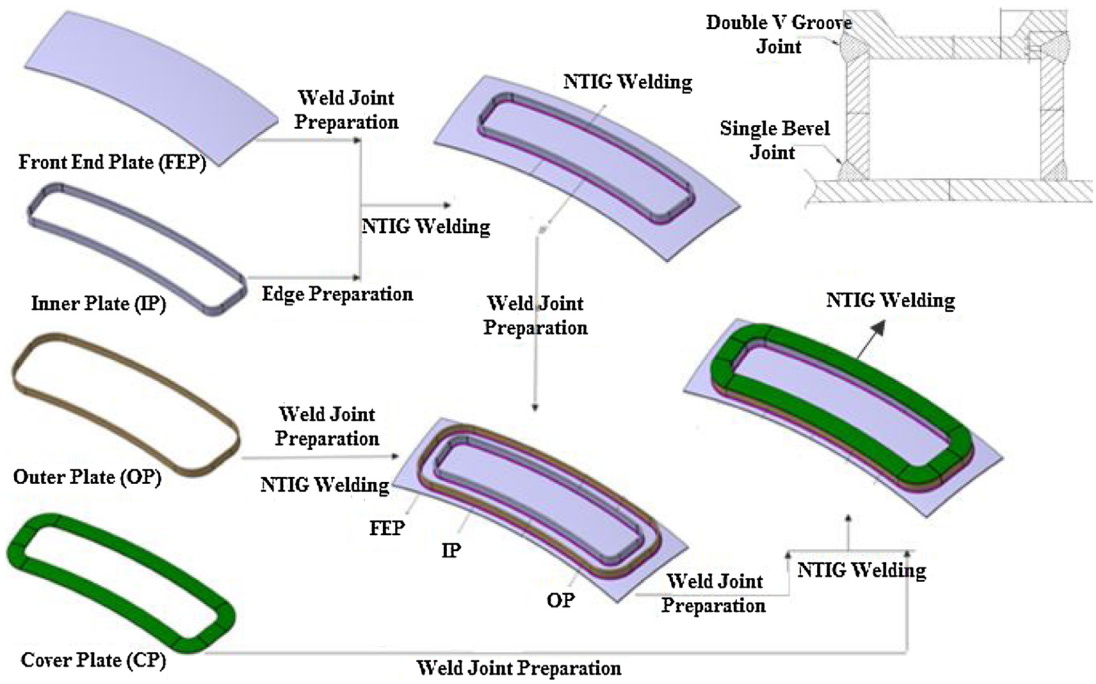

Fig. 1. Schematic representation for weld sequence and encasing of winding pack.

joints should sustain for ~20000 cycles without any failures with respect to operational requirements of JET. The maximum leak rate allowed for weld joint is in the order of 1×10^{-9} mbar liter/sec in vacuum mode and 3×10^{-6} mbar liter/sec in sniffer mode. During encasing, high temperature insulation of the winding pack needs to be prevented during welding operation. Any damage to the winding pack will result in degradation in the performance of the insulation. The welding procedure, weld parameters and weld joints have been designed and demonstrated on the Inconel 625 samples with an extensive trials [4]. The encasing methodology for winding pack has been optimized and demonstrated.

The double groove and the single bevel weld joints with an Inconel 625 filler have been used in the encasing of the winding pack. These weld joints needs to be verified for the weld defects in a fusion zone to qualify the weld process respecting technical requirements of the JET with applicable ASME standards [5]. Conventional X-ray radiography is a suitable process for NDE of the weld joints in the Inconel alloys. But due to complex shape and its weld configurations, it was not possible to implement radiography for evaluation of the ELM CC. With this motivation, it has been decided to develop NDE method for the ELM CC with implementation of the ultrasonic technique. The development of ultrasonic test procedures, selection of ultrasonic probes and beam angle along with simulations in commercially available CIVA software has been carried out. The establishment of probes by trials on welds samples; validation with the reference block and defect sensitivity studies has been systematically investigated. An optimization of the test parameters and their validation with the ultrasonic immersion technique has been discussed in this paper.

2. Development of ultrasonic test method

The methodology for encasing of the winding pack of an ELM coil is shown in Fig. 1. There are two types of weld joints used in the coil casing namely single bevel joint (between inner/outer plate and front end plate) and specially design double groove corner joint for the cover plate. The outer and inner plates have been joined using single bevel joint with front end plate by narrow gap tungsten inert gas (NGTIG) welding method using Inconel 625 as the filler material. The cover plate has been joined with double groove joint on the inner and the outer plate after insertion of a winding pack for ELM CC. Encasing approach for the winding pack of ELM CC has been developed through the extensive experiments and trials [4]. Following section describes the development and establishment of an ultrasonic technique suitable for NDE of the weld joints for ELM CC.

2.1. Ultrasonic velocity and attenuation measurement

In the ultrasonic testing (UT), a wavelength of an ultrasound has significant effect on the probability of detecting a discontinuity. It depends on the velocity and the relative attenuation of a beam inside the material. It is very essential to calculate the velocity and the attenuation coefficient for both the shear and the longitudinal waves propagating in the Inconel 625 specimens. The propagation time between the first and the second back wall echoes as well as pulse amplitude of these echoes has been estimated from the pulse echo displayed on screen of the ultrasonic flaw detector. The velocity and attenuation coefficient has been calculated by the following equations,

$$V = 2T/(t_2\text{-}t_1) \tag{1}$$

$$a = 20 \log (h_1/h_2)/2T \tag{2}$$

Where V and a are velocity and attenuation coefficient of the ultrasonic wave respectively. t is propagation time of back wall echo; h is pulse amplitude of back wall one. Subscripts 1 and 2 denotes the first and the second back wall echoes, respectively. T is thickness of specimen.

The velocities of a longitudinal and a transverse waves in the Inconel 625 plate (thickness – 8 mm) were found to be 5797 m/sec and 3691 m/sec respectively. An attenuation coefficient of a longitudinal wave in the Inconel 625 is measured around 0.20 and 0.34 at 4 MHz and 10 MHz respectively using Eq. (2).