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Research of butt welding of thin-wall jacket for superconducting cable and joint☆

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ABSTRACT

In superconducting magnetic system including with the accessorial equipment's for fusion device i.e., Tokamak, the linkage of the superconducting cable-in-conduit conductor (CICC) requires special designed structure named as superconducting cable joint. This joint connects the segmental superconducting cables electrically and in the meanwhile, coolant flow is maintained non-obstructively between two cable via the joint. For the case of "twin-box" structure joint, the boxes is sealed welded with the cable jacket. In realistic operational condition, the joint need to sustain complicated loads which can apply from various directions including the electromagnetic force and thermal stress. The action of the torque is the main factor that affects the welding seam quality between the joint and the cable jacket. In this scenario, the full penetration butt welding is the best choice. In International Thermonuclear Experimental Reactor (ITER) Feeder system, the cable jacket thickness is only 2 mm, and the allowable maximum temperature of the superconducting strands in cable should be lower than 250 °C during the whole welding stage. Therefore, special welding techniques should be developed, the welding for such thin-wall jacket limits the temperature rise of the strands and achieve the full penetration simultaneously. This paper describes the latest research and experiments in ASIPP, which aims to find a suitable method for Feeder cable jacket to joint box sealing weld.

1. Introduction

ITER Feeder system directs the room temperature electrical power to 4 K operational magnets using the Nb-Ti CICC, which is so-called Feeder busbar. The total length of the busbar is over 20 m and the scheme of assembly for such long busbar using "twin-box" type joints connects several sectional cables together [1–5]. In the typical Feeder system, most of the joints are located far away from the magnets, therefore, they are not overload excessively, but the joints between In-Cryostat Feeder (ICF), Cryostat Feed Though (CFT), and in the cryostat to match with the coil termination are exposed in the relevant high magnetic field region. The high bending force needs to be withstand on the main joint body, especially the welding seams, which are the critical position. The original design of the welding structure from the cable jacket to extension pipe on joint box is filet weld, as shown in Fig. 1(a). The filet weld is obviously benefit on welding and implementing the jacket of cable as the heat resistance which can resist the heat flow caused by welding arc, and ease to control the temperature rising on the milt-strand cable. But this filet weld is not the full penetration, and the intrinsic mechanical properties especially the anti-fatigue performance is indicating extremely low. With the recent modifications, the welding structure of joint to cable jacket is converted to butt weld as shown in Fig. 1(b). Butt joint weld can form complete penetration of the base material (316L stainless steel) of cable jacket and joint box. This joint may provide more advantages on mechanical strength. However, many distinct factors affect the weld qualification assurance of temperature control, including the 2 mm thickness jacket, the over 1300 °C melt point of 316L stainless steel, and only 0.1 mm stainless steel foil wrapping between jacket and strands. In order to avoid the degradation of the strands superconductivity caused by the overheating of weld [6,7], the strict allowable temperature of superconducting strands in cable are limited to be lower than 250 °C during the whole welding period.

In this research, several butt joint geometries were designed to test and qualify the butt for Feeder joint. The methods for restricting the conduct heat from jacket to strands were considered. ASIPP have applied several rounds welding simulation trials using the dummy Main Busbar (MB) of Feeder. The internal temperatures on superconducting strands were recorded during welding for temperature control. At this stage, butt welding technical route for MB

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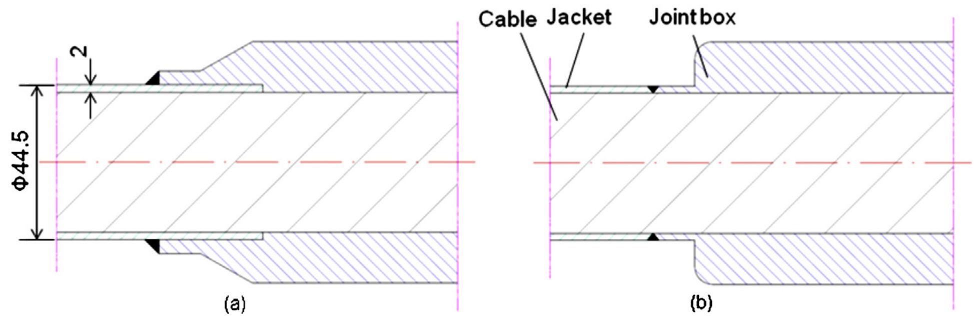

Fig. 1. The welding structure sketch of joint box to cable jacket, where (a) is the filet weld, (b) is the butt joint.

busbar joint is preliminarily confirmed. In this paper, we introduces the experimental progress of recent butt weld R&D activities, and these results will give significant utility for Feeder joint qualification.

2. Experimental welding procedure

2.1. Simulation structure of the welding sample

In order to make the simulation exactly reflect the real operational condition of the joint, a section of dummy MB busbar with the length of ~400 mm is used for the trials. In the dummy busbar, the superconducting strands were replaced by the copper wires with the same dimensions and the cable twisting pitches. The jacket with the length of ~200 mm cut off from one termination of the dummy busbar. The wrapped stainless steel foil was removed completely and all the copper strands were exposed out. Instead of a joint box, a section of stainless steel pipe with the same cross section dimension with cable jacket was used, which is directly assembled on the pre-treated cable, and finally formed a closed circular seam for welding.

Three different butt welding structures were experimented in the trials, as shown in Fig. 2. The first sample was square butt joint, the ends of the cable jacket and the mounted pipe were flatted and parallel to each other. The stainless steel foil under the welding seam kept reserved in this scenario. The second sample was the single-bevel joint, the jacket end is flat, and the mounted pipe edge is beveled with the depth of 1.5 mm, and the bevel angle is 50–55°, the stainless steel foil is reserved. The third sample is also the single-bevel joint, and 2 layers additional stainless steel strips with the total thickness of 0.5 mm were inserted between the jacket and wrapped foil.

2.2. Temperature sensors arrangement

Thermocouples, which are installed underneath the original stainless steel wrap of cable, were used to measure the strands temperature. 6-internal thermocouples were arranged uniformly at every 60° on the circumference of the welding seam. The instrumentation wires were twisted into the groove between two sub-cables, and after the pipe's assembly, the wires could be fed out from one termination and connected to the data acquisition systems (DAS) based on Keithley 2700 multimeter. The data was recorded and displayed for welding control, as shown in Fig. 3. Meanwhile, 6 external thermocouples were distributed on the surface of jacket with 20 mm length to the welding seam. This can be treated as the matched comparison to the internal thermocouples, and as the guide data for the practical welding of the real joint box. All the DAS equipments were shielded by the aluminum film to reduce the signal interference caused by the welding arc.

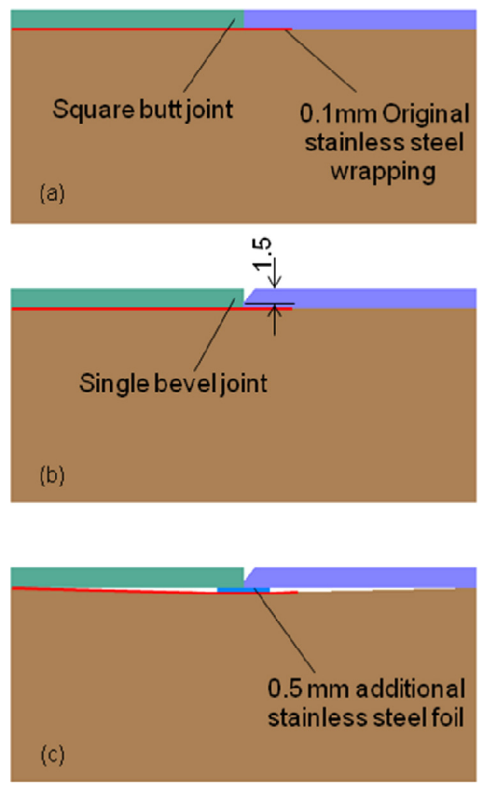

Fig. 2. Butt weld structure sketch for experiment, where (a) is the square butt joint sample, (b) is the single bevel joint sample, (c) is the single bevel joint + additional strips.

2.3. Welding process

The welding technical route is explored in the trials, including the welding parameters i.e., the welding steps. The constant current welding power is applied in the experiment and the amount of heat

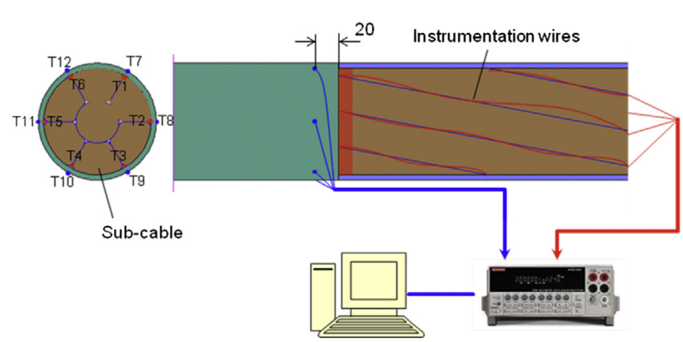

Fig. 3. DAS for temperature monitoring.