Remote Welding Equipment for TPX*

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ABSTRACT

Remote welding equipment and techniques are necessary for maintenance of the Tokamak Physics Experiment (TPX) Plasma Facing Components (PFCs). The processes identified for this application includes inside diameter (i.d.) and outside diameter (o.d.) Gas Tungsten Arc (GTA) welding of titanium and stainless steel alloys. Welding equipment developed for this application includes some unique features due to the specialized environment of the TPX vessel. Remote features of this equipment must include the ability to acquire and align the parts being welded, perform all welding operations and visually inspect the weld area. Designs for weld heads require the integration of industry proven hardware with the special features necessary to accomplish remote operations. Such features include compact size, remote manipulation, remote clamping and alignment, remote vision, full inert gas coverage, arc voltage control, wire feed, programmable weld schedules and failure recovery.

INTRODUCTION

The TPX project is being managed by Princeton Plasma Physics Laboratory (PPPL) for the Department of Energy (DOE). As a major participant in this project, General Atomics (GA) has responsibility for design of the PFCs and the Remote Handling (RH) tooling necessary to perform remote maintenance of these components within the TPX vacuum vessel. The operational goals and temperature limitations of TPX require that the PFCs be water cooled. Water cooling is accomplished through individual cooling lines connecting each PFC to the system cooling network. A significant part of the TPX remote maintenance task includes the operations of remote welding of cooling lines when installing or replacing a PFC.

INSIDE DIAMETER WELDING

Inboard and outboard divertor plasma facing components are water cooled using concentric cooling lines which penetrate the vacuum chamber wall to connect directly to the components. There are a total of 32 inboard and 32 outboard divertors each with its own cooling line exiting in radial directions from the vessel. Fig. 1 illustrates a lower outboard divertor module with its cooling line connection. This figure also shows a similar cooling line coming from the inboard divertor and passing through a clearance in the outboard module. The inboard divertor module is not shown in this figure. The cooling line to each divertor consists of a 127 mm (5 in.) o.d. titanium tube with a 76.2 mm (3 in.) o.d. concentric internal tube. Installation or replacement of a divertor requires the welding of the 127 mm (5 in.) cooling line to the divertor module at the point of connection inside the vessel. Since there is no access to the outside of this tube, the weld requires access through the inside of the 3 m length of 127 mm (5 in.) o.d. titanium cooling line. A specialized i.d. weld head is necessary to accomplish this weld.

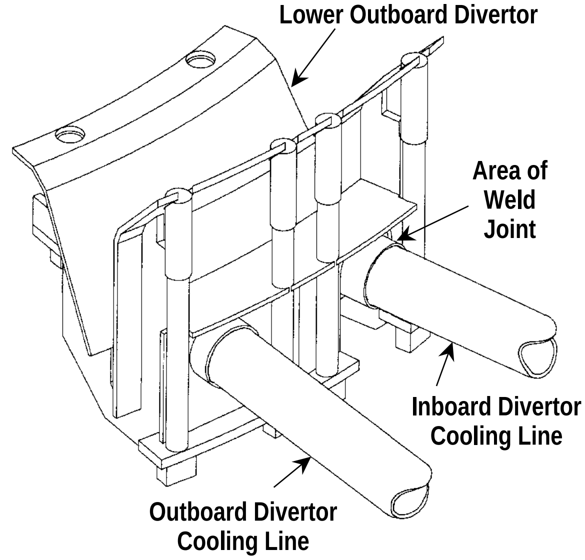

Fig. 1. TPX lower outboard divertor module.

Arc Machines in Pacoima CA. was contracted to design and build a weld head to accomplish this weld. The GTA weld process was selected based on the need for a precision weld of thin wall titanium tubing. The technology and process to accomplish this type of weld is well understood. The TPX application includes the challenge to configure the weld head small enough to fit inside the 127 mm (5 in.) tube through its 3 m length. Because of the reactive nature of titanium, strict requirements are imposed on inert gas shielding of the weld area to prevent oxidation and atmospheric contamination. Features required as part of the weld head include remote vision, lighting, clamping, cross seam adjustment, arc voltage control, inert gas shielding, wire feed and water cooling.

A special joint design configuration is necessary to accommodate the alignment of the weld joint and provide for cut and weld replacement. Fig. 2 illustrates a cross section of this joint connection at the interface with the divertor module. The 76.2 mm (3 in.) inner tube slides into the fitting and is sealed with piston ring seals. This tube is removed for

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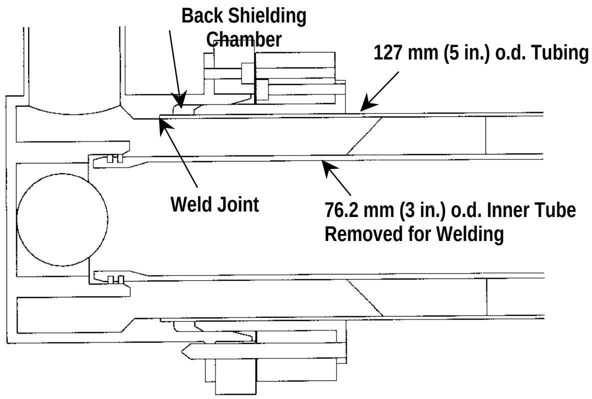

Fig. 2. 127 mm tube weld joint.

cutting and welding tool access. The joint connection configuration provides for a tapered mechanical “lead in” to help guide the 127 mm (5 in.) tube into place prior to welding since vision is impaired. The joint is designed to assure radial alignment of the mating pieces. Special insertion tools are planned for installation of the cooling line into the divertor joint. The connection must also provide for gas shielding of the o.d. of the weld seam since there is no access by the weld head or support equipment. This shielding is accomplished by providing a machined space around the o.d. of the weld which can be purged with inert gas prior to and during the weld. The 76.2 mm (3 in.) inside concentric tube is installed after the 127 mm (5 in.) tube weld is made and is sealed using a mechanical piston ring seal which does not require welding.

The weld head designed to accomplish this weld is shown in Fig. 3. Access to the weld is accomplished by sliding the weld head down the length of the tube until it reaches the weld location. Because of possible obstructions around the vessel periphery, the weld head and its support structure must breakdown into sections which are 1 m or less in length for purposes of installation and removal. The weld head itself is less than 1 m in length. All support equipment is located within 10 m of the exposed end of the pipe. This equipment consists of weld power supply, controls, water cooler, shielding gas supply, etc. The weld head is installed by an operator through the end of the cooling line. Once located at the proper depth, the weld head is clamped in place. All further adjustments and operation are done remotely from the control station which includes a TV monitor for set up, in process monitoring and final visual inspection of the weld.

OUTSIDE DIAMETER WELDING

All PFCs in TPX other than the divertor modules are connected to a network of cooling lines inside the tokamak vessel. A standard tubing size of 25.4 mm (1 in.) o.d. is planned for the PFC cooling lines. Other PFCs requiring water cooling include inboard stabilizers, outboard stabilizers, poloidal limiters, line of sight shields and neutral beam armor. Installation and replacement of these components requires the welding of the cooling lines after the components are mounted in location. During normal plasma operations, the cooling lines must be shielded from the plasma which requires that the cooling lines to be covered by tiles or be located behind structure or other protection. In the case of the inboard and outboard stabilizer, access to the cooling lines is made through a window in the stabilizer structure. Fig. 4 illustrates the proposed window opening showing access to the cooling lines and alignment rings. This window is normally covered with carbon tiles during operation. These selected tiles are removed for maintenance and replaced once the welding and inspection are complete. Other components are configured to locate cooling lines behind structure so as not to have a direct view from the plasma.

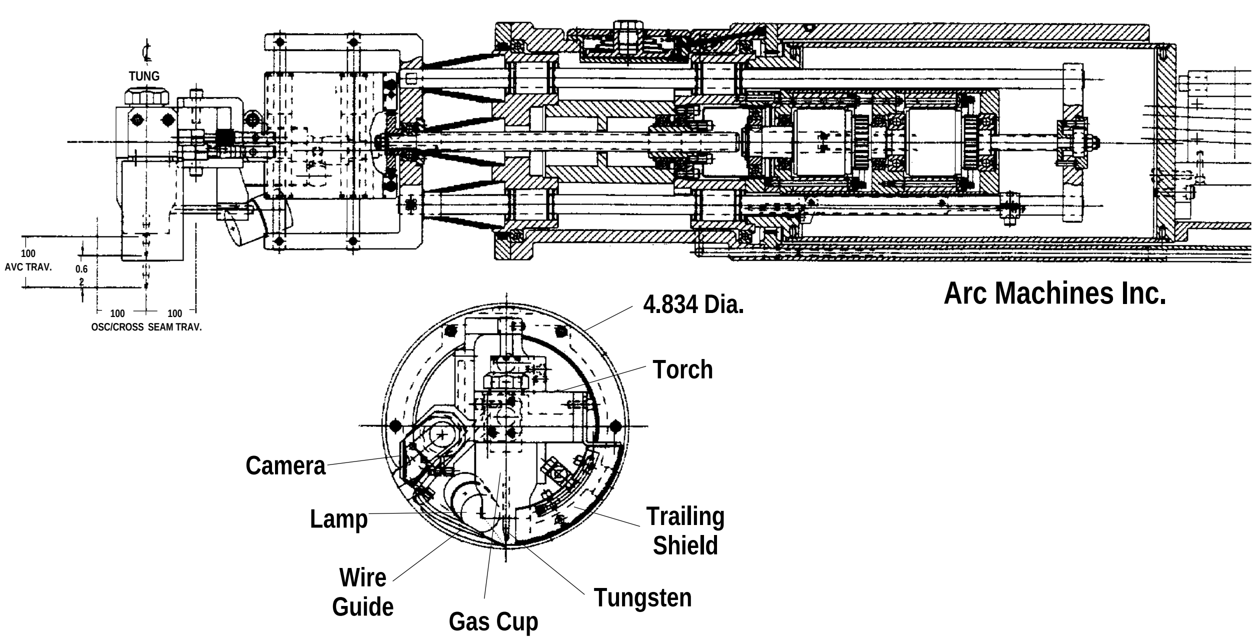

Fig. 3. i.d. weld head cross section.

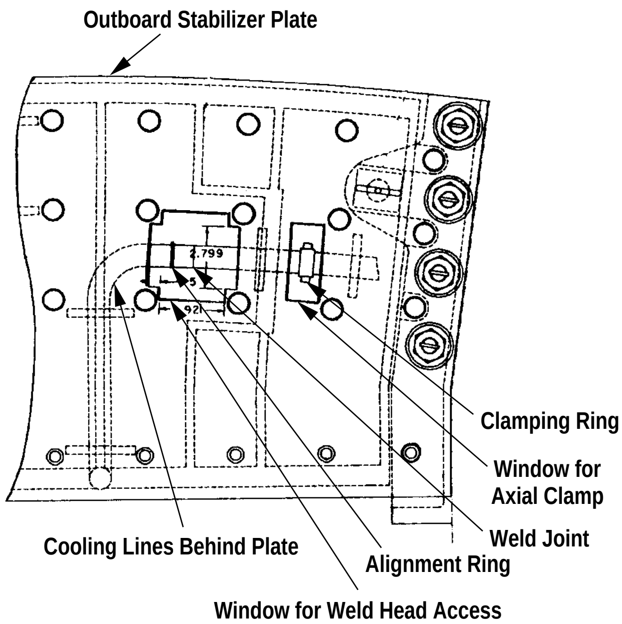

Fig. 4. Cooling line access through outer plate stabilizer.

A number of companies in the U.S. and Europe build GTAW enclosed orbital weld heads which are suitable for 1 in. o.d. titanium tubing. This equipment is typically designed with flexible but stiff clamping rings which grip and align both weld pieces to be concentric during the weld process. The electrode alignment and clamp actuation is accomplished by the operator during installation of the weld head. For the TPX application, the installation and alignment of the weld head must be done remotely requiring special modifications to the weld head.

A concept for the TPX o.d. weld joint is shown in Fig. 5. By adding an alignment ring to the tube on each side of the weld joint, a means of reference for remote alignment is provided. This ring has a register surface which is located a precise distance from the weld joint and provides for alignment of the electrode. Attaching a ring to each tube piece provides a gripping point for the weld head to apply the necessary axial force to assure a tight seam during welding. The concept of using internally machined grooves and alignment rings for axial clamping and tool alignment has been used by JET and is briefly described in Ref. [1].

OUTSIDE DIAMETER WELD SEQUENCE

A replacement sequence for a PFC requires cutting and welding of the cooling lines is illustrated in Fig. 6. For a series of replacements the rework sequence would be as follows. The alignment ring on the PFC side of the weld joint is located a precise dimension “B” from the end of the tube. The corresponding ring on the vessel tube is located a dimension “C” from the weld joint when the first weld is made. The first repair cut is made to the right of the weld joint (6 mm over as shown) leaving the weld connected to the PFC side of the cooling line.

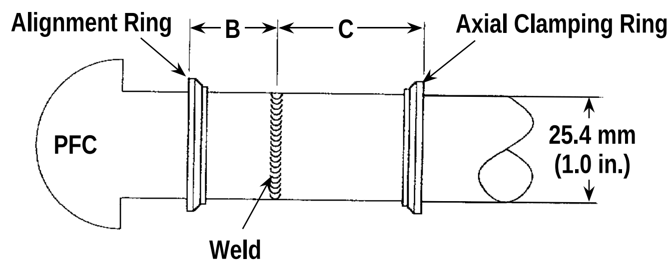

Fig. 5. o.d. weld joint configuration.

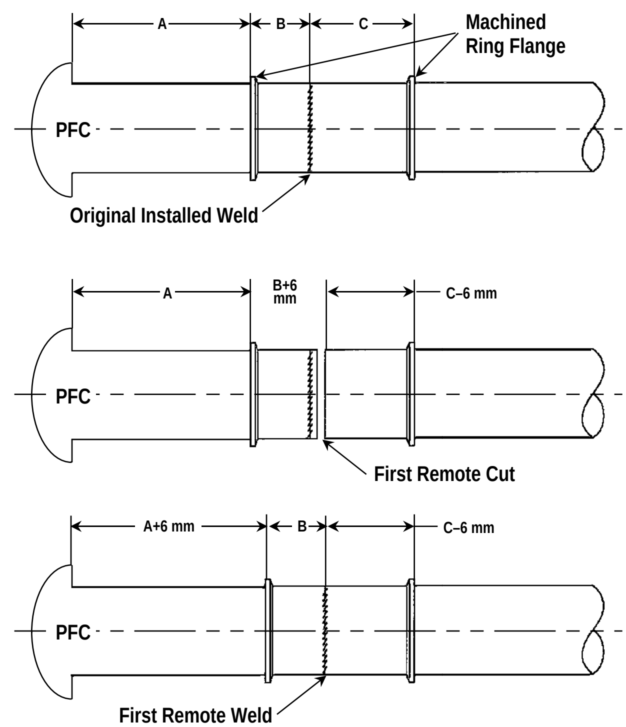

Fig. 6. o.d. weld repair sequence.

The PFC is removed for maintenance. The replacement PFC is configured with the alignment ring at the same “B” dimension from the end of the tube. As part of the PFC rework, the overall length of this tube must be increased by the 6 mm previously removed so there is a match with the tube remaining in the vessel. This modification would be accomplished outside the vessel. The “B” dimension must be maintained for weld electrode alignment. Once the PFC is installed and in place, the weld head is positioned on the tube and achieves its alignment from the ring on the PFC side of the weld joint. Axial clamping is accomplished using the ring on the vessel side of the joint. It should be noted that this ring has become closer to the weld joint by the 6 mm removed during the first cut. This effect of shortening requires that the axial clamping mechanism have enough range to accommodate this shift in location each time a repair is made. The clamping mechanism must also provide for any additional travel of the tube necessary to bring it into the correct position.

For the second repair, a similar sequence is followed. Each time a repair is made, the tube on the PFC side of the weld must be increased in length by 6 mm while maintaining the precise "B" dimension. Also each time a repair is made, the tube remaining in the vessel is shortened by 6 mm. This effect will limit the number of repairs possible because of available rework length on the in-vessel tube.

A full scale mockup of this weld head similar to that shown in Fig. 7 has been constructed. This mockup is non-functioning as a weld head but is built at scale size and includes the clamping ring concept to demonstrate its function. An outrigger clamp is included to demonstrate axial clamping operations. The mockup provides a means of demonstrating operation and access during the design of cooling line configurations.

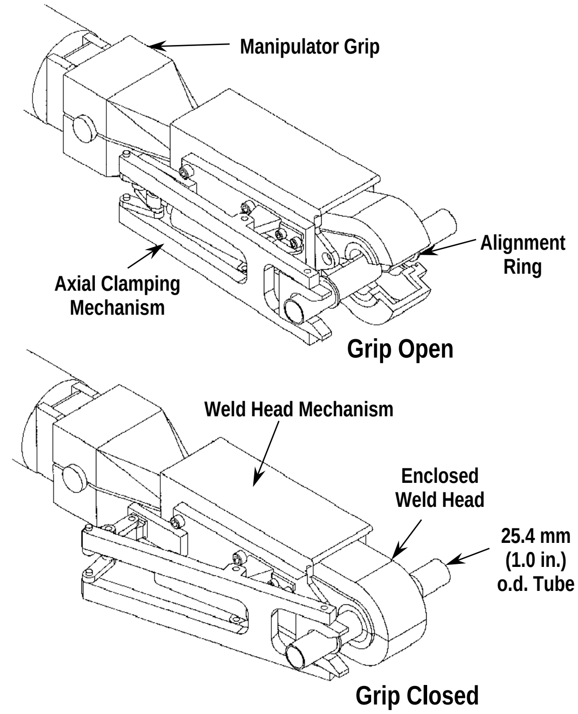

Fig. 7. o.d. weld head mockup.

CONCLUSIONS

Concepts for i.d. and o.d. welding for use in remote maintenance of TPX PFCs have been developed. An operational prototype i.d. weld head has been designed and is being fabricated. A mockup of the o.d. weld head concept has been built for use in further development of the TPX PFC design.

REFERENCE

[1] G.W. Silke, "Visit to JET Joint Undertaking," GA Report GA-C21929, November 1994.