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Vacuum Tight Threaded Junctions (VTTJ): A new solution for reliable heterogeneous junctions in ITER

P. Agostinetti*, M. Dalla Palma, F. Degli Agostini, D. Marcuzzi, A. Rizzolo, F. Rossetto, P. Sonato, P. Zaccaria

Consorzio RFX (CNR, ENEA, INFN, Universitá di Padova, Acciaierie Venete SpA), Corso Stati Uniti 4, 35127 Padova, Italy

HIGHLIGHTS

- Heterogeneous junctions represent a critical issue in Nuclear Fusion experiments.
- We have developed a new technique for heterogeneous junctions, called VTTJ, whose main advantages are low cost, high reliability and easiness of construction.
- The VTTJ junctions have passed all the tests required by ITER for the heterogeneous junctions of the divertor.
- Further tests have demonstrated wide margins for operation (up to 700 °C and 500 bar).

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ABSTRACT

A new technique, called Vacuum Tight Threaded Junction (VTTJ), has been developed and patented by Consorzio RFX, permitting to obtain low-cost and reliable non-welded junctions, able to maintain vacuum tightness also in heavy loading conditions (high temperature and high mechanical loads). The technique can be applied also if the materials to be joint are not weldable and for heterogeneous junctions (for example, between steel and copper) and has been tested up to 500 bar internal pressure and up to 700 °C, showing excellent leak tightness in vacuum conditions and high mechanical resistance.

The main advantages with respect to existing technologies (for example, friction welding and electron beam welding) are an easy construction, a low cost, a precise positioning of the junction and a high repeatability of the process. Due to these advantages, the new technique has been adopted for several components of the SPIDER experiment and it is proposed for ITER, in particular for the ITER Heat and Current Drive Neutral Beam Injector and for its prototype, the MITICA experiment, to be tested at Consorzio RFX.

This paper gives a detailed description of the VTTJ technique, of the samples manufactured and of the qualification tests that have been carried out so far.

1. Introduction

At Consorzio RFX of Padova (Italy), in the framework of the ITER project for thermonuclear Fusion, the PRIMA facility [1,2] is being built to install and test the neutral beam injector for ITER, hosting the SPIDER and MITICA experiments.

SPIDER (Source for Production of Ion of Deuterium Extracted from RF plasma) is a full-size 40 A negative ion source with a 100 kV electrostatic accelerator [3,4]. MITICA (Megavolt ITER Injector Concept Advancement) is a complete 1 MeV 16 MW Neutral Beam Injector system which includes Ion Source, Accelerator, Neutralizer, Residual Ion Dump and Calorimeter [5,6].

The design and construction of the injector has several criticalities because of the severe requirements in terms of heat loads, mechanical tolerances and long-term reliability. In particular, one of the most critical issues is represented by the junctions between copper and stainless steel of the high heat flux components (accelerator grids, radio frequency source, beam line components etc.), that must be compatible with high thermal and structural loads, and whose design is constrained by layout restrictions. During the research activity on this field, Consorzio RFX researchers have developed a new technique to make heterogeneous junctions, called Vacuum Tight Threaded Junction [7]. Due to its many

* Corresponding author. Tel.: +39 049 8295087; fax: +39 049 8700718.
E-mail address: piero.agostinetti@igi.cnr.it (P. Agostinetti).

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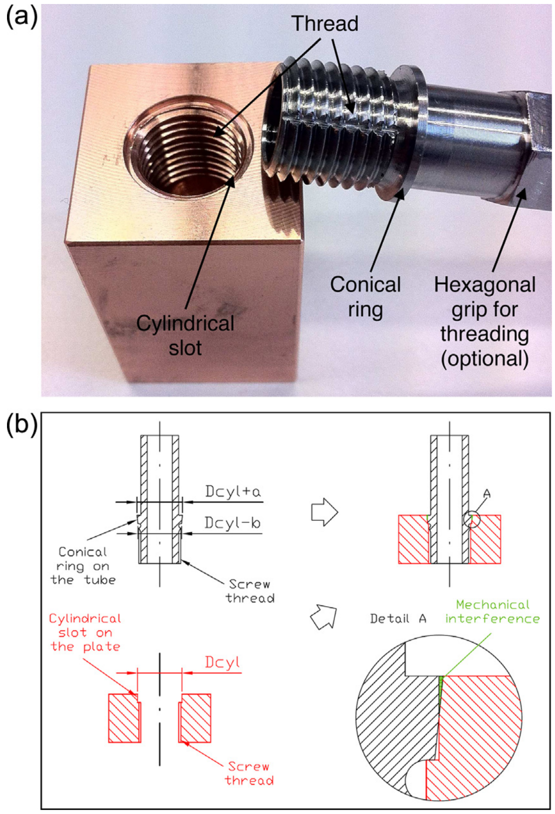

Fig. 1. The VTTJ concept: (a) VTTJ sample; (b) section drawing. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

advantages, like low cost and easy construction, VTTJ have been adopted in many parts of the SPIDER experiment.

2. How it works

The working principle of VTTJ is extremely simple. Two parts (at least one with tube shape) are screwed one into the other with a mechanical interference that creates a metallic seal. As an example, the sample of Fig. 1a represents a junction between a stainless steel tube and a copper block. A section drawing of the sample is given in Fig. 1b. The block presents a cylindrical slot with a certain diameter D_{cyl}. On the other hand, the tube presents a conical ring, whose diameter on the external part is slightly larger than the one of the slot ($D_{cyl} + a$), while on the internal part (toward the thread) it is slightly smaller ($D_{cyl} - b$). For a junction between steel and copper, the a and b dimensions are of around a tenth of a millimeter. In this way, when the tube is screwed into the block, a plastic deformation of the cylindrical slot occurs in the mechanical interference region (highlighted in green in Fig. 1b). It has to be noted that this interference region is located on the surface of the sample; this fact is important because it represents an optimal starting point for the following finishing operations. As a consequence of the plastic deformation of the softer material (in this case, copper) there is a certain increase on the screwing torque. The plastic deformation of copper generates an absolutely hermetic seal, as demonstrated by several tests carried out on various geometries of the junction.

To avoid the unscrewing of the two components, and to make the junction compatible also with high thermal and/or structural loads, one can proceed with a finishing phase using galvanic electrodeposition of copper. Practically, the junction region is covered with a layer of about 1 mm of copper. To have a good adhesion between the base materials and the electrodeposited copper, the base materials are subjected to a suitable surface cleaning and activation process. This can be made for example by treating the surfaces to be electrodeposited with a solution of water and hydrochloric acid. After the electrodeposition, the junction appears like in Fig. 2. In particular, the electrodeposited surface can be left as it is like in Fig. 2a, or flattened by milling like in Fig. 2b. The former sample was made for the SPIDER extraction grid, while the latter one for the SPIDER grounded grid. The pressure tests and leak tests, summarized in [8] were successful for both the samples.

As an alternative to the copper electrodeposition, some tests have been carried out also following a second finishing option, that foresees a surface laser welding. In this case, after screwing the tube, the surface of the junction circular border is heated with laser, so that a small quantity of material melts in the region that has been previously subjected to plastic deformation. The perfect contact between the two materials in that area, guaranteed by the previous plastic deformation, permits to obtain with a certain reliability a good quality of the laser welding, once suitable process parameters have been set up (Fig. 3).

Summarizing, the new VTTJ technique permits to manufacture junctions between copper and steel having a perfect seal (compatible with the requirements of high vacuum environments) that is reliable in time also in the presence of high temperatures and high structural loads. In the version with electrodeposited copper finishing, the process is carried out completely in cold conditions, hence in any phase the materials are prevented from possible damages due to overheating. On the other hand, using any other existing technique able to give a vacuum compatible seal (like friction welding, electron beam welding, brazing etc.) there is always a certain overheating in the junction area, with possible cracks or other types of degradation of the materials (annealing, recrystallization, inclusions, etc.). Following the second option, that foresees a laser welding finishing, although the process is not completely cold, the heat affected zone has in any case a very limited volume, because the penetration thickness of the laser welding is in the order of some tenth of millimeter.

The principle of VTTJ junction is also applicable if other materials are used (like aluminum, magnesium, nickel, chromium, bronze, zirconium etc.) or other geometries (for example, tube–tube junctions instead of tube–plate ones).

3. Possible applications

The VTTJ junction has been used so far in the all grids of the SPIDER extractor/acceleration system. In this regard, Fig. 2c and d shows the applications on the Multi Channel Prototype of the SPIDER extraction grid. This is a prototype featuring all the possible manufacturing issues of the SPIDER and MITICA grids. A comprehensive testing campaign has been carried out on the MCP, with all the tests successfully passed [8]. Moreover, VTTJ is presently one of the design options for the junctions of the MITICA accelerator grids. In principle, it could be used in other components of the ITER experiment, that are required to operate in vacuum conditions and under high heat loads. Among these, we can cite the Beam Line Components of the Neutral Beam Injectors, the blanket and the divertor.

Although developed for nuclear fusion applications, the new junction technique is applicable also to large scale production, in particular in the fields of heat engineering, thermotechnics, chemistry, cryogenics, nuclear, vacuum equipment, food and pharmaceutic industry.

4. Definition of suitable testing campaign

The document F4E/2009/ITER/5165 titled "Technical specification for the manufacturing of full tungsten monoblock components", issued by the Fusion for Energy (F4E) organization