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RF Contact Development for the ITER ICRH Antenna

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Abstract. In the framework of the Ion Cyclotron (IC) antenna design, ITER Organization requested qualification tests on sliding Radio-Frequency (RF) contacts, to verify that these contacts (quality class 1) are designed appropriately to guarantee a sufficient operational life time. These RF contacts will be integrated into the antenna structure at different locations to facilitate the assembly and decouple the different mechanical parts. This design will in addition lower the thermo-mechanical constraints and allow radial shimming of the antenna front face. As commercial contacts were not suitable for the ITER ICRH antenna operation, substantial efforts have been made on mechanical design of the new RF contact. Two prototypes have been manufactured and delivered to CEA for testing. In parallel a test stand facility (TITAN) has been refurbished to provide a way to test these RF contacts in relevant conditions (2.25kA @ 62.5MHz, vacuum pressure <10^{-3}Pa, 1000s). This paper reports on main results we get during the commissioning of the test stand facility. Roadmap of the tests is also detailed with RF power tests for long shot duration (1000s) under vacuum and extensive sliding tests in order to assess the reliability of the RF contact for a relevant life time duration (specified to 10 years). A description of the RF contact is also given with the latest results on the manufacturing process (copper and gold plating and brazing, general assembly).

Keywords: ICRH antenna, RF contact, Test bed facility
PACS: 84.40.Ba

INTRODUCTION

Due to the difficulties encountered in determining analytically the performance of RF sliding contacts (mainly expressed by a large number of uncertainties on contact electrical resistance and thermal exchange coefficient, [1],[2],[3]), the ITER organization requires the test of prototype components to validate the contact concept and guarantee the operational life time of 10 years. These RF contacts – classified as SIC-1 - will be integrated within the future ITER ICRH antenna structure to allow for assembly, while decoupling mechanical parts in order to allow for shimming of the antenna front face and generally lower the thermo-mechanical stress in the antenna. These contacts will be installed at different locations in the antenna plug, and will operate in a harsh. Qualification tests in relevant conditions and representative geometry are required to validate these critical components. The present program is intended to answer these questions and deliver confidence in the use of the foreseen RF contact. This program consists of two separate items – the T resonator upgrade and the RF contact R&D - done in parallel.

To date, no existing system can sustain the RF rates anticipated for ITER during long pulse duration. The matching system – so called T resonator - is a required part of the TITAN (Testbed for ITer icrh ANtena) [4], [5].

PROGRAM ROADMAP

To allow for the qualification of a suitable RF contact, an extensive program with dedicated tests has been devised in collaboration with the CYCLE team. At first, an upgrade of the resonator will provide a way for testing critical ITER ICRH components in relevant conditions. In parallel to this upgrade, an extensive R&D was achieved.

The RF contact requires extensive test at nominal RF currents under ultra-high vacuum (<10^{-4}-10^{-3}Pa). Moreover, sliding tests must be performed to ensure the qualification of the foreseen contact at high temperature and

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relevant displacement speed, induced by both thermal expansion and antenna shimming. The operating conditions are described as:

- 2.25kA (+ 20% of safety margin) at 62 MHz during quasi-continuous operation (20'-30')
- Vacuum pressure <10^{-3}Pa
- RF validation at nominal temperature of 90°C with short displacement (mimicking the relative thermal displacements of the ITER ICRH antenna)
- 15000 cycles for sliding qualification (corresponding to the component 10 years lifetime on ITER ICRH antenna)
- High temperature (to be defined during RF test) operation with sliding test to mimic the combination of RF heating and cooling temperature (90°C)

T-RESONATOR DESCRIPTION

The overall facility is composed of the T resonator (Fig.1), the RF power facility, the vacuum pumping, the cold water loop and the pressurized hot water loop.

One major issue is operating high RF currents (2.25kA) in steady state conditions. This requirement implies that the entire resonator is actively cooled with water (including both the inner and outer conductors). For the test piece, the hot water loop is used to better mimic the prevalent operating conditions during long pulse operation on ITER. The resonator is connected to the RF power plant which can deliver a few hundred kilowatts (a maximum of 2MW can be delivered to the tore supra ICRH antenna) to achieve the nominal RF voltage/current of 45kV/2.5kA with reasonable operating margins. A water cooled trolley (manufactured in house) is used to form the short circuit connection, whilst allowing for sliding motion over the contact. The trolley is also fed from the hot water loop to better represent the test contact environment on the ITER machine. The motion of the trolley is driven by a motor via a double bellows. On the non-test branch, a second trolley made with commercial contact technology from Multilam company (not thought suitable for ITER operation) is used to maintain the sensitive matching point of the resonator.

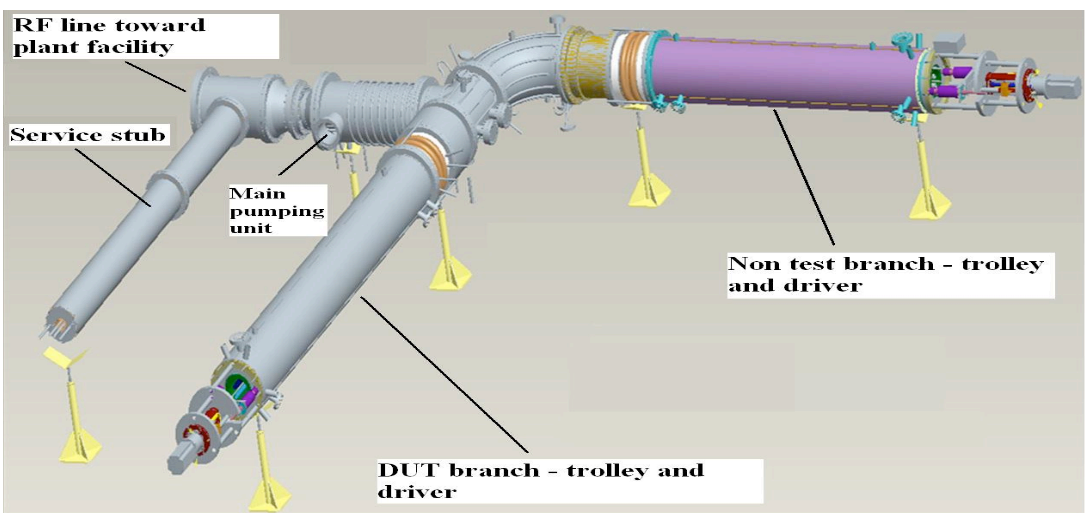

FIGURE 1. T-resonator description (DUT as Device Under Test).

T-RESONATOR COMMISSIONING

Trolleys, driver and resonator upgrade were completed after three months of manufacturing [6]. Assembly was completed and the drivers were adjusted to cope with commercial contact insertion force. During the T resonator commissioning a second trolley with commercial contact was setup into the test branch (DUT). This offers a fast track for completing the T resonator commissioning which is conducted in parallel of the RF contact R&D. For the final test campaign, commercial RF contact into test branch will be removed and replaced by the foreseen RF contact to be tested.

A higher insertion force than predicted was observed. The first displacements of trolley were successfully achieved with displacement monitoring working correctly. Although at first, a faulty Viton™ gasket at the end line prevented adequate vacuum performance, the resonator has now been pumped to below 5.10^{-4} Pa with a baking temperature of 120°C. The pressure was dropped to $2.2.10^{-5}$ Pa during the subsequent cool down to ambient temperature.

Today, the T resonator commissioning has been achieved (as presented in table 1) and all the system has been commissioned. Long RF shot under vacuum conditions was performed (60kW – 2kA±6%). Matching is well achieved and RF power was applied with a few ten of kilowatts (60-70kW). Outgasing was observed at the very beginning with an increase of pressure above 1.10^{-3} Pa and was followed by very fast recovery of vacuum pressure.

TABLE (1). Main results after T resonator commissioning.

ITEM	Achievable
Maximum test branch short circuit current	*2.28 kA ±6% peak (Pf = 71kW±5%)*
Maximum non test branch short circuit current	*1.36kA ±6% peak (Pf = 71kW±5%)*
Maximum voltage inside	*43.46kV ±6% (Pf = 71kW±5%)*
Maximum duration	*600s (60kW – 2kA ± 6% test branch side)*
Temperature - steady state operation	*Equilibrium temperature is reached after 30s*
Cold water loop	*Increase by 2°C of the test branch trolley temperature* *No temperature increase from distributed thermocouples (located along the outer part of the resonator) No hot spots detected (by vacuum window inspection)*
Vacuum pressure – steady state operation	*Pressure recovery is well observed on the two probes 10^{-3} Pa* *Better conditioning should improve the pressure value during operation*
Trolley and RF response	*Good response of matching capability at 62.5MHz± 1 MHz* *A slight increase of reflected power is observed (on scope) and a flat response after reaching the equilibrium temperature. In any case Pr <1kW* *Voltage probes respond well (no signal deterioration)* *No arcs during long pulse operation (60kW)*

RF CONTACT AND SAMPLE DEVELOPMENT

In parallel of the T-resonator upgrade, consequent R&D was performed in developing and manufacturing two samples with embedded RF contacts dedicated to the ITER ICRH antenna. When samples are completed, they are inserted into the end line of the test branch of the T resonator for extensive tests as described in the program roadmap.

Looking at the RF contact itself, the main conceptual idea is to dissociate both mechanical and electrical properties. RF current flows on copper lamellas which are welded at one extremity and left free at the other end. The RF current is flowing along the lamella thru the welded part which improves considerably the thermal exchange. On the other hand, mechanical spring property of RF contact is given by inserting a twisted spring under lamella. That should offer a sufficient working range of the RF contact and reliability during antenna assembly and operation (long baking time, vacuum conditions, and 10 years life time duration)

Before embedding the RF contact into the sample, several achievements and know-how were successfully completed step by step. Designed and manufactured samples must be relevant with the ITER antenna specifications (water cooling, material and assembly). Samples are made of titanium (grade 5) by special diffusion bounding technics which are relevant for the future RVTL (Rear Vacuum Transmission Line of ITER antenna) manufacturing. Copper plating of titanium sample is also highly required to minimize RF losses. This work was achieved and considerable know-how and confidence was gained. One layer (gold-palladium) was performed on sample to offer a good adherence after brazing cycle (RF contact are brazed on sample). Then a pure copper was coated and passed also brazing cycle (890°C). Final layer is a gold nickel strike to allow lubricant, anti-oxidation and hard wearing resistant finish. This layer is performed on sample and RF contact along RF current path. Successful manufactured samples with brazed RF contact are presented in Fig. 2.

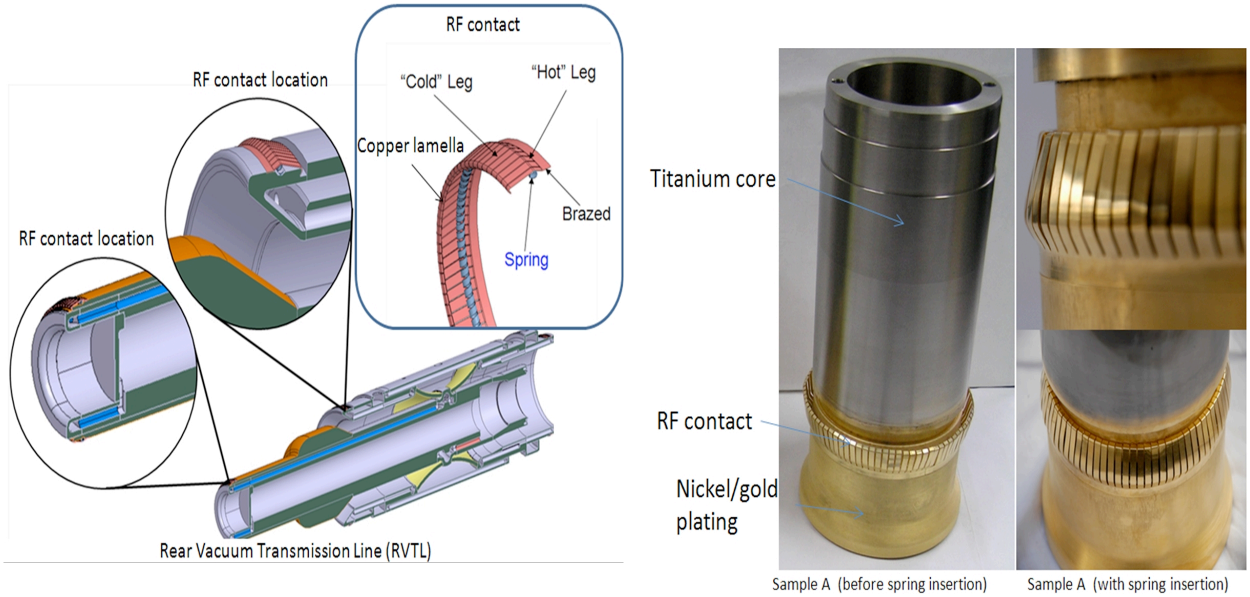

FIGURE 2. Left: RF contact localization and description). Right: Sample A manufacturing.

PRELIMINARY RESULTS

First insertion of the sample into the test branch end line of T resonator did not succeed due to unexpected spring stiffness. Investigations were done with sliding measurements (performed into a tensile test bed) and modeling to understand the excessive stiffness and solve this issue. Today, two curative actions are proposed. The first one is to increase the pitch of spring to reduce by a factor 2 the whole stiffness of the RF contact. The second one is to perform the insertion with power cylinders but does not allow further sliding tests with RF power into T resonator.

CONCLUSION

A considerable work has been carried out to tackle very challenging RF contact development for ITER ICRH antenna. The T resonator test bed was successfully commissioned and is now ready to utilize RF contacts. R&D on samples with embedded RF contact was also completed, resulting in significant know-how and good results (plating, diffusion bonding, brazing). Insertion difficulties due to high stiffness of RF contact did however involve some delays in the testing schedule. Curative actions are ongoing and trial insertion will be performed very soon, followed by RF power test.

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