HIGH POWER TESTS OF TRASCO RFQ COUPLERS

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Abstract

The TRASCO RFQ is powered by eight coaxial power couplers, magnetically coupled to the cavity by a loop-antenna. Couplers were designed to support up to 140 kW in cw operation. After a test-stand validation with a 10 kW power amplifier in Legnaro, the system was tested up to full power at CEA-Saclay. This paper covers the main steps of the coupler validation and conditioning results.

INTRODUCTION AND LOW POWER TESTS AT LNL

Two RF couplers were constructed based on the design developed in [1]. The RF coupler consists of the drive loop, the coaxial transmission line (inner diameter 19.4 mm, outer diameter 38 mm) and its associated cooling channels, and the coaxial alumina window (Figure 1).

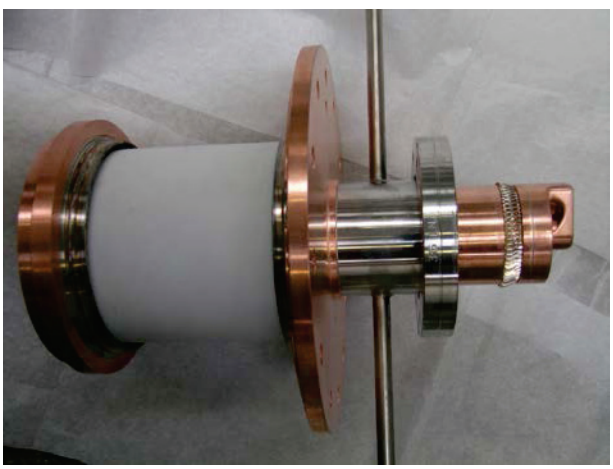

Figure 1: RF coupler system with loop, coaxial transmission line and coaxial alumina window.

In order to match the impedance of the coaxial line with the WR2300 waveguide used for the RF distribution, a "half doorknob" matching device is employed. The relatively small dimension of the coupler is determined by the 57 mm diameter of the RFQ port, in turn due to the small cross-sectional construction of the RFQ structure. The inner conductor of the loop is cooled via a coaxial SS tube and the outer conductor with a cooling SS sleeve. In particular, the CU OFE (inner coaxial, outer coaxial and drive loop) and the LN316 (flange and cooling sleeves) sub-assemblies were constructed and cleaned separately and then brazed together in a single brazing step. Prior to the brazing, the dimensions of the loop were determined after a set of measurements performed on the first two modules of the RFQ with on-purpose built aluminium dummy couplers. Finally, the cylindrical RF alumina windows were TIG welded on the coupler body. Such windows are the same used for the NC LEP couplers and can withstand up to 140 kW CW RF power.

In order to allow the RF processing of the couplers a bridge waveguide cavity was employed. Such cavity is made with aluminium and is water cooled through the cooling sleeves on its walls. An aluminium strip acts both as RF joint and vacuum seal. The cavity has two ports in order to allow the conditioning of two couplers, one connected to the RF source and the other connected to the load, with minimum reflection (RL=-15 dB). HFSS simulations showed that about 30% of the input power is dissipated on the cavity walls. Figure 2 shows the couplers connected with the bridge cavity.

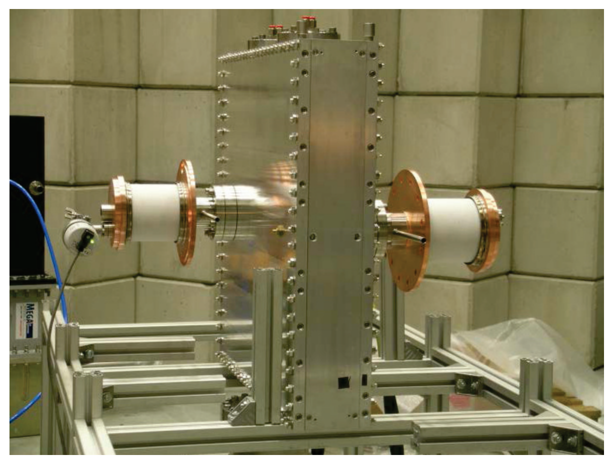

Figure 2: View of the two couplers connected with the bridge cavity. It is possible to notice the cooling channels and the RF windows.

A dedicated low power test-stand was installed at LNL for system validation, in which the RF source was provided by a 10 kW solid state amplifier. Before the final assembly, the coupler components were cleaned; the two couplers were inserted in the bridge cavity and baked out under vacuum with a maximum temperature of 150°C. During this baking process, one of the O-rings used to close the interface SS flange on the bridge cavity experienced problems at high temperature and started melting. The problem was not discovered during this test, because no vacuum analysis was available at the time and the O-ring melting had no impact on the vacuum level (later, it came out that the O-ring was not made of Viton®, as requested, but of NBR). However, after baking, a vacuum level of 1.9×10^{-8} mbar at the ceramic window location was measured.

The test in pulsed mode with 20 µs pulse length and a 500 ms repetition period started in March 2011. The power was increased from 100 W up to 9.5 kW playing

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with pulse length and repetition rate in order to speed up conditioning time. Two power levels required some hours conditioning time in pulsed mode: 400 W and 2 kW. Once these two levels were conditioned, CW operation was reached at 1 kW in few minutes and then power was increased up to 2 kW CW. At this point, power was raised with a 1.1 ms pulse length and 50 ms period length, thus reaching 9.5 kW in a short time. After conditioning in pulsed mode, CW operation at 8 kW was reached without any problem in a few minutes. The two observed multipacting levels were foreseen with Multipacting Calculator code with a 10% error.

HIGH POWER TESTS AT CEA SACLAY

After low power tests at Legnaro, the coupler test stand was disassembled and reassembled at CEA/Saclay (France). This installation differs from the previous one for the power amplifier, the RF distribution up to the coupler waveguide and for the power load. In particular, a 1 MW power klystron was used. The RF distribution consisted of a long WR2300 waveguide path connected to the coupler test system through a taper and a half height bellow. The power exiting from the bridge cavity via the output coupler was collected by a 100 kW coaxial water load (Figure 3).

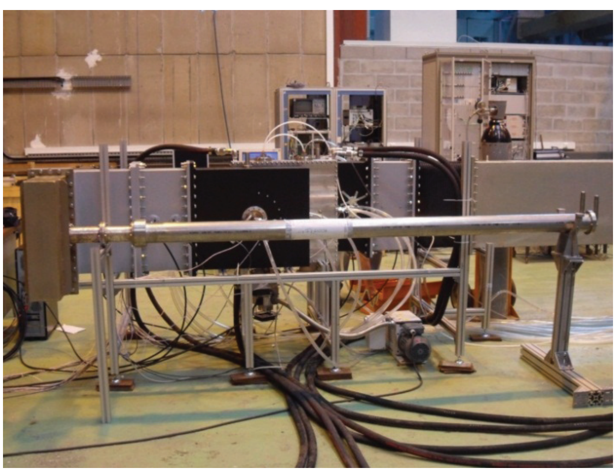

Figure 3: The RF couplers test stand assembled at CEA Saclay

The diagnostics equipment of the test stand included: forward and reflected power detection for both couplers, vacuum level on the two couplers in correspondence of the vacuum gauges placed on the top of the coaxial line, temperatures on the critical parts of the bridge cavity, of the couplers and of the water load, arc detectors placed in correspondence of the two RF windows on the air side and arc detectors placed on bridge cavity in front of couplers loops. Due to the fact that the power on the coupler connected to the load was less than the power on the drive coupler, the conditioning proceeded in two steps. In the first step, one of the couplers was conditioned up to 140 kW and the second one at 100 kW. In the second step the couplers configuration was reversed and the second couplers was conditioned up to 140 kW.

The Local Control System (LCS) manages data acquisition and storage, as well as diagnostics and interlock managements. Data acquisition and storage was performed by Siemens® S7-300 PLC connected via ethernet to a PC equipped with the HMI. The HMI, which includes archive functions, was developed with the software *WinCC*. In pulsed mode RF power levels had to be acquired in time correspondence with the power pulses. In order to do that, a particular PLC synchronization procedure was developed. In this way, it was possible to take measurements with an update frequency up to 50 Hz, for power pulses with width greater than 1.07 ms. For shorter pulse length the readings were taken manually, by looking at the vacuum controllers and the oscilloscope. As for interlocks is concerned, the LCS permits to set thresholds for vacuum, forward and reflected powers and temperatures, which, once they are overcome, the slow interlock (100 ms) is fired and RF power is cut, while the threshold value is overcome. As for arc detection, once an arc is detected, the fast interlock (few μs) directly connected with the klystron input cuts the RF drive signal, and permits the recovery of the RF power in 100 ms.

As a general rule, the conditioning rate was paced by the vacuum level or multipacting. As the duty cycle was increased, the presence of vacuum instabilities (typically above 10^{-6} mbar) drove the maintenance of the pulse length and rep rate up to re-establishment of the baseline vacuum level (from 10^{-7} mbar to 10^{-6} mbar depending on the average RF power). In case the vacuum instability was persistent, typically the pulse length was decreased in order to limit the outgassing activity before proceeding with higher power levels. In any case, during the absence of the operator overnight, the system was always left in a stable condition (no vacuum instabilities). As for multipacting is concerned, in addition to the level already conditioned at LNL, another level associated with the bridge cavity (also predicted by calculations) appeared at about 90 kW. The usage of short pulses in the order of 20 μs with 1 to 10 Hz rep rate allowed the conditioning of these levels, too.

Conditioning started on June 27th and, during the first part of the process, power was fed at very low duty cycle (0.05% at maximum) in full reflection conditions. This was caused by the lack of water in the load. After fixing the problem, full transmission was obtained with a reflected power at the first coupler of about 5%. This value was in perfect agreement with HFSS simulations. In this condition, the entire power range up to 155 kW peak power was explored with up to 2% duty cycle on June 30th. On the following day, the duty cycle was set to CW and the power was raised from 5 kW up to 116 kW. In this condition, the vacuum level did not exceed $4*10^{-6}$ mbar for most of the time.

The conditioning resumed at the end of July, but due to some issues involving the PLC cards of the LCS, it was only possible to act manually. In this session, the conditioning proceeded up to 75 kW average power. Above 130 kW peak power, outgassing phenomena up to 10^{-4} mbar and discharge events increased strongly. An enhancement of the radiation emitted by the cavity also appeared and this forced the improvement of lead shielding configuration. At power stop, the problem of the melted O-ring appeared. The system recovered in two hours, but it was decided to stop the conditioning and to start again after summer.

After the summer break and a period of scheduled maintenance of the CEA test stand cooling system, operations resumed on October 21st with 100 ms rep rate and with pulse length up to 0.5 ms up to the nominal power. Then RF pulse duration was increased on October 25th up to CW and 140 kW. At this point, in the afternoon of the same day, a series of severe arcs occurred and consequently the vacuum level deteriorated up to $5*10^{-5}$ mbar. This phenomenon forced the conditioning to restart by drastically reducing the pulse duration to 0.15 ms up to 7 ms and by ramping again the RF power from 30 kW to 140 kW on the following three days.

In the following week, RF average power was gradually increased, both by increasing pulse length and peak power. In Figure 4 it is possible to see the conditioning results between Nov 7th and Nov 10th.

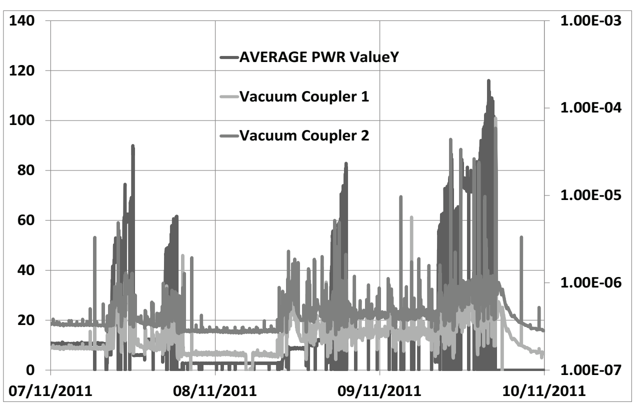

Figure 4: The average power and the vacuum level in the two couplers vs time.

On the following week, it was finally possible to get the nominal value of 140 kW for a run of some hours.

At this point, the system was disassembled to reverse coupler configuration. While the coupler close to the water load did not present any particular problem, the coupler conditioned at high power showed a strong aluminum sputtering on external surface. The problem can be explained in the following way: the melted O-ring was responsible for the vacuum tightness very near to the zone where the problem appears. In the same point the RF seal is present. As the SS flange and the aluminum cavity experience a thermal cycling due to average power variation, the bad vacuum seal due to the melted NBR O-ring causes some gas to penetrate in the zone of the RF seal. During conditioning, electric field penetrated in a region with poor vacuum, caused by the damaged O-ring, in which free electrons generated by aluminum oxide as well as brazing material in the brazing groove were present. This fact generated sparks at high values of electric field and aluminum sputtering on the copper surface (Figure 5), as already observed in July 2011. Moreover, since HFSS simulations showed that H field on the RF seal zone was equal to about 7000 A/m at 150 kW input power, during a discharge the current on a louver is likely to overcome the maximum design current of 1500 A. This caused a deterioration of the contact resistance of the seal itself and therefore a non-zero voltage across the gap between the coupler and the bridge cavity port that could enhance electron emission and sputtering on the copper.

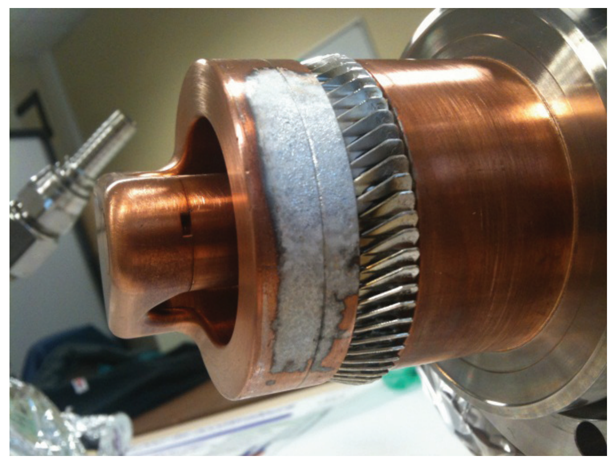
Figure 5: Particular of the coupler after the tests: the aluminum sputtering on the copper surface and the damaged spring contact are visible.

In order to mitigate the problem during conditioning of the reversed configuration, the vacuum threshold on the coupler was decreased and the recovery time after vacuum interlock was extended. With this new procedure, the conditioning of the second coupler was fast and with fewer sparks and the nominal power was reached as well.

CONCLUSIONS

Both the couplers were successfully tested up to nominal power and then they were used for the high power tests on the RFQ [2]. It should be noted that the issues met during conditioning were mainly due to a component, the O-ring, not pertaining to the coupler itself. Anyway, in order to improve reliability of the coupler itself, it will be necessary to improve the RF joint and, more generally, the interface volume between the coaxial and the RFQ body in terms of vacuum and field strength.

REFERENCES

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