

## TESTS OF 704 MHz 1MW POWER COUPLER AT SACLAY

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### Abstract

Coaxial 704 MHz power couplers have been developed for high intensity superconducting proton linacs. Projects like the Superconducting Proton Linac (SPL)[1] at CERN or the European Spallation Source ESS require up to 1 MW pulsed power with a high duty cycle in the high energy section of superconducting elliptical cavities. One pair of couplers has been successfully conditioned on the 704 MHz test stand at Saclay at room temperature at a maximum power of 1.2 MW, with 2 ms pulses and 50 Hz repetition rate, equivalent to 10% duty cycle. In order to test the coupler in realistic conditions with its cryogenic environment, we prepare a cold test with a cavity in the horizontal cryostat Cryholab.

### INTRODUCTION

The development of superconducting high intensity pulsed proton linacs with duty cycles in the 1-10% range requires RF couplers to deal with high peak power, since cavities are foreseen to run at high gradient with high peak currents. The average power is high enough that RF dissipation aspects have to be dealt with, both for thermal stability when the couplers are integrated on a cavity inside a cryostat, and for integrity of the components such as the ceramic window. We have developed a 704 MHz coupler [2] based KEK-B coaxial window design [3]. The outer conductor connecting the window to the cavity is a double walled stainless steel cylinder, 100 mm in diameter, incorporating gaseous He cooling channels. It has been copper coated at CERN using magnetron sputtering. A doorknob transition ensures the connection between the air side of the window and the WR1150 waveguide network (Fig.1 ).

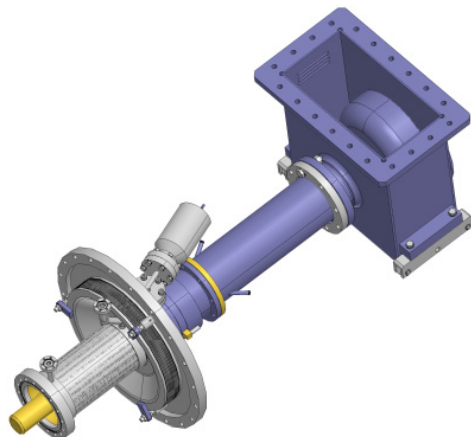


Figure 1: Schematic view of the coupler.

This coupler was originally meant to run at 250 kW peak power with a 10% duty cycle on a medium  $\beta$  5-cell cavity, but since the RF design permits a much higher power handling, the cooling scheme was designed accordingly, aiming at 1 MW peak power, 10% duty cycle. Two separate cooling circuits are built in the coupler, one for the whole inner conductor, one at the periphery of the ceramic disk. The inner channel cools the antenna tip, the inner part of the ceramic, and the air part of the coaxial line in that order. One requirement is to keep the coupler antenna from heating to minimize the radiative heat transfer to the superconducting cavity operating at 1.8 K. Water cooling has been preferred upon forced air since it is able to limit the temperature increase at the antenna tip below 1 K instead of 30 K at full reflected power, which represents a gain of 50% on the radiative heat transfer to the cavity.

### COUPLER TEST STAND

The RF power is delivered by a 1 MW klystron, driven by a high voltage modulator running at 50Hz and providing 2 ms pulses up to 90 kV[4]. The circulator and loads are able to withstand full reflection in all phase conditions.

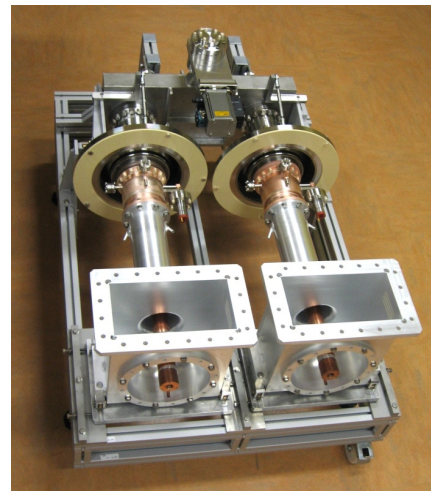


Figure 2: Couplers mounted on the coupling box.

The conditioning at room temperature is performed on a pair of couplers connected through a specifically designed vacuum waveguide, which is also used as a pumping port. This coupling box is made from stainless steel and is copper coated to reduce the RF losses at the maximum average power to a low level so no external cooling is required. The vacuum system consists in a 150 l/s turbomolecular pump and a scroll primary pump.

The couplers are mounted in horizontal position on the test stand, as shown on Figure 2.

Pressure, electron activity and light emission are monitored on each coupler in the ceramic window area. Electron activity is detected using a pickup antenna which is brought to a potential of 45 V and amplified with a fast electronic circuit. Visible light emitted in the coupler is amplified using a photomultiplier (PM). Antenna cooling circuits are connected in series, and 3 thermal sensors enable the measurement of water temperature increase in each coupler. The same configuration is used for the ceramic outer cooling circuits. The full test stand is shown in Figure 3:

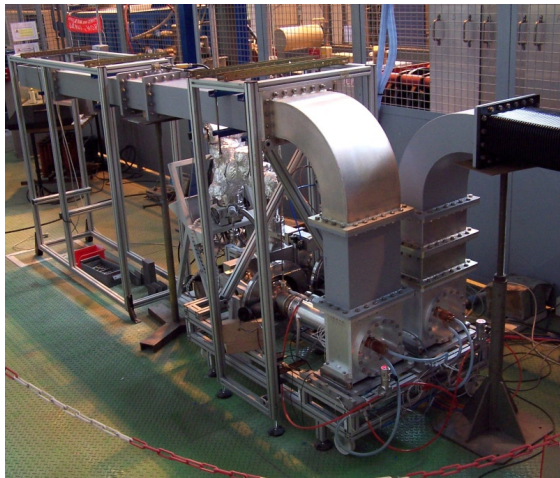


Figure 3: Test stand connected to the RF power station

### COUPLER PREPARATION

The coupler and coupling box have been assembled in our class 10 cleanroom. All components but the ceramic window have been cleaned in ultrasonic bath and rinsed with ultra-pure water. The windows and antennas have been blown with pressurized class 10 air before the final assembly. All subsequent transfers of the vacuum parts of the couplers has been carried out with the antennas in the vertical position, pointing to the ground in order to minimize transverse acceleration on bumps or small steps.



Figure 4: coupler assembly in the class 10 clean room

This vacuum parts have been baked at 180°C for 48 h on the test stand to remove water from the surfaces. The pressure in the windows after baking was  $7.10^{-8}$  mbar ( $6 \cdot 10^{-8}$  mbar before).

### COUPLER CONDITIONING

#### Conditioning Strategy

The enabling of RF is based on hardware interlocks : user defined threshold on the pressure level, on the water flow in the cooling circuit, and status of the main vacuum valve.

Faster interlocks are electron current in the pickup and the amplified light intensity. The voltage output of these diagnostics is compared to a threshold using analog electronics which permits to shut down the power during the RF pulse, and restore it in 50  $\mu$ s as the activity is reduced under the threshold. This is more efficient than disabling the whole RF pulse and wait for the next one. The general behavior of the power level is controlled by a Labview application which also records the RF levels, vacuum, electron and light measurements. The data are not recorded for every pulse due to the high pulse rate, but every 4 s instead. A screenshot of the RF and vacuum panels is shown in Figure 5.

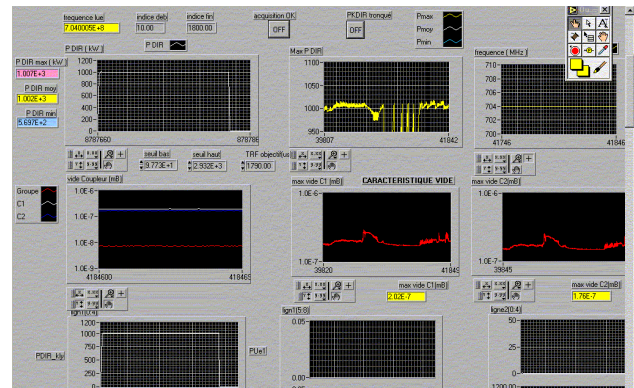


Figure 5: RF power, vacuum data recording panel

The RF power level is increased every N pulse according to a user defined step, only if no incident has occurred, otherwise it is reduced automatically. An incident is either an hardware interlock or a pressure reading by the NI/Labview acquisition system exceeding a software user defined threshold ( $2.7 \cdot 10^{-7}$  mbar for these tests). This later facility is used mainly by setting vacuum software threshold lower than hardware vacuum threshold ( $3 \cdot 10^{-7}$  mbar) in such a way as to reduce the number of hardware interlocks, but being at the edge of them most of the time. In this way, we maximize the outgassing rate, while reducing the number of large pressure bursts potentially dangerous for the couplers. This conditioning method was defined on our former 1.3 GHz coupler test stand [5].

#### Power Ramping in Travelling Wave

The first power ramping up to 300 kW was done with 50  $\mu$ s pulses exclusively, reducing the repetition rate  $F_{rep}$

from 50 Hz to lower discrete values of 25, 12.5 or 6.25 Hz to reduce the outgassing rate in some power ranges.

Around the 300 kW level, the RF was interrupted from the photomultiplier interlocks, but no pressure increase was involved, so the pulse were lengthened progressively in order to generate outgassing, and achieve a more efficient conditioning. The 310-520 kW range was processed at 50 Hz with 120  $\mu$ s pulses.

The 200-550 kW range was then processed using slow power ramps, gradually increasing the pulse length to 2 ms at 50 Hz, which is the nominal duty cycle of 10%. The 80 kW region had to be reprocessed, then the power could be raised up to 720 kW without vacuum events. Above this power level, the duty cycle was reduced to process the couplers up to 900 kW.

At 6% DC (1.2 ms pulses at 50 Hz) and 900 kW (54 kW average) a water leak and arcing occurred on the air part of the inner conductor of the downstream coupler, at the connection between the window and the doorknob. Inspection showed that arcing had cut the Viton gasket ensuring the water tightness. The RF surface was pitted but could be re-polished and cleaned. The ceramic disk of the window was not damaged in the process. It is difficult to determine if a small water leak started the arcing, or if an arc cut the gasket in the first place. The coupler was re-aligned and assembled using the original parts, only the gasket was replaced.

The processing was resumed with 100  $\mu$ s, 12.5 Hz pulses. Within 4 hours, the power could be raised to 1 MW, with light activity only at 400 kW. The pulses were then lengthened from 100  $\mu$ s to 1.6 ms, keeping a repetition rate of 12.5 Hz, up to 1 MW. Then the rate was doubled to 25 Hz, and the pulse length gradually increased from 1.2 to 2 ms, while ramping the power from 50 kW to 1 MW for 18 hours. The same procedure was then applied for  $F_{rep} = 50$  Hz, increasing the pulse length from 1ms to 2ms, by 200  $\mu$ s increments. Most of the processing occurred for the longer pulse length of 1.8 and 2 ms between 1 and 1.1 MW.

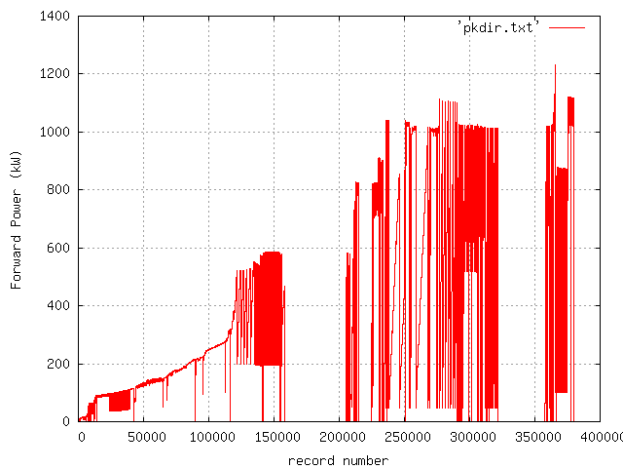


Figure 6: Klystron output power history

The complete power and vacuum history of the processing in TW is shown on Figure 6 and 7 respectively. Both coupler had very similar behaviour. The total RF time can be estimated to 300 hours for TW conditioning. The maximum power of 1.2 MW at 10% DC was obtained, limited by the klystron capabilities.

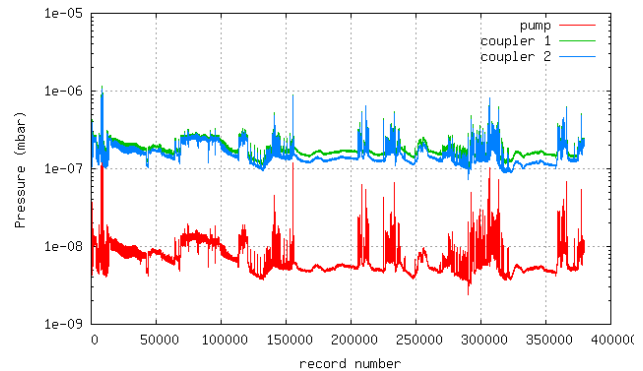


Figure 7: Vacuum history

Temperature measurements on the antenna water cooling circuits indicate that for a nominal flow of 2.4 l/min, the temperature increases by 1.6 K at 100 kW average RF power. This corresponds to a power extracted from one complete antenna of 270 W. A similar measurement on the external cooling channel of the window yields 33 W.

### Standing Wave Processing

The processing in SW had to be carried out with lower duty cycles due to a failure of the main 110 kV 2.5 A High Voltage Power Supply (HVPS).  $F_{rep}$  was reduced to 0.72 Hz and later 0.31 Hz, nevertheless, pulse length between 300  $\mu$ s and 2 ms could be obtained with a spare HVPS. The SW processing could not be conducted as thoroughly as foreseen due to repetitive problems with the spare HVPS. The scope of the processing was restricted to search for power levels and short circuit positions where mostly light activity was detected on the photomultipliers, in order to process them. The maximum forward power obtained was 940 kW, with 1 ms pulses at 0.31 Hz.

## CONCLUSION

The couplers have been conditioned up to 1.2 MW at 10 % duty cycle. One coupler has been transferred on a  $\beta = 0.5$  5-cell 704 MHz SC proton cavity in the class 10 clean room, and installed in CryHoLab to perform the full test of the system in realistic conditions. In particular, the efficiency of the He cooling circuit will be checked.

## ACKNOWLEDGMENTS

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**REFERENCES**

- [1] F. Gerick et al., "Conceptual design of SPL II", CERN-2006-006
- [2] G. Devanz et al., '704 Mhz High Power Coupler and Cavity Development for High Power Pulsed Proton Linacs', Proc. of Linac 08, Victoria BC, 2008.
- [3] S. Mitsunobu et al., "High Power Input Coupler for KEKB SC Cavity," Proceedings of the 9th Workshop on RF Superconductivity, Santa Fe, NM, 1999.
- [4] S. Chel et al., 'New 1 MW 704 MHz RF test stand at CEA-Saclay', Proc. EPAC08, 2008 Genoa.
- [5] C. Travier et al., "Design and test of a 1.3 GHz travelling wave window", Proc. 9th Workshop on RF Superconductivity, 1999, Santa Fe, NM.