CRYOGENIC TESTS OF A 704 MHz 1 MW POWER COUPLER

G. *Devanz*, D. Braud, P. Carbonnier, J.-P. Charrier, S. Chel, M. Desmons, A. Hamdi, H. Jenhani, D. Roudier, P. Sahuquet

CEA IRFU, F91191 Gif-sur-Yvette, France

Abstract

Coaxial power couplers capable of handling 1MW peak power have been developed for high intensity superconducting proton linacs. They have been conditioned in travelling wave up to the maximum power available on the Saclay test bench, 1.2 MW forward peak power, up to 10% duty cycle. One coupler has been assembled on a 5-cell medium beta cavity in the class 10 area of the clean-room, and installed in our horizontal test cryostat Cryholab. This paper focuses on the RF operation of the coupler in this cryogenic environment and thermal aspects.

INTRODUCTION

The development of superconducting high intensity pulsed proton linacs with duty cycles (DC) in the 1-10% range requires RF couplers to deal with peak power of the order 1 MW, as it is foreseen for SPL [1] and ESS [2] accelerators. We have developed a 704 MHz coupler [3] based on the KEK-B coaxial window design [4]. 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 coaxial window and the WR1150 waveguide network (fig. 1).

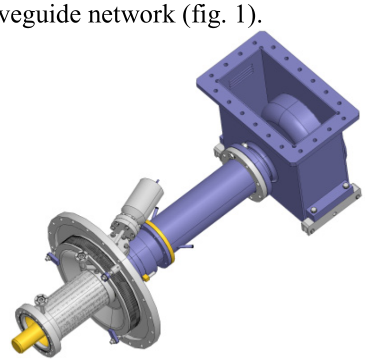

Figure 1: CAD view of the coupler

This coupler was originally meant to run at 250 kW peak power with a 10% duty cycle on a medium β 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

In the 704 MHz test area 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 [6]. The circulator and loads are able to withstand full reflection in all phase conditions. A pair of coupler has been processed on a coupling box up to 1.2 MW in travelling wave (TW) mode at 10% duty cycle [3]. SW conditioning was carried out up to 1 MW. The standing wave (SW) pattern was varied using a movable short, but only a few discrete positions were scanned before the failure of the high voltage power supply (HVPS). It was decided to proceed with the coupler assembly on the 5-cell beta=0.5 704 MHz cavity [5] to follow up with the high power test in pulsed mode of the full assembly in the Cryholab horizontal cryostat part of the SLHC-PP European programme, starting with a spare lower duty cycle HVPS.

COUPLER ASSEMBLY ON CAVITY

In order to prevent contamination of the cavity and subsequent field emission, the coupler installation must be carried out with the same level of cleanness than what is required as a standard for superconducting cavity preparation. Since previous cryogenic tests of this cavity had been plagued with field emission it was processed first with a light BCP and a high pressure water rinsing. The coupler and coupling box had been assembled in Saclay class 10 clean-room before the initial RF conditioning, then vented with dry nitrogen trough a calibrated leak and a metallic micrometric filter.

Figure 2: coupler assembly on the 5-cell cavity in the class 10 clean-room at Saclay/Orme des merisiers

A rail system has been designed and installed under the laminar flow (fig. 2) to support and move the cavity and coupler box in and out of the flow. They are heavy assemblies and cannot be handled manually with enough accuracy. Using the robot arm, the coupler is mounted on the cavity from above, with the coupler port facing up. The rails help in aligning the coupler and cavity beforehand. During all the operation, the coupler is never moved along the rails, only up and down. Instead, the coupling box and cavity are rolling under the suspended coupler. Compared to the horizontal installation, this choice has several advantages: the Conflat gasket can be installed easily on the cavity flange, and the tooling is kept simple for the specific configuration of this clean room. Additionally, the coupler sits on the cavity flange and seals the cavity before screws are even brought near this critical area for fastening. However, in contrast to the horizontal assembly scenario, the coupler remains for a short period of time over the open cavity port generating a large perturbation of the laminar flow.

CONDITIONING IN CRYHOLAB

Installation in Cryholab

The assembly was equipped with the magnetic shielding and installed in Cryholab (fig.3).

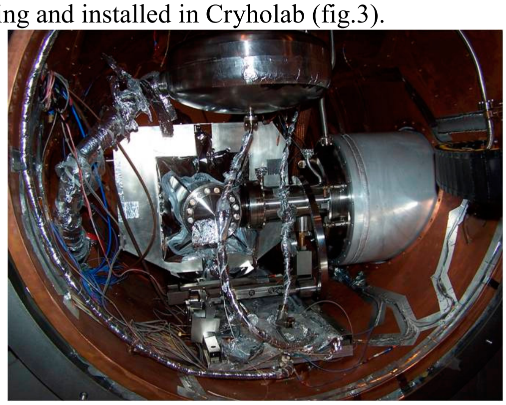

Figure 3: Cryholab during coupler and cavity installation.

The inlet of the cryogenic cooling of the double walled coupler outer conductor is connected to the main phase separator which provides liquid or gaseous He depending on the pressure drop across the circuit. The later can be varied between 0 and 150 mbar. The outlet of the coupler cooling is located inside the cryostat, connected to a heater and a room temperature control valve to maintain a constant the flow in the circuit.

First conditioning phase with detuned cavity

The conditioning was carried out with the same instrumentation and algorithm than described in [3] by gradually increasing the pulse length from 50 µs to 2 ms and ramping the forward power. For this first sequence we used a spare HVPS with a lower repetition rate of 5 to 6.25 Hz. The goal was to be able to provide 2 ms pulses with a peak power up to 500 kW to be ready for cavity experiments. While the cavity is in the superconducting state, its loaded Q is 1.85e6. The quench field would be exceeded with 2 ms rectangular pulses above 75 kW. To overcome this limitation on the forward power the cavity must be detuned with respect to the RF generator. In this case, no power is transferred to the cavity, which is acting as an open circuit seen from the coupler. The standing wave pattern in the coupler is constant in time.

During coupler processing light and electron emission was detected at discrete levels (90, 305 and 325 kW, see fig. 4). The light emission around 300 kW was difficult to process, in contrast to the electronic emission which disappeared in only several power ramps.

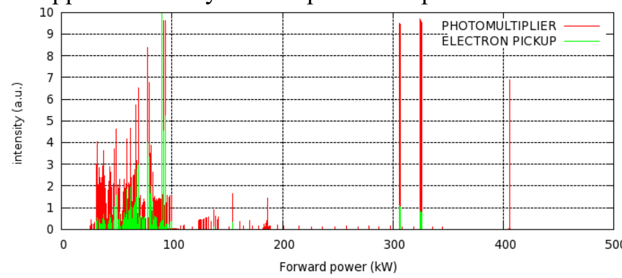

Figure 4: Photomultiplier and electron pickup signals for 1ms pulses during the first conditioning on Cryholab

On tune operation

After conditioning, the coupler could be used to feed the cavity for the for Lorentz detuning compensation tests with the piezo tuner up to 13 MV/m. Unlike in the detuned case of the first processing phase, continuously time-varying varying reflection conditions occur in the coupler when driving a cavity on tune in pulsed mode. In particular, a backwards wave travels through the coupler when the field decays in the cavity immediately after the end of the forward RF pulse. Some processing was necessary to get rid of light emission corresponding to the TW decay from the highest cavity fields, but otherwise no extra processing was required.

HIGH AVERAGE POWER OPERATION

Once the damaged HVPS was repaired and upgraded coupler conditioning was resumed on the detuned cavity, this time with repetition rates up to 50 Hz with 2 ms RF pulses (10% DC). The behaviour of the coupler was similar to what was observed during the first conditioning, with no activity observed above 325 kW peak power. Around 700 kW, breakdowns occurred in the circulator. A workaround was to inject N_2 in the waveguides, but this lead to breakdowns in the air side of the coupler between 700 and 800 kW. This situation ceased as soon as N_2 injection in the coupler was stopped. The arc detection protected the coupler but some copper was sputtered on the air side of the RF window during the incident.

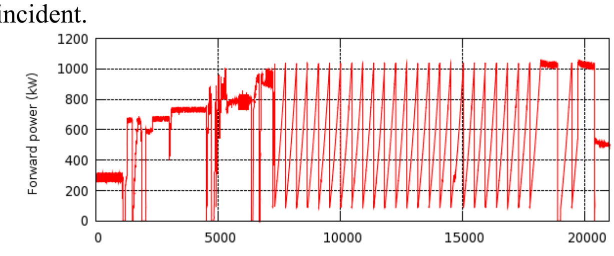

Figure 5: Forward power history at 10% DC

The ceramic disk was carefully cleaned in-situ. The operation resumed and 1 MW at 10% DC could be reached and maintained successfully, without any processing events (fig.5).

In the detuned case, E is maximum at the position of the ceramic disk (fig. 6), so dielectric losses in the ceramic disk are maximized. H is maximum very near the cavity to coupler connecting flange and gasket (fig. 7).

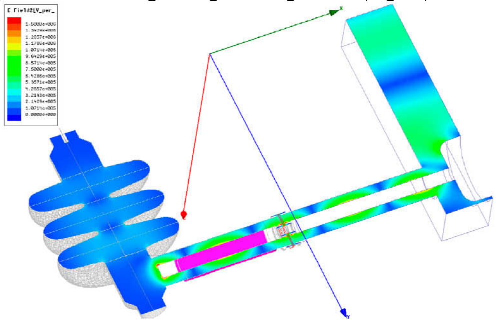

Figure 6: Electric field amplitude in the detuned case

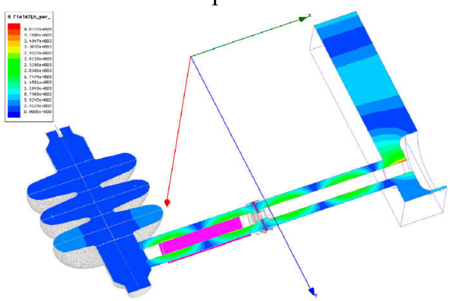

Figure 7: Magnetic field amplitude in the detuned case

Resistive losses on the outer conductor are inhomogeneous, so the power density is maximal. The detuned condition tested here is more demanding for the coupler cooling compared to a machine configuration with a tuned cavity.

Cryogenic cooling

The efficiency of the He cooling circuit can be measured with a compensation method using a calibrated heater installed on the superfluid He bath of the cavity. Starting with no He flow in the circuit, the heater is off, and the temperature of the superfluid is 1.8 K. The flow is then set to a fixed value (0.6 m^3/h for the measurements presented here), and the heater is adjusted to bring the Helium bath temperature back to its former value.

Without RF, the coupler contributes to the 1.8 K thermal load mostly by conduction. In this configuration we measured that 16.8 W were extracted with a He flow of 0.6 m^3/h in the coupler (measured at 300 K and atmospheric pressure). The measurement of the static heat load due to the coupler thermal conduction would have required a specific experimental setup and has not been carried out. A figure of 20 W can be computed, but this estimated value does not take into account the thermal resistance provided by the Conflat flange connection which is difficult to predict.

The RF induced thermal load on the 1.8 K circuit was measured with the same method. With forward RF at 1MW, 10% DC, it amounts to 12.3 W with the same He flow of 0.6 m^3/h. Halving the RF power led to 6.3 W, confirming the previous result. To achieve a better cooling efficiency, higher flow rates will be probed. It is interesting to measure the RF thermal load in the tuned cavity case. However it must be done at lower peak power and the required measurement sensitivity is not compatible with the current setup. An IOT capable of delivering 80 kW in CW is currently being installed in the test area, which will enable this measurement. With this new setup, it will be possible to shift the position of the standing wave pattern by progressively detuning the cavity to discriminate among the different contributions to RF losses.

Cooling of room temperature parts

Two separate cooling circuits are built in the coupler, one for the whole inner conductor, the other 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. De-ionized water has been used during all tests. At 1 MW, 10% DC operation, the window air side was only cooled by natural convection. Temperature measurements indicated that 370W were extracted from the antenna by the cooling water circuit. Comparatively temperature measurements in TW mode made on the conditioning test stand on the antenna water cooling circuits at 100 kW average RF power yielded 270 W for one complete antenna

CONCLUSION

The 704 MHz power coupler has been operated up to 1 MW at 10% duty cycle connected on a detuned $\beta = 0.5$ 5-cell SC proton cavity in the Cryholab horizontal test cryostat. The He cooling of the outer conductor has a good efficiency to compensate for static losses, but is not yet fully optimized to deal with the most demanding detuned case at full average and peak RF power normally not encountered on an operating machine.

AKNOWLEDGMENTS

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