704 MHz HIGH POWER COUPLER AND CAVITY DEVELOPMENT FOR HIGH POWER PULSED PROTON LINACS

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Abstract

In the framework of the European CARE-HIPPI program we develop components for superconducting high pulsed power proton linacs at 704 MHz. We have designed, fabricated and tested a beta 0.47 5-cell elliptical cavity with an optimized stiffening to reduce its sensitivity to Lorentz forces. A fast piezo tuner has been developed in order to be able to operate the cavity in pulsed mode in our horizontal test cryostat CryHoLab. We also have carried out the development of a fundamental power coupler. It is designed to transmit a power up to 1 MW at a 10 % duty cycle. A high power test area has been setup consisting of a 1 MW klystron, a pulsed high voltage power supply and a coupler test stand.

INTRODUCTION

Elliptical superconducting (SC) cavities will be used in future high intensity proton linacs like SPL[1] for relative velocities β above 0.6. One goal of the CARE-HIPPI program is to build and test SC cavities for the lower energy section of pulsed proton accelerators. We have built and tested in vertical cryostat a 704 MHz 5-cell cavity optimised for pulsed operation at 2 K with a geometrical beta of 0.47, with a reduced sensitivity to Lorentz detuning [2]. The results of the vertical test are shown on figure 1. The measured static Lorentz coefficient K_L is -3.8 Hz/(MV/m)^2.

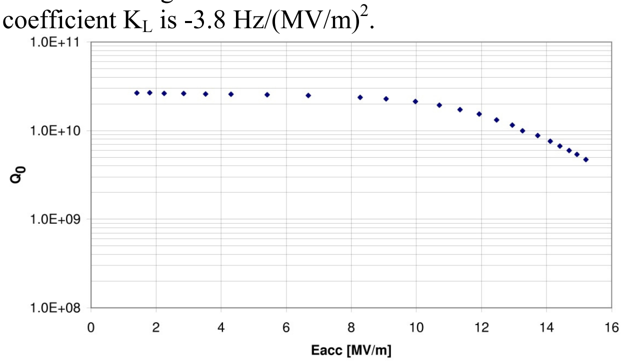

Figure 1: $Q_0(E_{acc})$ curve at 1.8 K.

The full test in pulsed mode in vertical cryostat requires developing of a fundamental power coupler (FPC) and setting up a pulsed power RF installation. Although the power needed for this type of cavity is limited to several hundreds of kW, the goal was to establish a 704 MHz test area enabling future developments demanding a higher power. In the higher energy section of SPL, a peak power of 1 MW must be transferred to the beam, this sets the target of our power coupler developments. The RF source has been commissioned reaching nominal parameters, 1 MW peak power, 2 ms RF pulse length at 50 Hz repetition rate [3]. The peak power can exceed 1.2 MW when the repetition rate is reduced. The circulator has been tested on a matched load at full power, filled with dry nitrogen. Tests have been performed in full reflection at all phases on a movable short, at nominal peak power and pulse length, but at the reduced repetition rate of 10 Hz. This limitation was due to a breakdown problem that occurred in the pulsed high voltage power supply which is being corrected.

Our horizontal test cryostat CryHoLab is being modified to accept the beta 0.47 cavity equipped with a FPC. The main changes are the larger FPC port, the LN2 copper thermal shield and the supporting systems for the cavities. Fig. 2 shows the new configuration with the cavity (mostly hidden by the magnetic shield) prepared for the low power measurements.

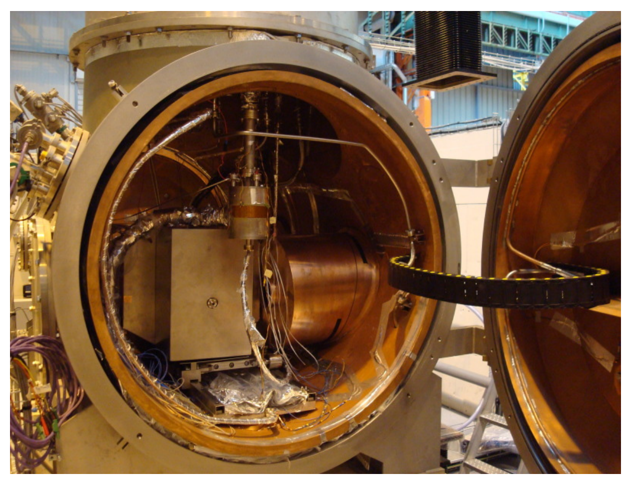

Figure 2: The new CryHoLab configuration.

PIEZO TUNER

We have developed a fast piezo tuner based on the Saclay-II tuner design [4] built and qualified on a 1.3 GHz 9-cell Tesla type cavity. The main difference is the size of the system, and the piezo support which consists of a stainless steel elastic frame holding a single 30 mm piezo stack. It is designed in order to apply an adjustable preload on the piezo, limiting the influence of the spring constant of the cavity. The slow tuning range is +/-2.5 MHz. The tuner is attached between the He tank and the beam tube flange opposite to the power coupler side. With our optimized design, the tuner does not increase the overall length of the cavity (fig. 3).

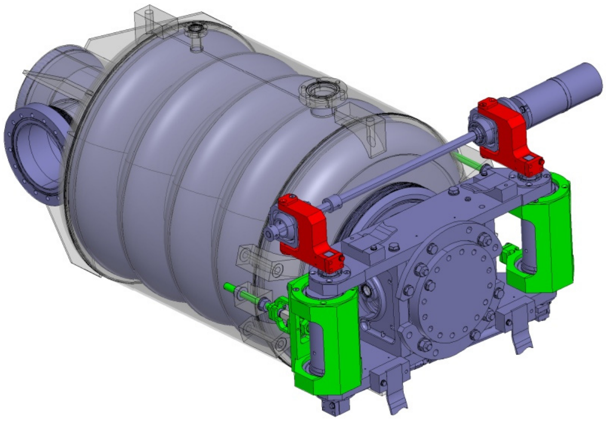

Figure 3: Cavity equipped with He tank and piezo tuner.

MAGNETIC SHIELDING

The CryHoLab horizontal cryostat is only partially shielded therefore a magnetic shield for the cavity had to be designed. The average magnetic field in CryHoLab at its new location is 20 µT. The surface resistance measured on the cavity is 6 nΩ at 1.8 K at very low accelerating field in a vertical cryostat which is well shielded. An extra shielding factor of 33 is needed to reach a maximal residual field of 0.6 µT. With this value is possible to limit the extra superconductor surface resistance due to trapped magnetic flux below 2 nΩ. The shield has been designed with Vector Fields OPERA code. Much effort was done to reduce the magnetic field penetration due to the coupler port. The shield is operating at 1.8 K and surrounds both the cavity and the tuner. It has been fabricated out of 1.5 mm thick Cryoperm® alloy. It can be seen partially on figure 1. Extra parts are attached to the base of the FPC when it is connected to the cavity.

FUNDAMENTAL POWER COUPLER

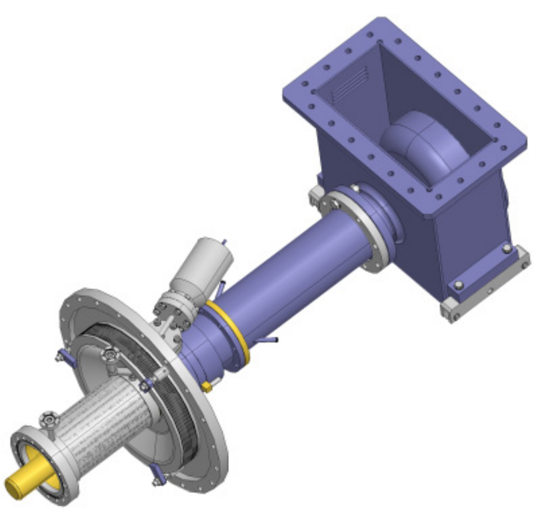

Figure 4: Overall view of the 704 MHz power coupler.

The peak power requirements to operate a cavity at 12 MV/m for typical beam current of 40 mA is around 120 kW. The power needed for the higher energy part of high intensity proton linacs such as SPL rises to 1 MW. We have aimed our design at this higher power levels. The duty cycle is targeted at 10% (100 kW average power). The design is similar to the KEK-B [5] and SNS [6] design, build around a coaxial disk window, and 100 mm coaxial line. The air part consists of a doorknob, which connects to a WR1150 waveguide (fig. 4).

The RF window is adapted from the KEK-B window, build around a ceramic disk. The RF adaptation is obtained using chokes on both inner and outer conductors. The coupler antenna is made of electropolished OFE copper to minimize thermal radiation on the Nb coupler port and beam tube and is electron beam welded to the window. Water cooling channels for the antenna are passing through the window core. The return channel is connected to the inner cooling channel of the ceramic. These coaxial cooling channels are connected to those of the inner conductor on the air-side, the inlet and outlets being at the doorknob. A prototype of the window with a shortened antenna has been built to check the RF transmission and the water tightness of the cooling channels connection.

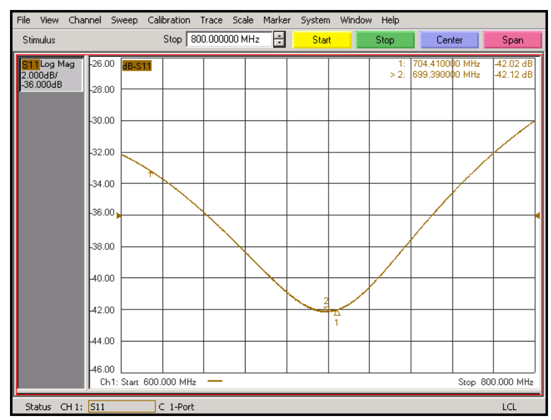

Figure 5: S_{11} measurement of the window prototype.

A measurement of the S_{11} is shown on figure 5, displaying a wide bandwidth of 200 MHz at -30 dB and a minimum reflection S_{11}=-42 dB at 700 MHz. Two complete windows have now been fabricated.

Figure 6: He cooled outer conductor.

The cold part of the coupler is a 100 mm in diameter, 50 Ω coaxial line. The outer conductor is a double walled stainless steel tube enclosing three separate spiral cooling channels. A counter-flow of He gas in used to adjust the temperature distribution along the conductor when operated in the cryomodule. The outer conductor has been plated with 10 microns copper at CERN, using microwave sputtering (fig. 6).

The length of the air side coaxial line is mostly constrained by the position of the cavity inside CryHoLab and the diameter of the vacuum vessel. The doorknob is made of aluminium (fig. 7). The knob itself is CNC machined to achieve mechanical tolerances. The junction between the antenna and the knob is of sliding type, so it can be electrically insulated to bias the inner conductor if needed during the conditioning. As expected, their bandwidth is only a few MHz.

Figure 7: Doorknobs with adaptors for RF measurements.

COUPLER TEST STAND

The conditioning bench is designed around a coupler pair interconnected by a coupling waveguide (fig. 8). The first coupler is connected to the 1 MW power source, while the second is either connected to a load or a variable short, to process them in TW or SW respectively. The coupling waveguide was coated with electrolytic copper to limit RF losses to 80 W at 100 kW average power. It is equipped with a pumping port, and connected to a dedicated vacuum system comprising a 150 L/s turbomolecular pump, backed up with a dry primary pump. The vacuum parts will be assembled in our class 10 clean room.

The instrumentation ports on the RF windows are equipped with an arc detector, an electron pickup, and a vacuum gauge. The logic of the interlock and processing automation is adapted from our former 1.3 GHz coupler test stand [7].

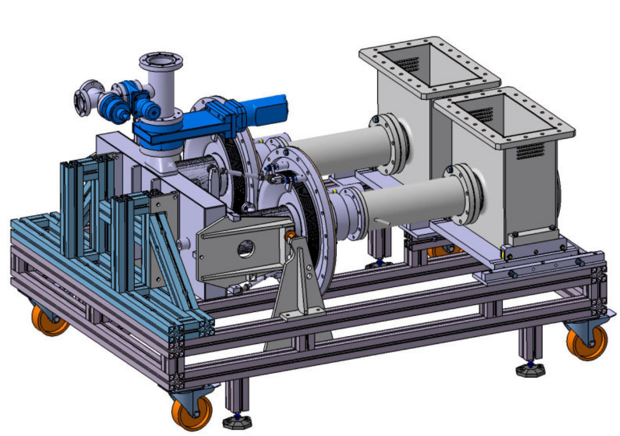

Figure 8: Coupler test bench.

Two couplers are now ready to be assembled and conditioned. One of the FPCs will then be connected to the β=0.47 cavity for the power tests in pulsed mode.

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