

STATUS OF 325 MHz MAIN COUPLERS FOR PXIE*

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Abstract

The Project X Injector Experiment (PXIE) at Fermilab will include one cryomodule with eight 325 MHz single spoke superconductive cavities (SSR1). Each cavity requires approximately 2 kW CW RF power for 1 mA beam current operation. A future upgrade will require up to 8 kW RF power per cavity. Fermilab has designed, procured and tested two prototype couplers for the SSR type cavities. Status of the 325 MHz main coupler development for PXIE is reported.

INTRODUCTION

A multi-MW proton accelerator facility based on an H-linear accelerator using superconducting RF technology, PIP II, is being developed at Fermilab to support the intensity frontier research in elementary particle physics. The PIP-II [1] baseline design includes two types of 325 MHz superconducting cavities, single spoke resonators, SSR1, with a $\beta=0.22$ and single spoke resonators, SSR2, having β of 0.47. The first cryomodule consists of eight SSR1 cavities and will be installed in PXIE at Fermilab [2]. Both type of cavities have a similar design and are equipped with the same size power coupler flanges. This will allow us to use the same design for power couplers that feed the RF power to both types of cavities. Power consumption of the cavities for both projects varies from 2 kW to 8 kW thus the 325 MHz power couplers should operate up to 10 kW in the CW regime. This paper presents the RF design and optimization, production and tests of this coupler.

COUPLER STRUCTURE

The coupler structure is presented in Figure 1. The parts inside the vacuum include a 3 inch stainless steel tube with 0.4 mm wall thickness, 0.5 inch copper antenna and 6 mm thickness ceramic window. The stainless steel pipe has no copper coating and the ceramic window is coated with TiN.

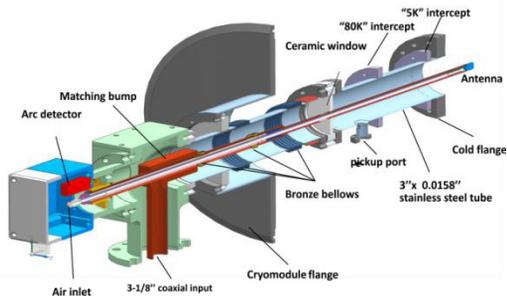


Figure 1: Structure of 325 MHz main coupler.

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The copper antenna is cooled with dry air. The coupler has two thermal interceptors at “5K” and “80K”. The parts that are not in a vacuum consist of copper tubes with Ni bellows coated with copper. Here, the inner conductor has a bigger diameter than the antenna to match the ceramic window. This design allows us to apply a high voltage (HV) bias in order to suppress any possible multipactor.

Three experimental couplers were fabricated. Figure 2 presents a coupler on a test bench for low power measurements and tuning. Figure 3 presents the coupler pass band after tuning; the pass band is about 20 MHz (~6%) at the level of $S_{11} < -20\text{dB}$.

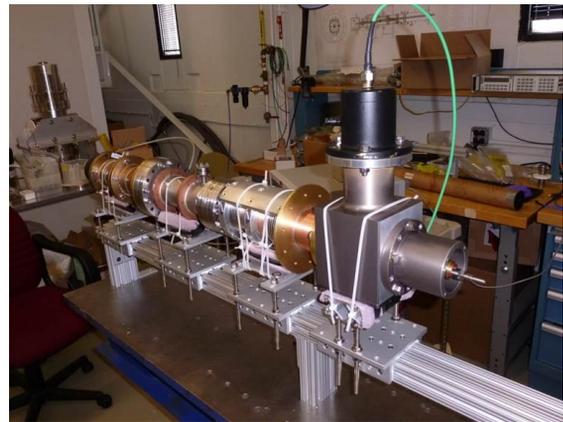


Figure 2: Coupler at test bench for tuning.

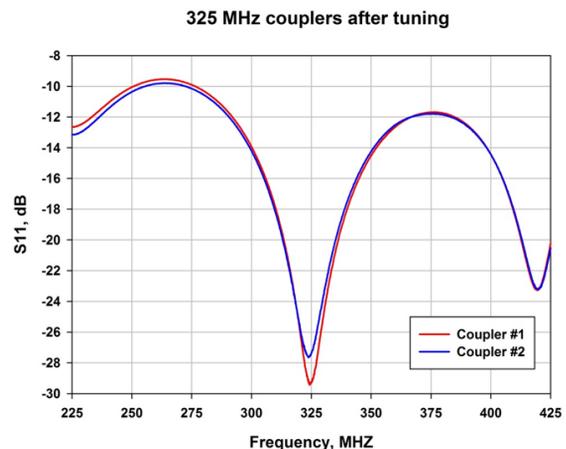


Figure 3: Pass band of couplers after tuning.

DC BLOCK

In order to apply HV bias, the internal conductor of the coupler has to be isolated from the internal conductor of the rf coaxial waveguide. For this purpose a so called DC block was designed. The structure of the DC block is presented in Figure 4. Both input and output of the DC

block are standard 3 1/8 inch, 50 Ohm coaxial waveguide. The central conductor is divided by a thin kapton film which forms a capacitor which passes RF power and blocks direct (DC) high voltage (HV). To protect the RF source in case of kapton breakdown, a DC short is installed on the RF source side. This DC short is made in a spiral shape and is transparent to 325 MHz RF power. This spiral is air cooled.

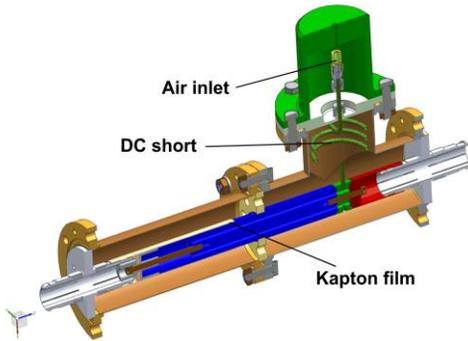


Figure 4: Structure of DC block

Pass band of DC block is > 100 MHz ($S_{11} < -20$ dB) and is presented in Figure 6. DC block and couplers were tested with HV up to 5.5 kV with an expected operating voltage of 2 kV.

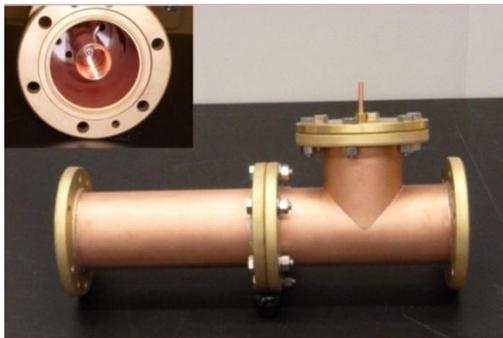


Figure 5: DC block. Tested up to 5.5 kV DC HV.

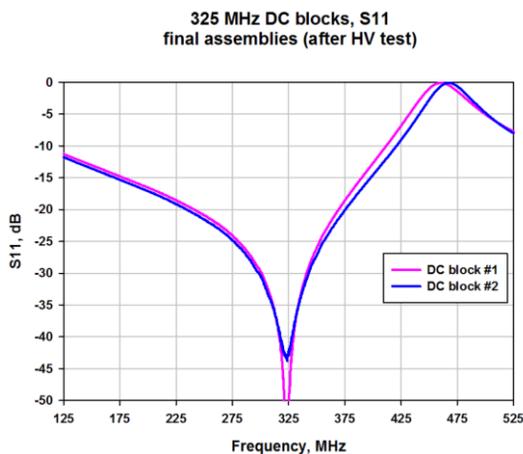


Figure 6: Pass band of DC block.

TEST ASSEMBLY

The test assembly consists of two couplers connected back to back through a test cavity. The cavity is a half-wave coaxial resonator and is sized to avoid multipactor in the cavity volume at any power within in the operating range. Since losses in the cavity are expected to be small, the outer shell is made of stainless steel while the inner conductor is made of copper. Figure 7 presents the test cavity assembled with the vacuum parts of the couplers. Figure 8 shows the full assembly of cavity with couplers ready for testing.

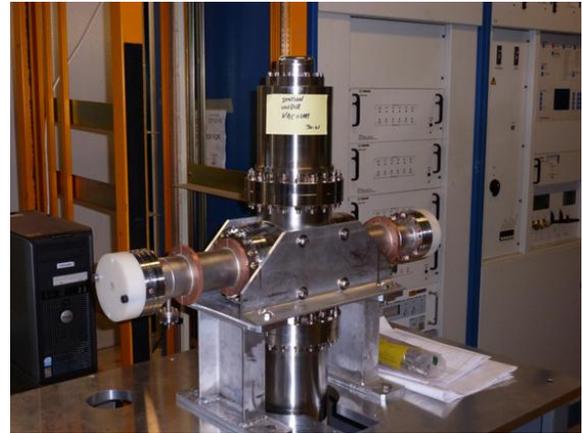


Figure 7: Test cavity assembled with vacuum parts of couplers.



Figure 8: Full assembly of test cavity with couplers ready for testing.

Figure 9 illustrates locations where various measurements are made. Each coupler has three points of temperature measurements: one is on the outer case of the ceramic window and two are on the outer stainless steel tube. Two temperature measurements points were placed at test cavity. Each coupler has one e-pickup (current monitor) and one arc detector. E-pickups allow for the detection of multipacting. The arc detector is a photomultiplier looking at the air side of the ceramic window. A set of directional couplers allows for

measurements of the forward and reflected RF power both before and after the test assembly. Vacuum was maintained by an ion pump and monitored using an ion gauge. Vacuum levels without RF power were ~ 1E-8 mbar.

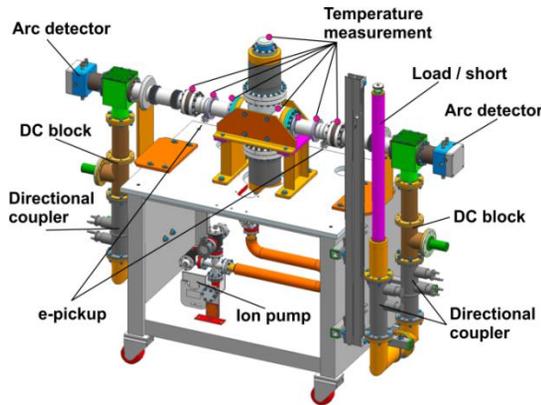


Figure 9: Structure of test assembly.

TEST RESULTS

For testing we used an RF amplifier with a maximum output of 10 kW in continuous wave (CW) mode. For transmission of the power from the RF source to the coupler test stand about 200 feet of 1&5/8 inch heliax was used. Due to this length, 8.5 kW of power could be applied to the couplers. The first stage of coupler testing used the travelling wave (TW) mode –here the output of the assembly was terminated by a matching load. In this configuration multipactoring was observed at power levels ≥ 4.5 kW. Evidences of multipactor were vacuum activity and signals from e-pickups. Conditioning was started with short pulses (widths of 0.1 ms). As the couplers conditioned the pulse length was gradually increased till CW mode was achieved. During one day, couplers were conditioned up to a maximum power ~ 7.5 kW, CW (RF amplifier limitations). During the next day the couplers were tested at a power ~7.8 kW, CW for 7 continuous hours; there were no trips due to the couplers. There was no evidence of multipactor – no vacuum activity, no signals from e-pickups. Temperature rise at the ceramic windows and on stainless steel tubes of the couplers were insignificant, ~ 5 C.

For the second stage of testing the matched load was replaced with a moveable short and the couplers were tested in a standing wave (SW) mode. In SW mode, multipactor was more significant and started at a power level ~ 3.5 kW. The short was moved in steps of 5 cm and at each position the couplers were conditioned up to the maximum power. The short was moved a total of 20 cm (5 positions), at which point the heliax cable from the rf source developed a short. Before damaging the cable we were able to reach the maximum power at each of the five positions in CW mode. Vacuum levels were ~ 1e-6 mbar. Vacuum activity was observed up until the end of conditioning which implies a small amount of multipactoring continued. Temperature rises in monitored points were moderate, ~ 10 C.

Once the cable was repaired, operation continued only in the pulse mode with a maximum pulse length of 0.5 s and 1 pps repetition rate. At this stage the HV bias was applied to the couplers. We found that the HV bias suppresses multipactor very effectively; at a setting of +1.5 kV (+ at the antenna) all multipactoring was completely eliminated up to the maximum power at any short position (0 – 50cm, 5 cm step). Negative polarity of the bias was not as effective – it requires about -3kV to suppress multipactor.

In the future we will install new 3 inch heliax which is rated well above our testing conditions. After this, testing in CW mode will be continued. Modification of couplers will be done based on test results. One of the possible modifications is a double window.

DOUBLE WINDOW

Disputes are still continuing over how many (one or two) ceramic windows a coupler should have. Two windows are more reliable but it is more difficult and expensive for high CW power couplers. One of the difficulties concerns how to provide effective cooling to the antenna. An interesting approach we are looking at combines advantages of both two and one windows. In this approach two windows are brazed into one unit. This unit has a small longitudinal size and a common antenna through both windows. In this case the antenna can easily be cooled. The volume between windows is filled with nitrogen to a pressure less than atmospheric pressure. By monitoring pressures inside the accelerating structure and in the volume between windows we can determine which window is broken in case of failure; if pressure changes in the accelerating structure, it means the internal window has a crack. Volume between windows is small (~ 50 cm³) and any leak should not damage the accelerator. If pressure changes in the volume between windows and not in the accelerating structure, it means the external window has a crack. The concept of a double window coupler is presented at Figure 10.

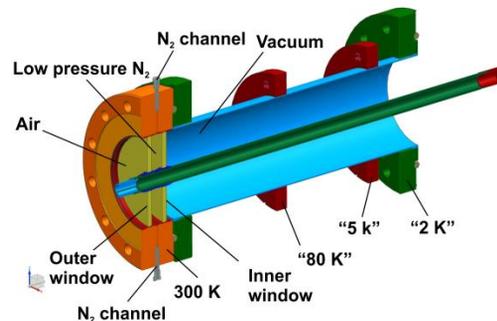


Figure 10: Double window concept.

REFERENCES

- [1] V. Lebedev, “PIP-II and PXIE”, PIP-II Meeting, February 2014, Document 1260, Project X database.
- [2] S. Nagaitsev, et al., “PXIE FRS”, Project X database.