LATEST PROGRESS IN DESIGN AND TESTING OF PIP-II POWER COUPLERS*

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Abstract

Proton Improvement Plan - II (PIP-II) project is underway at Fermi National Laboratory. Main part of the project is the 800 MeV proton superconducting accelerator which includes 116 superconducting cavities of 5 different types and three (162.5, 325 and 650) MHz frequencies. Key elements of the accelerator which determine a reliable operation are the main couplers for superconducting cavities. This paper describes the latest progress in design and testing of main couplers for PIP-II projects.

INTRODUCTION

The goal of PIP-II are the upgrades to the Fermilab accelerator complex capable of providing a proton beam with power of more than 1 MW on the target of the Long Baseline Neutrino Facility. Main element of the project is 800 MeV, 2m, H- superconducting accelerator. Accelerator consist of room temperature injector, which includes 162.5 MHz RFQ and superconducting section. Superconducting section includes:
162.5 MHz Half-Wave Resonators (HWR), 8pc;
325 MHz Single Spoke Resonators, type 1 (SSR1), 16pc;
325MHz Single Spoke Resonators, type 2 (SSR2), 35pc;
650MHz Low Beta Elliptical Cavities (LB 650), 33pc;
650MHz High Beta Elliptical Cavities (HB 650), 24pc.

In this paper we will discuss main couplers for RFQ, SSR and Elliptical Cavities. It is supposed that SSR1 and SSR2 cavities will utilize a common coupler, "325 MHz coupler". LB650 and HB650 will utilize common coupler "650 MHz coupler".

Power requirements for the coupler comes from accelerator parameters: RFQ couplers have to operate at power level ~ 70kW, 325 MHz couple at power ~ 15kW and 650 MHz coupler at power level ~50 kW. All couplers operate in CW mode.

RFQ COUPLER

The 162.5 MHz RFQ cavity is powered through two couplers. Each coupler must operate reliably at RF power level ~ 70 kW CW. Two designs of RFQ couplers were made. First design is presented at Fig. 1 and window unit is showed at Fig. 2 [1]. Window unit of first design is based on 3-inch diameter and 6mm thickness ceramic disk made of alumina. Window is brazed to outer conductor and to inner conductor which forms RF loop in vacuum side of coupler. Loop is not grounded, and it allows to apply high voltage bias up to 5 kV to suppress multipactor. Surface of ceramics is not coated. Loop is formed by two cooper tubes. Tubes are cooled by air. Two couplers and four windows units were fabricated. After about ~500 hours of operation at CW mode two windows were cracked.

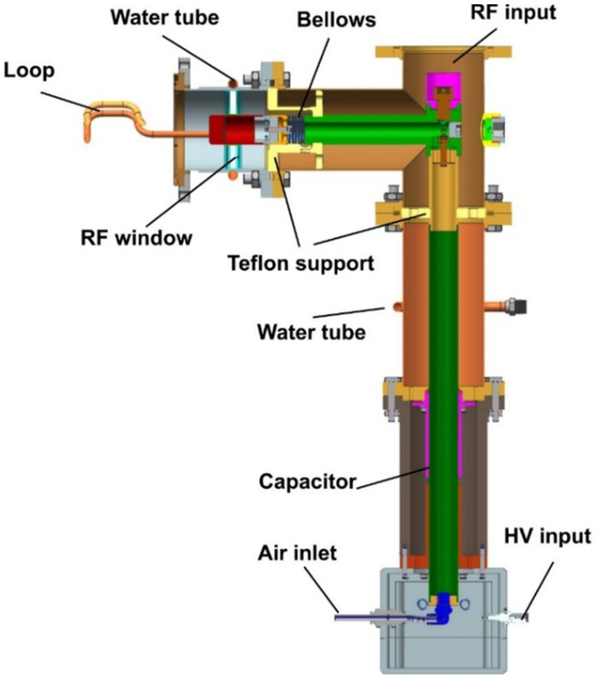

Figure 1: First design of RFQ coupler.

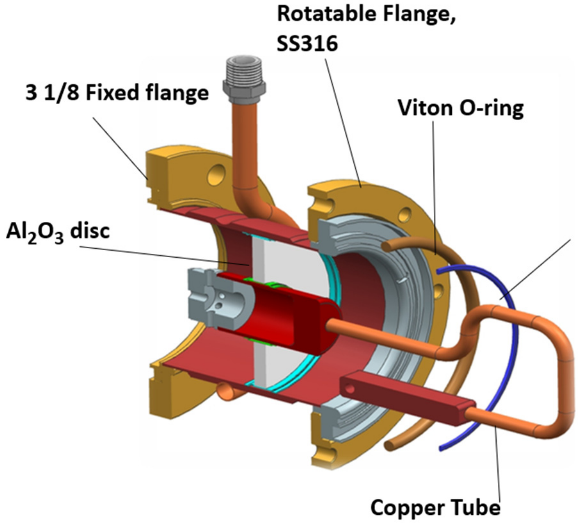

Figure 2: First design of RF window unit.

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After this outcome, a new window unit design was made (second) with replaceable ceramic disk. The new window unit design is presented in Fig. 3. Diameter of ceramics was increased up to 6 inch and thickness was reduced to 4mm. Vacuum sealing is provided by Viton O-rings. Thus, ceramic disk is not brazed to metal environment anymore and can be easy replaced in case it is broken. It saves production and operating costs. Viton rings are placed in narrow slots between metal walls to reduce RF fields in the rings and to reduce RF loses in Viton. This is the reason why the thickness of ceramics was reduced to 4 mm. In the new design the ceramic disk is cooled by air from outer perimeter. Loop has the same shape and is not grounded as well. New window units are compatible with the rest of the coupler parts. Two window units were fabricated and installed to RFQ and they successfully work without signs of degradation.

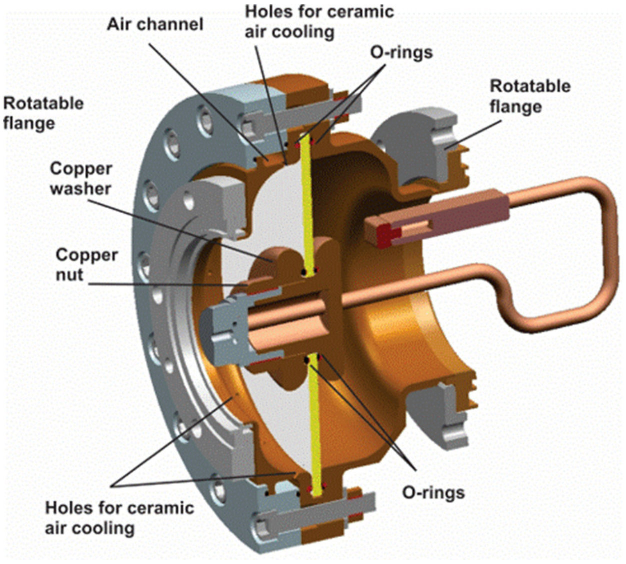

Figure 3: Second design of RFQ RF window unit with replaceable ceramics disk.

325 MHZ COUPLERS

We did two designs of 325 MHz coupler as well. First design was reported in [2]. Main features of design are: single warm window made of alumina. Diameter of window is 3-inch, thickness is 6mm, ceramics are not coated with TiN. Antenna is copper tube of OD 0.5 inch cooled by air. Outer conductor is 3-inch stainless steel tube with wall thickness 0.8mm. Outer conductor is not coated with copper - it improves a reliability of coupler and simplifies its production. Design of coupler allows to apply high voltage bias up to 5 kV to suppress multipactor. All produced couplers were tested at a room temperature test facility in CW mode with full reflection at four phase points of reflected power with 90 degrees phase steps. Typically, couplers do not require conditioning and work without multipactoring from the beginning if HV bias is applied. Table 1 summarizes the statistics of testing. First row is the power level of the test, second row is number of tested couplers / numbers of broken couplers during the test.

Table 1: Statistic of 325 MHz Coupler Testing

Power	10 kW	20 kW	30 kW	47 kW
Tstd/Brkn	17/0	5/1	2/0	2/1

Eight couplers are installed to SSR1 cryomodule string and presented at Fig. 4.

Figure 4: Eight 325 MHz couplers are installed to cryomodule string.

After learned lessons working with 325MHz couplers, the improved design of the 325MHz coupler was developed. New design is presented in Fig. 5. Here is the list of main changes made: (1) diameter of ceramics was increased up to 90mm to make coupler more powerful and reliable; (2)thickness of ceramics was increased to 8mm to increase a mechanical strength; (3) configurations of brazing regions, where ceramic is brazed to inner and outer conductors, were changed – lengths of copper sleeves were increased to simplify the brazing and reduce mechanical stresses during operations; (4) copper iris and disk were added to outer conductor and to antenna respectively. These parts will protect ceramics from charged particles which can propagate from cavity and deposit an electrical charge on the ceramics surface. Besides, the iris will reduce thermal radiation from warm ceramics in to cold cavity. Operating temperature of iris will be about 70K;(5) cooling and mechanical strength of antenna were improved; (6) two cooper inserts were added in to stainless steel outer conductors to reduce dynamic cryogenic loadings. These inserts do not increase static losses but reduce dynamic cryogenic loading to 2K and 5K significantly. Other stainless-steel parts of outer conductor are not coated; (7) cryogenic loading of coupler for 15kW, CW +20% reflection operating power level is presented in Table 2. Other small changes were made to make assembling of the coupler more convenient. New design is compatible with previous one and will be used for SSR1 and SSR2 cavities

Table 2: Cryogenic Loading of 325 MHz Coupler

Temperature	2K	5K	50K
Cry-loading	0.36W	1.7W	6.9W

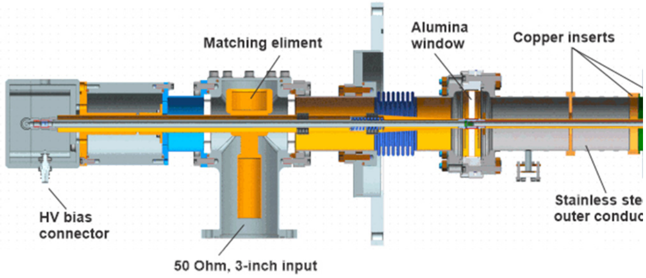

Figure 5: Improved design of 350 MHz coupler.

650 MHZ COUPLERS

650 MHz couplers will be used to feed two types of elliptical cavities with beta factor 0.65 and 0.95. Couplers have to provider reliable operation at the power level of about 50 kW in CW mode. We tried to avoid a copper coating in the vacuum part of the coupler to elevate a reliability. Because of the higher frequency and higher power, it is impossible to use pure stainless steel as we did in the case of 325 MHz couplers. We made a design with shields made of solid copper that replace copper coatings. Design is presented in Fig. 6 and the scheme of vacuum part is presented in Fig. 7a. Advantages of this design are impossibility of copper flakes and better cryogenic properties.

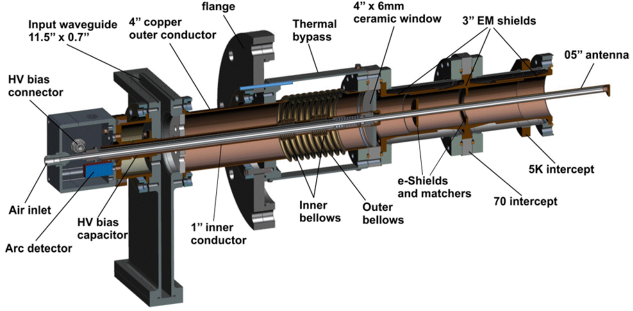

Figure 6: Cut view of 650 MHz coulesrs with electomagnetic shields.

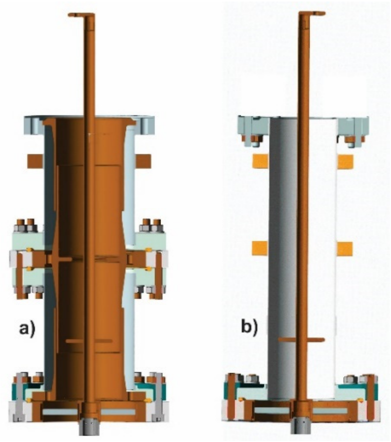

Figure 7: Cut views of vacuum parts of 650 MHz coupler with electromagnetic shields (a) and of conventional coupler with copper coating (b).

Backup conventional design with copper coating was made as well. Outer conductor of first design is replaced with stainless, still outer conductor coated with copper, Fig. 7b.

Main parameters of couplers: single room temperature window based on the alumina ceramics disk with 4-inch diameter and 6-mm thickness; ceramic disk is not coated with TiN; multipactor is suppressed by high voltage bias up to 5 kV; antenna is 0.5-inch air cooled copper tube.

One of the questions is if there is a possibility to assemble the outer conductor with copper shields in clean room without generating particles which can contaminate superconducting cavity. We did experiment of assembling vacuum outer conductors with copper shields and conventional type. The Teflon jig was used to provide concentricity of outer conductor stainless steel parts and copper shields. All parts were cleaned in ultrasonic bath and were cleaned by flow of Nitrogen just before assembling. Then outer conductors were assembled and cleaned by Nitrogen flow again counting particles. Both assemblies showed zero number of particles at the end of procedure. Final Nitrogen cleaning took several minutes. Hereby we proved the possibility of using these designs for superconducting RF applications. Figure 8 shows the assembly sequence of outer conductor with coppers shields using Teflon jig. Figure 9 demonstrates moments of assembly experiments.

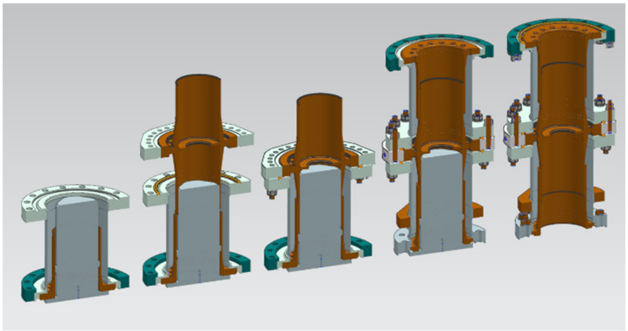

Figure 8: Assembly sequence of outer conductor with copper shields using Teflon jig.

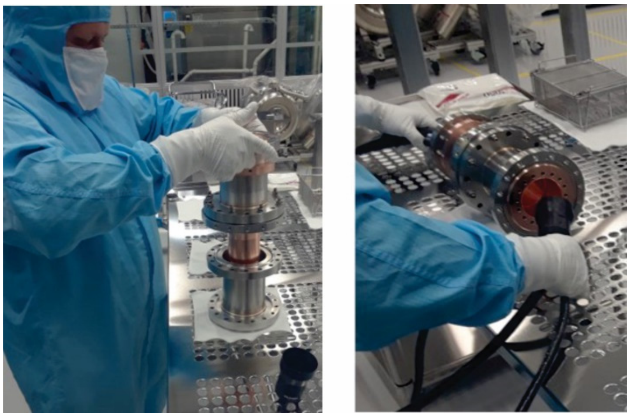

Figure 9: Assembling experiment in clean room.

Four vacuum parts were produced – two of the designs with copper shields and two of the conventional designs

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with copper coating. Figure 10 demonstrates appearances of new and conventional outer conductors.

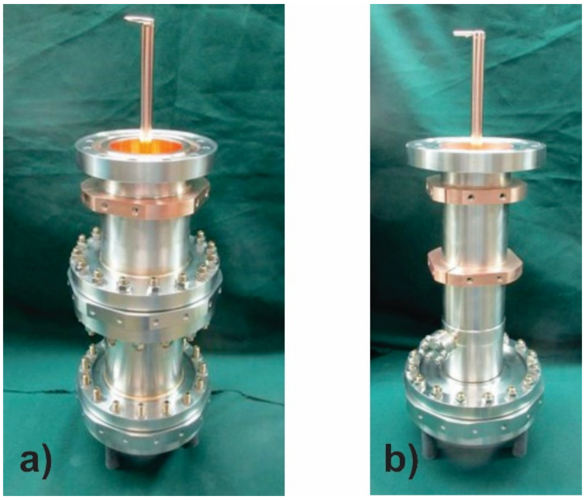

Figure 10: Apprance of outer conductors with coppers shields, a) and outer conductor with copper coating.

Right now, couplers with conventional outer conductors are under high power test. Couplers are tested in full reflection mode to increase possible RF power level. The facility allows us to test couplers up to 100 kW in CW mode. Figure 11 presents RF scheme of test facility, a) and 3d model of stand with two 650 MHz couplers b). 650 MHz coupler test banch photo are shown on Fig. 12.

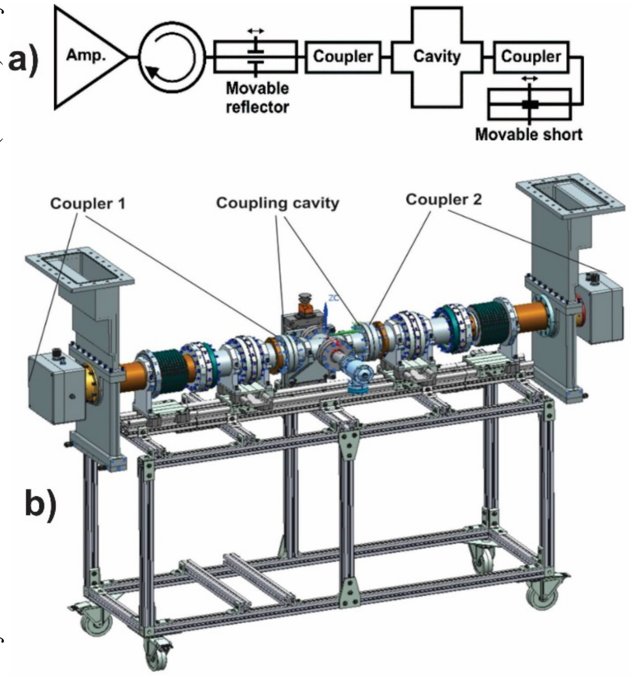

Figure 11: a) RF scheme of 650 MHz coupler test facility; b) 3-d model of test banch b).

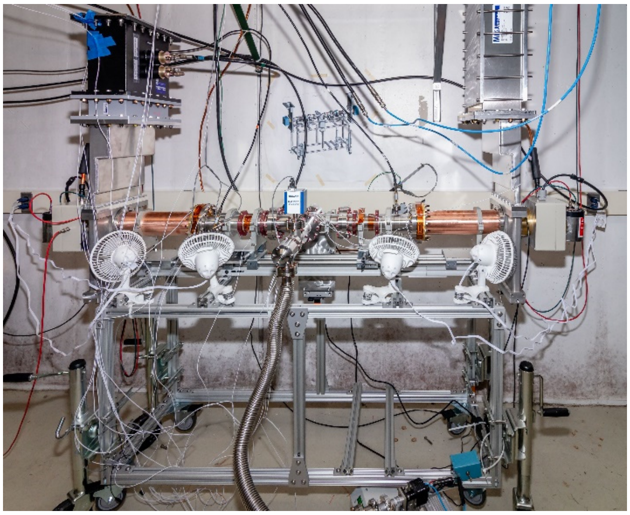

Figure 12: 650 MHz coupler test banch.

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