DESIGN AND COMMISSIONING OF FRIB MULTIPACTING FREE FUNDAMENTAL POWER COUPLER*

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Abstract

The original Fundamental Power Coupler (FPC) of Half-Wave Resonator (HWR) for the Facility of Rare Isotope Beams (FRIB) requires multipacting conditioning at operating RF power which is up to 5 kW Continuous Wave (CW). Conditioning takes a lot of time and RF power, and its elimination is highly desirable. To significantly shorten the RF conditioning, we developed a multipacting-free coupler design. This paper reports the latest progress in the optimization and prototype tests of multipacting-free coupler. The choke structure is removed and coupler geometry is further modified to protect the coupler RF window from the electron bombardment. The comparison result of multipacting-free coupler with original coupler was performed on automatic conditioning system, which showed significant time reducing for RF conditioning.

INTRODUCTION

In the Technology Demonstration Cryo-Module (TDCM) test at FRIB, we found heavy multipacting in the FPCs for HWR cavities. It is a phenomenon of secondary electrons' resonance which can breakdown FPC and superconducting RF cavity in the worst case. Even though it can be conditioned by RF power, it always takes a long time and cost consuming. For example, the overall RF conditioning time for power coupler used in FRIB TDCM was more than two weeks.

A suppressing method of the multipacting in FRIB FPC was first introduced in [1]. Subsequently to the optimized method, a multipacting-free coupler design was developed and highly recommended to apply in FRIB by the Accelerator Systems Advisory Committee (ASAC). In this paper, section 2 reports the latest upgrade in the design, section 3 introduces the automatic conditioning system which was developed for RF conditioning of FRIB FPCs, and section 4 reports the comparison tests between original couplers and multipacting-free couplers.

LATEST PROGRESS IN THE DESIGN OF MULTIPACTING-FREE COUPLER

A simple multipacting law for the coaxial couplers was derived in [2].

$$P_n = \frac{A\omega^4 (r_2 - r_1)^4 m^2}{(2n-1)^2 \pi \eta e^2} (\ell n(\frac{r_2}{r_1}))^{-1} \quad (1)$$

P_n is the power where multipacting turned on, r_1 and r_2 are the inner and outer conductor radius respectively, η is the wave impedance in vacuum (377 Ω), A is 1 for traveling wave and 0.25 for standing wave due to superposition theorem, e is electron charge, m is electron mass, ω is RF angular frequency, n is the order of two-point multipacting (for instance n=1 for two-point 1st order multipacting).

Based on Equation (1), we can predict the location and the RF power level where multipacting turns on. A multipacting-free coupler design was proposed according to the law, further upgrade has been applied recently to improve the performance. Figure 1 shows the latest multipacting-free coupler design for prototyping.

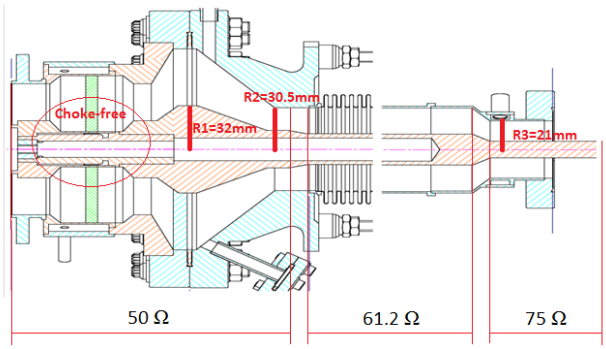

Figure 1: Latest multipacting-free coupler design.

The choke structure near the RF window is a standard techniques for the impedance matching [3], however it is complex and delicate. In order to make the coupler design simple and easy to fabricate, the choke structure was eliminated in the latest multipacting-free coupler design. The inner conductor radius R1 is increased to be larger than R2 in the latest design so that the RF window can be masked from the electrons from beam line.

AUTOMATIC CONDITIONING SYSTEM

The old coupler conditioning system in FRIB used standing wave RF power which can only condition one coupler at time. Due to the characteristic of standing wave, only one local region of coupler is conditioned with old system, thus other parts of coupler remain unconditioned. New conditioning system uses travelling wave RF power which can condition two couplers at the same time and each coupler is fully conditioned. The maximum RF power used for new system is 20kW with 20% duty cycle (limited by heat load of conditioning resonator). The 20 kW is suitable to condition FRIB couplers which have a maximum forward power of 5 kW.

Baking is applied before RF conditioning to initialize the pressure of the whole system below 1e-8 torr. It was operated by PID controller to keep the temperature of system around 120°C. Two protections were used to keep it safe for overnight operation without people onsite. One is fuse wire installed on the controller to keep the current of heat tapes under 5A. The other one is using

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thermocouples to construct a temperature map of the system which can trip the power supply in the case one of the thermocouples' reading is higher than 200°C.

Since multipacting conditioning is time consuming, an automatically conditioning system (see Figure 2) based on PI algorithm was developed to improve the conditioning efficiency and save man power. The control Process-Value is the pressure reading form cold cathode gauge installed on the coupler, the default value of Set-Point is 4e-7 torr. The initial pressure before conditioning is under 1e-8 torr, the pressure will rise once field emission or multipacting occurred, the PI algorithm will control the RF power level or RF duty cycle automatically to maintain the pressure reading around 4e-7 torr to keep the conditioning ongoing constantly. Several interlocks were applied in order to keep the system safe when running 24 hours without people onsite: pressure interlock, trip RF once reading is higher than 1e-6 torr; spark detector, trip RF once spark is detected; reflected power meter, trip RF once the reflected power is higher than 30% input power; input and pickup power meters, trip RF when either one's reading is higher than 20kW; water leak detector, trip RF when a water leak is detected from the cooling lines. In addition, pico-ammeters and thermocouples were installed to monitor multipacting on the coupler.

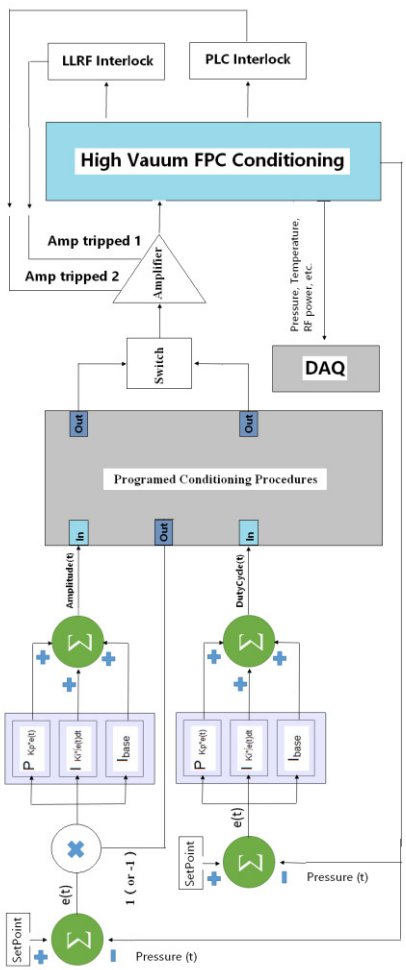

Figure 2: Diagram of new conditioning system.

The conditioning procedures were programed as follows:

a) Ramp up RF power from 1kW to 20kW with 0.1% duty cycle;

b) Keep 20kW RF power, ramp up duty cycle from 0.1% to 5%;

c) Keep 5% duty cycle, ramp down RF power from 20kW to 1kW;

d) Keep 5% duty cycle, ramp up RF power from 1kW to 20kW;

e) Keep 20kW RF power, ramp up duty cycle from 5% to 20%;

f) Keep 20% duty cycle, ramp down RF power from 20kW to 1kW.

The new conditioning system was commissioned at FRIB and confirmed to work well and its robust performance. This system was transferred very recently to FPC vendor for their onsite FRIB coupler RF conditioning. The user friendly interface supports very well the vendor coupler conditioning. It runs very smoothly and they already processed four couplers within one week.

For further manpower free processing, we will introduce machine learning to construct a conditioning model which can tune the control parameters by itself. The conditioning model can learn from measurement data and it will become more and more mature after every conditioning run.

COMPARISON TESTS BETWEEN ORIGINAL COUPLERS AND MULTIPACTING-FREE COUPLERS

FPC vendor delivered two prototypes of FRIB original coupler design and two prototypes of multipacting-free coupler design (see Figure 3) in December 2015. Commissioning those four couplers was performed on the new conditioning system as a comparison test.

Figure 3: Pictures of IC prototypes (left one is original design, right one is multipacting-free design).

The purpose of comparison test was to figure out which kind of coupler is better to be implemented as FRIB's Fundamental Power Coupler for more than 200 HWR cavities. The test included two sections, first one is conditioning of two original design FPCs. Figure 4 shows the test setup. Two couplers were installed on the conditioning resonator, about 93% RF power transmitted

from one coupler to another one through the conditioning resonator, and finally absorbed by the dummy load.

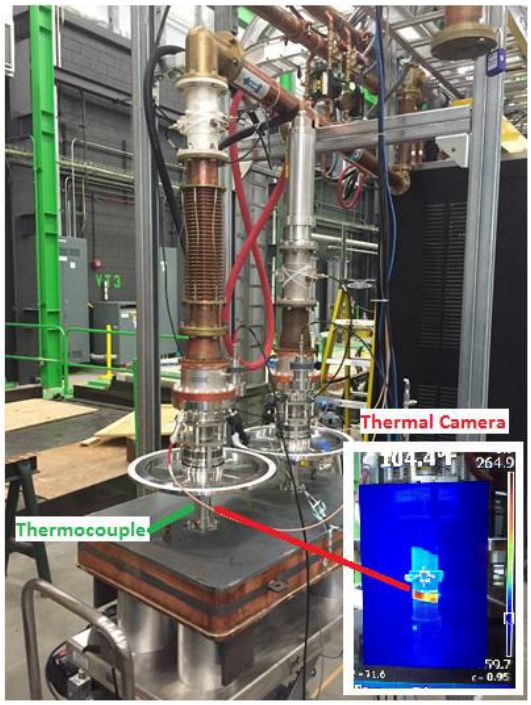

Figure 4: First section of comparison test with original design FPCs.

It took about 40 hours RF conditioning for the original design FPCs to condition the multipacting barrier and achieve 20kW 20% duty cycle input power level. Even though these FPCs did achieve the FRIB room temperature test requirement, a serious heating was observed along the coupler outer conductor whose radius is 21 mm. Another 40 hours RF conditioning efforts was attempted to improve this heating issue, but it failed. Thermocam and thermocouples were used to measure the heating issue. The thermocouple measurement was shown in Figure 5, the temperature of outer conductor rose from 18 °C to 81 °C in 17 minutes. The maximum heating was at the input RF power equal 8 kW traveling wave, this is consistent with multipacting barrier [2].

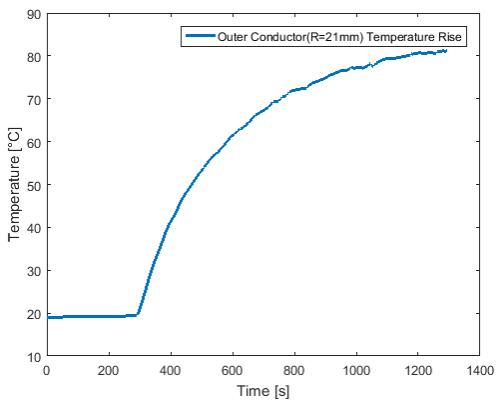

Figure 5: Temperature rise of original coupler's outer conductor (R=21mm).

The other section of comparison test was conditioning two prototypes of multipacting-free coupler, the test setup was the same. Even though we had a spark inside the resonator during the conditioning, it took only 18 hours to achieve 20 kW 20% duty cycle. Multipacting-free design saved 22 hours conditioning time compared to original design couplers. More importantly, there was no heating problem on multipacting-free couplers which was an evidence for multipacting absence.

Due to the tight FRIB cryomodule assembly schedule, we needed 8 FPCs before the comparison test above. We ordered 8 FPCs with the original design for the cavity coldmass assembly. We received these couplers in January 2016. RF conditioning was also performed on those couplers and increased the statistics with the original design. As a summary for the original design couplers, the average conditioning time for one run was about 60 hours, only three of ten couplers had no heating problem after RF conditioning.

In addition, one of the multipacting-free prototypes was tested with HWR53 cavity at 2K in a vertical Dewar as a final integrated validation test, which was a success.

Since outer conductor heating is a common issue for original design, and also the reduction of conditioning time is significant for multipacting-free design, FRIB has decided to implement multipacting-free design for more than 200 production HWR power couplers.

CONCLUSION

The original design of FRIB HWR power coupler has multipacting issue found in the Technology Demonstration Cryomodule test, a new design was developed to suppress this multipacting barrier. Two prototypes of new multipacting-free design were produced by vendor. Conditioning tests were implemented on two multipacting-free prototypes and ten original design couplers. The test result shows that multipacting-free design has significantly reduced conditioning time compared with original design. In the meantime, a heating problem was found during the conditioning on those ten original design couplers due to multipacting barrier. Even with long time RF conditioning (average 60 hours), more than half of these couplers still cannot be overcome the heating problem. Considering that this heating issue may cause an additional cryogenic heat load for FRIB cryomodules, FRIB has selected the multipacting-free design as the Fundamental Power Coupler for more than 200 HWR cavities.

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