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TESTING AND PROCESSING OF PRE-PRODUCTION 325 MHz SINGLE SPOKE RESONATOR POWER COUPLERS FOR PIP-II PROJECT

N. Solyak[†,1], B.Hanna[1], J.Helsper[1], S.Kazakov[1], D. Passarelli[1], S. Wallmon[2]
[1]FNAL, Batavia IL, USA
[2]Université Paris-Saclay, SNRS/IN2P3, IJCLAB, Orsay, France

Abstract

Fundamental 325 MHz power couplers are designed, built and tested for SSR cavities in PIP-II project. Couplers should work in CW mode at power level 7.5 kW w/o beam and ~15 kW with the 2 mA beam. At pre-production stage we built and tested 6 couplers, produced by CPI (FNAL) and PMB (IJCLab) and 4 more couplers will be tested soon. Two of tested couplers had TiN coated ceramic window. In warm test stand two couplers were mounted on the coupling chamber and tested in SW regime at full reflection with phase controlled by position of short and reflection insert. Couplers were tested at pulse mode (up to 25 kW) and cw mode (12 kW) with HV bias or without bias. Test results demonstrated that 3.5 kV DC bias completely suppresses multipactor in coupler. Vacuum activity in coupler was controlled by e-pickups and build-in vacuum gauges, located near the vacuum side of window. Power processing without DC bias was done for several couplers with and without TiN coating on ceramic window. Test results are presented and discussing in paper.

INTRODUCTION

First generation of SSR couplers, called prototype, was built for pre-production SSR1 cryomodule (ppSSR1) [1-3]. Finally we tested around 10 couplers in warm test stand and in cold environment on STC (superconducting test cryomodule) with SSR1 cavities. Eight of them were then assembled on pre-production SSR1 cryomodule and successfully tested at full available power, 8 kW CW [4-6]. Based on experience with prototype coupler as well as experience with 650 coupler we modified design of SSR2 coupler taking into account higher power requirements for SSR2 cavities [7]. For example, design of the ceramic window brazed to flange is practically the same as for 650 pre-production coupler, which allow to use same proven brazing technology. General view of 325 MHz coupler is shown in Fig. 1.

It consist of vacuum end assembly, air side assembly and instrumentation box. Ceramic window separates vacuum from air side. Vacuum gauge and pick-up antenna (not visible here) are located on vacuum outer conductor flange near the window. More details on coupler design can be found in paper [7] presented in this conference. Same design of coupler are used for SSR1 and SSR2 couplers, required coupling is provided the appropriate geometry of the coupling port in cavity.

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†solyak@fnal.gov.

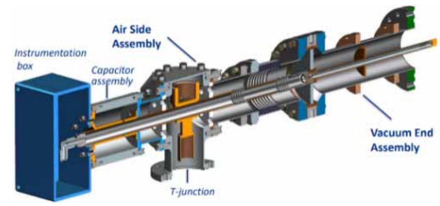

Figure 1: Cut view of the 325 MHz coupler.

At pre-production stage we built 5 full couplers and one antenna assembly in CPI. Additional to that PIP-II partner lab, IJCLAB, built 4 couplers in PMB, two cold parts were delivered to Fermilab for testing. Two vacuum end (one CPI, one PMB) have a problem with antenna (bent or damaged) and were not used in RF qualification tests. Other six couplers were successfully tested. Window on two couplers (one CPI and one PMB) were TiN coated from vacuum side. All couplers were tested with DC bias 3-3.5 kV (baseline regime of operation), but in test where we have TiN coated coupler we also did power processing without DC bias to clean coupler surfaces by MP discharge. 3 RF qualification tests were completed:

- coupler 1&4 (CPI, both no TiN coating) – with DC bias
- coupler 3&6 (both CPI, one TiN coated) with and without DC bias
- coupler 2&1' (CPI uncoated and PMB TiN coated) with and without DC bias

COUPLER TEST STAND

Two vacuum ends of the couplers are assembled on coupling cavity in clean room, pumped out and leak checked. After vacuum baking at 120°C for 48 hours with active pumping and RGA measurements. Subassembly then moves to the testing cave where air side of the couplers, DC blocks and other connections are assembled in warm test stand as shown schematically in Fig. 2.

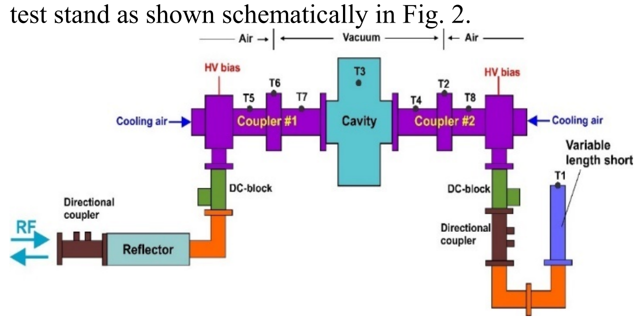

Figure 2: Schematic view of coupler test stand.

In this setup we have a resonance condition with standing wave between short and reflector, it allow amplify power by factor of 4-5 to get 30-40 kW using available 8 kW power source.

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Fully assembled coupler test stand is shown in Fig. 3. Air cooling of coupler antennas and air parts connected through the instrumentation box for each coupler separately, external cooling is provided by two fans. Temperature sensors measure temperature of window flange, coupling cavity and DC block for each coupler.

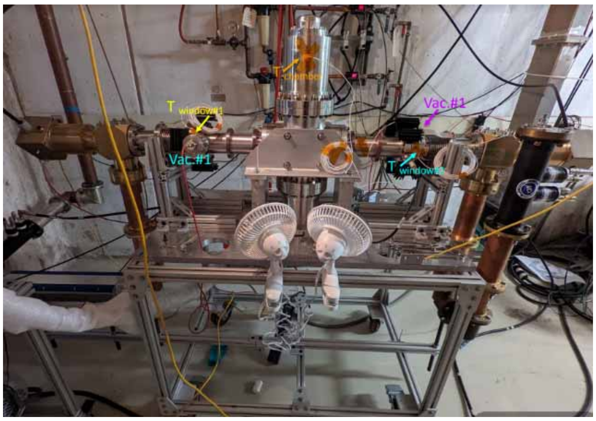

Figure 3: 325 MHz couplers assembled for Rf tests.

Testing Protocol

Testing requirements for the coupler are defined by Technical Specification Requirement (TRS) document. For all 325 couplers we use requirements for SSR2 system as more severe: coupler should be tested at 12kW CW with full reflection at arbitrary reflection phase. In test stand we use 4 reflection phases (0°, 90°, 180°, 270°) and for each phase configuration the testing regime for RF qualification test is the following:

- Pulse mode (1 Hz): 10; 100; 300; 500 ms, power ramp up to 25kW; stay few minutes at maximum power.
- CW mode: ramp up power to 12kW. Stay >1.5 hours to reach equilibrium temperature.

Conditions/Interlocks

- Air flow rate ~3 g/s per coupler
- External air cooling: radiators on window flange, 2 fans for cooling
- DC bias 3.5kV – in each coupler (separate PS)
- Vacuum interlocks 2.e-6 Torr for each vacuum gauges
- Ceramic flange temperature, interlock ~140°F

Diagnostics

- Vacuum: 2 vacuum gauges on couplers and vacuum in pump line
- Temperature: window flanges (2), coupling cavity (1), DC blocks (2);
- DC bias: voltage (1) and current
- pick-up probe (2) signal

TEST RESULTS

Field amplitude near ceramic window are different for each coupler and depends of the reflection phase. Having pickup antenna near window we measured field amplitude in each coupler as a function of reflection phase (Figure 4).

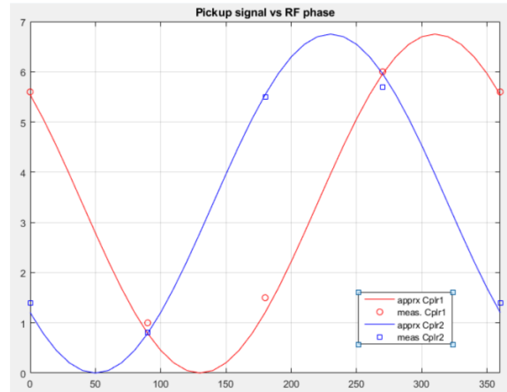

Figure 4: RF Signal from pickup antennas measured at 10kW SW in two couplers. No MP activity during measurements. Antenna located near ceramic window.

RF Qualification with DC Bias

The typical results of the coupler RF qualification is shown in Fig. 5 (test 3 for CPI and PMB couplers) for four reflection phases where presented RF power, readings from vacuum gauges and pulse length (for CW this parameter is equal 0). DC bias was set to 3-3.5kV for each coupler.

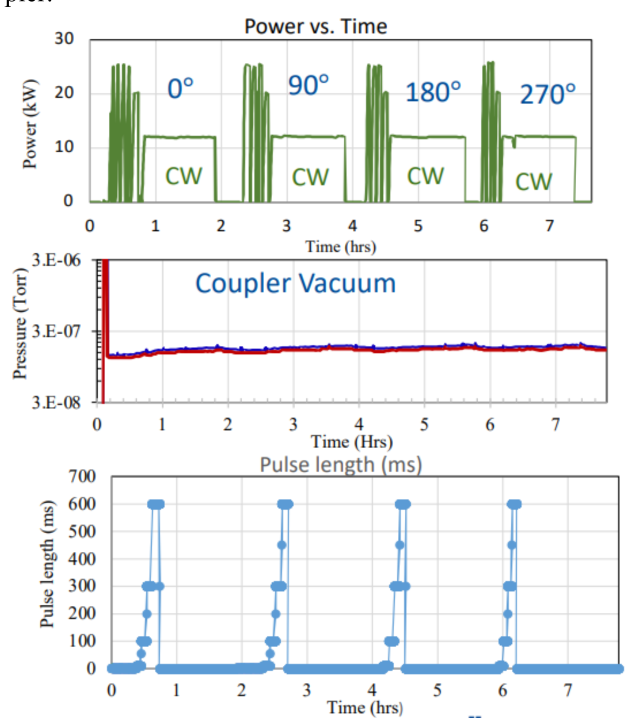

Figure 5: Top plot - RF power; middle-Vacuum gauge signal (red-coupler1, blue-coupler2). Below –pulse length, 0-corresponds CW mode.

From vacuum plot it is clear that multipactoring (MP) activity is completely suppressed by DC bias in full range of tested power 0-25 kW. Temperature of both window flanges and coupling cavity is shown in Fig. 6. Ceramic

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temperature <95F, well below specification ~140F). We can conclude that both couplers are working properly and met the specification requirements.

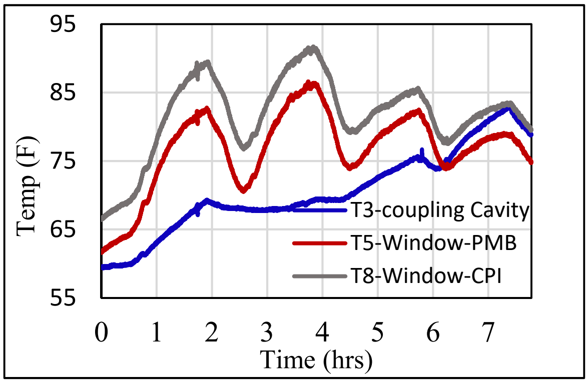

Figure 6: Temperature of the window flanges and cavity at different reflection phase.

POWER PROCESSING W/O DC BIAS

After completing RF qualification test two assembles, with one uncoated and one coated ceramics were power processed without DC bias on one or both couplers. Goal of these studies to demonstrate that we can effectively clean coupler by outgassing surface by MP discharge.

Processing Protocol:

For each reflection phase we run three cases:

- No bias on TiN coated ceramic only (Cplr2)
- No bias on uncoated ceramic only (Cplr1)
- No bias on both couplers

For each case we start with short pulse increasing power and the go to CW mode

- Pulse mode: 1,3,10,30,100,300,600 ms, Pmax=16-20 kW
- CW mode; Pmax = 12-13 kW

During MP processing power was ramping keep vacuum near interlock level 2.e-6 Torr.

Results

For couplers assembly with CPI uncoated and PMB coated couplers total processing time was around 30 hours, including: Phase 0° = 10 hours; Phase 90° = 11 hours; Phase 180° = 6 hours; Phase 270° = 3 hours. Figure 7 shows history of power processing for each case. Arrows shows 12kW CW run without MP activity in both couplers w/o bias. In last run for 270° reflection phase no any MP activity was seen in pulse or CW mode.

For second pair with CPI couplers 3&6 one uncoated and another TiN coated, full processing time was longer ~80 hours, including: Phase 270° ~ 60 hours; Phase 0° ~ 14 hours; Phase 90° = 2.5 hours; Phase 180° = 2.5 hours.

One can see that most time was spent for first reflection phase, for last two reflection phases processing done much quickly. MP activity was not processed completely for at least one phase, still some residual MP activity remains.

Inspection of the ceramic after heavy power processing does not indicate any degradation or discoloration. We concluded that after processing it can be used for cavity installation.

Future testing plans

We are preparing to test two remaining couplers with deformed antennas (CPI and PMB). For that we modified coupling element in cavity to accommodate larger gap between antenna and fixture.

Our partner IJCLab is planning to send to FNAL last two coupler vacuum ends produced by PMB and all 4 air assemblies. They also will be tested after inspection.

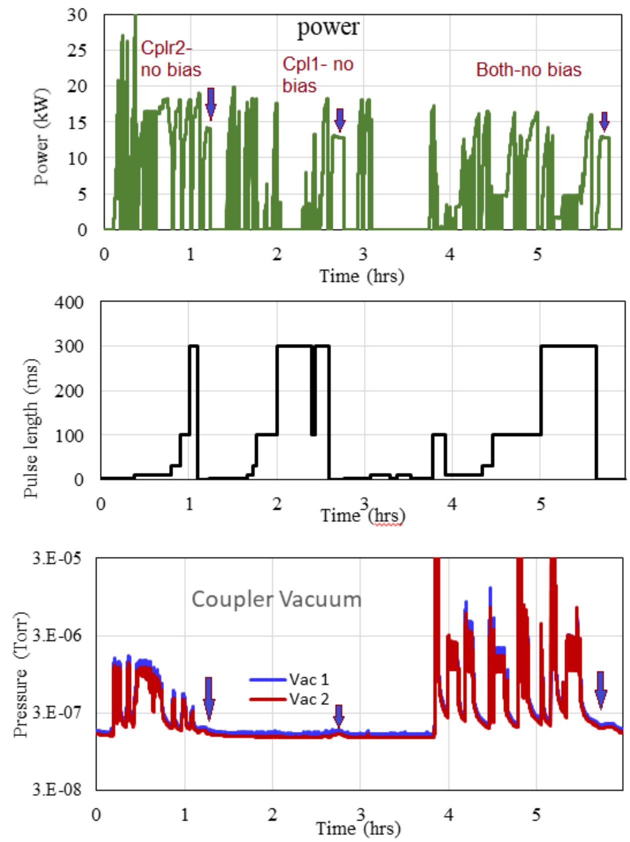

Figure 7: History of power processing without DC bias. Reflection phase 180°. Arrows shows time of CW operation at 12-13 kW.

CONCLUSION

In summary, the ppSSR2 325 MHz couplers procured by both FNAL and IJCLAB met the technical requirements necessary to be used as part of the ppSSR2 CM String. Six couplers (including two with TiN coated ceramic windows) were already successfully qualified in warm test stand with DC bias at specified 12kW CW power and four reflection phases. Additional 4 couplers (3 of them from IJCLab) will be tested this summer.

Two ppSSR2 couplers with TiN coating on vacuum side of ceramic window (one produced by CPI, another PMB) were also high power (HP) processed without DC bias on coupler warm test stand. In each test we used one TiN coated and one uncoated coupler and switched off bias for

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one of them or both. After pulse processing at ~20 kW, both couplers were cleaned and does not show MP at 12 kW CW without bias for all 4 reflection phases. Total processing time was ~30 hours for one test and ~80 hours for the second test. With a small statistics we could not clearly conclude that TiN coated ceramic perform better than uncoated in HP tests.

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