TESTING OF 325 MHz COUPLERS AT TEST STAND IN RESONANCE MODE

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Abstract

The linear accelerator for the PIP-II program utilizes two types of 325 MHz Single Spoke resonator cavities: SSR-I and SSR-II. Operating power of SSR-II is about 17 kW and requires input couplers which can reliably work at power levels > 20 kW with full reflection at any reflected phase. Currently only one 10 kW RF amp is available for coupler testing. To increase testing power, a special resonance configuration was used. This configuration allows us to raise RF power approximately 3 times. The testing scheme and results are discussed in the paper.

INTRODUCTION

The proton accelerator facility based on an H- linear accelerator which utilizes superconducting RF technology, PIP-II, is now being developed at Fermilab to support the intensity frontier research in elementary particle physics. The PIP-II design includes two types of 325 MHz superconducting cavities, single spoke resonators SSR-I, with β=0.22 and single spoke resonators, SSR-II, with β=0.47. The total number of spoke cavities is 51. Both types of cavities have similar design and utilize the same design of the main coupler. Maximum RF power per cavity is 17 kW. The PIP-II upgrade plan intends to use the Linac in a continuous wave (CW) mode [1]. This means that the main coupler must reliably operate at a power level > 20 kW under conditions of full reflection. Prototype 325 MHz couplers were designed and tested at power levels ~ 8 kW in both CW modes: travelling wave (TW) and standing wave (SW) [2]. Power was limited by the maximum power of RF amplifier. In order to further increase RF power, a resonance scheme with a movable reflector was designed and built. A set of shorted coaxial waveguides with different lengths was used to change reflection phases. RF power that circulated between the movable reflector and RF short was more than 3 times higher than input power from amplifier.

325 MHz COUPLER AND DC-BLOCK

The structure of the 325 MHz coupler is presented in Fig. 1. A more detailed description of the coupler's configuration is presented in [2]. Three couplers were produced. Two of them were tested on the coupler test stand [3] at room temperature. The third coupler was tested with a cold superconducting spoke cavity in the test cryomodule.

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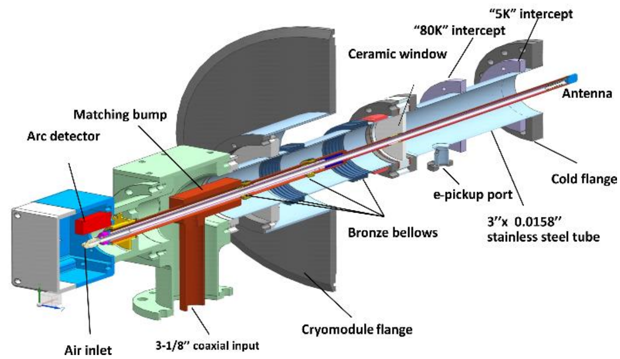

Figure 1: Structure of 325 MHz coupler.

To supress multipactor in the coupler, high voltage (HV) bias is used. To isolate the coupler input and protect the RF amplifier from HV bias, a DC-block is utilized. The structure of the DC-block is shown in Fig. 2 [2]. Power requirements for the DC-block are similar to coupler power requirements: reliable operation at power level > 20 kW, CW. Two DC-blocks were installed on the test stand and tested simultaneously with two couplers. A HV bias of up to 5 kV was applied during the test.

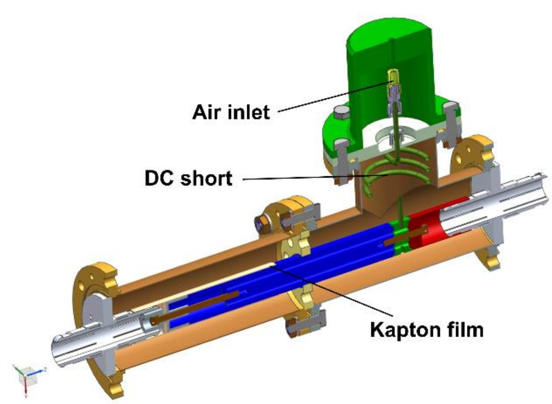

Figure 2: Structure of 325 MHz DC-block.

Configuration of the test stand is presented in Fig. 3 [3]. Two couplers are connected to a 6'' stainless steel cavity. Two DC-blocks are attached to the couplers inputs. The movable reflector (not presented at the drawing) is connected to the input of the first DC-block. Several directional couplers are used for power measurement and shape monitoring. RF power is measured twice: before and after the reflector. The ratio of these values is the power amplification of this resonance setup.

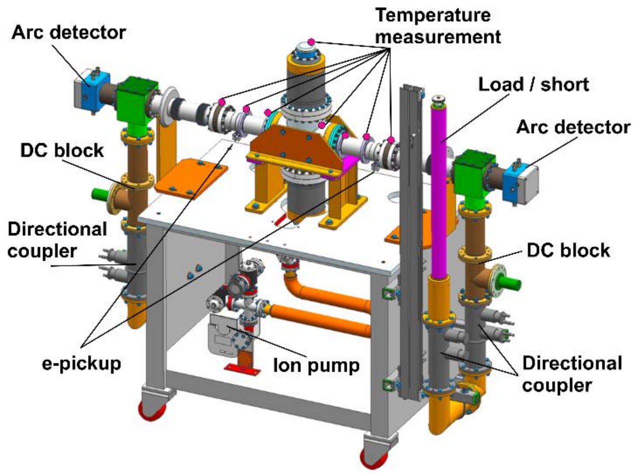

Figure 3: Configuration of the test stand.

TEST CONFIGURATIONS

The first stage of coupler testing was performed in two configurations: TW and SW, Fig. 4, 5. Power was limited to 10 kW by the amplifier. Due to the long length of 3" heliax needed to go from the amplifier to the test stand only about 8 kW of power was delivered to the couplers.. Couplers and DC-blocks were successfully tested in these configurations in the CW regime [2].

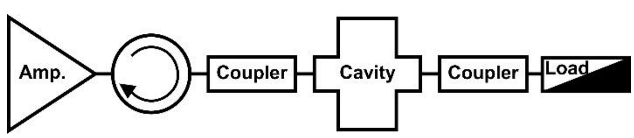

Figure 4: TW configuration of couplers testing.

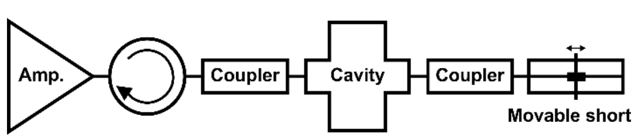

Figure 5: SW configuration of couplers testing.

To continue testing at higher power levels, the resonance configuration was used, Fig. 6. For this purpose the reflector was designed, Fig. 7.

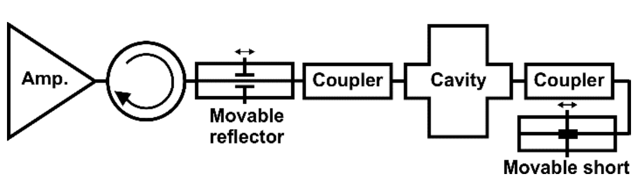

Figure 6: Resonance configuration of couplers testing.

This reflector is based on 3-1/8'' coaxial waveguide with a movable reflecting element, which can move a distance slightly more than half of the wavelength. Measured reflection coefficient is ~ 0.63 (-3.95 dB). This allows us to get power amplification of ~ 4 times and means that the couplers can be tested at power level ~ 30 kW, CW.

In this configuration the movable short was replaced by the set of coaxial waveguides with different length and a shortening plate at the end of each waveguide. The position of movable reflector was adjusted for each shortening waveguide to get the maximum power amplification.

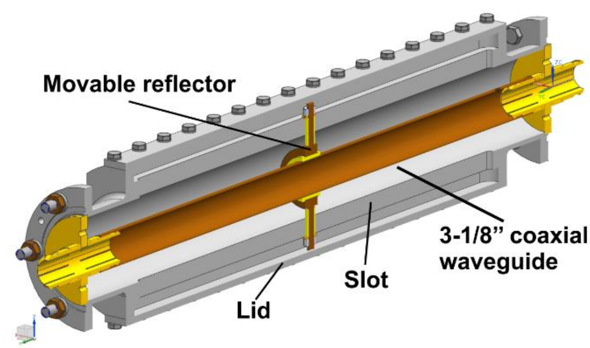

Figure 7: Movable reflector.

WEAK POINTS

Several weak points in DC-block and the coupler were identified during the tests in the resonance configuration. First, the RF breakdowns were detected between the DC-block copper coil (DC short, Fig. 2) and the outer conductor. To avoid the breakdowns, the coil was placed inside a heat-shrinkable plastic tube. After that no evidence of breakdowns was detected at these points.

We then found that the number of kapton layers on the DC-block capacitors and couplers capacitors was insufficient. We found that after ~ 15 min at maximum power and HV bias one of the capacitors would fail. The initial number of DC-block kapton layers was 3 while thenumber of coupler layers was 2. The thickness of the kapton film was 25 micron. We increased the number of layers to 5 for both cases. After that the devices worked without breakdowns at maximum RF power and HV bias up to 5 kV.

PROCEDURE OF TESTING

For each position of shortening waveguide the conditioning started in pulse mode with duty cycle 0.5 and pulse length 0.5s. Power was gradually increased up to the maximum. Multipactor was observed at some levels of power. The multipactor was conditioned keeping pressure level less than 2.5E-6 Torr. After reaching maximum power the HV bias was applied to suppress multipactor completely. After that we transitioned to CW mode. RF power was gradually increased again, from minimum to maximum level. After reaching maximum, the system was left for two hours. If no trip occurred the test was considered a success and the length of shortening waveguide was changed. This testing procedure was

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repeated starting from the pulse mode.We performed a total of four runs with different shorting waveguides.

The graphs in Fig. 8, 9 and 11 demonstrate various parameters' behaviour during a typical testing cycle. Figure 10 shows points of temperature measurements. The pressure rise shown in Figure 9 (red) can be explained by the temperature rise in the coupling cavity, , point T2 in Figure 10, green line at Figure 11.

In addition, one coupler was tested with a cold superconducting spoke cavity SSR-I installed in a test Cryomodule. The cavity achieved nominal voltage of 2 MV. Since the coupling was not optimal, the necessary RF power applied to the cavity through the coupler exceeded optimal power several times and reached ~ 10 kW, CW. Signs of multipactor were observed at a RF power level ~ 7 kW: "dark" current coming from cavity was observed. After applying HV bias this dark current vanished.

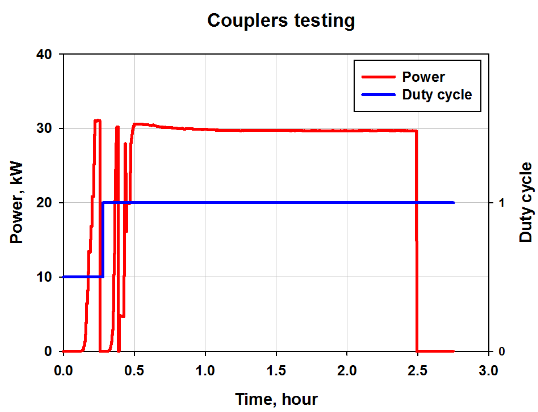

Figure 8: Typical testing procedure: time vs. power and duty cycle.

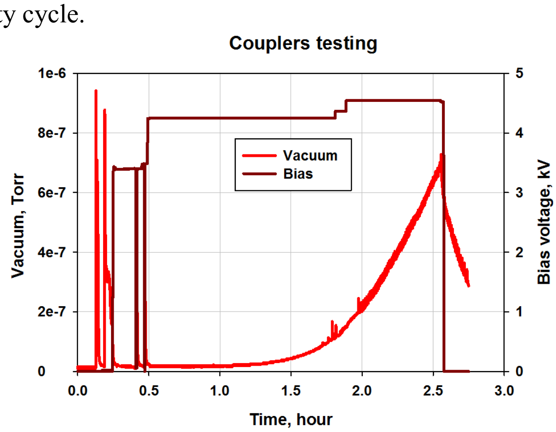

Figure 9: Typical testing procedure: time vs. vacuum and bias voltage.

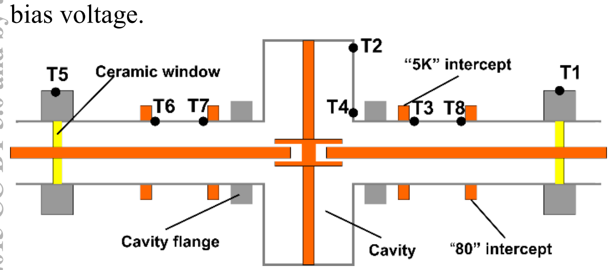

Figure 10: Points of temperature measurements.

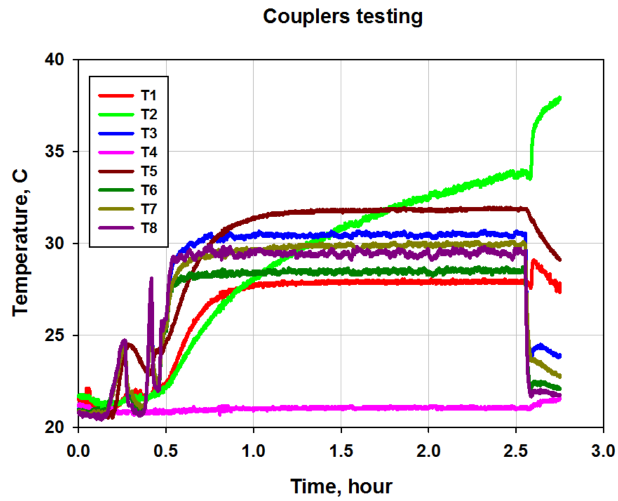

Figure 11: Typical testing procedure: time vs. temperature.

CONCLUSION

The resonance configuration installed at the coupler test stand allowed us to test couplers and DC-blocks at power level about 3 times greater than the power of the RF source. After some modifications, the couplers and DC-blocks demonstrated the ability to work at power level ~ 30 kW, CW and full reflection with arbitrary phase.

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