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HIGH POWER TEST OF THE ANTENNA ADJUSTABLE POWER COUPLER FOR 325 MHz SUPERCONDUCTING CAVITIES

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Abstract

The fabricated power coupler was a coaxial capacitive-type coupler based on a conventional $3\frac{1}{8}$-inch Electronic Industries Alliance 50-Ω coaxial transmission line with a titanium nitride (TiN)-coated single ceramic window. A high-power test was performed with a 20 kW and 325 MHz solid-state power amplifier. The power coupler was connected to a rectangular test cavity with high vacuum and various measuring equipment, such as an arc detector, a power meter, and an electron pick-up probe. The interlock system under vacuum and arc instrumentations prevented the RF window from breaking the power coupler window during the high-power test. We conducted high-power tests for more than 12 h at 12 kW in a 325 MHz continuous wave mode to verify the performance of the designed power coupler.

INTRODUCTION

Figure 1 shows the manufactured model of the 325 MHz power coupler. The antenna of a fundamental power coupler (FPC) was designed to allow an adjustment of ±3 mm, enabling the resonant frequency and Q_{ext} to be adjusted for changes in cavity variables during the horizontal cryogenic tests of the superconducting cavity and for changes in beam current during beam operations. Table 1 shows the design characteristics of the power coupler and detailed design progress is described in Reference [1].

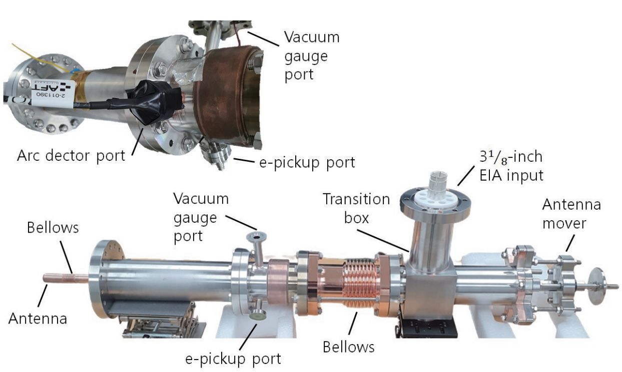

Figure 1: Manufactured model of the 325 MHz power coupler.

Table 1: Design Characteristic of the Power Coupler

Parameters	Values	Note
Operating Frequency	325 MHz	-
Impedance	90 Ω	-
S_{11} (at 325 MHz)	< -30 dB	(FPC only)
Operating Power	3 kW	-
Q_{ext}	3 ~ 6.5 $\times 10^6$	Q_0 = 5 × 10^9
Coupling method	Variable	Stroke ± 3 mm

PERFORMANCE VERIFICATION

Test Bench Set-Up

Figure 2 shows a schematic diagram of the high-power test of the power coupler. The solid state power amplifier (SSPA) capable of an RF power output of up to 20 kW at 325 MHz was operated with the signal generator and the waveform generator. Two directional couplers were connected to each power coupler to detect the amplitude and frequency of the power passing through, which were measured by a power meter and a spectrum analyzer. After the directional coupler of the FPC2, a water-cooled dummy load was positioned to attenuate the applied RF power. A vacuum gauge was connected to the test cavity and used for pre-experimental vacuum checking. The detectors connected to the pick-up ports can measure the arc discharge, electronic emission, and vacuum level variation to prevent RF window breakage [2]. The interlock system was not operated but was activated at high vacuum level (> 1 × 10^{-5} mBar) or when the light intensity around the RF window was greater than 1 lx [3].

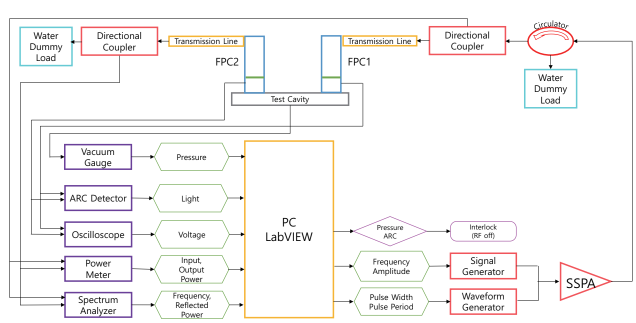

Figure 2: Test bench diagram for the high-power test of the power coupler.

Figure 3 shows the test bench setup for the power couplers and a test cavity. For the temperature interlock system operation, 12 temperature sensors were attached to the FPC

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and test cavity and used for the high-power test. The test cavity is based on a waveguide, and the resonant frequency of the test cavity can be adjusted by the spacer in the center of the cavity. The power coupler is assembled on ports located at the top of the test cavity and can be checked for arc discharge and antenna condition from the viewport located on the bottom side. Two ports for vacuum pump connections are placed on the side of the test cavity, and the pick-up port on the other side is fitted with an electron probe to detect the electron emissions inside the cavity.

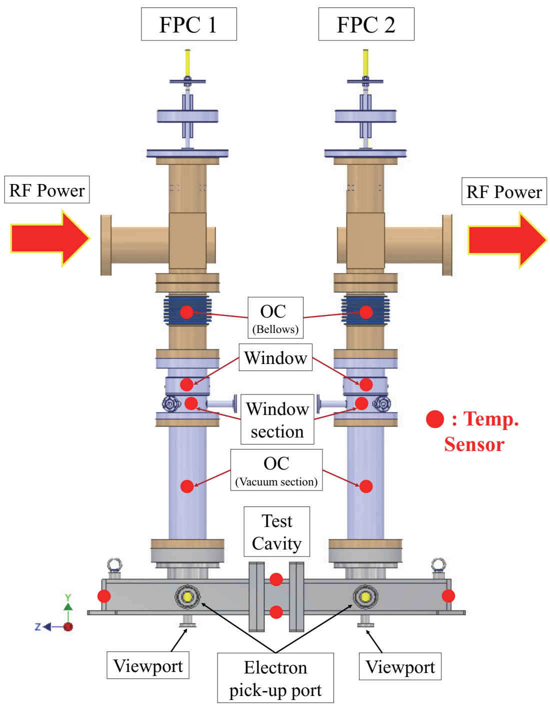

Figure 3: (a) Test bench setup of the power couplers and a test cavity and (b) geometry of a test cavity.

High Power Test

We performed power tests at 12 kW with traveling wave conditions, which is four times more than the operating power of 3 kW, in 325 MHz to verify the power coupler performance. For the high-power test of power couplers, RF conditioning was performed from the initial 0.001% low-duty cycle to 68%. The repetition frequency (f_{rep}) was increased from 1 Hz to 34 Hz, and the pulse width increased from 10 µs to 20 ms. From the initial stage, the vacuum level increased owing to multipacting, the frequency of interlock occurrence was low, and the duty ratio increased by 5%. In contrast, the duty ratio increased by approximately 1%. The increase rate of the duty ratio was mitigated owing to concerns about window breakage in the high-power tests. Multiple RF conditioning steps for 1–3 h were performed in accordance with the vacuum level changes caused by the multipacting effects, and a total of 132 h of conditioning was performed.

Figure 4 shows example data of the RF conditioning steps, and the vacuum level stabilized after 8% of duty cycle. This means that the multipacting effects can be suppressed. The multipacting effects occurred in the test cavity and power couplers and were measured using an oscilloscope. Multipacting in the test cavity had a band and nonnegligible strength for the RF power, which were not found in the power couplers. This is because the RF window of the power coupler has a lower SEY through the TiN coating, but the test cavity was made of aluminum and had a higher SEY than those of OFHC copper and TiN of the power coupler [4].

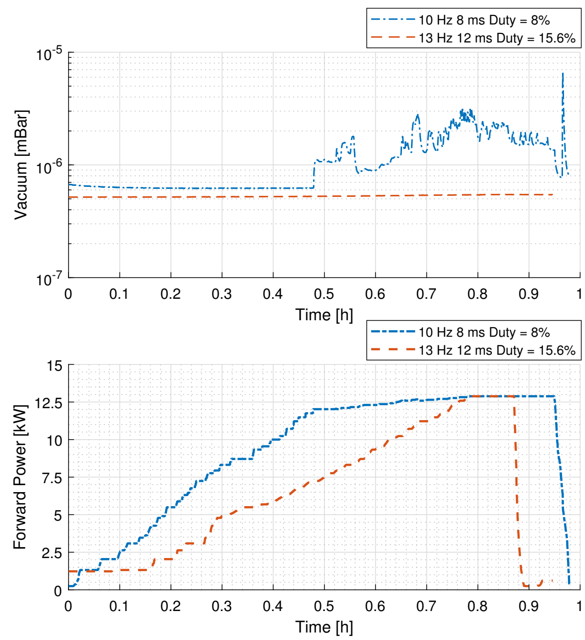

Figure 4: RF conditioning: time evolution of the vacuum pressure (top) and forward power at directional coupler of the SSPA (bottom).

The RF conditioning made the internal surface of the power coupler suitable for high-power tests. The SSPA was operated in a CW mode following the RF conditioning with a duty factor greater than 68%, so that the power passing through the directional coupler of each power coupler could be adjusted to approximately 12 kW. In the case of electron emission, the interlock system was operated on the basis of the vacuum level (1×10^{-5} mBar).

Figure 5 shows the results of the 14-h CW high-power test. The forward power measured on the power meter was maintained at 12 kW and was operated for 14 h without the multipacting effects or interlocks during the measurement.

Figure 6 shows the temperature variations with changes in the RF power. All temperature values were recorded after saturated, and in particular, the temperature at 12 kW is the maximum temperature while maintaining the RF power for more than 14 h. The temperature of the test cavity was determined by the average value of four temperature sensors, and it increased by approximately 4.3 °C. The biggest temperature changes were observed in the RF window of

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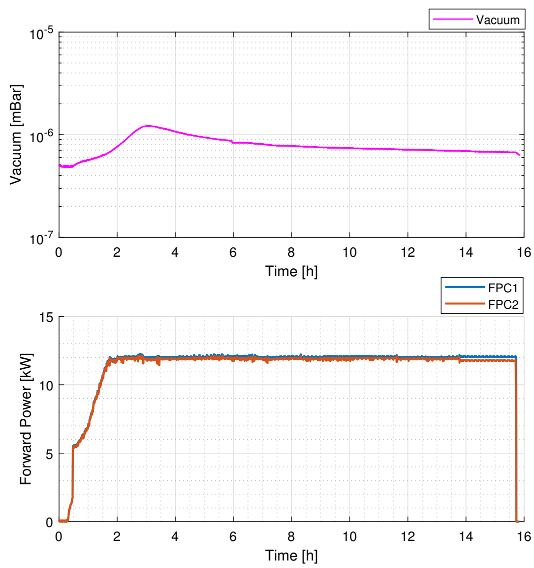

Figure 5: CW high-power test: time evolution of the vacuum pressure (top) and forward power at the directional coupler (bottom) for 14 h.

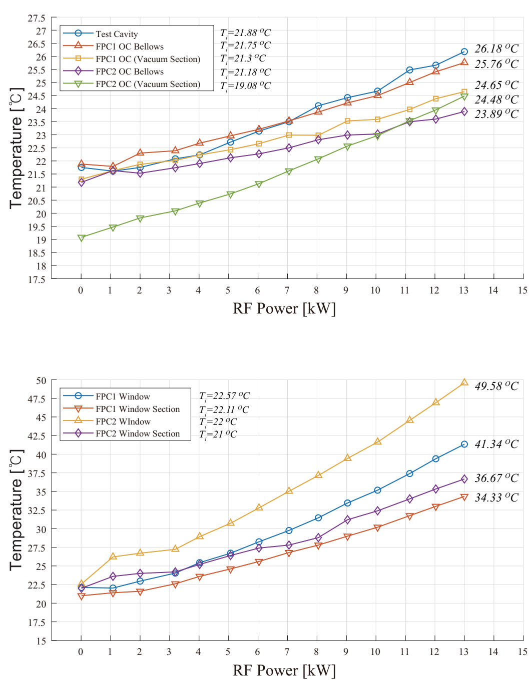

Figure 6: Temperature variation by applied RF power: (a) the test cavity (circle), FPC1 bellows at the outer conductor (triangle), FPC1 outer conductor (square), and FPC2 bellows at the outer conductor (diamond), and FPC2 outer conductor (inverted triangle); (b) the FPC1 RF window (circle), FPC1 window section (inverted triangle), FPC2 RF window (triangle), and FPC2 window section (diamond).

the FPC2, which increased by approximately 27.58 °C. The temperature increased by RF power was lower than the 60 °C where the interlock system was operating.

CONCLUSION

The coupler comprised an antenna moving system to adjust the external quality factor before and after the assembly with a cryomodule. Two 3 kW power couplers were fabricated and tested for high-power performance verification. The reflection coefficients were below −30 dB at the resonant frequency of the fabricated model, which satisfied the performance requirements. The high-power test was conducted at 12 kW for more than 14 h in the traveling CW mode. The multipacting effect was measured over a wide RF power range during the high-power test. However, multipacting could be overcome by RF conditioning. Our future research plan is to perform a standing wave test with a test cavity at room temperature and a horizontal test with a 325 MHz superconducting cavity at 2 K to verify the static/dynamic heat load of the power coupler.

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