POWER COUPLER DEVELOPMENT FOR ERL MAIN LINAC IN JAPAN

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Abstract

We started to develop an input power coupler for a 1.3GHz ERL superconducting cavity for main linac[1]. We fabricated power coupler components such as ceramic windows and bellows and carried out the high-power test of the components by using a CW 30kW IOT power source [2]. During this test, the ceramic window was broken by the sudden heat load. We found that this heat load occurred by the unexpected dipole mode. We renewed the ceramic window and successfully carried out the high power test up to CW 27kW input power.

INTRODUCTION

A power coupler is one of the important items of the superconducting cavity for ERL operation [1]. Table.1 shows the parameters of power coupler for main linac. Thanks to the mechanism of energy recovery, we can reduce the input power of the main linac. However, the minimum input power will be restricted by the cavity detuning due to the microphonics from the cryomodule. Therefore, 20kW is needed for main linac operation.

Table 1: Parameters of power coupler for main linac.

Frequency	1.3GHz
Accelerating voltage	Max 20MV/m
Input power	Max CW 20kW (Standing wave)
Loaded Q (Q)	$5x10^6 \sim 2x10^7$(variable)

Fig.1 shows the design of the input power coupler for our main linac. Two coaxial ceramic windows are set; One, which is called as "cold window" is set on the cold parts at 80K and the other, which is called as "warm window", is on warm parts at 300K for safety. Purity of ceramic material is 99.7% to reduce the heat load of ceramic. The impedance of coupler is 60Ω to reduce the heat load of inner conductor. Furthermore forced air cooling was applied to inner conductor. Detailed design strategy and parameters are expressed in Ref.[2].

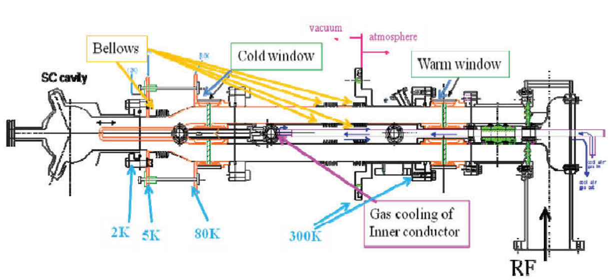

Figure 1: Schematic design of input coupler for main linac

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It is important to check the heat load and temperature rise of an input power coupler. We fabricated power coupler components, warm ceramic windows with bellows and cold windows, and carried out the high-power test of the components by using a CW 30kW IOT power source as shown in Fig.2. In this component test, the sudden temperature rise at cold ceramic window was observed in feeding RF power of 8kW and resulted in the break of the cold ceramic window as shown in the right of Fig.2 [2]. This heat load was considered due to the power loss of the unexpected resonance mode excitation. In this paper, we describe the detailed research of the correlation between the sudden temperature rise and this resonance mode. In addition, we describe the fabrication of the improved ceramic window and results of its high power test.

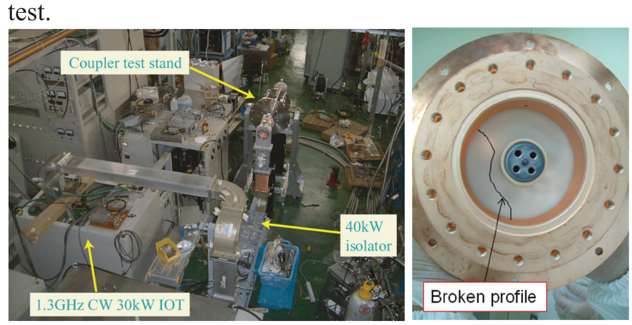

Figure 2: (Left) Setup of the coupler test stand. (Right) Picture of the cold window with broken profile.

RESEARCH OF CERAMIC WINDOW

Since the warm windows with bellows were fortunately survived in the previous high power test, we continued the high power test by using this warm window. Fig.3 shows the setup of high power test of warm window with standing wave. RF power was fed into the warm window from 30kW IOT via doorknob exchangers and reflected by the end plate. Therefore standing wave was excited at warm window and bellows. We tried two types of end plates so that two cases of standing wave were excited at the warm ceramic window; one makes the magnetic field maximum on the ceramic window (warm_1) and the other makes electric field maximum (warm_2). Same kind of standing field is maximum at the middle of the bellows as that of the ceramic window. Temperatures of bellows and warm window were monitored. Forward RF power (P_in_for) and reflected RF power (P_in_ref) were also measured at the upstream of the doorknob exchanger. The inner conductor and bellows were cooled via rod by an air compressor and the amount of air flow was monitored. An arc sensor was set on the end plate. The volume between the warm window and the end plate was pumped by an ion pump and the vacuum pressure was measured by CCG. After baking at 150 C° for 24 hours, the vacuum pressure of $6x10^{-7}$ Pa was achieved before high power test.

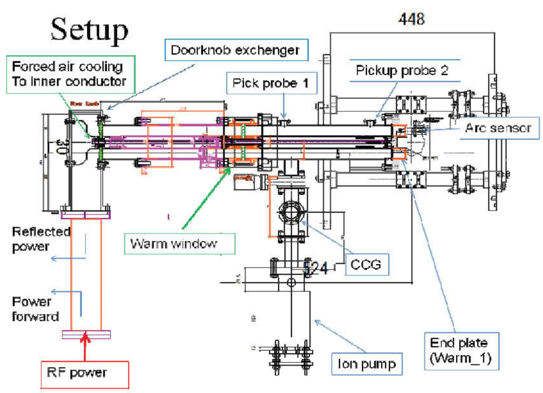

Figure 3: Setup of warm window high power test with standing wave.

We applied the RF power to warm window in the case of "warm_1". Detailed RF processing procedure was expressed in Ref.[2]. After some processing of the ceramic window, finally we could increase the input RF power up to 20kW with a standing wave. Power loss was not observed although the power loss was occurred in the previous high power test of the cold window. No vacuum leak or damage of ceramic windows was observed at this high power test.

Next, we changed the end plate so that the electric peak of standing wave was excited in the warm window (warm_2). When the power increased up to 7kW, we also found the power loss and the sudden vacuum leak occurred. The ceramic window was broken again. To survey the power loss in detail, we set the thermometer (YOKOKAWA 53006) instead of the arc sensor for directly measuring the temperature rise of the ceramic window. We found the resonance peak at 1.307GHz by the low power level measurement. We changed the drive frequency of signal generator (SG) to the IOT in order to intentionally excite the resonance mode in the ceramic window. Fig.4 shows the measurement results of the power loss and temperature rise of the ceramic window corresponding to the changing the drive frequency. In this test, we only applied 1kW power to avoid increasing the temperature caused by other components except for the ceramic window. In addition, to excite the resonance mode for lower frequency below 1.302GHz, we intentionally controlled the temperature of ceramic window by adding the heater. When the drive frequency was changed from 1.3GHz to 1.3015GHz, the sudden temperature rise of the only ceramic window was observed corresponding to fast response of the power loss (P_in_ref/P_in_for). No other temperature rise, for example that of the outside of the warm ceramic window, was observed in this measurement. This means that the resonance mode was excited and produced the heat load inside the ceramic window. This is one of the evidences of the heat load and the break of ceramic window.

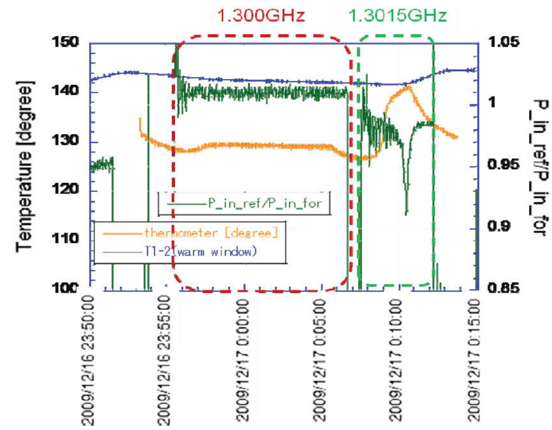

Figure 4: Measurement results of the power loss (green), the temperature rise of thermometer (orange) and the outside of warm window (blue) when the SG frequency was changed. Left (right) axis shows the temperature rise (the power ratio of "P_in_for/P_in_ref").

In order to investigate the causes of warm ceramic window break at the electric field maximum in the ceramic window, we calculated the eigenmodes of cold/warm ceramic window by using HFSS and MW-stdio simulation code [3]. We also found that the resonance peak near 1.3GHz, which represents the TE dipole mode as shown in Fig.5. In the case of "warm_1", however, we found that the dipole mode could not be excited at ceramic window by cancelling the forward and backward RF waves to and from the end plate. We think this is the reason why the power did not occur in the case of "warm_1".

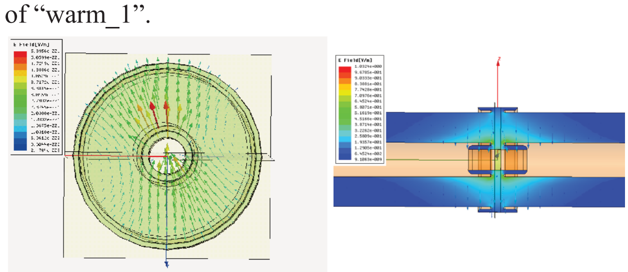

Figure 5: Calculated dipole mode standing on the ceramic window near 1.3GHz by HFSS.

STUDY OF NEW CERAMIC WINDOW

From the previous results of high power tests, it is important to operate by escaping from the resonance frequency of the unexpected dipole mode. The detailed parameter searches of the RF simulation of the resonance mode at the ceramic window are summarized in Ref.[3]. Fortunately, the frequency of this dipole mode depends on the thickness of ceramic window as shown in the left of Fig.6. To escape this dipole mode, we planned to modify the ceramic window by changing the thickness down to 5.4mm (new ceramic), which is thinner than present thickness of 6.2mm (old ceramic). We fabricated the new ceramic window. The right of Fig.6 shows the results of low level measurement of the resonance modes of the old and new ceramic window. The measured resonance frequency difference between old and new ceramic windows was 30.0 MHz, which almost agreed well with the result of simulation of 31.2 MHz. We could shift the resonance frequency to upper side as the calculation expressed.

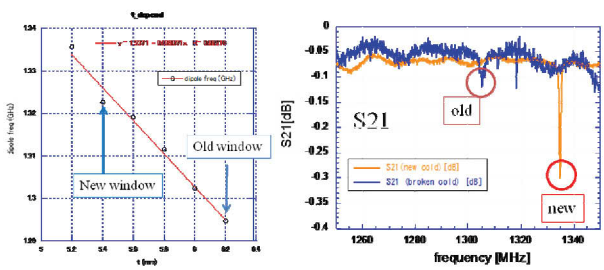

Figure 6: (Left) Frequency dependence of dipole mode corresponding to the thickness of ceramic calculated by HFSS. (Right) Low level measurements of S-parameters (S21) of the old and new ceramic window.

Next, we applied the RF power to the new ceramic window with standing wave. The setup of the high power test was almost same as Fig.3. The volume between the window and end plate were pumped by an ion pump and the vacuum pressure was measured by CCG. After baking at 150 C° for 24 hours, the vacuum pressure of 1.1×10^{-6} Pa was achieved before high power test. The inner conductors were cooled by air flow of 90 l/min.

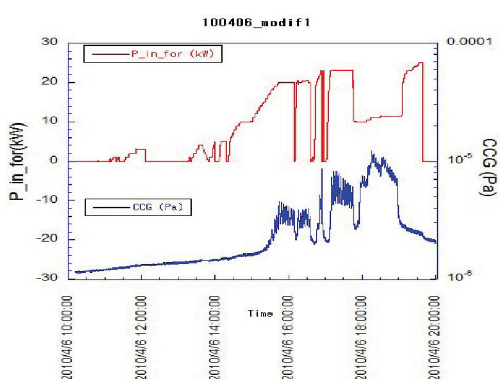

Figure 7: Results of high power test of new ceramic window. Left (right) axis shows the P_in_for (vacuum pressiure).

Fig.7 shows the results of the high power test of the new ceramic window. We could smoothly increase the RF power up to 27kW. When the power increased, the vacuum pressure level was increased due to the outgassing mainly produced at the bellows of inner conductor. The vacuum pressure level decreased by the baking effect of RF power with time. No arc interlock, vacuum leak or power loss were observed in this high power test. We measured the temperature rise by keeping the 20kW of input power as shown in Fig.8. Temperature rise of ceramic window measured by thermometer without outside cooling of ceramic window was 40K while adding 90l/min inner conductor cooling. No sudden temperature rise was observed in this test. This temperature rise of 20 kW input power was small enough for ERL operation. New ceramic window satisfied our requirements.

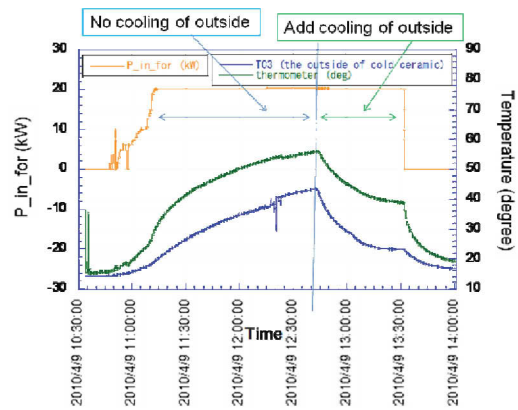

Figure 8: Results of high power test of new ceramic window. The left axis shows the P_in_for. The right axis shows the temperature of ceramic window measured by the thermometer (green line) and the outside of ceramic window (blue line).

SUMMARY

We studied the ceramic window of ERL main linac. We found the resonance of the dipole mode in ceramic window made the sudden temperature rise and the break of ceramic window. We fabricated the new ceramic window by changing the thickness of ceramic window. We finally achieved 27kW in the high power test by using new ceramic window. The high power test of the components of power coupler was successfully carried out. We also carried out the cool-down test of cold ceramic window at 80K. We will fabricate the first input coupler for main linac in this year.

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