INPUT COUPLERS FOR 972 MHZ SUPERCONDUCTING CAVITIES IN THE HIGH INTENSITY PROTON LINAC

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Abstract

Prototype coaxial input couplers with a planar rf window were designed and were fabricated. The high power test stand with a 972MHz pulsed klystron was completed. Rf processing of two pairs of the input couplers had been successfully carried out. Input rf power of 2.2MW in a pulsed operation of 0.6msec and 25Hz was transferred to the input couplers without any problem.

INTRODUCTION

In the KEK-JAERI joint project named J-PARC (Japan Proton Accelerator Research Complex), a superconducting linac is required to boost the energy of the H^- beam from 400MeV to 600MeV. The 600MeV beam will be used for ADS (accelerator-driven system) experiments in the second phase of the J-PARC project. In the present system design of the superconducting linac, eleven cryomodules containing two 972MHz nine-cell niobium cavities will be installed in the linac tunnel. The accelerating gradient has been set at about 10MV/m, and the operating temperature is 2K. A prototype cryomodule with β=0.725 (424MeV) was designed and has been constructed for an essential R&D work [1]. Up to the present, four 972MHz input couplers were fabricated and tested in order to confirm the high power capability and reliability. Rf processing of input couplers needed for installation in the cryomodule was successfully carried out. The experimental set-up, the processing procedure and the test results with high rf power are described in this paper.

RF DESIGN OF INPUT COUPLERS

Input couplers are used for transferring rf power to superconducting cavities. Basic design of the 972MHz input coupler was carried out with referring the 508MHz input coupler for the TRISTAN superconducting cavities [2]. Similar design is also found in the KEKB and SNS superconducting cavities [3, 4]. Heat load dissipated at copper surface and a ceramic disk is considerably reduced due to a pulsed operation, in comparison with the 508 MHz couplers in a cw operation. On the other hand, heavy irradiation caused by an intense proton beam has to be taken into consideration in the design.

A fundamental specification of the 972MHz input coupler is summarised in Table 1. The operating accelerating gradient, Eacc, is about 10MV/m and the synchronous phase angle is set to –30 degree. The required input rf power is 250kW for the beam current of 30mA, and the external Q (Qext) in the corresponding matched condition is 8×10^5. Lower Qext is preferable to suppress the oscillation of accelerating gradient due to Lorentz detuning. Therefore, the Qext of 5×10^5 and then the input rf power of 300kW were determined for the specification of the input coupler. Here, the bandwidth is about 2kHz and the filling-time is ~0.2msec.

External Q of the input coupler was calculated by HFSS in the model single-cell cavity with two antennas, as shown in Figure 1. The distance of X was finely adjusted so as to minimise reflect power (S11). The calculation method of Qext is completely the same as that in a cold test of a cavity. Loaded Q was obtained by the bandwidth of transmitted power (S21) to the input coupler of ϕ80. Unloaded Q was 26000 in copper surface. External Q strongly depends on the antenna location (L and T) and the diameter of the beam tube (D). The calculated results of Qext in a 9-cell cavity are shown in Figure 1. Consequently, the dimensions of L=95, T=35 and D=126 were selected for obtaining the Qext of 5×10^5. This result was confirmed with rf measurements in an actual copper cavity. The measured values were consistent with the calculation within an error of about 20%.

Table 1: Specification of the 972MHz input couplers

External Q value	5×10^5	
Input rf power	300 kW,	(I_b= 30 mA)
Pulsed operation	3.0 msec,	25 Hz

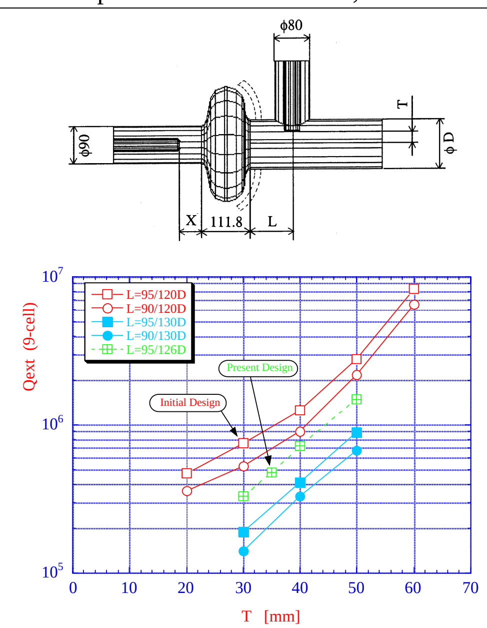

Figure 1: Model cavity and the calculated external Q.

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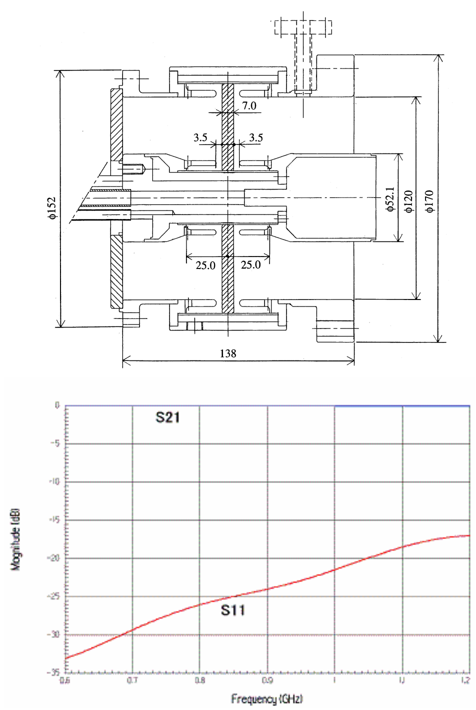

Figure 2: Drawing of a 972MHz coaxial ceramic window and the calculated S-parameters.

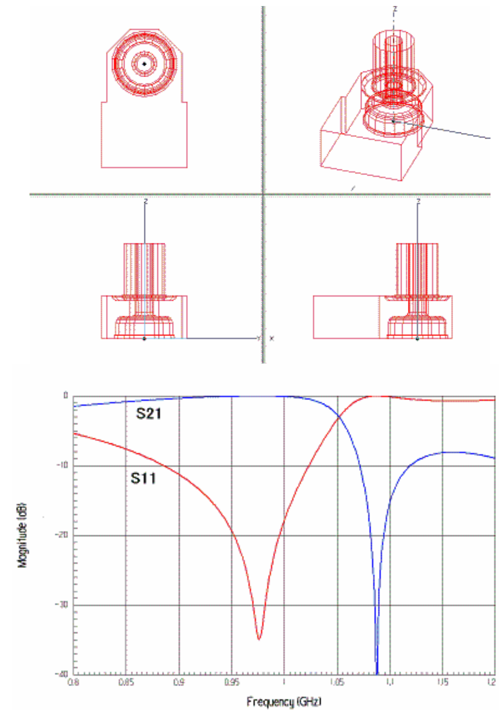

Figure 3: Designed structure of a 972MHz doorknob and the calculated S-parameters.

The optimum structure of a coaxial window with a planar ceramic disk, a doorknob transformer to a waveguide system and a pair of coupling waveguide with a pumping port was determined with the HFSS code.

The detailed dimensions of a 972MHz coaxial window with a choke structure and the calculated rf characteristics are shown in Figure 2. The ceramic disk is made of Al_2O_3 with the purity of 95%, and the thickness is 7.0mm. Coating with TiN on the surface of the vacuum side was carried out. The rf window is connected with a coaxial line (80D) of 50Ω. The inner conductor made of a cupper pipe is equipped with a built-in cooling channel.

The doorknobs are used for transition between the coaxial line of 120D and the WR975-waveguide. The optimised structure and the calculated S-parameters are shown in Figure 3. The bandwidth of S11 was about 50MHz at the level of –20dB.

The rf measurements of each component (rf windows, doorknobs and coupling waveguides) were carried out, and the VSWR at 972MHz is shown in Table 2. The measured values were in good agreement with the calculations by HFSS. The assembled whole rf system was terminated with a dummy load cooled by water. The measured S-parameter is shown in Figure 4. The matching condition was just fitted to the operating frequency, as expected.

Table 2: VSWR in the rf measurements

RF Components	VSWR (972MHz)
Rf window	1.13 and 1.14
Doorknob	1.05 and 1.08
Coupling WG with couplers	1.37
Assembled whole rf system	1.05

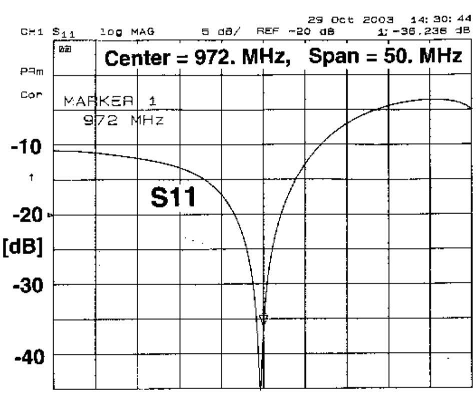

Figure 4: Measured S-parameter (reflected power) in the high power test stand.

HIGH POWER TEST STAND

The input couplers and the coupling waveguides were carefully rinsed with ultra-pure water. They were dried for one day and were assembled in a clean room. Then, pumping was carried out by a vacuum system composed of a turbo molecular pump of 500 l/s and a rotary pump of 16000 l/h. The input coupler system was baked out at 120°C for 24 hours prior to rf processing. The vacuum pressure at room temperature had reached to about $1x10^{-6}$ Pa. An experimental set-up for high power tests is shown in Figure 5 and Figure 6. An ionization gauge, a cold cathode gauge and a residual gas analyser are installed in the vacuum system. An ionization gauge, an arc detector and an electron pick-up probe are attached at three small ports close to the rf window of each input coupler. These monitoring instruments are very important to prevent a fatal sparking discharge around the rf window. Two video cameras locating at the bottom of the coupling waveguides can observe visible lights like a glow discharge by multipacting. A water-cooling system for the inner conductors is equipped with thermocouples and flow meters, which are used for a calorimetric measurement of the rf loss (see, Figure 13). A 972MHz pulsed klystron is a prototype for normal conducting cavities aiming at performances of 0.6msec, 50Hz and the maximum power of 3.0MW [5]. A longer pulsed operation is required for superconducting cavities. Therefore, modification in the rf control system and adjustment of the DC power supply system were carried out. In the present operated condition, the maximum available rf power is 370kW in the long pulse mode of 3.0msec and 2.2MW in the short pulse mode of 0.6msec.

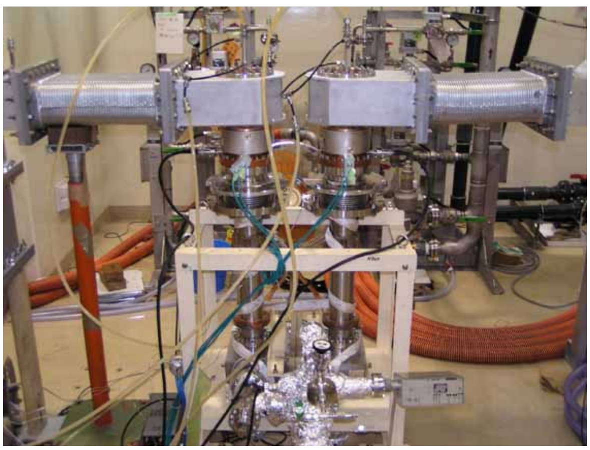

Figure 5: High power test stand.

RF PROCESSING

Up to the present, high power tests have been carried out once on the input couplers (#3 and #4) needed for installation in the prototype cryomodule and four times on the prototype input couplers (#1 and #2), as summarised in Table 3 and Table 4, respectively.

The initial rf processing in both cases was started with a low duty factor of 0.1msec and 10Hz. The interlock level of vacuum pressure at the rf window was set to 5×10^{-4} Pa. The first deterioration of the vacuum pressure was observed around 25kW in both cases.

In the initial test of the #3 and #4 input couplers, the input rf power had been carefully increased as seen in Figure 7. The processing time up to 300kW was 11 hours (14 hours up to 1100kW). There was no work of interlocks due to vacuum burst or arc detection in the rf processing. The components of desorbed gasses causing the vacuum deterioration were mainly H_2 and N_2+CO, as shown in Figure 8. After the initial processing, gradual increment of the duty factor was carried out in the successive tests, as seen in Figure 9. Severe vacuum deterioration like in the initial test was not observed any longer, and the processing time up to 1000kW came to be remarkably short. Finally, the maximum rf power of 1000kW in the short pulse mode of 0.6msec and 50Hz was transferred. The average rf power was 30kW.

A temperature rise at the antenna tip without cooling water of the couplers was investigated. The temperature rise reached to about 100°C at the average rf power of 20kW. Therefore, the necessity of forced cooling in the inner conductor was concluded, and the water-cooling was started in the successive processing.

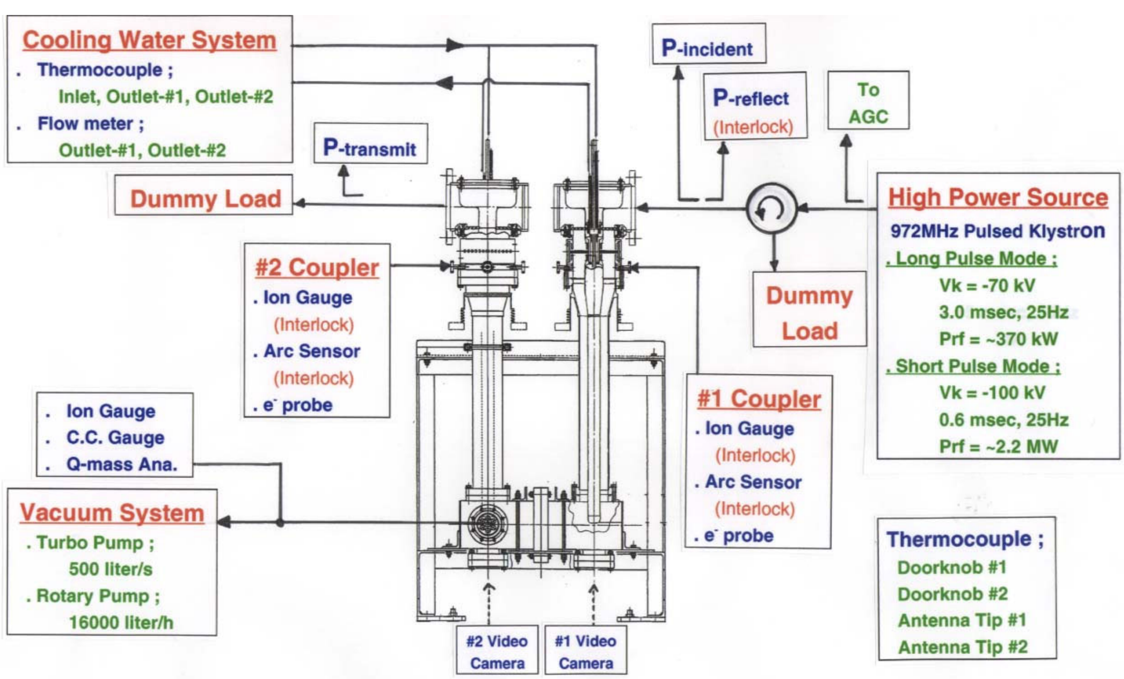

Figure 6: Experimental instrumentation for high power tests.

In the third test of the #1 and #2 couplers (Table 4), 2.2MW in the short pulse mode of 0.6msec was fed to the input couplers without any trouble. However, degradation of the vacuum pressure had been still observed between 400kW and 800kW even after processed up to 2.2MW, as shown in Figure 10. The vacuum degradation in this power range was simultaneously accompanied with detection of electrons by the pick-up probe and observation of glow lights by the video camera. The cause must be due to multipacting at the rf window or coaxial line nearby. The main residual gas components desorbed by multipacting were mainly H_2 and N_2+CO, similar to those during rf processing as seen in Figure 8.

Table 3: Procedure of rf processing (#3 & #4)

Test	Pulsed operation	Max. rf power	
1. Initial Tests:			
	0.1msec / 10, 25Hz	1100kW	(Fig. 7)
	0.6msec / 10, 25, 50Hz	1000kW	(Fig. 9)

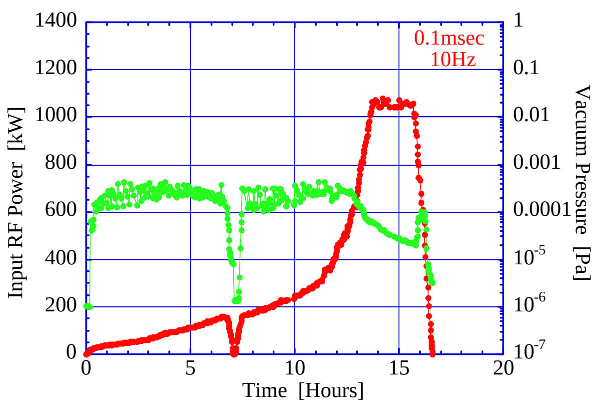

Figure 7: Rf processing logs in the initial test.

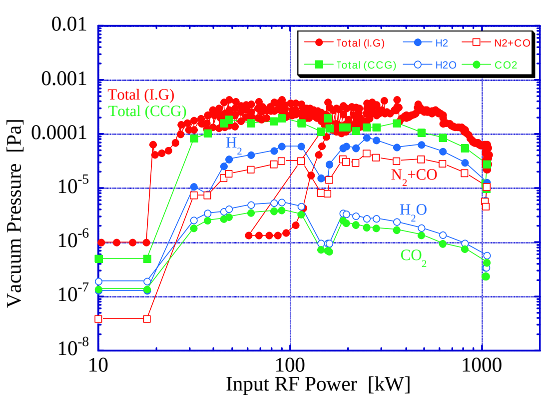

Figure 8: Residual gas components during the processing.

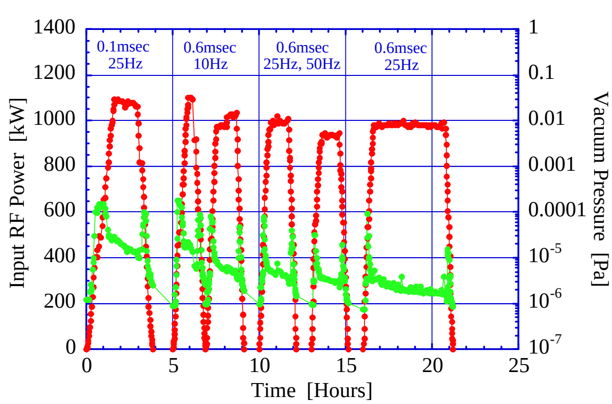

Figure 9: Rf processing logs in the successive tests.

Table 4: Procedure of rf processing (#1 & #2)

Test	Pulsed operation	Max. rf power	
1. Initial Tests:			
	0.1msec, 10Hz	300kW	
	2.45msec, 25Hz	350kW	
2. Exposure to N_2 gas:			
	0.1msec, 10Hz	300kW	(Fig. 12)
	2.45msec, 25Hz	350kW	
	0.6msec, 25Hz	1100kW	
3. Kept for one month without pumping:			
	0.1msec, 25Hz	1700kW	(Fig. 12)
	0.6msec, 25Hz	2200kW	(Fig. 10)
	Standing Wave	650-800kW	(Fig. 11)
4. Exposure to air:			
	0.1msec, 25Hz	360kW	(Fig. 12)
	3.0msec, 25Hz	370kW	
	Standing Wave	370kW	

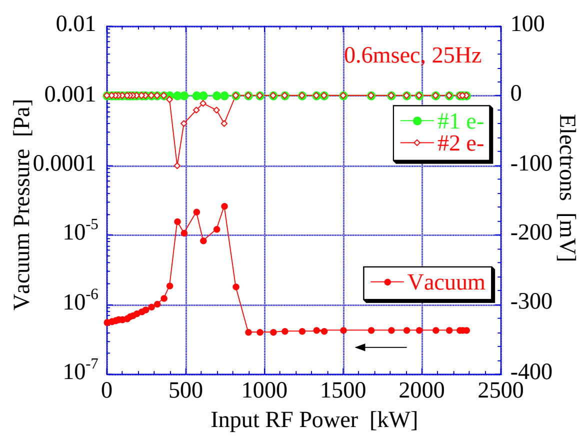

Figure 10: Vacuum pressure and electron activities after processed up to 2.2 MW.

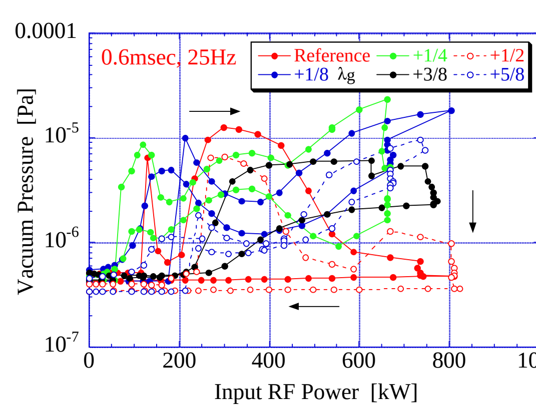

Figure 11: Rf processing in the standing wave.

RF processing in the standing wave was carried out, just after processed at 2.2MW in the travelling wave. Figure 11 shows the results in various phase conditions performed by successively changing the short-end position by 1/8 λg. Since the distribution of electromagnetic fields along the coaxial line of the couplers changes with the phase, the location of multipacting has shifted in each phase. Here, the vacuum deterioration had occurred at considerably low rf power above 50kW, even just after processed at 2.2MW. Therefore, it is suggested that further careful rf processing is needed again in the input couplers installed in the actual cryomodule, because the rf matching condition becomes to the total reflection, (i.e. standing wave).

In order to investigate memories of the rf processing effect, the input couplers were exposed to N_2 gas and air for a few days, (and residual gases in vacuum without pumping for one month). Baking at 120°C for 24 hours was always carried out after the exposure. As seen in Figure 12, the processing time up to 300kW was less than two hours in any case. Therefore, no major influence due to the exposure was observed, at least after baking.

Rf loss at the rf window and the inner conductor was measured in various power levels by a calorimetric method. The rf loss was about 0.2% of the average input rf power, as shown in Figure 13.

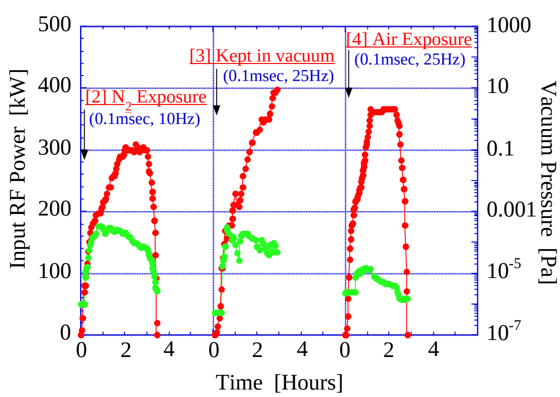

Figure 12: Effect after exposure to N_2 gas and air.

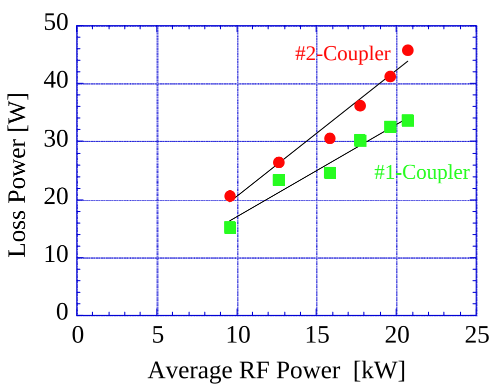

Figure 13: Rf loss at the rf window and the inner conductor.

SUMMARY

A high power test stand consisting of coaxial input couplers with a planar rf window, doorknobs and coupling waveguides was installed in a 972MHz pulsed klystron system. Rf processing of the input couplers was successfully carried out.

The processing time up to 1.0MW was about 14 hours in the initial test. The maximum input rf power of 2.2MW in a pulsed operation of 0.6msec and 25Hz (370kW in 3.0msec and 25Hz) was transferred to the input couplers. Multipacting levels between 400kW and 800kW might be persistent. There was no influence in the processing time due to exposure to N_2 gas and air.

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