RF PROPERTY OF THE PROTOTYPE CRYOMODULE FOR ADS SUPERCONDUCTING LINAC

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Abstract

A prototype cryomodule containing two 9-cell superconducting cavities with β of 0.725 and the frequency of 972MHz has been constructed under the collaboration of Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK) on the development of superconducting LINAC for Accelerator Driven System (ADS). Design and performance of the RF components are reported.

INTRODUCTION

Construction of the J-PARC (Japan Proton Accelerator Research Complex) is being carried out aiming at the commissioning in 2007. The 181MeV linac section, which consists of normal conducting accelerating structures, will be completed in 2006. A superconducting linac will be added in the second phase of the project, and the 600MeV H^- beams will be delivered to the ADS experimental facility. The R&D work on superconducting linac for ADS is being continued in collaboration with KEK and JAERI. A prototype cryomodule with β=0.725 (424MeV) was designed and has been constructed, [1]. Recently, the first cool-down test of the cryomodule was successfully carried out. Design and performance of the RF components and the initial results of a horizontal cold test are presented in this paper.

CRYOMODULE

Typical design parameters of the prototype cryomodule are listed in Table 1. The cryomodule includes two 972MHz nine-cell niobium cavities, which are operated in a pulsed mode. Assembling of the cryomodule was carried out at JAERI. Two cavities named R (right-side) and L (left-side) were united on the special bed in a class 10 cleanroom. Then, they were joined with a liquid He reservoir tank and were inserted into the vacuum vessel in a class 100 cleanroom, (see Fig. 1).

Table 1: Design parameters of the cryomodule.

Pulsed Operation	3.0 msec,	25Hz
Beam Current	30.	mA
Temperature	2.	K
Eacc	10.	MV/m
Qo	$> 1.x10^{10}$	
Input RF power	300.	kW
Qext (Input)	$5.x10^5$	

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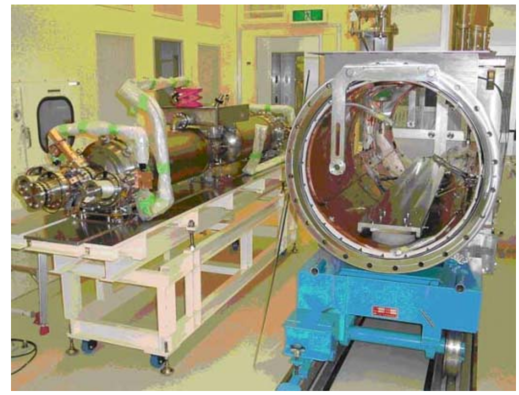

Figure 1: Assembling of the prototype cryomodule.

CAVITIES

A designed 9-cell cavity is shown in Fig. 2, and the main RF parameters calculated by SUPERFISH are summarised in Table 2. The niobium cavity is covered with a titanium jacket for filling liquid He of 2K. A titanium bellow for a cavity tuning system is attached at the He vessel. Four ports for couplers (an input, a monitor and two HOM; higher order mode) are located at the beam tubes. A diameter (φ126) of a larger beam tube was determined with a simulation for obtaining the Qext (Input) of $5.x10^5$, [2]. The cavities were made of niobium sheets of 4mm thick with RRR~250. Field flatness above 98% was obtained in the pre-tuning of each cavity, as shown in Fig. 3. Their cavity performance was finally qualified after repeated vertical cold tests, [3]. High pressure rinsing with ultra-pure water was carried out as a final surface preparation before assembling of the cryomodule.

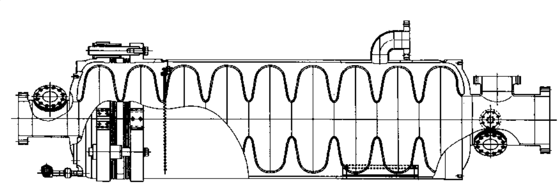

Figure 2: A 972MHz 9-cell cavity of β=0.725, (L cavity).

Table 2: RF parameters of the cavities.

Esp/Eacc	3.07	
Hsp/Eacc	55.4	Oe/MV/m
R/Q	478.	Ω
Geometrical factor	208.	Ω
Cell-to-cell coupling	2.80	%

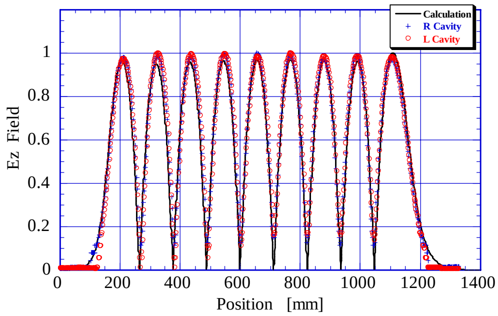

Figure 3: Field distribution after pre-tuning.

INPUT COUPLERS

Figure 4 shows two coaxial input couplers with a planar RF window installed in the high power test stand, [4]. An ionization gauge, an arc detector and an electron pick-up probe are attached at three small ports close to the RF window in order to prevent a fatal sparking discharge nearby. Thermal anchors at 80K and a liquid He line at 5K are attached on outer surface of the outer conductor.

The initial RF processing was started with a low duty factor of 0.1msec and 10Hz, and the processing time up to 1.0MW was 14 hours, as seen in Fig. 5. Then, the duty factor was gradually increased. The input power of 1.0MW with 0.6msec and 50Hz was finally transferred with no work of interlocks. The input couplers were disassembled in a cleanroom and were installed in the cryomodule.

Figure 4: Input couplers at the test stand.

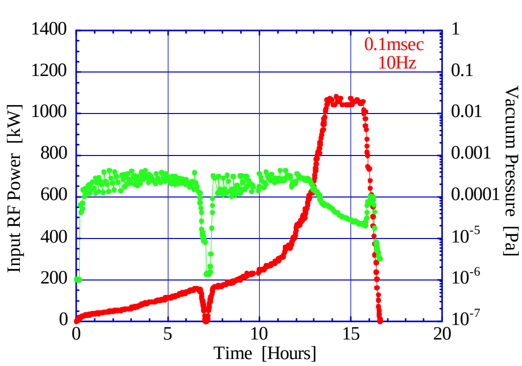

Figure 5: RF processing in the initial test.

HOM COUPLERS

Four types of HOM couplers with a different coupling were prepared for the prototype cryomodule, as shown in Fig. 6. Two HOM couplers made of Nb and Cu were installed in each beam tube (ϕ126 and ϕ90, respectively) of the cavity. The typical dimensions of four HOM couplers are summarised in Table 3. The detailed drawing is also found in Ref. [1]. The RF filter structure to suppress coupling with an accelerating mode was designed with a simulation by HFSS. The calculated frequency characteristic is shown in Fig. 7, and it is in good agreement with the results in the RF measurement.

Figure 6: Four types of HOM couplers.

Table 3: Typical dimensions of four HOM couplers. [mm]

Cavity	ϕ_{-BT}	Material	S	D
R	126.	Nb	38.	14.
R	90.	Cu	35.	20.
L	126.	Nb	38.	26.
L	90.	Cu	38.	20.

ϕ_{-BT} ; Diameter of the beam tube.
S ; Space between the antenna tip and the beam axis.
D ; Diameter of the antenna tip.

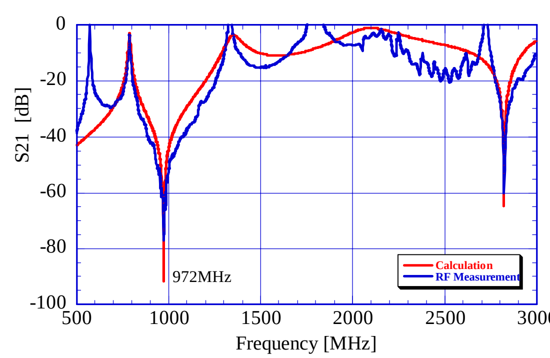

Figure 7: Frequency characteristic of a HOM coupler.

HORIZONTAL COLD TEST

After the final assembling of the cryomodule was finished, the initial cool-down test was carried out. Experimental set-up for the horizontal cold test is shown in Fig. 8. The cryogenic system, which consists of a joint box, a valve box and Dewars, supplies liquid N_2 at 80K, liquid He at 5K and 2K to the three independent cooling lines of the cryomodule. The detail of the cryogenic performance is described in Ref. [5]. Only low-level RF measurements at 2K were carried out in this experiment.

High power tests with a 972MHz pulsed klystron will be scheduled in this autumn.

Measured resonant frequency (fo) and external quality factors (Qext) for the accelerating mode are listed in Table 4. Frequency shift (Δfo) due to cool-down from 300K to 2.0K was about +1.5MHz. Therefore, the target frequency in the final pre-tuning should be set to 969.5MHz, taking account of Δfo=+1.0MHz due to tuning load applied by a motor tuner. The Qext of the input couplers is in agreement with the design value of $5.x10^5$ within an error of 20%. The Qext of other couplers are also controlled very nicely. The tuner system, [1], consisting of a stepping motor and piezo has worked well. Sensitivities of the frequency change due to a motor tuner, a piezo tuner and vacuum pressure are summarised in Table 5. The tuning range is wide enough, and the accuracy is precise enough. Pass-band frequencies of assigned HOMs are shown in Fig. 9, together with the calculation by MAFIA. Measured loaded quality factors (Q_L) of TM110 and TE111 modes are shown in Fig. 10. Several modes with high Q_L value above 10^6 were found in TM110 around 1.3GHz. Some improvement is needed for lowering the Q_L.

Figure 8: Experimental set-up for the horizontal test.

Table 4: Low-level RF tests of the accelerating mode.

Cavity		R	L	
fo_{300K}	(tuner free)	969.97	970.40	MHz
$fo_{2.0K}$	(tuner free)	971.48	971.94	MHz
Qext	(Input)	$4.6x10^5$	$4.0x10^5$	
Qext	(Monitor)	$1.0x10^{12}$	$1.2x10^{12}$	
Qext	(HOM-Nb)	$2.0x10^{12}$	$5.4x10^{11}$	
Qext	(HOM-Cu)	$5.7x10^{13}$	$1.2x10^{14}$	

Table 5: Sensitivities of the frequency change.

Cavity	R	L	
Motor Tuner	206.	204.	kHz/mm
	1.43	1.40	kHz/kg
Piezo Tuner	~3.0	~3.5	kHz/kV
Vac. Press.	0.706	0.701	kHz/kPa

Motor Tuner ; The full stroke is 10 mm.
Piezo Tuner ; The maximum applied voltage is 1 kV.
Vac. Press. ; Vacuum pressure in the He vessel.

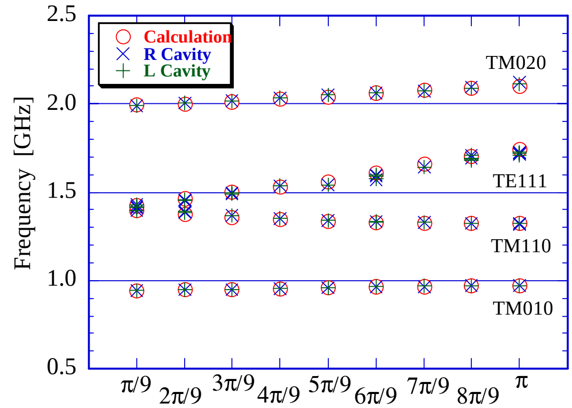

Figure 9: Frequency distribution of HOMs.

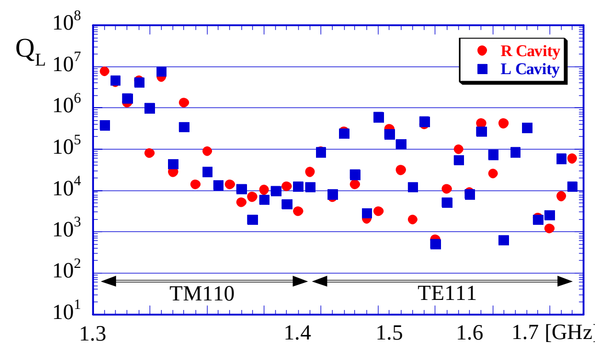

Figure 10: Measured Q_L of TM110 and TE111 modes.

SUMMARY

After RF components like cavities and couplers were tested individually, the final assembling of the 972MHz prototype cryomodule has been completed. The initial horizontal cold test was successfully carried out. RF properties obtained in the low power measurements were in good agreement with their design values.

ACKNOWLEDGEMENTS

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