600MHZ PROTOTYPE CRYOMODULE FOR HIGH INTENSITY PROTON LINAC AT JAERI

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Abstract

A 600MHz prototype cryomodule for a high intensity proton linac has been developed at JAERI in order to study cavity installation process, cavity performance in the cryomodule and the stability of the accelerating field in the pulsed operation. The cryomodule includes two 5-cell cavities of β_g=0.6. The cryogenic deign has been made for 2K operation. Fabrication, assembling and preliminary horizontal test has been carried out. The results obtained in this program contribute to the development of the superconducting proton linac for the High Intensity Proton Accelerator Project promoted by JAERI and KEK. This paper describes the design, assembling and the results of the preliminary horizontal test of the prototype cryomodule.

1 INTRODUCTION

Development of superconducting cavity for high intensity proton accelerator has been continued at JAERI since 1995. Good performance of the single- and multi-cell cavities was obtained in the vertical tests [1,2]. As the next step of the R&D work, a prototype cryomodule has been fabricated and the preliminary horizontal test has been performed. The purpose of the program is to study cavity installation process into the cryomodule in a clean room, to demonstrate of cavity performance in the cryomodule and to study the stability of the accelerating field in a pulsed operation. This program is based on the JAERI original project (the Neutron Source Project), which is merged into the High Intensity Proton Accelerator Project promoted by JAERI and KEK now. The results of this program contribute to the current High Intensity Proton Accelerator Project, while the specifications of the cavity are different from those of the JAERI original project. This paper describes the design, assembling and the preliminary test results of the 600MHz prototype cryomodule.

2 CRYOMODULE DESIGN

Figure 1 shows the overview of the cryomodule. The cryomodule includes two 5-cell cavities of β_g=0.604. The cavities are named to be J6001 and J6002. Details of the cavity design, surface treatment, pretuning and results of the vertical tests are presented in Ref. 3.

Jacket type liquid helium vessel is applied as shown in Fig. 1. The jackets are made of stainless steel. The joint between niobium and stainless steel has been performed by the HIP (Hot Isostatic Pressing) method, where copper plate of 1mm thick is used as an insertion material between niobium and stainless steel. Two jackets are connected through a reservoir tank located above the jackets. The volumes of each jacket and the reservoir tank are about 80 and 30 litters, respectively. The cryomodule is designed to achieve 2K operation. Figure 2 shows the cryogenic flow diagram. Liquid helium at 4.2 K is fed from a Dewar vessel and cooled down by a heat exchanger and a JT valve to 2K. Pre-cooling line is also prepared for each jacket. Thermal intercepts at 4.2K are located at beam pipes, RF input couplers and a cavity support in order to reduce heat leak to the 2K jackets. Thermal shield at 80K is also located between a vacuum vessel and 4K thermal intercepts. Table 1 summarizes the heat load estimation of the cryomodule.

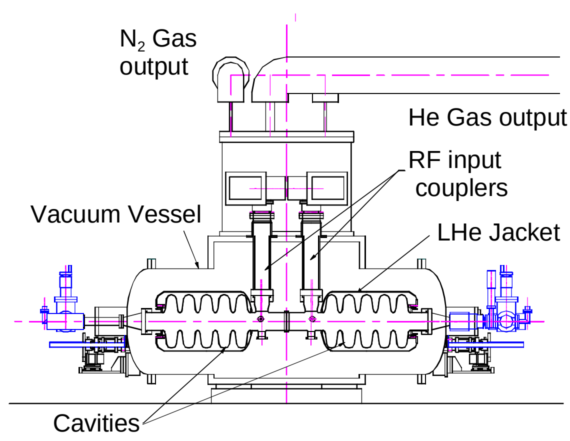

Fig. 1 Overview of the cryomodule

Coaxial type RF input couplers are installed for the cavities. The design and the high power tests of the couplers are presented in Ref. 4. Magnetic shield of the Permalloy (2 mm in thickness) is placed on the inner surface of the vacuum vessel.

In order to reduce the Lorentz force detuning, rigid support of both ends of the cavity is very important.

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Therefore, the cavity tuning system is designed so that the tuning force is applied only between the cavity beam pipe and the liquid helium jacket. The rigidity of the tuning system and the liquid helium jacket is expected above 60kN/mm. The tuning for each cavity is performed by a pulsed motor.

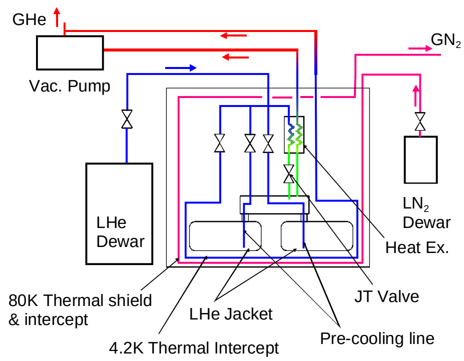

Fig. 2 Cryogenic flow diagram

Table 1 Heat load estimation (W)

	2K	4K	80K
Static			
Coupler	0.08	10.66	8.20
Beam Pipe	0.01	0.15	1.68
Tuner	0.93	2.94	8.44
Support	0.02	0.30	7.95
Cables	0.18	0.04	0.10
Valves, Joints, etc.	0.29	1.01	19.37
Radiation	0.23	1.15	21.39
Dynamic			
RF coupler	0.00	0.36	2.51
RF cavity	10.0		
Total	11.74	16.61	69.64

3 ASSEMBLYING

3.1 Residual magnetic field

Prior to the cavity installation into the cryomodule, residual magnetic field on the beam axis is measured. The results are shown in Fig. 3; the residual magnetic field strength has been confirmed to be low enough except for the south end of the cavity, where it was measured to be 62.4mG.

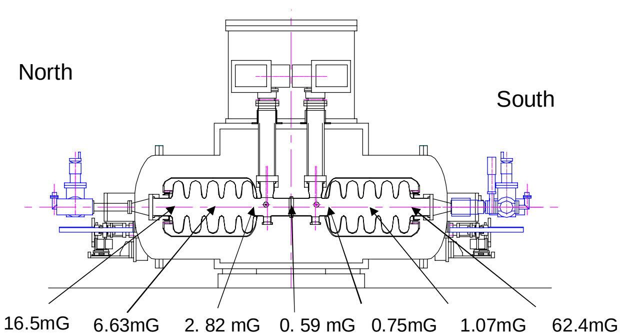

Fig. 3 Residual magnetic field on the beam axis

3.2 Cavity installation

Niobium flanges connected with cavities, beam pipes, pickup ports, RF input ports and HOM ports, are sealed with indium wire of 1mmϕ. For the HOM ports, blank flanges of niobium were connected.

Pairing of the cavities and connection of beam pipes were carried out in a class-10 clean room. Leak tests of the cavities, installation of cavities in the vacuum vessel and installation of RF input couplers were performed in a class-100 clean room.

Alignment errors after both the pairing and the cavity installation were evaluated by measuring positions of both ends flanges of the cavities. The alignment errors were listed in table 2. After the pairing, both ends of the cavities are higher than the pairing center by 1.9mm, which is due to the cavity deformation. Alignment errors after the cavity installation were up to 2.1 and 0.5 mm in vertical and horizontal direction, respectively.

Table 2 Alignment errors (mm)

Cavity	J6001		J6002	
	Tuner side	Center	Center	Tuner side
Cavity pairing				
Vertical	+1.9	(0.0)	(0.0)	+1.9
Horizontal	-0.6	(0.0)	(0.0)	-0.6
Cavity installation				
Vertical	+2.1	+0.3	+0.5	+1.4
Horizontal	-0.3	+0.4	+0.5	0.0

3.3 Tuning test

After assembling the cryomodule, tuning tests have been carried out at the room temperature. The tuning sensitivities obtained in the tests are presented in table 3. The experimental results agree well with the design values.

Table 3 Tuning test results

	J6001	J6002	Design
Tuning sensitivity			
Hz/Pulse	0.597 ±0.002	0.609 ±0.003	0.646
Hz/mm	188 ±1	190 ±1	194

4 PRELIMINARY HORIZONTAL TEST

4.1 Measurement of static loss

Cool down and preliminary horizontal test at 4.2K have been performed. Static loss of the liquid helium jacket was measured at 4.2K to be 17 W. The estimation of the static loss is only 1.74 W as listed in table 1. The reason of this disagreement has not be clear yet, but possible reasons are; helium flow rate of the 4K thermal intercept was not enough, the 4K thermal intercept was not yet cold sufficiently, or the calculation of the static loss has some problems.

4.2 Loaded Q measurement

Loaded Q was measured at 4.2K for each cavity using a network analyzer. The measured loaded Q's were 1.25×10^6 and 1.13×10^6 for J6001 and J6002, respectively. The dispersion between two cavities, about 10 %, is considered due to the fabrication error of the RF input coupler and the cavities or the experimental error. The design value for the loaded Q was 1.6×10^6, which was calculated using the MAFIA code. The disagreement between measured and calculated values was considered due to the uncertainty of the calculation. We are planning to make recalculation using the HFSS code to achieve more accurate estimation.

4.3 Horizontal test

As the preliminary horizontal test, CW and pulsed operations were carried out for each cavity individually. In both operations, amplitude and phase of the forward RF into the cavity were stabilized by a low level RF control system in order to observe the behavior of the cavity.

The CW operation up to Esp(surface peak field)=10 MV/m was performed without any RF conditioning. Fluctuation of the pickup phase, i.e. detune angle of the cavity, was less than ±2deg. In the CW operation, the external Q's of the pickup were measured to be 6.99×10^{11} and 7.05×10^{11} for J6001 and J6002 cavities, respectively. The agreement between two cavities is very well.

The pulsed operation up to Esp=16 MV/m, which is a design field of the cavities, was carried out, where RF pulse processing was necessary above Esp>10MV/m for several hours. After the RF processing, amplitude and phase of the cavity were measured in the condition of repetition rate of 50 Hz, rise time of 0.7 ms, flat top of 0.6 ms. Figure 4 shows the dynamic Esp and forward RF power. In this measurement, RF power was fed between every pulse, where Esp~1MV/m as shown in Fig. 4, in order to observe the behavior between each pulse. The RF power in the rise time and the flat top were about 40kW, which is maximum power of the RF source, and about

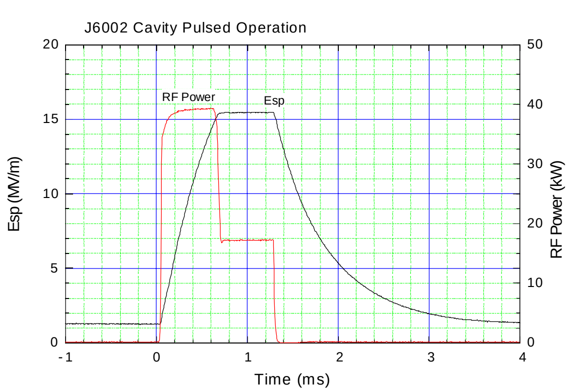

Fig. 4 Surface peak field (Esp) and RF power in the pulsed operation

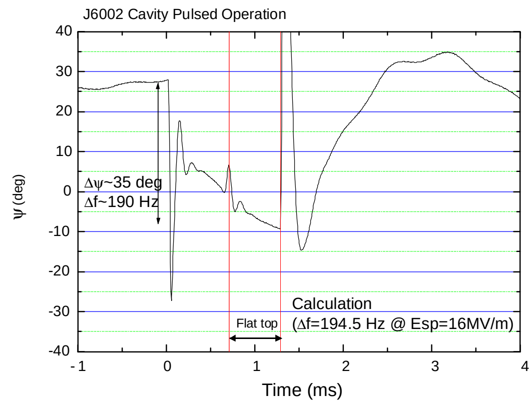

Fig. 5 Dynamic detune angle in a single pulse

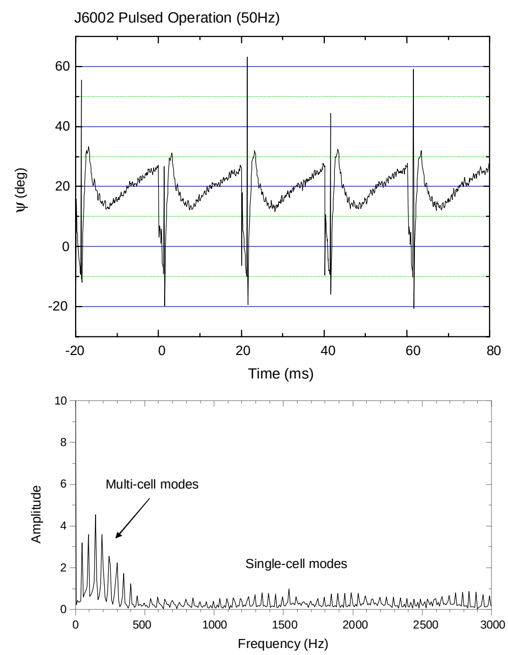

Fig. 6 Dynamic detune angle for 5 pulses and its spectrum

17kW, respectively. The fluctuation of the Esp at the flat top was less than ±0.3%.

Figure 5 shown the dynamic detune angle within a single pulse. Fast fluctuations at the beginning of the rise time, beginning and end of the flat top were due to the response of the feedback loop in the low level RF control system. Slow fluctuation was due to the Lorentz force detuning. The variation of the detune angle from the beginning of the pulse to the flat top was about –35 deg, which corresponds to the detuning of about –190 Hz. The experimental result for the Lorentz force detuning agreed with the calculated value of –194.5 Hz at Esp=16MV/m. However, it looks that the detuning increases for the longer pulsed operation. Therefore, it is necessary more precise experiments for the comparison to the calculated results. Figure 6 shows the dynamic detune angle during 5 pulses and its spectrum. In Fig. 6, the large fluctuations correspond to the RF pulse. In addition, detune angle vibrates after the RF pulse, which is considered to be due to the multi-cell mode of the cavity vibration [5]. In the spectrum, low frequency components less than 500Hz and high frequency components above 1kHz are considered to be caused by the multi-cell and single-cell mode vibrations, respectively [5].

5 SUMMARY

The 600MHz prototype cryomodule for a high intensity proton linac has been developed at JAERI in order to study cavity installation process, cavity performance in the cryomodule and the stability of the accelerating field in the pulsed operation. The preliminary horizontal test has been performed successfully in achieving design field of Esp=16MV/m in a pulsed operation.

Further experiments are necessary for demonstration of 2K operation and study of the dynamic behavior in a pulsed operation. Final goal of this prototype cryomodule is demonstration of stable accelerating field in pulsed operations of two cavities driven by a single RF source, which is a operation scheme designed for the superconducting proton linac of the High Intensity Proton Accelerator Project. A new helium liquefier has been constructed at JAERI, which has a capability of 100 L/h, for the R&D of the superconducting proton linac. Thr further R&D work will be carried out in 2002 using the liquefier. The results will contribute to achieve stable accelerating field for the superconducting proton linac in the High Intensity Proton Accelerator Project.

6 REFERENCES

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