COLD TEST OF 600MHZ SUPRECONDUCTING CRYOMODULE FOR HIGH INTENSITY PROTON LINAC

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Abstract

Development of a superconducting proton linac is in progress in collaboration with KEK. In order to demonstrate cavity performance and to study stable accelerating field in a pulsed operation, a 600MHz superconducting cryomodule has been fabricated. The cryomodule includes two 5-cell superconducting cavities of β=0.6 and is designed to perform 2K operation. Cold tests of the cryomodule have been performed at the temperature of 4K and 2K. In the tests, heat leak to the cavities, loaded quality factors, tuning sensitivities, frequency shifts against helium vessel pressure and Lorentz force detuning of the cavities were measured. As the preliminary horizontal test of the cryomodule, high power RF test has been also performed. This paper presents the results of the cold tests as a status report of the R&D of a superconducting proton linac at JAERI. The results of the R&D work will contribute to the construction of a superconducting linac in the High Intensity Proton Accelerator Project being promoted by JAERI and KEK.

1 INTRODUCTION

JAERI proposed the Neutron Science Project (NSP) for the investigations of basic science and the nuclear waste transmutation technology using a high intensity proton accelerator [1]. Development of superconducting proton linac for the NSP started in 1995 in collaboration with KEK. A 600MHz superconducting cryomodule was fabricated on the basis of the NSP in order to demonstrate cavity performance in the cryomodule and to study stable accelerating field in a pulsed operation. The NSP in JAERI and the Japan Hadron Facility (JHF) in KEK were combined into the High Intensity Proton Accelerator Project [2]. R&D results of the 600MHz cryomodule, especially for the study of the stable accelerating field in a pulsed operation, will contribute to the construction of the Phase-II of the High Intensity Proton Accelerator Project, in which a superconducting linac will be operated in a pulsed mode.

Figure 1 shows the overview of the 600MHz cryomodule. The cryomodule includes two 5-cell cavities of β=0.6, which are referred to as J6001 and J6002. In the vertical tests of the cavities performed prior to the assembling of the cryomodule, surface peak fields of 31 and 40 MV/m were achieved, which are high enough for the operating point of the cryomodule, 16 MV/m. The cavity design, surface treatment, pretuning and the vertical tests are presented in Ref. 3 in detail. Coaxial type RF power couplers are applied to each cavity [4].

Jacket type liquid helium vessel is applied as shown in Fig. 1. In order to achieve 2K operation, the cryomodule includes JT valve and heat exchanger. The liquid helium vessel was evacuated down to 4kPa by a vacuum pump at room temperature. Thermal shield of 80K and thermal intercept at 4K, which are cooled by liquid nitrogen and liquid helium, respectively, are also installed to reduce heat leak to the cavity. Installation of the cavities and the RF power couplers were carried out in a clean room to avoid contamination. The cryogenic design and assembling are presented in Ref. 5 in detail.

As the first step of the experiments of the cryomodule, the cryogenic performance tests, low power RF tests and preliminary high power RF tests were performed. This paper describes the experimental results for these tests.

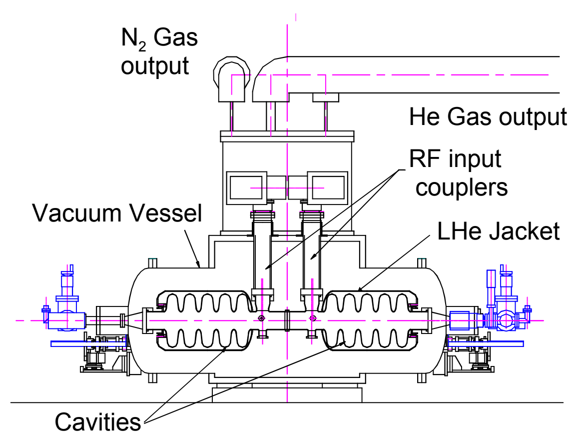

Figure 1 Overview of the 600MHz Cryomodule

2 CRYOGENIC PERFORMANCE

2.1 Cooling Down

The cryomodule was cooled by liquid helium and liquid nitrogen using portable Dewar flasks. Figure 2 shows the

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temperature trends for 80K thermal shield, 4K thermal intercepts, cavities and liquid helium jackets during cooling down from room temperature to 4K. This experiment took about 45 hours with liquid helium of about 2000L. The consumption of liquid helium was reasonable. Figure 2 indicates that cooling speed of one of the 4K thermal intercepts is very slow. The reason for this long cooling time is too small cooling pipe (3/8" in diameter) of the thermal intercept to cool the cavity support.

The cooling of the cavity from 4K to 2K took about 3 hours. It was confirmed that the JT valve, heat exchanger and the vacuum pump works well to achieve 2K operation.

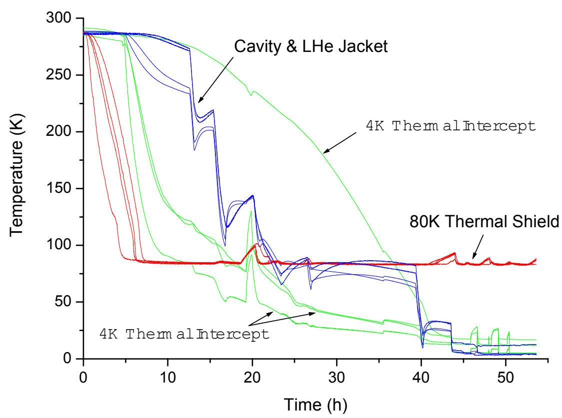

Figure 2 Temperature trends for cooling down from room temperature to 4K

2.2 Heat Leak

The heat leak to the cavities was measured by observing evaporation rate of liquid helium at both 4K and 2K. In the measurement at 2K, the pressure of the liquid helium vessels was kept at 3.280±0.005kPa to avoid temperature change. The measured values of heat leak were 9.7W and 10.4W at 4K and 2K, respectively. The agreement between 4K and 2K measurements is very well, while, the measured values are much larger than the design value of 1.7W. The reason for this large heat leak has not yet been clarified. It is necessary to find the path providing the large heat leak.

3 LOW POWER RF TEST

In the low power RF test of the cryomodule, loaded quality factors, tuning sensitivities and frequency shifts against helium vessel pressure of the cavities were measured.

3.1 Loaded Quality Factor

The loaded quality factors of the cavities were measured at the temperature of 4K using a network analyser. The measured Q's are 1.25×10^6 and 1.13×10^6 for the cavities of J6001 and J6002, respectively. In the case of superconducting cryomodule, the loaded Q is determined mainly by the external Q of the RF power coupler, which is much smaller than the unloaded Q of the cavity. The measured values for the two cavities agree very well with each other but are smaller than the design value of 1.6×10^6, which is calculated by the MAFIA code. The disagreement between measured and calculated values is considered due to the uncertainty of the calculation, because of the limited calculation time. We are trying to calculate the external Q by the HFSS code for more precise estimation.

3.2 Tuning Sensitivity

The resonant frequency of the cavity in the cryomodule is tuned by changing the length of the cavity using a stepping motor. The resonant frequency was measured as a function of the cavity length shift for each cavity at 4K. Figure 3 shows the results of the tuning tests. Both the frequencies of the two cavities are very linear to the cavity length shift as shown in Fig. 3. The tuning sensitivity was derived from the slope of the fitted function for each cavity. The sensitivities obtained in the experiments were 184 and 193 kHz/mm for J6001 and J6002 cavities, respectively. These values agree well with the calculated value of 194 kHz/mm.

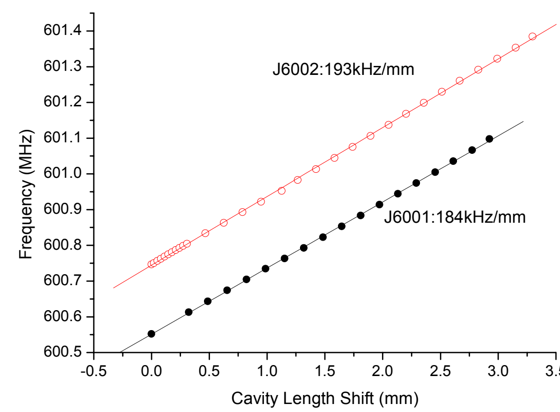

Figure 3 Experimental results for tuning tests

3.3 Frequency Shift against He Vessel Pressure

The pressure of the liquid helium vessel decreases from atmospheric pressure to about 4kPa during the cooling down from 4K to 2K. The frequency shift during the cooling down was measured for each cavity and compared with the calculated data. Figure 4 shows the resonant frequencies as a function of the vessel pressure. The resonant frequencies decreased linearly as the pressure decrease. The coefficients of the frequency shift were derived to be 681.7 and 715.8 Hz/kPa for J6001 and J6002 cavities, respectively. The structural analysis of the cavity was performed to calculate the deformation due to the external pressure using the ABAQUS code, where both ends of the cavity were assumed to be fixed. The coefficient of the frequency shift was also calculated to be 887.6 Hz/kPa, which are agreed well with the measured data.

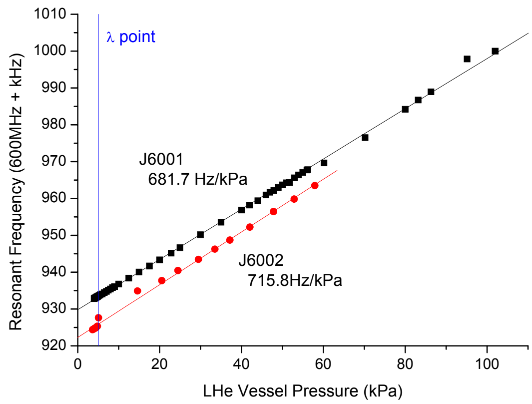

Figure 4 Resonant frequency shift measured during the cooling down from 4K to 2K

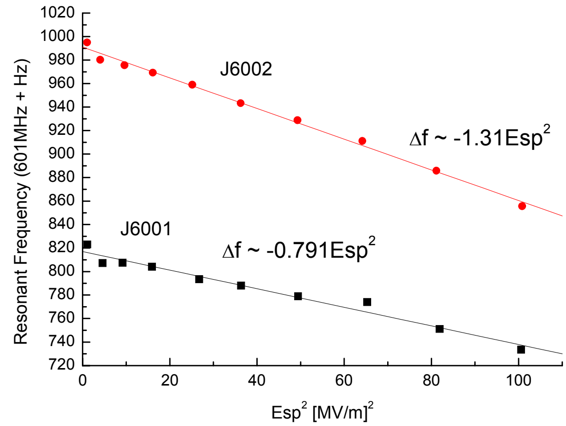

Figure 5 Lorentz force detuning plotted as a function of square of the surface peak field $(Esp)^2$

4 PRELIMINARY HIGH POWER RF TEST

Preliminary high power RF test was performed at 4K and 2K. In this test, RF power was fed to each cavity, independently.

In the CW operation, the surface peak field of 10MV/m was achieved for each cavity at both 4K and 2K. The Lorentz force detuning was measured at 4K. In the higher field operation, the pressure of the liquid helium vessel increased because of the cavity heating. Therefore, the measured raw frequency was corrected for the effect of the pressure change using the coefficient described in the previous section. Figure 5 shows the resonant frequency obtained in the experiment as a function of square of the surface peak field (Esp^2). The coefficients of the Lorentz force detuning were derived to be 0.79 and 1.31 $Hz/(MV/m)^2$ for the J6001 and J6002 cavities, respectively. The value calculated with the combination of structural and electromagnetic analysis was 0.76 $Hz/(MV/m)^2$. The experimental value for the J6001 agreed with the calculated one but that for the J6002 was larger by about 65%. The reason of the disagreement has not yet been clarified. We are planning to measure the Lorentz force detuning at 2K, in which the less effect of cavity heating is expected because of the higher Q_0. In general, the Lorentz force detuning constant, k, is defined as $\Delta f/(Eacc)^2$. Using the description, k=9.4 and 15.6 $Hz/(MV/m)^2$ for the J6001 and J6002 cavities, respectively, because of Esp/Eacc=3.45 for these cavities.

The pulsed operation was also carried out at 4K and the surface peak field of 16 MV/m, which is the design field strength of the cryomodule, was achieved. The typical result of the pulsed operation is presented in Ref. 5.

5 CONCLUSION

The 600MHz cryomodule was fabricated in order to demonstrate cavity performance in the cryomodule and to study stable accelerating field in a pulsed operation. Cryogenic performance test, low power RF test and preliminary high power RF test were performed successfully. However, there are some issues to be solved; the reason of large heat leak, precise calculation for external Q of the power coupler and disagreement of the Lorentz force detuning constant.

Final goal of the test for the cryomodule is demonstration of stable accelerating field in a pulsed operation in a system of two cavity operation with a single RF source using the method described in Ref. 6. Now, a low level RF control system is being optimised for the high power pulsed operation. The demonstration will be done in these two years.

6 REFERENCES

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