R&D ACTIVITIES FOR SUPERCONDUCTING PROTON LINAC AT JAERI

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Abstract

In JAERI, we have been working on a development of superconducting(SC) cavities for a high intensity proton linac. Two superconducting single-cell cavities of β=0.5 were fabricated and tested. Maximum surface electric field of 44 MV/m and unloaded quality factor of 2.8×10^{10} have been achieved at the temperature of 2 K. These performances are good enough for the SC linac specifications. Resonant frequency shifts due to vacuum load and Lorentz force were also measured in the experiment. These experimental data are consistent with the results from the computer simulation.

1 INTRODUCTION

Japan Atomic Energy Research Institute (JAERI) is proposing the Neutron Science Project (NSP) for investigations in the nuclear waste transmutation technology and fundamental science fields[1]. For the project, we have been working on the development of a high intensity proton linac with acceleration energy and maximum current of 1.5 GeV and 5.3 mA, respectively. A superconducting(SC) linac is a main option for the high energy part above 100 MeV because the characteristics of the SC cavities are suitable for high current accelerator with high duty or CW operation.

There is no operated SC cavity for proton accelerators.

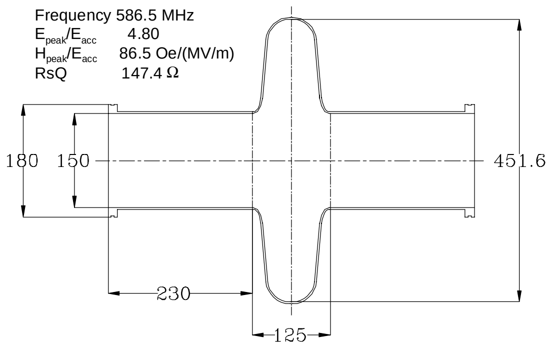

Fig. 1 Cross sectional view of the prototype single-cell cavity of β=0.5

The cavities have high E_{peak}/E_{acc} and H_{peak}/E_{acc} ratios[2] compared to those for high energy electrons because of the squeezed shape at lower beam velocities, where E_{peak}, H_{peak} and E_{acc} are maximum surface electric and magnetic field, and accelerating gradient, respectively. Severe multipacting is also feared for the squeezed cavities. According to the conceptual design of the SC proton linac[3], the operating field strength is E_{peak}=16MV/m; that is a requirement for the cavity performance.

Development work on the SC cavity began in 1995 in the collaboration with KEK. A test facility has been constructed for the 600 MHz SC cavity[4]. As the first step of the cavity development work, two prototype SC single-cell cavities of β(ratio of the proton velocity to the light velocity)=0.5 were fabricated. The performance of these cavities was tested. The resonant frequency shifts due to the vacuum load and the Lorentz force were also measured in the test. The cavity fabrication and experimental results are described in this paper.

2 CAVITY FABRICATION

2.1 Cavity design

The cavity design for the prototype single-cell cavities of β=0.5 developed in this work has been based on the preliminary design work[5]. Figure 1 shows the cross sectional view of the cavity. The design was carried out using the SUPERFISH code; the resonant frequency is 586.5 MHz. The ratios of E_{peak}/E_{acc} and H_{peak}/E_{acc} are estimated to be 4.80 and 86.5 Oe/(MV/m), respectively, which are very high compared to those of β=1 cavities; typically ~2.0 and ~40 Oe/(MV/m), respectively.

2.2 Machining

The cavity fabrications were carried out mainly at the KEK workshop. Niobium sheets; 3mm in thickness and RRR of ~250, were supplied by Tokyo Denkai Co. Ltd. The fabrication process consists of three parts; deep drawing of the half cells, trimming of half cells and beam tubes and electron beam welding. The welding was performed from inside at equator and from outside at iris.

2.3 Surface treatment

Figure 2 shows the flow chart of the surface treatment and the performance test for the two cavities.

For the 1st cavity, the barrel polishing (BP) [6] and the electropolishing (EP1) [7] were adopted, where the average removal thicknesses are 51 μm and 23 μm, respectively. After the electropolishing, the heat treatment (HT), at 750 °C for 3 hours, was carried out at Tokyo Denkai Co. Ltd. to degas hydrogen absorbed during the EP1. Then the high pressure water rinsing (HPR), pressure of 8~9 MPa for 1.5 hours, was carried out at JAERI as a final rinsing. Then, the #1 performance test was done. After the #1 test, additional electropolishing (EP2) and the #2 test were performed as shown in Fig.2.

For the 2nd cavity, the BP and the EP1 were also adopted. The average removal thicknesses of the BP and EP1 were 96 μm and 33 μm, respectively, which were increased compared to those for the 1st cavity. The HT for the 2nd cavity was done using new furnace at JAERI. After the HT and the HPR, the performance test was carried out.

3 CAVITY PERFORMANCE

In each test, the measurement was done at both 4.2 and 2.1K to obtain E_{peak}-Q curves. Figure 3 shows the experimental results of the E_{peak}-Q curves. Corresponding E_{acc}, the surface resistance(Rs) and wall loss of the cavity are also presented in the figure.

3.1 #1 test of the 1st cavity

In the #1 test of the 1st cavity (filled and open triangles in Fig. 3 for 2.1 and 4.2 K, respectively), E_{peak} value of 26.6 MV/m was obtained at 2.1 K. Q values of 1×10^{10} (2.1K) and 7×10^{8} (4.2K) were achieved in the low field measurement. The Q values, however, dropped quickly as the field increased. As a result, Q values of 6×10^{9} at 2.1 K and 3.4×10^{8} at 4.2 K were obtained at the design field strength of E_{peak}=16MV/m.

3.2 #2 test of the 1st cavity

In the #2 test of the first cavity (filled and open squares in Fig. 3 for 2.1 and 4.2 K, respectively), a significant improvement in Q values was found due to the EP2. In addition, maximum E_{peak} increased to 30 MV/m at 2.1 K. Field emission was observed at E_{peak}>20MV/m and caused Q drop in this region. The Q values at E_{peak}=16MV/m were 2.2×10^{10} and 8.6×10^{8} at 2.1 and 4.2 K, respectively. The corresponding Rs values were 7 nΩ and 170 nΩ, respectively.

3.3 2nd cavity test

In the 2nd cavity test (filled and open circles in Fig. 3 for 2.1 and 4.2 K, respectively), we obtained good performance. The field strength of E_{peak}=44MV/m was achieved at 2.1 K measurement and is much higher than that of the design value of 16 MV/m. The severe multipacting was not observed. The Q values obtained at E_{peak}=16MV/m, 2.8×10^{10} at 2K and 7.3×10^{8} at 4.2K, were similar as those of the #2 test of the 1st cavity. The Q drop in the higher field strength above 30 MV/m was also due to the field emission.

3.4 Wall loss of the cavity

According to the results of #2 test of the 1st cavity and the 2nd cavity, the wall loss at the field strength of E_{peak}=16MV/m at 2.1 K was about 0.6 W, which is less than 1/30 of the wall loss at 4.2 K, ~20 W. Therefore, the operating cost for 2K operation is much less than that for 4K operation even though the refrigerating efficiency (~1/1000 at 2K and ~1/300 at 4K) is taken into account. Therefore, 2K operation is a main option in the conceptual design.

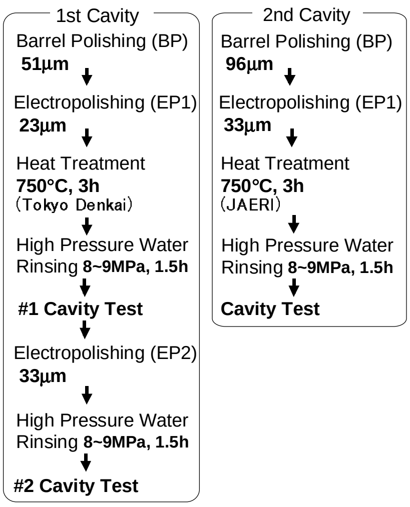

Fig. 2 Flow chart of the surface treatments and the performance tests

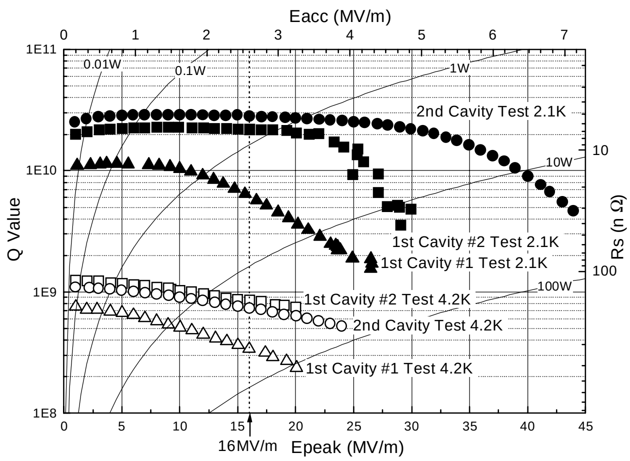

Fig. 3 Results of the performance tests for the two prototype cavities; Q values as a function of the surface peak electric field (E_{peak})

4 FREQUENCY SHIFT MEASUREMENT

The frequency shifts due to the vacuum load and the Lorentz force were also measured in the test.

During cooling down from 4.2 K to 2.1 K, the resonant frequency was changed because the pressure of the liquid helium (LHe) decreased and the vacuum load on the cavity was released gradually. Figure 4 shows the measured frequency as a function of the LHe pressure. The measurement was carried out at the constant field strength of E_{peak}~1MV/m to eliminate the effect of the Lorentz force. The frequency increases linearly as the pressure decreases. Fitting to the linear function was performed to obtain a proportional constant of the frequency shift for the vacuum load, -4.29×10^{-4} MHz/Torr.

The Lorentz force due to the RF field in the cavity decreased the resonant frequency. The frequency shift is proportional to the square of the field strength. Figure 5 shows the resonant frequency as a function of E_{peak}. The measurement was carried out at 4.2 K to keep the pressure of LHe constant. Fitting to the parabolic function was also performed to obtain a proportional constant of the frequency shift due to the Lorentz force, -3.61×10^{-6} MHz/(MV/m)^2.

Those frequency shifts depend on the constrained condition of the cavity. In these tests, both ends of the cavity were supported by four rods made of stainless steel. Simple modeling was performed for the simulation; one end of the cavity is constrained and the other is supported by a spring. In the case of the spring constant of 10000 N/mm, the simulation provides reasonable results for the proportional constant; -3.76×10^{-4} MHz/Torr for the vacuum load and -4.30×10^{-6} MHz/(MV/m)^2 for the Lorentz force. Differences between measured and calculated values are less than 20%.

5 CONCLUSION

As the first step of the SC cavity development for the high intensity proton linac proposed in JAERI, two prototype single-cell cavities of β=0.5 were fabricated, and good performance was demonstrated in the tests. The test results indicate that our fabrication process is good enough to apply to the SC proton linac.

Resonant frequency shifts due to the vacuum load and the Lorentz force were also measured. Reasonable results were obtained in the simulation for the frequency shift.

6 REFERENCES

[1] M. Mizumoto et al., 'A Proton Accelerator for the Neutron Science Project at JAERI', in these proceedings.

[2] N. Ouchi et al., 'Proton Linac Activities in JAERI', Proc. of the 8th workshop on RF Superconductivity, Abano Terme, Italy, to be published.

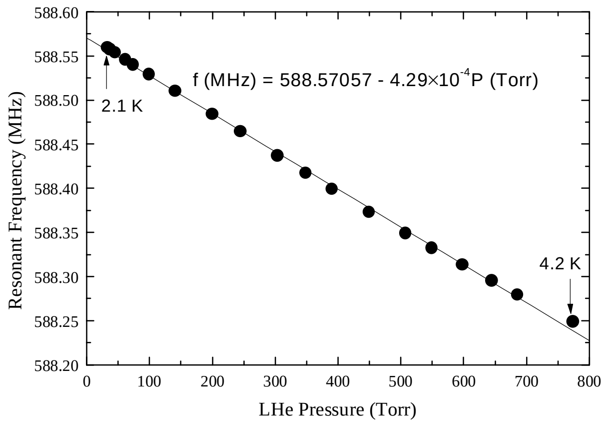

Fig. 4 Resonant frequency as a function of the pressure of the liquid helium

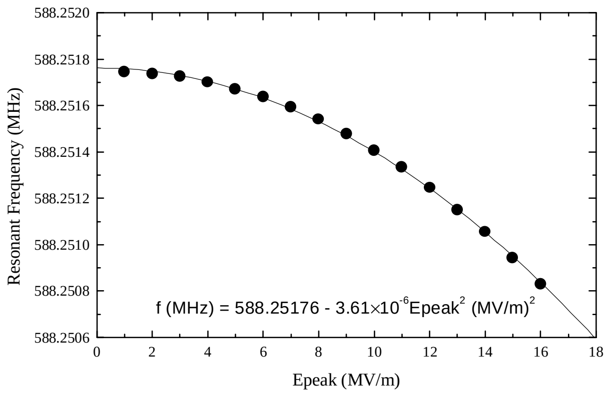

Fig. 5 Resonant frequency as a function of the surface peak electric field (E_{peak})

[3] Y. Honda et al., 'A Conceptual Design Study of Superconducting Proton Linear Accelerator for Neutron Science Project', in these proceedings.

[4] N. Ouchi et al., 'Design and Development Work for a Superconducting Proton Linac at JAERI', Proc. of the 8th workshop on RF Superconductivity, Abano Terme, Italy, to be published.

[5] N. Ito et al., 'Development of a Superconducting Cavity for the High Intensity Proton Linac in JAERI', Proc. of the 18th Int. Linear Accelerator Conf., Geneva, Switzerland, p671 (1996).

[6] T. Higuchi et al., 'Investigation on Barrel Polishing for Superconducting Niobium Cavities', Proc. of the 7th workshop on RF Superconductivity, Gif-sur-Yvette, France, p723 (1995).

[7] K. Saito et al., 'R&D of Superconducting Cavities at KEK', Proc. of the 4th workshop on RF Superconductivity, Tsukuba, Japan, P635 (1989).