DEVELOPMENT OF SUPERCONDUCTING SINGLE-CELL CAVITY FOR A PROTON LINAC IN THE NEUTRON SCIENCE PROJECT AT JAERI

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Abstract

The Superconducting(SC) cavity development has been carried out since 1995 as a main option of high energy portion from 0.1 to 1.5GeV for an 8MW proton linear accelerator in the Neutron Science Project (NSP) at JAERI. A construction of test stand, a design work of cavity shape and fabrication of single-cell cavities were made in collaboration with KEK. Recently, a peak surface electric field of 44MV/m was achieved at a vertical test of β=0.5 single-cell SC cavities. The paper describes the fabrication of the single-cell SC cavities, the performance of the SC cavity test facility and the result of the present SC cavity vertical test at JAERI.

1 INTRODUCTION

JAERI has been proposing the Neutron Science Project (NSP) for exploring basic research and nuclear waste transmutation technology based on a next generation spallation neutron source driven by the high-intensity proton accelerator.[1] The main features of the accelerator are an energy of 1.5GeV, a maximum average current of 5.3mA with operation mode of both pulse and CW to generate a beam power of 8MW. In the conceptual design of the high-intensity proton accelerator, SC cavity linac covers energy range above 100MeV to 1.5GeV. The SC cavities are separated for each 8 β-section group according to the proton energy range[2]. The detailed parameters of β-section groups are listed in Table 1. The development of the SC cavity for the proton accelerator has been continued since 1995 in collaboration with KEK. The principal parameters for the SC cavity development are the resonant frequency of 600MHz, an elliptical cavity shape, bulk niobium cavity, 3 or 4 mm thickness of cavity wall, an operating peak surface electric field(Ep)=16MV/m. The fabrication technique is based on the KEK-TRISTAN SC cavity.

Several difficulties are pointed out to achieve the SC cavity in the range of lower β up to β=0.7 caused by a squeezed elliptical cavity shape. The squeezed shape conduct to a high Epeak/Eacc ratio and high Hpeak/Eacc ratio in the cavity. These characteristics give a possibility of a multipacting or an field emission at a high field operation. Also the squeezed shape has a low mechanical strength due to atmospheric pressure.

To demonstrate the designed performance of the cavity and to examine the procedure of the fabrication and surface treatment, two single-cell cavities of β=0.5 were manufactured and tested.

Table 1 Basic parameters of β-sections in the SC proton linac

β Sections	1	2	3	4	5	6	7	8
βc	0.453	**0.499**	0.549	0.604	0.665	0.732	0.805	0.886
No. of Cavities	20	20	20	24	24	32	48	96
Energy range[MeV]	100 ~ 125.7	125.7 ~ 159.6	159.6 ~ 204.0	204.0 ~ 273.3	273.3 ~ 362.2	362.2 ~ 511.7	511.7 ~ 795.1	795.1 ~ 1500.0
Eacc[MV/m]	2.4~2.	2.9~3.4	3.4~4.1	4.0~4.8	4.8~5.5	5.4~6.3	6.3~7.1	7.1~8.0
Power/Cavity [kW]	21~25	28~33	36~43	47~56	61~70	77~89	97~111	122~138
Lattice length[m]	4.11	4.23	4.35	4.49	4.64	4.81	4.99	5.30

2 FABRICATION OF SINGLE-CELL CAVITIES

2.1 Design of the cavity

Figure 1 shows the designed shape of β=0.5 single-cell cavity. The cavity has an Epeak/Eacc ratio of 4.80 and a Hpeak/Eacc ratio of 86.5 Oe/(MV/m). The resonant frequency for the single-cell cavity is 586.5MHz which correspond to 600MHz for the multi-cell cavity with π-mode operation. The wall thickness of 3mm of niobium is chosen to ensure a mechanical strength against atmospheric pressure. The diameter for beam pipe is φ150mm with the reasons to maintain a work space for the electron beam welding (EBW) on the equator and to use a large bore electrode at the electropolish (EP) process which keep a required electric field to the equator in the process. Also the diameter is effective to extract a HOM power from the center cell region at the multi-cell cavity. The designed peak surface electric field (Ep) is 16MV/m

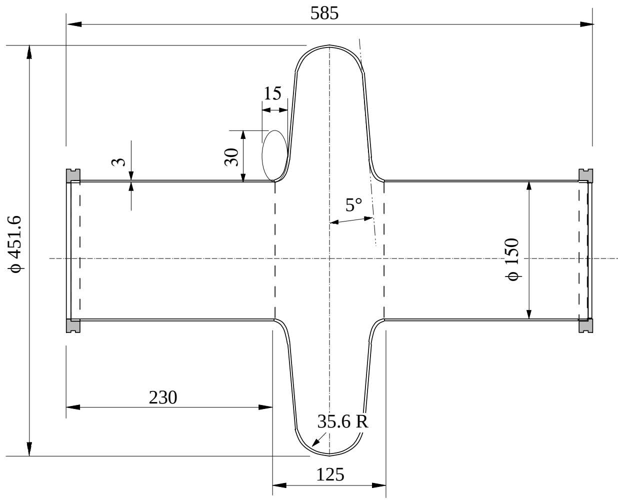

Fig. 1 Designed shape of 600MHz β=0.5 bulk Nb single-cell cavity. (Proton energy range: 145 MeV)

2.2 Fabrication of the cavity

Two units of β=0.5 single-cell cavities namely J5001 and J5002 were fabricated. As the cavity material, the niobium sheets with the residual resistance ratio (RRR) of more than 200 were used which supplied by Tokyo Denkai Co. Ltd., Japan. The fabrication procedure is composed of four parts; (1)deep drawing of the half cells, (2)trimming of the half cells and beam tubes, (3) EBW at the equator and the iris and (4)surface treatment of the cavities. The fabrication is mainly carried out at the workshop in KEK. The surface treatment procedure consist in four processes; (a)mechanical (barrel) polishing (BP) [3], (b)electropolishing (EP), (c)heat treatment (HT) and (d)high pressure rinsing with ultra-pure water (HPR). The EP technique is adopted to make a smooth surface of the cavities which lead to high peak surface electric field[4]. Average thickness of about 50μm and about 30μm were removed in the BP and EP processes, respectively. The HT (750°C, 3h) make a degassing of H_2 which is adsorbed in the niobium cell during the EP process. The HPR is using as a final cleaning process of the fabrication with a pressure of ~9MPa, the resistivity of the water of 17~18MΩ-cm and the process period of 1.5 hours, respectively.

3 VERTICAL TEST FACILITY

The test facility has been installed at the JAERI Tokai site to examine the performance of 600MHz SC cavity for variable proton energy ranges. The installed test facility includes a clean vacuum furnace, an ultra pure water generating system, a high pressure rinsing system(HPR), an ultra high vacuum evacuation system and a cryostat for vertical test. The cryostat has dimensions of 800mm in diameter and 3,500mm in depth. This cryostat can be used for a vertical test up to High-β (β=0.886) 5-cell cavity. The cross-sectional view of the cryostat is illustrated in Fig. 2. The summarized characteristics of the test facilities are shown in Table 2.

Table 2 Performance of the vertical test facility of JAERI

Cryostat :	
Test Area Dimension :	
Diameter :	800 mm
Height :	1,500 mm
Residual Mag. Field :	< 20 mGauss
Heat leak :	2.2 W
Cooling Speed(RT to 4.2K) : 2 h	
Ultimate Temperature :	1.90 K
LHe Feed Speed :	2.5 LPM
Clean Room :	
Clean Level (Class 10) :	< 10 p/ft^3 (>0.3 μm)
High Pressure Rinsing :	
UPW Pressure :	8 ~ 9 MPa
Flow Rate :	14 LPM
UPW Resistivity : > 17.6 MΩ-cm	
TOC Level :	70 to 300 ppb
Cavity Evacuation System :	
Ultimate Vacuum Pressure :3 x 10^{-9} Pa (oil Free)	
Clean Vacuum Furnace :	
Operating Pressure :	10^{-4} Pa at 950°C
Work Area Dimension:	830H x 830W x 1800L

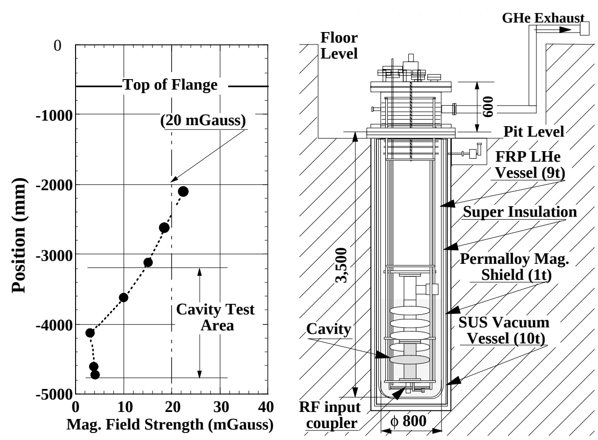

Fig. 2 Cross-sectional view of the cryostat and residual magnetic field strength in the cryostat

4 VERTICAL TEST OF SINGLE-CELL CAVITIES

After the fabrication of the β=0.5 single-cell cavities (J5001 and J5002), the vertical tests were carried out at the test facility. The evaluated parameters are peak surface electric field(Ep), Q value, surface resistance(Rs) and resonant frequency(fo). Prior to the high field experiment, the fundamental resonant frequencies were measured which were 586.5 MHz at J5001 and 588.3 MHz at J5002 at 4.2K. In the 2K operation of J5001, both Q values and Ep stayed at 1 x 10^{10} and 27MV/m, respectively after the 1st EP process. After the 2nd EP process, both Q values and Ep were increased. Initial Q was 2 x 10^{10} and maximum Ep was slightly increased for 30MV/m when Q value was 3 x 10^{9} at 2K. Field emission was observed at high field experiment more than 24 MV/m and it made a Q degradation.

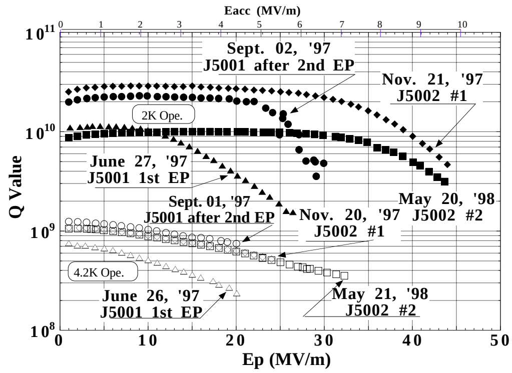

Fig. 3 Q values of the J5001, J5002 cavities as a function of peak surface electric field (Ep)

In the case of J5002, which has no 2nd EP, maximum Ep of 44MV/m is marked at the 2K operation. The Q values kept high enough as 3 x 10^{10} till Ep of 30MV/m. At the 2nd measurement for J5002, the cavity was exposed to air in the clean room class-10 for 6 months, the observed Q values of 1 x 10^{10} was decreased compare than the 1st measurement. This phenomena may be caused with a surface deterioration of the cavity. The Q values as a function of Ep, however, was kept constant till Ep of 32MV/m in spite of the decreased Q values. The maximum Ep of ~44MV/m is reached again at the 2nd 2K operation. The result of Qo-Ep experiments is shown in Fig. 3.

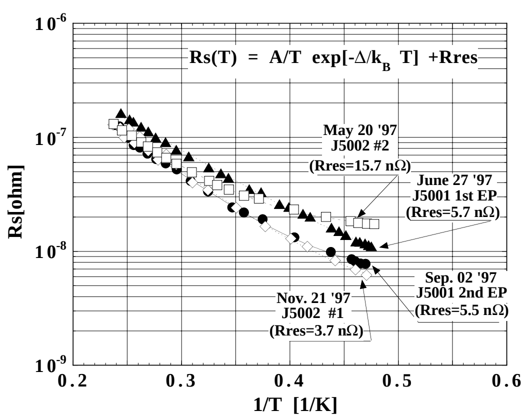

Fig. 4 Temperature dependence of surface resistance at J5001, J5002 Cavities

The temperature dependence of the residual surface resistance(Rres) of the cavities were measured. The Fig. 4 shows the results of the measurement. The Rres is evaluated by the well known BCS formula :

$$Rs(T) = A/T \cdot \exp(\Delta/k_B T) + Rres$$

The Rres of the fresh surface cavities were ~5nΩ which were lower than ordinary 7 nΩ based on further experience in KEK. For the J5002, a surface deterioration due to the long term air exposure is confirmed by the evaluated Rres of 15.7 nΩ.

Figure 5 shows the resonant frequency(fo) variance observed due to the Lorentz force as a function of the Ep in the cavity. The frequency shift at the designed Ep of 16MV/m is about 900 Hz for both CW and pulse mode operation which can be fitted with the parabolic function. Also it indicates the same values at 4.2K and 2K in CW mode.

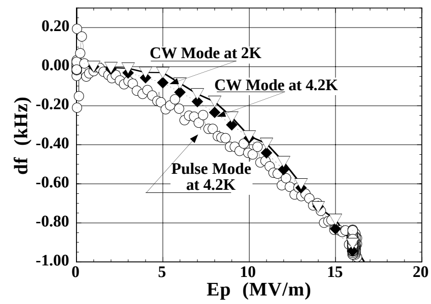

Fig. 5 Resonant frequency variance as a function of the peak surface electric field (Ep)

5 CONCLUSION

The R&D work for SC cavity for a high-intensity proton accelerator is progressed. Two low-β (β=0.5) single-cell cavities were fabricated and tested at the vertical test facility in JAERI as a first step of the development. At the 2K operation, the performance of the cavities demonstrates the feasibility for the design parameters. Typically, peak surface electric field : Ep of 44MV/m and minimum residual surface resistance : Rres of ~ 5nΩ were obtained. The test facility was applied successfully to the vertical test. The procedures of fabrication and the surface treatment are reliable to be applied for the construction of the SC proton linac.

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