

DEVELOPMENT OF A SUPERCONDUCTING CAVITY FOR THE HIGH INTENSITY PROTON LINAC IN JAERI

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Abstract

The R&D work of a superconducting (SC) cavity for the high intensity proton linac in JAERI has been started in collaboration with KEK. The RF field calculation and the structural analyses of the cavity have been made for the design in the proton energy range between 100 and 1500 MeV. The results indicate the feasibility of the SC proton linac, while more optimization is required. A vertical test stand with a cryostat, a clean room and a water rinsing system has been constructed. We present the preliminary cavity design and the overview of the test stand.

Introduction

The Neutron Science Research Program has been proposed in JAERI for the basic research and the engineering application[1]. This program requires a high intensity proton linac with an average current of several mA and an accelerating energy of 1 GeV class. The high energy section is the main part of the linac and has issues to be considered, i.e., beam loss, capital and/or operating cost, availability, reliability and the total linac length. A superconducting (SC) linac, which is considered to have capability to solve these problems, is selected as the first option of the high energy section. SC accelerators for electron and heavy ions have been operated successfully[2],[3], but an SC proton linac has not been realized yet. Therefore, the R&D work of the SC linac for the proton energy range between 100 and 1500 MeV has been started in collaboration with KEK.

SC cavity shape of the proton linac are flatter than those of the electron accelerators due to smaller β value ($\beta=0.43\sim 0.92$ at the energy range mentioned above), that results in some difficulties with the RF characteristics and the structural strength. We have carried out these studies and defined preliminary cavity design. Parallel to those work, a test stand has been prepared for the vertical test of the cavity. In this paper, we present the results of the design work and the overview of the vertical test stand.

RF Characteristics

The cavity has been decided to be elliptical shape as used for the electron cavity. The resonant frequency has been

chosen to be 600 MHz which is triple frequency jump of the low energy section frequency, 200 MHz.

The RF field calculations in the half cell geometry have been made by the SUPERFISH code. The schematic view of the cavity and the shape parameters are presented in Fig. 1. The shunt impedance (ZT^2), the ratios of the maximum surface electric and magnetic field to accelerating field (E_p/E_{acc} and H_p/E_{acc}) were obtained under the various shape parameters. The dependence of these characteristics on the shape parameters are summarized below.

Under the same β ($=4L/\lambda$) condition,

(1) smaller iris radius (a) makes larger ZT^2 and lower E_p/E_{acc} ,

(2) smaller wall slope angle (α) makes larger ZT^2 but does not vary E_p/E_{acc} so much, and

(3) shorter semiaxis length of ellipse at iris ($R1, R2$) makes larger ZT^2 and higher E_p/E_{acc} .

In comparison with different β cavities,

(4) lower β makes much smaller ZT^2 ,

(5) lower β makes higher E_p/E_{acc} , i.e., the E_p/E_{acc} values are 4~6 at $\beta=0.43$ and 1.5~3.5 at $\beta=0.92$, and

(6) lower β makes higher H_p/E_{acc} , however, the value (35~130 Oe/(MV/m)) will not limit the field strength.

Reduction of a and α is effective to obtain good RF characteristics but will make difficult to do surface treatments. In any case, it is difficult to obtain better RF characteristics at lower β cavities.

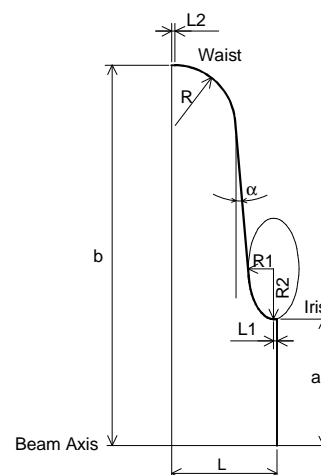


Fig. 1 Schematic view of the cavity and shape parameters

Structural Analysis

SC cavities are made from niobium sheets. The structural analyses have been made by the ABAQUS FEM code for the cavities at $\beta=0.5, 0.7$ and 1.0 with the various shape parameters. The max. von MISES stress has been obtained under the vacuum load in the conditions of iris free or fixed. The cavity thickness is assumed to be 3 mm. The dependence of the max. von MISES on the shape parameters is listed below.

(1) Dependence on wall slope angle (α);

In the case of iris free, the max. von MISES is significantly decreased by increasing α and saturated at about $10\sim 20$ degree, where that values are $\sim 1/3$ of those at 0 degree.

In the case of iris fixed, the max. von MISES does not depend on α so much.

(2) Dependence on semiaxis length of ellipse ($R1, R2$);

The max. von MISES varies by $20\sim 30\%$.

(3) Dependence on iris radius (a);

The max. von MISES does not vary so much.

(4) Dependence on β ;

Lower β makes much greater max. von MISES. In the case of iris free, the values are $80\sim 190$ MPa at $\beta=0.5$ and $20\sim 85$ MPa at $\beta=1.0$. In the case of iris fixed, the values are $40\sim 65$ MPa at $\beta=0.5$ and $14\sim 26$ MPa at $\beta=1.0$.

From a viewpoint of structural analysis, α should be as large as about 10 degree. This competes with the RF characteristics. In any case, much greater strength is required for lower β cavities against the vacuum load.

The yield stress of niobium at room temperature depends on RRR, work hardening and heat treatment. Since the yield stress after the heat treatment at about 700 °C is considered to be $70\sim 100$ MPa, additional stiffening structure or more thickness of about 5 mm is required for $\beta<0.6\sim 0.7$ cavities. On the other hand, the yield stress of niobium used for the cavity fabrication should be confirmed experimentally.

Preliminary Design

The consideration about the RF and structural characteristics indicates the feasibility of the SC proton linac, while more estimation is required especially for lower β

cavities from standpoints of those considerations as well as the fabrication and surface treatment. The surface treatment is important to obtain designed performance of the cavity. We are considering electropolishing combined with barrel polishing[4] as the surface treatment.

For the preliminary design, we attach great importance on the surface treatment. Therefore, the iris radius (a) has been fixed to be 7.5 cm which is obtained by referring the shape of TRISTAN cavity[5]. Table 1 presents the preliminary design and calculated results for the RF and structural analysis. The design will be optimized from the results of the vertical tests.

Overview of Test Stand

To measure Q-value, surface resistance and maximum Eacc of the cavity, a vertical test stand for 600 MHz cavities has been prepared at JAERI Tokai site. The test stand consists of a cryostat for the tests, a clean room for cavity assembly, a high pressure water rinsing system and a data acquisition system. Figure 2 illustrates the overview of the system.

An SC cavity with the number of cells up to 4 can be installed in the cryostat with liquid helium (LHe) vessel of 0.8 m i.d. and 3.5 m long. The SC cavity can be cooled at about 2 K by evacuating LHe vessel. Therefore, the vertical tests will be performed at both 4.2 K and 2 K. The LHe vessel is covered with permalloy sheet to shield magnetic field. The field strength at room temperature has been measured to be $3\sim 15$ mG at the place where the cavity is located.

The clean room for cavity assembly is divided into class $10, 100$ and 10000 areas. The cavity after rinsing is opened only in the class 10 area. In the class 10000 area, a cavity is evacuated by an oil-free vacuum pumping system. In the class 10 and 100 areas, any dusts above 0.5 μm were not detected by a particle counter under the condition without persons.

The high pressure water rinsing system consists of an ultra-pure water production system, a high pressure water pump of 8.5 MPa, a filter of 0.1 μm in mesh size and a cavity mount system. The ultra-pure water production system has a capability of 90 l/h, that makes an hour rinsing for the single cell cavity. The cavity mount system is placed in the class 100 area. Therefore, sequential works of rinsing, assembling and

Table 1 Preliminary design and their results of the RF and structural analysis

β	E (MeV)	a (cm)	b (cm)	R (cm)	$R1 \times R2$ (cm)	α (deg.)	L (cm)	ZT^{2*} (M Ω /m)	ZT^2/Q (Ω /m)	Ep/Eacc	Hp/Eacc (Oe/(MV/m))	Max. von MISES (MPa)	
												Iris Free	Iris Fixed
0.43	100	7.5	22.98	2.57	1.5x3	5	5.37	1.42	75.5	5.92	117.2	127.6	54.8
0.50	145	7.5	22.58	3.56	1.5x3	5	6.25	2.96	127.7	4.80	86.5	110.7	44.7
0.60	235	7.5	22.28	4.96	1.5x3	5	7.49	5.98	208.7	3.87	64.9	91.1	35.7
0.70	376	7.5	22.63	5.08	2x4	10	8.74	8.46	274.6	2.95	57.8	55.6	26.5
0.80	626	7.5	22.44	6.18	2.5x5	10	9.99	11.91	345.5	2.40	50.8	47.5	22.7
0.875	1000	7.5	22.31	7.33	2.5x5	10	10.93	14.93	394.7	2.24	46.0	40.3	20.0
0.92	1500	7.5	22.31	7.58	3x6	10	11.49	16.20	419.2	2.01	45.0	38.9	18.9

* Calculated from the electric conductivity of Cu

L1 = L2 = 0.2 cm

cavity evacuation are carried out in the clean room.

Conclusion

The RF characteristics and the structural analysis have been done for the SC proton linac with the energy range between 100 and 1500 MeV. The results indicate the feasibility of the SC proton linac, even more estimation is required. The preliminary design has been made based on these analyses and the considerations of the surface treatment.

The vertical test stand has been completed. The performance of each component; the cryostat, the clean room, the cavity evacuation pump and the high pressure water rinsing system, will be tested in collaboration with KEK.

According to the preliminary design, a SC cavity of $\beta=0.5$ with single cell is on fabrication now. The first vertical test is scheduled in this year. The vertical tests of the cavities with various shape parameters will be performed. Optimization of the cavity design will be made according to these test results.

RF field calculations with multi-cells are being made for optimization of the end cell shape and considerations of the higher order modes.

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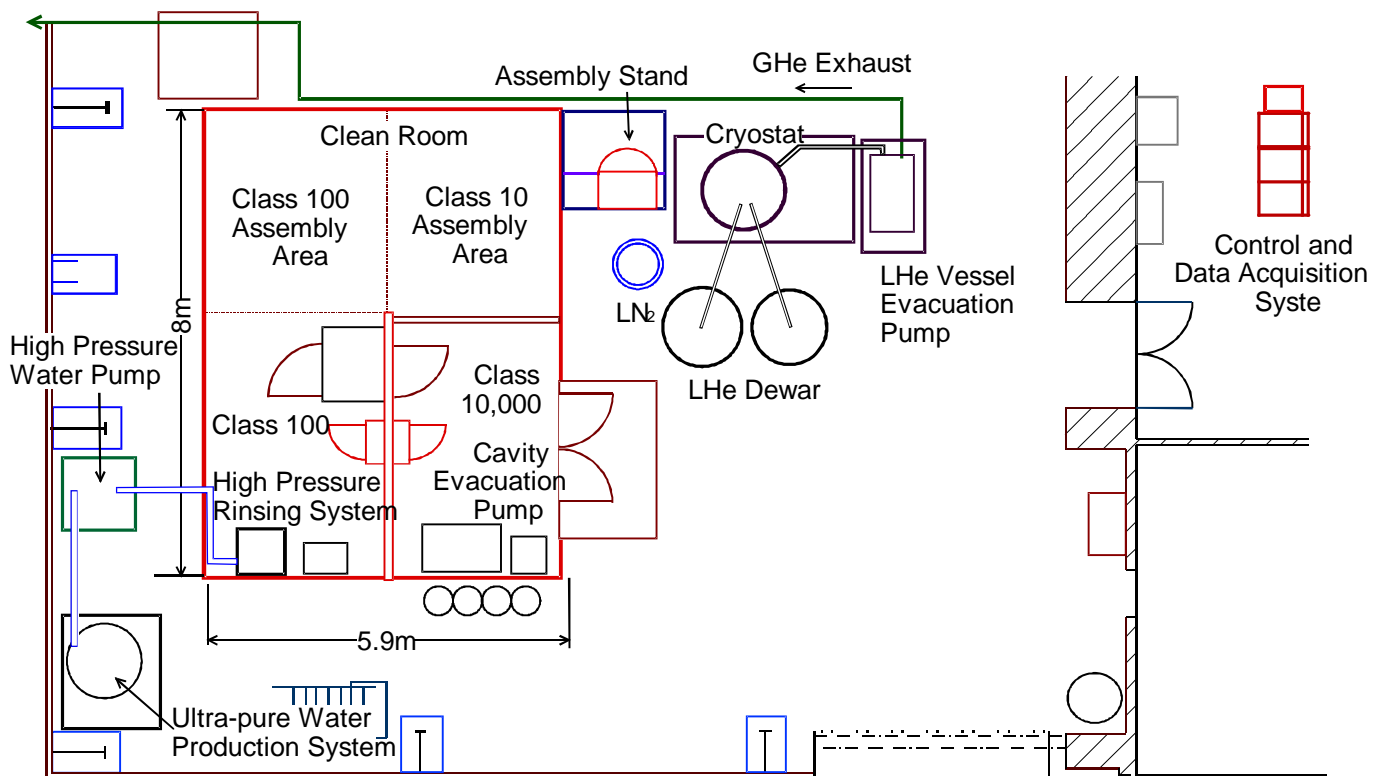


Fig. 2 Overview of the test stand for the vertical test