# DESIGN AND DEVELOPMENT WORK FOR A SUPERCONDUCTING PROTON LINAC AT JAERI

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## 1. Introduction

Japan Atomic Energy Research Institute (JAERI) is proposing the Neutron Science Project (NSP) for the investigations in the nuclear waste transmutation technology and fundamental science fields based on an intense spallation neutron source[1]. For the NSP, we have been working on the development of a proton linac of which acceleration energy and maximum current are 1.5 GeV and 5.3 mA, respectively. A superconducting (SC) linac is a main option for the high energy part of the linac above 100 MeV.

There are difficulties to be solved on the SC cavities for proton accelerator because of a flatter shape. They have high $E_{peak}/E_{acc}$ and $H_{peak}/E_{acc}$ and low mechanical tolerance[2] compared to the cavities for high energy electrons. The cavity development work has been continued since 1995 under the collaboration with KEK. A test facility including a clean room, a cryostat, a high pressure rinsing system and a high vacuum furnace was prepared in JAERI for R&D of SC cavity. A single cell cavity of $\beta$(ratio of the proton velocity to the light velocity)=0.5 has been fabricated and the performance has been evaluated in the vertical tests.

The test facility, the cavity fabrication and the experimental results are described in this paper. The overview of the NSP, a conceptual design for the SC proton linac and the SC cavity design work are given in Ref. 3.

## 2. Test facility

The test facility has been constructed in JAERI for the vertical test of 600 MHz cavities. Figure 1 shows the overview of the test facility which includes a clean room for cavity assembling, a high pressure water rinsing (HPR) system for cavity final rinsing and a cryostat for vertical tests.

The clean room is divided into class 10, 100 and 10000 areas. The HPR is carried out in the class 100 area. The class 10 area is used for cavity assembly after final rinsing. The cavity is evacuated by an ultra-high vacuum pumping system in the class 10000 area. Therefore, all of the processes from cavity rising to evacuation can be carried out in the clean room. A cavity is sealed off before mounting in the cryostat and the vertical test is carried out without cavity evacuation.

A schematic view of the cryostat is shown in Fig. 2. The SC cavity with up to 5 cells can be measured in the cryostat. Magnetic shields are installed in the cryostat and the sufficiently weak residual field less than 15 mGauss was confirmed at cavity mount position. The lowest attainable temperature of the cryostat was measured to be 1.9 K that is low enough for the cavity R&D.

The HPR system consists of an ultra-pure water production system, a high pressure pump of 9 MPa, a filter of 0.1 μm in mesh size and a cavity mount system. The resistivity of ultra-pure water is above 17.6 MΩ·cm and the typical TOC (Total Organic Carbon) level is 70~300 ppb.

In addition to these systems, a high vacuum furnace has been prepared for the cavity heat treatment. It allows the heat treatment of a cavity with the number of cells up to five. The maximum temperature for heat treatments is 950°C. A completely oil free evacuation system is adapted and the ultimate vacuum pressure is $10^{-6}$ Pa at room temperature and $10^{-4}$ Pa at 950°C.

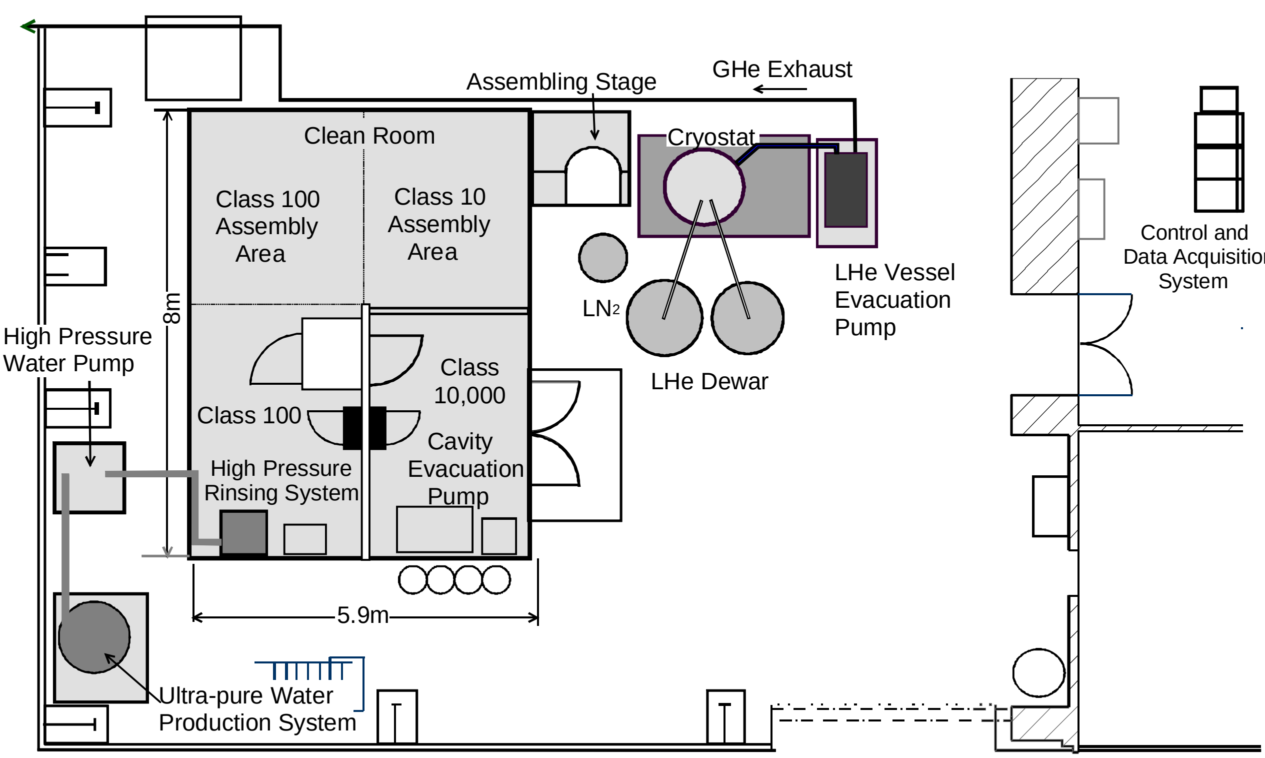


Fig. 1 Overview of the test facility for the cavity vertical tests

## 3. Fabrication of a β=0.5 single cell cavity

As the first step of the SC cavity development for the NSP proton linac, a single cell cavity of β=0.5 was fabricated and tested. Figure 3 shows the cross sectional view of the cavity developed in this work. The design is based on the preliminary cavity design work[2]; the cavity shape parameters are listed in table 1. The resonant frequency of the cavity is 586.5 MHz, while that of π mode in the multi-cell cavity is 600 MHz. The ratios of electric and magnetic surface peak field to the accelerating gradient were calculated to be 4.80 and 86.5 Oe/(MV/m), respectively.

The cavity was mainly fabricated at the workshop in KEK. Niobium sheets, of which thickness and RRR are 3 mm and ~250, respectively, were supplied by Tokyo Denkai Co. Ltd. The fabrication process consists of four parts; 1)deep drawing of the half cells, 2)triming of half cells and beam tubes, 3)electron beam welding at the equator and the iris and 4)surface treatment of the cavity.

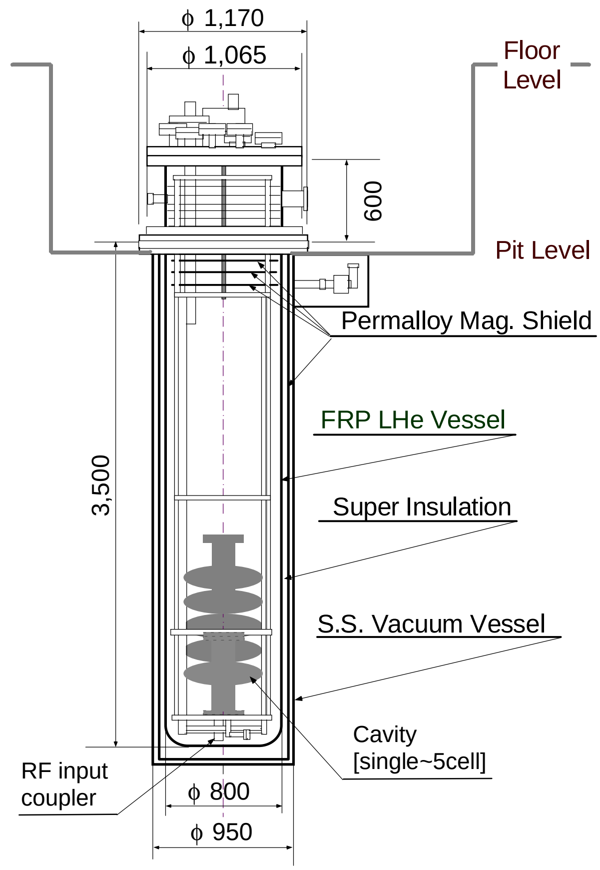

Fig. 2 Schematic view of the cryostat

The deep drawing was applied by a press machine with a load of $1.5\times10^{6}$ N. After a triming of the half cells, the fabrication error was measured; the maximum error of about 0.5 mm was found at the equator curvature. The error is considered to result from the spring back.

The surface treatment which consists of barrel polishing (BP) [4], electropolishing (EP) [5],

Table 1 Shape parameters for the single cell cavity of β=0.5

| | |
|---|---|
| Equator radius (mm) | 225.8 |
| Iris radius (mm) | 75.0 |
| Equator curvature radius (mm) | 35.6 |
| Semiaxis length of ellipse at iris (mm) | 15×30 |
| Slope angle (deg) | 5.0 |
| Cell length (mm) | 125 |
| Equator straight length (cm) | 4.0 |
| Iris straight length (cm) | 2.0 |

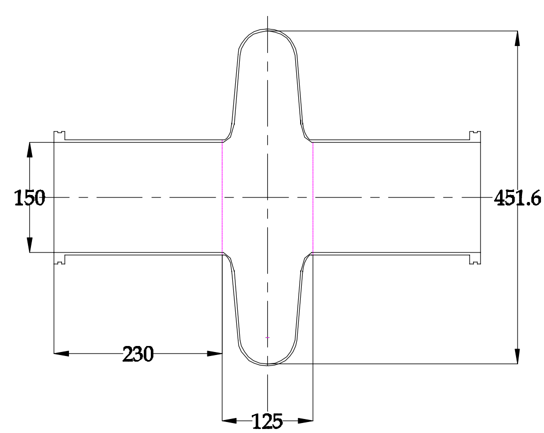

Fig. 3 Cross sectional view of the single cell cavity of β=0.5

heat treatment (HT) and HPR was applied. EP processes were carried out twice before and after the HT, which are named EP1 and EP2, respectively. After the sequential processes of BP, EP1, HT and HPR, the first vertical test was performed. Then, the EP2, the HPR and the second vertical test were carried out.

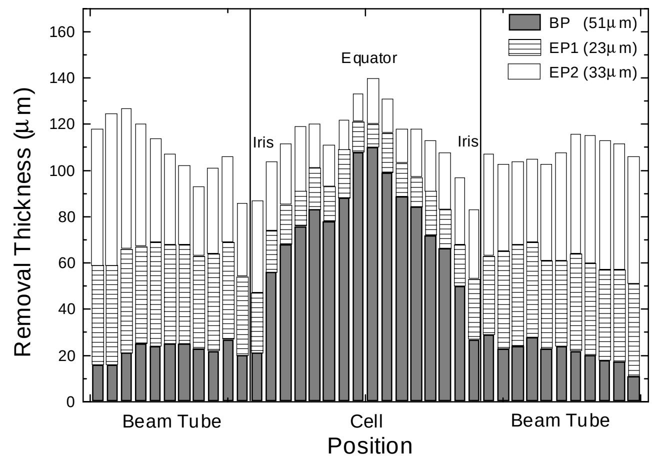


Fig. 4 Distribution of removal thickness in the barrel polishing (BP) and the electropolising (EP1, 2)

Average removals of 51 μm, 23 μm and 33 μm were obtained in the BP, EP1 and EP2 processes, respectively. Figure 4 represents the distribution of removal thicknesses. In the BP process, removal thickness at the equator (>100μm) is much larger than that at the iris and the beam tube (~20μm). On the other hand, the iris and the beam tube were polished much more than the equator by the EP1 and the EP2. Then, the total removals of ~140 μm and ~80 μm were achieved at the equator and the iris, respectively. It is noted that the BP is very simple method to remove mechanically the surface including welded area, while it requires a long period of about 10 days.

After the EP1, the heat treatment was carried out at 750°C for 3 hours at Tokyo Denkai Co. Ltd. to remove the hydrogen which was absorbed in the niobium during the EP1. Prior to each vertical test, the HPR is adopted as a final rinsing. The flow rate, pressure and the period in the HPR were 14 L/min, 8~9 MPa and 1.5 hours, respectively.

## 4. Vertical tests of a β=0.5 single cell cavity

In order to demonstrate the performance of the β=0.5 single cell cavity, the achievable field strength, Q value and the surface resistance were evaluated in the vertical tests. Vertical tests were carried out before and after the EP2 as described in the previous section. At each test, measurements at the temperature of both 4.2 K and 2.1 K were performed. Typically, the vertical test requires 3 days; first day for set up and pre-cooling, second day for feeding LHe and measurement at 4.2 K and last day for cool down to 2.1 K and the measurement. The results of the vertical tests are summarized in Fig. 5. The Q values obtained in the tests are plotted as a function of peak surface electric field ($E_{peak}$). Surface resistance ($R_s$), accelerating gradient ($E_{acc}$) and wall loss are also presented in the figure.

In the test before the EP2 (filled square and circle in Fig. 5), $E_{peak}$ values of 26.6 and 20 MV/m were realized at 2.1 and 4.2 K, respectively. Q values of $1\times10^{10}$ (2.1K) and $7\times10^{8}$ (4.2K) were achieved in the low field measurements, while Q degreased at high field measurement due to field emission. Surface resistance values at the design field strength of $E_{peak}$=16 MV/m [3] were evaluated to be 20 nΩ and 400 nΩ at 2.1 and 4.2K, respectively.

After the EP2, significant improvements have been found in the cavity performance as shown in Fig. 5 (open square and circle). Q values of $2\times10^{10}$ and $1\times10^{9}$ have been obtained in the low fields. Notable Q degradation was not found at $E_{peak}$<20 MV/m, while field emission reduced Q value at $E_{peak}$>20MV/m in the 2.1 K measurement. The maximum $E_{peak}$ of 30 MV/m was achieved in the 2.1 K measurement; that is high enough for the design value of 16 MV/m. At 2K, the $R_s$ value at $E_{peak}$=16MV/m was 7 nΩ that is lower than our expectation of 15 nΩ [3]. The results indicate that our fabrication and surface treatment were good enough to apply to the SC proton linac.

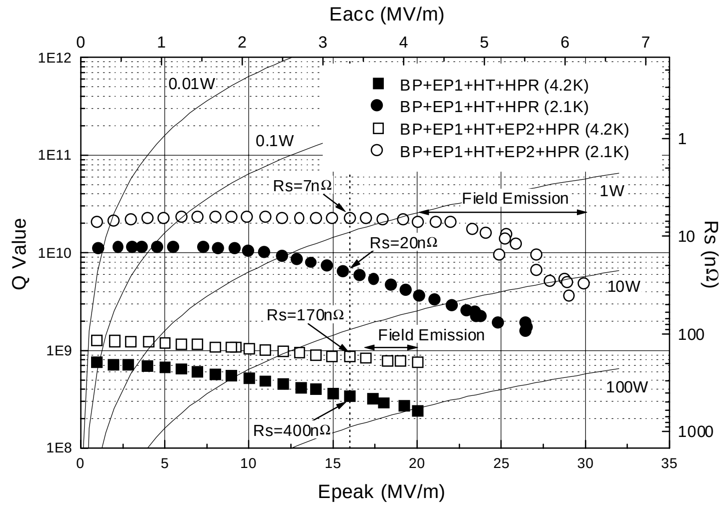


Fig. 5 Q values of the β=0.5 single cell cavity as a function of peak surface electric field ($E_{peak}$)

## 4. Conclusion and further plans

In the SC cavity development work, the test facility has been completed and the first cavity of β=0.5 has been fabricated and tested. The test facility was applied successfully to the vertical tests. Good cavity performance, which satisfied the design parameters, was obtained in the vertical tests. Consequently the objects of the first step R&D have been accomplished in this work.

In addition to this work, the second single cell cavity of β=0.5, which has the same shape as the first cavity, has been already fabricated. The test will be carried out within 1997.

In the next step, we have other R&D items; developments of higher β cavities and multi-cell cavities. For these items, fabrication of a single cell cavity of β=0.886 and a 5-cell cavity of β=0.5 has already begun. The measurements of these cavities will be performed within 1998.

## References

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