RF DESIGN OF A 972MHZ SUPERCONDUCTING CAVITY FOR HIGH INTENSITY PROTON LINAC

E. Kako† and S. Noguchi
KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801 JAPAN

Abstract

A 972MHz, β=0.725, 9-cell niobium cavity with an optimised cell-shape was designed by using electromagnetic codes such as SUPERFISH, MAFIA and HFSS. External Q of an input coupler was computed in a model single-cell cavity. A prototype 9-cell cavity with coupling ports was designed so that the external Q of $5x10^5$ is obtainable. Frequency and R/Q in higher order modes were calculated in the prototype cavity. A 972MHz input coupler with a coaxial rf window, a doorknob and a coupling waveguide were designed and fabricated. Preparation for high power test of the input couplers is in progress.

1 INTRODUCTION

In the JAERI-KEK joint project for high intensity proton accelerators [1], a superconducting linac is required to boost the energy of the H^- beam from 400MeV to 600MeV. The 600MeV beam will be used for ADS (accelerator-driven system) experiments in the second phase of the joint project. The superconducting linac will be operated with a beam current of 30mA, a beam pulse width of ~1msec and a repetition rate of 25Hz. Rf frequency of 972MHz is the same as that of normal-conducting cavities used between 200MeV and 400MeV. In the present system design of the superconducting linac, accelerating gradient has been set at about 10MV/m. Eleven cryomodules containing two 9-cell cavities will be installed in the linac tunnel. The niobium cavities are covered with titanium jacket for filling liquid helium of 2K. Capacity of a helium refrigerator is estimated to be 3.0kW at 4K with a margin of 30%.

The key issue in the superconducting linac is rf control in the pulsed operation and reliability of the hardware components. Fabrication of a prototype cryomodule prior to the construction is an essential R&D work to confirm above solution. Design of the first 972MHz cryomodule with β=0.725 (424MeV) was finished last year [2]. Fabrication of two 9-cell cavities and two input couplers for installation in the prototype cryomodule has just completed. In this paper, the cavity and the input coupler are described in detail from the viewpoint of rf properties.

†eiji.kako@kek.jp

2 MODEL CAVITY

A 972MHz, β=0.725, 9-cell niobium cavity with no coupling port, as shown in Figure 1, was designed and fabricated as the first cavity in order to establish its fabrication method and demonstrate its rf performance. The cell-shape was determined by optimising rf parameters in the accelerating mode and avoiding harmful trapped modes in higher order modes (HOM) [3]. The bore radius at iris is 45mm. The main rf parameters calculated by SUPERFISH are listed in Table 1. Each half-cell has a same cell-shape, and only flat length at equator in both end-cells is adjusted to obtain a uniform field distribution. Both calculated and measured field distributions are shown in Figure 2. The field flatness of 98% was obtained after pre-tuning.

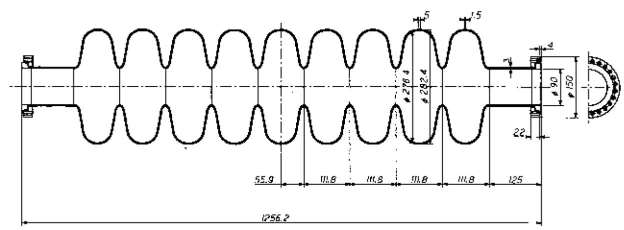

Figure 1: A 972MHz, β=0.725, 9-cell model cavity

Table 1: Main rf parameters of the model cavity

Esp/Eacc	3.03	
Hsp/Eacc	55.0	Oe/MV/m
R/Q	496.	Ω
Geometrical factor	206.	Ω
Cell-to-cell coupling	2.85	%

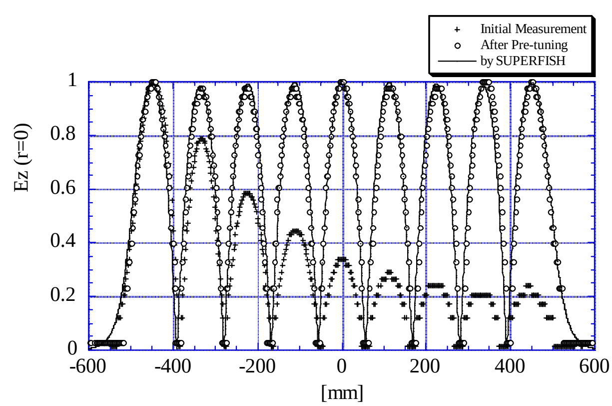

Figure 2: Field distribution of the accelerating mode

3 EXTERNAL Q OF INPUT COUPLER

The operating accelerating gradient, Eacc, is about 10MV/m and the synchronous phase angle is set to –30 degree. The required input rf power is 250kW for the beam current of 30mA, and the external Q (Qext) in the corresponding matched condition is $8x10^5$. Lowering the Qext is an effective way to suppress the oscillation of accelerating gradient due to Lorentz detuning. Therefore, the Qext of $5x10^5$ and the input rf power of 300kW were determined for the specification of the input coupler. Here, the band-width is ~2kHz and the filling-time is ~0.2msec.

External Q of the input coupler was simulated by HFSS in the model single-cell cavity with two antennas, as shown in Figure 3. The distance of X was finely adjusted so as to minimise reflect power (S11). Calculation method of Qext is completely the same as that in a cold test of a cavity. Loaded Q was obtained by band-width of transmitted power (S21) to the input coupler of ϕ80. Unloaded Q was 26000 in copper surface. External Q is strongly dependent on the antenna location (L, T) and the diameter of beam tube (ϕD). The calculated result of Qext in a 9-cell cavity is shown in Figure 4. Consequently, the dimensions of L=95mm, T=35mm and ϕD =126mm were selected for obtaining the Qext of $5x10^5$. This result will be compared with measurement in an actual copper cavity.

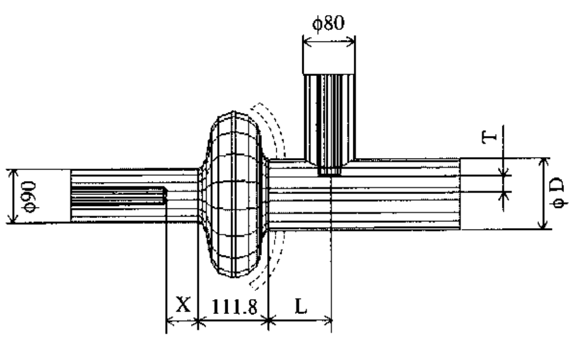

Figure 3: Model cavity for calculation by HFSS

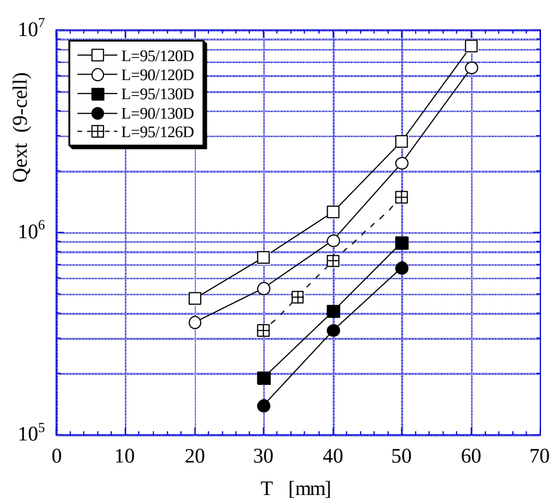

Figure 4: External Q in a 9-cell cavity as a function of antenna location

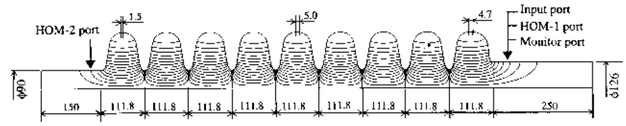

Figure 5: Prototype 972MHz 9-cell cavity with coupling ports

Table 2: Main rf parameters of the prototype cavity

Esp/Eacc	3.07	
Hsp/Eacc	55.4	Oe/MV/m
R/Q	478.	Ω
Geometrical factor	208.	Ω
Cell-to-cell coupling	2.80	%

4 HIGHER ORDER MODES

According to the simulation of Qext, a prototype 9-cell cavity with coupling ports was designed as shown in Figure 5. Only half-cell in the right end-cell has a different cell-shape with the beam tube of ϕ126. A HOM coupler is installed on the both beam tubes. The main rf parameters calculated by SUPERFISH is listed in Table 2.

Calculation of higher order modes in the prototype 9-cell cavity was carried out by MAFIA. Figure 6 shows R/Q in monopole modes and Rt/Q at 20mm off-axis in dipole modes. Here, several modes localising only around the beam tubes are ignored. In dipole modes, no conspicuous mode with high Rt/Q is found except 6π/9 and 7π/9 in TM110 (1.3GHz). Large value of R/Q in monopole modes exists in only TM011-5π/9 (2.3GHz), and the loss-parameter is about 0.03V/pC. Total loss-parameter and HOM power extracted by two couplers is roughly estimated to be less than 0.1V/pC and less than 1W at 30mA, respectively. No trapped mode was found in the frequency range less than 2.5GHz. Therefore, there will be no serious problem in the HOMs.

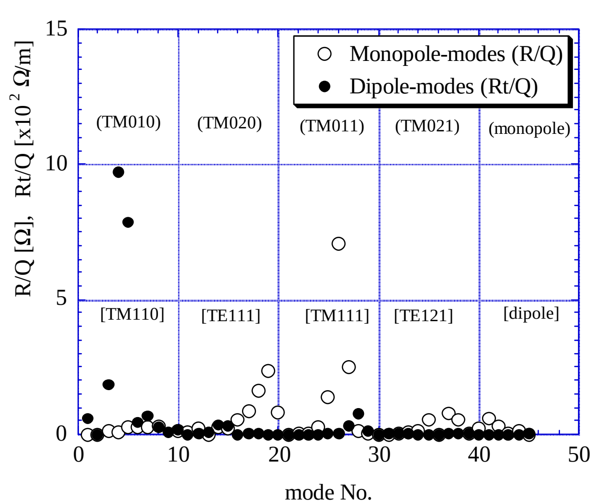

Figure 6: R/Q (Rt/Q) in monopole (dipole) modes

5 INPUT COUPLER SYSTEM

Basic design of the 972MHz input coupler was carried out with referring the 508MHz input coupler used for the TRISTAN superconducting cavities [4]. Heat load dissipated at copper surface and ceramic disk is considerably reduced due to pulse operation in duty of 5%, in comparison with the 508MHz coupler in cw operation. On the other hand, heavy irradiation has to be taken into consideration in the design.

The 972MHz input coupler system consists of a doorknob for transition between coaxial line (120D) and waveguide (WR975), a coaxial rf window of ϕ120, a coaxial line (ϕ80) with an antenna and a coupling waveguide (WR975). Frequency dependence of S-parameters computed by HFSS is shown in Figure 7. The design value of VSWR at 972MHz is 1.05 in the doorknob, 1.15 in the coaxial window and 1.05 in the coupling waveguide. Drawing of the 972MHz coaxial window is shown in Figure 8. The ceramic disk was made of Al_2O_3 with purity of 95%, and the size is ID=32mm, OD=136mm and t=7.0mm. Coating with TiN on the surface of the vacuum side was carried out.

High power test stand for the 972MHz input couplers is shown in Figure 9. Each component has been already fabricated. Preparation for high power test is in progress.

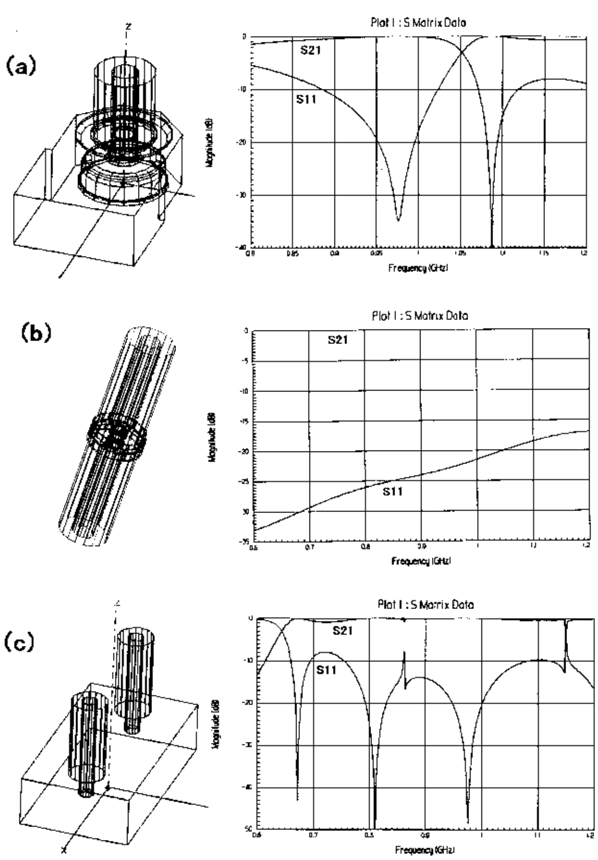

Figure 7: Computed frequency dependence of S-parameters; (a) Doorknob (b) Coaxial window (c) Coupling waveguide

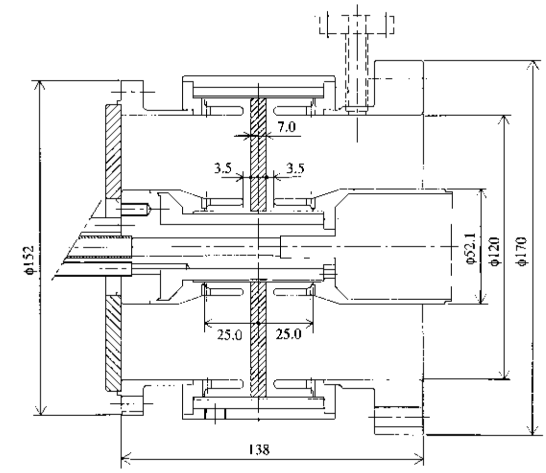

Figure 8: A 972MHz coaxial ceramic window

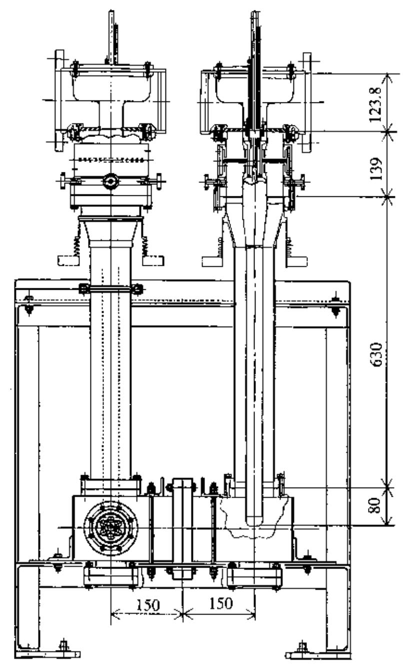

Figure 9: High power test stand for 972MHz input couplers

6 REFERENCES

[1] Y. Yamazaki, "The JAERI-KEK Joint Project", in this conference (TUZGB003).

[2] S. Noguchi, "SRF Linac in the JAERI/KEK Joint Project", Proc. of 10th Workshop on RF Superconductivity, Tsukuba, Japan (2001), to be published.

[3] E. Kako, "Cell-shape Design of 972MHz Superconducting Cavity for High Intensity Proton LINAC", Proc. of 25th Linac Meeting in Japan, Himeji (2000) p323-325.

[4] S. Noguchi, E. Kako and K. Kubo, "Couplers – Experience at KEK", Proc. of 4th Workshop on RF Superconductivity", Tsukuba, Japan (1989) p397-412.