High Power Test of RF Cavity for SPring-8 Booster Synchrotron

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Abstract

Slot-coupled 5-cell rf cavities are adopted for SPring-8 (Super Photon Ring 8GeV) booster synchrotron. They are operated at 508.58 MHz with 250 kW CW and designed to have 1.7% of coupling coefficient and more than 21 MΩ/m of shunt impedance. A mock-up cavity, made of class-1 oxygen free Cu, has been fabricated for high power tests with a 1 MW klystron. This paper represents the structural features, the thermal analysis, the rf characteristics and the high power test.

1 INTRODUCTION

The rf system in the synchrotron must provide adequate voltage and power to accelerate electron or positron beam, to compensate for synchrotron radiation losses and also to give overvoltage for a proper beam lifetime. The rf power is mainly dissipated at cavity wall, since the maximum beam current is only about 10 mA. The design requirement for the cavity is to realize a high shunt impedance to reduce the wall losses. So that a multi-cell type cavity that consists of 5 cells was chosen. The synchrotron uses 508.58 MHz rf system, the same frequency that will be used for the storage ring. Two 1-MW KEK-type klystrons will be used in the synchrotron. The rf parameters are listed in Table 1.

Table 1 The rf parameters of the synchrotron

Beam energy	(Injection)	1.0	GeV
	(Extraction)	8.0	GeV
Magnetic bending radius		29.539	m
rf frequency		508.58	MHz
Harmonic number		672	
Repetition rate		1	Hz
Beam current		10	mA
Radiation loss at 8GeV		12.27	MV/turn
Overvoltage factor		1.52	
Maximum required voltage		18.6	MV
rf voltage at injection		6	MV
Number of cavities		8	
Synchrotron frequency at 8GeV		32.7	kHz
Klystron power		1	MW
Number of klystrons		2	

2 STRUCTURE OF THE CAVITY

A.General Description

The prototype 5-cell slot coupled cavity is shown in Fig.1. The cavity is designed to operate in the π-mode thus a cell length of 294.74 mm is equal to a half wavelength of the rf frequency. The adjacent cells are inductively coupled each other with four azimuthal slots in a common disk. Nose cones are shaped on disks to make a shunt impedance higher. Diameter of both end cells are

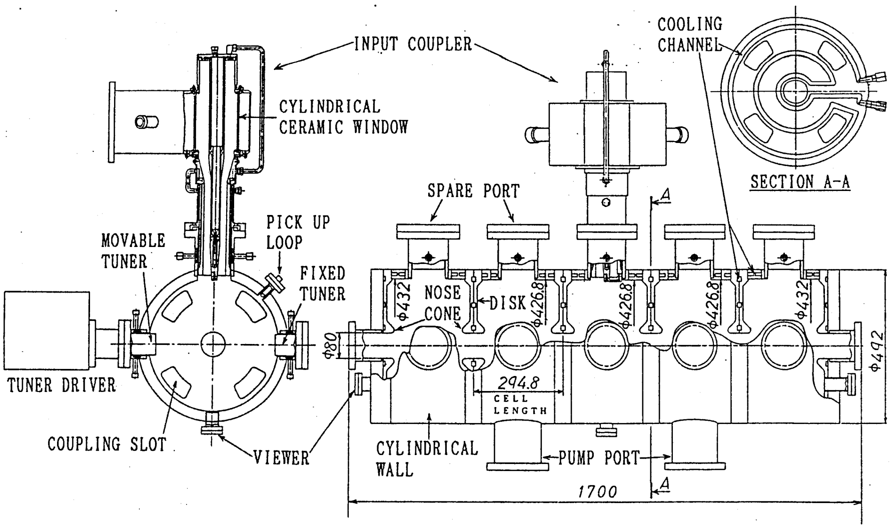


Figure 1. Cross sectional view of the prototype cavity

slightly larger than that of inner three cells to realize a flat accelerating field distribution called as 'flat-π mode'.

The material of the cavity is class-1 oxygen free Cu because of high electrical and thermal conductivity and low outgassing rate. The computer code 'SUPERFISH' was used for designing the cavity. Detailed dimensions were determined experimentally using an aluminum model cavity[1]. The cavity is 1700 mm long. The inner diameter of the cavity is about 430 mm. The bore radius is 40 mm.

B. Water cooling channel

Water cooling channels run azimuthally inside the disks and the cylindrical wall. The heat load of 250 kW on the inner surface of the cavity is effectively removed through direct cooling channels. A water flow rate for a whole cavity is 200 l/min. Figure 2 shows the results of an axisymmetric thermal analysis carried out by using the computer code 'NASTRAN'. A heat load distribution on the inner surface of the cavity was computed by 'SUPERFISH'. Non-axisymmetric structures such as the slots are neglected in these calculations. The power dissipation and water flow rate per cell are 50 kW and 34 l/min, respectively. An inlet temperature of the cooling water was assumed to be 30 degree and temperature rise of the water in the cavity was taken into account.

The maximum temperature of the cavity is 73 degree and the maximum frequency shift due to thermal deformation in the diameter of the cavity was estimated to be about -330 kHz at maximum. This is much smaller than tuning range of movable tuners.

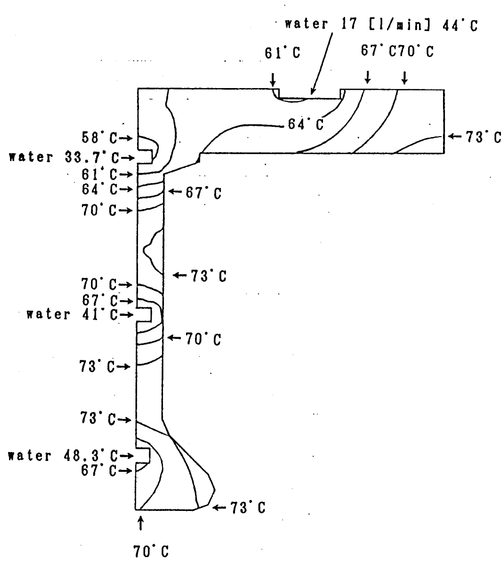


Figure 2. Temperature distribution in a quarter cell of the cavity

C. Tuner

Each cell is equipped with two tuning plungers with diameter of 70 mm. One of them is the fixed tuner which corrects fabrication errors. The other is the movable tuner by which the thermal detuning and the beam loading effect are dynamically compensated during operation. All of the five movable tuners are driven together with an over all stroke of 70 mm.

D. Input Coupler

The waveguide mode of rf power (250 kW) is transformed into a coaxial mode through a cylindrical or disk type window of 95% alumina ceramic which seals the vacuum of rf cavity. Inner wall of the ceramic window is coated with TiN 6 nm thick to reduce the secondary electron emission. The cylindrical type of the input coupler has been used in TRISTAN of KEK for the APS cavity with the maximum input power of 300 kW [2]. The disk type of one is made for the test. Figure 3 shows the input coupler with the disk type ceramic window.

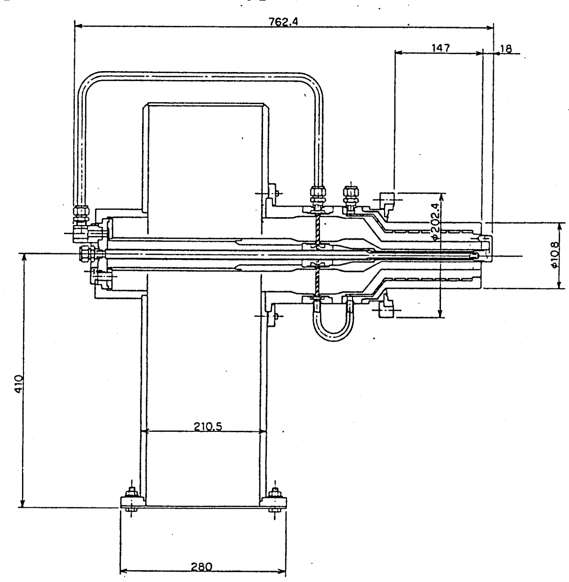


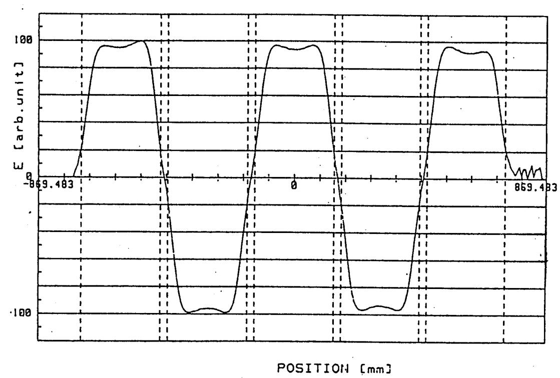
Figure 3. Input coupler with the disk type window

3 RF CHARACTERISTICS

The measured values for accelerating mode are listed in Table 2. Figure 4 shows an electric field distribution of the accelerating flat-π mode along the cavity axis, which was measured by perturbation method. The coupling coefficient K is defined as $K = 2(f_0 - f_\pi) / (f_0 + f_\pi)$ where f_0 and f_π are rf frequency of 0 and π mode. The coupling coefficient of 1.68% seems to be considerably large compared with other slot coupled type cavities [3]. The shunt impedance per unit length is about 23 $M\Omega/m$ which satisfies the requirement of the booster synchrotron.

Table 2. rf characteristics of the accelerating mode

rf frequency	508.580	MHz
Unloaded Q (Q0)	29300	
Effective shunt impedance	23	MΩ/m
Coupling coefficient	1.68	
Tuning range of tuners	1.9	MHz



Figere 4. Field distribution of the accelerating mode

4 HIGH POWER TEST OF THE POROTOTYPE CAVITY

The high power test of the prototype cavity was carried out. The maximum input power is 250 kW CW. The 1-MW KEK-type klystron is used for the rf source. The power is reduced 250 kW or less by tuning the anode and cathode voltage. The rf power feeds the cavity through a circulator, for the protection of the klystron from the reflected rf power. The temperature of the ceramic window, the vacuum and the inside of the cavity were monitored under the test. Figure 5 shows the set up of the high power test.

This experiment is the first one. The aging of the cavity and the input couplers have to be given at the same time. At first the rf feeds through the input coupler with a cylindrical ceramic window, which has been used in TRISTAN KEK. After aging of five days, the input rf power of 250 kW CW was achieved. At this time the temperature of the cavity wall is 50 degree and the pressure is $1.7x10^{-4}$ Pa.

Next time the disk type ceramic window was tested. The cavity cooling efficiency of the disk type ceramic window is better than the cylindrical type. The input power of 250 kW or more is expected. The input power of 180 kW is achieved in two days. At the input power of 200 kW, the ceramic window was broken and the vacuum break was happened. It proved that the cruck was made from the boundary of ceramic and metal.

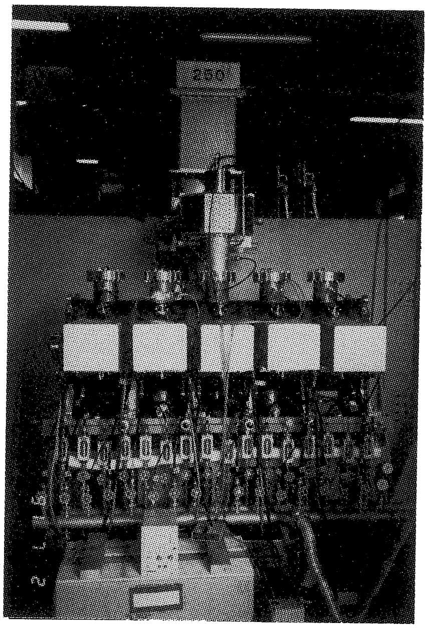


Figure 5. Set up of the high power test

5 CONCLUSION

The rf characteristics of the cavity for SPring-8 booster synchrotron were measured. Flat-π mode was realized by adjusting the fixed tuner. The shunt impedance meets the requirement of the booster synchrotron. The input rf power of 250 kW CW was achieved at the high power test.

6 REFERENCES

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