Development of 5-cell RF Cavity for SPring-8 Booster Synchrotron

H. Suzuki, T. Harami and Y. Miyahara
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

T. Rizawa, S. Satoh, Y. Tanabe, K. Yoshiyuki,
T. Nagafuchi, S. Kawazu and M. Nakano
Toshiba Corporation
1-1-6, Uchisaiwai-cho, Chiyoda-ku, Tokyo, Japan

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 including higher order modes and the beam instability.

I. 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	1.48	
Maximum required voltage	18.2	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	

II. 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 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.

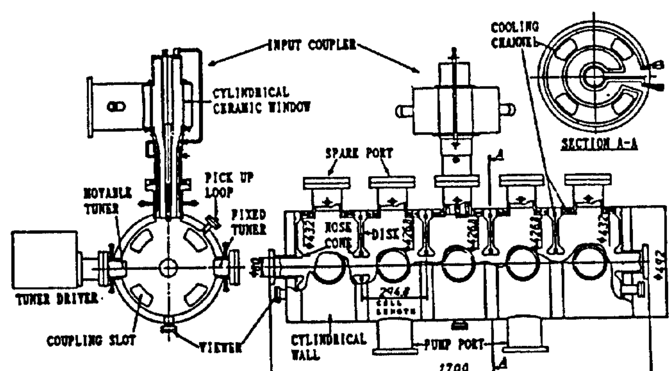

Figure 1. Cross sectional view of the prototype cavity

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.

Each disk consists of two half disks. After machining the cooling channels onto the one side of each half disk as shown in Fig. 1, both of them were bonded by diffusion under high temperature and high mechanical pressure. Cylindrical wall and ports of the cavity were at first sliced into short pieces, in which water cooling channels were made with the above technique. After precise shaping of all disks and the cylindrical walls, they were integrated by means of the diffusion-bonding with thin silver inserts. The use of silver insert can reduce the bonding pressure which does not cause a serious deformation on the cavity.

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 °C and temperature rise of the water in the cavity was taken into account.

The maximum temperature of the cavity is 73° C 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.

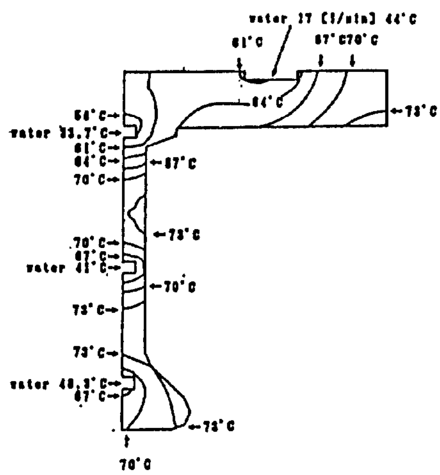

Figure 2. Temperature distribution in a quarter cell of the cavity

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 (250kW) is transformed into a coaxial mode through a cylindrical 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. This type of input coupler has been used in TRISTAN of KEK for the APS cavity with the maximum input power of 300 kW [2] .

Four spare ports at the top of the cavity are prepared to allow adding higher order mode (HOM) dampers.

III. RF CHARACTERISTICS

A. Accelerating mode

The measured values for accelerating mode are listed in Table 2. Figure 3 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(f0-fπ) / (f0+fπ) where f0 and fπ 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 MΩ/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)	29000	
Effective shunt impedance	23	MΩ/m
Coupling coefficient	1.68	
Tuning range of tuners	1.7	MHz

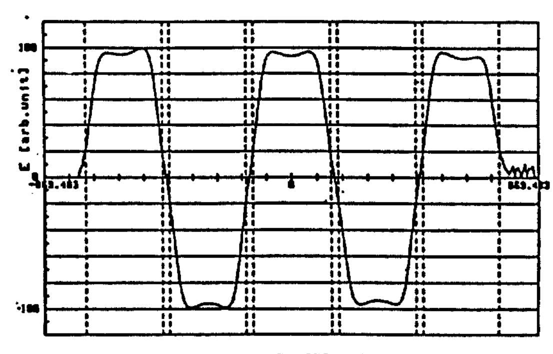

Figure 3. Field distribution of the accelerating mode

B. Higher Order Mode

Four groups of mode TM010, TM011, TM110 and TM111 are important as for beam instability. Therefore these mode in the cavity were identified by perturbation method and their characteristics are shown in Table 3.

As for TM010 mode, R/Q0 values except that of π mode are negligibly small because their transit time factors become nealy zero. TM010 and TM011 modes have longitudinal coupling impedance. TM110 and TM111 modes have transverse one, and each of these modes are split into horizontal and vertical modes because the symmetry of each cell is broken by some ports. The vertical modes of TM110 have smaller Q0 compared with the horizontal mode because their magnetic fields are high and disturbed at the vacuum ports. TM111 modes have no field at the center mirror plane, and the effect of unsymmetry is not strong. Thus their mode separation between horizontal and vertical is not clear.

Table 3 rf characteristics of the HOM

MODE		F0(MHz)	Q0	R/Q0(Ω)	R(MΩ)
TM010	1π/5	516.334	37403	0	0.0
	2π/5	514.134	32008	0	0.0
	3π/5	511.488	35288	0	0.0
	4π/5	509.347	30818	0	0.0
	5π/5	508.580	27699	1162	32.2
TM011	1π/5	720.352	16417	0	0
	2π/5	727.767	17658	57.8	1.02
	3π/5	737.050	21515	163.9	3.53
	4π/5	745.050	24093	57.1	1.38
	5π/5	747.154	23270	28.9	0.672
TM110 (V)	1π/5	854.542	1876	317.3	0.595
	2π/5	850.481	1828	-----	-----
	3π/5	846.100	5826	418.5	2.44
	4π/5	842.561	5027	1.0	0.005
	5π/5	841.158	5886	87.9	0.517
TM110 (H)	1π/5	859.117	38639	292.2	11.3
	2π/5	855.003	29148	640.6	18.7
	3π/5	849.987	35665	354.8	12.6
	4π/5	846.286	31368	18.6	0.583
	5π/5	844.940	32423	89.8	2.91
TM111	1π/5	998.457	11522	5418	6.24
		998.710	22389	5839	13.1
	2π/5	1007.178	6722	34.7	0.233
		1007.882	15781	7.3	0.115
	3π/5	1020.586	11373	723.6	8.23
		1020.885	19814	690.4	13.7
	4π/5	1031.571	22688	28.8	0.653
		1032.331	22471	15.1	0.339
	5π/5	--------	-----	-----	------
		1038.436	17736	134.9	2.39

----- : Impossible to measure

IV. BEAM INSTABILITY DUE TO THE CAVITY

The beam spends a relatively short time, less than 1 second, in the synchrotron and the maximum current required for the synchrotron is at most 10 mA and 1 mA for multi-bunch and single bunch operation, respectively. However, the beam is injected into the synchrotron at relatively low energy, 1 GeV, and this might enhance beam instability, while the radiation damping time is about 1 sec. As for the higher order modes given in Table 3, numerical estimation of the beam instability at the injection energy was carried out using the computer code ZAP.

At 1 GeV the injected beam has a momentum spread about 1.5% so that the threshold current of the longitudinal microwave instability is quite high. In Fig. 4, the rf voltage dependence of the single bunch threshold is shown. The threshold current per bunch is 10.9 mA at an rf voltage of 6 MV. This instability at injection is not expected.

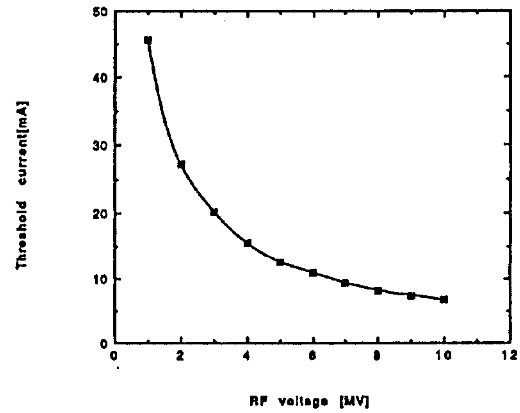

Figure 4. rf voltage dependence of the threshold current of microwave instability at 1 GeV

The growth time of the head tail instability is as short as 10 msec for the single bunch operation. It is necessary to correct the chromaticity in the synchrotron with sextupole magnets.

The growth time of the longitudinal coupled bunch instability predicted by ZAP are in the order of seconds. The instability will be easily suppressed by stronger radiation damping during beam acceleration.

The growth time of the transverse coupled bunch instability predicted are about 10 msec. The instability can be suppressed by a tune spread in the order of 10^{-4}.

V. 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. As a result of the calculation by the ZAP code, some cures might be necessary to suppress transverse coupled bunch instability.

VI. REFERENCES

[1] T. Rizawa et al., "rf Characteristics of 508MHz Slot-coupled Multi-cell Cavity" Ploc. of 2nd European Particle Accelerater Conf., Nice, France, June 1990, pp. 916-918.
[2] T. Higo et al., "rf Cavity for TRISTAN Main Ring", Ploc. of 1987 IEEE Particle Accelerator Conf., Washington D.C., March 1987, pp. 1945-1947.
[3] H. Gerke et al., "Das PETRA-Cavity", DESY PET-77/08, August 1977.