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RF CAVITY FOR TRISTAN MAIN RING

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#### 1. Introduction

In the TRISTAN  $e^+e^-$  storage ring<sup>1)</sup> 52 subsections with a total length of 276 meters are dedicated for RF acceleration by 508.58 MHz normal conducting cavities2) . At present each of 32 subsections is occupied by an accelerating unit with 18 accelerating cells. The accelerating unit shown in Fig. 1 is composed of a pair of cavities of an alternating periodic structure (APS) with nine electrically coupled accelerating cells. RF power of 1 MW generated by a CW klystron is fed to four cavities (two accelerating units) through a circulator and magic tees with a 10 percent power loss. Each cavity is operated up to an input power of 225 kW with a cooling water flow of 150  $\ell/min.$  Fabrication method of the cavity is described in ref. 3. In this paper, the design and performance of the cavity are described.



# 2. Design of the cavity

The dimensions of one accelerating period of APS are shown in Fig. 2. The quality factor Qa and shunt impedance Rsh calculated by SUPERFISH<sup>4</sup> are 42,400 and 26.7 M\Omega/m for  $\rho = 1.70 \times 10^{-8} \Omega \cdot m$ , respectively. The beam bore diameter of 100 mm was chosen to be larger than the beam stay clear aperture, while the disk thickness was chosen to be 20 mm to make the space for cooling water channels in it. With these dimensions a bandwidth of 1.2 percent is obtained for the operating mode passband.



Fig. 2 Unit period of APS.

In designing the APS cavity operated at high CW power, the following two factors should be taken into account. First, if the resonant frequencies fa's of accelerating cells deviate from the accelerating mode frequency Fa of the cavity, the coupling cells are excited. Then, the total Q value of the cavity de-creases, since the Q value Qc of the coupling cell is only 20 percent of the Q value Qa of the accelerating cell. The decrease of the total Q value is not only dependent upon the amounts of the deviations  $\delta fa$ 's of the accelerating frequencies, but also upon the distribution of  $\delta fa's$  among the accelerating cells. The decrease becomes maximum for the distribution where  $\delta f \boldsymbol{a}$ is negative for the first to fourth cells and positive for the other cells, or for the reversed distribu-tion<sup>5)</sup>. As the fabricational error for fa's is  $\pm 0.1$ '. As the fabricational error for fa's is  $\pm$  0.1 MHz in the present case, the maximum decrease of the total Q value is expected to be as large as 30 percent. The total Q value further decreases if the thermal detuning of fa's due to the high power input is compensated only by a few tuners, since the deviation of  $\delta fa\, 's$  are further enhanced. To avoid this large amount of decrease, we equipped every accelerating cell with a tuner and tuned it within ± 10 kHz.

Second, it is better to tune fc as close to the resonant frequency Fa = 508.58 MHz as possible to obtain a uniform field distribution. However, the thermal distortion of the disks decreases the coupling cell frequency by 0.6 MHz at the maximum power of 225 kW. Since fc should not be lower than Fa from the stability criterion for the field distribution among the accelerating cells, we set fc to Fa + 0.6 MHz at low power level. Then, as the wall loss increases, fc approaches to the confluent condition fc = Fa, resulting in a more uniform field distribution. At low power level rather large stopband of fc - Fa = 0.6 MHz appears, and then the field distribution becomes non-uniform if fa's deviate from Fa. Although the deviation offa's can be reduced to less than ± 10 kHz by tuners, the field tilt along the nine cells amounts to 6 percent in the worst case where fa's of the left half of the nine accelerating cells are - 10 kHz, while those of the right half + 10 kHz. However, ofa's are expected to distribute randomly within ± 10 kHz, and thus the non-uniformity of the field be much smaller.

The shunt impedance Rsh decreases as the coupling cell gap gc becomes large. On the other hand, gc should be as large as possible to obtain high Q value Qc, small thermal detuning of fc and small amount of the excited fields in coupling cells. Taking into account these advantages for large gc, we considered it tolerable that Rsh is lower by 2 percent for gc = 30 mmcompared to that of the practically smallest gc of 15 mm.

There is no coupling cell beyond the end accelerating cells (the first and ninth cells). Thus, the first cell is tuned to the normal one by increasing the curvature of the beam port. On the other hand the ninth cell (junction cell) should be designed to guarantee the RF isolation between the two 9-cell structures. In order to reduce the coupling, the length of the beam hole is increased to 130 mm by reducing the accelerating cell gap ga by 30 mm. The resulting coupling is as small as 1.2 kHz, and induces a phase error of only 2.1° in one structure even when the other is completely detuned. The small ga reduces the shunt impedance only by about 1.5 percent.

### 3. Tuner

A plunger of 70 mm in diameter is used as a tuner for the accelerating cell. The structure is shown in Fig. 3. All of the nine tuners of a cavity are attached to a common bar and moved by the same amount. Although, nonlinear dependence of fa on tuner position gives rise to differences of fa's in addition to initial tuning errors of  $\pm$  10 kHz, total differences amount to  $\pm$  18 kHz. The resulting reduction of the total Q value is less than one percent even in the worst distribution of fa's,

We determined the gap width between the plunger and the tuner port to be 1.5 mm near the cavity surface

to suppress multipacting in the gap due to the leak-age field of the operating mode $^{6/2}$ . On the other hand . On the other hand, the  $\text{TM}_{011}$  modes (around 865 MHz) excited by the beam and the asymmetry of the field of the operating mode (508.58 MHz) induce the TEM mode transmitting through the coaxial structure. Therefore, the far side of the structure from the cavity surface should be designed to reduce the coupling of the tuner to the field for both frequencies. A choke structure of 200 mm in length is effective for both frequencies, but it is difficult to equip the structure with a sliding contact at the place where the current flow through it is small. In order to reduce the current, the outer diameter of the coaxial was stepped up from 73 mm to 140 mm. The position of the step and that of the shorting plane were determined so that the impedance seen from the cavity into

the tuner became zero at 508.58 MHz. Actually, the excited magnetic field inside the tuner casing was calculated by SUPERFISH and compared to that of the choke without the step. The current at the contact are 20 and 7 times smaller for 508.58 MHz and 865 MHz, respectively.



## 4. Input Coupler

A schematical view of the input coupler is shown in Fig. 6 of ref. 2. The input coupler transforms the wave guide mode to the coaxial mode and feeds the power of 225 kW to the fifth accelerating cell through loop coupling. A cylindrical RF window made of 95 % alumina ceramics for vacuum seal is located at the transition part from the wave guide mode to the coaxial one. The vacuum side of the ceramics is coated with TiN of 60 A thickness to reduce the coefficient of secondary electron emission. The transition part is matched by adjusting the position of the shorting planes in the wave guide and coaxial line. The coupling loop is apart from the transition part by more than  $\lambda/2$  to prevent undesirable interference between them.

### 5. Instabilities

Instabilities may arise from the higher order modes (HOM) and the axial asymmetry of the cavity. The former causes the coupled bunch instabilities and the latter the strengthing of synchrobeta resonances.

Characteristics of the HOM with large coupling impedances up to 1.1 GHz are summarized in Table 1. To suppress the transverse coupled bunch instabilities, a feedback damper with a damping time of 500  $\mu s$  is operated. However, if all the cavities have the same resonant frequencies for a dipole HOM and satisfy the instability condition, the upper limit of the stored current at the injection energy of 8 GeV will be about 4 mA. Therefore, the total coupling impedances along the ring should be reduced by a factor of 3 to obtain the design value of 10 mA. For this purpose the frequencies of HOM's of the cavities along the ring are made distributed on the order of ± 100 kHz by changing Ra's within  $\pm$  36  $\mu$ m. Then, the total coupling impedances remains within 2.5/N times that of one cavity  $^7$ **、**where N is the number of the cavities.

In order to reduce the coupling impedances further, HOM dampers were developed. A damping antenna of a 50  $\Omega$  coaxial line type will be installed to each cavity in order to reduce the impedances of TM<sub>011</sub> and TM<sub>111</sub> modes. The antenna 8.66 mm in diameter is

inserted into the cavity by 30 mm. The coupling of the damper to the accelerating mode was measured and found to be negligibly small. The parameters related to the coupling impedance of a cavity with and without a HOM damper at the fifth cell are listed in Table 1. As seen in the table, the impedance for the  $TM_{111}$  mode is reduced by a factor of 3. Considering the effect of the variation of Ra's and dampers, we estimate the threshold current for  $TM_{111}$  to be well above the design current.

The axial symmetry is mostly broken by the tuners which are in the horizontal median plane. To prevent the asymmetry effect on the synchrobetatron resonances from being cumulative, two types of accelerating units are lined up alternately. One type has the tuners inside the ring while the other outside. As the phase advance of the betatron oscillation is only 18° per an accelerating unit, this arrangement would greatly reduce the asymmetry effect.

Table 1

mode	TM <sub>011</sub> <sup>3</sup> / <sub>8</sub> π	TM <sub>110</sub> 5/9π	$TM_{111} \frac{\pi}{9}$
calculated for a cavity			
freq.	865 MHz	794 MHz	1040 MHz
Qo	37000	49000	41000
R	7.3 MΩ	65 MΩ/m	109 MΩ/m
α5	0.13		0.22
measured	for a cavity		
Q <sub>0</sub>	< 27000	35000	16500
R		46 MΩ/m	44 MΩ/m
Q <sub>L</sub>			5000±300
measured	for a HOM damper	in a single cell	
Q <sub>ex</sub>	1600±200		900±150

 $(\alpha_5$  is the calculated ratio of the stored energy of the cell with a HOM damper (fifth cell) to that of the full cavity.)

### 6. Frequency and Q value of each cell

Fig. 4 shows typical histograms of fa's measured for two kinds of the accelerating cells with different targets of Ra's. It is seen from the figure that the average values of fa's agree well with those aimed at. The standard deviation of fa's for each target is about 30 kHz. The resulting deviation of the acceleratng mode frequencies of the cavities (average values of nine fa's) is  $\pm$  10 kHz. As the target values of Ra's were varied by a step of 8 µm and the corresponding step of fa's was 20 kHz, it is estimated that we obtained the approximately uniform distribution of the HOM frequencies necessary to reduce the total coupling impedances. The Qa's for individual cells were also measured and the values were 88.5  $\pm$  0.5 percent of that calculated by SUPERFISH.

We measured the properties of the coupling cells by a plunger method after constructing a cavity where (cells)



the neighbouring accelerating cells are detuned by plungers. The fc's were adjusted by small tuners and the final deviation was within 10 kHz. The Qc's ob-

tained were  $89.0~\pm~0.4$  percent of that calculated by SUPERFISH.

## 7. Performance of the Cavity

Each accelerating cell was tuned to minimize the excitation of the accelerating mode in the coupling cells. Since the fields in the coupling cells are significantly affected by the mode neighbouring to the accelerating one through the finite Q values, the field components of the accelerating mode were distinguished by measuring the frequency dependences of the fields. Using the excited fields thus obtained all of the optimum relative positions of the tuners were determined at the same time.

Usually the tuning converged after about two iterations and the deviation of fa's is within  $\pm$  10 kHz corresponding to the tuner position errors of about  $\pm$ 0.2 mm. After this tuning the obtained Q value was 90  $\pm$  2 percent of that calculated by SUPERFISH. Fig. 5

shows the stored energies of the coupling cells excited at the operating frequency before and after the tuning. It is seen from the figure that the stored energy of the coupling cells were reduced, though there remained the field pattern of the  $8\pi/9$  mode just below the accelerating mode. The  $8\pi/9$  mode was excited through its small Q value and was not cancelled out by the  $10\pi/9$  mode, since the confluent condition was not satisfied at low power.

The thermal variation of fa and fc were measured versus wall loss power and compared with those calculated. The shift of fa was deduced from the movement of the tuner. The coupling cell

frequency fc of the cavity was deduced from the dispersion curve. In order to obtain the dispersion curve with the high power input, the amplitude of the generator power was modulated so that it included a small amount of the frequency components other than the accelerating mode, and the frequency spectrum of the cavity field was measured. As seen from Fig. 6 the rates of the decreases of fa and fc are in good agreement with those calculated.

It is difficult to measure a Q value of a cavity with a high power input. Thus, we estimate the actual shunt impedance of the cavity as follows. The Q values of the cavities were measured after the conditioning up to the input power of 300 kW/9 cells and the baking at  $135^{\circ}$ C for ten days. The obtained value at 20°C is about 92 percent of that calculated by SUPREFISH. As the wall loss power increases to 225 kW per nine cells, the surface temperature reaches about 65°C on the average with cooling water of 30°C. Then, the volume resistance of copper increases resulting in the reduction of the Q value by 10 percent. At the same time, the tuners are inserted by about 5 mm. The insertion also reduces the Q value by about 1 percent.



before

Fig. 5 Relative stored energies in the coupling cells of a cavity with 11 accelerating cells. these factors, we estimate the shunt impedance of the cavity higher than 80 percent of that calculated, that is higher than 21.5 M $\Omega/m$ , even at maximum input power of 225 kW/9 cells.

All of the 52 accelerating units were conditioned up to 300 kW/9 cells at the conditioning station. Tuners were controlled to keep the phase between the cavity field picked up by an antenna at the end cell and the The RF windows were input RF. blown from the upstream side of the wave guide by a blower. The surface temperature distribution was monitored by a thermoviewer. The vacuum side of the coupler was also monitored by TV camera. Each cavity of a unit was evacuated by a turbo molecular pump of 300 l/sec. The pressure was monitored by a cold cathode gauge and the value was used to control the conditioning process. We divided

the pressure range into five regions to control the input power: fast rise, moderate rise, hold, down and RF off for less than 0.5  $\times 10^{-6}$ ,  $4 \times 10^{-6}$ ,  $7 \times 10^{-6}$ ,  $8 \times 10^{-6}$  Torr and larger than the last value, respectively. It is to be noted that the conditioning curves — input power versus integrated time — showed similar shapes for all the units.



Fig. 7 Input power per a cavity versus integrated time of conditioning. The dashed line is for the cavity before baking while the solid line after baking.

All of the curves exhibited the stagnant behaviours around 30, 40, 50, 80, 120 and 200 kW/ 9 cells as shown in Fig. 7. It should be noted that the units often helding  $t = 12^{10}$  for the dump of the state of th

after baking at  $135^{\circ}$ C for ten days show no stagnation at about 1 kW/9 cells contrary to those before baking. Even after conditioning for more than 100 hours above 200 kW/9 cells, there remains the region of the input power around 120 kW/9 cells where the pressure increases. The conditioning around this region seems effective, but its effectiveness disappeared after somewhat long term idling.

All the 104 input couplers were tested up to 300 kW and none of them were broken. The hottest region of the cylindrical ceramic window was around the top or bottom of the cylinder. The typical temperature rise at the hottest spot was 0.2°C/kW.

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