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DEVELOPMENT OF AN APS CAVITY FOR TRISTAN MAIN RING

T. HIGO, Y. YAMAZAKI, T. KAGEYAMA, M. AKEMOTO, H. MIZUNO and K. TAKATA

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Summary

Normal conducting 508 MHz cavities of alternating periodic structure (APS) with nine accelerating cells will be installed in the TRISTAN main ring (MR). Rationale for this choice was discussed in ref. 1. The structure is biperiodically loaded with straight disks. The cells are coupled only electrically through the beam apperture of a 100 mm diameter and the coupling constant is about one percent. The length of the coupling cell is 15 mm. The adopted dimensions are shown in Fig. 1. The parameters of the cavity were calculated by SUPERFISH and listed in Table 1. It was found that each accelerating cell frequency should be tuned well to obtain a high Q value. Thus, tuning plungers were installed to all of the accelerating cells. The shunt impedance was estimated to be 23 MΩ/m and this value was 85 percent of the calculated one. It was also found from model calculations that the frequency of the coupling cell fc should be higher than or equal to that of the accelerating cell fa to stabilize the power distribution among the accelerating cells. The cavity designed under this constraint was excited up to 220 KW (CW) which was 150 percent of the designed power dissipation. The measured shifts of fa and fc due to the thermal distortion arising from the power dissipation were in agreement with those estimated from a computer analysis of thermal distortion. The transverse instability caused by the deflecting mode of the cavity was observed in the TRISTAN accumulation ring (AR). The measured growth rate was in agreement with that calculated with a coupled-bunch instability theory.

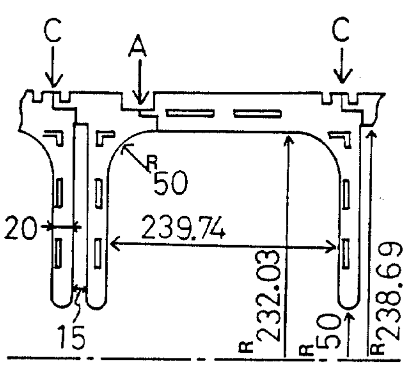

Fig. 1 Dimensions of the APS cavity.

Table 1

Calculated parameters of the cavity

Qa	43830
Qc	4830
ZT^2	27.6 MΩ/m

Design of the APS Cavity

For the APS cavity of the TRISTAN MR, fa decreases by 200 KHz, when the power dissipation of the cavity becomes the maximum designed value of 150 KW. Although a small number of tuners in the nine cell cavity are sufficient to compensate this thermal frequency shift, every accelerating cell should have a tuner for the following reason[1,2]. Consider two accelerating cells with a coupling cell between them. Regardless of whether the confluent condition fa=fc is satisfied or not, the field at the coupling cell increases in proportion to the frequency difference δfa between two accelerating cells. Since the Q value of the coupling cell is low compared with that of the accelerating cell, the excitation of the coupling cell decreases the Q value of the accelerating mode. For example, if δfa amounts to 1 MHz, the Q value decreases by about 23 percent. Therefore, all of the accelerating cells should be tuned well to keep the Q value high.

Ideally the confluent condition should be satisfied in order to keep the accelerating field uniform against the frequency differences among the accelerating cells. As fc's of the cavity shown in Fig. 1 decrease by 1 MHz at the maximum power dissipation of 150 KW, it is practically impossible to adjust fc's to fa. As a compromise, fc's are set to fa+1 MHz at low power[2]. In this setting the operational condition of the cavity becomes confluent as the power dissipation of the cavity approaches the maximum value.

Fabrication

One period unit of the cavity is composed of two parts separated at the positions indicated with the arrows A and C in Fig. 1. Each part is made of low carbon steel and the inner surface is electroplated with Cu of a 100 μm thickness. After plating, each contact plane is machined to obtain an edge contact for RF surface current. Then these parts are stacked and welded with a TIG method. The welding provides not only a mechanical rigidity and a vacuum seal but also a good RF contact with a stress of 200 kg/cm[1]. The obtained Q value was about 85 percent of that calculated by the computer code SUPERFISH[3].

The frequencies fa's and fc's were measured before and after the welding. The deviation of the frequencies from the designed value before the welding arose at machining and plating. The measured deviations were Δfa = ± 0.02 MHz and Δfc = ± 0.6 MHz. The frequency shift resulting from the welding was well controlled as Δfa = 0.14 ± 0.04 MHz and Δfc = - 1.75 ± 0.2 MHz.

High Power Test

First of all, the accelerating cells were tuned at low power by minimizing the stored energy in the coupling cells. At the early stage of conditioning discharge was observed at an input power of about 2 KW. After the conditioning at about a few KW for an hour, the input power was smoothly increased up to 220 KW (CW) which was 150 percent of the designed power dissipation. The discharge at the input power of 2 KW is considered as a result of the excitation of the coupling cell arising from the remnant small errors of fa's. In fact, when we increased the frequency difference between the adjacent accelerating cells beyond 1 MHz to excite the coupling cell, the discharge occured at only a few ten watts.

The thermal frequency shifts of fa and fc were measured versus input power. In Table 2, the results at the input power of 150 KW are listed together with the calculated ones estimated from a computer analysis of the thermal distortion[4].

Table 2

Frequency shift at the input power of 150 KW

(units MHz)

	measured	calculated
Δfa	- 0.2	- 0.08
Δfc	- 1.0	- 0.87

The shift of fa was measured from the change of the tuner position. After the power was raised rapidly, fa increased at first for about a minute and then began to decrease slowly to an equilibrium value. This behavior is explained as follows. In the first stage the temperature distribution throughout the cavity is not in a state of equilibrium. As a result the disk bends towards the coupling cell and fa increases. However, as the temperature distribution approaches an equilibrium and the thermal expansion of the cavity cylinder sets in, fa begins to rather decrease. The agreement between the measured shift and the estimated one using the calculated distortion of the cavity in a thermal equilibrium is fairly good.

It is important to measure the shift of fc due to the thermal distortion, because this shift should be included in the setting of fc at low power as discussed above. Though we can not measure fc directly during the operation, we can estimate the value fc-fa by measuring the frequency difference Δn between the $n\pi/8$ mode ($n=0\sim16$) and π (accelerating) mode, because Δn's are functions of fc-fa. The values Δn's were measured during the high power operation by sweeping the frequency of the amplitude modulation on the klystron power and analysing the frequency spectrum of the signal picked up from the cavity. The results are shown in Fig. 2. The shift of fc is mainly arising from the bending of the disk due to thermal stress and agrees with that estimated from the computer analysis of the thermal distortion.

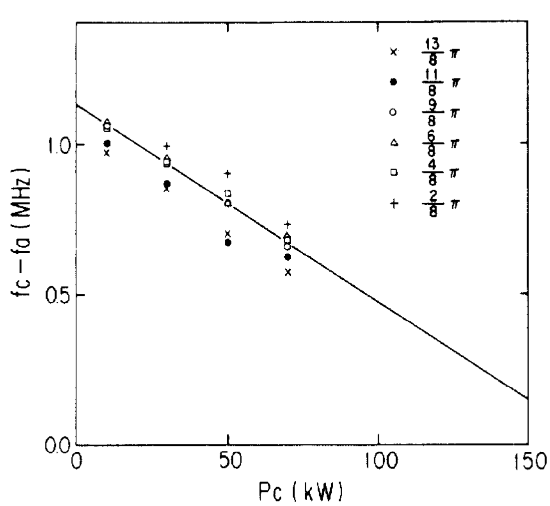

Fig. 2 Measured stopband fc-fa versus power dissipation in the cavity.

It is important to test whether the RF edge contact remains good after repeating the heat cycle many times. The Q value of the accelerating mode was used as a figure of merit of the contact. For three month operation in AR, the input power was modulated up and down below 50 KW with a nominal period of several minutes. The Q value did not change under this operation. The baking at 130°C for a day was also performed several times, but no change of the Q value was observed.

The input coupler has a cylindrical ceramic window, where a wave guide mode is transformed to a coaxial mode. Some of the input couplers showed abnormal temperature rise of the ceramic window even at an input power of 20 KW. If the input power was further increased, the ceramics cracked in some cases. This temperature rise is thought to be a one-side multipactoring on the ceramic surface[5]. To suppress the secondary electron emission, the inner surface of the ceramics was coated with a 30 Å TiN layer. The temperature rise of the ceramics was monitored by a thermocouple before and after the coating. The results are shown in Fig. 3. The temperature rise was remarkably reduced with the coating and the coupler was stably operated up to 220 KW (CW). In the coupler there is a 1 mm gap between the outer conductor of the coupler and the cavity port for the coupler. The depth of the gap is about λ/2 from the cavity surface to have a choke property at 508 MHz.

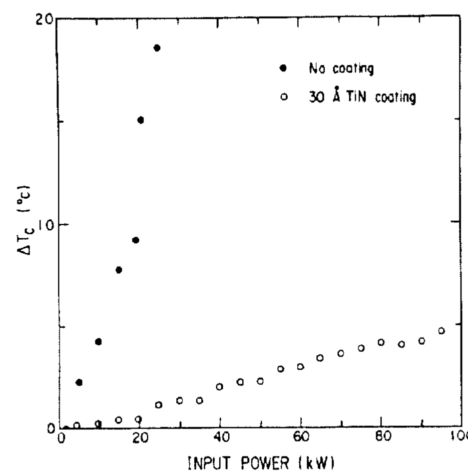

Fig. 3 Temperature rise of the coupler versus input power.

<u>Vacuum</u>

The area of the inner surface of the cavity is about 10 m^2. The inner surface is electroplated first with Ni to form a thin layer and then with Cu of a 100 μm thickness. The cavity was evacuated with a turbomolecular pump (250 ℓ/s) and an ion pump (500 ℓ/s). After the baking at 130°C for a day, the final pressure became 5×10^{-9} Torr, and the main component was the H_2 gas. Although the other components were reduced by the bake-out procedure, the outgassing rate of H_2 seemed to rather increase. However, it was found that with a successive baking at a lower temperature of 70°C for a day the H_2 outgassing rate was reduced and the final pressure of 1×10^{-9} Torr was obtained[6].

During three-month operation in AR the base pressure decreased from 1×10^{-8} Torr to 1×10^{-9} Torr without any bake-out procedure *in situ*. The pressure at an RF input power of 50 KW with a stored current of 20 mA also decreased from 5×10^{-8} Torr to 1×10^{-8} Torr.

When the TM_{011} mode frequency of the cavity was at a harmonic of the beam revolution frequency, the vacuum of the cavity became worse. However, the vacuum pressure was improved by one hour conditioning with the beam.

Interaction with the Beam

The dispersion curves of the TM_0 and HEM_1 mode[7] up to 1 GHz are shown in Fig. 4. The transverse coupling impedances were calculated by the computer code URMEL[8]. In the TM_{110} and TM_{111} passbands, the calculated values were 64 MΩ/m/9cell and 128 MΩ/m/9 cell, respectively, for the modes which satisfy approximately v_p=c, where v_p is a phase velocity. Actually the transverse narrow band instability attributed to the TM_{110} modes of the cavity was observed in AR[9].

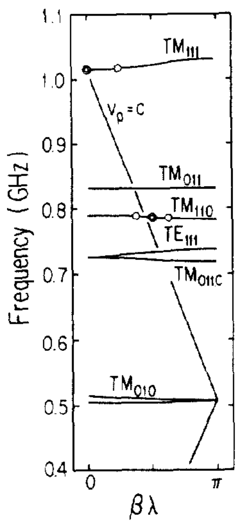

Fig. 4 Dispersion curves of the APS cavity. Only the TM_0 and HEM_1 modes up to 1 GHz are shown. The modes whose transverse coupling impedances are higher than 50 MΩ/m/9cell are indicated by double circles, and those than 10 MΩ/m/9 cell by single circles.

If the deflecting mode frequency fres, the revolution frequency f_0 and the betatron oscillation frequency f_β satisfy the relation

$$f_{res} = nf_0 - f_\beta \tag{1}$$

where n is an integer, the transverse instability growth rate becomes $B{\cdot}R_t{\cdot}F{\cdot}I$, where B is a factor determined from machine parameters, R_t the transverse coupling impedance of the mode, F the bunching factor and I the beam current[10]. When this growth rate exceeds the damping rate, the instability occurs.

In AR the damping rate is determined by the damping due to the transverse feedback system, the head tail effect and the synchrotron radiation[11]. Therefore, the threshold current I^{th} of the instability in AR is determined from the following equation

$$B{\cdot}R_t{\cdot}F{\cdot}I^{th} = \alpha_{fb} + \alpha_{ht}(I^{th}) + \alpha_{rad} \tag{2}$$

where I^{th} is the threshold beam current and α_{fb}, α_{ht} and α_{rad} are the damping rate due to the feedback damper, the head tail effect and the synchrotron radiation, respectively. First we measured the threshold current under the condition which satisfied Eq. (1). We also measured α_{fb} versus loop gain of the feedback system and α_{ht} versus beam current. Using these values in Eq. (2), the value F was obtained as F = 0.95 ± 0.3 where we estimated the value R_t from the calculated R_t/Q and the measured Q value. The obtained F value is in reasonable agreement with the theoretical one for a short bunch[12].

Using the value F thus obtained, we estimated the threshold current of the transverse instability for MR. If Eq. (1) happens to be satisfied by all of the 104 cavities in MR, the threshold current becomes lower than the designed value of 10 mA even with a feedback damper designed for MR. If we slightly vary the dimensions of the cavity and get a frequency spread of more than ±100kHz for the higher modes among 104 cavities, the total Rt value will be reduced by a factor of four[13]. Although this procedure is enough to suppress the instability due to the TM_{110} mode, it will not be sufficient to suppress the instability due to the TM_{111} mode. Therefore, a higher order mode damper is under development to suppress the TM_{111} mode.

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