BEAM CAVITY INTERACTION IN A DAW CAVITY

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SUMMARY

Three disk-and-washer cavities have been installed in the TRISTAN accumulating ring. Although there exist many parasitic modes in a DAW cavity, we have not yet observed any transverse instability that is clearly attributed to a deflecting mode of the cavity. Some experiments of artificial excitation of transverse instabilities are reported.

INTRODUCTION

The TRISTAN accumulating ring (AR) has a circumference of 377m with the bending radius 23.3m and the average radius 60.0m. The injection energy is 2.5GeV and the extraction energy is 8GeV. The vertical and horizontal betatron tunes are 10.25 and 10.17 respectively. The RF frequency fa is 508.58MHz with the harmonic number 640. The beam is accelerated in a single bunch mode and the natural bunch length is 1.9cm. The design value of the current is 30mA. The betatron function at the RF section is about 10m.

Three disk-and-washer (DAW) cavities have been installed since May 1984. Two of them have the dimensions optimized for shunt impedance (type A). The other one is designed so that the four passbands which overlap fa in the type A cavity are shifted up above the region of fa (type B). The parameters of the two types of DAW are shown in Table 1 and Fig.1. Their dispersion curves are compared in Fig.2[1]. Each of the type A cavities has twelve cells, while the type B cavity has nine cells.

In a DAW cavity, the number of resonances is larger than that in a conventional structure below the cutoff frequency of the vacuum chamber. This has been regarded as a disadvantage of the DAW structure because of a larger parasitic mode loss and higher possibility to kick the beam.

In operating AR, we have observed several instabilities, like the head-tail instability, the Robinson instability and the microwave instability. The latter two were caused by londitudinal beam-cavity interaction[2]. However, any transverse instability has not been found that is evidently caused by the cavity. Therefore, we have made experiments to excite transverse instability artificially. Because of the time and the equipment restrictions the present studies were limited to a frequency region near fa.

Table 1
Two types of DAW cavity

Type	A	B
Rc(cm)	45.45	33.36
Rd(cm)	40.25	25.0
Td(cm)	7.2	10.0
G (cm)	10.25	10.51
Rw(cm)	24.45	25.0
Tw(cm)	0.95	1.0
Tr(cm)	0.95	2.5
Rh(cm)	5.0	5.0
L (cm)	15.0	15.0
T	0.765	0.759
R(Mohm/m)	76.49	60.07
RT^2(Mohm/m)	44.76	34.59
P(kW)	3.922	4.996
Q($\times 10^4$)	11.25	5.447
R/Q(kohm/m)	0.680	1.10

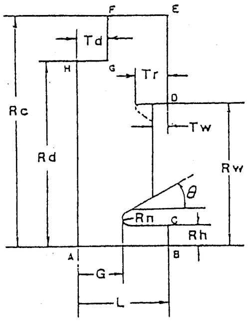

Fig.1
Geometrical notation

TRANSVERSE COUPLING IMPEDANCE

The transverse coupling impedance Zt is expresssed by

$$Z_t = \frac{R_t\, \omega_a/\omega}{1 + j Q_a (\omega/\omega_a - \omega_a/\omega)}, \qquad (1)$$

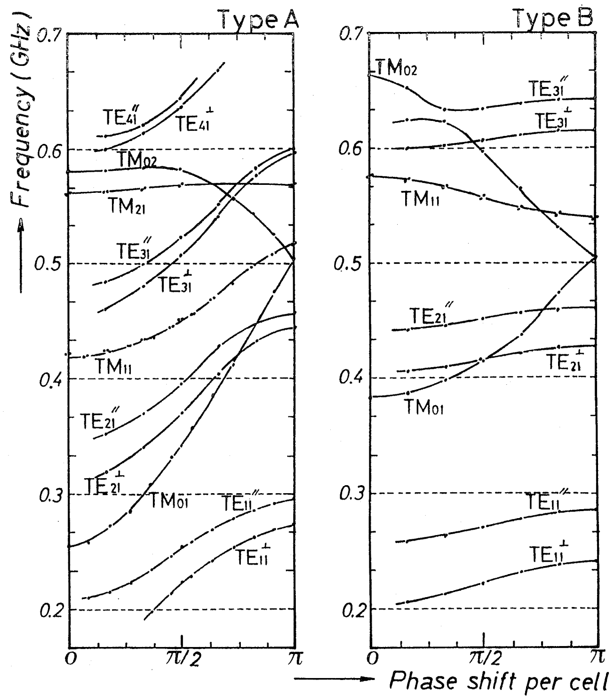

Fig.2 Brillouin diagram of DAW

where ω_a and Qa are angular frequency and the Q-value of a resonance respectively. The transverse shunt impedance Rt is defined by

$$R_t = Q_a c \left| -\int (\mathrm{grad}\, E_{az})_t \cdot \exp(jkz)\, dz \right|^2 / \varepsilon \omega_a^2. \qquad (2)$$

Using a computer program URMEL[3], the transverse shunt impedance Rt of the single-cell (for both types) and 12-cell (for type A only) cavities were calculated. Table 2 shows the Rt of the single cell and Fig.3 shows the Rt/k of the type A 12-cell cavity. The numerical values of the 12-cell cavity at the second HEM1- 0 and π modes are 1.54 and 1.65Mohm/m respectively. Corresponding values of the single-cell cavities are 20.0 and 0.35Mohm/m respectively. This suggests that the value of the 0 mode cancels out and that the value of the π mode adds up in the 12-cell cavity due to the phase relation. Applying this ratio to the type B cavity, we roughly estimate the impedance for the 9-cell cavity. They will be around 0.5 and 3Mohm/m at 0 and π mode respectively.

Table 2 Transverse shunt impedance
of a single-cell DAW cavity

Cavity Type	Mode	Frequency meas. (MHz)	Frequency calc. (MHz)	Q ($\times 10^4$)	R_t/Q (ohm/m)	R_t (Mohm/m)
A	1st HEM1-0	153	160	4.47	4.52	0.20
A	1st HEM1-π	241	275	5.92	436.	26.
A	2nd HEM1-0	422	424	6.34	313.	20.
A	2nd HEM1-π	517	514	5.45	6.45	0.35
A	3rd HEM1-0		620	4.65	2.98	0.14
A	3rd HEM1-π		648	5.38	0.90	0.05
A	4th HEM1-0		750	6.58	194.	13.
A	4th HEM1-π		640	11.5	171.	20.
B	1st HEM1-0	203	204	1.32	9.36	0.12
B	1st HEM1-π	241	239	1.78	296.	5.3
B	2nd HEM1-0	576	567	2.47	237.	5.9
B	2nd HEM1-π	539	533	2.10	30.	0.63
B	3rd HEM1-0	686	682	5.02	0.25	0.05
B	3rd HEM1-π	693	722	4.28	4.44	0.19
B	4th HEM1-0	835	826	5.14	208.	11.
B	4th HEM1-π	779	776	6.36	346.	22.

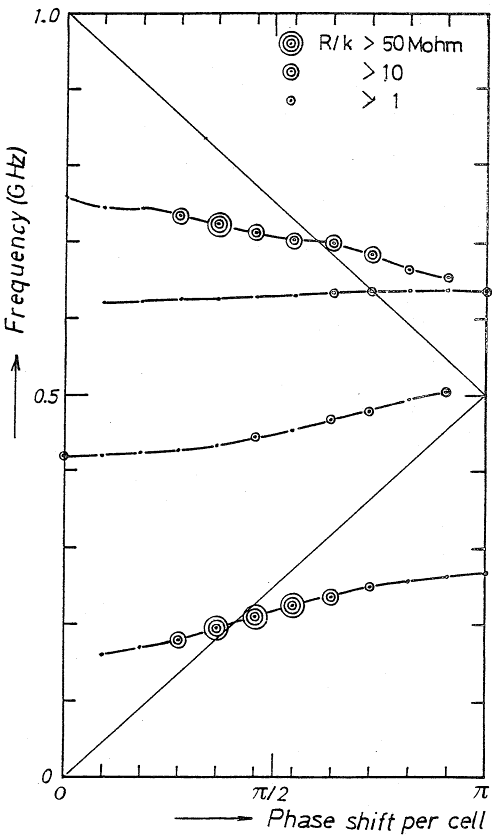

Fig.3 Transverse shunt impedance of the 12-cell type A cavity

THRESHOLD CURRENT

In a storage ring, a deflecting mode with the resonant frequency

$$f_r = (n - \Delta Q) f_0 \qquad (3)$$

has a possibility to induce the transeverse instability, where n is an integer, ΔQ the fraction of betatron tune and f_0 the revolution frequency[4].

When the growth rate of the transverse instability

$$-\mathrm{Im}\,\Delta\omega = e I f_0 \beta_t R_t / 2E, \qquad (4)$$

where β_t is the betatron function at the cavities and E the beam energy, exceeds the inverse of radiation damping time τ_β, the beam is expected to become unstable. Substituting E = 2.5GeV, τ_β = 42ms, β_t = 10m, and f_0 = 794.65kHz, we obtain the following relation.

$$I(mA)\, R_t(Mohm/m) = 15. \qquad (5)$$

If we use Rt = 1.54Mohm/m (type A) and Rt =0.5Mohm/m (type B) estimated above at the second HEM1-0 mode, the threshold currents become 10mA and 30mA respectively, when the relation Eq.(3) is satisfied.

EXPERIMENTS

In the present operating system, the change of the frequency of the accelerating mode due to temperature drift is compensated by two movable tuners. As a preliminary study showed that this situation makes the frequency of the parasitic mode indefinite, we isolated one of the three (two before the installation of type B) cavities from the power source. The RF power were supplied to the remaining two (one) cavities. Therefore, we could tune the isolated cavity independently of the accelerating cavity or feed the RF power with nonaccelerating frequency. In the experiments the stored beam was in a single bunch mode and the energy was maintained at 2.5GeV.

The stableness of the beam was monitored by a DCCT and a radiation profile screen. The beam signal from an electrostatic pickup (one of the electrode of the position monitor) was observed with a spectrum analyser (Anritsu MS 710A or HP8554B). The excited field in the cavity was monitored with the same analyser.

(1) The beam kick by an external excitation was attempted. (This experiment was tried before the type B cavity was installed.) The accelerating RF power was fed to one of the two type A cavities. A wide band power amplifier (output power 35 to 60W for 0 to 560MHz) was connected to the other cavity, and the input frequency was swept so that the resonant condition might be satisfied. However, no instability was observed. The driving power may not be strong enough to kick the beam, or the frequency of the signal generator may not be tuned accurately to that of the deflecting mode of the cavity.

(2) An attempt was made to excite the transverse instability by adjusting the deflecting mode frequencies to the value of Eq.(3). For this purpose , the frequency vs. tuner position of the type B cavity were measured as shown in Fig.4. Those curves correspond to the HEM1 mode with the magnetic field perpendicular to the stem. The integral multiples of the revolution frequency are also shown by the horizontal lines. The vertical and horizontal betatron frequencies were 201.0 and 138.3kHz respectively. Thus the frequency of the 0 and 5/9 π modes can be adjusted by the tuner to satisfy Eq.(3) as seen from Fig.4, while the adjustment is impossible for the π mode.

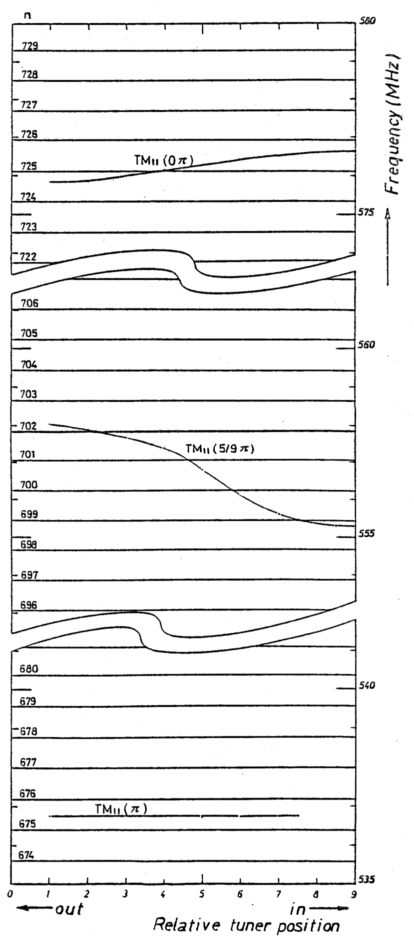

Fig.4 Frequency vs. relative tuner position

The power was fed to the two type A cavities and the coupler port of type B cavity was terminated by a dummy load. After the storage of electron beam in AR about 50 to 100mA, the tuner of the type B cavity was moved to the required frequency. The arrowed peak appeared as shown in Fig.5, when the cavity is tuned to $(700-\Delta Q_V)f_0$ for the $5/9\pi$ mode. Also Fig.6 shows the case of $(725-\Delta Q_V)f_0$ for the 0 mode. However, the appearance of the arrowed peaks was not associated with the loss of the beam.

Even if the cavity was not tuned to satisfy Eq.(3), the other peaks in Figs.5 and 6 were observed, which seemed to be related with very weak vertical oscillations induced in a rather wide range of the tuner position. When the current was decreased, the amplitude of these peaks became smaller.

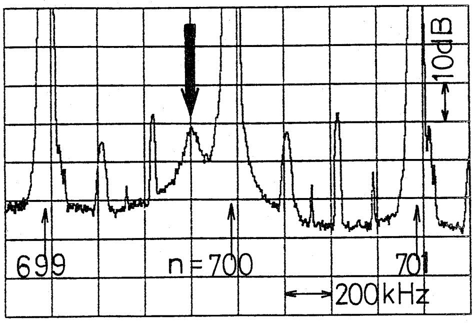

Fig.5 Tuning for HEM_1-$5/9\pi$ mode

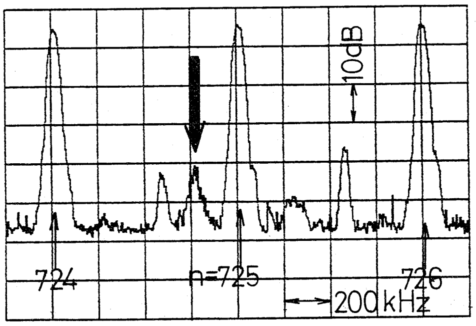

Fig.6 Tuning for HEM_1- 0 mode

(3) The instability was studied by changing the closed orbit distortion at the type B cavity. Here, the cavities were connected in the same way as Exp.2. At first the closed orbit was distorted by 8mm vertically at the type B cavity (and by the symmetry of lattice at one of the type A cavity). When the current exceeded 22mA, the vertical oscillation was observed in the beam profile monitor. When the COD was adjusted to 4mm, no instability was observed until 33mA. The frequency spectrum excited in the cavity ranged up to 7GHz. However, the vertical oscillation did not seem to be dependent upon the tuner position.

DISCUSSION

In Exp.2, the cavity was tuned around the excitation condition Eq.(3) at the second HEM1- 0 and $5/9\pi$ mode, where the expected threshold current is 30mA. Although the peaks appeared at the expected frequencies in the frequency spectrum, no beam loss was observed below the maximum stored current 95mA. If the actual impedance is not far from the calculated one at the examined modes, the other damping mechanism of the transverse coherent oscillations than the radiation damping may have to be introduced to explain the present experimental results. In this context it is interesting to note that the measured threshold current of the transverse coupled-bunch instability in the photon factory (PF) in KEK was about thirteen times higher than that predicted with the measured coupling impedance. Although we could not make experiments at π mode, the calculation predicts nearly the same threshold.

As can be seen from Fig.3, the first HEM1 modes have very large transverse coupling impedance around $\pi/2$ mode. Our next study will be concentrated on this region.

As for the weak vertical oscillations excited at different frequencies from Eq.(3) a further study is necessary, since the character of the oscillation will not be so simple as predicted by the standard theory. It seems that the frequency of $(n-\Delta Q_V-\Delta Q_H)f_0$ is excited for every integer value of n. Also, as for the instability caused by the closed orbit distortion, more study will be necessary to understand the mechanism. In order to study the weak oscillation observed on a profile screen, another monitor like a diode-array monitor for the synchrotron radiation light will be helpful.

ACKNOWLEDGEMENT

We would like to express our sincere thanks to Prof.Kimura for the support of DAW work and the discussion. We are indebted to Prof. Ezura, Drs. M.Ono, H.Hayano and every members of RF group in many respects. We thank Drs. K.Satoh, S.Kamade, K.Oide, H.Fukuma and the members of the operational group for the work of instability study together.

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