12-CELL DAW STRUCTURES IN THE TRISTAN ACCUMULATION RING

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INTRODUCTION

Two 12-cell DAW structures for the TRISTAN Accumulation Ring have been constructed and measured. The cavities have a high shunt impedance and a good geometrical tolerance, but they have two drawbacks. One problem is that the attainable Q value normalized to the value from SUPERFISH is lower than those for other cavities. The other is a mode mixing problem of the accelerating mode with a neighboring HEM_{11} mode. Both problem become severe with increasing number of cells. Although the mode mixing really occurred in our 12-cell cavities and made the measurement hard, the mixing ratio of the stored energy could be suppressed lower than 4 %.

The cavities are in operation with a shunt impedance of 27 MΩ/m and have stored the single bunch of up to 66 mA at 2.5 GeV.

DESCRIPTION OF THE CAVITIES

Fig. 1 shows the 12-cell cavity. The cavity is mostly made of iron (SB-42) and copper plated by 100 μm. The end cap is contacted and vacuum sealed by a copper HELICOFLEX at the washer plane where the wall current is minimum. The end washer was supported by two horizontal stems from the end cap at an early stage, but finally it was changed to be supported by a single radial stem like the other washers in order to moderate the mode mixing problem. Stems are made of stainless steel of 27 mm in diameter. The contact between the stems and the outer wall is especially minded. Cu-Be edged rings of 77 mm in diameter are used, which are pressed with a pressure of 10 tons. The results of the low power measurements showed that the degradation of the Q value was negligible with a pressure above 5 tons.

The cavity has 6 tuner ports at the disk plane and 4 at the washer plane. Two fixed tuners are set at the disk plane of cells No.3 and 10 to reduce the mode mixing and preset the frequency of the accelerating mode. Two other tuners at the disk plane of cells No.5 and 8 are used as dynamic tuners for the resonant frequency. The diameter of the tuners is 105 mm. The tuning range is 350 kHz, which covers the frequency change of 270 kHz due to deformation by heating.

An antenna type input coupler is set at the central washer plane horizontally. It has a diameter of 66 mm and a couplig β of 1.7 with a projection of 58 mm.

The Q value and R/Q calculated by SUPERFISH are 1.00×10^5 and 418 Ω/m, but the measured Q value is 65 % of the calculated value.

LOW POWER MEASUREMENTS

The cavity was measured with differnt condition in supporting the end washers. Firstly it was supported by two horizontal stems from the end cap. When the plane defined by two stems was set at the vertical plane, two π modes of almost same electric field strength at the beam axis were observed around the accelerating frequency. In the second test, when the stems were set at the horizontal plane, the mixing became small. The measured frequency, Q value and the averaged frequency shift (Δf) by an Aℓ bead (φ25 mm) on the beam axis are listed in Table I.

Table I

Summary of the measurements with 2 horizontal stems

	Mode	f_0(MHz)	Q	Δf(kHz)
SUPERFISH		508.58	1.00×10^5	-31
Vertical	π	509.85	5.2×10^4	-18
	π'(HEM_{11})	507.01	5.0×10^4	-14
Horizontal	π	508.76	6.0×10^4	-24
	π'(HEM_{11})	506.05	5.0×10^4	-8

The field around the beam axis was measured in detail using different types of beads. The results are summarized as follows.

(1) Both modes have electric field maximum at upper or lower side of the beam axis depending on cells. The displacement is smaller in π mode (∿ 2 cm) than in π' mode (∿ 10 cm).
(2) π' mode has a large vertical transverse elctric field component (∿ 40 %) at the beam axis of cells No.3, 4 and 5, and a magnetic field at the beam axis of cells No.2 and 6.
(3) In the π mode, a transverse elctric field component is less than 5 % of the total electric field and no magnetic field is observed at the beam axis.

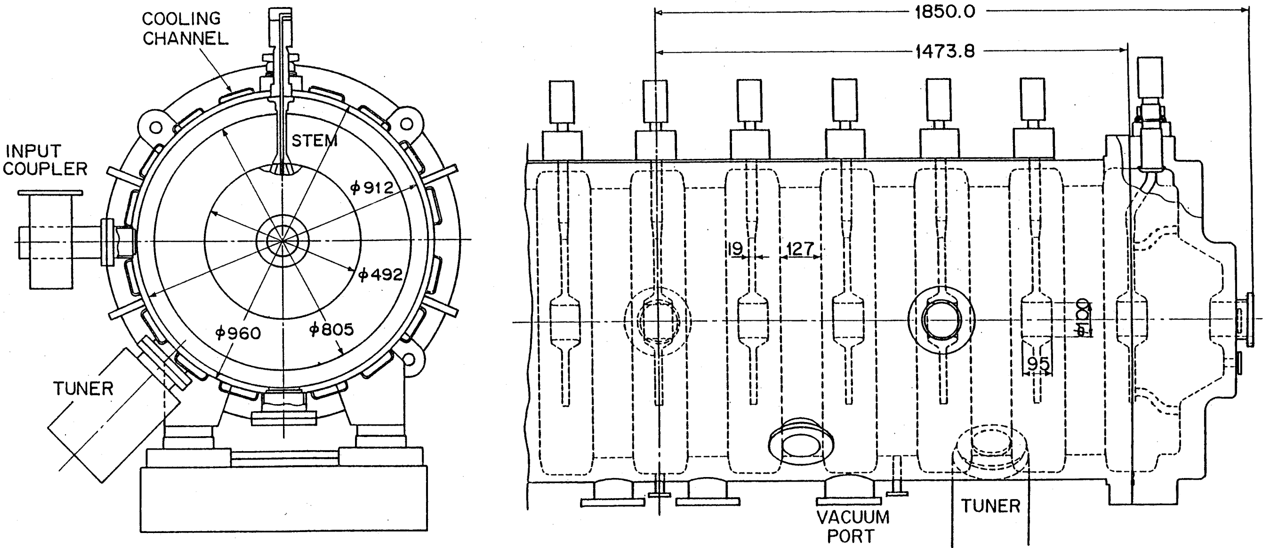

Fig. 1 12-cell DAW cavity.

In order to investigate the mode mixing further, the effect of 4 disk plane tuners was measured. The measured dependence of the frequency, the Q value and the frequency shift due to an Aℓ bead on beam axis are shown in Fig. 2 and 3. These results show that the mixing is almost resolved with a frequency separation larger than 4 MHz, where the measured Q value and the accelerating field is 65 % and 100 % of the calculated value by SUPERFISH. The measured field pattern indicates that the π' mode is a vertically polarized TE_{11} like 10/12 π mode.

Finally the end washer was supported by a single radial stem. Fig. 4 shows the measured dispersion curves for TM_{01} and HEM_{11} modes together with the lowest HEM_{11} modes calculated by URMEL. The mode mixing was also observed in other modes as well as the accelerating mode. The measured Q values of TM_{01} modes normalized to the values of SUPERFISH are shown in Fig. 5 together with other results1). As is seen, Q is much reduced in the mode where the mixing happens. The effect of tuners was measured in detail. The washer plane tuners degrade the Q value of the accelerating mode and the disk plane tuners in cell No.5 and 8 are effective to separate the frequencies of two mixed modes. So the combination of 4 disk plane tuners was adopted as is described before. The frequency change of the accelerating mode and the two nearest HEM_{11} modes by the tuners in cell No.3 and 5 are shown in Fig. 6, where the fixed tuners are set at 6 cm inside from the outer wall. A single tuner can change the frequency by 120 kHz, which causes an unbalance of 13 % to the accelerating field distribution in the left and the right halves. Fortunately in high field operation, where the tuners must be projected deeper, the shunt impedance becomes higher. The final field distribution on the beam axis is shown in Fig. 7.

DISCUSSION

Mode mixing

As is described above, the mode mixing is one of noteworthy problems of these cavities. This is analyzed by the equivalent circuit theory of two coupled resonators with a coupling constant k. If one resonator is excited with its resonant frequency f_1 (parameters are specified by subscripts 1 and 2), then the ratio of the energy stored in two resonators is given by

$$R = \frac{w_2}{w_1} = \left\{\frac{f_2\, k}{2(f_1 - f_2)}\right\}^2 \quad , \qquad (1)$$

where $Q_2 >> f_2/|f_1 - f_2|$ is assumed. The Q value of the mixed mode becomes

$$\frac{Q}{Q_1} = \frac{1 + R}{1 + R\,\dfrac{Q_1}{Q_2}} \quad . \qquad (2)$$

In the present case under consideration, the TM_{01}-π mode (mode 1) has no transverse impedance and the HEM_{11} mode has no longitudinal impedance. So the mixed accelerating mode has a longitudinal impedance

$$Z_{\parallel} = \frac{Z_{\parallel 1}}{1 + R\,\dfrac{Q_1}{Q_2}} \quad . \qquad (3)$$

In the same way, it has a transverse impedance

$$Z_{\perp} = \frac{R\, Z_{\perp 2}}{R + \dfrac{Q_2}{Q_1}} \quad . \qquad (4)$$

The coupling constant k can be obtained from the data. In Fig. 8, Q values of two mixed modes and the mean value of the frequency shift measured by an Aℓ bead at the gap on the beam axis are shown as functions of a mode separation. The Q value and the frequency shift of the accelerating mode are saturated above a mode separation of 4 MHz. On the other hand the Q value of the HEM_{11} mode is not saturated, because the field enters into the tuner ports in this mode. If the Q values at no mixing are assumed to be 6.5×10^4 and 4.4×10^4 for the accelerating and the HEM_{11} mode respectively, the coupling constant of about 3×10^{-3} is obtained.

The other way to estimate k is to use the field distribution. The accelerating mode has only the longitudinal electric field Ez on the beam axis and the HEM_{11} mode has only the transverse components, $E_\perp$ and $H_\perp$. Then the resonant frequency shift by the metal bead is given as

$$\text{for the accelerating mode} \qquad \frac{\Delta f_1}{f_1} \propto -\frac{E_z^2}{w_1} \quad , \qquad (5)$$

$$\text{for the } HEM_{11} \text{ mode} \qquad \frac{\Delta f_2}{f_2} \propto -\frac{E_\perp^2 - \dfrac{\mu_0}{2\varepsilon_0} H_\perp^2}{w_2} \quad , \qquad (6)$$

The frequency shift of the mixed mode is given as

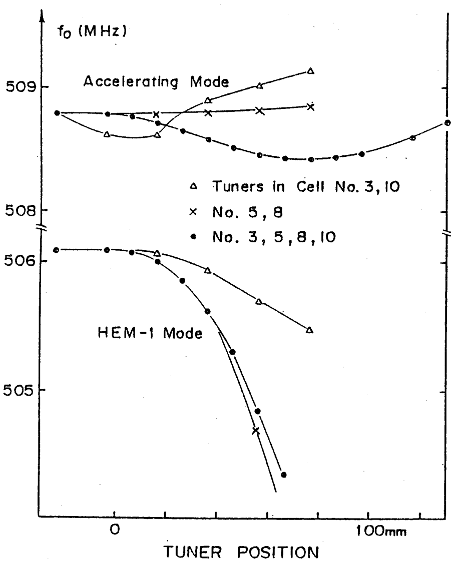

Fig. 2 Tuner effect on f_0.

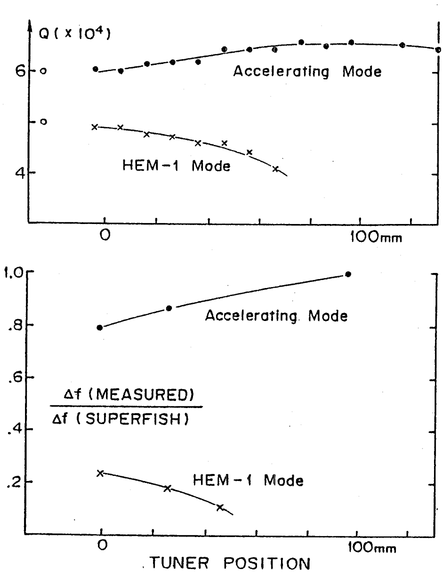

Fig. 3 Tuner effect on Q_0 and Δf.

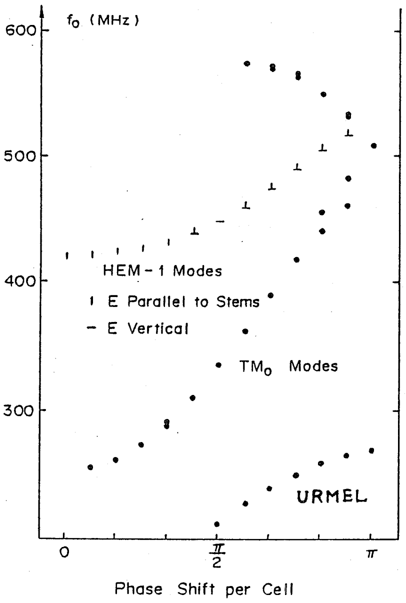

Fig. 4 Measured dispersion curves.

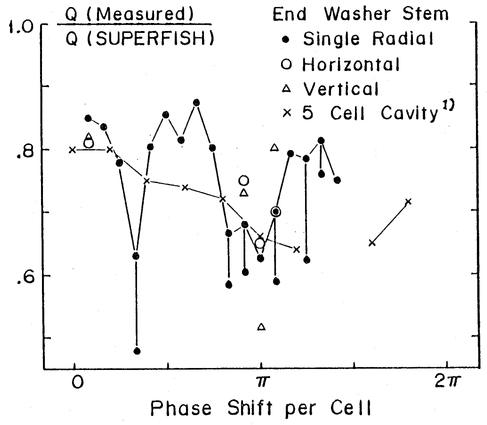

Fig. 5 Attained Q values.

$$\frac{\Delta f}{f} \propto \frac{1 + R\,\frac{\Delta f_2/f_2}{\Delta f_1/f_1}}{1 + R}\,\frac{\Delta f_1}{f_1} \quad . \qquad (7)$$

Using the ratio of the frequency shift with and without the mixing, one can estimate the mixing ratio R. This analysis also gives 3 × 10^{-3} for the coupling constant.

The same analysis gives the value of about 6 × 10^{-4} for the compling constant between the accelerating and the HEM_{11} - 11/22 π mode, and the value less than 1 × 10^{-4} for the nearest TE_{31} like mode.

Degradation of Q

As is shown in Fig. 5, the attained Q value of the accelerating mode is very low comparing with the other modes of no mixing. The effect of the mode mixing on the Q value is only few %, so the other effect must be considered. The model measurements show that the field on the outer wall is much deformed by the stems already in a 2-cell cavity. This effect is estimated to be about 10 %$^{2,3)}$. But in our multi cell cavity, the attained Q value is lower by 20 % for the 5-cell cavity$^{1)}$ and by 24 % for the 12-cell cavities, if taking this effect of the stems and incompleteness of the plated copper into consideration. The measurements on the other type of DAW show that the remaining effect has a dependence on the number of cells, which is saturated above 10 cells, indicating some coherent effect probably due to stems.

SUMMARY

The mode mixing can be solved by tuners and does not affect the beam stability, because the mixed HEM_{11} mode has very small transverse impedance (0.02 MΩ/m) and the betatron oscillation is not in phase with the accelerating frequency. The mode mixing is also solved by a little change of the dimensions in the cavities of a small number of cells. In long structures, it is better to separate the pass band of HEM_{11} modes from the accelerating mode. The one way is to reduce the diameter of the cavity, but the attainable Q value becomes comparable with that of other type of cavities. The other way is to lower the HEM_{11} pass band below the accelerating frequency by making a stop band between the accelerating and the coupling mode. SUPERFISH calculation shows that the separation between the accelerating mode and the HEM_{11} - 8/9 π mode is 10 MHz with a stop band of 10 MHz in a 9-cell structure. Because of high cell to cell coupling, this stop band of 10 MHz is negligible.

The degradation of the Q value is much serious than the mode mixing. Although the extensive study is need, the only way to solve this problem is probably to make stems by low loss insulator like ceramics. Nevertheless the DAW structure has a highest impedance in the conventional RF structures. The optimized 9-cell DAW cavity has a shunt impedance of 42 MΩ/m, so it will have a impedance of 27 MΩ/m assuming a degradation of 65 %.

As for the transverse modes, the most dangerous mode is a TM_{111} like 0 mode around 1 GHz, because the transit time factor is additive in this mode. The transverse coupling impedance calculated by URMEL is 16 MΩ/m for a single cell. So the impedance in the 12-cell cavity is 150 MΩ/m, assuming a 20 % decrease of the Q value. This value is larger than that of the superconducting cavity tested in the Accumulation Ring$^{4)}$. So damping coupler or fast transverse feedback system will be needed, if this mode is tuned to the betatron oscillation frequency.

ACKNOWLEDGEMENTS

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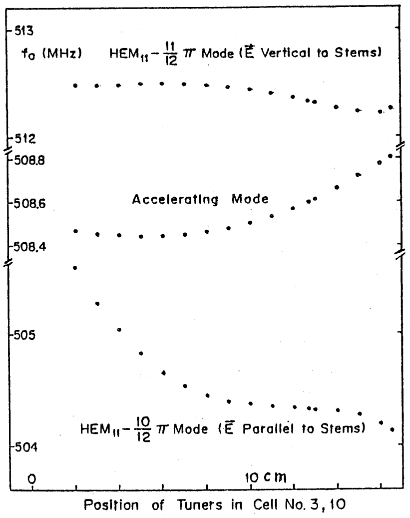

Fig. 6 Tuner effect on f_0.

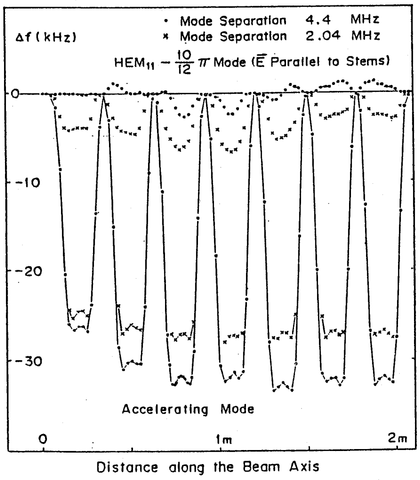

Fig. 7 Examples of field distribution.

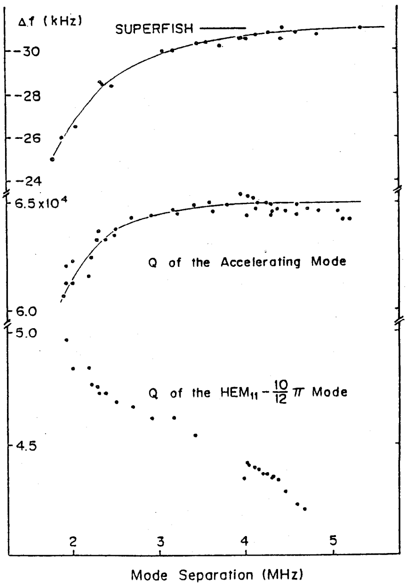

Fig. 8 Effect of the mode mixing.