

DISK AND WASHER STRUCTURE FOR AN ELECTRON STORAGE RING

K. Takata, S. Inagaki, H. Nakanishi, K. Kitagawa, H. Ishimaru and Y. Yamazaki

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

P. Grand

Brookhaven National Laboratory
Upton, N.Y. 11973, U.S.A.

Summary

The result is given of test cavity measurements of a 500 MHz disk and washer structure which will be used for the TRISTAN electron storage ring, where the shunt impedance is required to be higher than 35 MΩ/m. While the calculated shunt impedance is 44.8 MΩ/m, the measurement indicates that 40.0 MΩ/m is attainable with a single radial stem for the washer support and 35.8 MΩ/m with a 2-longitudinal-stem support.

Introduction

For the TRISTAN electron ring¹, a peak RF voltage of 310 MV is required at the luminosity optimized energy 27 GeV with the cavity dissipation power not exceeding 8 MW. As the effective RF length available is at most 360 m, the accelerating structure should have a shunt impedance of at least 35 MΩ/m. For an operating frequency of 500.99 MHz chosen for the ring, the shunt impedance of ordinary structures, however, is at most around 25 MΩ/m. At present the disk and washer (DAW) structure would be an only possible choice to realize the desired shunt impedance as some preliminary results show.^{2,3,4} Furthermore it has a large group velocity which is in favor of field stability against beam loading effects and machining errors. Hence it was decided to adopt a DAW structure in the TRISTAN ring. Computer calculations were carried out to get an optimum structure and then various types of the washer supporting system were tried with a full-size test cavity made of an aluminum alloy. In this report is summarized the result and also is given some design consideration of a 12-cell DAW accelerator.

Calculation of an Optimum DAW Structure

In LASL's report⁴, parameters of a DAW structure for $\beta=1.0$ which operates at 1.35 GHz are shown for various sizes of the beam aperture R_H . The following set of the parameters, which would have an optimum impedance for our operating condition, $f = 500.99$ MHz and $R_H = 50$ mm, was tentatively deduced from the report; $L = 150$ mm, $R_C = 454.5$ mm, $R_D = 402.5$ mm, $t_D = 72$ mm, $g = 102.5$ mm, $t_W = 9.5$ mm, $R_W = 244.5$ mm, $R_N = 7$ mm, $\theta = 30^\circ$, where the same notation as the report is used and shown in Fig. 1.

Around this set of values, an extensive computer calculation with the SUPERFISH program was carried out. It is confirmed that the impedance is almost optimized except that a smaller t_W and a larger R_C or R_D would still improve it. However t_W thinner than the above value would be impractical. Furthermore the 0-mode frequency of the upper passband is very close to that of the TM_{020} mode of an empty structure without the washer, and hence the width of this passband becomes narrower as R_C or R_D increases. For the above parameters the upper 0-mode is at 584 MHz and v_g at the accelerating frequency is supposed to be still larger than 0.4 C. Therefore we fixed t_W , R_C and R_D as above. Calculations of both the accelerating mode and the coupling one were carried out for a small

change of parameters, and the result is shown in Fig. 2. From this figure the confluence condition that the both frequencies coincide with each other is attained by changing t_D to 66 mm. This new set of parameters for a confluent DAW structure was used for the following measurement. The detail of calculated results is summarized in the table below, and Fig. 3 shows the field pattern of the both modes.

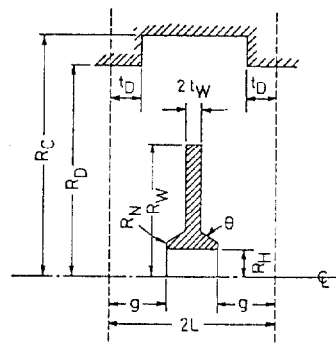


Fig. 1 Unit cell of a DAW structure with the definition of the dimensions.

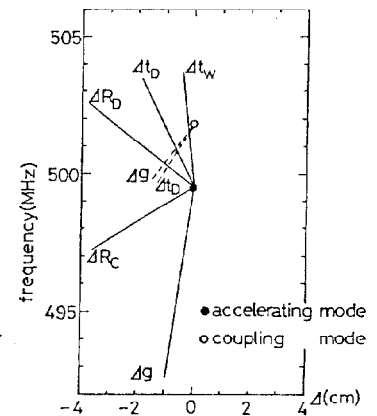


Fig. 2 Frequency shift due to a small change of any one of the parameters.

Table I

Calculation of a confluent DAW structure

($L = 150$ mm, $R_C = 454.5$ mm, $R_D = 402.5$ mm, $t_D = 66$ mm, $g = 102.5$ mm, $t_W = 9.5$ mm, $R_W = 244.5$ mm, $R_H = 50$ mm, $R_N = 7$ mm, $\theta = 30^\circ$)

Resonant frequency $f_0 = 500.80$ MHz
Infinite cell-chain (copper; $\rho = 1.70 \times 10^{-8} \Omega \cdot m$)
 $Q_0 = 113,200$
 $Z_0 = 44.8$ MΩ/m

Relative wall loss for single cell
washer 29.50%
cylinder 9.18%
shorted plane 61.32%

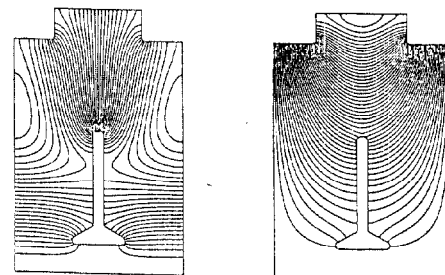


Fig. 3 SUPERFISH output of the electric field pattern for the accelerating mode and the coupling one.

Test Cavity Measurement

In order to attain the calculated shunt impedance in an actual structure, the washer should be supported in such a way that supporting stems cause as small a perturbation as possible on the cavity field. The effect of a stem has, however, not been made clear enough in the published references. Therefore several kinds of supporting system were investigated here. For the evaluation of the shunt impedance in test cavity measurement the most crucial is to get a reliable Q value. Hence the measurement of the accelerating mode was solely done with full size cavities made of an aluminum alloy the resistivity of which was estimated by measuring the Q value of an empty cell without washer for the TE₀₁₁ mode at 653 MHz. The Q value was 53% of that which would be obtained for a copper pill box cavity with $R = (R_C + R_D)/2$ and the same length. Hence the material used is estimated to have a resistivity ρ of $6.041 \times 10^{-8} \Omega \cdot m$, and the Q value of the accelerating mode would be 23,200, 33,500 and 60,000 for a single-cell, double-cell and an infinite-cell-chain structure, respectively, of the dimension listed in Table I.

The following three cases were investigated: (i) radial stem, (ii) longitudinal stem, (iii) crossbar stem. For the radial stem, insulators (pure aluminum oxide: 10 mm ϕ , 2.5 mm t and sapphire: 10 mm ϕ , 1 mm t) and metal (aluminum: 20 mm ϕ) were used. For the case of a radial support the number of stems is four at maximum with each being 90° apart from the other. The longitudinal stem is an aluminum rod of 20 mm ϕ . It is placed at an spacing of 120° on the periphery of the washer. The crossbar is also an aluminum rod of 20 mm ϕ .

For the cases with the radial insulator stems and the longitudinal stems, f and $1/Q$ change linearly with the stem number, and can be roughly extrapolated to the theoretical values $f = 500.8$ MHz, and $1/Q = 1/23,200$ (single-cell DAW) or $1/Q = 1/33,500$ (double-cell DAW). For the case with aluminum radial stems the Q value was rather poor and similar for the two to four stems, but it drastically improved for a single stem, though the reason is not yet clear. The crossbar stem was originally conceived because the radial electric field would be less perturbed by it than by the radial stem. However the Q value was enormously poor. Those results are shown in Fig. 4. The insulator radial stem was considered because it also perturbs the radial electric field not so much as a metallic radial stem and also a very low loss material is available. But Fig. 4 shows $(1/Q)$ does not seem to depend on the dissipation factor, for sapphire is almost an order of magnitude less dissipative than aluminum oxide and still $\Delta(1/Q)$ due to the presence of stems differs only 23%.

The axial electric field measured was in agreement with the SUPERFISH calculation within an error of a few percent. Hence the shunt impedance can be given with a good approximation by multiplying the theoretical value with the following factor

$$\eta = [1 + Q_0 \Delta(1/Q)]^{-1}$$

where Q_0 is the Q value for an infinite cell-chain and $\Delta(1/Q)$ the contribution of a particular stem system. The required shunt impedance more than 35 M Ω/m means that η should be greater than 78%. As Q_0 for the aluminum alloy is estimated to be 60,000 from Table I, $\Delta(1/Q)$ should be lower than 4.70×10^{-5} for the present test cavities.

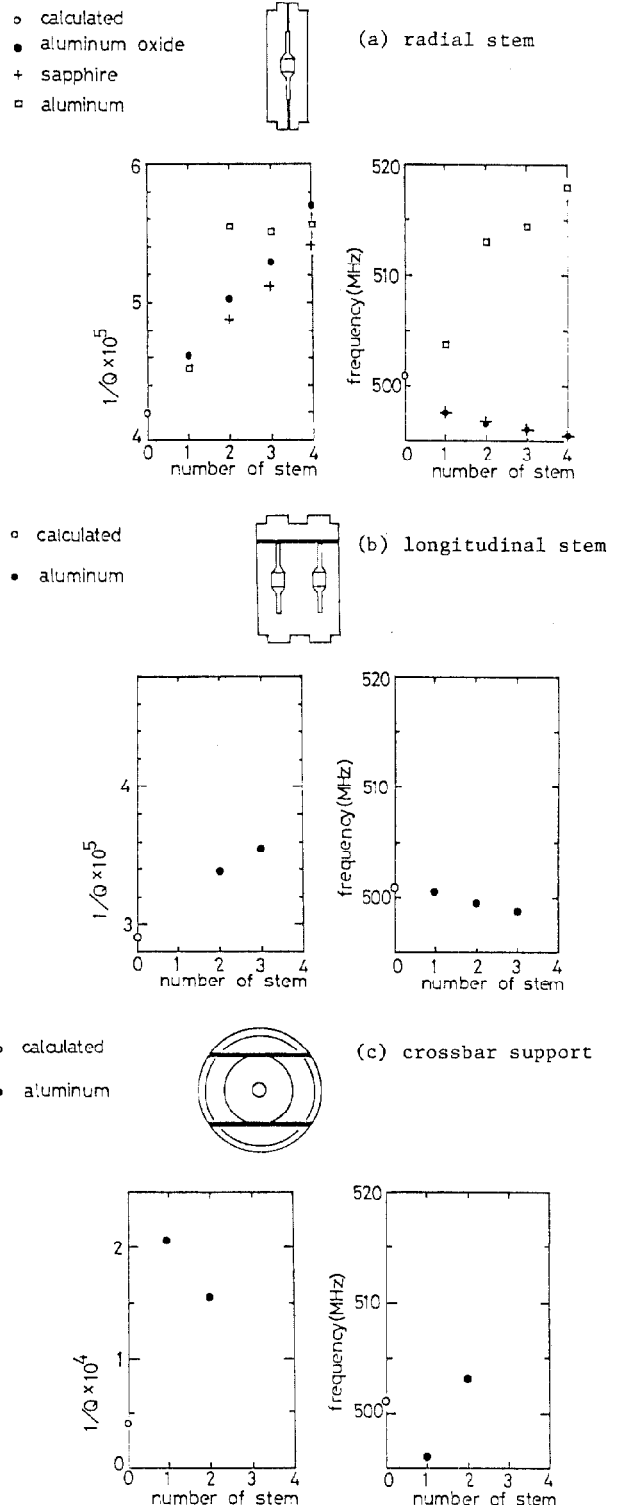
Figure 4 shows that the above condition is satisfied by a single radial stem support and also by

a two-longitudinal stem support. Rejecting the insulator stem because of being impractical, we have the following two choices.

Table II
washer-supporting-system with $Z > 35$ M Ω/m

	η	Z (M Ω/m)
(i) single radial stem	0.894	40.0
(ii) two longitudinal stems	0.805	35.8

Fig.4 Q value and resonant frequency of the accelerating mode for various types of support for the washer.



Dispersion Characteristics

One of the major defects of a DAW structure is that a large number of modes exist not only above the accelerating mode but also below it. Restricting ourselves only to TM_0 modes, we can find about 20 passbands below the cutoff frequency 2300 MHz of the beam aperture with the SUPERFISH calculation. Survey of the passband behavior around and below the accelerating frequency was carried out with multi-cell structures scaled to 1/3 of the actual size. The result is represented in Fig. 5, where the frequency is multiplied by 1/3 for convenience sake. The general feature of the passband behavior was rather similar irrespective of the stem system. The TM_{01} mode is in good agreement of the calculation for both the upper and lower passband. Beside this, there appear two HEM_1 passbands below the accelerating frequency. One has the π mode at around 300 MHz and the 0 mode frequency seems to be 230 MHz which is close to the cutoff frequency of the TE_{11} mode for a hollow cylinder of radius $(R_D+R_C)/2$. The other has the 0 mode at 420 MHz which is also very close to the cutoff frequency of the TM_{11} mode for the above hollow cylinder. The passband behavior seems to suggest that

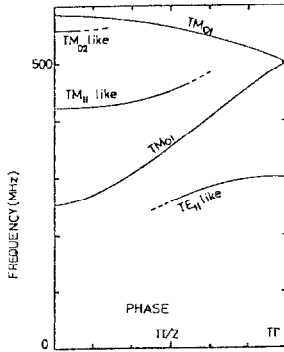


Fig. 5 Typical passband behavior of a DAW structure.

this TM_{11} -like mode approaches near the accelerating frequency at $\phi = \pi$, but the resonance was not found for the structure with a half-cell termination. It is not still clear whether this mode would have some effect or not on the accelerating mode of a DAW structure with stems. Around the upper passband of TM_{01} mode there is a narrow passband which is thought to be a HEM_2 mode because it is near the cutoff frequency of the TM_{21} mode of the above hollow cylinder.

Design of a 12-cell DAW Accelerator

As Table I indicates, this structure has a comparatively large loss on the terminating wall. Therefore a structure should be as long as possible to attain a large impedance. In the TRISTAN ring the space between Q magnets is 8 m. However, from the view point of feasibility and cost of machining, the length of an accelerator is desired to be within 5 m. Therefore, it is planned to set 2 accelerators in a straight section, each of which has an RF length of 3.6 m with 12 accelerating cells. This structure would have neighbouring modes around the accelerating mode with a spacing of about 15 MHz. The cell-to-cell difference due to machining errors should cause frequency errors Δf less enough than the above spacing. As Fig. 2 shows the most stringent is the washer to washer spacing $2g$, which should be maintained with an accuracy of 0.5 mm if Δf is to be kept within 1.5 MHz.

Preliminary tests were carried out for a tuner

Fig.6 Frequency shift due to a cylindrical tuner.

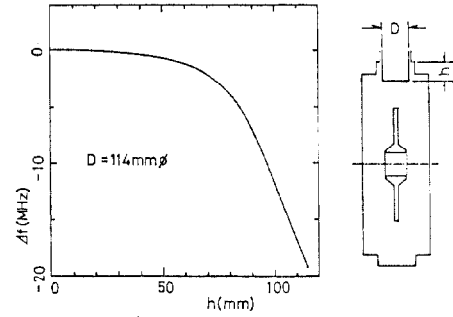
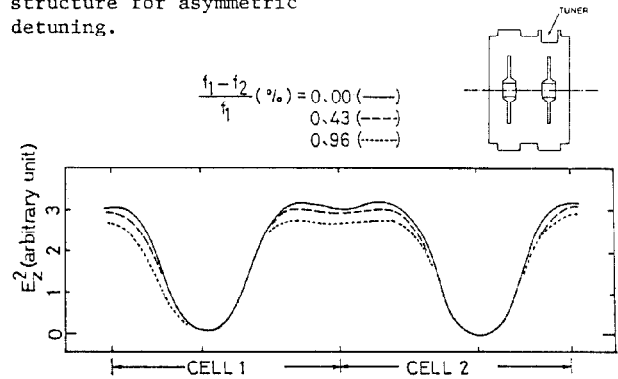


Fig.7 Axial electric field distribution in a two-cell structure for asymmetric detuning.



and check of the field stability against an unbalanced detuning of a 2-cell structure. The result is shown in Fig. 6 and 7. The tuner plunger is to be placed just on the same plane as the washer. It perturbs the electric field and the resonant frequency decreases as it intrudes into the cell. For a plunger diameter of 114 mm ϕ , an intrusion of 90 mm provides a tune shift of more than 6 MHz for a single cell as Fig. 6 indicates. This means only a few tuners are enough for the 12 cell structure. The coupling to the accelerator is also to be provided at the same plane as the tuner at the middle of the whole structure. This couples also to the radial electric field and hence its structure would be simpler than that of an ordinary loop coupler.

At the present stage a single radial washer support seems to be the best choice. Only a 20 mm ϕ stem was tested, and further investigations on various stem diameters are desirable. But at the designed operating condition, the loss per a washer is about 4.5 kW and the water cooling would not be difficult with a single stem of this diameter.

References

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