LIMITATIONS OF THE DISK-AND-WASHER STRUCTURE*

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Summary

A preliminary analysis of measurements on β = 0.6 and 1.0 disk-and-washer linac cavities has indicated some limitations on washer support methods. In particular, the use of radial supports should be avoided until further testing provides a complete understanding.

Introduction

The disk-and-washer cavity geometry[1] for an accelerating structure offers many advantages including high rf conversion efficiency and high coupling factor. A detailed study was initiated which included computer calculations and experimental measurements, to determine limitations, if any, which would have to be considered in an operational system.

Other than geometrical choices that have been discussed elsewhere,[2,3] the method used to support and cool the washer must be considered carefully because of the implications it has on compensation procedures required to give acceptable on-axis electric field distributions, and on structure tuning. An earlier study[3] of support methods with aluminum cavities, shows the importance of symmetrical washer support schemes, because they either eliminate or reduce the complexity of these compensating procedures. Figure 1 shows the support methods studied (L, TO and radial). The radial support appeared to offer the most advantages, but the effects this scheme would have on quality factor, Q, and structure impedance, Z, were unknown. For this reason, computer studies were initiated and β = 0.6 and 1.0, copper structures were fabricated to investigate the effects of symmetrical support techniques on Q and Z.

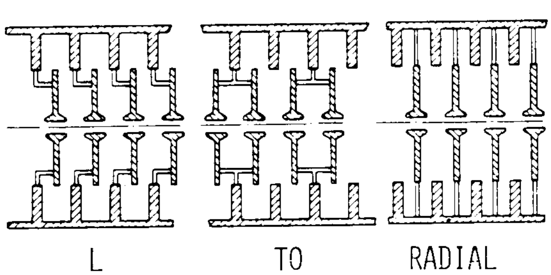

Fig. 1.
Washer support methods.

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Calculations

Computer calculations for the different cavity geometries have been done using the code SUPERFISH.[4] Geometrical parameters for this study are shown in Fig. 2.

Radial Support Effects

The effects that radial support diameter and length have on cavity quality factor are illustrated in Fig. 3. The ratio of quality factor Q, with stems, to the quality factor Q_0, without stems, is shown as a function of stem length and diameter in dimensionless units based on the resonance wavelength. The β = 0.6 disk-and-washer cavity geometry with radial support stems was simulated by a coaxial cavity with its axis of rotation centered on the stem and washer, because SUPERFISH does not handle three-dimensional geometries. (See Fig. 4.) Size and volume of the washer, disk, outer cylinder, and stem were scaled to give a 1320-MHz coaxial mode that had a field distribution equivalent to the accelerating mode field distribution of the real cavity. Stem effects were determined by comparing calculated

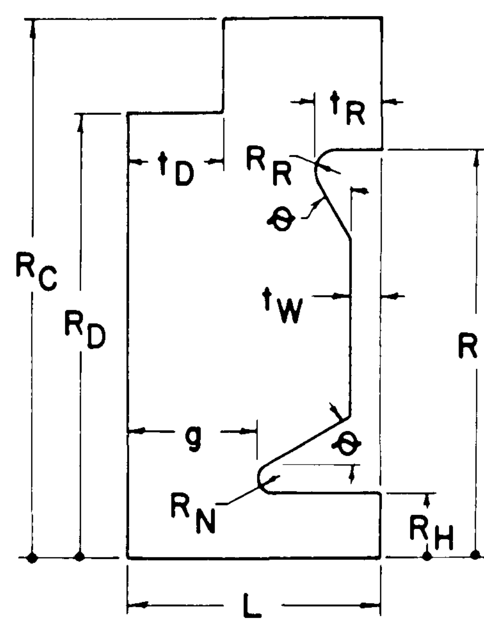
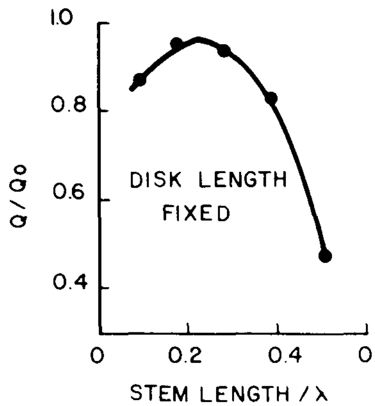
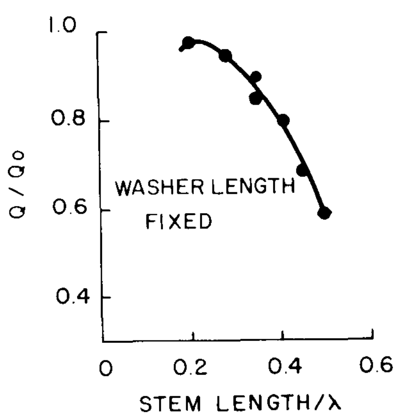


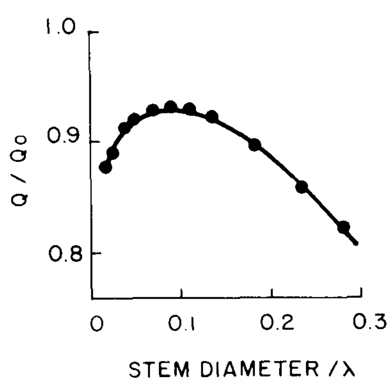
Fig. 2.
Geometrical parameters of disk-and-washer structure.



a. Q/Q_0 vs stem length for fixed disk length.



b. Q/Q_0 vs stem length for fixed washer length.



c. Q/Q_0 is stem diameter for stem length = 0.28 λ.

Fig. 3.
Study of β = 0.6 cavity quality factor using a coaxial model.

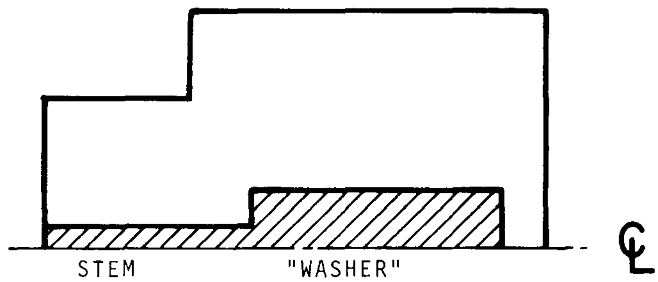


Fig. 4.
SUPERFISH simulation model with coaxial geometry used to study the β = 0.6 cavity.

results with and without a stem. Variation of stem length was accomplished in two ways, both with similar results. The first method, shown in Fig. 3a, was to change the washer length keeping the disk length or coaxial cavity length fixed. Figure 3b shows results of calculations for the washer length fixed and disk length or coaxial cavity length changing. Both methods show that the length of the radial support stem should be close to a quarter wavelength to achieve approximately 96% Q/Q_0. Results not shown in the figure demonstrated that the radial stem should be an odd multiple of λ/4 in length; the smaller the multiple, the lower the losses. Figure 3c shows the ratio Q/Q_0 as a function of stem diameter for a 0.28λ length stem. An optimum stem diameter of approximately 0.09λ is indicated for this geometry. For four support stems, this would be equivalent to approximately 0.045λ.

These results indicate that there should be a resonance between the stem and the rest of the cavity, such that the resonant frequency of the structure with a stem should cross through the resonant frequency of a stemless structure as the stem length is varied from, say, λ/8 to 3λ/8. It was thus proposed to look for this effect experimentally.

<u>Optimum ZT^2 for λ/4 Radial Supports</u>

Computations were also done to investigate the consequences upon effective shunt impedance, ZT^2, when radial support stems must be approximately λ/4 long. An optimum gap between noses no longer can be selected to maximize ZT^2, because the gap must be adjusted to achieve the required π/2 accelerating mode frequency, π/2A. The frequency was held at 1350 MHz, and the washer radius, R_W, set equal to the cavity radius, R_C, minus λ/4. Figure 5 shows how ZT^2 varies as a function of the outer cylinder radius, R_C, for particle betas from 0.4 to 1.0. There is an optimum R_C for each beta that maximizes ZT^2. Table I lists some of the calculated parameters for different beta geometries.

TABLE I

DISK AND WASHER PARAMETERS

(1350 MHz, $t_W = t_R = 10.35$, $\theta = 30°$, $R_H = 1.1$ cm, $R_N = 0.25$ cm)

Beta	R_C	R_D	g/L	t_D	Q	T	ZT^2 (MΩ/m)	Max. Surface Field (MV/m)	% Power Deposited in Metal Walls: Outer Cyl.	Disk	Washer
0.4	13.57	8.57	0.070	0.35	14457	0.881	16.32	15.9	< 0.1	1.2	98.8
0.4	16.57	11.76	0.315	0.35	19319	0.849	33.56	5.3	< 0.1	1.0	99.0
0.4	17.89	13.12	0.842	0.35	21165	0.758	18.70	2.4	< 0.1	1.1	98.9
0.6	14.45	10.29	0.229	0.9	24109	0.909	43.94	6.5	< 0.1	3.3	96.7
0.6	16.45	12.40	0.525	0.9	31687	0.822	55.51	3.8	< 0.1	3.9	96.1
0.6	17.18	13.18	0.895	0.9	34647	0.735	35.34	1.9	< 0.1	4.2	95.8
0.8	14.50	11.17	0.387	1.68	34061	0.887	65.99	4.8	0.2	8.8	91.0
0.8	15.50	12.23	0.550	1.68	41438	0.822	73.73	3.9	0.4	10.5	89.1
0.8	16.38	13.16	0.921	1.68	49736	0.720	51.87	1.6	0.5	13.2	86.3
1.0	12.84	10.57	0.331	2.65	36046	0.918	56.55	5.9	0.9	17.4	81.7
1.0	14.45	12.17	0.588	2.65	50789	0.810	82.85	3.9	1.3	24.4	74.3
1.0	15.34	13.11	0.937	2.65	66066	0.708	65.21	1.8	1.8	33.6	64.6

For a slight overall loss in ZT^2, a common R_C can be selected for all beta. The choice obviously depends upon the particle accelerated and the final energy. For electrons, a radius would be used that is heavily weighted in favor of highest ZT^2, where $\beta = 1.0$. For the Pion Generator for Medical Irradiation, PIGMI,[5] which requires structures with beta from 0.5 to 0.8, a common outer radius of 15.75 cm could be used, because this dimension not only matches available pipe size, but makes a reasonable compromise for ZT^2. A common R_C for all beta structures leads to the same R_W for all the washers. Fabrication and material procurement should be simplified because of the common radii. Externally, the accelerator would have the same diameter for all beta, which could simplify alignment and installation fixtures.

Measurements on Radial Supports

Measurements of Z and Q have been done on $\beta = 0.6$ and $\beta = 1.0$, OFHC copper, disk-and-washer cavities that were built at 1320 MHz for tests of PIGMI geometry.[3] Only a preliminary analysis of these measurements will be presented here. The cavity Q was measured using lightly coupled loops to determine the shape of the resonance curve for the π/2A mode. The 0 and π-mode Q's were also checked for reference, because radial supports have very little effect on these modes. In all instances, proper care was taken to insure good contact and clean surfaces. Measurements were repeated many times to insure there were no systematic errors or inconsistencies in the data. Measurements of Z/Q were done using standard beadpull techniques.

In this study, washers were supported by radial support stems of different diameters and materials (copper, aluminum, and stainless steel). Effects of metal supports were determined by comparison to measurements made with the washer supported by a low-loss, dielectric material such as Teflon. The highest quality

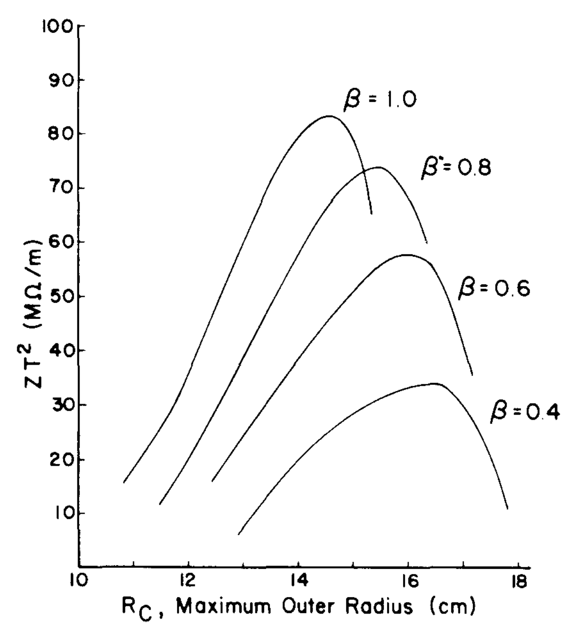


Fig. 5.
Shunt impedance versus cavity outer radius at 1350 MHz.

factor was obtained using the smallest diameter supports consistent with constraints of rigidity and supplying cooling. As expected, the lowest resistivity (copper) supports yielded the best results. A value at 91% of the theoretical Z was achieved for a cavity without supports, with a β = 0.6 PIGMI geometry with radial support stem length of approximately 0.28λ. A slight improvement in Q was obtained when the stems were soldered in place. An additional measurement was made in which one of the four radial supports was converted into a stub tuner extending beyond the outer cavity wall. The result was similar to that shown in Fig. 3a.

Measurements with the β = 1.0 PIGMI geometry gave G's less than 80% of theoretical for a geometry with a stem length of about 0.35λ. A special, copper plated-aluminum cavity was built for the β = 1.0 PIGMI washer to make the stem length $\lambda/4$, but again, less than 80% of theoretical Q was measured for the $\pi/2A$ mode. A series of measurements was then made to look for effects as predicted in Fig. 3, by using an aluminum pillbox cavity and copper washers of different diameters, thus requiring different stem lengths. The predicted trends were not observed and there was no indication of a stem resonance effect.

Conclusions

Incomplete agreement between theoretical and experimental results on radial washer supports in the disk-and-washer structure indicate that radial stems should not be used unless further measurements and calculations show better results. There appears to be some agreement for the β = 0.6 cavity, but not for the β = 1.0 structure. The reduction in Q and Z presently observed for the β = 1.0 structure, at least, appears to preclude the use of radial stems. For low-beta cavities, it appears that radial stems should be about $\lambda/4$ long and have the smallest diameter consistent with other design constraints.

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