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TITLE: LIMITATIONS OF THE DISK-AND-WASHER STRUCTURE

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LIMITATIONS OF THE DISK-AND-WASHER STRUCTURE*

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Summary

A preliminary analysis of measurements on
$\beta = 0.6$ and 1.0 disk-and-washer linac cavities
has indicated some limitations on washer support
methods; in particular, that the use of radial
supports should be avoided until further testing
is completed.

Introduction

The disk-and-washer cavity geometry[1] for
an accelerating structure offers many advantages
including high rf conversion efficiency and high
coupling factor, so we initiated a detailed
study that included computer calculations and
experimental measurements to determine limita-
tions, if any, that 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 distribu-
tions, 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 $\beta = 0.6$
and 1.0, copper structures were fabricated to
investigate the effects of symmetrical support
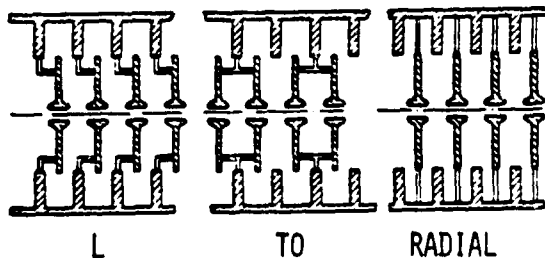techniques on Q and Z.

Fig. 1.
Washer support methods.

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 wave length. The
$\beta = 0.6$ 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
1370-MHz coaxial mode that had a field dis-
tribution equivalent to the accelerating mode
field distribution of the real cavity. Stem
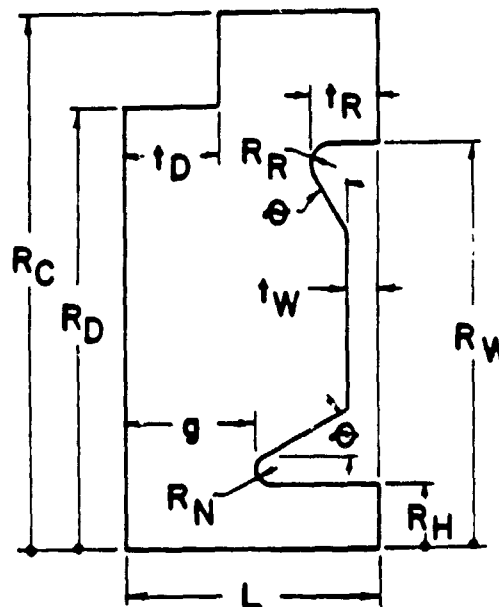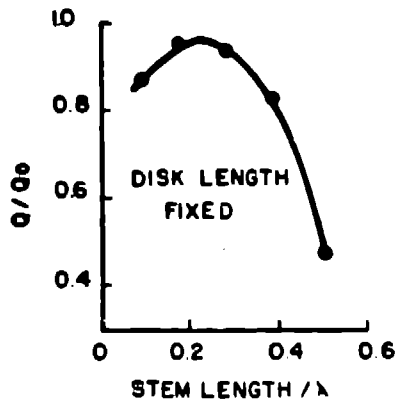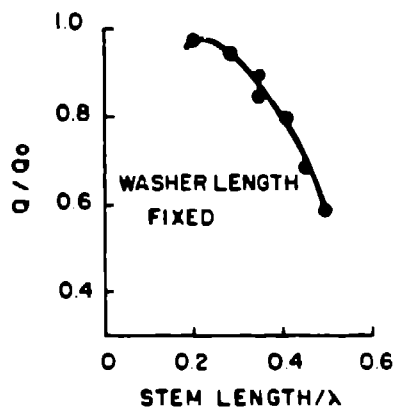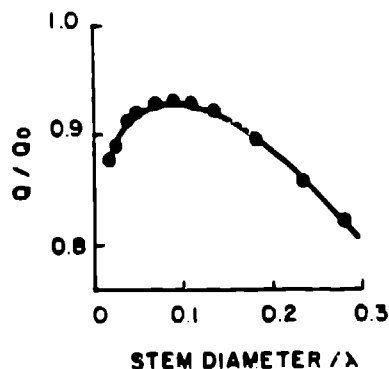effects were determined by comparing calculated

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 step length = 0.28 λ.

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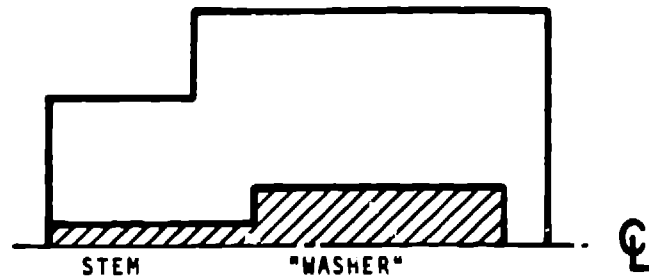Study of β = 0.6 cavity quality factor using a coaxial model.

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, 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 $\lambda/4$ 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 0.28 λ length stem. An optimum stem diameter of approximately 0.09 λ is indicated for this geometry. For four support stems this would be equivalent to approximately 0.045 λ.

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, $\lambda/8$ to $3\lambda/8$. It was thus proposed to look for this effect experimentally.

Optimum ZT^2 for $\lambda/4$ Radial Supports

Computations were also done to investigate the consequences to effective shunt impedance, ZT^2, when radial support stems must be approximately $\lambda/4$ 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 $\pi/2$ accelerating mode frequency, $\pi/2A$. We held the frequency at 1350 MHz, and the washer radius, R_W, equal to the cavity radius, R_C, minus $\lambda/4$. 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.

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TABLE I

DISK AND WASHER PARAMETERS

(1350 MHz, t_W = t_R = 10.35, θ = 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	17.80	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	0.805	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	36044	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 on 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 R = 1.0. For the Pion Generator for Medical Irradiation, PIGMI,[5] that 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 si.. 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 β = 0.6 and β = 1.0, OFHC copper, disk-and-washer cavities that were built at 1320 MHz for tests of PIGMI geometry.[5] 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 Qs also were 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). We determined effects of metal supports by comparison to measurements made with the washer supported by a low-loss, dielectric material such as Teflon. The highest quality
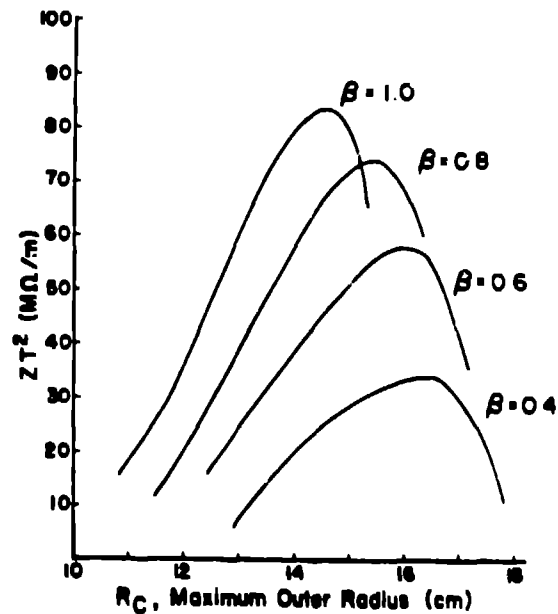

Fig. 5.
Shunt impedance versus cavity
outer radius at 1350 MHz.

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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. We achieved 91% of theoretical Z of a cavity without supports with a ß = 0.6 PIGMI geometry that has a radial support stem length of approximately 0.28 λ. We obtained a slight improvement in Q when the stems were soldered in place. We made an additional measurement 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 ß = 1.0 PIGMI geometry gave Qs less than 80% of theoretical Q for a geometry that has a stem length of about 0.35 λ. A special, copperplated-aluminum cavity was built for the ß = 1.0 PIGMI washer to make the stem length λ/4, but again, less than 80% of theoretical Q was measured for the π/2A mode. We then ran a series of measurements 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. We did not observe the predicted trends, and there was no indication of a stem resonance effect.

Conclusions

Problems with 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 ß = 0.6 cavity, but not for the ß = 1.0 structure. The reduction in Q and Z presently observed for the ß = 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 λ/4 long and have the smallest diameter consistent with other design constraints.

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