© 1983 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

INTEGRAL RADIAL STEMS ON ALUMINUM β=1 DISK-AND-WASHER STRUCTURES

S.O. Schriber

Atomic Energy of Canada Limited, Research Company
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0

Summary

Aluminum test cavities were manufactured with integral radial stems to support the washers of a β=1 2500 MHz disk-and-washer structure. Difficulties in making stem joints were therefore eliminated. From one to four integral stems were studied. Measurements showed that four stem support was best and that two stems mounted at 180° to each other created rf problems. The frequencies of higher order mode passbands can be shifted to result in a structure with good rf efficiency, coupling and quality factor for the $\pi/2$ operating mode.

Introduction

The disk-and-washer geometry has properties that make it attractive for structures in linear accelerators[1-5]. Two of its most attractive properties are the high degree of coupling between adjacent rf cavities and the high efficiency for converting rf power into beam power. The high degree of coupling results from the very open geometry and is important for reducing structure sensitivity to tuning and assembly errors, beam loading effects and transients. The second property is important for possible savings from reduced rf power and reduced heat removal or higher average accelerating gradients for the same investment in rf sources.

Two aspects of the disk-and-washer (DAW) geometry always identified for more investigation were higher order mode studies and selection of a suitable support technique for the washers that dissipate most of the rf heat. Because the operating passband encompasses the frequency region from the TM_{010}-like mode to the TM_{020}-like mode (a consequence of the DAW's main asset - its high coupling constant), it was obvious from published mode charts for right circular cylinders that the TE_{111}-like, TM_{110}-like, TE_{211}- like and TM_{210}-like passbands would be in the vicinity of the $\pi/2$ operating mode over the practical range of geometric dimensions. Calculations[6,7] using newly developed computer codes (which determine rf properties of the azimuthally periodic modes excited in cavities with azimuthal symmetry) have shown passband overlapping characteristics for relatively large diameter β = 0.4 to 0.8 DAW cavities. Measurements[7,8] underway at Los Alamos National Laboratory have identified higher order modes and their rf characteristics for washers supported by T-stems[2] in β = 0.5 to 1.0 DAW cavities.

The DAW geometry has higher order modes in the neighbourhood of the operating mode, a situation with consequences similar to those in other structures that have higher order mode passbands at frequencies close to an integer times the operating frequency and have other modes of the operating passband in close proximity to the operating mode. For any structure, it is important to know the mode locations and their field distributions, mode rf characteristics as a function of geometric changes and mode influence on beam transmission. With this information, geometries can be selected and methods can be employed to minimize or eliminate unwanted effects.

Initial measurements[3] with radial stems obtained almost theoretical rf efficiency with a β = 0.6 cavity but not with a β = 1 cavity. Because of the poor β = 1 results, further work[7-9] concentrated on T-stems. The initial β = 1 results are suspect because the cavity suffered from poor copper plating and it is now known that excellent rf contact must be achieved on the radial stem joints at the washer and at the outer cylinder.

Because of their symmetry and accessibility, radial stems can lead to many simplifications in assembly, fabrication and rf tuning of on-axis fields and frequencies. For these reasons, an experimental program was initiated with aluminum, β = 1, DAW cavities that have radial stems integral to the outer cylinder-washer segments to study stem length effects[3] and higher order modes as a function of outer diameter. Results for the first set of measurements with a 13 cm diameter DAW cavity are presented below.

Experimental Equipment and Calibrations

Aluminum coaxial segments were fabricated at 1/5 scale of the 500 MHz DAW being studied[10,11] for the TRISTAN accumulator ring. Structures were made by assembling and clamping coaxial components consisting of end segments, disk segments and washer segments. Figure 1 shows the structure assembly for one full and two half accelerating cavities terminated to allow excitation of the $\pi/2$ accelerating mode. This assembly technique could be applied to high power DAW structures. Assemblies were also terminated to produce two full accelerating cavities and allow excitation of the $\pi/2$ coupling mode.

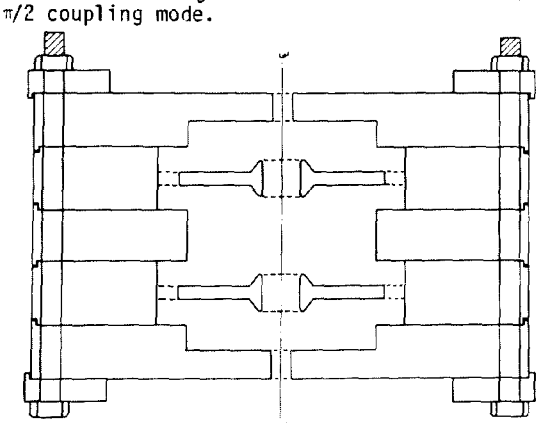

Fig. 1 Structure assembly consisting of a disk segment, two washer segments, two $\pi/2$ accelerating mode termination segments and clamping rings.

Sets of two washer segments were fabricated with four radial stems (90° separation), two radial stems (two with stems at 180° and two with stems at 90°), one radial stem and no stems (plastic supports required). Figure 2 shows washer segments with four, two and one integral radial stems. The stems (7 mm x 7 mm cross-section) were formed in the washer segment by milling slots between the outer cylinder and washer.

Table 1 lists the range of calculated DAW parameters (copper structure) that can be investigated with these segments by progressively machining the washer radius (R_W), the disk radius (R_D) and the outer

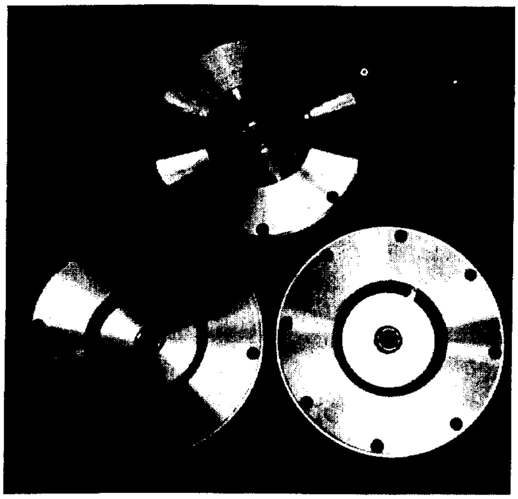

Fig. 2 Aluminum washer segments with four, two and one integral radial stems.

Table 1

2500 MHz β = 1 DAW Cavity Parameters

R_c (cm)	R_w (cm)	R_D (cm)	Radial Stem Length (Fraction of $\lambda/4$)	ZT^2 (MΩ/m)	Q
6.5	5.38	4.93	0.37	65.3	14,900
7.0	5.15	5.61	0.62	76.0	16,400
7.5	5.05	6.22	0.82	82.5	17,400
8.0	4.99	6.80	1.00	87.4	18,000
9.0	4.93	7.94	1.36	96.1	19,100
10.0	4.90	9.04	1.70	101.7	19,700
11.0	4.88	10.12	2.04	106.3	20,100

cylinder radius (R_c). Other dimensions for the 2500 MHz cavity are 10 mm bore hole radius, 30 mm half cavity length, 13 mm half disk thickness, 3.5 mm half web thickness, 1.4 mm nose radius and a gap-to-length ratio of 0.684. Mode frequency changes for the operating passband are shown in Fig. 3 for the R_c range listed in Table 1. An equivalent shaped copper cavity would have a ZT^2 of 76 MΩ/m at 2500 MHz.

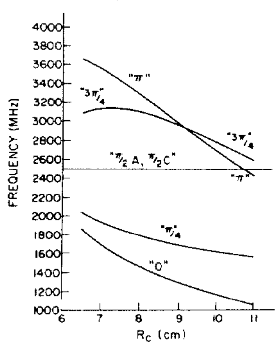

Fig. 3 Mode frequencies of the operating passband as a function of R_c.

The ability to measure quality factor (Q) and Z/Q reliably was verified using excitation of the TM_{010}-like and TM_{020}-like modes in segment assemblies that did not have washer segments. In this manner radial stem effects did not have to be considered for calibration purposes. The 4 mm diameter copper bead used for determining on-axis field amplitudes during bead pulls was also calibrated with these assemblies. The calibration measurements demonstrated that good quality segment joints could be obtained with the clamping jig and that measurements were repeatable.

Experimental Measurements

Rf characteristics of structure modes were measured to 4.3 GHz, the equipment limit, for assemblies that included two washer segments. Assemblies with and without a single washer segment were also studied to assist with passband identification. Mode characteristics were determined for two different systems of segment assemblies - one to excite the $\pi/2$ accelerating mode and the other to excite the $\pi/2$ coupling mode. This double measuring procedure permitted a direct intercomparison of observed modes for a particular number of radial washer supports. Interpreting the DAW cavity as similar to an annular coupled cavity with long coupling slots helped in identifying passband modes.

In all cases, Q and Z/Q measurements on the zero and π modes of the operating passband were used to calibrate those for the $\pi/2$ accelerating mode. The effect of the radial stems on the zero and π modes should be minimal because of the cavity field distributions. Measured quality factors for the different assemblies were consistently about 95% of theoretical values for the zero and π modes. Measurements of Z/Q for the zero and π modes indicated no noticeable change in stored energy associated with the radial stems, unlike results for the $\pi/2$ accelerating mode.

A summary of results for the $\pi/2$ accelerating mode is presented in Figs. 4 and 5. The $\pi/2$ mode splits into two components (determined by field distribution measurements) for two stems at 180° with a > 300 MHz frequency separation. The same splitting was noted with three stems oriented at 90° intervals. These results were verified on the zero and one stem washer segment assemblies by introducing brass rods through appropriately located threaded holes in the outer cylinder. The latter measurements demonstrated the importance of excellent rf joints for the radial stems. The brass rods (also aluminum and copper test rods) were designed to produce knife edge contacts between the washer and the stem because contact pressure was not adequate to obtain expected mode properties. The $\pi/2$ mode did not split for washer segments with two stems oriented at 90°. Figure 4 shows that the stem frequency perturbation was about 39 MHz per stem.

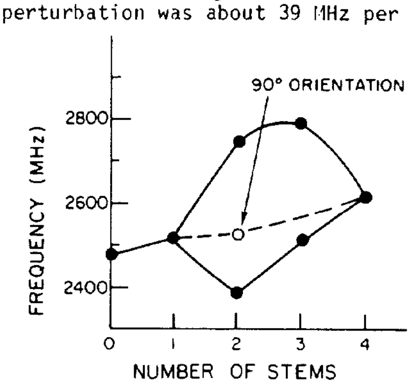

Fig. 4 The $\pi/2$ accelerating mode frequency versus number of radial stems.

Configurations with one stem segments and those with two stems at 90° had a 140 MHz frequency splitting for the $3\pi/4$ mode of the operating passband, a splitting verified with the coupling mode terminations. The orientation of one washer segment relative to the other was changed in steps of 45° but no significant changes were noted in mode splitting nor in the general passband characteristics.

The lowest part of the TM_{110}-like passband was at least 300 MHz higher in frequency than the $\pi/2$

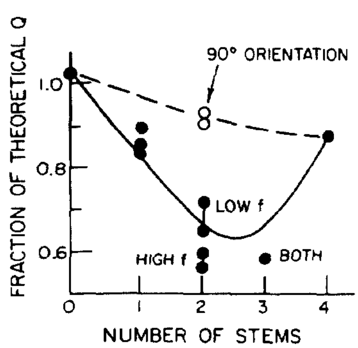

Fig. 5 Fraction of theoretical Q for the $\pi/2$ accelerating mode versus number of radial stems.

accelerating mode. Other measured passbands were at least 250 MHz distant, with the TE_{111}-like passband lower in frequency. A disturbing feature noted for some of the modes in the TM_{110}-like and TM_{210}-like passbands was a strong on-axis electric field in the central cavity of the coupled structure. These field distributions imply that a well centered beam could couple power to a blowup mode through interactions in the central part of the structure and this coupling could be cumulative if the mode frequencies were appropriately related to the beam microstructure.

Figure 5 shows the $\pi/2$ accelerating mode quality factor as a function of the number of stems for different assemblies of the same configuration. The split modes had much lower quality factors. The on-axis bead pulls for the $\pi/2$ accelerating mode yielded Z/Q values that were 1.04, 0.88, 0.61, 0.50, 0.98 and 1.02 of theoretical SUPERFISH values for zero, one, two at 180° (low f), two at 180° (high f), two at 90° and four stems, respectively. Experimental to theoretical Z ratios can be obtained by multiplying these results by those in Fig. 5. The Q and Z/Q measurements show that two stems at 180° have higher rf losses than other support configurations, due mainly to changes in the field pattern in the vicinity of the stems. The best support configuration for obtaining a high percentage of theoretical rf efficiency is with four stems (90%) followed by two stems at 90° (89%) and a single stem (80%).

Discussion

Present results for the small diameter DAW geometry show that four stems are the best support configuration. Two stems at 180° are not recommended.

Based on locations of the TM_{110}-like passband from measurements presented here and elsewhere[7,8] a 1.25 λ outer diameter geometry should result in a structure with the TM_{110}-like passband lower limit at least 2% higher than the $\pi/2$ accelerating mode and with a theoretical rf efficiency 10% higher than that of an equivalent shaped cavity. Larger diameters with associated higher efficiencies can be used as long as the location of other modes is known and techniques are employed to ensure that they will not be excited by the rf drive or beam.

The results of this study have implications in the design of linear accelerators both at low and high frequency. The DAW geometry can provide an efficient structure as long as precautions related to higher order modes are observed. For instance, a "diskless" disk-and-washer structure would simplify fabrication of low frequency $\beta = 1$ structures. The structure would have an open stopband (coupling mode frequency 1.15 times the accelerating mode frequency), however the high coupling constant stabilizes the structure against beam loading and transient effects (demonstrated by calculations using coupled RLC loops, field stability is proportional to the stopband width divided by the square of the coupling constant - DAW stopbands can be 100 times larger than those for structures with shaped cavities and about 5% coupling constants).

The DAW geometry would be suitable for a 100 MeV/m accelerator. A 10 GHz structure with 0.3 cm bore radius could be assembled with flat washers to permit higher operating gradients. The structure would not be operated above 1.75 times the Kilpatrick limit, ensuring a relatively safe margin from breakdown. Development of suitable rf sources would be required because the structure requires about 70 MW/m peak rf drive for a structure that has 85% of theoretical efficiency. Duty cycle for the structure should not be greater than 0.0005 to ensure that heat removal would not exceed 100 W/cm^2 on the washers.

Further rf measurements on passband modes will be undertaken with the 2500 MHz $\beta = 1$ aluminum segments to investigate characteristics of larger diameter geometries. To obtain a more complete understanding of radial stem effects, the studies will include Q and Z/Q measurements for the 0, $\pi/2$ and π modes of the operating passband.

Additional structure studies and related beam blowup calculations are required on the on-axis electric fields observed for some of the TM_{110}-like passband modes. These modes should not cause any interference problems with the present geometry, however they will be closer to the operating frequency for larger diameter geometries.

Acknowledgements

The author thanks the KEK laboratories in Japan which had most of the cavity segments fabricated and assisted with collecting equipment necessary for the preliminary measurements. In particular, the author thanks S. Inagaki, H. Nakanishi, K. Kitagawa and K. Takata.

References

1. S.O. Schriber, "Room-Temperature Cavities for High-Beta Accelerating Structures", Proc. of Conf. on Future Poss. for Electron Accel., Univ. of Virginia, L-1 (January 1979).
2. J.M. Potter et al., "Experimental and Calculated RF Properties of the Disk-and-Washer Structure", IEEE Trans. Nucl. Sci., NS-26 (3), 3763 (1979).
3. S.O. Schriber and J.M. Potter, "Limitations of the Disk-and-Washer Linac Structure", Proc. of 1979 Linac Conference, Brookhaven National Laboratory Report No. BNL-51134, 176 (1979).
4. S.O. Schriber, "High Beta Linac Structures", ibid., 164 (1979).
5. S.O. Schriber, "Accelerator Structure Development for Room-Temperature Linacs", IEEE Trans. Nucl. Sci., NS-28 (3), 3440 (1981).
6. V.G. Andreev et al., "EH_{11n} Modes of E Type in the Disk and Washer Accelerating Structure", Nucl. Instr. and Meth., 204, 285 (1983).
7. D.A. Swenson, Los Alamos National Laboratory, private communication (1983).
8. L.M. Young and J.M. Potter, Los Alamos National Laboratory, private communication (1982).
9. L.M. Young and J.M. Potter, "The DAW Structure for the NBS/Los Alamos Racetrack Microtron", Proc. of 1981 Linac Conf., Los Alamos National Laboratory Report No. LA-9234-C, 335 (1981).
10. S. Noguchi et al., "Test of a 5-cell DAW Cavity", Proc. of 4th Symp. on Accel. Sci. and Tech., 255 (November 1982).
11. S. Inagaki et al., "Properties of the Disk-and-Washer Cavity", ibid., 257.