

INVESTIGATION OF THE DISC-AND-WASHER STRUCTURE*

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Introduction

About 1971 a proposed accelerating structure was described by the Radiotechnical Institute, Moscow, which was intended for proton acceleration in a planned meson factory linac.¹ The structure has several quite useful features and has been subsequently investigated by AECL (Chalk River, Canada), LASL (UC Los Alamos, NM) and Argonne National Laboratory. A sketch of the structure is shown in Fig. 1, which reveals the origin of the name "disc-and-washer structure (DAW)".

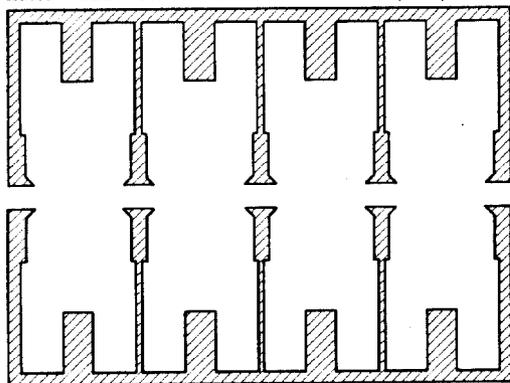


Fig. 1

The origin and development of the concept upon which the structure is founded is provided from considerations of a chain of individual TM₀₁ cavities designed to produce kinetic energy gain to a bunched beam transiting their common axis. It is assumed the cavities are individually excited without inter-coupling; so that for maximum energy gain there is a specific phasing requirement based on the transit time from the previous cavity. Such a system would be very complex to operate and would only be considered in the special case of a few cavities as, for example, the LASL PHERMEX.

What is wanted is an automatic or self-phasing system. This system could be provided by a coaxial drive line that in the ultimate case included the accelerating cavities within the center conductor, Fig. 2. The principal draw-back to such a simple system, in addition to the stored energy in the feed-line, is that in the case of periodic positioning of the cavities the consequent periodicity of the coupling apertures, and the associated reactances, would cause in the coaxial line a propagation constant which would depend on details of the coupling apertures and therefore the phasing of the cavities would not be automatically optimized. This defect could, of course, be corrected by including periodic compensating reactances in the coaxial line so as to produce a filter network with the appropriate phase shift per periodic length, which results in the structure shown in Fig. 3. Alternatively, one can view this structure as being composed of two sets of cavities with different modes of resonance where, in the standing wave case, alternate,

unexcited cavities are removed from the beam line. This is, of course, the principle of the side-coupled waveguide designs.

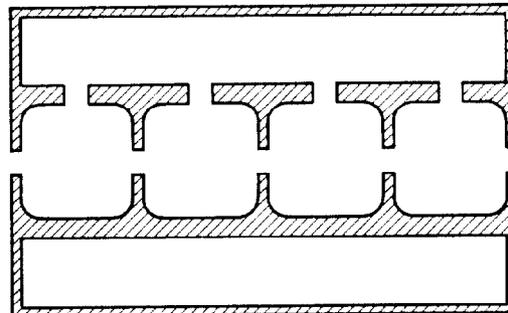


Fig. 2

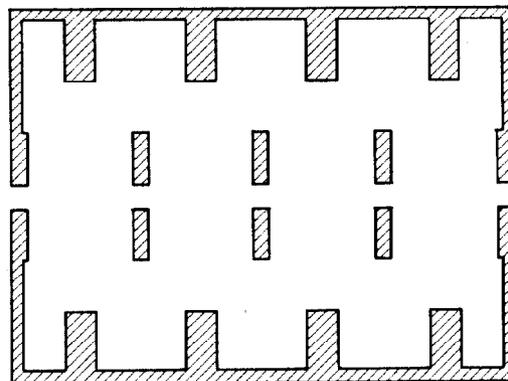


Fig. 3

Again, one can view the structure as a length of shorted radial transmission line (outer cavity) matched to another radial transmission line including the axis (inner cavity). In any case, what is accomplished in the DAW structure is to provide a cavity resonant in a TM₀₁ like mode but with improved transit time factor.

Field Description

In a physically complicated structure, such as the DAW, one cannot hope to find a solution of the wave equation which also satisfied Maxwell's equations, both conditions being necessary to describe a wave which will exist. The usual technique of solving this sort of problem is "mode fitting", that is, to describe in each region of the structure a supposed set of modes which match the boundary conditions and each other at their common boundary. Such a program has been described by Andreev, *et al.*,² but the results are too complicated to be practical. For the purpose of determining the appearance of the cavity modes, a practical program consists of experimentally producing a resonance in each of the two types of cavities at the intended frequency. This is done in the present case by fabricating two cavities, shown in Fig. 4, corresponding to the beam line and side-coupled cavity severed in the planes of symmetry. The dimensions of the cavities are varied to

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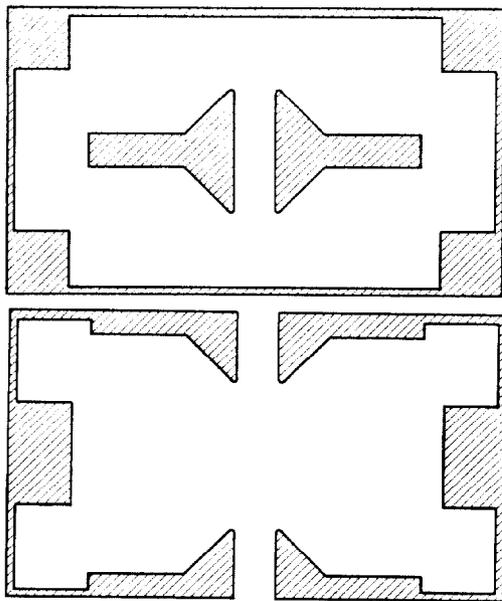


Fig. 4

produce a TM resonance in each at the same frequency, and the cavities when part of a periodic structure will be the $\pi/2$, or intended mode. In this process certain dimensions will not be varied, for example, the drift tube (nose cone) and the washer thickness. Of course, the periodicity of the structure is fixed by the operating frequency and phase velocity. The inside diameter of the waveguide is, interestingly, set approximately by the solution of $J_0(p_0) = 0$, i.e., $\lambda = d$, the condition for propagation in the TM-02 mode (assuming the lowest TM-mode on the axis is intended).

Exploration of the fields in the structure, by means of perturbation theory, using needles and small dielectric and metallic spheres, revealed the patterns shown in Figs. 5, 6 and 7. There is no quantitative significance to the sketches; the lines shown are the conjectured electric lines.

What is wanted by accelerator designers is the shunt impedance (group) velocity and attenuation coefficient (or Q) of the structure, and these can be measured in a conventional manner. Some experimental values for phase velocities $0.4 < V_p/c < 0.8$ have been given, based on S-band scaled models by Andreev³ and an extensive study in the phase velocity range $0.4 < V_p/c < 1.0$ has been done by computer simulation by Schriber.⁴ By scaling laws, one can anticipate that

$$\frac{r_1}{r_2} = \sqrt{\frac{f_1}{f_2}} \quad \frac{Q_1}{Q_2} = \sqrt{\frac{f_2}{f_1}}$$

insofar as frequency dependence of surface resistance can be ignored. Group velocity does not depend on wavelength, i.e., is a constant in scaling. Also, the computer simulation (LASL SUPERFISH) program can only accommodate cylindrical symmetry⁵ and must use a conjectured surface resistance, which depends on the material and the surface finish of the material

Experimental Program

For the purpose of estimating the difficulties to be encountered in fabricating this structure and determining the achievable microwave properties an experimental study was undertaken. In every case the studies were for $3 = 1$ only; for an electron linac application only this phase velocity is of interest.

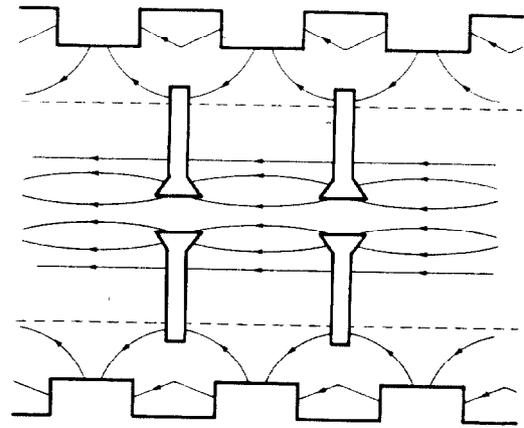


Fig. 5. 0-mode

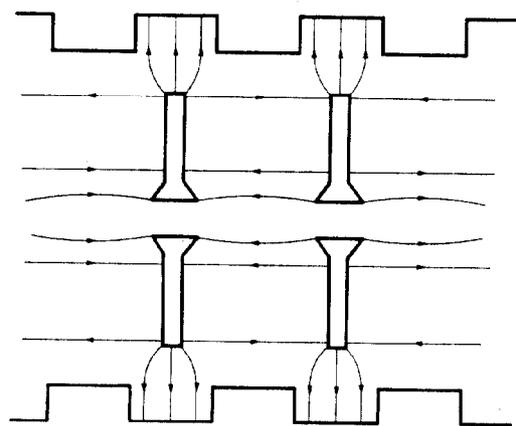


Fig. 6. $\pi/2$ mode

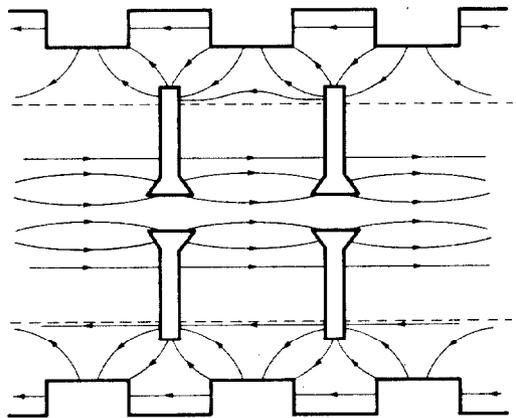


Fig. 7. π -mode

First, it is of interest to determine what non-varying parameters can be set to avoid prolonged investigation. It is well known that the maximum energy gain in a TM-01 mode cavity occurs when the diameter/length ratio is $7/4$; in the present case, this maximum occurs when the interaction gap (g) and the periodic length (p) are in the ratio $g/p = 2/3$. The nose cone details are not of serious importance and one can advantageously use klystron cavity design (30 degree rake with radius $r/\lambda = 0.15$). The above decisions are in accord with the studies of Schriber⁵ and Manca.⁶ Of course the periodicity of the structure is given by $p = (v_p/c)(\lambda/2)$ but there is no analytic way to decide the ratio of disc thickness to periodic length. In this study we were guided by Schriber's discovery that maximum shunt impedance occurs when the disc thickness is about half the periodic length,⁵ that is, much

thicker than the original RII model.⁴ Obviously the ID of the disc was adjusted for resonance when the OD of the washer was chosen.

The first part of the present study was an examination of S-band structures, because of fabrication costs. Three structures were fabricated and tested at 2450 mcs:

DESIGNATION	S-1	S-2	S-3
Cyl diam., $2R_C$, in.	5.570	5.896	6.872
Disc diam., $2R_D$, in.	4.448	4.972	5.974
Wash diam., $2R_W$, in.	3.948	3.874	3.810
In every case:			
Cyl length, t_C , =	1.834 in.		
Wash thkn., t_W , =	0.150 in.		
Disc thkn., t_D , =	0.574 in.		
g/L ratio	= 0.6		
Nose Cone, θ	= 30°		

For these models the following properties were determined.

DESIGNATION	v_g/c	K	$(r/Q)_{eff}$	T	G	Z_S M Ω /sqm
S-1	0.42	0.69	46.8 Ω/cm	.82	3.97 cm	.57
S-2	0.58	0.69	43.7	.82	4.06	.39
S-3	0.76	0.70	38.8	.82	4.11	.26

v_g/c is normalized group velocity
 K is the coupling coefficient
 $(r/Q)_{eff}$ is the effective r/Q
 T is the transit time factor
 $G = (\int E \cdot dz)^2 / \int E^2 dz$ is the gap field shape factor
 Z_S is the series impedance

At this point there was no object in continuing to increase the cylinder diameter because the Brillouin diagram showed the π -mode was dropping down to the $\pi/2$ -mode (Fig. 8). In addition, the washers were so thin that the possibility of cooling them by inside water passages appeared to be impractical. The values given in the table above are only comparable to those given by Andreev since the disc thicknesses were designed to be thin as in the RII model. Some indication of the usefulness of the structure is ordinarily given by the product $(2\pi/\lambda) (r/Q) (c/v_g)$, the series impedance of the structure. Because of the high energy velocity, the structure appears to be of little use; as a traveling wave structure it is of no use (a typical value of series impedance is 20 M Ω /sqm in S-band), but it is a consequence of the intended mode of operation (resonant) that this unusual structure has great usefulness.

Because of the necessity of obtaining a value of Q, in the L-band study aluminum models were investigated and the final model (best structure) was dip-brazed and copper plated. This best version had the dimensions:

- cylinder length, t_C , = 6.030 cm
- cylinder diameter, $2R_C$ = 34.772 cm
- disc length, t_D = 5.501 cm
- disc diameter, $2R_D$ = 30.724 cm
- washer thickness, t_W = 0.726 cm
- washer diameter, $2R_W$ = 18.144 cm
- g/L ratio = 0.60
- nose cone angle = 30°
- beam aperture diameter $2r_h$ = 2.283 cm
- geometrical periodic length L = 11.531 cm

The experimental properties were:

- $(r/Q)_{eff}$ = 2327 Ω/m
- v_g/c normalized group velocity = 0.593
- transit time factor, T = 0.818
- gap form factor, = 8.11 cm
- figure of merit, Q_0 = 22,000

While the Q is not impressive, that is probably owing to the finite length of the structure, as well as the quality of the plating (contaminants, etc). No deleterious effects were observed from the radial support rods, as has been reported. By interpolating into computer simulation data⁵ the microwave properties of this structure do not compare well.

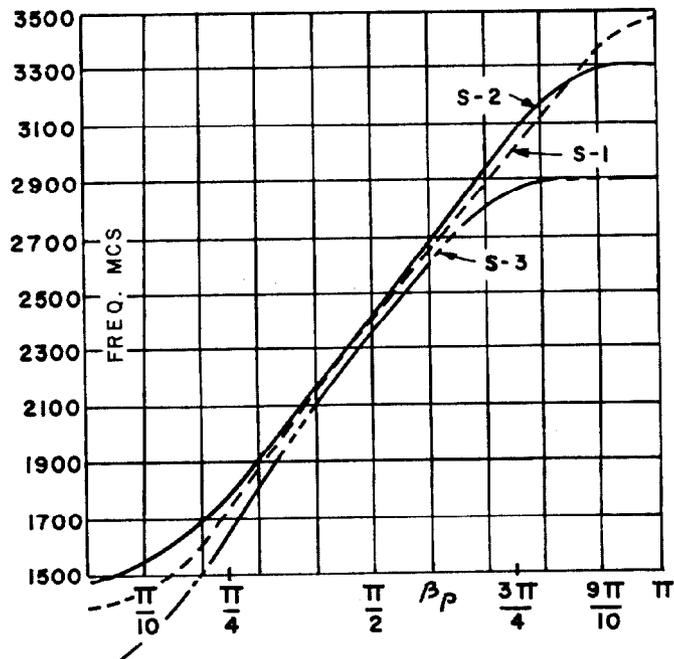


Fig. 8

References

1. V. G. Andreev, Zh. Tekh. Fiz. 38, 1306 (1968), transl. Sov. Phys. 13, 1070 (1969).
 V. G. Andreev, et al., Zh. Tekh. Fiz. 40, 523 (1970) transl. Sov. Phys. 15, 405 (1970).
 V. G. Andreev, et al., Science (Moscow) II, 150 (1972).
2. V. G. Andreev, Zh. Tekh. Fiz. 41, 788 (1971), transl. Sov. Phys. 16, 617 (1971).
3. V. G. Andreev, et al., Investigation of the Accelerating Structure for the Second Part of the Meson Factory Linac, Proc. of the 1976 Proton Linac Conf. AECL Rep. No. AECL 5677 (1976) p. 269.
4. S. O. Schriber, Room Temperature Cavities for High-Beta Accelerating Structures, Proc. Conf. on Future Possibilities for Electron Accelerators, Charlottesville, VA, LASL Report No. LA-79463 (undated).
 J. Potter, et al., Experimental and Calculated RF Properties of the Disc-and-Washer Structure, IEEE Trans. Nuc. Sci. (1979); LASL Rep. No. LA-79685 (undated).
5. See ref. 4 and K. Halbach et al., Properties of the Cylindrical RF Cavity Evaluation Code SUPERFISH, Proc. of the 1976 Proton Linac Conf. AECL Rep. No. AECL-5677 (1976) p. 122.
6. J. Manca, et al., Optimization of the Disc-and-Washer Accelerating Cavities, LASL Rep. No. LA-7407 (1978).