STUDY OF HIGH-ENERGY PROTON LINAC STRUCTURES

by

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ABSTRACT

Two $\pi/2$-mode standing wave structures are described, one of which contains annular coupling cells and the other is loaded with disks interspersed with conducting washers. Both structures can be used in a proton linac with a higher than 100 MeV output energy. Calculated parameters of structures are presented together with results of experimental studies of models thereof.

I. INTRODUCTION

The $\pi/2$-mode accelerating structures with coupling cavities at the structure periphery have high efficiency and field stability within the range of β between 0.4 and 1.0. One such structure was reported to be thoroughly studied and successfully applied at the Los Alamos Meson Physics Facility (LAMPF).[1] Two more accelerating structures--one with outer annular coupling cavities and the other loaded with discs interspersed with conducting washers are being studied at the Radiotechnical Institute under the program of designing a 600-MeV proton linac. A brief description and main results of theoretical and experimental studies of these structures are presented below.

II. ACCELERATING STRUCTURE WITH ANNULAR COUPLING CAVITIES

The structure is shown in Fig. 1. It operates in the $\pi/2$-mode and comprises 180° phase shifted toroidal accelerating cells as well as coupling cells formed by annular H-shaped cavities. Azimuthally uniform electrical field parallel to the structure axis is excited in the annular cavities. Each accelerating cell is coupled with the annular one through slots.

The structure shunt impedance is determined mainly by the rf loss in the accelerating cells. The results of calculation of its effective value vs β are presented in Fig. 2 (curve 1). The actual shunt impedance is somewhat less than the calculated one because the actual rf loss in copper is slightly greater than the theoretical one. Also, there exists influence of coupling slots on rf power loss that is attributed to wall currents redistribution and to direct field penetration from an accelerating cell into the coupling one. When two adjacent slots face each other, the power radiated into the coupling cell is less than when the slots are azimuthally shifted. It has been shown experimentally that in the former case the structure shunt impedance is slightly greater.

The electric field stability is known to become higher with an increase in the cell coupling coefficient. This can be achieved through greater slot dimensions; however, model experiments[2] have demonstrated that, in this case, the structure shunt impedance goes down. For instance, when the coupling coefficient was 6-8%, the decrease of the shunt impedance due to the slot influence was between 10 and 15%. Actual values of the structure effective shunt impedance taking into account both the rf loss in coupling elements and the actual rf loss in copper are shown in Fig. 2 (curve 2).

It should be noted that when adjacent slots face each other, which favors an increase in the shunt impedance, there appears direct coupling between the adjacent accelerating cells leading to some dispersion curve asymmetry. This can be seen in Fig. 3, where the dispersion curve of an experimental 16-cell demountable cavity section is presented. However, in a cavity with a greater number of cells, the total dispersion curve asymmetry does not lead to any essential increase of field perturbations because these are determined mainly by the adjacent modes falling into a small linear region of the dispersion curve.

In choosing the geometrical dimensions of annular cavities, the following has been taken into consideration. In order to decrease the accelerating structure outer diameter, it is expedient to decrease the gap between the protrusions, $2B_k$ (Fig. 1). But this decrease should not be excessive since it is accompanied by an increased effect of fabrication errors. It was found that the optimum gap width is $B_k = (0.25 + 0.3)\ L_k$, and taking it constant, the protrusion width for mimimum structure diameter is approximately equal to the half-length of the annular cell. In order to increase the coupling, one should increase the magnetic field in the axial region of the annular cell. For this purpose one should move the protrusions in an annular cell towards the axis.

An experimental cavity 1 m long and 0.4 m in diameter with 15 cells (Fig. 4) was designed in order to test the fabrication procedure and the rf parameters. It comprises 30 uniform segments, each forming an accelerating half-cell and a coupling one. These segments were machined from OFHC copper. The cavity was brazed with a silver alloy in a hydrogen furnace during one warming-up cycle. Prior to brazing, the cavity had been assembled and tuned.

The measured parameters of the experimental cavity are given below:

Relative particle velocity	$\beta = 0.4$
Resonant frequency	$f = 994$ MHz
Effective shunt impedance (Calculated value $ZT^2 = 33$ MΩ/m)	$ZT^2 = 27$ MΩ/m
Q factor	$Q = 13 \cdot 10^3$
Coupling coefficient	$k = 5.7\%$

The experiment showed that cavity wall deformations during brazing do not lead to any essential change of the resonant frequency and field distribution ($\Delta f/f \leq 0.4 \times 10^{-4}$, $\Delta E/E \leq 2\%$). At present, a possibility of fabricating cavity segments from copper discs by cold-punching is being investigated. Punched-out segments are shown in Fig. 5. Punching is expected to be advantageous in that it provides for identical segments requiring no further mechanical processing of complicated shaped surfaces with only segment junctions and tuning surfaces to be processed additionally.

III. ACCELERATING STRUCTURE LOADED WITH DISCS INTERSPERSED WITH CONDUCTING WASHERS

The second type of accelerating structure is shown in Fig. 6(a). It is a cylindrical cavity with conducting washers (1) interspersed with discs (2). In order to make the interaction between the rf field and the particles more efficient, the washers are supplemented with drift tubes (3). The washers are attached to the cavity by two or more metal stems (4) parallel to the axis and placed in the rf electric field node. The stems serve also to cool the washers, for which purpose bores to pass a cooling liquid are envisaged in the stems and washers.

It is convenient to assemble a cavity from several modules. The cross section of a module is shown in Fig. 6(c). The junction of two adjacent modules is placed in the rf current node, i.e., in the transversal median between the discs.

One can represent a disc-and-washer loaded cavity as a chain of two interchanging types of cells. The cells of the first type are in the axial region between two adjacent washers while the cells of the second type are in the peripheral region between the adjacent discs.

The dispersion curve of such a chain has two branches. Its matching to obtain a single curve linear around the $\pi/2$-mode is conveniently performed by changing the cavity diameter while the cavity tuning to a given frequency is attainable by varying washer diameters.[3]

The calculated effective shunt impedance and Q factor of a cavity with drift tubes of 4 cm i.d. at a frequency of 1000 MHz are shown in Fig. 7 and 8. These calculations represent the case when the drift tube separation and disc thickness are such that the rf power loss is minimum. The application of conical drift tubes makes it possible to decrease the cavity rf loss by some 3 or 5%. The calculation takes into account the rf loss in two stems of 2 cm o.d. (approximately 5% of the total loss). The shunt impedance and the Q of a cavity with finite length ended by two accelerating half-cells are somewhat less, due to rf loss in the end faces. This decrease depends on the total number of accelerating cells, N, in the cavity and is proportional to 1/N. In order to test the calculation accuracy, cavity models have been fabricated and their parameters measured. The measured ZT^2 and Q are 5 to 10% lower than the calculated ones. The dispersion curve for a disc-and-washer loaded cavity is shown in Fig. 9. From this curve it follows that in the $\pi/2$-mode region the dispersion curve is practically linear and symmetrical. The coupling coefficient that characterizes the frequency separation between the 0-mode and the π-mode is approximately 37%. Some decrease of coupling due to the dispersion curve deformation in the 0-mode region does not practically affect the curve slope in the π-mode region. For example, the relative group velocity for $\pi/2$-mode equals 0.3. A coupling coefficient of approximately 50% in a structure with unperturbed dispersion curve corresponds to such a velocity.

Figure 10 shows the axial electric field distribution in a cavity comprising 20 accelerating cells ($N = \frac{1}{2} + 19 + \frac{1}{2}$). The field deviation from the mean value does not exceed 1%. Detuning of an end half-cell followed by a relative shift of cavity resonant frequency by 0.1% gives rise to a field tilt of less than 0.5%, thereby demonstrating an extremely high field stability of this accelerating structure.

IV. CONCLUSION

Calculation of rf parameters and the experimental studies on structure models have shown that both accelerating structures can be used in proton linear accelerators for energies above 100 MeV.

The structure loaded with washers and discs has an extremely high coupling and correspondingly high field stability.

The structure with annular coupling cavities is attractive due to its simple fabrication (punching out uniform segments, one-cycle brazing, etc.). The final choice between these two structures in the 600-MeV proton linear accelerator project being carried out at the Radiotechnical Institute is to be made after the relevant models have been tested at high power levels and the fabrication procedures have been worked out on an industrial basis.

REFERENCES

1. E. A. Knapp, B. C. Knapp, and J. M. Potter, Rev. Sci. Instr. 39, 979 (1968).

2. V. G. Kulman, E. A. Morochnik, and V. M. Pirozhenko, Prib. Tekh. Eksp., No. 4, 56 (1970). In Russian.

3. V. G. Andreev, Zh. Tekh. Fiz., No. 4, 41, 788 (1971). In Russian.

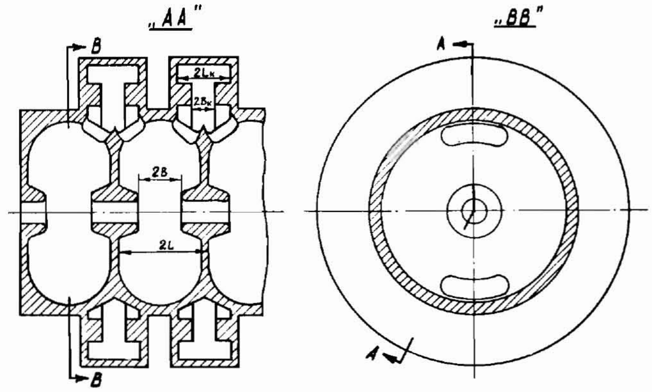

Fig. 1 Cross section of accelerating structure with annular coupling cavities.

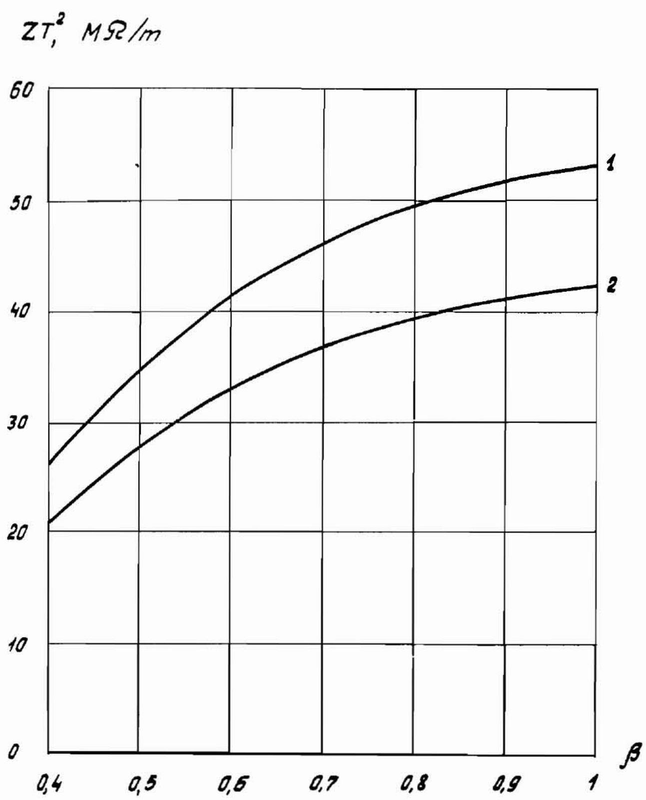

Fig. 2 Effective shunt impedance of accelerating structure with annular coupling cavities. Curve 1, calculated values; curve 2, actual.

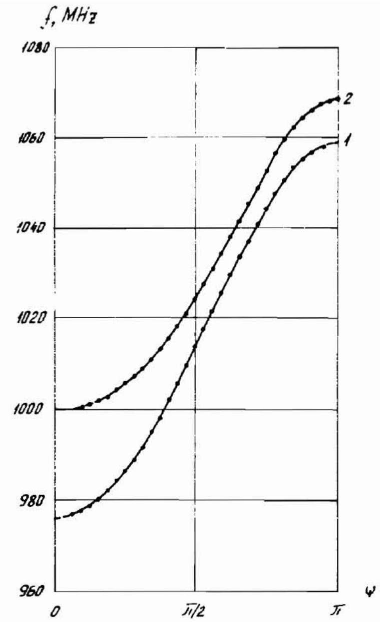

Fig. 3 Dispersion curve of accelerating structure with annular coupling cavities. 1, coupling slots between cells aximuthally shifted; 2, slots are in opposite position.

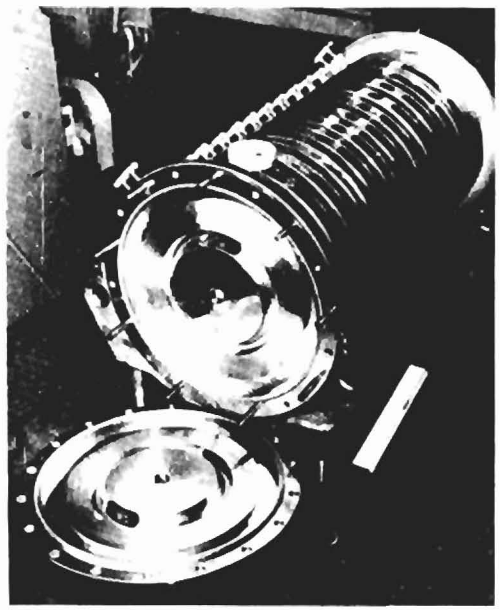

Fig. 4 Model of accelerating structure with annular coupling cavities.

Fig. 5 Punched cavity segments

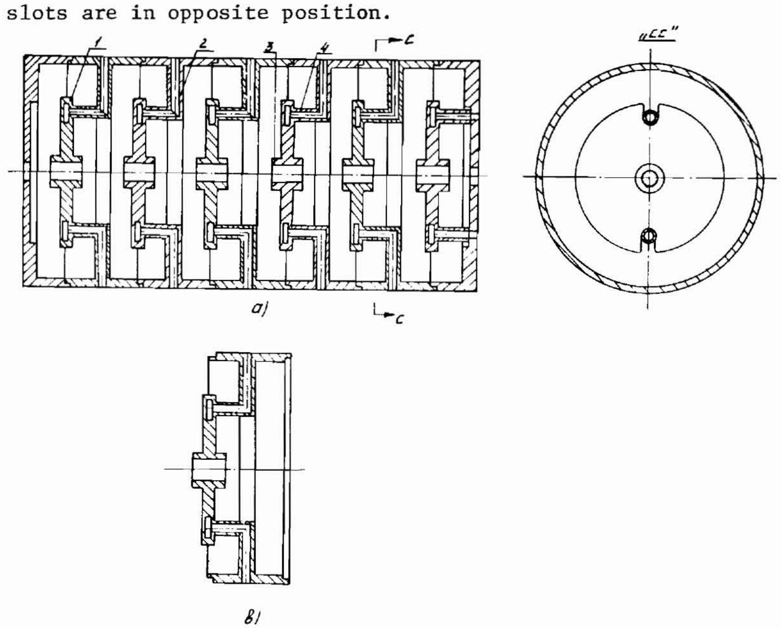

Fig. 6 Cross section of disc-and-washer loaded accelerating structure

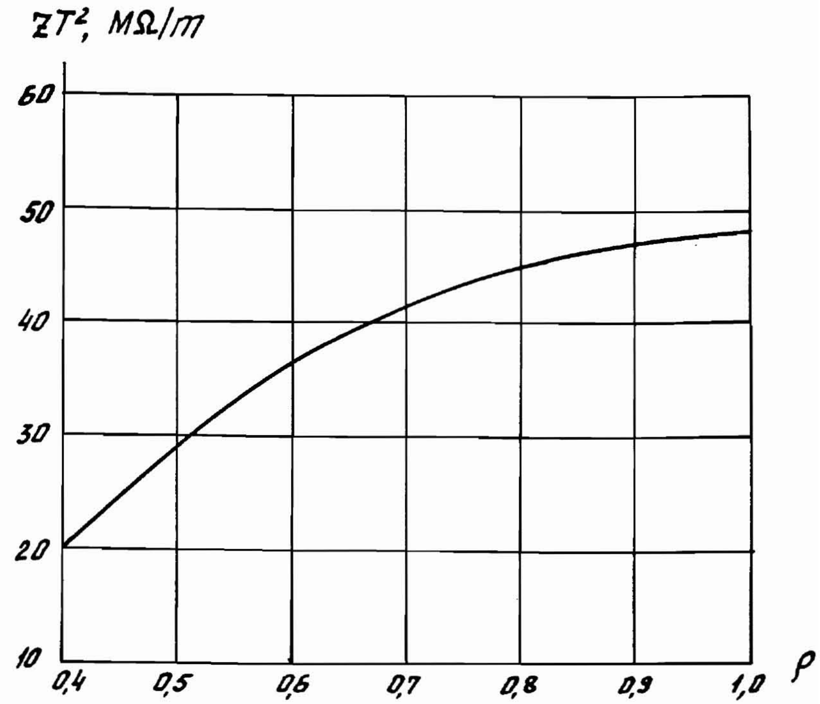

Fig. 7 Effective shunt impedance of disc-and-washer loaded accelerating structure (calculated values).

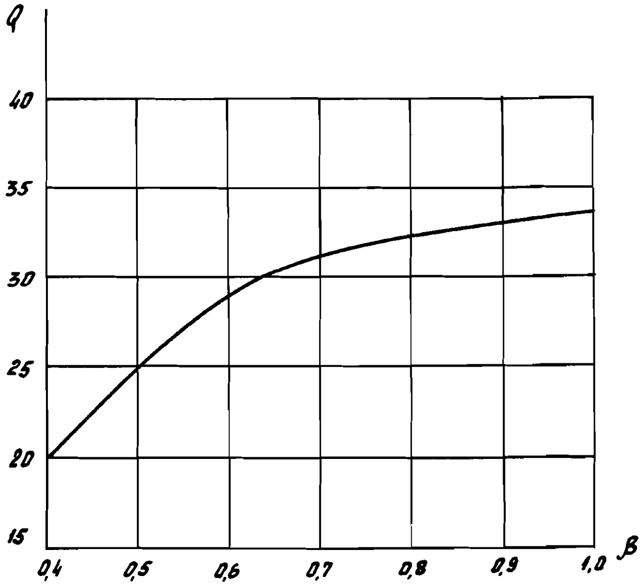

Fig. 8 Q-factor of disc-and-washer loaded structure (calculated values)

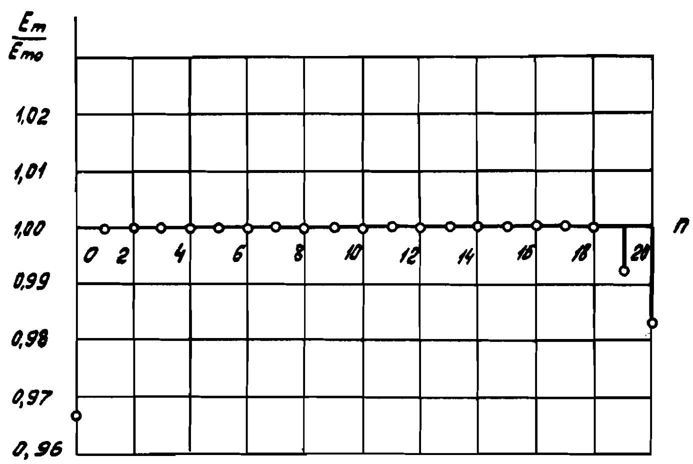

Fig. 10 Electric field distribution in model of disc-and-washer loaded accelerating structure; n is the consecutive number of accelerating gap.

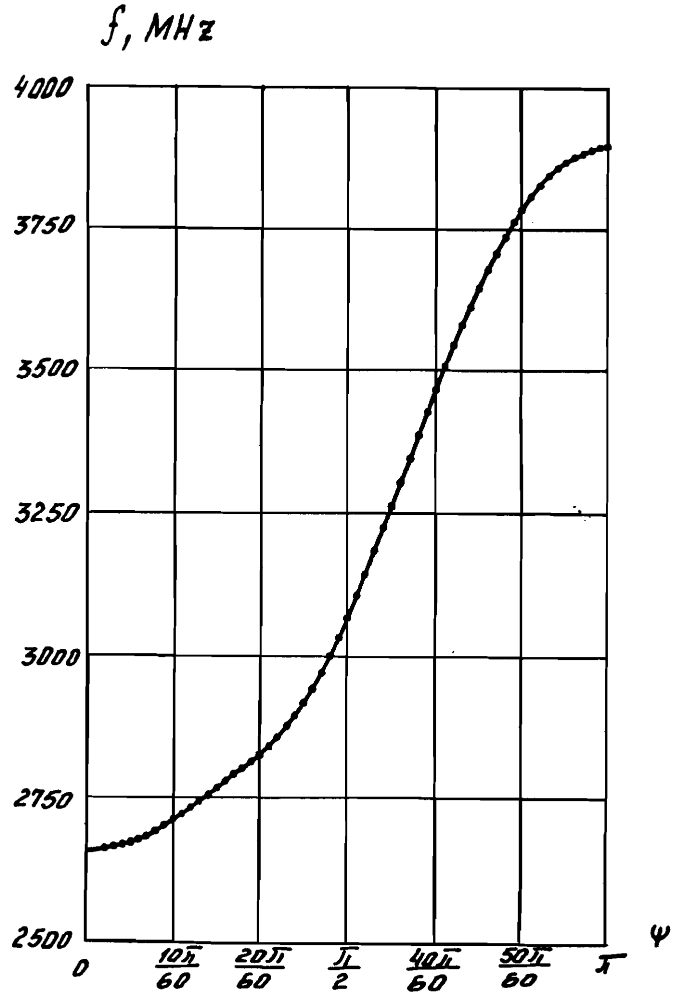

Fig. 9 Dispersion curve of disc-and-washer loaded structure

DISCUSSION

Wilson, SLAC: What was the inner diameter of the first structure?

Elyan: 4 cm.

Miller, SLAC: Can you compare shunt impedance of annular and side-coupled structures?

Elyan: The shunt impedance should be the same, but fabrication is simpler.

Chairman Wheeler: Is the project funded?

Elyan: Yes, the design study is funded.