RECTANGULAR MICROTRON ACCELERATING STRUCTURE

N.P. Sobenin, and V.N. Kandrunin, Moscow Engineering Physics Institute,
Moscow, Kashirskoe sh. 31, 115409, Russia.
V.N. Melekhin, Institute for Physical Problems, Russian Academy of Science,Moscow, Russia
A.I. Karev, Physical Institute, Russian Academy of Science, Moscow, Russia.
V.I. Shvedunov, Institute of Nuclear Physics, Moscow State University, Moscow, Russia.
W.P. Trower, Physics/Virginia Tech, Blacksburg VA 24061 USA.

To simplify construction and improve first orbit dynamics for our mobile 70 MeV Race-Track Microtron we have studied a biperiodic accelerating structure with rectangular cavities. This structure has somewhat higher effective shunt impedance than a biperiodic circular structure with inner coupling cells. It also focuses in one direction and so can be used to construct accelerating-focusing sections for other types of particle accelerators. We present here the results of our experimental and simulation investigations of the electrodynamic parameters of this structure.

I. INTRODUCTION

A biperiodic accelerating structure has as its principle advantage over a disk-loaded guide the possibility of attaining a desired energy with a given **R**adio **F**requency power in a shorter structure, an essential feature for a **R**ace-**T**rack **M**icrotron. We employed such a biperiodic structure based on cylindrical cavities in our original multi-purpose mobile 70 MeV RTM design [1]. Further advantages accrue for our application by using a so-called rectangular structure linac without axial symmetry [2] despite some particle dynamic peculiarities from the changed focusing conditions. In a classical circular microtron the relativistic particle transverse momenta are increased proportional to $J^{-1/2}$ when traversing a rectangular cavity with circular apertures [3]. For vertical motion $J_v = \dfrac{B^2}{A^2+B^2}$, where A and B are, respectively, the vertical and horizontal cavity dimensions. For the corresponding horizontal motion, $J_h = \dfrac{A^2}{A^2+B^2}$. In square and circular cross section cavities there is no momentum change in either motion so there is no focusing after several RTM orbits. On the contrary, a vertically elongated resonator focuses in the vertical while defocusing in the horizontal for all electron orbits, $\Delta p_h = -\Delta p_v$. This result is shown in Fig. 3 of ref. 2 as linac focal lengths with electron energy.

Taking into consideration the above, we have found the electrodynamic parameters of the proposed structure which we present here. The results of our beam dynamics calculations for a RTM with the rectangular biperiodic structure are reported elsewhere [2].

II. THE STRUCTURE

A biperiodic accelerating structure based on prismatic cavities is shown in Fig.1. The accelerating cells have the dimensions of a regular rectangular waveguide, B=55 mm and A=110 mm, while the coupling cell narrow wall dimensions are determined with consideration for coupling slots and central beam apertures in tubes. The coupling coefficient between adjacent cells, as well as the central aperture diameter and drift tube dimensions, were chosen to be close those of our original axially symmetrical biperiodic structure [1]. We calculated and experimentally investigated two biperiodic structure variants with prismatic cavities whose dimensions are presented in Table I.

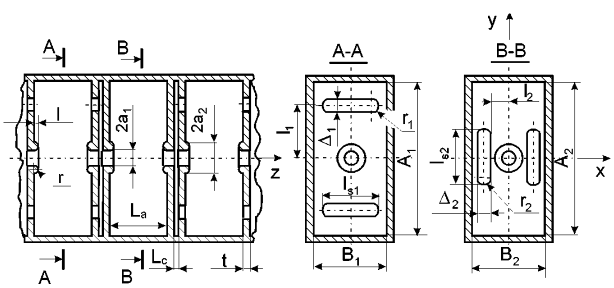

Fig. 1. Biperiodic structure with a rectangular cavities.

To determine the coupling cells dimensions which provide the desired coupling coefficient we use [4]

$$k_c = -\frac{Z}{Z_0} N \frac{l_s^3}{6} H_{n.a} H_{n.c} \quad , \qquad (1)$$

where Z is the coupling slot wave impedance and Z_0, is the free space impedance. $H_{n.a}$ and $H_{n.c}$, the normalized magnetic fields at the slot position, can be written as

$$H_{n.a} = \sqrt{\frac{H_a^2 \mu}{2W_a}} \quad , \qquad H_{n.c} = \sqrt{\frac{H_c^2 \mu}{2W_c}} \quad , \qquad (2)$$

where W_a is the energy stored in the prismatic accelerating cell and W_c in the coupling cell when operating in E_{110} mode. H_a and H_c can be determined by averaging over the coupling slot area, S , the rectangular cavities being exited in E_{110} mode:

$$H_a = \frac{1}{S}\int_S H_a(x,y)dS \quad , \qquad H_c = \frac{1}{S}\int_S H_c(x,y)dS \quad . \qquad (3)$$

Table I. Structure dimensions in millimeters.

N	A_1	B_1	L_a	A_2	B_2	L_c	t	$2a_1$	$2a_2$	r	l	Δ_1	l_1	l_{s1}	r_1	Δ_2	l_2	l_{s2}	r_2
1	110	55	42.5	110	53.5	3	4.2	10	20	2.5	3.85	8	41.5	32.9	4	8	20	18.0	4
2	110	55	42.5	110	51.33	3	5.5	10	20	---	2.85	8	41.5	32.9	4	8	20	19.7	4

III. ELECTRODYNAMIC CHARACTERISTICS

We calculated the electrodynamic parameters of two biperiodic structures with rectangular cavities using the upper half of the structure between planes A-A and B-B of Fig.1. For electric walls the 0, $\pi/2$, and π modes are excited. For magnetic walls the $\pi/2$ coupling cell mode is excited. For an electric-magnetic wall combination the structure supports the $\pi/4$ and $3\pi/4$ modes. We used a 50,000 nodes in our simulations [5] and took β_{ph} = 0.994 in variant 1 which gave a Q factor of 12,500. For variant 2 we chose the relative phase velocity to be β_{ph}=1 at $f_{\pi/2}$ = 2,941 MHz with the resulting structure dispersion curve shown in Fig. 2. The coupling coefficient, K_c, is 3.5%, the field nonuniformity coefficient, K_d, is 1.01, the unloaded Q factor is 12,430, and the effective shunt impedance, $r_{sh.eff,}$, is 95.6 MΩ/m. The electric field overstrength coefficient, defined as the ratio of the maximum electric field at the structure surface (x = 3.75 mm, y = 9.86 mm, and z = 15.65 mm) to that on the structure axis, is ~2.5. All these parameters, the effective shunt impedance excepted, differ only slightly from those of our biperiodic structure with cylindrical cavities [1]. $r_{sh.eff}$ increases by almost 25% which is encouraging for our compact RTM application. To experimental tune the structure the sensitivity functions are very important and were calculated for variant 2 to be:

$$\frac{\partial f}{\partial B_2} = -40\frac{\text{MHz}}{\text{mm}}, \quad \frac{\partial f}{\partial l_{s1}} = -1.5\frac{\text{MHz}}{\text{mm}},$$
$$\frac{\partial f}{\partial 2a_2} = -45.5\frac{\text{MHz}}{\text{mm}}, \quad \frac{\partial f}{\partial l_{s2}} = -33\frac{\text{MHz}}{\text{mm}}.$$

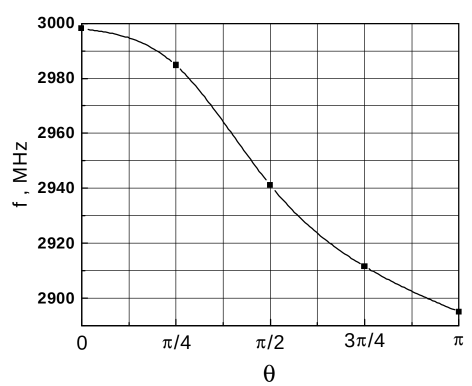

Figure 2. Structure variant 2 dispersion curve.

IV. ACCELERATING STRUCTURE MEASUREMENTS

We conducted experiments to determine the structure dimensions which would support the $\pi/2$ mode frequency with phase velocity, β_{ph}, of 1, coupling coefficient of ~3%, and a uniform field over the entire accelerating structure length. With these conditions realized we could compare the effective shunt impedance, unloaded Q factor, and field overstrength coefficient of this structure with our original one having cylindrical cavities.

We made experiments and calculations to find accelerating and coupling cells coupling slot positions as shown in Fig.1. The slot width in both disks, Δ_1 and Δ_2, were chosen to be 8 mm with rounded ends of radius 4 mm. The coupling slot dimensions in disks which were cut parallel to the narrow cavity walls were approximated using eqns. (1)–(3), then corrected using uniform periodic structure prototype data, and were l_1 = 41.5 mm, and l_{s1} = 32.9 mm. The coupling slots cut parallel to the cavity broad walls had Δ_2 = 8 mm at a distance of ~20 mm from the structure axis, l_2. The desired coupling was achieved by varying the slot length l_{s2}. To determine the accelerating and coupling cells frequencies, $f^a_{\pi/2}$ and $f^c_{\pi/2}$ we assembled resonant prototype sections. We detuned the accelerating and coupling cells, seen in Fig.3a and b, respectively, using massive cylindrical bushes having an inner diameter of 2a. During tuning we maintained the accelerating cell frequency constant and adjusted the coupling cell frequency by changing B_2 until $f^a_{\pi/2} = f^c_{\pi/2}$.

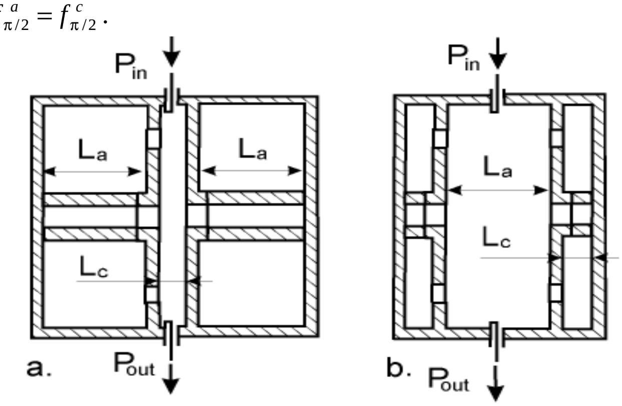

Fig. 3. Resonance tuning of (a) coupling and (b) accelerating cells.

To check the accelerating and coupling cells tuning we assembled a resonant prototype consisting of an accelerating cell, two accelerating half-cells, and two coupling cells in which we measured the resonance frequency and electric field distribution using the small perturbations technique [4]. If a disruption in the dispersion curve at π/2 mode occurred or if unequal field amplitudes appeared in the full and half accelerating cells we changed the coupling coefficient by varying l_{s2} When the field amplitude in the full cell was higher than that in the half cells the l_{s2} slots dimensions in the adjacent disks were increased. After this procedure we remeasured $f^c_{\pi/2}$ and $f^a_{\pi/2}$, and adjusted $f^c_{\pi/2}$ so that $f^c_{\pi/2} = f^a_{\pi/2}$.

To measure the field we used 0.14 mm diameter cylindrical metallic beads with the lengths of 2.5 and 3.5 mm and form factors $k^b_z = 2.37\times10^{-20}$ and $8.9\times10^{-21}\,\mathrm{m^2s/\Omega}$, respectively. In some measurements we used 0.9 mm diameter ceramic bead with the length of 6 mm and form factor $k^c_z = 8.2\times10^{-20}\,\mathrm{m^2s/\Omega}$. Since our experiments preceded our calculations we did not obtain β_{ph}=1 for the first tuned structure variant. We only got β_{ph}=0.994 at the frequency 2,898 MHz so we continued our experiments with the variant 2 structure.

The measured electric field strength on the structure 2 prototype axis is shown in Fig. 4, where the length is 102 mm. We calculated the effective shunt impedance using this field distribution to be ~98 MΩ/m and the π/2 mode frequency was 2,938.7 MHz.

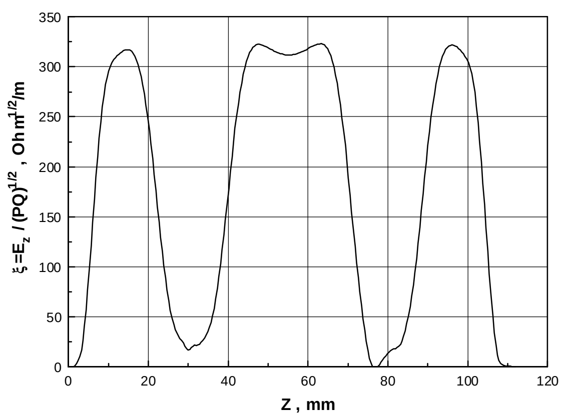

Fig. 4. $\xi = \frac{E_z}{\sqrt{PQ}}$ vs Z-coordinate.

V. CONCLUSIONS

For RTMs a prismatic cavity biperiodic structure is preferred to a cylindrical cavity structure because the injection scheme is simplified since the electron beam can make a full first orbit rotation without additional equipment. This asymmetric structure has a Q factor and field overstrength coefficient equal to, and effective shunt impedance larger than, other possible accelerating structures while additionally focusing in one transverse direction.

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