HIGH-FREQUENCY RECTANGULAR ACCELERATING STRUCTURE FOCUSING IN THE 70 MeV RACE-TRACK MICROTRON

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Abstract

Our mobile 70 MeV race-track microtron has a narrow rectangular accelerating structure so that it can be bypassed by electrons on the first orbit. Rare-earth permanent magnet dipoles recirculate the beam and provide vertical focusing. Extended oval vertical slots in the accelerating structure provide horizontal high-frequency focusing.

1 INTRODUCTION

In our previous 70 MeV mobile **R**ace**T**rack **M**icrotron designs, we first used a circular crossection accelerating structure into which the beam was reflected after the first linac passage [1,2]. We then introduced a rectangular crossection accelerating structure sufficeintly narrow in the median plane so as to be bypassed by first passage electrons [3,4].

Beam focusing, provided by a quadrupole singlet or wiggler-like lenses, increased the size, complicated the construction, and made difficult the tuning of the RTM. We have solved these problems using **H**igh-**F**requency focusing first suggested for circular microtrons [5]. Here we introduce oval vertically elongated transit slots in the accelerating cavity. The resulting horizontal focusing overwhelms the HF magnetic field defocusing causing the beam to focus horizontally and defocus vertically.

The nonuniform two-dimensional end magnet field, which decreases linearly with distance from the magnet inner edge, provides the necessary vertical focusing [1,6]. On the first orbits the reverse magnet fringe field is used to focus. We generate both the main and reverse fields using **R**are-**E**arth **P**ermanent **M**agnets [7], and the linac and end magnets alone accelerate and focus the beam, thus reducing the RTM design complexity to that of a circular microtron.

2 HIGH-FREQUENCY FOCUSING

The transit slot focusing forces at small horizontal, x, and vertical, z, displacements from the slot axis coinciding with the cavity axis (RTM median plane has z = 0) are [8]

$$E_x \approx -(1-\alpha)x\frac{\partial E_y}{\partial y}, E_z \approx -\alpha z\frac{\partial E_y}{\partial y} \qquad (1)$$

where by Maxwell equations and symmetry $\alpha \approx 1$ for horizontally extended slots, $\alpha \approx 0$ for vertically extended slots, and $\alpha \approx 0.5$ for circular slots. The universality of these realationships is borne out by analytical solutions and computer simulations [9].

The HF magnetic field vertical focusing power near a rectangular cavity axis is deterimined by the cavity crossectional dimensions [8],

$$G = \frac{{d_x}^2}{{d_x}^2 + {d_z}^2}, \qquad (2)$$

The high energy electrons in their passage through the cavity acquire a vertical momentum

$$\Delta p_z = \frac{eE_0 z}{c}\left[(G-\alpha_i)cos\phi_i - (G-\alpha_o)cos\phi_o\right] \qquad (3)$$

where E_0 is the on-axis cavity accelerating field amplitude, ϕ is the accelerating phase of electrons near the inner cavity walls, and the indices i and o refer to the slots at the entrance and exit, respectively. To calculate Δp_x we let $z \to x$, $G \to 1 - G$, $\alpha \to 1 - \alpha$.

For symmetric slots and cavities, either circular or square, $G = \alpha_i = \alpha_o = 0.5$, $\Delta p_x = \Delta p_z = 0$, and slot entry focusing is exactly canceled by the sum of the HF magnetic field and the slot exit defocusing. Thus, the transverse momentum varies only due to transverse coordinate change [8] and so the focal length varies quadratically with electron energy [10].

In the high energy limit

$$\frac{\Delta p_x}{x} = -\frac{\Delta p_z}{z} \qquad (4)$$

for all possible cavity and transit slots shapes with quadrupole symmetry. This relation is useful in verifying numerical calculations.

Under the usual approximations [5,8], the field distortion near the transit slots at an electron trajectory position, ΔE_y, changes the energy gain,

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$$\Delta W = \frac{eE_0\lambda}{2\pi}\left[\sin\phi_o - \sin\phi_i + Ax^2 - Az^2\right],$$
$$A = \frac{2\pi^2}{\lambda^2}\left[\alpha_i \sin\phi_i - \alpha_o \sin\phi_o\right] \quad (5)$$

where λ is the accelerating field wave length. $A = 0$ and so the energy gain is independent of position in axially symmetric cavities. In all other cases this position dependence perturbs the RTM phase motion.

3 THE NUMERICAL RESULTS ON BEAM DYNAMICS

Using our code [11] based on focusing theory [5,8], we simulated the RTM beam dynamics with HF focusing and found that our accelerator parameters, summarized in Table I, are similar to those previously obtained [3]. However, our present design, seen in Fig. 1, is much simpler in that we now have only the **E**lectron **G**un, the chicane magnets (**MC1**-**3**), the rectangular **A**ccelerating **S**tructure, the REPM end magnets (**M1**-**2**), the extraction magnets (**ME1**-**2**), and the correcting **C**oils.

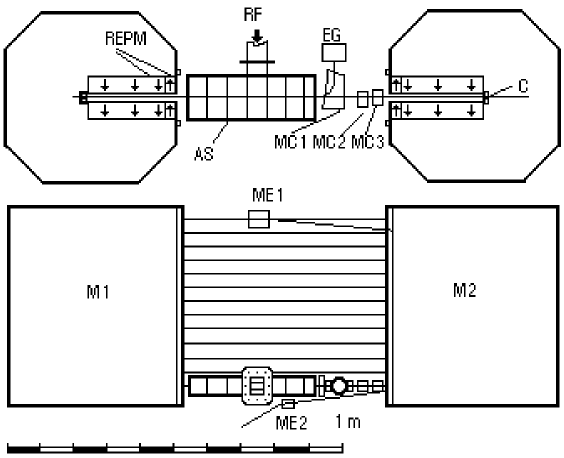

Figure 1. RTM schematic.

Table I RTM parameters.

Injection energy	55 keV
Energy gain per turn	5.2 MeV
Number of turns	14
Output energy	73 MeV
Current at 73 MeV	31 mA
Emission current	340 mA
Electron efficiency	70%
Operating frequency	2450 MHz
Klystron pulsed power	5 MW
End magnets induction	0.9 T
RTM dimensions	1.8x0.6x0.6 m^3

Transverse oscillations are stable within an initial phase interval $\Delta\phi \approx 40°$. Evaluating a variety of slot and cavity shapes, we found G = 0.28 (d_x/d_z = 0.62) was optimal and gave α = 0.8 for the accelerating structure entrance cavity slot and α = 0.075 for the rest of the structure. At 73 MeV the ratio of output-to-total power absorbed by the beam is 70% determined mainly by the phase capture, which can be increased using a prebuncher [3].

4 CONCLUSION

Using our analytic HF magnetic field focusing results to validate our simulations, we found that most of the focusing/defocusing in each accelerating structure cavity cancel which requre that these fields be calculated with high accuracy. The three-dimensional computer cavity field simulations are required to account for aberrations and to find transit slot and cavity shapes that result in the α and G obtained here. As a result of such simulations our electron efficiency will possibly slightly be changed, however, the principal RTM design features presist -- a rectangular accelerating structure with oval transit slots and nonuniform end magnet fields -- as well as our design goals of simplicity, compactness, reliability, and economy.

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