DESIGN OF A RACETRACK MICROTRON TO OPERATE OUTSIDE THE PHASE STABILITY REGION

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Abstract

The beam optics design of a small 5-turn cw racetrack microtron is described. This microtron is the first stage of a two-stage microtron of 31 MeV maximum energy, and 50 μA maximum current. The microtron booster is fed by a 1.8 MeV injector linac. This configuration was chosen in order to maximize the final energy of the system with the available RF power, and, as a result, it was necessary to operate the first stage outside the ideal orbital stability region. The separation between successive return orbits is not constant, and the system presents large phase oscillations from one orbit to another. Nevertheless it was possible to find geometrical and magnetic field strength configurations that allow the extraction of a 4.9 MeV beam, within the design goals for the main acceleration step.

INTRODUCTION

The Physics Institute of the University of São Paulo (IFUSP) is building a 31 MeV continuous wave (cw) racetrack microtron [1,2]. This two-stage microtron includes a 1.8 MeV injector linac feeding a five-turn microtron booster that increases the energy to 4.9 MeV. After 28 turns, the main microtron delivers a 31 MeV cw electron beam. The injector has a capture section and a pre-accelerating section; therefore the complete accelerator has four RF accelerating sections, operating at 2450 MHz. Figure 1 shows an isometric view of the machine in the accelerator building.

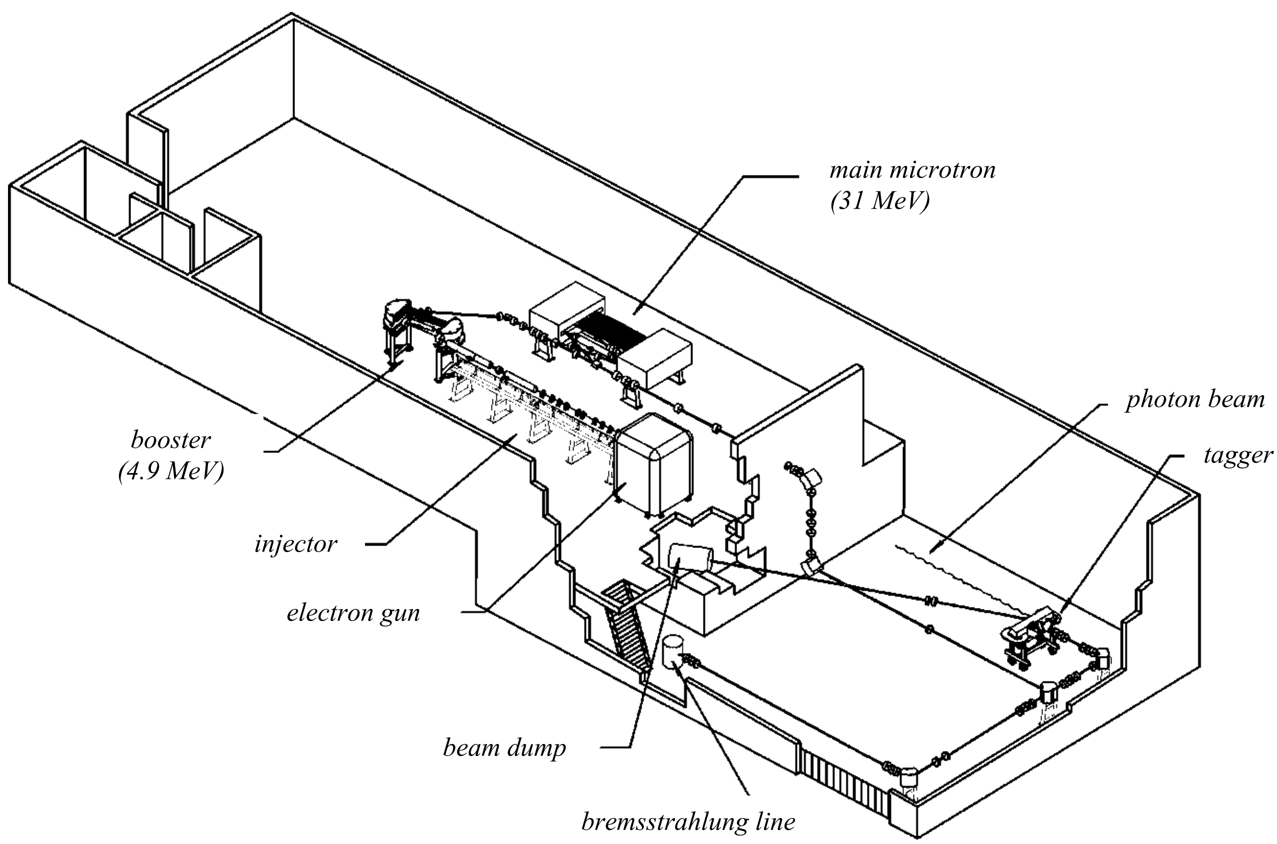

Figure 1 – Isometric view of the accelerator in the accelerator building.

This cascaded configuration was adopted in order to maximize the final energy of the system, keeping costs within our limited budget, what meant powering the whole system with a single RF source, namely a 50 kW cw klystron. Several configurations were tried, with different power distributions, but the one that allowed achieving the highest final energy, with reasonably conservative parameters, included a microtron booster. This solution allowed increasing the injection energy of the main microtron to close to 5 MeV, reserving enough RF power to push the final beam energy to 31 MeV, approximately 20 % higher than the other configurations.

In this paper we describe the design of the first stage of this configuration, the microtron booster. Due to the low injection energy, 1.8 MeV, the booster operates outside the phase stability region, and so is restricted to a small number of turns.

STABILITY CONDITIONS

The stability conditions of a racetrack microtron are those that allow synchronous acceleration of the electrons and constant spacing between consecutive orbits. They are very well known and identical to those of the conventional microtron [3]:

$$\frac{2\pi r_1 + 2L}{\lambda \beta_1} = \mu \quad (1)$$

$$\frac{\Delta W}{m_0 c^2}\frac{B_0}{B} + \frac{2L}{\lambda}\left(\frac{1}{\beta_{n+1}} - \frac{1}{\beta_n}\right) = \nu \quad (2)$$

where μ is the length of the first orbit in integral numbers of wavelength;

r_1 is the first orbit radius;

L is the separation between magnets;

ΔW is the energy gain per turn;

λ is the accelerating RF wavelength;

β_n is the ratio between the electron speed at turn number n and the velocity of light;

B is the magnetic field of the end magnets;

$B_0 = \dfrac{2\pi m_0 c^2}{e\lambda}$ is the cyclotron field;

ν is the integral increment in the period between two consecutive orbits.

For ultra-relativistic electrons, $\beta_{n+1} \approx \beta_n \approx 1$, and eqn. (2) becomes much simpler. That is the situation in ordinary microtron designs, when the injection into the recirculating path is done with sufficiently high energy. In our case, however, it is not possible to apply the above approximation, and the period increment between orbits is not constant. This clearly prevents phase stability, but we were able to find a reasonably stable condition for a few turns, increasing the beam energy high enough to allow insertion on the second stage. The simulation, using the PTRACE code [4}, was divided in two steps: first we simulated a closed RTM (without insertion or extraction magnets) just to look for a possible solution. After finding a reasonable solution, we introduced the insertion and extraction devices and optimized the configuration.

Figure 2 shows some results of the first simulations, namely the phase shift versus energy gain per turn on a hypothetical 10-turn machine.

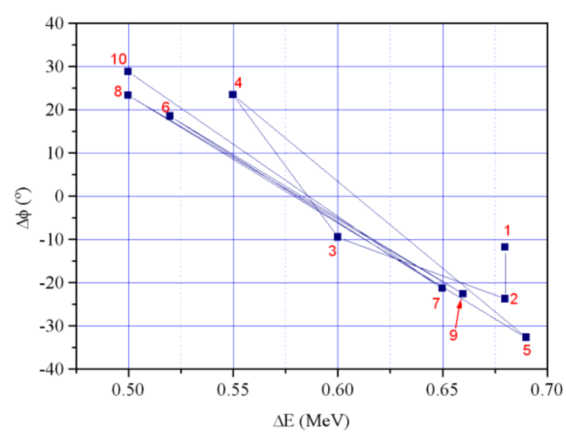

Figure 2 – Phase shift versus energy gain per turn

It is clear from Fig. 2 that a large phase shift oscillation builds up after the fourth turn, but it is also clear that, if one limits the number of turns to five, it is possible to design a stable RTM, that will increase the energy from 1.8 to 4.9 MeV, which is high enough for injection on the main accelerator.

Next step was the simulation of a more realistic machine, including injection and extraction devices. The injection line introduced a new difficulty, due to the proximity between one of the end magnets (N magnet) and a small 15°-dipole (D3) necessary to make the return line of the injected beam parallel to the accelerating structure, as shown in Fig. 3.

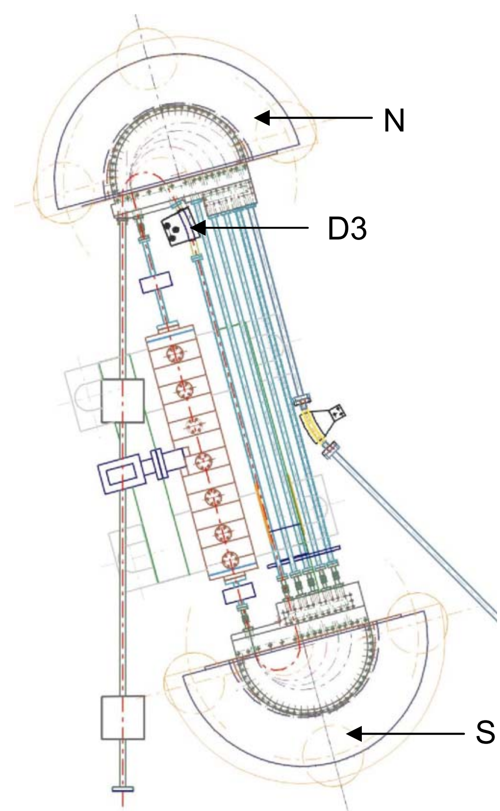

Figure 3 – Schematic drawing of the booster. The distance between the pole faces of the end magnets is 1555.4 mm

The magnetic induction field of the D3 dipole is much smaller than that of the end magnet, and the distance between their pole faces is only about 10 cm, so the field in this region is a combination of their fringing fields. Figure 4 shows the field configuration resulting from the measured fields of both magnets [5,6] and their composition [7].

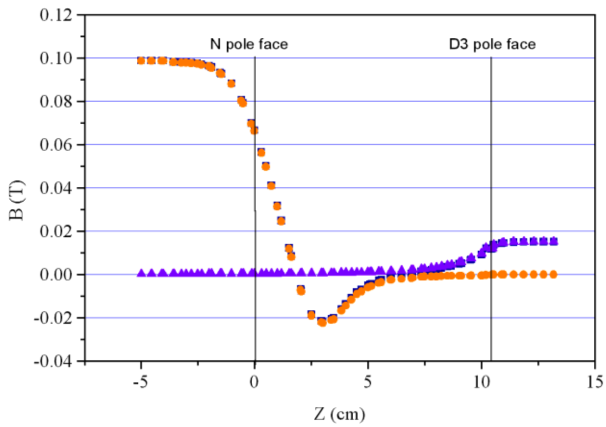

Figure 4 – Field distribution in the region between the end magnet N and the D3 dipole. N end magnet, circles; D3 dipole, triangles; composition, squares.

RESULTS AND CONCLUSIONS

Using the combined field shown in Fig. 4, we optimized the configuration of the booster with the PTRACE code. Table 1 summarizes the main characteristics of the booster, after the optimization process.

As can be seen from Table 1, the path length increment was not constant, nevertheless this configuration is able to boost the beam energy to a level appropriate for injection in the main RTM, with an average energy gain of 0.625 MeV per turn. The mechanical design shown in Fig. 3 was made after the optical design suggested by these simulations.

With this configuration, the RF power from the klystron tube is divided as: 9 kW for each of the structures of the injector linac, 7 kW for the booster and 13 kW for the main stage microtron.

ACKNOWLEDGMENTS

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Table 1 – Main characteristics of the booster

Turn	E (MeV)	β	ν	ΔL (cm)	ΔE (MeV)	Δϕ (º)
Injection	1.77	0.9746	0.8816			
1	2.44	0.9849	1.0373	12.643	0.68	-11.81
2	3.12	0.9900	0.9657	13.048	0.68	-23.75
3	3.72	0.9927	0.9066	12.563	0.60	-9.50
4	4.27	0.9943	1.1371	11.444	0.55	23.40
5	4.95	0.9956		13.353	0.69	-32.74

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