THE IFUSP MICROTRON NEW CONFIGURATION

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Abstract

In this work we present a new design for the IFUSP main microtron accelerator. The new configuration improves the maximum output energy and eases the operation of the machine. The accelerator will be able to deliver 38 MeV after 43 turns. The input energy was reduced from 4.9 to 2.5 MeV, so that the first microtron stage, the booster, could be eliminated, reducing the number of synchronous stages and easing the operation. We present results for the energy, energy gain and phase slip per turn. We also discuss the design of the insertion and extraction lines.

INTRODUCTION

The Laboratório do Acelerador Linear (LAL) of the Instituto de Física da Universidade de São Paulo is building a continuous wave (cw) electron race-track microtron (RTM). The IFUSP RTM [1] is a two-stage microtron that includes a 1.8 MeV injector linac feeding a five-turn microtron booster [2] that increases the energy to 4.9 MeV.

The Lab will have two main beam lines, one serving the photon tagger (bremsstrahlung monochromator), and the other dedicated to the production of X-rays by coherent bremsstrahlung.

BASIC PRINCIPLES

The basic conditions for synchronous acceleration in an RTM, which can be seen schematically on figure 1, are the following:

1) The period of the first orbit must be equal an integral number (μ) of periods of the RF accelerating field; and

2) The period of each orbit must be an integral number (ν) of RF periods larger than that of the previous orbit. These two conditions may be written in the form:

$$\mu = \frac{2\pi W_o}{c\lambda B} + \frac{2D}{\lambda} \qquad (1)$$

$$\nu = \frac{2\pi}{c}\frac{\Delta W}{\lambda B} \qquad (2)$$

where W_o is the initial beam energy (in MeV), B is the magnetic field (in T), λ is the RF wave length, D is the distance between the magnets, and ΔW is the energy gain per turn (in MeV). The other constants have their usual meaning.

Equations 1 and 2 consider that the initial energy of the beam is ultra-relativistic; it means that there is no significant change in the particle velocity during the acceleration process.

In addition to that, it was considered that the magnets have a hard edge fringe field (HEFF); therefore, the trajectory of the particles in the magnets is a perfect semi-circle. A real magnet, however, has fringe fields (FF) that introduce deviations from the ideal trajectory, these variations being more severe on the low-energy orbits. In practice there are some ways to minimize the effects of the FF [3].

Another important aspect is the phase of the beam with respect to the RF (φ). In order to have a stable solution [2-4], the maximum phase is given by:

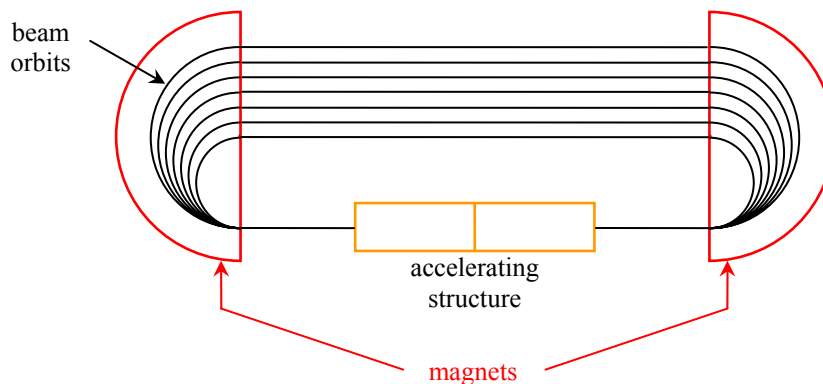$$\varphi = -\tan^{-1}\left(\frac{2}{\nu\pi}\right) \qquad (3)$$

Figure 1: Schematic drawing of a race track microtron.

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THE IFUSP MAIN MICROTRON

The IFUSP main microtron operates with a frequency of 2.45 GHz (λ = 12.24 cm). The accelerator structure has a length of 104.0 cm [5]. The magnets use reverse clamps to minimize FF effects [6].

From equations 1 and 2, and characteristics of the accelerating structure, we obtain the theoretical operation values. These values are summarized on table 1.

Table 1: Theoretical operation values for the microtron

ν	1
μ	6
λ (cm)	12.24
B (T)	0.1409
ΔW (MeV/turn)	0.82
W_o (MeV)	4.94
φ_{max} (degrees)	32.5
D (cm)	257.04

The particle phase (φ) with respect to the RF was chosen to be 22°.

Longitudinal Simulations

In order to optimize the operation values given above, simulations were done using the PTRACE code [7]. To be sure that the input energy is such that all orbits satisfy the conditions for synchronous operation, we have done the simulation backwards, that is, we start the simulation using the expected final energy and use a negative energy gain per turn. The result of this simulation is shown on figure 2.
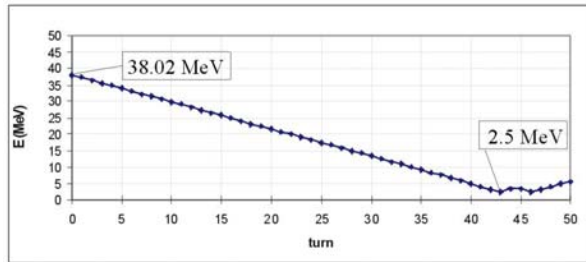

Figure 2: Energy per turn (negative energy gain).

As it can be seen, the energy has a linear evolution down to 2.5 MeV. This means that the injection energy in the main microtron could be reduced from 4.94 to 2.5 MeV, suggesting that the machine could operate without the microtron booster.

The simulations suggest that the initial phase should be located outside the region of stability given by equation 3.

Using these results, we have simulated the microtron running now with positive energy gain. Figures 3, 4 and 5 show, respectively, the energy, energy gain and particle phase per turn.
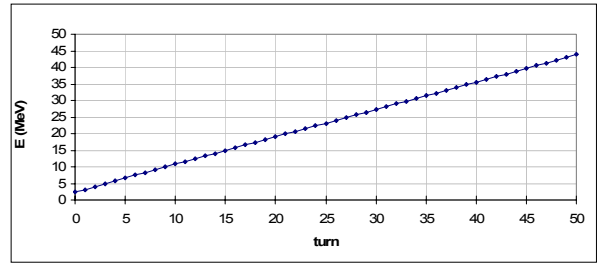

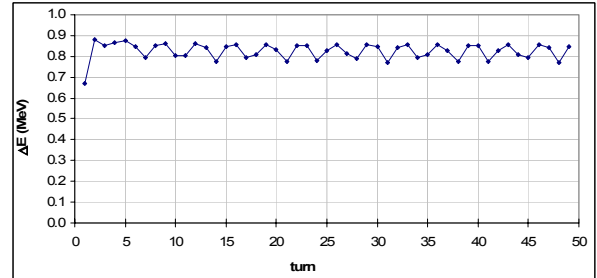Figure 3: Energy per turn (positive energy gain).
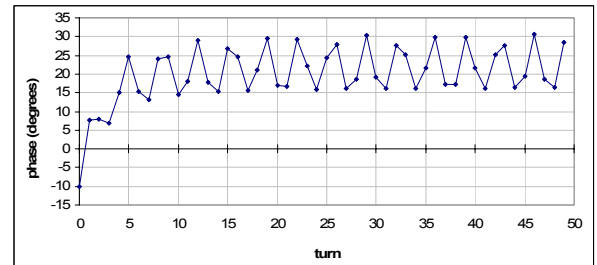

Figure 4: Energy gain per turn.

Figure 5: Particle phase per turn.

The final energy, 38 MeV, is reached after 43 turns. The average energy gain is 0.83(3) MeV/turn. As mentioned before, in order to reduce the initial energy to 2.5 MeV, it is necessary to inject the particles with a phase located outside the region of stability (-10°). This unusual injection gives to the beam, during the first 3 turns, an energy gain per turn that is not in accordance with the classical microtron stability conditions given by equations 1 and 2.

Nevertheless, the results show that the Microtron could reach a stability condition after 4 turns with an average particle phase of $22(6)^o$.

Table 2 summarizes the results of the simulations.

Table 2: Optimized operation values for the microtron

B (T)	0.1410
ΔW (MeV/turn)	0.825
W_o (MeV)	2.503
$\varphi_{initial}$ (degrees)	-10.1
D (m)	256.65

INJECTION AND EXTRACTION

The results obtained with the simulations presented above imply in a new design for the injection and the extraction lines.

Extraction

The previous version of the main microtron had a final energy of 31 MeV [8]. The beam line that conduces the beam from the main microtron to the experimental room could be maintained [9] because the dipole and quadrupole magnets can handle this more energetic beam [10-11].

The beam extraction from the main Microtron will be done in two steps: a first magnet gives to the beam a small kick and a second septum-like magnet gives the complementary extraction bending. These magnets are being designed.

Injection

The new configuration initial energy is 2.5 MeV. This can be easily reached if we use the accelerator structure of the booster as a third structure of the injector linac.

The two-structure linac delivers 1.8 MeV. The booster accelerating structure can give the additional 0.7 MeV necessary to inject the beam directly from the injector into the main microtron. This implies that we can suppress one synchronous stage, making the operation of the whole machine much easier. On the other hand, a new injection line, from this linac to the main microtron, should be designed. This beam line is under study now.

CONCLUSIONS

The new simulations show that it is possible to reduce the injection energy of the main microtron to 2.5 MeV. In this way we can suppress the microtron booster, reducing the number of the synchronous stages without big changes on the original concept, and easing the operation of the whole machine.

The 4.9 MeV stage (booster) is being commissioned and should start operation during 2005. The mechanical design of the end magnets for the main microtron is being completed. So, during the construction of the main magnets, which should start early next year, we will have some time to operate the booster and decide whether to keep it or not.

ACKNOWLEDGMENTS

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