ELECTRON INJECTION IN CIRCULAR MICROTRON

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Abstract

The circular microtron is a useful machine in the range of 10–30MeV electron energy for applications.The possibilities of injecting the electrons in microtron are analysed, describing various systems. Numerical computations of electronic motion in the resonant cavity were performed, resulting a capture coefficient of about 1/24. In the microtron from the Institute of Atomic Physics, Bucharest the average beam power is 0.5 kW at 10 MeV energy in the first accelerating mode and at 16 MeV energy in the second accelerating mode . In the end possibilities of increasing the capture coefficient are presented.

1 INTRODUCTION

The circular microtron seems to be a possible solution for applications in non-destructive testing, electron beam processing, radiotherapy or activation analysis when an electron accelerator with energy from 5 MeV to 30 MeV is needed. Advantages like simplicity, low cost and easy commissioning are to be mentioned [1]. This is true especially for a small developing country with no previous experience in the accelerator field.

The development of the microtron was a consequence of the efficient injection system proposed by V. N. Melekin [2] and O. Wernholm [3]. In the following , there will be described the two efficient electron injection methods, the calculations performed to develop a model of the injection process and the results obtained at the microtron from the Institute of Atomic Physics, Bucharest.

2 EFFICIENT INJECTION SYSTEMS IN MICROTRON

Computations performed by O.Wernholm [3] proved that in order to increase the capture, it is necessary to inject the electrons with an initial energy of several tenths KeV or higher since the emission has not to depend upon the electrical field from the resonator. Until then, the electrons were injected by field emission from the internal surface of the resonator with the maximum value at non-convenient phases for future stable acceleration [4]. The solution developed by Wernholm was to use a pulsed electron gun located outside the cavity. This was technologically feasible and this solution war further improved up to commercially available microtrons produced by SCANDITRONIX.

Pulse beam currents of 200 mA at 8 MeV energy were reported. Another advantage of this method is the long life of the cathode (about 1000 hours [5]). This fact is due to relative low electrical field strength in the electron gun (comparing with the other injection system where the cathode is located inside the resonant cavity) and due to better capture coefficient, 8-10% [5], so the cathode is not forced to give an emission current too large . The larger cathode lifetime is very important especially in applications as non-destructive testing and radiotherapy and this is a possible explanation of the fact that commercially available microtrons use the electron gun injection system.

The second efficient injection system, developed by V. N. Melekhin, uses a cathode inside the resonator [2]. Due to large microwave electrical field in the cylindrical cavity, electrons gain some energy inside the resonator and they enter the acceleration gap with phases convenient for further stable acceleration [2]. There are possible two accelerating modes: first with Ω =1.2 and the second with Ω =1.8 (see next chapter for the definition of Ω). Both of them were calculated in details and the results were experimentaly confirmed [2]. There is no commercially available machine using this system and a reported pulse current value of 110 mA at 7 MeV [7] is considered non-operational [2].

However, this system is simpler than the electron gun method. In the first accelerating mode there is a relatively large permissible value range and, moreover, there is no need of supplementary modulator supply for the electron gun, like in the Wernholm system. Followingly, microtrons from developing countries -Romania [8], or India [9] - uses the internal cathode injection system.

Improvements in the cathode lifetime when using the Melekhin injection system were reported by the Frascati team [10]. Values of more than 500 hours were obtained [10].

3 THEORETICAL COMPUTATIONS

If we use the natural system of units[2], the motion equation,

$$\frac{\partial}{\partial t} \cdot \frac{m \cdot \overrightarrow{V}}{\sqrt{1 - \frac{\left|\overrightarrow{v}\right|^2}{c^2}}} = e \cdot \overrightarrow{E} + \frac{e}{c} \left(\overrightarrow{V} \times \overrightarrow{H} \right)$$

projected on the axes, becomes:

$$\frac{\partial}{\partial t} \cdot \frac{u}{\sqrt{1 - B^2}} = -\Omega \cdot v + \epsilon \cdot \Omega \cdot v \cdot J_1(x) \sin \varphi$$

$$\frac{\partial}{\partial t}\cdot\frac{u}{\sqrt{1-B^2}}=\Omega\cdot u+\epsilon\cdot\Omega\cdot J_0(x)-\epsilon\cdot\Omega\cdot u\cdot J_1(x)\sin\varphi$$

$\overrightarrow{V}$ is the electron velocity vector, $\overrightarrow{E}$ and $\overrightarrow{H}$ are the electrical and magnetic fields, J_0 and $J_1$the Bessel functions. We considered a cylindrical resonant cavity excited in the TM_{010} mode. The use of the natural system simplifies the computation.

So, $x=\frac{2\pi}{\lambda}\cdot X$, $y=\frac{2\pi}{\lambda}\cdot Y$, (X, Y , the cartesian coordinates; x, y , the corresponding values in the natural system, λ ,the wavelength of the microwave accelerating field inside the cavity, $\varphi=\omega\cdot t$ and $u=\frac{\partial x}{\partial\varphi}$, $v=\frac{\partial y}{\partial\varphi}$, and $\Omega=\frac{H}{H_0}$ where H_0 is the cyclotronic field corresponding to the frequency of the accelerating voltage and $\epsilon=E\cdot/\cdot H$.

The equations (2) and (3) wholly describe the electron motion in the cavity and they can be considered as a model of the electron capture and dynamics. They were numerically integrated with initial values chosen as in [11]. The results showed that, if electrons are injected with an initial energy of 70 keV, from an electron gun, the optimum value of the cavity length is 1.2, in the natural system. In fig. 1 the resonator length, for minimum deviation from the synchronous energy is plotted vs. entrance phase in the cavity.

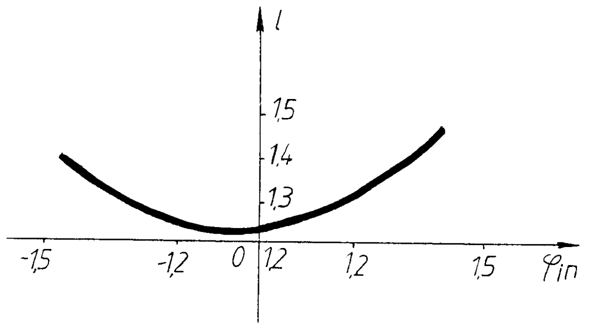

Figure 1: The resonator length, for minimum deviation from the synchronous energy vs. entrance phase in the cavity

4 LIMITATIONS ON THE MAXIMUM BEAM CURRENT

The coherent radiation generated by the electron bunches introduces a first limitation of the beam current accelerated in the microtron. A detailed computation was made by S. P. Kapitza and L.A. Vainshtein [6]. For $\Omega=1$ and an electron energy of 20 MeV, the maximum value of the current was found to be about 1 A [6]. This is far beyond the common values of the accelerated currents in the microtrons and it has only a theoretical importance

The microtron has some particularities.

The beams from all orbits are simultaneously in the resonant cavity. Followingly there is a permanent interaction between these beams and between all these beams and the microwave field from the resonator. When using the Melekhin injection system, the electron beam during injection is interacting with all the other beams from different orbits. These is due to the fact that the whole injection process takes place inside the resonator. Due to these particularities, the interaction between the electron beam and the microwave field inside the resonator leads to oscillations [13]. These cause the shift of the cavity resonant frequency, but the limit is also much higher than the actual beam power in the microtron [2].

Nonlinear resonances in phase motion of single electrons produces high current instability and probably they limit the number of orbits at about 30-40, as in usual microtrons [13], meaning an energy limit of 40-50 MeV. The values of 27 MeV energy, 80 mA - pulse current, 35 μA average current obtained with a 28 -orbit microtron seems to be the best obtained [13].

Since the theoretical limits are not yet to be practical for usual microtrons, simpler ways to increase the beam power are possible. Higher efficiency mode [2], non-sinusoidal accelerating field [14] or optimization of the resonator length [13] are practical solutions of this problem. But increasing the generated microwave power is also a practical possibility. This way, a microtron working with a frequency of about 500 MHz can be another approach. In this frequency range, vacuum tubes - triodes - with high generated power are available. Of course, the microtron sizes will be larger, but limiting at 8 orbits, about 5-6 MeV using the higher efficiency mode can be an interesting perspective. This way, at 5-6 MeV energy (a sufficient value for radiation processing) the microtron is small enough and this solution is to be developped in the future.

5 ELECTRON INJECTION IN THE MICROTRON FROM THE INSTITUTE OF ATOMIC PHYSICS , BUCHAREST

In the 17-orbit microtron from the Institute of Atomic Physics, the internal cathode injection system, developed by V. N. Melekhin is used. The main argument was its technological simplicity and the absence of an additional power modulator for the electron gun needed for the Wernholm injection system.The shorter cathode lifetime is a disadvantage wich can be overpassed, as shown in [10].

In our case, pulse beam current was about 40 mA at 11 MeV (first accelerating mode) and 15-20 mA at 16.5 MeV (second accelerating mode). The duty ration is about 10^{-3} (pulse length 2.5 μs and repetition frequency 400 Hz). These values are stable during microtron operation [8].

The cathode lifetime is about 100 hours. There will be performed work to improve this value, according to the method described in [10].

6 REFERENCES

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