SOME CONSIDERATIONS ON ELECTRON INJECTION IN THE 17-ORBIT MICROTRON FROM THE INSTITUTE OF ATOMIC PHYSICS, BUCHAREST

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1. INTRODUCTION

Among the electron accelerators with energies between 5 MeV and 30 MeV, the circular microtron seems to be an advantageous solution for applications as non-destructive testing, electron beam processing, radiotherapy and activation analysis. For a small, developing country, its simplicity and its easy commissioning due to the large range of permissible values of the acceleration parameters are serious arguments when deciding which type of electron accelerator is better to develop [1].

The development of the microtron was a consequence of the efficient injection systems proposed by V.N. Melekhin [2] and O.Wernholm [3].

The progress in injection system improved the electron capture and made possible high values of the average beam power, comparable to those obtained in linear accelerators [2].

The study of the mechanism of the electron capture in stable acceleration is performed by considering the electron dynamics inside the resonant cavity and, as shown, is very important for the microtron efficiency.

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 (fig.2). This was technologically feasible and this solution was 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 or 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], as in fig.1. 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 $\Omega = 1.2$ and the second with $\Omega = 1.8$ (see next chapter for the definition of Ω).

Both of them were calculated in details and the results were experimentally confirmed [2]. Some reports showed that the pulse electron beam of 250 mA at 10 MeV was obtained [6]; in practice the accelerated beam current is lower than in the case of the electron gun injection system. 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 values 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 choose the system of coordinates like in the fig. 3 and we use the natural system of units [2], the motion equation;

$$\frac{d}{dt}\left(\frac{m\vec{V}}{\sqrt{1-\frac{|\vec{V}|^2}{c^2}}}\right) = e\vec{E} + \frac{e}{c}(\vec{V} \times \vec{H}) \qquad (1)$$

projected on the Ox and Oy axes, becomes:

$$\frac{d}{dt}\left(\frac{u}{\sqrt{1-\beta^2}}\right) = -\Omega v + \epsilon\, \Omega v J_1(x)\sin\varphi \qquad (2)$$

$$\frac{d}{dt}\left(\frac{v}{\sqrt{1-\beta^2}}\right) = \Omega u + \epsilon\, \Omega J_0(x) - \epsilon\, \Omega u J_1(x) \sin\varphi \quad (3)$$

V is the electron speed vector, E and H are the electrical and magnetic fields, J_0 and J, 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, $x = 2\pi X/\lambda$, $y = 2\pi Y/\lambda$;

(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),

$\varphi = \omega t$ and $u = dx/d\varphi$, $v = dy/d\varphi$, $\beta = V/c$, $\Omega = H/H_0$, where H_0 is the cyclotronic field corresponding to the frequency of the accelerating voltage, $H_0 = (mc2\pi f)/e$ and $\epsilon = E/H$.

Outside the cavity, electrons move under constant magnetic field and the transformation of the motion parameters is:

$$u_{k+1} = u_k - \frac{\Omega l}{\Gamma_k}; \quad v_{k+1} = -\sqrt{\beta_k^2 - u_k^2}$$

$$x_{k+1} = x_k - \frac{\Gamma_k}{\Omega}(v_k - u_k); \quad y_{k+1} = 0 \qquad (4)$$

where $\Gamma_k = \frac{1}{\sqrt{1-u_k^2-v_k^2}}$ is the electron energy, l is the resonator length expressed in the natural system where the length unit is $\lambda/2\pi$ and k, k+1 are the numbers of the orbits.

The equations (2), (3) and (4) wholly describe the electron motion in the microtron 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 the electron are injected with an initial energy of 70 keV from an electron gun, the optimum value of l is about 1.2. In fig.5 the resonator length, for minimum deviation from synchronous energy is plotted versus entrance phase in cavity.

To estimate the capture, the deviation from synchronous energy, $\Delta\gamma$, measured in units equal to the rest energy of the electron was computed using this model. The results are shown in fig.4. From this picture a capture coefficient of about 1/24 was obtained [11].

All computations were performed for only one orbit, in the case of the injection system with an external electron gun. The estimated value of the capture coefficient is confirmed in the case of microtrons working with this injection system [3], [12].

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

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 which 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 ratio 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].

5. CONCLUSIONS

In this paper, the efficient electron injection systems in microtron were presented with their advantages and disadvantages.

A theoretical model for the electron injection in the microtron was proposed. The numerical computations showed a good agreement with results obtained experimentally.

There was described the injection system in 17-orbit microtron from the Institute of Atomic Physics, Bucharest and the values of the pulse beam current. The experience in the microtron operation proved this is a stable machine, suited for many applications as NDT, activation analysis and electron beam processing.

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FIGURE CAPTIONS

Fig. 1 Electron injection system proposed by V.N.Melekhin
a) First accelerating mode
b) Second accelerating mode.
Fig. 2 Electron injection system proposed by O.Wernholm.
Fig. 3 The system of coordinates in the microtron resonator.
Fig. 4 Energy deviation vs. entrance phase.
Fig. 5 The resonator length corresponding to minimum energy deviation vs. entrance phase.

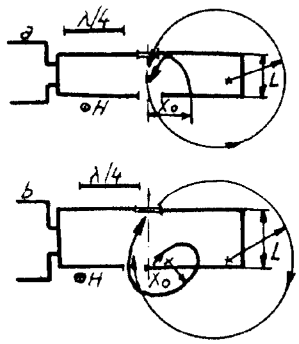

Fig. 1

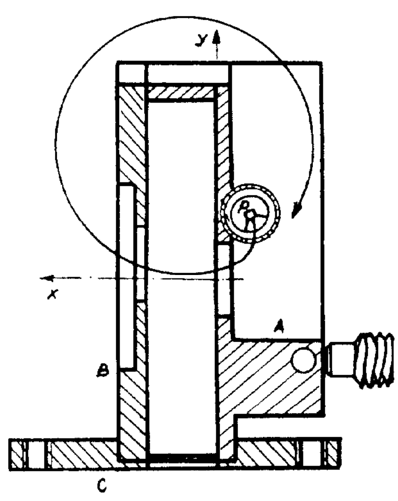

Fig. 2

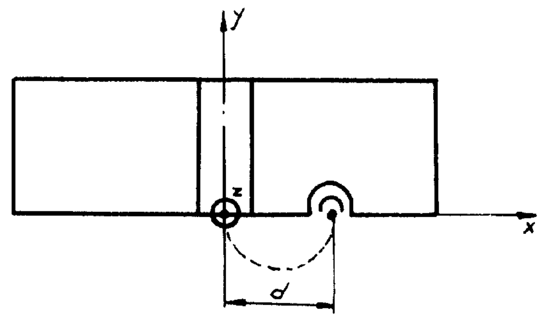

Fig. 3

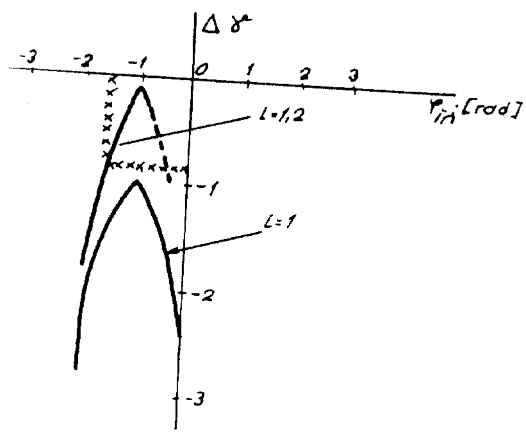

Fig. 4

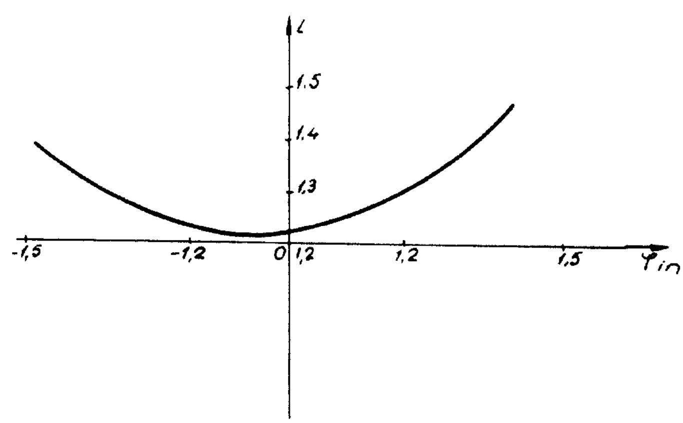

Fig. 5