EXTERNAL INJECTION INTO JINR PHASOTRON – COMPUTER SIMULATION III

L.M. Onischenko, E.V. Samsonov
JINR, Dubna, Russia

Computer simulation of the beam dynamics is reported for the external injection into the JINR Phasotron of the preliminary bunched 5 MeV beam. The capture efficiency is found to be 65.5% and not too much dependent on the scattering by the foil.

PACS numbers: 29.20.Bd, 83.10.Rs

1 COMPUTER SIMULATION

Calculations of the external injection (Fig. 1) into the Phasotron [1, 2] were carried out with a program PHASMOT which integrates the full motion equations in the space (r, r′, z, z′, w, φ) for 1002 particles (334 particles inside each of 3 successive bunches). Initial conditions are determined by their random choice from the above-mentioned 6D phase space of the transverse coordinates, momenta, energy and phase.

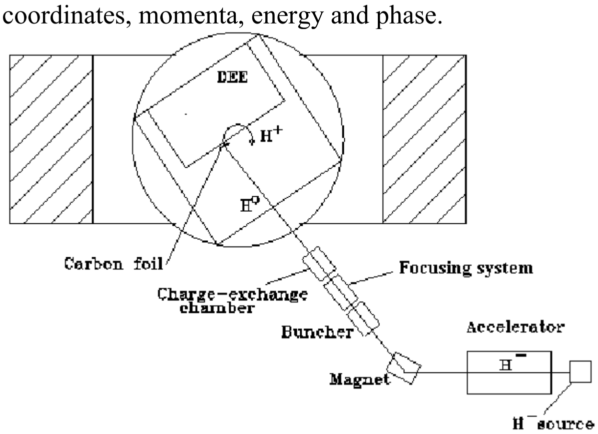

Fig. 1. Phasotron external injection scheme.

Doing this we suppose their homogenous distribution in energy (50 keV for the central bunch and ~70 keV for the other two), phase (20° for the central bunch and ~30° the other two) and the Gaussian distribution for r, r′, z, z′ inside the 20π mm·mrad emittance.

The initial distribution of particles in the phase-time plane is shown in Fig. 2.

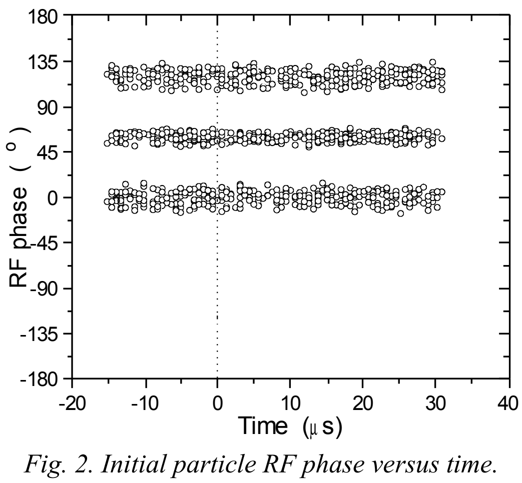

Fig. 2. Initial particle RF phase versus time. At Time=0 the RF frequency is equal to the orbital one.

The initial distribution of the injected particles in the radial and axial phase space is shown in Fig. 3 and Fig.4.

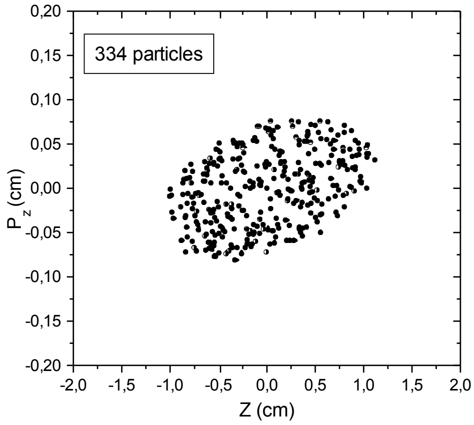

Fig. 3. Initial distribution of 334 injected particles in the axial phase space.

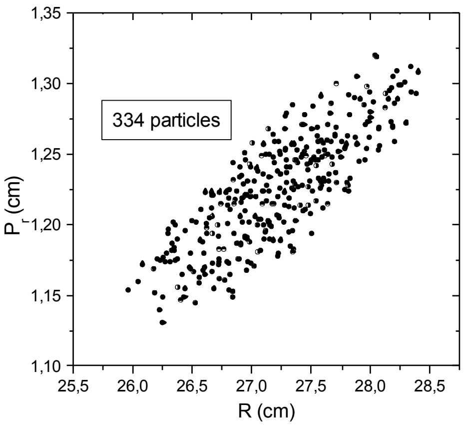

Fig. 4. Initial distribution of 334 injected particles in the radial phase space.

Experimental dependencies of the magnetic field on the radius and of the accelerating frequency on time are shown in Figs. 5 and 6.

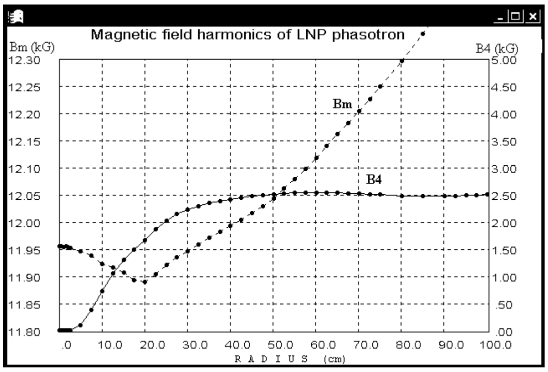

Fig. 5. Average value B_m and amplitude of 4-th harmonic B_4 of magnetic field in the Phasotron central region.

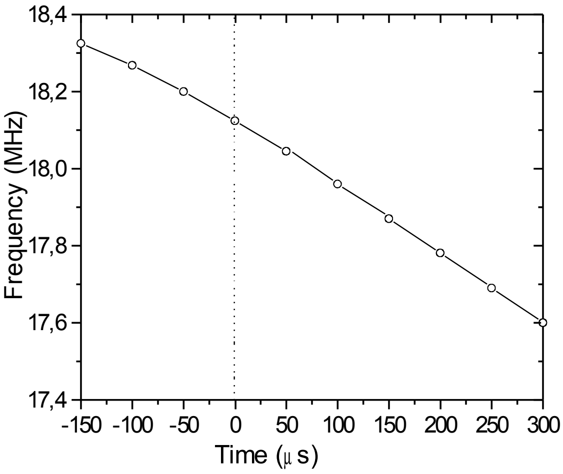

Fig. 6. Initial part of the Phasotron frequency program.

The orbital frequency (18.124 MHz) of the 5 MeV injected particles is equal to the RF for the time t=0 in Fig. 6.

The three bunches shown in Fig. 2 have different average energies: – 4.67, 5.0 and 5.33 MeV.

Axial as well as radial emittance is 20π mm·mrad. The carbon recharging foil 20 μg/cm^2 thick is placed at the radius R=27.2 cm. During the capture process protons pass through the foil many times. Multiple Coulomb scattering due to passage through the foil gives the Gaussian distribution of the scattering angles with the mean-square scattering angle

$$\theta_0^2 = \frac{13.6MeV}{\beta cp} z \sqrt{\frac{x}{X_0}\left[1 + 0.033 \cdot \frac{x}{X_0}\right]} \quad (1)$$

Here p, βc and z are the momentum, velocity and charge number of the incident particle and x/X_o is the thickness of the foil in radiation lengths. X_o for carbon is 42.7 G/cm^2 [3]. For the 20 μg/cm^2 carbon foil and 5 MeV protons θ_o=0.45 mrad.

The particle is considered as lost if its radius at the acceleration process became less than 5 cm (losses due to returning to the center), as well as if its axial amplitude became more than 2 cm. The particle which had the energy less than 50 MeV after 4000 turns is also considered as lost one. All other particles are considered as captured to acceleration. The starting positions of 655 such particles are shown in Fig. 7. 17% of particles are lost due to returning to the center, 11.5% due to the phase loss and 6% due to the axial loses.

The positions of the captured particles and the particles lost due to phase loss after 4000 turns is shown in Fig. 8 in the W-R plane. The captured particles after 4000 turns are shown in Fig. 9 in the W – Phase plane.

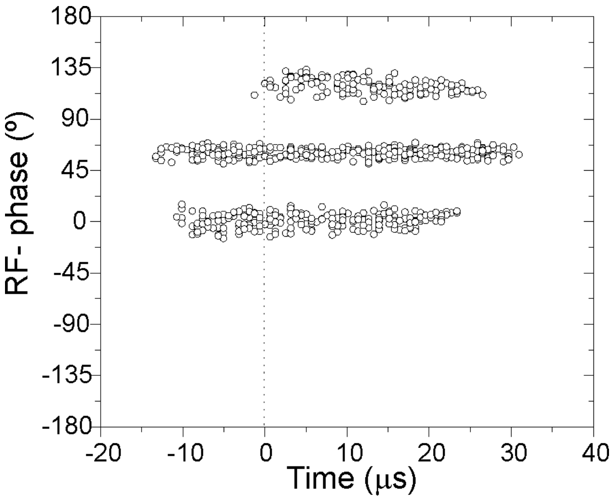

Fig. 7. Starting distribution of 655 captured particles.

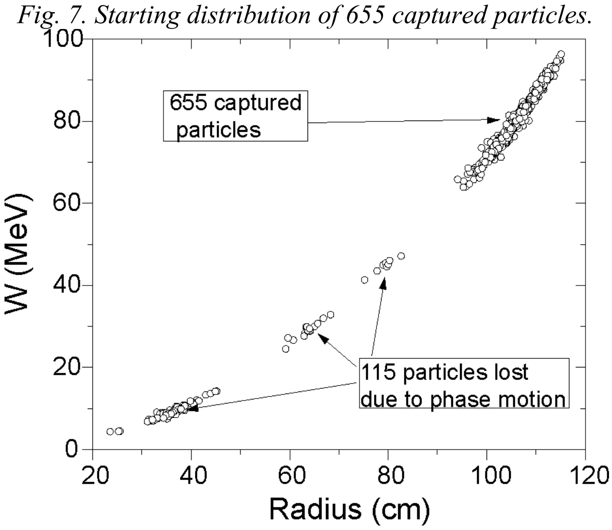

Fig. 8. Captured particles and phase-lost particles in the W-R plane after 4000 turns.

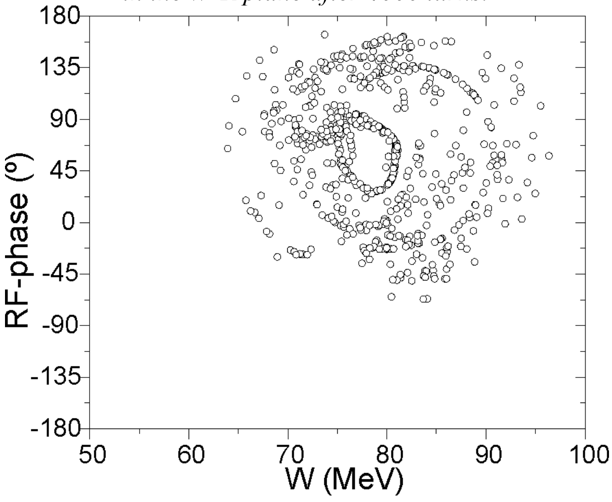

Fig. 9. Captured particles after 4000 turns in the W-Phase plane.

The multiplicity of the particle passing through the foil is shown in Fig. 10. The average multiplicity is 28.

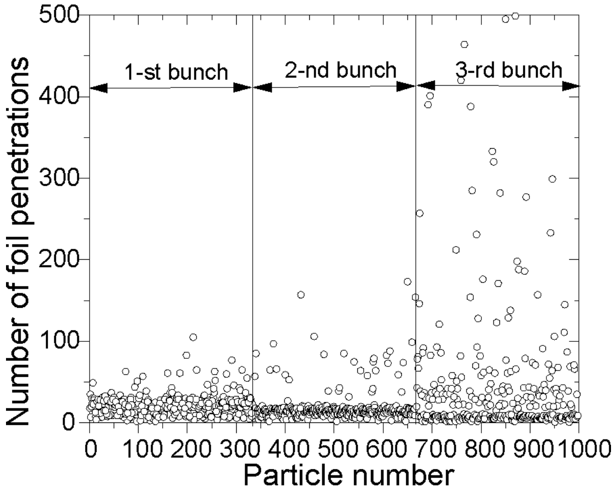

Fig. 10. Number of foil penetrations versus particle number.

The free oscillation amplitude distributions after 4000 turns are shown in Fig. 11 (R plane) and Fig. 12 (Z plane).

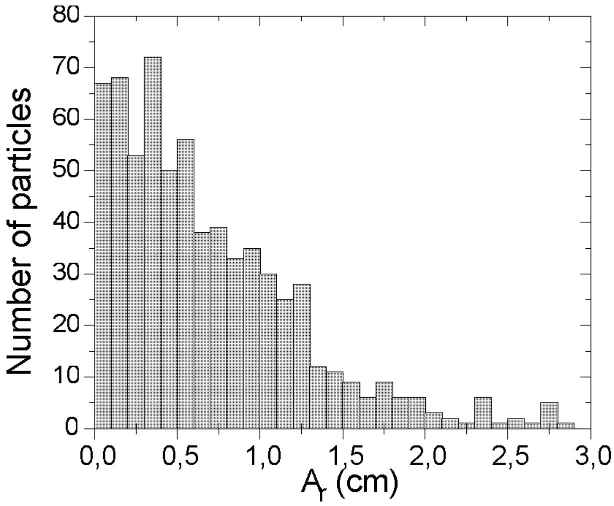

Fig. 11. Distribution of radial free oscillation amplitudes after 4000 turns.

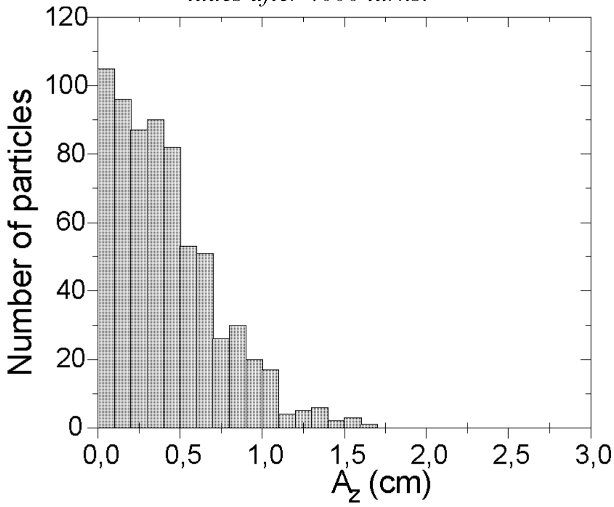

Fig. 12. Distribution of axial free oscillation amplitudes after 4000 turns.

2 CONCLUSIONS

The computer simulation of the bunched beam dynamics shows that 65.5% of particles are captured into acceleration during 46 μs.

Average multiplicity of the passage through the foil is 28. The foil with the above-mentioned parameters produces negligible influence on the capture efficiency and rather small on the emittances.

For 90% of the captured particles the radial amplitudes are less than 15 mm and the axial ones are less than 10 mm.

The space charge effects will be considered at the next step of calculations.

REFERENCES

1. O.N.Borisov, L.M.Onischenko // *Proc. of EPAC 1998*, Stockholm, p. 2097.
2. L.M.Onischenko, E.V.Samsonov // *Proc. of the 16-th Cyclotron Conference*, 2001, East Lansing, P4-04.
3. *European Physical Journal*. 1998, v. 3, N 1-4, p. 76 and p. 146.