Influence of the ionization loss in the diagnostic foil on the phase motion in the phasotron

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Abstract

In the present paper it is shown that the influence of the ionization loss in the foil on the longitudinal motion consists of the synchronous phase shift followed by the phase oscillation amplitude compression.

The secondary emission monitors (SEM) [1] are used for the beam diagnostics of the JINR phasotron [2]. An SEM consists of the aluminium foil the several μm thick and $3 \div 5$ mm in radial size. The foil plane forms an angle of 45° to the horizontal plane (the plane of the beam circulation); the foil is places on the fixed azimuth and is moved along the radius.

Secondary electrons emitted by the proton beam passing through the foil are collected and this signal is used to measure the intensity and some other parameters of the proton beam.

The SEM influence on the transversal motion of the beam particles is analyzed in the [3]. The SEM influence on the longitudinal beam particle motion is discussed in the present paper. The beam particles passing through the SEM have a lower energy gain because of the ionization loss in the SEM. The value of the energy loss ΔW depends (for the chosen foil) on the beam energy. It is $3 \div 10$ keV per revolution and makes up a considerable part of the synchronous particle energy gain eV $cos\,\varphi_S$ which is about 20 keV per revolution [4].

When the accelerated particles do not pass through the foil their full energy E changes as [5]

$$\frac{1}{f}\frac{dE}{dt} = \mathrm{eV} cos\,\varphi\,, \tag{1}$$

where f — particle revolution frequency,

φ — particle phase relative to the accelerating voltage.

If the parameters of the synchronous particle (whose revolution frequency is exactly equal to the accelerating voltage frequency $f_\circ$ at the moment) are given an index 's', then the synhronous phase will be

$$cos\,\varphi_S = \frac{1}{\mathrm{eV} f_S}\frac{dE_S}{dt}\,. \tag{2}$$

Let us introduce $K = -\frac{E_S}{f_S}\left(\frac{\partial f}{\partial E}\right)_S$, which only depends on the magnetic field structure and describes the phase stability properties of this type of accelerator. Then we obtain the following expression for $cos\varphi_S$

$$cos\,\varphi_S = -\frac{E_S}{\mathrm{eV} f_S^2 K}\frac{df_\circ}{dt}\,. \tag{3}$$

In the presence of ionization loss equation (1) comes to

$$\frac{1}{f}\frac{dE}{dt} = \mathrm{eV}\, cos\,\varphi - \Delta \mathrm{W}\,. \tag{4}$$

Emergence of the term $\Delta W < \mathrm{eV}$ on the right–hand side of the equation can be interpreted as a change of the synchronous phase, the expression for which now will be

$$cos\,\varphi_S = -\frac{E_S}{\mathrm{eV} K f_S^2}\frac{df_\circ}{dt} + \frac{\Delta W}{\mathrm{eV}}\,. \tag{5}$$

The both terms on the right–hand side of (5) are positive. Thus, ionization loss causes the increasing of $cos\varphi_S$, i.e. the decreasing of the phase stability region. Therefore, the phase oscillation amplitudes have to change.

To verify this conclusion the numerical solution of the equation (4) was done. The computer program LONMOT [6] was used with the real magnetic field and the real accelerating voltage frequency dependence on time.

Two modes of the acceleration process were investigated — slow ($cos\varphi_S = 0.003$) and fast ($cos\varphi_S = 0.17$). In fig. 1 the particle with the initial energy 650 MeV and the initial phase 65° is accelerated in the slow mode with dee voltage 15 kV. In fig. 1-a the particle is accelerated without ionization loss, while in fig. 1-b the energy loss is 10 keV per revolution. Obviously, the synchronous phase is changed and the phase oscillation amplitude decreases.

In fig. 2 the same process is shown, but for the initial phase 90°. In this case the synchronous phase is also changed, but the phase oscillation amplitude increases.

In both above cases the value of energy losses in the acceleration process was fixed. The real situation, when the SEM is used for measuring, is different. At first the particles are accelerated without passing through the foil, but after gaining some radius (energy) they begin to pass through the foil and lose the energy. At the transition from acceleration without losses to acceleration with losses the phase oscillation parameters should be changed. It is obviously from the qualitative considerations that the oscillation amplitudes smaller than the synchronous phase shift should be increased and large ones should be decreased.

In fig. 3 the results of modelling this process are shown. In fig. 3-b the particle with the initial phase 90° is accelerated in the slow mode, at first it does not pass through the foil. Its oscillation amplitude is small. When its energy reaches 651 MeV the energy losses of 20 keV are introduced. The synchronous phase then moves to 40°, and the oscillation amplitude is increased. The results of such a manipulation with the particle of the 65° initial phase are shown in fig. 3-a.

In fig. 4-a the results of the same calculation are shown for the fast mode ($cos\varphi_S = 0.17$) of acceleration of a number of the particles with initial phases from 20° to 100° and initial energy 650 MeV. At first the particles are accelerated without energy losses, and after gaining the energy of 654 MeV they begin to interact with the foil and to lose 10 keV per revolution. The significant damping of the phase and energy oscillations is seen.

In fig. 4-b the results of the similar calculation are shown for other initial energy 649 MeV.

Thus, we can conclude, that the influence of the interaction between accelerated particles and the foil on the phase motion consists in
— the shift of the synchronous phase, $\Delta\varphi_S$ which increases with the energy losses;
— the change of the phase oscillation amplitude. For the slow acceleration process small amplitudes (less then $\Delta\varphi_S$) are increased but the large ones are decreased, i.e. the amplitude spectrum is compressed. For the fast acceleration all amplitudes are decreased, independently of the initial amplitude. It can be explained by the phase with which the particle comes to the foil. For the slow acceleration this phase is always almost equal to the synchronous one. For the fast acceleration this phase depends on the oscillation amplitude, but it is always found at that part of the phase trajectory, where the phase and the energy are increased.

The influence of the ionization loss in the foil may be significant in the multiturn injection of heavy ions with a stripping foil.

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References

[1] A.V.Demjanov et al. JINR Phasotron and its Beams. XIII Meeting on Particle Acc., JINR, D9–92–380, Dubna, 1992.

[2] V.V.Kolga, et al. Proc. of the XI Meeting on Particle Acc. JINR D9-89-52, v.2, p.178, Dubna, 1989.

[3] A.L.Beljajev et al. JINR 13-88-575, Dubna, 1988.

[4] L.M.Onischenko et al. JINR P9-91-226, Dubna, 1991.

[5] A.A.Kolomensky, A.N.Lebedjev. Theory of cyclic acc. Physmatgis, Moscow, 1962.

[6] O.N.Borisov, L.M.Onischenko. Beam stretching by phase displacement. XIII Meeting on Particle Acc., JINR, D9-92-380, Dubna, 1992.

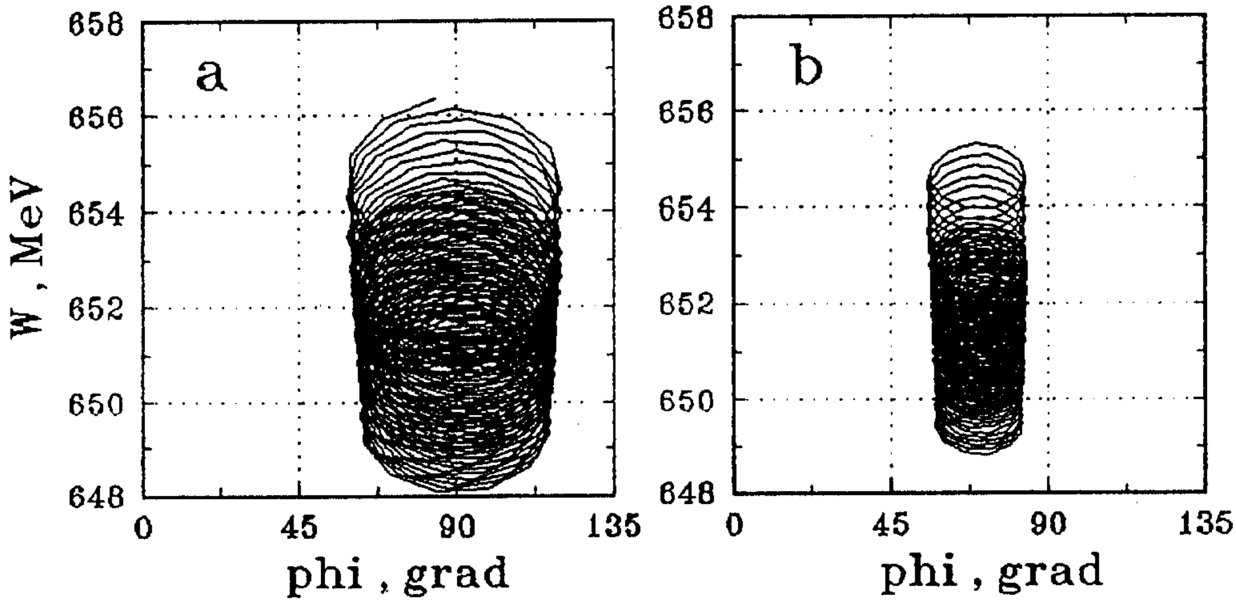

Figure 1: $df_o/dt = -8.3 \cdot 10^6\ s^{-2}$, $\varphi_o = 65°$, a) $\Delta W = 0$, b) $\Delta W = 10$ keV

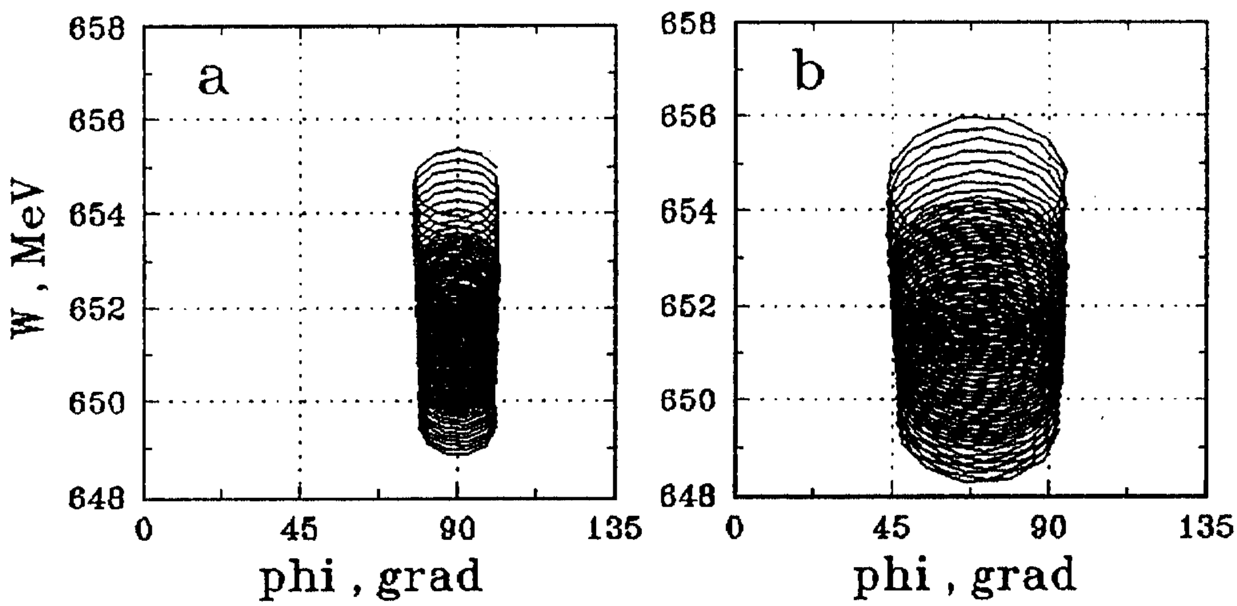

Figure 2: $df_o/dt = -8.3 \cdot 10^6\ s^{-2}$, $\varphi_o = 90°$, a) $\Delta W = 0$, b) $\Delta W = 10$ keV

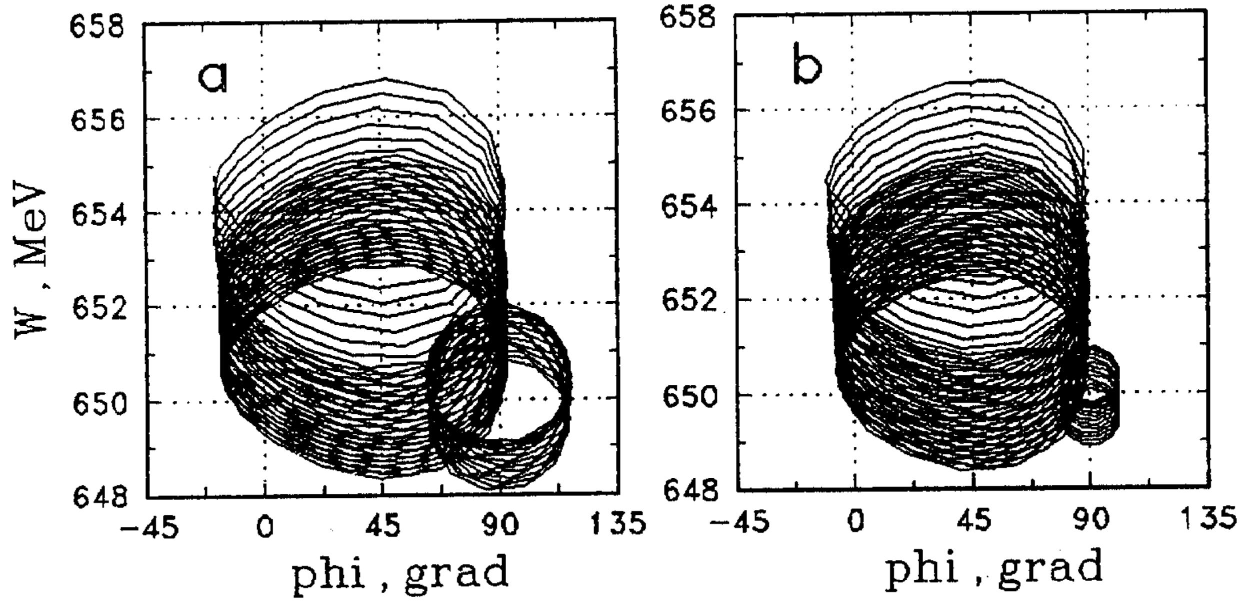

Figure 3: $df_o/dt = -8.3 \cdot 10^6\ s^{-2}$, $\Delta W = 20$ keV for $W > W_1$,
a) $\varphi_o = 65°$, $W_1 = 652$ MeV; b) $\varphi_o = 90°$, $W_1 = 651$ MeV.

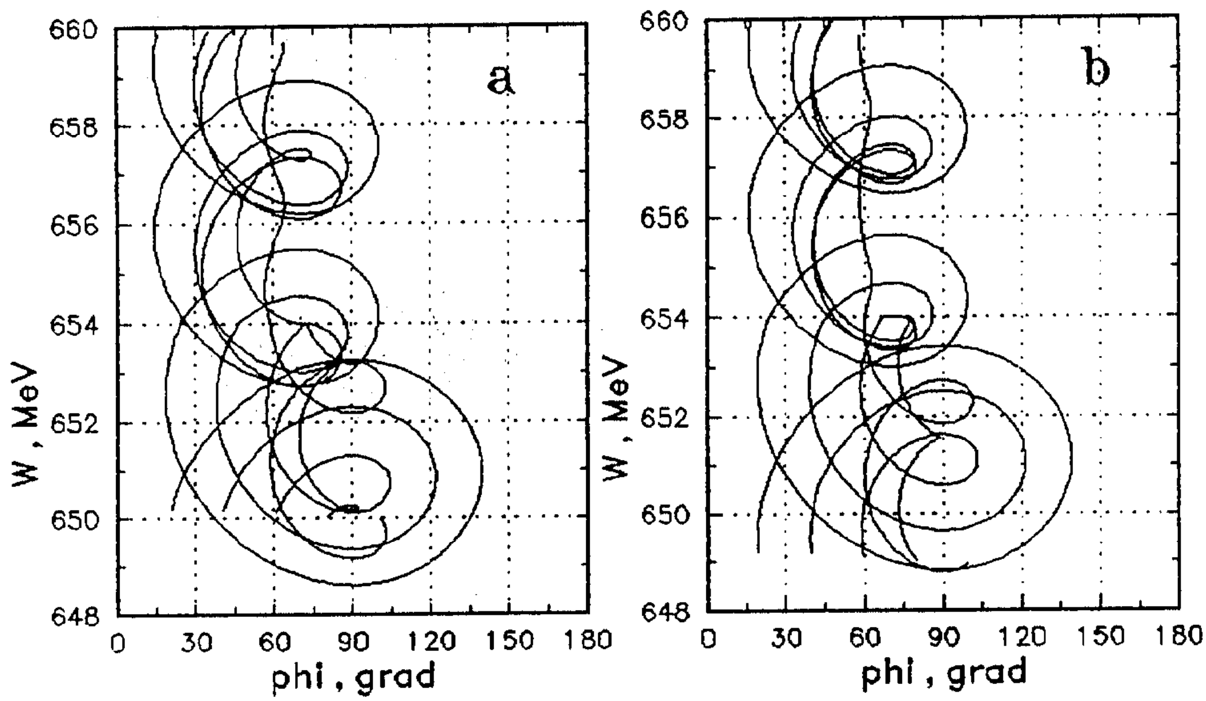

Figure 4: $df_o/dt = -5 \cdot 10^8\ s^{-2}$, $\Delta W = 10$ keV for $W > W_1$, $W_1 = 654$ MeV,
$\varphi_o = 20°, 40°, 60°, 80°, 100°$, a) $W_o = 650$ MeV, b) $W_o = 649$ MeV