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INFLUENCE OF THE IONIZATION LOSS IN THE DIAGNOSTIC FOIL ON THE LONGITUDINAL PHASE MOTION IN THE PHASOTRON

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This paper is devoted to the influence of the ionization loss in the diagnostic foil on the longitudinal motion of a charge particles at the JINR phasotron. The energy loss in the foil results in synchronous phase shift and phase oscillation amplitude compression. Two modes of the acceleration process were considered : slow ($\cos\varphi_S$=0.003) and fast ($\cos\varphi_S$=0.17). The results of numerical calculations are presented.

KEY WORDS: Phase motion

JINR phasotron[1,2] is a synchrocyclotron with azimuthally varying magnetic field. Protons are accelerated to energy 680 MeV ($R = 270$ cm). RF system has 180° dee with $V_{\max} = 40$kV (at end of frequency range $V = 15$kV) and frequency range $18.2 \div 14.4$ MHz. Acceleration duration is 3.2 msec.

Secondary emission monitors (SEM)[3] are used for the beam diagnostics at the JINR phasotron. The SEM consists of a several μm thick aluminium foil. The SEM influence on the transversal motion of the beam particles is analyzed in the paper.[4] The SEM influence on the longitudinal beam particles motion is discussed in the present paper. The beam particles passing through the SEM have lose their energy due to the ionization loss in the SEM. The value of the energy loss ΔW depends (for the chosen foil) on the beam energy. It is 10 keV per revolution.[5] The above mentioned value 10 keV is an average or most probable value of energy losses due to ionization. The energy losses distribution function is given by L. Landau.[6] In our case (proton energy 680 MeV, aluminium foil thickness of several μm) the energy losses of more than 67 % of protons lie inside 20 % of the average value. We will suppose further that all particles have the same value of energy losses wich is equal to the most probable one. When the accelerated particles do not pass through the foil their full energy E changes as[7]

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

where f particle revolution frequency, and φ the 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 synchronous 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 (for JINR phasotron $K = 0.8$ on finish radius). 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) becomes

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

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, which becomes

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

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 a numerical solution of equation (4) was done for the extraction energy range. The computer program LONMOT[8] was used with the measured magnetic field and measured frequency dependence on time nearby extraction radius. Two modes of the acceleration process were investigated — slow ($\cos\varphi_S = 0.003$) and fast ($\cos\varphi_S = 0.17$).

In Figure 1 the particles with initial energy 650 MeV and initial phase 65° are accelerated in the slow mode with dee voltage 15 kV. In Figure 1-a the particle is accelerated without ionization loss, while in Figure 1-b the energy loss is 10 keV per revolution. Obviously, the synchronous phase is changed from 89.8° to 70° and the phase oscillation amplitude decreases.

In Figure 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.

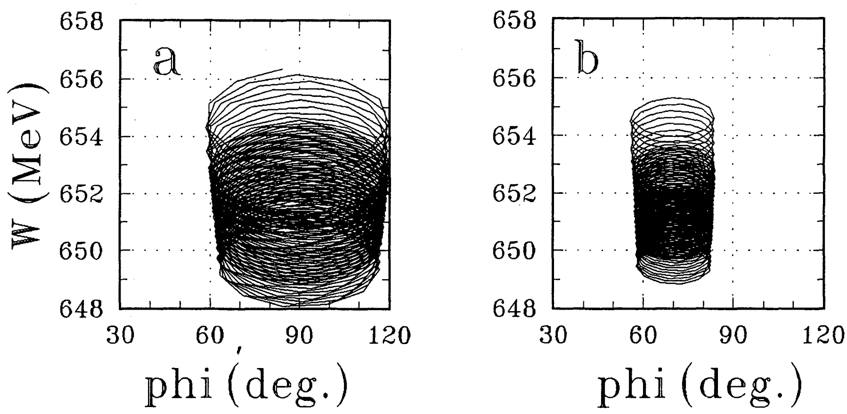

FIGURE 1: $df_o/dt = -10^7\ s^{-2}$, $\varphi_o=65°$: a) $\Delta W=0$, b) $\Delta W=-10$ keV/turn

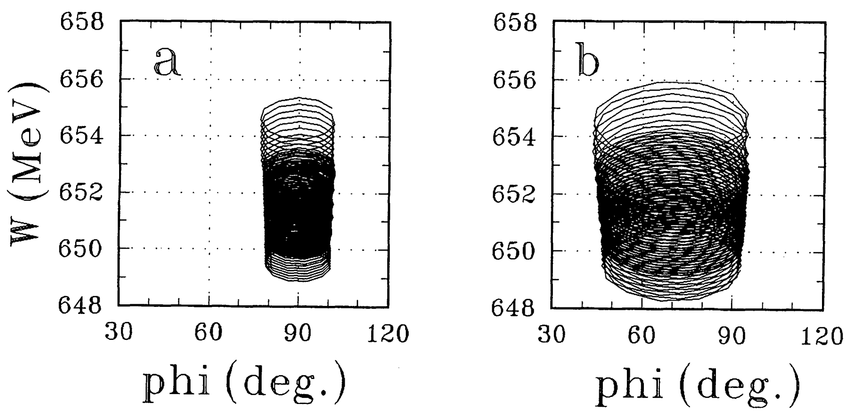

FIGURE 2: $df_o/dt = -10^7\ s^{-2}$, $\varphi_o=90°$: a) $\Delta W=0$, b) $\Delta W=-10$ keV/turn

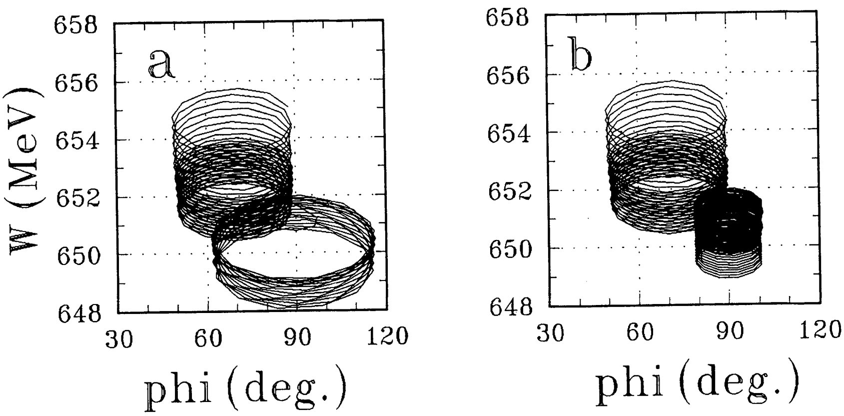

FIGURE 3: $df_o/dt = -10^7\ s^{-2}$, $\Delta W = -10$ keV/turn for $W > 652$ MeV : a) $\varphi_o = 65°$, b) $\varphi_o = 90°$

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 energy. At the transition from acceleration without losses to acceleration with losses the phase oscillation parameters became different.

In the next calculations the energy losses appear at the time when particles reach the radius (energy) corresponding to the position of the foil. For the slow mode ($\cos\varphi_S = 0.003$) the particles get on the foil with phase nearby of the synchronous phase. In this case the particles with different starting phases will have an equal phase defining by the difference between old and new synchronous phases, i.e. the amplitude spectrum is compressed.

In Figure 3 the results of modelling this process are shown. In Figure 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 10 keV are introduced. The synchronous phase then moves to 68°, and the oscillation amplitude is increased. The results of such a manipulation with the particle of the 65° initial phase are shown in Figure 3-a. For the fast mode ($\cos\varphi_S = 0.17$) of acceleration the phase of the particles at the foil will have a different value but it is always found in that part of the phase trajectory where the phase and the energy are increased. In this case particles have a varying phase oscillation amplitude but the maximum oscillation amplitude is decreased.

In Figure 4-a the results of the same calculation are shown for 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.

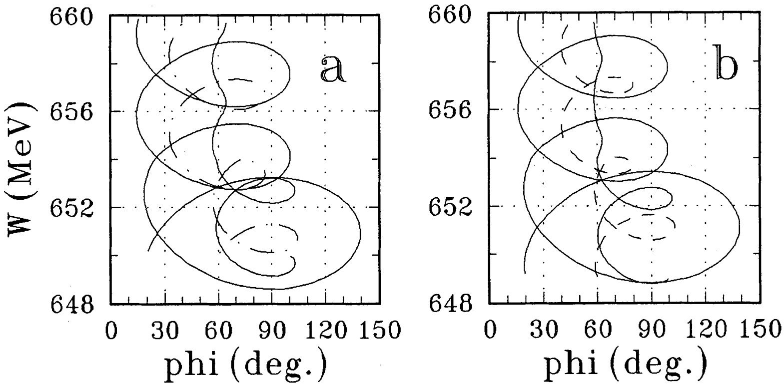

FIGURE 4: df_o/dt = -5·10^8 s^{-2} , $\Delta W = -10$ keV/turn for $W > 654$ MeV , $\varphi_o = 20°, 60°, 100°$: a) $W_o = 650$ MeV , b) $W_o = 649$ MeV

The significant damping of the phase and energy oscillations is seen. In Figure 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 energy losses because 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;
- for the slow acceleration process all phase oscillation amplitudes are compressed nearby equal amplitude;
- for the fast acceleration process maximum phase oscillation amplitude are decreased.

The influence of the ionization loss in the foil may be significant in storage rings with internal targets and in the multiturn injection of heavy ions with a stripping foil.

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