THE BEAM BUNCH EFFECTS IN THE CIRCULAR ISOCHRONOUS CYCLOTRON

Yu.G. Basargin, V.I. Vasil'ev, R.N. Litunovsky

D.V. Efremov Scientific Research Institute of Electrophysical Apparatus, Leningrad, USSR

Abstract

Numerical modelling calculation results for the acceleration process in an isochronous cyclotron and its influence on longitudinal size of the beam are presented. Two possible modes of beam bunching in a circular isochronous cyclotron with a double accelerating system are discussed. Two dee systems operate at frequencies differing by an integer and with dee voltage amplitudes approximately equal. In the first case the accelerated beam phase is shifted from the minimum at the curve $\Delta E(\psi)$ to the maximum value in the non-isochronous acceleration region. In this case effective bunching is observed. In the other version bunching effects are produced at the ion bunch input into the additional dee which is connected to the main one. Ultra-short accelerated particle bunches obtained by this method can be successfully used in time-of-flight experiments.

* * * *

The discrete acceleration nature of the isochronous cyclotron and the presence of the accelerating electrical field component transverse to the orbit perturb the transverse and longitudinal ion motion. The most noted effect is phase bunching at acceleration start, when the accelerating slit width is not so small compared with the orbit curvature radius. Nevertheless the accelerating slit influence is noted during further acceleration. Since the accelerating field is a time function, the turn frequency error is also a particle phase function. In this case the right part of the phase equation

$$\Delta E_0 F(\varphi)\,d\varphi = 2\pi q \left(\frac{\delta\omega_1(E)}{\omega} + \frac{\delta\omega_2(\varphi)}{\omega} \right)_{\delta\omega_2 = 0.} dE \qquad (1)$$

is not already invariant as at $\delta\omega_2 = 0$. The influence of the dee accelerating field on the phase motion has previously been reported [1,2,3]. The radially varying transverse and longitudinal accelerating field component causes broadening or compression of the phases depending on the accelerating system type and its orientation relative to the magnetic structure. In this case phase band changing can be a result of non-uniform distribution of the electrical field along the accelerating slit, of a change in the dee angular length, or of a change in the energy gain per turn $F(\psi)$ function of the phase equation. This effect can be used to produce longitudinal beam bunching in the isochronous cyclotron. There are two possibilities of effective bunching in the circular isochronous cyclotron with doubled accelerating system. In the first case the effect of changing the longitudinal bunch width is used at phase passing (in non-isochronous acceleration mode) from the "well" to the maximum as is shown in Fig. 1 (top). The accelerating system consists of the main dees plus additional ones, operating at the q'th harmonic of the main frequency. The voltage amplitude at additional dees is selected on condition of obtaining the required function form

$$F(\varphi) = \cos\varphi - a\cos q\varphi$$

$$a = \Delta E_q / \Delta E_0$$

Investigation of the transverse and longitudinal motion in the circular cyclotron shows full stability in both the radial and the vertical direction. The relation of the initial and final bunch duration at phase passing from the "well" to the maximum

$$F(\varphi)\Delta\varphi = P(\varphi_0)\Delta\varphi_0 - \frac{\Delta\varphi_0^3}{6}(1 - aq^2) \qquad (2)$$

determines the bunching degree.

At q=3, a ≈ 0.8-0.9 the bunching factor is 6-10.

The longitudinal bunching occurs in the accelerating structure when the additional dees begin at a certain radius. In this case the function F(ψ) changes; the observed changes of the phase band are illustrated in Fig. 1 (bottom).

If $\Delta E = \Delta E_0 \cos\psi$ before the entrance into the additional dees and $\Delta E = \Delta E_0(\cos\psi - a \cos q\,\psi)$ after the entrance into them, then with q = 2 phase changing is given by the expression:

$$\frac{1 - \cos\varphi}{\sin\varphi} = \frac{1 - \cos\varphi_0}{\sin\varphi_0}\, e^{-a} \qquad (3)$$

At opposing switching a > 0 phase band broadening is observed, but at the matched one a < 0 compression of the band is noted.

When investigating the longitudinal and transverse motion at the entrance into the additional dee and further acceleration, the experimental data of the magnetic and electrical field measurements have been used in carrying out the numerical integration of the linear motion equations.

In Fig. 2 the energy-ion phase dependence is shown for the isochronous acceleration region at the entrance into the additional dee, having opposing switching to the main dee when the phase is shifted to the maximum of the energy gain per turn. It is apparent that the phase band broadening at the entrance into the dee is sufficiently compressed by the additional bunching. At matched dee switching phase band compression appears (Fig. 3). The vertical motion is fully stable. The action of the transverse magnetic field affects the radial motion. But these perturba- (Fig. 4) do not cause excessive distortion of the radial emittance. The diagram given for longitudinal bunching can be applied successfully in the circular isochronous cyclotron. For example, 6-fold bunch compression can be obtained at accelerating amplitude voltages of 44 kV and 100 kV in the 4-sector cyclotron with an accelerating system consisting of two 45^0 dees (q=1) and two additional 45^0 dees (q=3).

Literature

1) Yu.G. Basargin, V.I. Vasil'ev, R.N. Litunovsky, O.A. Minyaev, Proc. VI Inter. Conf. on Cyclotrons, Vancouver, Canada, 322 (1972).

2) R.W. Muller, R. Mahrt, Nucl. Instr. and Methods, 86, 241 (1970).

3) W. Joho, Particle Accelerators, 6, No. 1, 41 (1974).

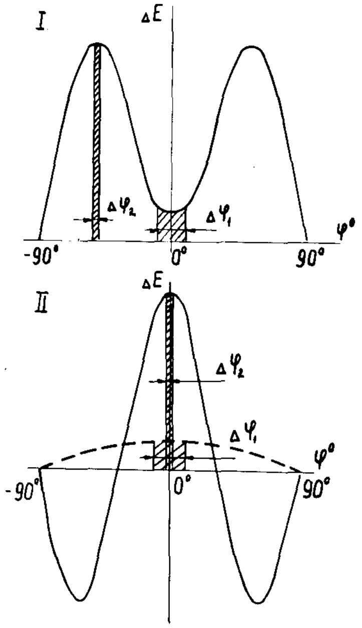

Fig. 1. The diagram of the longitudinal bunching in the isochronous cyclotron: I - with doubled accelerating system at phase bunch shift; II - with additional accelerating system beginning with a certain radius.

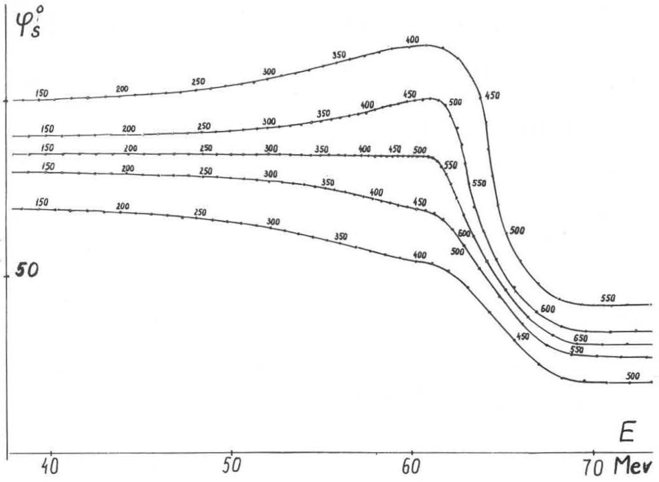

Fig. 2. Energy ion phase dependence with opposing switching of the additional dee ψ = 0°, ±5°, ±15°

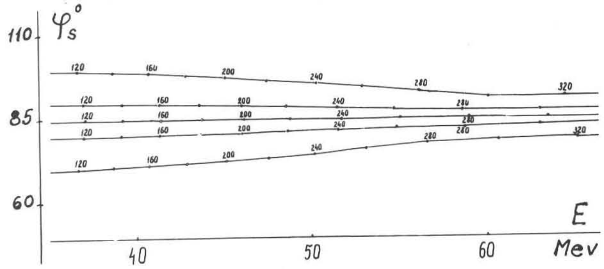

Fig. 3. Energy ion phase dependence with matched dee switching. Isochronous acceleration ψ = 0°, ±5°, ±15°

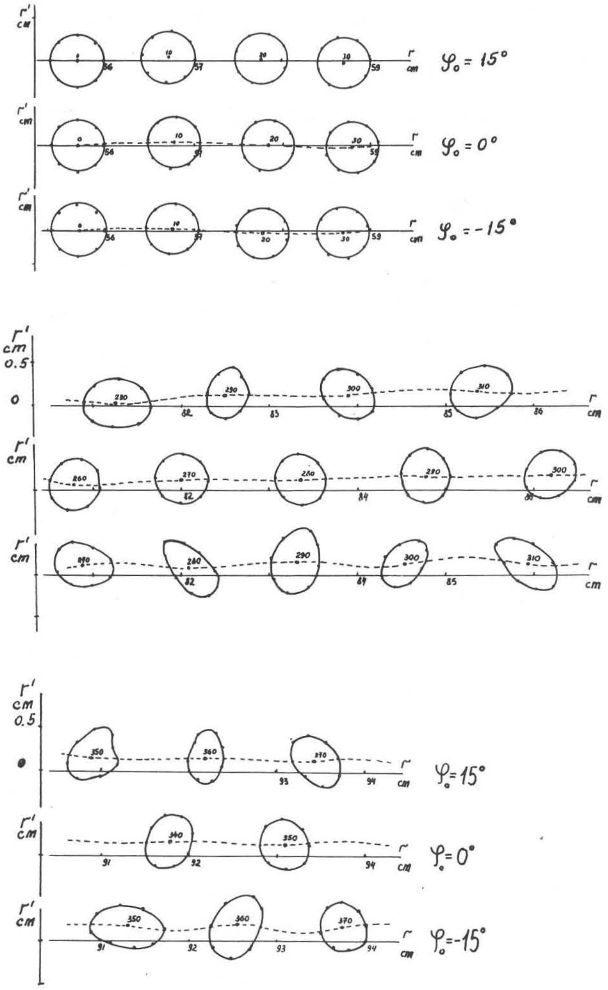

Fig. 4. Radial emittance conversion (ρ = 3mm), ψ = 0°, ±5°, ±15° . Matched dee switching mode.

0018-9499/79/0400-2398$00.75 ©1979 IEEE