AN EXTRACTION OF ELECTRONS FROM A SYNCHROTRON ON FOURTH ORDER RESONANCE

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Abstract: The nonlinear fourth order resonance of the radial betatron oscillations have been successfully used for a slow extraction of the electron beam on the 1.2 GeV Synchrotron "Pakhra".

Introduction

Nowadays the family of third order resonances of radial betatron oscillation is used on a wide scale for an extraction of particles from cyclic accelerators. However sometimes it is rather difficult to apply resonance of these type for the beam extraction. Thus for the 1.2 GeV Electron Synchrotron "Pakhra" the distingished resonance of radial betatron oscillation $\nu x=2/3$ lies unacceptly far from the working point of the synchrotron. At the same time the fourth order resonance $\nu x=3/4$ is situated much close to the point. This fact has impeled us to study the opportunity of employment of the resonance for the electron extraction [1,2]. It was proved that for exiting the fourth order resonance the introduction of the proper azimuthal harmonic of cubic nonlinearity of the guiding magnetic field is required. In present paper the extraction of electron beam from the "Pakhra" Synchrotron is discussed.

Basic outline

Required resonant conditions are fulfiled by two pole face windings, and there are separate pairs of quadrants for either winding. The gradient winding plased at the first and third quadrants brings the index of magnetic field from working value 0.51 ($\nu x=0.802$, $\nu z=0.819$) to resonant one 0.63. The necessary third azimuthal harmonic of cubic nonlinearity of magnetic field exiting resonance growth of electron oscillations is forming by octupole winding. The winding occupies second and fourth quadrants. The resonant build-up of electron oscillation results in electron throw into the first septum magnet aperture. This magnet instaled in the linear gap between the first and second quadrants deflects electron toward the center of the synchrotron. Having run over the second quadrant electron hits into the second extraction magnet which kicks it outside with the result that passing some part of the third quadrant the electron beam escaps from the synchrotron vacuum chamber.

At resonance the amplitude of the radial betatron oscillation a will increase if the following condition will meet

$$A_3 \cdot a^2 > 12 \cdot |\ \nu x - 3/4\ | \quad , \qquad (1)$$

where $A = \frac{R_0}{3!H_0}(\partial^3 H_z / \partial x^3)$ is the amplitude of magnetic field, Ro is the equilibrium orbit radius in the guiding magnetic field H_0. In this case the amplitude increment at two succesive passage (within four revolutions) near by the exterior current sheet of the first septum magnet, whose distance from the central orbit is x_s, is equal to

$$\Delta a_{8\pi} = \frac{2\pi}{3} A_3 x_s^3 \quad . \qquad (2)$$

The extraction efficiency is determined just by this expression. Having defined A_3 from (2) the boundary frequency detuning $\delta=|\nu x0-3/4|$ can be find according to known distribution of the betatron oscillation amplitudes (see (1)).

Extraction system equipment

Now we are going to description of individual units of the slow extraction system.

Pole face windings

Gradient winding: The gradient winding contains 38 straight conductors lying on the magnet pole which are connected with reverse conductors such that 19 are internal and 18 are external relative to the magnetic gap. One ampere current in this winding excites in the center of the working space the gradient equal to $\partial H_z/\partial x=0.524$ Oe/cm.

Octupole winding: The octupole (cubic) magnetic field is formed by 17 straight conductors. The current in three centraly located conductors flows in reverse direction from current in the remaining fourteen conductors [3]. Six internal and five external reverse conductors are used. The radial dependens of the field and the gradient of the winding are shown in Fig. 1.

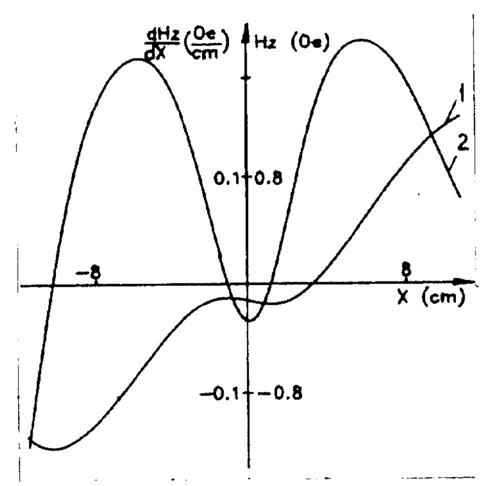

Fig. 1. Magnetic field (1) and gradient (2) distributions introduced by the octupol winding.

One ampere current excites in the center of the working space the octupole field $\partial^3 H_z/\partial x^3=0.0445$ Oe/cm^3.

Besides required nonlinearity there are others accompaying nonlinearities. Thus it is rather essential the presence of the constant (dipole) component of the field H_z=-0.160 Oe. At the large distances from the equilibrium orbit it is appreciable fifth order nonlinearity $\partial^5 H_z/\partial x^5$=-0.194 Oe/cm^5.

It can has an influence on the particle motion at x_s as a result, the amplitude increment $\Delta a_{8\pi}$ can be reduced in comparison with value given by (2) [4]. Indeed for the real "octupole" field distribution shown in Fig. 1 dramatical changing is observed. The electron motion on phase plane at the azimuth of the first septum magnet for following parameters $I_{\Delta n}$= 4.956 A, I_{x3} = 10.5 A is shown in Fig. 2. The rate of the betatron oscillation growth reduce in comparison with equation (2).

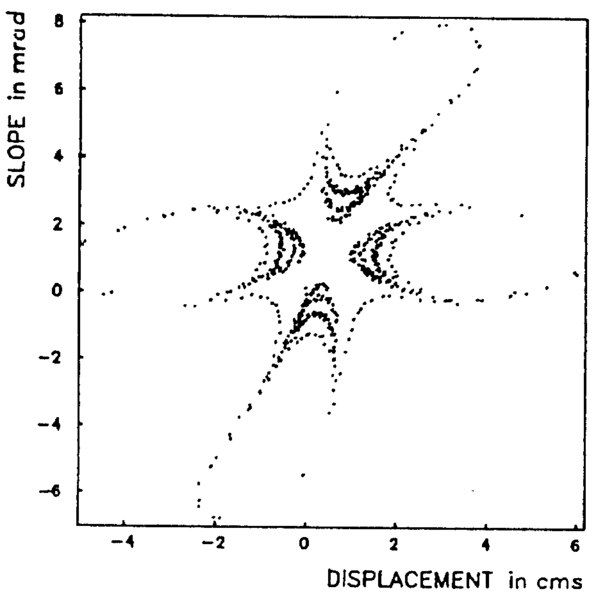

Fig. 2. Computed phase plot of the electron resonance betatron oscillation.

The third azimuthal harmonic of the pertubation is produced by reversing the current direction in the octupole winding in going from second quadrant to fourth one. Its amplitude is $(\partial^3 H_z/\partial x^3)_3$=0.58$(\partial^3 H_z/\partial x^3)$, where $(\partial^3 H_z/\partial x^3)$ is constant within the quadrants [2]. Under such connection circuit the dipole component of octupole winding introduces first harmonic of the azimuthal distortion of the equilibrium orbit.

Ejection magnets

First septum magnet: The first septum magnet consist of four magnetic blocks which are splited by three coper brackets [5]. The dimension of the gap are 1.2 cm height and 3.6 cm width. Septum thickness is 0.1 cm. The fringing field at distance more than 0.1 cm from septum is less than 2% of the field in the core gap. At the maximum current at the first septum magnet equal to 800 A strength of the magnetic field in the gap is 800 Oe. The magnet length is 42 cm.

Second septum magnet: The second septum magnet is composed of four just the same magnetic blocks as first one. Its septum is water cooling and has 0.5 cm thickness. The field strength in the gap of this magnet can be raise up to 4000 Oe at the current 4000 A.

Both magnets location relative to central orbit can be changed by means of the displacement equipment in 5 cm range.

Pulsers

The pole face windings and septum magnets are feeded by four current pulsers. The pulses shapes are designed to work on the flat top part of the pulse of the guiding magnetic field of the synchrotron. The leading edge of these pulses is 1 msec and their flat peaks range from 2 msec to 3 msec. Repetition rate is 50 Hz. The accuracy of current stabilization at the flat peak is 0.3%. The possibility of deformation of the top of the gradient winding current pulse is foreseen. The range of this change is few per cent of the height. A standard current pulse in the gradient winding is shown in Fig.3 at the bottom. All current pulses are turn on

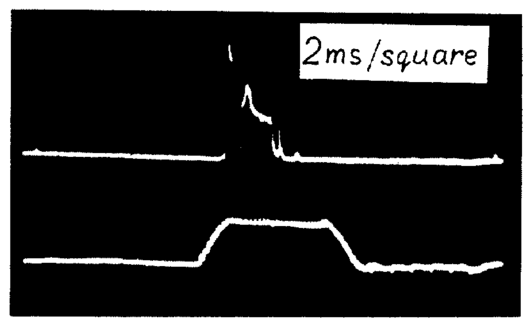

Fig. 3. Oscillogram of a gradient winding current pulse (bottom trace), time structure of the external beam, 2 ms/square.

simultaneously. The triggering moment measured from the injection can be variated over a wide range.

Extraction process

The extraction was accomplished after the electrons had reached 670 MeV energy not far from maximum of synchrotron magnetic field which has been sinusoidaly changed. The amplitude of accelerating voltage on the synchrotron cavity was almost constant. Due to the sharp radial dependence of the gradient introduced by the octupole winding it is esential to accurate select the frequency of accelerating voltage which determines position of the equilibrium orbit. The starting detuning of the radial betatron oscillation frequency at which extraction is beginning is determined not only by the amplitude of this oscillation but also by synchrotron one. The dynamic of the electron beam at it acceleration in the "Pakhra" Synchrotron was investigated in Ref. [6]. It is shown that both betatron and radial-phase oscillations make a contribution into radial beam dimension and the latter is twice as much former. In the circumstances the range of the resonance action is being widened in comparison with (1)

Time dependence of the circulating current at slow extraction mode is shown in Fig. 4. The gradient and octupole currents are accordingly $I_{\Delta n}$=4.4 A and I_{x3}=20 A. This picture is very sensitive to the $I_{\Delta n}$ current, whose value is choosing that way to obtain the

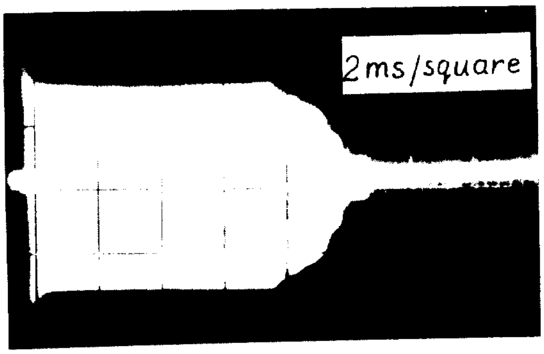

Fig. 4. Circullating current during extraction process, 2 ms/square.

very smooth fall down of circulating during extraction current. The typical extraction duration is between 2 and 3 msec, which at 50 Hz frequency of repetition magnetic cycle corresponds to a dute factor of 15 per cent. Fig. 4 displaies more than 80% of accelerated particles leaving the synchrotron vacuum chamber. The octupole winding current was choosed to minimize the gamma-quanta flux from the current sheet of the first septum magnet. The flux given by electrons striking the sheet was registred by a scintillation detector and an ionization chamber placed opposite the septum magnet exit for this reason there is a special window in the vacuum chamber. Then fine tuning of $I_{\Delta n}$ current was carry out. The beam goes out the vacuum chamber through an one-millimeter aluminium window.

External beam

The window azimuthal position (36° from the start of the quadrant) is determined by an ambrasure for the extracted beam in an accelerator hall wall. Required currents in the first and the second septum magnets are equal to 450 A and 2460 A respectively. A profile of the external beam right away the window was finded by photography. The transverse section of the beam is ellipse with vertical axis 0.6 cm and horisontal one 1.2 cm. Center of the beam at the window is 12.5 cm away the synchrotron central orbit.

Time structure of the external beam is shown in Fig.3 (upper line). Located close to the route of the beam scintillation gamma-quanta detector has been used. This pulse inhomogenity as well as nature of steps on Fig.4 very likely is caused by the manifestation of synchrobetatron resonances.

Moving through the machine fringing field electrons undergo radial defocusing and vertical focusing. The beam sizes at five meteres away from the exiting window are vertical 1.2 cm radial 12 cm. Certain contributions into these sizes are making by multiple electron scattering in the window and air as well as changing of the guiding synchrotron magnetic field. The external beam intensity has been measured by an ionization chamber and a quantometer. About a third of all extracted particles has been catched by the quantometer. Measurerd beam intensity was approximatly 10^{10} electrons per second.

Conclusion

Thus it has been experimentaly proved that fourth order betatron oscillation resonance can be successfuly used for slow extraction of particles from synchrotrons.

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