Control of Gamma-Beam Generation at the Synchrotron "Pakhra" by Nonlinear Resonance Excitation of Accelerated Electron Bunches

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ABSTRACT

Control system of homogeneous extraction of gamma-beam from the 1.2 GeV electron synchrotron "Pakhra" is discussed. Accelerated electrons are slowly brought to the tungsten target, which is placed inside the synchrotron vacuum chamber. During extraction high frequency voltage on accelerator's cavity is hold constant. Limited electron betatron oscillations are exiting by means of the gradient and the octupole pole face windings. Time uniformity of gamma quanta flow is provided by a special choice of the time dependence of the index of the synchrotron guide magnetic field. Control of the extraction process by a computer with usage of a feedback circuit will be performed.

INTRODUCTION

Generally at electron synchrotrons stretched beams of bremsstrahlung are obtained by means of modulation of accelerating high-frequency voltage. In the present paper a possibility to use the nonlinear resonance excitation of accelerated electrons for high energy gamma-beam generation at the synchrotron is discussed. 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" [1]. The main synchrotron parameters are given in [2].

BASIC OUTLINE

Required resonant conditions are fuilfiled by two pole face windings, and there are separate pairs of quadrants for either winding. The gradient winding placed 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 ocupies second and fourth quadrants.

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

$$A_3 a^2 > 12|\nu_x - 3/4|. \quad (1)$$

where $A_3 = R_0(\partial^3 H_z/\partial x^3)/(3!H_0)$ is the amplitude of third azimuthal harmonic of cubic nonlinearity of magnetic field, R_0 is the equilibrium orbit radius in guiding magnetic field H_0. In this case the amplitude increment at two succesive passage (within four revolutions) near the target, whose distance from the central orbit is x_s, is equal to

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

The exrtaction 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

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 centrally located conductors flows in reverse direction from current in remaining fourteen conductors. Six internal and five external reverse conductors are used. The radial dependence of the field and gradient of the winding are shown in Fig. 1. One ampere current exites in the center of the working space the octupole field $\partial^3 H_z/\partial x^3 = 0.0445$ Oe/cm^3. Besides required

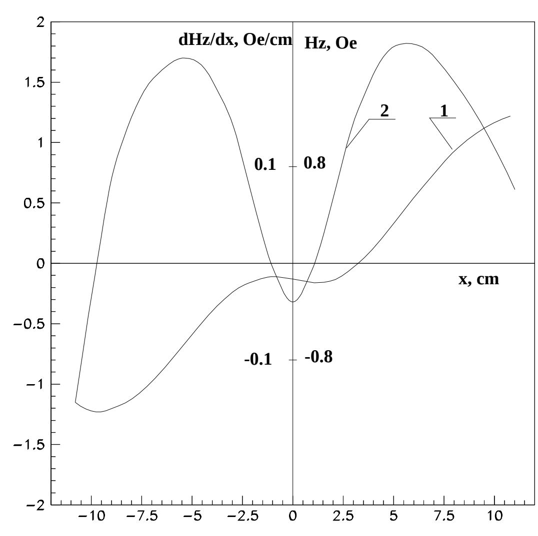

Figure 1: Magnetic field (1) and gradient (2) distributions introduced by the octupole winding.

nonlinearity there are others accompanying 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). Indeed for the real "octupole" field distribution shown in Fig. 1 dramatic changing is observed. The electron motion on phase plane at azimuth of the target for following parameters $I_{\Delta n} = 4.956$ A, $I_{x3} = 10.5$ A is shown in Fig. 1. The rate of the betatron oscillation growth is reducing in comparison with equation (2).

The third azimuthal harmonic of the perturbation 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. Under such connection circuit the dipole component of octupole winding introduces first harmonic of the azimuthal distortion of the equilibrium orbit.

Pulser

The pole face windings are feeded by two current pulsers. The pulses shapes are designed to work on the flat top part of the pulse of the guiding magnetic field of the sychrotron. 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. All current pulses are turn on simultaneously. The triggering moment measured from the injection can be varied over a wide range.

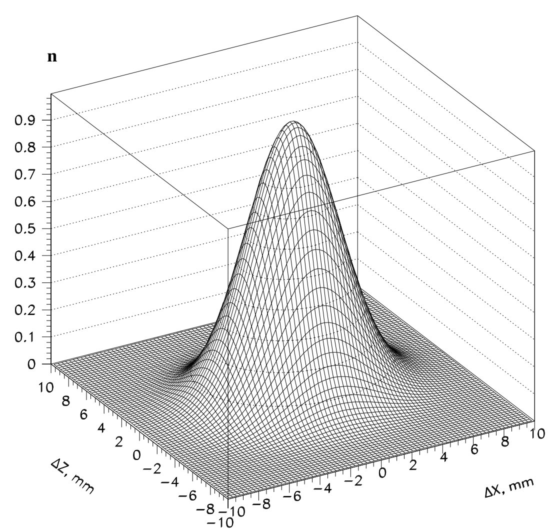

Figure 2: Two-dimensional distribution of electrons in the transverse cross-section of the beam.

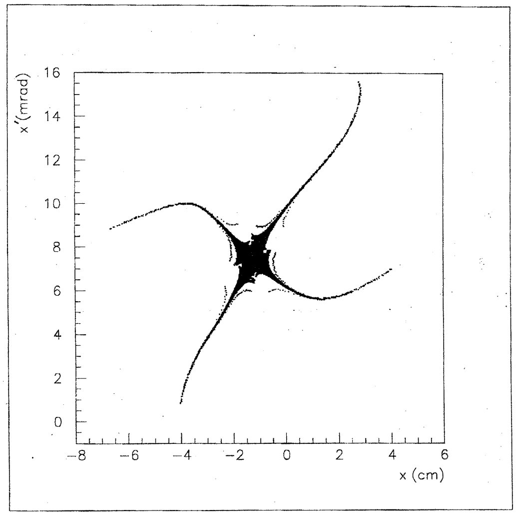

Figure 3: Computed phase plot of the electron resonance betatron oscillation.

EXTRACTION PROCESS

The extraction was accomplished after the electrons have reached 670 MeV energy. 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 (see fig. 1) it is essential to accurate select the frequency of accelerating voltage wich determines position of the equilibrium orbit. The starting detuning of the radial betatron oscillation frequency at wich extraction is beginning is determined not only by the amplitude of this oscillation but also by synchrotron one. The dynamic of the electron beam in the "Pakhra" synchrotron was investigated in Ref. [3]. Two-dimensional distribution of electrons in the transverse cross-section of the beam is shown at fig 2. Both betatron and radial-phase oscillations make a contribution into radial beam dimension and the later 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 show at 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 to obtain during extraction the very smooth fall down of the circulating current. The typical extraction duration is between 2 and 3 msec, which at 50 Hz repetition rate of magnetic cycle corresponds to a duty factor of 15 per cent. Fig. 4 displasies more than 80 % of accelerated particles leaving the synchrotron chamber. Note that the nature of the steps on fig. 4 very likely is caused by the manifestation of sunchrobetatron resonances.

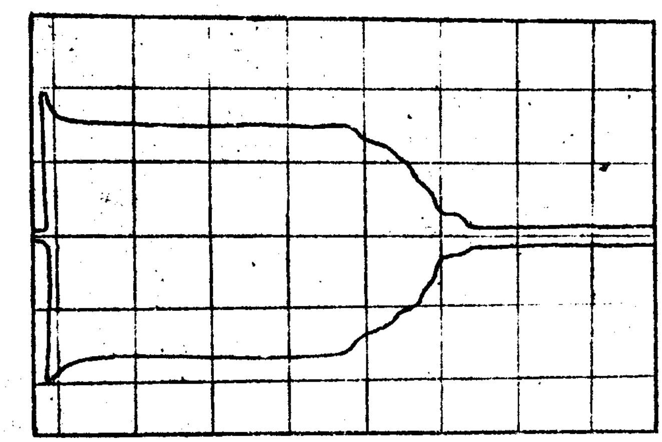

Figure 4: Time dependence of the electron current circulating in the synchrotron (signal from pick-up electrodes) during slow extraction process, 2 ms/square.

CONCLUSION

Time uniformity of gamma quanta flow is provided by a special choice of the time dependence of the index of the synchrotron guide magnetic field. To hold the gamma-beam intensity in the given range it is suggested to use special circuit wich will process signal from gamma-beam intensity monitor and then introduce proper correction into the gradient winding current.

References

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