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DYNAMIC APERTURE OF THE PULSE STRETCHER RING PSR-2000 FOR OPERATION IN THE LOW RADIATION EMITTANCE REGIME

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Abstract The chromaticity compensation of the magnetic focusing system which is necessary for pulse stretcher ring operation in the low radiation emittance (LRE) regime is achieved by means of sextupole magnets. As a result, the betatron frequency shift becomes dependent on the betatron oscillation amplitudes. Numerical simulation and analytical calculations have been made to estimate the influence of the sextupole fields on the dynamic aperture of the magnetic system. Some ways of correcting the dynamic aperture in the LRE regime are discussed.

The magnet lattice of the pulse stretcher ring PSR-2000 designed at the Kharkov Institute of Physics and Technology[1] may provide high-brilliance synchrotron-radiation (SR) beams. The operation of the PSR-2000 as a SR source is achieved by increasing the magnetic rigidity. This, however, results in the enhanced chromaticity which may be compensated by increasing the strength of the sextupole lenses located in the drift spaces between the bending magnets. The presence of the sextupole fields at large amplitudes of betatron oscillations gives rise to undesirable nonlinear effects which essentially decrease the dynamic aperture defined as a stability boundary of betatron oscillations. In view of this, we have undertaken a study to find the optimum stretcher-ring dynamic aperture for the SR source regime. The results of this study are presented in this report.

The studies were carried out for the PSR-2000 operating conditions specified by the peculiarities of injection: ν_x=7.22, ν_z=7.27 and ν_x=8.26, ν_z=7.167. The ampli-

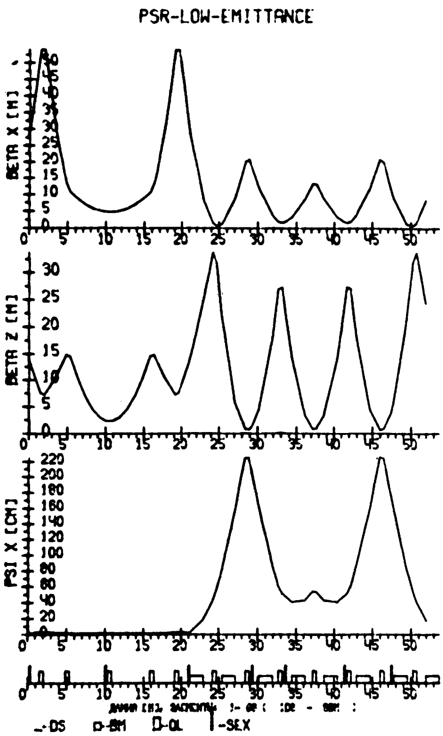

FIGURE 1 Amplitude (beta x, beta z) and dispersion (psi) functions on one period of focusing. $\nu_x = 7.22$, $\nu_z = 7.27$. DS: drift space, BM: bending magnet, QL: quadrupole magnet, SEX: sextupole magnet.

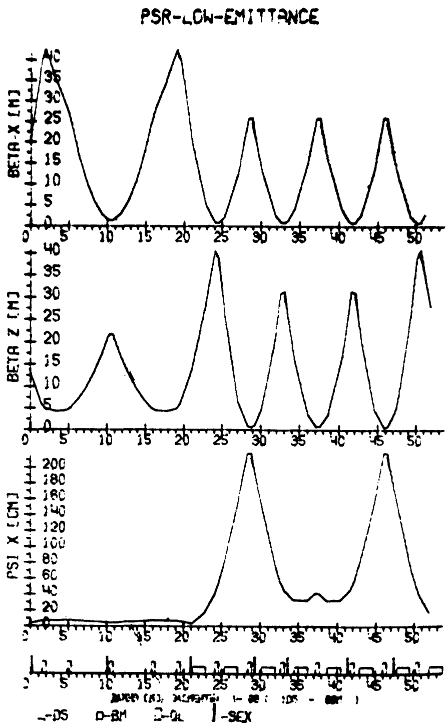

FIGURE 2 The same as in Fig. 1 but for $\nu_x = 8.26$, $\nu_z = 7.167$.

tude and dispersion functions for these options are shown in Figs. 1 and 2, respectively.

The strengths of the sextupole lenses employed for chromaticity compensation at E = 1.5 GeV were $-0.88\ m^{-2}$, $2.4\ m^{-2}$ ($\nu_x = 7.22$, $\nu_z = 7.27$, $\Delta\nu_x P/\Delta P = -18.6$, $\Delta\nu_z P/\Delta P = -16.5$), and $-0.8\ m^{-2}$, $2.6\ m^{-2}$ ($\nu_x = 8.26$, $\nu_z = 7.167$, $\Delta\nu_x P/\Delta P = -20.3$, $\Delta\nu_z P/\Delta P = -19.5$).

The dynamic aperture was investigated both analytically and by using the numerical simulation of particle tracks for 50 to 1000 turns of beam.

The analytical estimates of the dynamic aperture were obtained for the nonresonance approximation from the relations[2]

$$\Delta\nu_x = 2A_x J_x + A_{xz} J_z \qquad (1)$$

$$\Delta\nu_z = A_{xz} J_x + 2A_z J_z \qquad (2)$$

where A_x, A_{xz}, A_z are the functions of the sextupole lens strength, the tune, and the focusing functions on the azimuths of lens alignment; $J_{x,z}$ are related to the deviations x , z by the relation $x,z=\sqrt{2\beta_{x,z}J_{x,z}}\cos\varphi_{x,z}$ ($\varphi_{x,z}$ is the corresponding phase variable). $\Delta\nu_{x,z}$ is the detuning from the adjacent integer resonance or the third-order resonance.

For the tune ν_x =7.22, ν_z =7.27, the A_x , A_{xz} , A_z values are, respectively, equal to $1.322\cdot10^2$ m^{-1}, $3.008\cdot10^3$ m^{-1}, $-1.648\cdot10^2$ m^{-1}.

The value of the dynamic aperture for the given tune is determined by the detuning from the resonances $\nu_{x,z}$ = 7.

Figure 3 shows the dynamic apertures in the centre of the achromatic straight section ($\beta'_{x,z}$ = 0), as calculated by formulas (1) and (2), and as obtained by numerical simulation. As seen from the figure, the value of the dy-

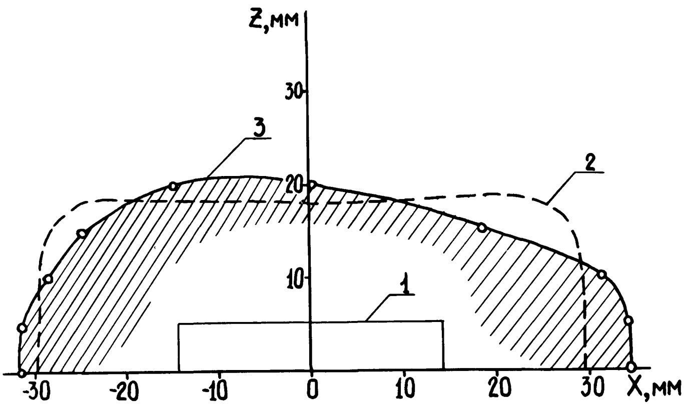

FIGURE 3 Dynamic and geometric apertures in the centre of the achromatic space. ν_x =7.22, ν_z =7.27, β_x =4.46, β_z=2.36, $\beta'_{x,z}$=0. 1: geometric aperture, 2: calculated dynamic aperture, 3: particle tracking dynamic aperture. The shaded area is the instability region due to equilibrium trajectory distortions ($|\Delta x|\leq 2$ mm, $|\Delta z|\leq 1$ mm).

namic aperture, with making allowance for the influence of the chromaticity-compensating sextupole lenses, is by a factor of 2 greater than the geometric aperture size. The equilibrium trajectory distortion diminishes the dynamic aperture by approximately 20%.

For the tune $\nu_x = 8.26$, $\nu_z = 7.167$ we obtained $A_x = -2.788 \cdot 10^2\ m^{-1}$, $A_{xz} = 1.23 \cdot 10^4\ m^{-1}$ and $A_z = -4.16 \cdot 10^3\ m^{-1}$. These values are by an order of magnitude greater than in the case considered above.

The radial and vertical sizes of the dynamical aperture depend on the detuning from the resonances $\nu_x = 8$ and $\nu_z = 7$.

The greatest dynamic aperture values calculated in the nonresonance approximation are found to be $X = -10.8$mm, $z = 0$ and $z = -35$ mm, $X = 0$ in the centre of the achromatic straight section.

Figure 4 shows the dynamic apertures obtained from the trajectory simulation (curve 1) for the same azimuth

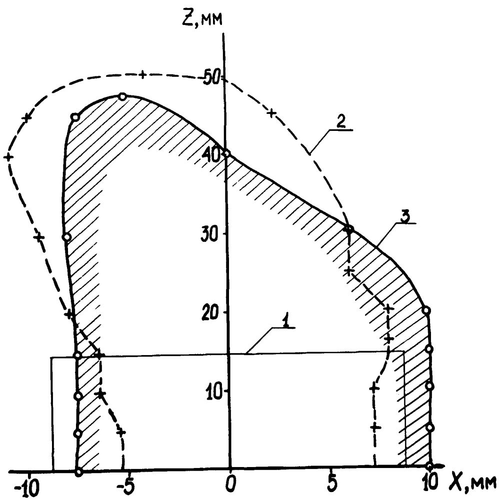

FIGURE 4 Dynamic and geometric apertures in the centre of the achromatic straight section. $\nu_x = 8.26$, $\nu_z = 7.167$, $\beta_x = 1.33$, $\beta_z = 22.5$, $\beta'_{x,z} = 0$. 1: geometric aperture, 2: dynamic aperture before correction, 3: dynamic aperture after correction. The shaded area is the instability region due to equilibrium trajectory distortions ($|\Delta x| \leq 2$ mm, $|\Delta z| \leq 1$ mm).

as in Fig. 3. It is seen that in this case the dynamic aperture in the radial direction is smaller than the geometric one. For this reason we applied a correction to compensate the influence of the sextupole lenses situated in the chromatic section by using three sextupole lenses (see Fig. 2) located in the achromatic straight section.

The A_x, A_{xz}, A_z values are, respectively, $-1.95 \cdot 10^3$ m^{-1}, $3.8 \cdot 10^3$ m^{-1} and $-1.219 \cdot 10^3$ m^{-1} for the strengths of the correcting sextupole lenses equal to -0.8 m^{-2}, -2.6 m^{-2}. These coefficient values are optimum for the given disposition of the sextupoles in the achromatic gap.

The greatest dynamic aperture values were calculated to be $X = -13$ mm, $z = 0$ and $z = -50$ mm, $X = 0$.

Curve 2 in Fig. 4 corresponds to the dynamic aperture defined from trajectory simulation with taking into account the influence of the correcting sextupole lenses. In this case the radial dynamic aperture value increased by 40%.

Thus, the results obtained in the present work lead to the following conclusions:

(i) for the operating conditions with $\nu_x = 7.22$, $\nu_z = 7.27$, the dynamic aperture, specified by the action of the sextupole lenses which compensate the chromaticity, imposes no restrictions on the particle dynamics and needs no correction;

(ii) for $\nu_x = 8.26$, $\nu_z = 7.167$, the dynamic aperture, specified by the action of the chromaticity-compensating sextupole lenses, is smaller than the geometric aperture; the undertaken correction made it possible to bring the dynamic aperture closer to the geometric one; this however did not completely eliminate the detrimental effect (in view of the equilibrium trajectory distortions) on the beam lifetime.

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