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THE BEAM SLOW EXTRACTION FROM A MAGNETIC RING OF MOSCOW MESON FACILITY

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The beam slow extraction from the circular accelerators or stretcher rings is generally realized by the resonant excitation of betatron oscillations. A precise betatron frequency control is proved to be quite necessary for high-efficient slow ejection. The Coulomb field turns out to have a significant influence upon the slow extraction from the high-current medium energy proton storage rings. It prevents resonant excitation at a reasonable rate and reduces the ejection efficiency.

The proton storage ring of Moscow meson facility (design intensity - 3.10^{13}, kinetic energy - 600 MeV) is an example of a stretcher with a noticeable beam space charge /1,2/. Incoherent Coulomb shift of betatron oscillation frequencies is equal to $\Delta Q=-0.1$ at uniform particle distribution and exceeds this value at other distributions. The detailed investigation of the resonant ejection, having been performed for our stretcher, resulted in the conclusion that extracted beam average current should be limited by the value of 50 μA, which is only 10% of the linac design current. The considerable beam loss creates a severe activation of the stretcher equipment.

The search for the alternative version to the resonant ejection made us to analyze in details and to develop an old-fashioned method, based on the radial betatron oscillation excitation while the beam is being gradually shifted onto the thin target. This method has been used to extract the protons from the weak-focusing synchrotrons /3,4/. Its new possibilities are disclosed in the present-day strong focusing magnetic rings/5/.

The essence of this method consists in reduction of particle momentum p_o by some magnitude $\Delta\bar{p}$ while single crossing a thin condensed target. Respectively the radial position of the particle closed orbit jumps by the value

$$\Delta r_t=\psi_t(\Delta\bar{p}/p_o) \qquad (1)$$

where ψ_t is the dispersion function at the target azimuth.

The amplitude of the excited betatron oscillations is $|\Delta r_t|$ if $\psi_t'=0$. We suppose the beam is made to expand outward onto the target. The first extreme inward excursion of the particle occurs at a half betatron wavelength downstream where it can be separated from the rest circulating beam and emerged away. The additional particle deviation at the septum azimuth will be the following:

$$\Delta r_s=-(\beta_s/\beta_t)^{1/2}\psi_t(\Delta\bar{p}/p_o) \qquad (2)$$

where β_s and β_t are the amplitude functions.

The condition of the ejected and circulating beams separation is

$$|\Delta r_s|>\left[(\beta_s\varepsilon)^{1/2}+\psi_s(|\Delta p_{max}|/p_o)\right], \qquad (3)$$

where ε, $|\Delta p_{max}|/p_o$ - are the circulating beam radial emittance and relative momentum spread respectively.

The momentum loss $\Delta\bar{p}/p_o$ should satisfy the inequality

$$\frac{\Delta\bar{p}}{p_o}>\frac{(\beta_s\varepsilon)^{1/2}+\psi_s(|\Delta p_{max}|/p_o)}{(\beta_s/\beta_t)^{1/2}\psi_t} \qquad (4)$$

The target thickness δ must be extremely small to reduce nuclear interactions and large angle scattering of the beam. On the other hand, the value of $\Delta\bar{p}/p_o$ is proportional to δ and should be sufficient to satisfy (4).

Consider what should be the magnetic lattice functions to minimize $\Delta\bar{p}/p_o$. First of all, the dispersion function at the target azimuth should be ultimately large and that at the septum-magnet azimuth equal to zero. Then, instead of (4), we have

$$\frac{\Delta\bar{p}}{p_o} > \frac{(\beta_t\varepsilon)^{1/2}}{\psi_t} \tag{4a}$$

Momentum loss additional reduction is possible as a result of fitting the β_t to mimimum value at the target azimuth.

The modern practice of designing the strong-focusing accelerators and storage rings permits to construct the stretcher ring lattice according to above-mentioned requirements. There were no such possibilities in the weak-focusing accelerators. In particular, practically there was no ψ-function azimuthal variation. As a result the ejection efficiency was less than 50%. In Moscow meson facility proton storage ring the momentum loss in the target $\Delta\bar{p}/p_o$ is limited to the value 0.2% and the ejection design efficiency is about 97%.

The main characteristics of the beam slow extraction from the Moscow meson facility proton storage ring are given below:

Target thickness (carbon)		4.4 mm
R.m.s. angle of multiple scattering		$2.4.10^{-3}$
Beam expansion rate		3 μm/rev
Intensity loss for nuclear interactions		1%
Intensity loss due to elastic scattering		1.5%
Intensity loss at splitter-magnet		0.2%
Emittance of the ejected beam:	radial	0.5 cm.mrad
	axial	7 cm.mrad

Fig.1 shows the magnetic ring structure. The main ring comprises 8 dipoles (1D1-1D8). The transverse focusing is provided mainly by these dipoles edge fields. Betatron frequency tuning and β-function azimuthal variation are well provided by quadrupoles (1Q7, 1Q11, 1Q14) installed in zero dispersion straight section. Bump-magnets 3B1, 3B2 located symmetrically on both sides of the target (DT) are

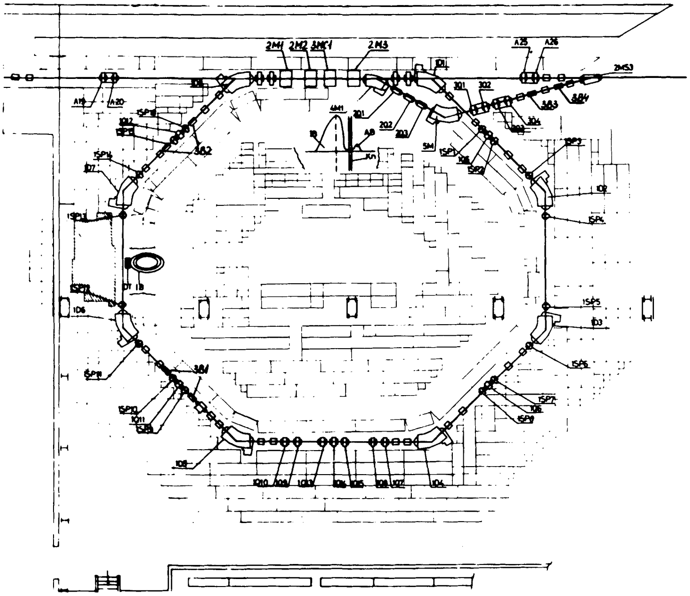

Fig.1. The magnetic storage ring structure

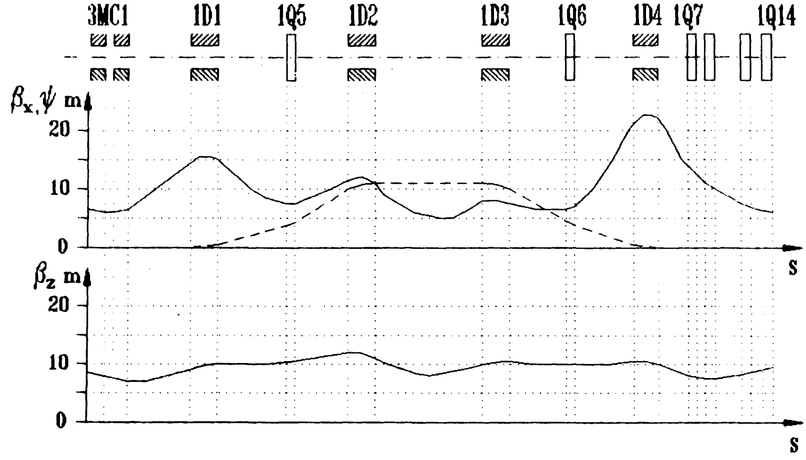

Fig.2. The main functions of the magnet lattice (half of the circumference)

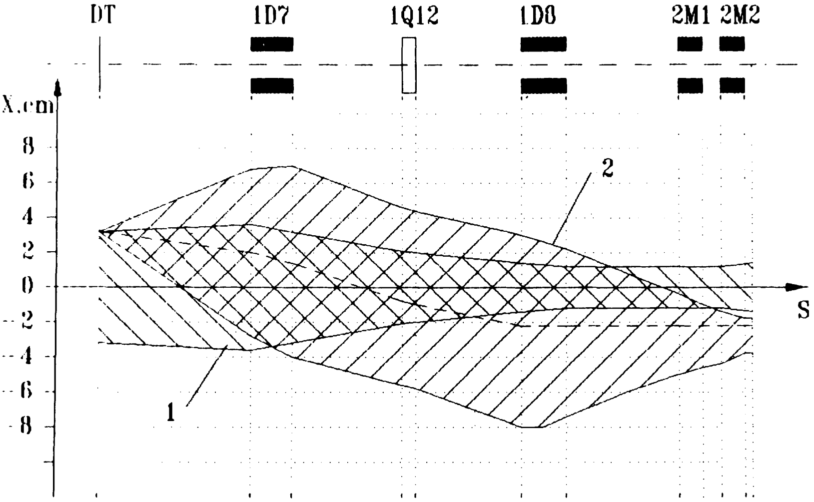

Fig.3. Envelope of the circulating (1) and ejected (2) beams in median plane

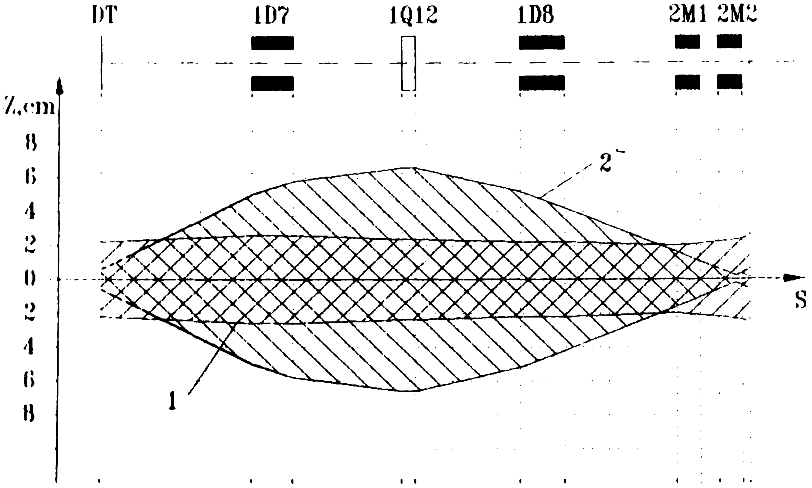

Fig.4. Envelope of the circulating (1) and ejected (2) beams in axial direction

aimed at beam gradual shifting onto target. The extracted beam enters the gap of the splitter-magnet (3MC1) and is deflected inward. Quadrupoles 1Q5, 1Q6, 1Q11, 1Q12 are aimed at ψ-function and momentum compaction factor correction. The bump-magnets (3B3, 3B4) should be used to stabilize the emittance position on the phase plane during the whole period of beam ejection.

The structure functions are given in Fig.2. Figs.3 and 4 show the circulating and ejected beam envelopes on a part of circumference from the target to the splitter-magnet in radial and axial directions respectively.

To decrease the ejected beam axial emittance, vertical dimension of the target is chosen to be less than the beam one. Thus,

$$\varepsilon_z = 4\ \Delta z\ z'_m, \qquad (5)$$

where Δz is the target half-height; z'_m is the maximum angular acceptance of the storage ring and the ejection channel, z'_m=7.5mrad. There are 98.5% of protons having interacted with the target in this angular interval.

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