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

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One of the main functions of Moscow-meson facility proton storage ring /1,2/ is uniform stretching of each accumulated proton macropulse to reach meson facility duty-factor comparable to 100%, the linac repetition rate is 100 Hz. There are 3.10^3 protons in each 100 μs macropulse. Multiturn injection into the storage ring is performed changing the charge of accelerated H^--beam. Accumulated current reaches the value of 12 A; incoherent Coulomb shift of the betatron oscillations for reasonable stored beam emittances is $|\Delta Q| = 0.25 \div 0.1$. Slow resonance extraction of particles in this case is unacceptable. The intense beam non-linear self-field prevents the particle resonant excitation at a reasonable rate and reduces the ejection efficiency. The considerable beam loss creates a severe activation of the storage ring equipment.

The search for the alternative version to the resonant ejection made us to analize in details and to develop /3/ an old-fashioned method, based on the radial betatron oscillations 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 synhrotrons /4,5/. Its new possibilities are disclosed in the present-day strong-focusing magnetic rings.

The essence of this method consists in reduction of particle momentum p_0 by some magnitude Δp while single crossing a thin condensed target. Respectively, the radial position of the particle closed orbit jumps by the value:

$$\Delta r_t = \Psi_t \frac{\overline{\Delta p}}{p_0} \qquad (1)$$

(Ψ_t - is the dispersion function at the target azimuth). The amplitude of additionally 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 splitter - magnet azimuth will be the following:

$$\Delta r_s = -\left(\frac{\beta_s}{\beta_t}\right)^{1/2} \Psi_t \frac{\overline{\Delta p}}{p_0}, \qquad (2)$$

where β_t, β_s - are the amplitude functions.

The condition of the ejected and circulating beams separation is given below:

$$|\Delta r_s| > \left[(\beta_s \mathcal{E})^{1/2} + \Psi_s \frac{|\Delta p_{max}|}{p_0}\right], \qquad (3)$$

where $\mathcal{E}$, $|\Delta p_{max}|/p_0$ are the circulating beam radial emittance and relative momentum spread, respectively.

The amount of momentum loss $\overline{\Delta p}/p_0$ should satisfy the following relation:

$$\frac{\overline{\Delta p}}{p_0} > \frac{(\beta_s \mathcal{E})^{1/2} + \Psi_s |\Delta p_{max}|/p_0}{(\beta_s/\beta_t)^{1/2} \Psi_t} \qquad (4)$$

The target thickness must be extremely small to reduce the nuclear interaction and large angle scattering of the particles. However, the target thickness $\delta \sim \overline{\Delta p}/p_0$ should be sufficient to satisfy the inequality (4), from which it is seen what should be the magnet lattice functions to minimize $\overline{\Delta p}/p_0$.

First of all, the dispersion function at the target azimuth should be ultimately large and that at the splitter magnet azimuth-equal to zero. Then, instead of (4) we have

$$\frac{\overline{\Delta p}}{p_0} > (\beta_t \mathcal{E})^{1/2} \Psi_t \qquad (4a)$$

Momentum loss additional reduction is possible as a result of selection the β -function low value at the target azimuth and beam radial emittance decrease if it isn't accompanied by intensity reduction.

The modern practice of designing the strong-focusing accelerators and storage rings permits to construct the stretcher ring magnet 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 than 50%. In Moscow meson facility proton storage ring the momentum loss in the target $\overline{\Delta p}/p_0$ is limited by the value 0.2% and the ejection design efficiency is 97%.

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Fig.1 shows the magnetic ring structure. The main ring comprises 8 dipoles (ID1-ID8); 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 ψ dispersion straight section. Bump-magnets 3B1, 3B2 located symmetrically on both sides of the target (DT) are aimed at beam gradual shifting onto the target. The extracted beam enters the gap of the splitter-magnet (3 MSI) and is deflected inward. Quadrupoles 1Q5, 1Q6, 1Q11, 1Q12 are aimed at ψ-function and momentum compaction factor correction.

The structure functions are given in Fig.2.

To decrease the ejected beam axial emittance, vertical dimension is chosen to be less than the beam one. As a result, the protons strike the target when their excursion **from** the median plane is less than the target half-height. The beam axial emittance is the following:

$$\varepsilon_z = 4 \Delta z z'_m$$

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

With the target vertical dimensions reduction, the problems of heat withdrawal became more complicated. In our case, these problems can be solved when $2\Delta z \geqslant 5$ mm.

Fig.3 and 4 shows the circulating and ejected beam envelopes on part of circumference from the target to the splitter-magnet in radial and axial directions, respectively.

The ejected beam radial emittance is defined not only by the particles angular distribution due to multiple scattering, but also by the fluctuations of energy loss in the target and momentum spread in the circulating beam. The latter factors turn out to be more important that the first one. The abovesaid effects result in the ejected beam emittance increase. This growth can be eliminated by transporting the ejected beam through the achromatic ejection channel with its origin at the target azimuth, 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 main characteristics of the beam slow extraction from the Moscow meson facility proton storage ring are given in Table I.

Table I

Kinetic proton energy	600 MeV
Circulating beam maximum intensity	$3 \cdot 10^{13}$
Radial emittance	2π cm.mrad
Axial emittance	6π cm.mrad
Relative momentum decrease at target crossing	$2 \cdot 10^{-3}$
Target thickness (carbon)	4.4 mm
R.m.s. angle of multiple scattering	$2.4 \cdot 10^{-3}$
Spill time	8.5 ms
Beam expansion rate	3 μm/rew
The depth of proton penetration into the target	0.3 mm
Heat deposition in the target at maximum intensity	1 KWt
Intensity loss for the **nuclear** interaction in the target	1%
Intensity loss at splitter-magnet	0.2%
Intensity loss due to elastic scattering in the target	1.5%
Dispersion function magnitude	
at the target azimuth	11.3 m
at the splitter magnet azimuth	0
β-function magnitude at the target azimuth	6 m
Emittance of the ejected beam	
radial	0.5cm·mrad
axial	7 cm.mrad

The accepted extraction method is distinguished by high flexibility of the beam time structure control. Alongside with the beam uniform extraction, the pulsing beam can be obtained in future. The point is that the amplitude of particles penetration into the target is only 0.3 mm at uniform beam extraction. Therefore, it is possible to shift the beam onto the target and back quickly, thus organizing any necessary temporal structure of the ejected beam. With this aim in view two identical deflectors exciting the variable electric fields are installed in the symmetrical points at each side of the target. The ejected particles time structure is specified by the pulsed fields.

In our case the electric field strength $E \leq 1$ kV/cm is sufficient at 0.5 m deflector length.

It's important that pulsing beams formation doesn't result in average beam intensity reduction in comparison with the operating meson facilities. The particles extraction efficiency is the same.

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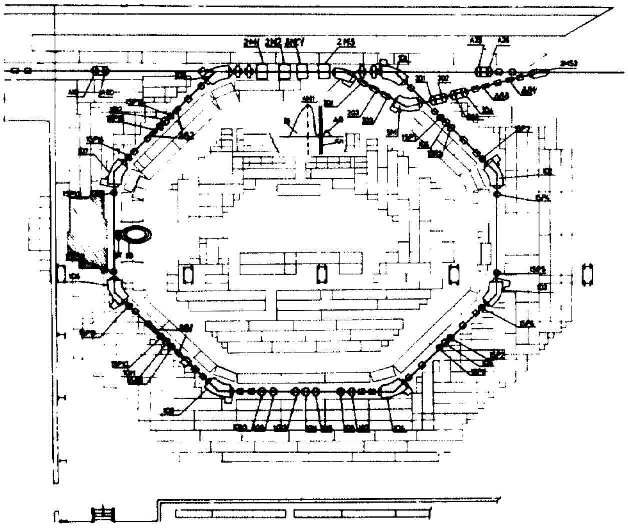

Fig.1. The magnetic storage ring structure

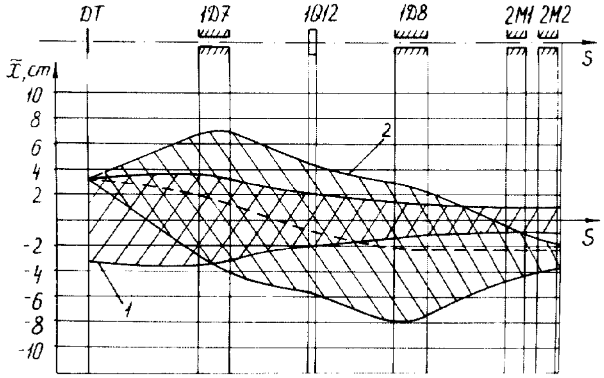

Fig.3. Envelope of the circulating (I)·and ejected (2) beams in median plane

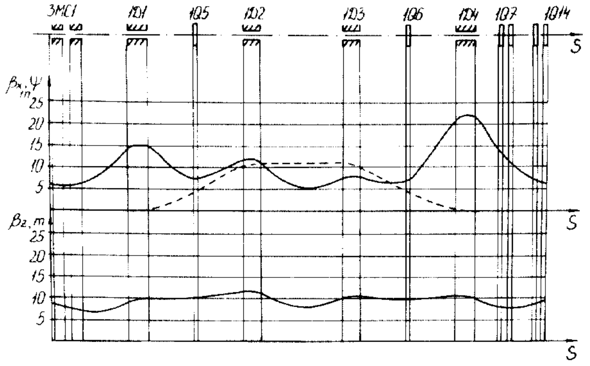

Fig.2. The main functions of the magnet lattice (half of the circumference)

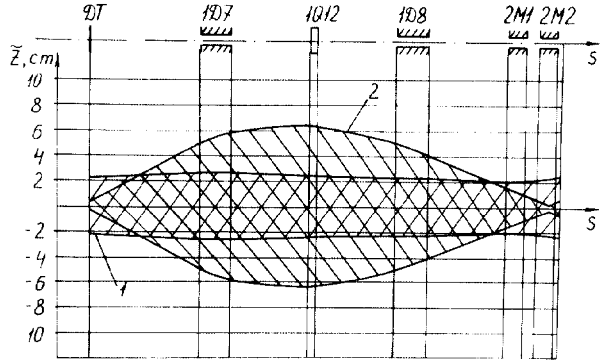

Fig.4. Envelope of the circulating (I) and ejected (2) beams in axial direction