ION PULSE COMPRESSOR AND STRETCHER RING FOR LINEAR MESON FACTORY

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Summary

The time structure of the accelerated H^- beam of Moscow meson factory is defined by technical features of linear acceleration and inadequate to the demands of a considerable part of the physics program envisaged. A new type of a magnetic ring for ion pulse time structure transformation is proposed. The most essential operating modes are as follows: 1) the compression of every stored pulse up to the hundreds times; 2) slow ejection of every pulse over 10 ms. Multiturn charge-changing $H^- \rightarrow H^+$ injection will be used for the effective storage. The magnetic ring is an isochronous one ($\gamma = \gamma_{tr}$) for the pulse compression mode. Bunch beam structure is maintained without RF bunching system. The beam will be slowly ejected by the modified Piccioni method. The 99% ejection efficiency can be achieved, but the special azimutal distribution of a dispersion function is needed. The main beam dynamics features are shown together with the magnet ring configuration.

Introduction

The acceleration of H^- ions is a main operating mode of Moscow linear meson factory now under construction [1]. So it will be possible to store each linac macropulse in a magnetic ring by multiturn charge-changing injection [2,3]. The beam phase space density can be increased many times. The design parameters of the meson factory beam essential for our aim in view are listed below

H^- ion kinetic energy.	600 MeV
Peak beam current.	50 mA
Pulse duration	100 μs
Repetition rate.	100 Hz
Beam emittance	0.3π cm.mrad
Relative momentum spread . . .	$\pm 2\cdot 10^{-3}$

Beam storage

Each accelerated H^- ion macropulse will be injected into the magnetic ring by ion stripping ($H^- \rightarrow H^+$) while crossing through a thin carbon foil (200 μg/cm^2). It will be installed inside the ring vacuum chamber at the straight section with zero dispersion. The local distortion of the closed orbit will be used during injection. H^- beam does not cross the nonlinear magnetic fields at injection area, so no significant beam emittance dilution can be expected.

The H^- beam emittance is smaller by a factor of ten than that of the stored one. So it is possible to adjust the stored beam phase space distribution by time-dependent variation of incoming beam transverse position as well as that of the beam emittance shape parameters at injection azimuth. Besides one can choose different betatron numbers and thus additionally control the density distribution in four-dimentional phase space. It is reasonable to achieve homogenious charge distribution within the beam cross section.

The essential characteristics of the beam storage process are as follows:

Orbit circumference.	102.8 m
Circulation period	430 ns
Stored turns	240
Max. intensity per pulse . . .	$3\cdot 10^{13}$
Max. particle linear density .	$3\cdot 10^{11}$ m^{-1}
Stored beam emittance.	3π cm.mrad
Max. incoherent tune shift (Smooth approx.)	-0.09

Macropulse compression

Time compression of the linac macropulse is achieved by the particle storage and one-turn ejection as soon as filling process is terminated. One has to provide an azimutal void to exclude beam loss during the rise time of kiker-magnet field. Ring magnet structure is an isochronous one i.e.

$$\alpha = \gamma^{-2}, \qquad (1)$$

where α is a momentum compaction factor, γ is beam energy. There is no RF system to keep the bunch structure. Similar storage idea has been proposed and experimentally studied by K.Reich [4]. The condition (1) might be maintained in our case only approximately. For example 10% deviation of α from the precise value gives 4 m bunch lengthening in 100 μs period of macropulse storage. The transverse electromagnetic self-field of the stored beam distorts the isochronism. Different particles have their own α-values and α-deviation depends on the local charge density. In our case $\Delta\alpha_{max} = 0.018$.

It is essential to eliminate the initial RF beam microstructure during storage. So charge density is smoothing along the bunch. The smoothing occurs naturally if the ring circumference L is not divided exactly by $\beta\lambda$ (β is a particle velocity, λ is a linac RF wave length).

Specific beam dynamics point in isochronous system is a low threshold for microwave instability. Fortunately rise times become very long near transition, especially for low mode numbers n, responsible for beam macrodeformation. In the real situation ($n = 10^2$, $\alpha - \gamma^{-2} = 1\cdot 10^{-2}$, $Z_L/n = 30\,\Omega$), instability growth times exceed considerably the storage time.

The main parameters of macropulse compression mode are as follows:

Bunch length in the ring up to	75 m
Max.intensity.	$2,3\cdot 10^{13}$
Peak circulating current . . .	11 A
Momentum compaction factor . .	0.371
Kiker-magnet strength.	0.02 T.m
Kiker-magnet rise time	100 ns

Macropulse stretching

This operating mode includes azimuthally homogeneous storage of particle macropulse and further slow ejection of the stored

0018-9499/85/1000-2709$01.00© 1985 IEEE

beam within time interval between the successive linac pulses. The wide-spread methods of resonant slow ejection is difficult to utilize in our case. Nonlinear intense beam self-field prevents particle excitation at a reasonable rate and reduces the ejection efficiency.

We have studied present-day possibilities of the old-fashioned slow ejection method. The main point here is the excitation of radial betatron oscillations while the beam is gradually shifting onto the thin target due to the local radial distortion of the closed orbit. This method was realized for slow beam ejection from weak-focusing proton synchrotrons [5,6].

The particle momentum decreases by Δp due to ionization losses while crossing the condensed target. The radial position of the particle closed orbit shifts abruptly by the value

$$\Delta r = \psi(\Delta p/p_o), \qquad (2)$$

where ψ is a dispersion function. The amplitude of additionally excited betatron oscillation is equal to $|\Delta r|$. The first maximum inward excursion of the particle occurs at half a betatron wavelength downstream where it can be separated from the rest circulating beam and emerged away.

The maximum tolerable operational losses at slow ejection are assumed to be near 1%. The source of residual activity must be identified and rather well localized. Nuclear interaction and large angle scattering of the particles crossing the target and hitting the septum are the main processes responsible for activation. So the target thickness must be extremely small but sufficient enough to separate the ejected particles from the rest circulating beam. Taking into account the mentioned above it is reasonable to construct the magnet lattice so that ψ-function should be extremely large at the target azimuth and equal to zero at half a betatron wave length down stream (septum azimuth). In accordance with (2) the betatron oscillations are excited the most effectively. The radial distance between the ring principal orbit and the septum does not depend on circulating beam energy spread but on the radial betatron emittance only.

The approximate condition of the ejected particle separation from the circulating beam is

$$\Delta p/p_o \geq (\beta_t \varepsilon)^{1/2}/\psi_t, \qquad (3)$$

where β_t, ψ_t are structure functions at the target azimuth, ε is radial emittance.

The main characteristics of slow ejection are as follows:

Max.beam intensity.	$3\cdot10^{13}$
Relative loss of particle momentum	$2\cdot10^{-3}$
Target thickness (carbon)	4 mm
R.m.s. multiple scattering angle	$2\cdot10^{-3}$
Mean depth of proton penetration into target	100 μm
Max.target heat deposition. . . .	1 kWt
Intensity loss in the target. . .	0.8%
Intensity loss in the septum. . .	0.2%
ψ-function value at the target azimuth	12 m
β-function value at the target azimuth	8 m

Magnet lattice is a nonisochronous one at slow ejection operating mode. It will be necessary to cure the instabilities of the intense circulating beam. Those ones connected with residual gas interaction will be eliminated by maintaining gas pressure at the level of 10^{-9} Torr. The ring vacuum chamber and the equipment in-side it ought to be manufactured so as to provide the adequate electromagnetic properties of the beam surroundings. The transverse feed-back damping system is needed.

Magnet lattice

The ring magnet lattice (Fig.1) cosists of two cells. Each cell is an achromatic one with almost independent tuning of transverse and longitudinal dynamics parameters. Wide-spread tuning of the betatron numbers is well provided by the quadrupoles 1-Q installed in zero dispersion straight sections. The deflecting system of each cell has two-fold mirror symmetry, i.e. it is symmetrical against the plane A-A' and besides that each its half is symmetrical against B-B'. Dispersion function maximum value occurs at the azimuth A-A'. It is possible to adjust the dispersion at this point by tuning quadrupoles 1-K without an achromaticity distortion.

Fig.2 represents the cell main functions for different values of α. The betatron numbers are $Q_x = 2,4$; $Q_z = 2,3$.

Second-order aberrations depending on $(\Delta p/p_o)^2$ and emittance $\varepsilon_{x,z}$ have negligible influence on the bunch lengthening at isochronous operation mode (less than 1 m for 100 μs).

Compressed and stretched beams are emerged away into the common transporting channel 3-L. Septum-magnets 3-S are used for deflection of both beams mentioned.

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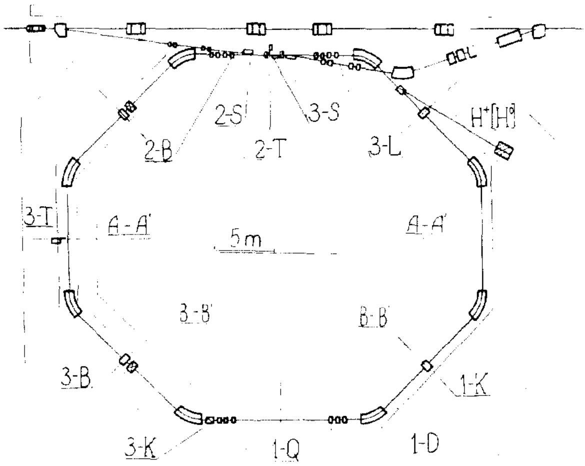

Fig.1. Plan view of storage ring.
1. Ring magnet: 1-D - dipole; 1-Q - quadrupole; 1-K - quadrupole for correction α.
2. Injection system: 2-T - stripping foil; 2-S - septum-magnet; 2-B - bump-magnet.
3. Ejection system: 3-S - septum-magnet; 3-L - external beam channel; 3-K - kiker-magnet; 3-T - slow ejection target; 3-B - bump-magnet for beam spilling

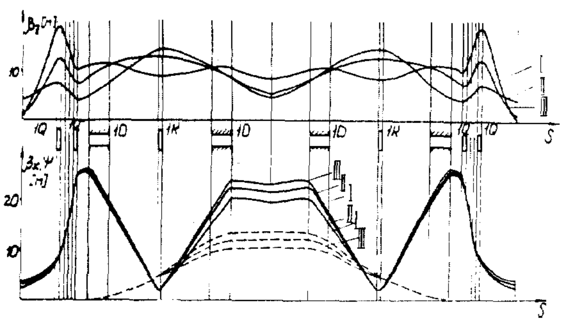

Fig.2. The cell functions for macropulse compression operating mode: ——— $-\beta_{x,z}$; - - - ψ.
Curves I,II,III correspond to different α-values: $\alpha-\gamma^{-2}$ = 0; 0.044; -0.044