MAGNETIC RING FOR TRANSFORMATION OF THE HEAVY IONS CHARGE STATES

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Heavy ions are often accelerated in two stages. For higher acceleration efficiency ions are stripped after the first stage being finished. As a result, the charge states spectrum is formed. For further acceleration only one charge component - the most intensive-is selected. Thus, higher acceleration efficiency is accompanied with the reduced current of the beam (Kr, Xe beams by a factor of 4-5, U - beam - by a factor of 6).

Special magnetic ring of a simple design permits to avoid significant ion losses /1/. It's natural to christen such a device booster.

As an example, Fig.1 shows schematically the magnetic ring designed for transforming of heavy ion charge states (up to Xe) with the energy 1 MeV/n. This ring consists of four dipole magnets (M1, M2) with uniform field and edge focusing. To provide necessary dispersion, there are also two quadrupoles (Л). β - functions and dispersion function ψ at a half perimeter are given in Fig.2.

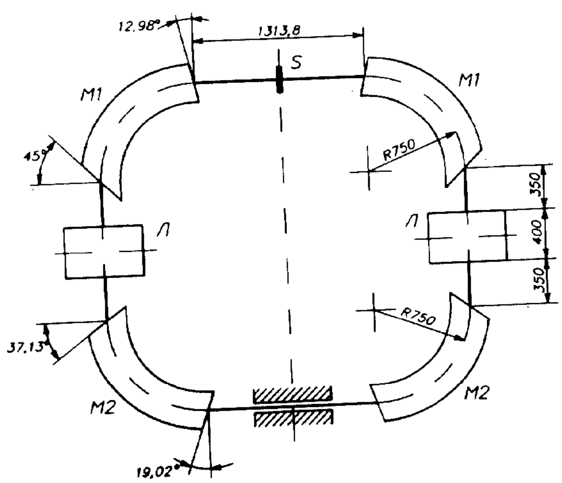

Fig.1. Scheme of magnetic ring for an ion beam charge transformation

In case of single type ions, the magnetic field is constant. Other types of ions need changing of the magnetic induction level in the dipoles and quadrupoles in accordance with the ion magnetic rigidity.

The operation principle of the booster ring is as follows. The ion beam, the charge several times less than equilibrium is directed onto the target - S (Fig.1). After its single crossing the equilibrium charge state is formed. Examples of charge states distributions with 1 MeV/n energy are shown in Fig.3.

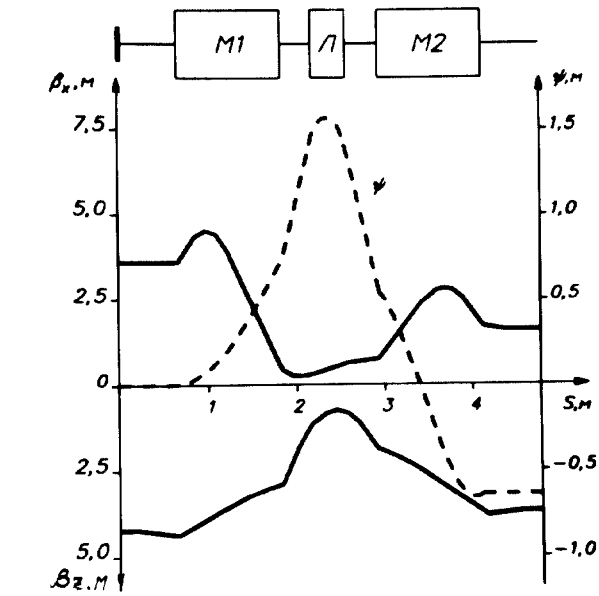

Fig.2. β and ψ - dispersion functions at a half perimeter

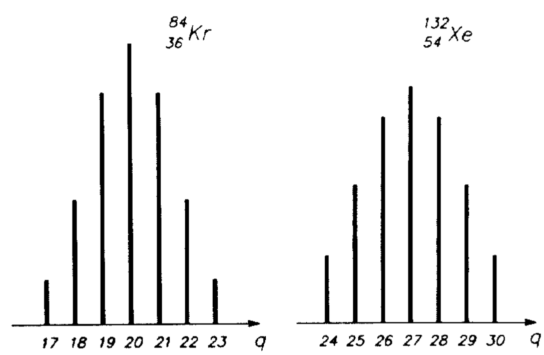

Fig.3. Charge distribution in an ion beam after single crossing of the recharging target

Ions with equilibrium charge are supposed to move along the central orbit. Ions with the charges different from equilibrium by Δq move along the orbit which radial deviation from the central one is $\Delta r = -\psi \Delta q / \bar{q}$, where ψ is the ring dispersion.

At subsequent crossing of the target the ion charge state is transformed, still being in the limits of equilibrium spectrum. With the most probability the mean charge state $q = \bar{q}$ is formed. In the process of multiple crossing, the condition $\psi = 0$ at

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the target azimuth is very important. Only in this case the ion charge state transformation isn't accompanied with the betatron oscillations excitation. On the diametrically opposite azimuth of the ring the dispersion is rather high and fractional beams, different in charges by unity, are completely separated.

The device schematically shown in the ring straight section (Fig.1) is symmetrical splitter-magnet with horizontal field and two channels (Fig.4)

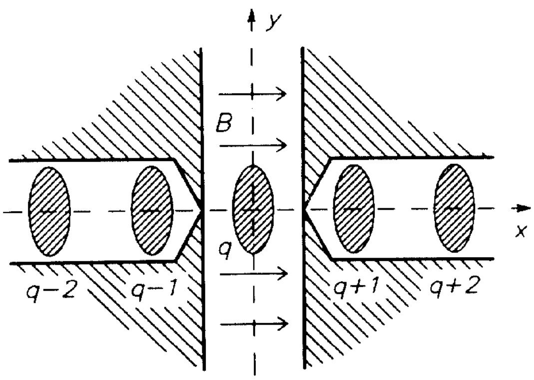

Fig.4. Splitter-magnet for ions extraction with the selected charge

The splitter-magnet field deflects in the vertical direction one of the charge components (in our case $\bar{q}$) and fractional ion beams with the charges $\bar{q} \pm 1$, $\bar{q} \pm 2$, etc travel in the channels with zero magnetic field. Splitter-magnet function in this case is extraction of ions with the most probable charge $\bar{q}$ from the ring. Ions with other charges continue their cyclic movement and gradually all of them leave the ring with the charge state $\bar{q}$. For κ -turns, the relative fraction - η of all ions equal /1/: $\eta(\kappa,\varepsilon) = 1-(1-\varepsilon)^{\kappa}$ will be in the charge state $\bar{q}$ (where ε is the fraction of charge in equilibrium distribution). For 5-6 turns approximately 70% of circulating beam is extracted, for 10 turns-practically the whole beam.

The content of the most probable charge $\bar{q}$ in Kr and Xe -spectra are 25 and 21%, respectively. Therefore booster application permits, in principle, to increase the beam intensity approximately by a factor of 4-5 in comparison with the traditional practice of one charge component acceleration. The current circulating in the ring exceeds that injected by ε^{-1} -times.

Two effects connected with the target multiple crossing should be evaluated. These effects are the less, the thinner target is and the lower is κ-number. The minimum target thickness necessary to obtain charge equilibrium after single crossing of carbon target is δ = 10-15 μg/cm^2 with 1 MeV/n energy, independently on ions type. This is approximately the least thickness which still permits to hope that the mechanical strength of the carbon film will be provided. Various ions strike the recharging target differently, the result is an additional energy dispersion in the beam to be accelerated. Energy losses for ionization at single crossing are approximately equal for all ions being of practical interest (and proportional to q^2/A, where A is an atomic number). At 1 MeV/n energy we have $\Delta W/W = -5.10^{-4}(\kappa-1)\delta$ /2/, where κ is number of crossings, δ is target thickness in μg/cm^2. The unity in the brackets appears due to the fact that all ions are subjected to the first crossing and therefore the energy dispersion is remained. At δ = 10 μg/cm^2, κ = 5 we have $\Delta W/W$=2.10^2. In the process of further acceleration this will be considered as an additional energy dispersion $\Delta W/W = \pm$ 1.10^2.

2. Multiple scattering in the target material will increase the beam emittance. R.m.s. scattering angle is given by an expression /3/:

$$\langle \theta^2_{x,y} \rangle^{1/2} = \frac{E_s \bar{q}}{2^{3/2} W} \left(\frac{\kappa \delta}{X} \right)^{1/2}$$

where E_s = 21.2 MeV, W - is kinetic energy of ions, X is radiation length. Assuming W = 132 MeV (Xe), X = 42.5 g/cm^2, δ = 10 μg/cm^2, κ = 5, we obtain: $\langle \theta^2_{x,y} \rangle^{1/2} = 1,6\ 10^{-3}$.

The importance of the beam circulation time reduction and expediency of the most probable charge component $\bar{q}$ extraction are supported by the above evaluations.

Thus, multicharged beam could be transformed into mono charged at a price of its density reduction in 6-dimensional phase space. Booster application is advantageous in those cases when the acceptance of the accelerator used at the second stage is sufficient to utilize such a beam.

References

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