ABOUT STORING OF LOW ENERGY IONS

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It shown, that using of two internal targets – the atomic jet and plasmas one – permits to store different ions of low energy. The magnetic structure and main parameters of proposed 150 keV tritium ions storage ring are given.

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1. INTRODUCTION

The main factor, which for a long time impeded creation of heavy particles storage rings with high phase density of circulating beam, was absence of cross and longitudinal oscillations damping because of very small value of power losses on synchrotron radiation.

In work [1], for particles cross oscillations damping, it was offered to use as braking force the energy losses for ionization of solid-state or gaseous internal target. The longitudinal oscillation damping in this case is not provided [2].

In work [3] it has been shown, that the using as a braking force the non-elastic energy losses when particle passes through the substance, in certain range of speeds ($\upsilon_p \leq 4*10^8$ cm/s), makes possible to provide the damping both cross and longitudinal oscillations. This fact was taken in a basis of offers on non-relativistic particles storage ring designing [3, 4].

2. THE MAIN PARAMETERS OF THE STORED ION BEAM

2.1 THE STEADY-STATE ENERGY SPREAD

The steady-state energy spread is determined by expression [5]:

$$\overline{\Delta E^2}^{\frac{1}{2}} = 0.5\left(\dot{N}\overline{\varepsilon^2}\tau_s\right)^{\frac{1}{2}}. \qquad (1)$$

Here $\overline{\varepsilon^2}$ is an average square of the energy lost by a particle in the single act of scattering, $\dot{N}$ is an average number of collisions received by particle at unitary passage of a target, τ_s is the damping time of synchrotron oscillations.

From the work [6] data it follows, that the power losses spectrum of proton with energy 10-80 keV which interacts with target, is close to normal distribution with dispersion $\sigma = 10^{-2}\overline{\Delta E}$, where $\overline{\Delta E}$ is the average energy lost by particle at passage of target. Taking into account expressions for τ_s [4] and for $\dot{N}\overline{\varepsilon^2}$ [5], for hydrogen isotope ions with energy ~50 keV/nucl. and hydrogen target one obtains $\overline{\Delta E^2} \approx 1.3*10^{-11}N_s$. Here N_s is surface density of a neutral target. At $N_s=10^{17}$ atom*cm^{-2} the steady-state energy spread is equal to ~1140 eV.

The capture and deduction in circulation mode particles with such energy spread from the point of view of the necessary RF-separatrix creation does not represent any problem.

2.2 THE PARTICLES LIFETIME IN THE STORAGE RING

The heavy particles lifetime in the storage ring is basically conditioned: a) by scattering on an angle greater than maximum permissible for given magnetic structure and b) by neutralization (or charge exchange) circulating particles on the target atoms.

a) The life time caused by scattering on angle greater than maximum permissible for given magnetic structure. At passage through a target the particle multiply non-elastically scatters on its atoms. The angle of multiple scattering can be estimated with help of distribution function reduced in [7a].

In Table 1 are represented, calculated according to [7a], the values of root-mean-square scattering angle of the particles moving with speed $3 \cdot 10^8$ cm/s, on atoms of a hydrogen target with density 10^{17} cm^{-2}.

Table 1. *Mean square scattering angles of particles*

Particle	Proton	deuteron	triton
$\overline{\Theta^2}$	$3.86*10^{-4}$	$2.9*10^{-4}$	$2.6*10^{-4}$

So as the relative number of the particles which left circulation mode after single target passage did not exceed 10^{-6}, the magnetic system should provide capture of particles which were scattered on an angle $\sim 5\overline{\Theta^2}^{1/2}$.

b) The lifetime caused by neutralization (or charge exchange) circulating particles on the target atoms. At interaction of nonrelativistic heavy particles with an atomic or molecular target the lifetime determining reactions are reactions with atom electron level excitation or with electron redistribution between interacting particles (reactions of ionization, neutralization, and charge exchange).

The ratio of neutral particles number to charged particles number in the beam after target passage is equal [4]:

$$\frac{n_0}{n_+} = \frac{\sigma_{10}(1 - \exp[-n_{sm}(\sigma_{01} + \sigma_{10})])}{\sigma_{01} + \sigma_{10}\exp[-n_{sm}(\sigma_{01} + \sigma_{10})]}. \qquad (2)$$

Here σ_{10} and σ_{01} are accordingly neutralization and ionization cross-sections on atomic target; $n_{sм}$ is surface density of this target.

$N_+/n \approx n_0/n = 0.5$ for protons, deuteron and tritons with energy ~50 keV/nucl ($\sigma_{10} \approx \sigma_{01} \approx 10^{-16}$ cm^2). That means practically complete beam loss after single target

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passage. Obviously, the least power-intensive way of neutrals ionization is ionization by electron impact in high-ionized plasma.

For case $\upsilon_i = \upsilon_e = 3 \cdot 10^8$ cm/s ionization σ_I and neutralization σ_0 cross-sections in completely ionized hydrogen plasma are equal $7.5 \cdot 10^{-16}$ cm^2 and ~$6.7 \cdot 10^{-23}$ cm^2 accordingly. As $\sigma_i >> \sigma_0$ in the further calculations the ions neutralization by plasma electrons was not taken into account. Thus, the plasma target with surface density $N_{sp} \sim 1.7 \cdot 10^{16}$ cm^{-2} is "thick", i.e. provides practically complete ionization of beam neutral component.

The particle energy losses at passage through plasma are given by expression [7b]:

$$-\left(\frac{dE}{dx}\right)_{пл} = -\frac{dE}{dt}\frac{1}{v} = \frac{4\pi Z_1^2 Z_2^2 e^4}{Mv^2} NL. \qquad (3)$$

(3)

Here M is mass of the field particle; v is speed of the trial particle; N is plasma volumetric atomic density; L is Coulomb logarithm ($L \approx 5$ when $N \sim 10^{16}$ cm^{-3}); $Z_{1,2}$ is charge of a field or trial particle accordingly.

From expression (3) one can see that the energy loss by a particle at passage through plasma is caused, mainly, by electron collisions, does not depend on particle mass and does decrease, if the particle's speed increases, it can reduce in the swing of longitudinal oscillations [2].

Hence, the plasma target density, on the one hand, should be sufficient to provide complete ionization of neutral component of the beam and, at the same time, it must provide the synchrotron oscillation decrement positive and great enough.

In particular, if the neutral target density is $N_t = 1.7 \cdot 10^{17}$ cm^{-2}, the plasma target should have density $N_p = 1.7 \cdot 10^{16}$ cm^{-2} and ionization degree must be not worse 0.99999. In this case the damping time of longitudinal oscillations τ_s equals $1.2 \cdot 10^{-2}$ s.

As the prototype of device for back ionization of neutrals can be the installation described in [8], on which was received plasma with following parameters: density is $10^{14} \ldots 10^{15}$ cm^{-3}, duration is 0.4 ms, ions temperature $T_i = 100 \ldots 500$ eV, electron temperature $T_e = 0.5 \ldots 3$ keV. Last circumstance provided a high degree of plasma ionization.

The device represented plasma trap. Ionization was effected by pulsed electron beam.

The estimations, which had been made on the basis of experimental data, testify that for creation the plasma target with required parameters (superficial density, ionization degree, pulse duration) it is necessary the reserved energy ~200 kJ.

3. THE MAGNETIC STRUCTURE OF TRITIUM ION STORAGE RING

The basic requirement presented to magnetic structure of tritium storage ring is provision of capture in circulation mode the beam with divergence ~0.08 rad (see Table 1).

Besides, the storage ring magnetic structure must contain the straight sections with length sufficient to mount injection and RF systems, plasma and neutral targets. With taking into account all these requirements, the tritium ion storage ring magnetic system was chosen.

The tritium ion storage ring magnetic structure and its focusing and dispersion functions are represented on Fig. 1a,b.

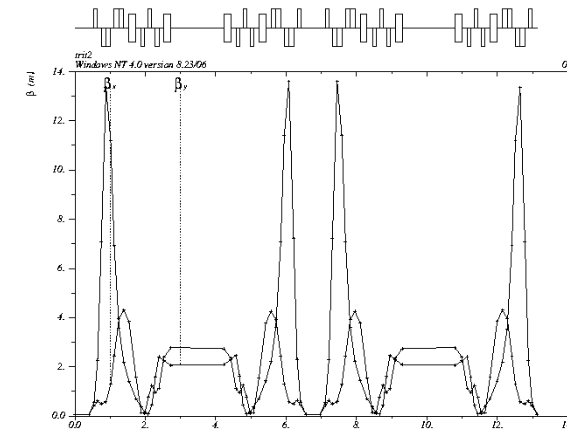

Fig. 1a

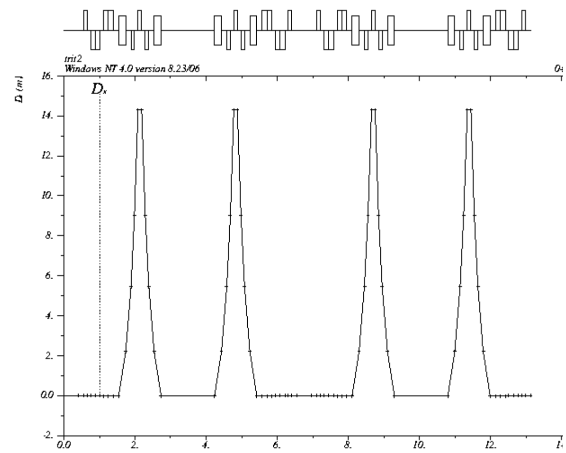

Fig. 1b

The structure contains two solenoids (S_1, S_2) 0.4 m long which are placed on focus azimuths ($0 \le S_1 \le 0.4$ m, 6.565 m $\le S_2 \le 6.965$ m). Solenoid S_2 belongs to a plasma target, solenoid S_1 provides geometrical length equalizing of super-period with conservation of its focusing properties. The magnetic field strength of solenoid was chosen by such a way that the ratio $\sin(KL) = 0$ is fulfilled.

Here L is the solenoid length, $K = B(0)/(2B\rho_0)$, where $B(0)$ is the solenoid magnetic field strength, $B\rho_0$ is an equilibrium particle momentum. Under this condition the matrix, which describes solenoid, is unitary and solenoid does not act on the particles dynamics in linear approximation. The parameters of magnetic structure are represented in Table 2.

4. CONCLUSIONS

The reduced numerical estimations allow to make inference that influence of neutralization and charge exchange processes on life time of low-energy ions circulating beam can be suppressed by ionization with the help of pulse plasma target [9]. The length of plasma pulse should be about the damping time of synchrotron oscillations.

Table 2. *The parameters of tritium storage ring*

Parameter	Value
Ion type	T^+
Energy, keV	~150
Storage ring perimeter, m	13.13
Number of superpriods	2
$\beta_{x,z}$, max., m	4.3; 10.8
$\beta_{x,z}$, min., cm	6.1; 5.5
D_x, max., m	14.3
Betatron oscillations number $Q_{x,z}$	4.214; 3.341
Achromacity	ξ_x=-354 ξ_z=-514
Achromatic sections length, m	1.5
The length of sections with focuses, m	0.7…1.
The bending magnets number	8
The bending magnet length, cm	19.635
The bending magnet vertical aperture, cm	±2.6
Magnetic field strength, T	0.3876
The magnetic field gradient, n	0
The quadrupole lens number	24
Min. and max. quadrupole lens length, m	0.27; 0.1
Max. aperture of quadrupole lens, cm	a_x=±4.1 a_z=±6.2
Max. magnetic field gradient in quadrupole lens, T/m	6.6
Max magnetic field strength on lens pole, T	0.21
Solenoid length, m	0.4×2
Solenoid magnetic field strength, T	0.3…3.

From Table 2 data it is evident, that parameters magnetic elements of triton storage ring (the aperture of magnetic elements, strength and gradients of magnetic fields) are not critical and, hence, such installation is quite cashable. One of the probable spheres of such installation use, in authors' opinion, may be research on controlled thermonuclear synthesis initiated by heavy ion beams [9].

REFERENCES

1. A.A. Kolomenskiy. About oscillation decrements in accelerator with arbitrary energy losses // *Atomn. Energ.* 1965 v. 19 p. 534-535 (in Russian).
2. Yu.M. Ado, V.I. Balbekov. About possibility to use ionisation friction for heavy ions storing // *Atomn. Energ.* 1970 v. 31, p. 40-44 (in Russian).
3. E.V. Inopin, O.S. Tarasenko. Non-relativistic tritium ions storage ring as neutron source // *Ukr. Fiz. J.* 2000, v. 45 (11), p. 1301 (in Ukrainian).
4. I.S. Guk, A.V. Paschenko, et al. The physical bases of low-energy hydrogen isotope ions storage ring // *Problems of Atomic Science and Technolgy .Series: Nucl. Phys. Invest.* 2002, №2(40), p. 86-89.
5. H. Bruck. *The cyclic accelerators of charged particles* Moscow: "Atomizdat", 1970, p. 205 (in Russian).
6. J.I. Phillips. The energy loss of low energy protons in some gases // *Phys. Rev.* 1953 v. 90(4), p. 532.
7. Yu.V. Gott *The charged particles interaction with substance.* Moscow: "Atomizdat", 1978, a) p. 156; b) p. 63 (in Russian).
8. M.Yu. Bredikhin, A.I. Maslov et al. Plasma heating with power electron beams // *Journ. Tekhn. Phys.* 1973, v. 43 (3) p. 517 (in Russian).
9. *The HIDIF Study.* Report of the European Study Group on Heavy Ion Driven Inertial Fusion for the period 1995-1998. GSI-98-06 REPORT, August 1998, Gesellschaft fur Schwerionenforschung, Darmstadt.

О НАКОПЛЕНИИ НИЗКОЭНЕРГЕТИЧНЫХ ИОНОВ

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Показано, что использование двух внутренних мишеней – плазменной и струйной, позволяет накапливать низкоэнергетичные ионы. Приведена магнитная структура и основные параметры предлагаемого накопителя ионов трития с энергией 150 кэВ.

ПРО НАГРОМАДЖУВАННЯ НИЗКОЕНЕРГЕТИЧНИХ ІОНІВ

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Показано, що використання двох внутрішніх мішеней – плазмової та струменевої, дозволяє нагромаджувати низькоенергетичні іони. Наведено магнітну структуру та основні параметри пропонованого нагромаджувача іонів тритію з енергією 150 кеВ.