THE NONLINEAR TRANSFORMATION OF AN IONS BEAM IN THE PLASMA LENS*

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Abstract

The plasma lens can carry out not only sharp focusing of ions beam. At those stages at which the magnetic field is nonlinear, formation of other interesting configurations of beams is possible. Plasma lens provides formation of hollow beams of ions. Application of the several plasma lenses allow to get a conic and a cylindrical beams. The plasma lens can be used for obtaining a beams with homogeneous spatial distribution. Calculations and measurements were performed for a C^{+6} and Fe^{+26} beams of 200-300 MeV/a.u.m. energy. The obtained results and analysis are reported.

INTRODUCTION

The ion beam focusing in the plasma lens is carried out as shown in Fig.1. The discharge current produces an azimuthal magnetic field. The ions are injected along the lens axis, and the radial Lorentz force focuses the ion beam [1].

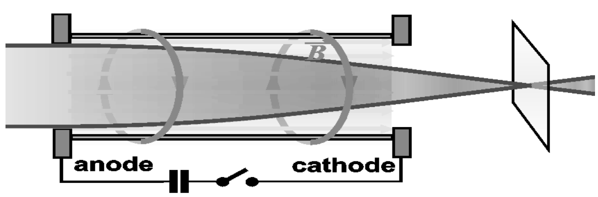

Figure 1: Ion focusing in a plasma lens.

In the current generator (Table 1) cold-hollow cathode

Table 1: Features of discharge current generator

Short pulse mode	
Switch (2 pcs) Discharge current pulse duration Max discharge current	Thyratron TDI1-150/25 T = 5 µs at C = 25 µF I = 200 kA at T = 5 µs
Long pulse mode	
Switch (2 pcs) Discharge current pulse duration Max. discharge current	ThyratronTDI1-200k/25H T = 20 µs at C = 160 µF I = 400 kA at T = 20 µs

thyratrons (pseudospark switches) TDI1-200k/25H [2] are employed to form a stable discharge with peak current up to 250 kA. TDI-thyratrons in plasma lens generator avails to operate in a mode of long energy-intensive pulse. The time sweep of the luminosity of the plasma and the discharge current for short pulse mode and long pulse mode are shown on Fig. 2 and 3.

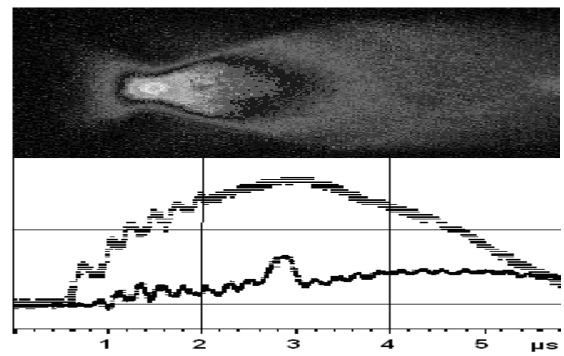

Figure 2: Time scanning of a discharge luminescence and a discharge and beam currents for short pulse mode.

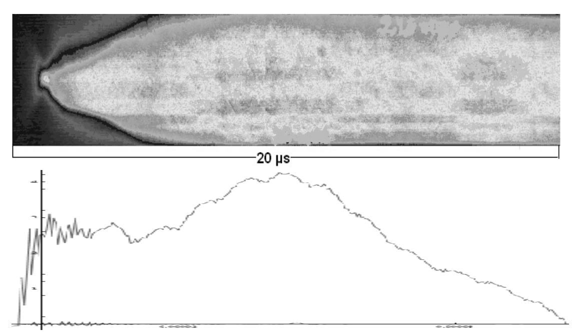

Figure 3: Time scanning of the discharge luminescence and current for long pulse mode.

Hamped shape of the long current due to the fact that part of the capacity (25 µF) have low self-inductance. The focusing properties of plasma lenses depend on the current density distribution along the radius of the plasma discharge. The current distribution across the tube changes significantly during the discharge. Therefore, plasma lens, in general, is nonlinear. Uniform current distribution exists for a limited time, so the plasma lens, as a device for sharp focusing, operates for about 1 µs or less. As a non-linear focusing device, the plasma lens can be used to produce beams of special shape. The researches were conducted on the follows parameters: the discharge tube radius R = 1 cm and its length L = 10 cm,

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argon pressure – 1-8 mbar, the ion beam duration – 300ns.

FORMATION OF THE HOMOGENEOUS BEAM

Usage of ions beams for irradiation of various objects, in particular, in medical purposes, demands creation of a homogeneous field of an irradiation. The initial beam, as a rule, has the gaussian distribution. For alignment irradiation fields use the special filters-absorbers. This solution spoils however quality of irradiation fields and essentially reduces efficiency of beams. The solution of this problem is possible by means of the nonlinear focusing device. A simulation were conducted for to research opportunities of plasma lenses to solve this problem. It appears that it is possible to get homogeneous distribution of ion density for a case of equilibrium distribution of a discharge current. At enough large duration of a current pulse of >10 μs, current distribution is tending to equilibrium one. A similar distribution is the "quasibennett" distribution, was applied in the study of a high-current arc discharge [3]:

$$j = I(1+ \tilde{A}\,) / \pi R^2 \,(1 + \tilde{A}\,(r/R)^2)^2, \tag{1}$$

where R - plasma lens aperture, I discharge current. The value $\tilde{A}$ is a function of the discharge current, the plasma temperature and the plasma conductivity.

The results of the first experiments (beam of ions C^{+6} with energy 300 MeV/n, current half-wave - 20 μs) are presented in Fig. 4 The density ions distribution was obtained by averaging of the scintillator luminocity over the angle around the beam axis.

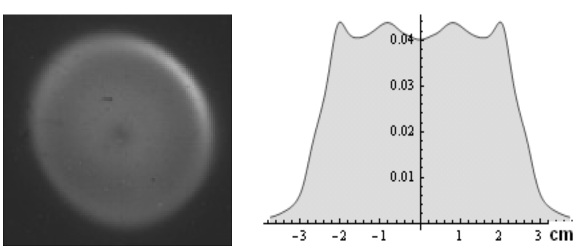


Figure 4: The light output from the scintillator and the density distribution of the ion C^{+6} at 8.5 μs after beginning of discharge at distances of 110 cm for current of 80 кA. The spot rms diameter is 40 mm.

The calculated distributions of density of ions in a beam of C^{+6} (300 MeV/n, z = 150 cm) is shown on Fig.5.
The initial distribution is adequate to the beam injected into the plasma lens. The transformed distribution was obtained in the plasma discharge which has the "quasibennett" distribution (1) where $\tilde{A} = 0.85$.

As we can see, transformation of a gaussian beam into a homogeneous can be carried out effectively, and with observance of the geometrical sizes demanded at a medical irradiation: the size of a beam spot and drift distance behind the lens.

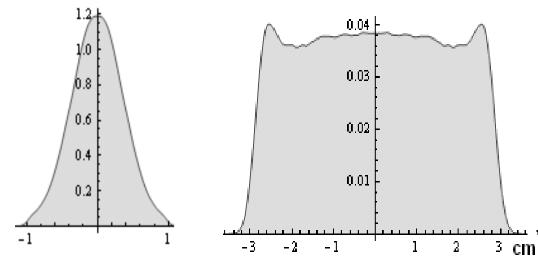


Figure 5: The initial and transformed distributions.

FORMATION OF HOLLOW BEAMS

Hollow beams can be used for the implosion of thermonuclear targets [4]. Possibility of that transformation of ion beams has been demonstrated experimentally in GSI [5]. Researches carried out on the ITEP plasma lens confirmed this opportunities in a wide range of operating modes lens. [6].

Experimental results concerning formation of a hollow beam of small diameter, less than 1 cm, is shown on Fig.6.

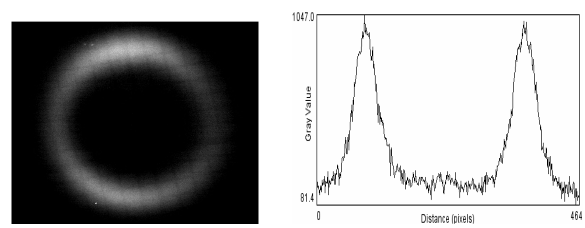


Figure 6: Light output from scintillator and the density distribution of ion Fe^{+26} at 1.7 μs after beginning of discharge at distances of 30 cm for current of 150 кA. The ring diameter is 9 мм .

The paraxial beam with zero emittance is converted to a tube beam, when the distribution of azimuthal magnetic field in the plasma lens is as follows

$$B = a + br, \tag{2}$$

where a and b - constants. This distribution takes place, when distribution of the discharge current density is a superposition of a homogeneous distribution and a singular one, inversely proportional to radius r:

$$j = I_o/\pi R^2 + I_s /2\pi Rr \tag{3}$$

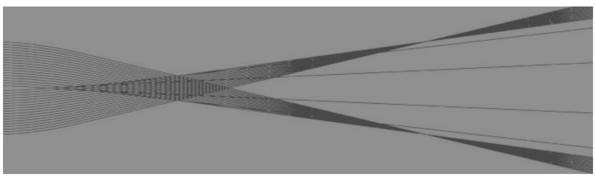
Here R - plasma lens aperture, within which there are a homogeneous current I_o and a singular one I_s. In this lens the ion beam is focused into a ring of radius

$$\rho = R\, I_s /I_o \tag{4}$$

at a distance

$$Z_o = R\,\mathcal{R}/B_oL, \qquad (5)$$

where L - length of the lens and $\mathcal{R}$ – rigidity of the beam of ions. Note that Z_o is equal to the focal length of the lens in the absence of a singular component of the current. The role of the latter is to create a independent from r component of the field, which causes the coherent deflection of ion trajectories on the angle ρ/Z. The picture of ions trajectories is shown in Fig. 7.



|-*L*-|------------------*Z*---------------------|

Figure 7: The picture of trajectories of a beam of ions

Our mathematical model gives (fig. 8) adequate ion beam distribution for the described experiment, if $Is/Io = 0.3$.

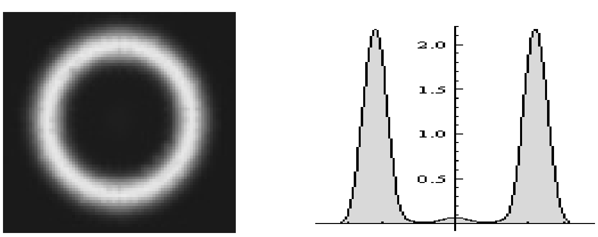


Figure 8: The light output from a scintillator and the distribution of ion Fe^{+26} density calculated in the model approximation for the experimental condition.

TWO-STAGE BEAM TRANSFORMATION

Other possible application of a plasma lens is formation a converging conic beam by means of two plasma lens. In this case the problem of an irradiation of certain area is solved in such a way as to not affect the previous adjacent zone. The results of calculations for C^{+6} (200 MeV/n) beam was focused by two lenses are shown on Fig. 9.

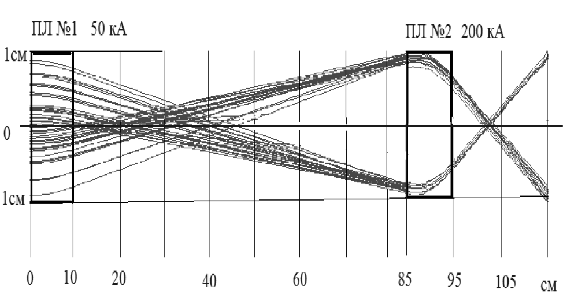


Figure 9: Formation a converging conic beam by means of two plasma lens.

In this case we used the distributions of a discharge currents of close to real ones. We can see that it is possible to get a conic beam and, as a special case, cylindrical one.

CONCLUSION

The plasma lens can carry out not only sharp focusing of ion beam with considerable reduction sizes of focal spot. At those stages of the plasma discharge at which the magnetic field is nonlinear, formation of other interesting configurations of beams is possible.

The plasma lens can be used for transformation of beams with gaussian distribution of particles density in a beams with homogeneous spatial distribution.

The plasma lens provides formation of hollow beams in a wide range of parameters that allows to consider it as a possible variant of a terminal lens for realization of inertial thermonuclear synthesis.

Application of the several plasma lenses which are in different stages of the plasma discharge, presumes to create some special spatial configurations of ions beams.

Thus, the plasma lens essentially represents the universal device is able to form beams for scientific and technical applications.

REFERENCES

[1] E.Boggasch, M.Dornik, D.H.H.Hoffmann, M.de Magistris, W.Laux, A.Tauschwitz, H.Wetzler IEEE Trans. on Plasma Sci. 23, 388-392 (1995).

[2] V.A.Gribkov, M.Scholz, V.D.Bochkov, A.V.Dubrovsky, R.Miklaszewski, L.Karpinski, S.Lee, Pseudosparks in nanosecond range of its operation: firing, jitter, and disconnection, Journal of Physics D: Appl. Phys. 37 (2004) 2107–2111.

[3] P.C.Thonemann and W.T.Cowhing, The Role of the Self Magnetic Feald in High Current Gas Descharges, Proc. Phys. Soc., 64, 345 (1951).

[4] N.Alexeev, M.Churazov, A.Golubev, D.Koshkarev, B.Sharkov, P.Zenkevich, "Heavy ion fusion energy program in Russia", Nucl. Instr. and Methods in Phys. Res. Sec.A: , 464 (2001), 1-3, pp. 1-5.

[5] U.Neuner, R.Bock, C.Constantin, D.Hoffmann, M.Geeissel, J.Jacoby, A.Kozyreva, M.Roth, N.Tahir, A.Tauschwitz, and D.Varentsov, "Shepping of intence ion beams into hollow cilindrical form", Phys. Rev. Lett. 85, 4518, (2000).

[6] A.Drozdowskiy, N.Alexeev, S.Drozdovskiy, A.Golubev, S.Savin, B.Sharkov, V.Yanenko, "Investigation of the formation of a hollow beam in the plasma lens", IPAC'10, Kioto, http://cern.ch/AccelConf/IPAC10 /MOPE040.

[7] A.Drozdovskiy, A.Golubev, B.Sharkov, S.Drozdovskiy, A.V.Yanenko, Formation of Hollow Heavy Beams in Plasma Lens, Physics of Particles and Nuclei Letters, 2010,Vol. 7, No. 7, pp. 534-538