Simulation of a Laser Ion Source for Injection into a Linear Resonant Accelerator with High Frequency Focusing

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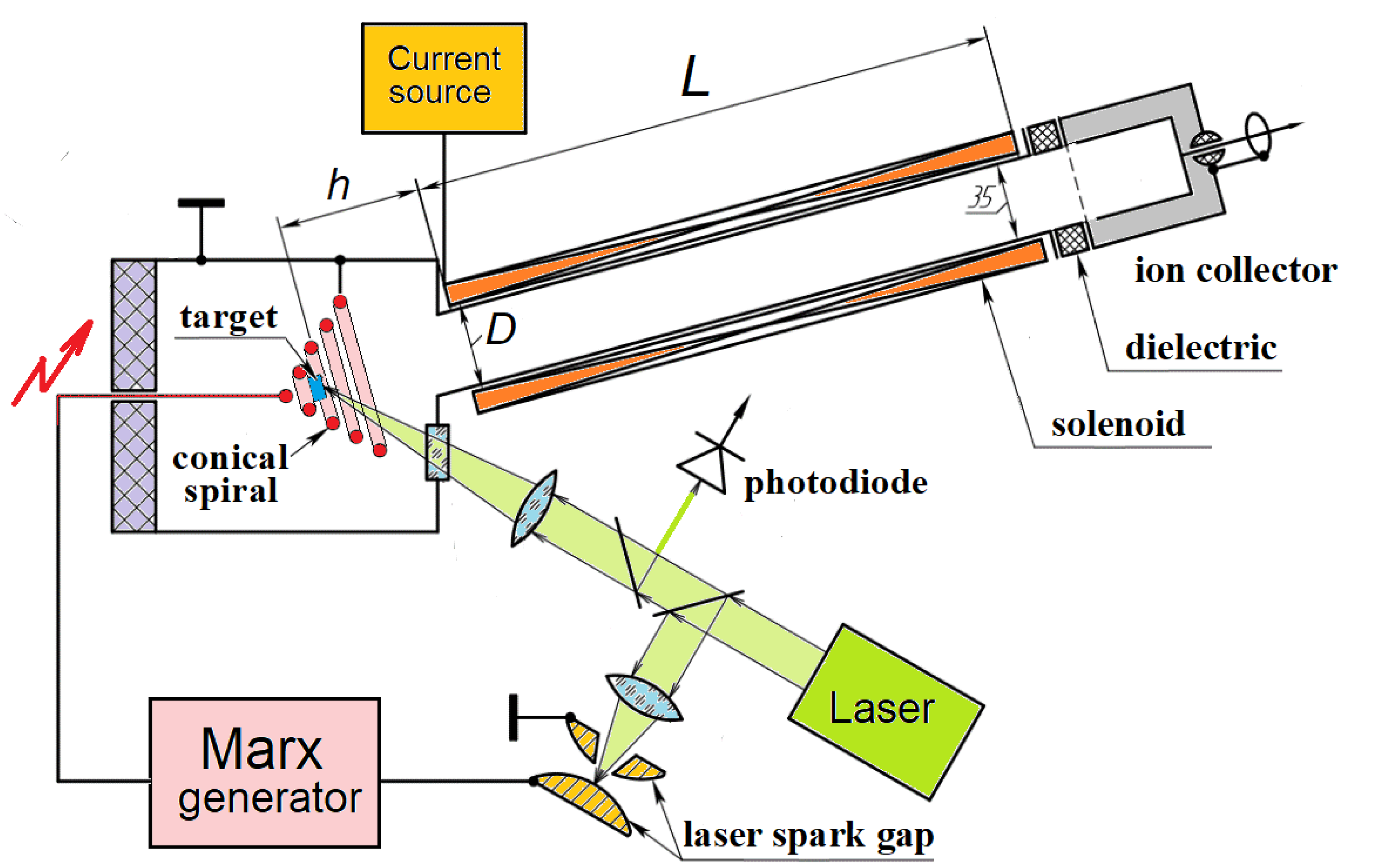
This work deal with the use of laser plasma to increase the efficiency of ion injection into a resonant linear Radio Frequency Quadrupole accelerator for the NICA project. To effectively capture ions in the acceleration mode, it is necessary to increase the duration of ion packets due to the expansion of the laser plasma (LP) into the drift space. At the same time, the effect of a magnetic field on the ion beam reduces the requirements for the energy of the laser pulse without reducing the particle flux density.

The prototype for the experiments was the results of work [1], in which the fluxes of carbon ions C^{4+}, C^{5+} и C^{6+} with the number of particles, respectively, 1.2 x 10^{11}, 1.0 x 10^{10} and 1.2 x 10^{9} were obtained at a pulse duration of 3.4 microseconds. In this paper, the possibility of a combined use of the permanent magnetic field of the solenoid and a more complex spatio-temporal structure of the magnetic field formed by a conical spiral expanding in the direction of the propagation of laser plasma is considered [2].

1. Experiment

The installation consists of a laser ion source, a drift tube, ion collector and a magnetic field generation system. To generate a high-speed magnetic field (HSMF) near the laser target, a conical spiral coil was used. Constant magnetic field (CMF) was created in the solenoid that surrounded the drift tube.



YAG: Nd^{3+} лазер

$E \le 0{,}85$ Дж, $\tau \approx 10$ нс

The studies were carried out for two values of the laser radiation energy:

E_1 = 125 mJ

(q_1 = 1,3 x 10^{11} W/cm^2)

and E_2 = 515 mJ

(q_2 = 5,0 x 10^{11} W/cm^2).

The pressure of the residual gas in the vacuum chamber was about 10^{-4} Pa, which ensured the free propagation of laser plasma ions to the collector.

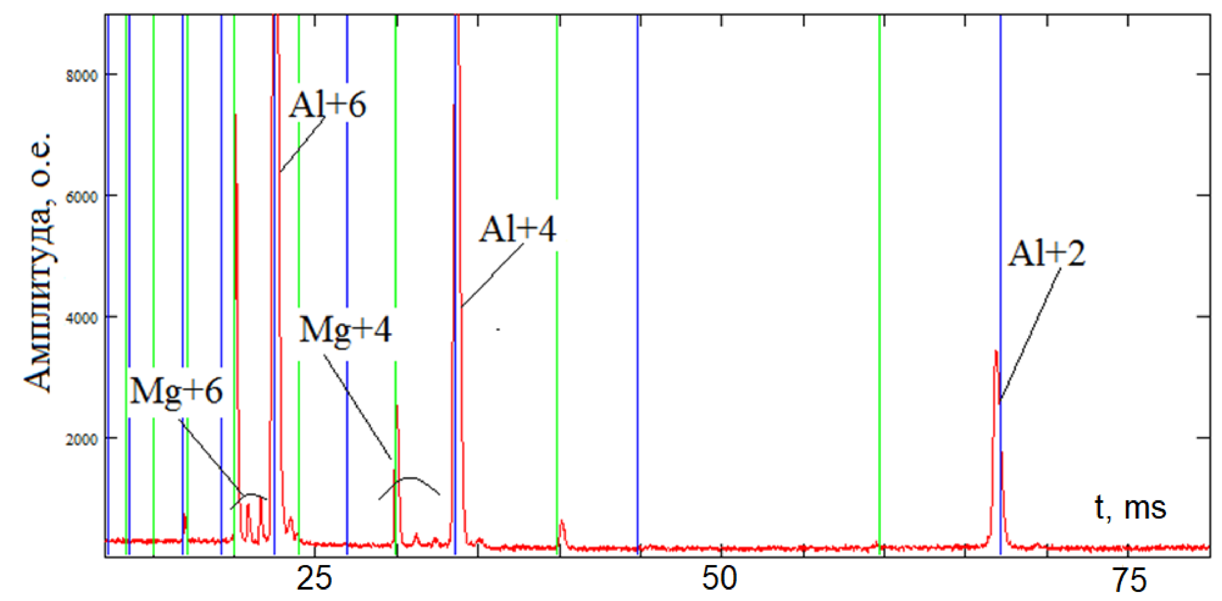
- Drift tube length L = 1650 mm. The ion current was recorded by an ion collector made in the form of a Faraday cylinder.
- A high-speed magnetic field was created as a result of a discharge on the conical spiral coil of the Marx generator.
- A constant magnetic field was created by a current in the solenoid winding. The current value varied in the range of 1-20 A. At the same time, the induction of a constant magnetic field varied from 0 to 14.6 mT, respectively.

The final data of collector measurements for the laser radiation energy E_2 = 515 mJ are presented in Table 1. As can be seen, with an increase in the CMF induction from 0 to 14.6 mT, the duration of the laser plasma flow increased from 3.0 to 4.8 microseconds, while the number of particles that reached the ion collector increased from 3,4 × 10^{11} to 2,3 × 10^{12}. Also note that the HSMF pushes the laser plasma in the direction of the collector. Also note that the HSMF pushes the laser plasma in the direction of the collector. However, the number of particles reaching the collector for the HSMF and CMF variant is less than when using only CMF.

It is possible that the decrease in the signal when using the HSMF is associated with the appearance of some deviation from the axis of the drift tube during the propagation of laser plasma. Figure 2 shows the signals from the ion collector registered for various combinations of magnetic fields, which illustrate this situation.

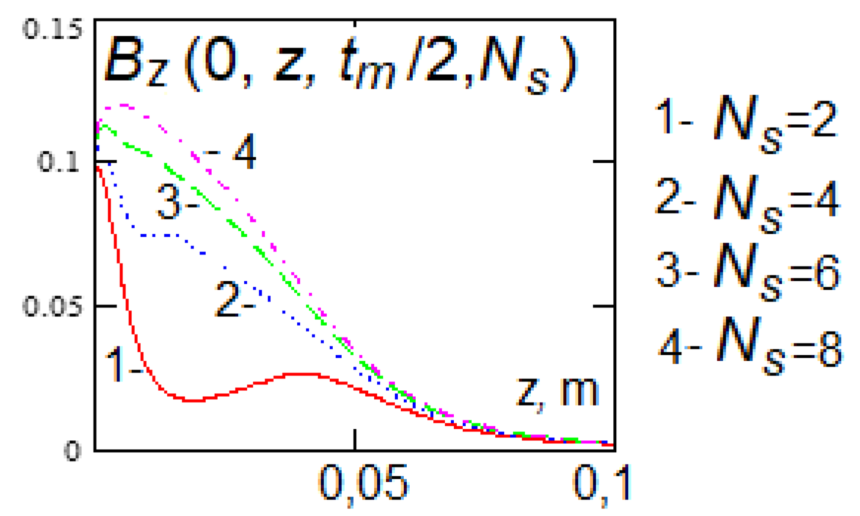
	Without MF	CMF	HSMF	HSMF + CMF
B, мТл	0	14.6	0	14.6
τ_3, мкс	8.8	8.4	6.8	6.8
$\tau_{1/2}$, мкс	3	4.8	4.4	3.2
$U_К$, В	0.24	3.8	0.35	1.6
$I_К$, мА	4.8	76	7	32
$N_И$	$3.4\cdot10^{11}$	$2.3\cdot10^{12}$	$1.9\cdot10^{11}$	$6.4\cdot10^{11}$
vф, м/с	$1.9\cdot10^{5}$	$2.0\cdot10^{5}$	$2.4\cdot10^{5}$	$2.4\cdot10^{5}$
vср, м/с	$1.5\cdot10^{5}$	$1.5\cdot10^{5}$	$1.7\cdot10^{5}$	$1.8\cdot10^{5}$

A fragment of the mass spectrum of a laser plasma. Based on a set of such mass spectra, the time distributions of aluminum ions of different charges are calculated.



2. Simulation

Computer simulation of BMP modes is performed for a coil, which is a conical spiral with a longitudinal size *Hs*, consisting of *Ns* rings located at a distance *Hs* /(*Ns*−*1*) from each other. The longitudinal component of the MF induction, the discharge current in the spiral and the time of reaching the maximum current are



$$B_z(r,z,t,\mathrm{N}_s) = I(t,N_s)\sum_{i=1}^{\mathrm{N}} b_z[r,a_i(\mathrm{N}_s),z-z_i(\mathrm{N}_s)]$$

$$I(t,\mathrm{N}_s) \approx U\sqrt{\frac{C}{L_s(\mathrm{N}_s)+L_g}}\frac{\omega_0(\mathrm{N}_s)}{\omega(\mathrm{N})}\exp[-\beta(\mathrm{N}_s)t)\sin[\omega(\mathrm{N}_s)t]$$

$$t_m \approx \sqrt{[L_s(\mathrm{N}_s)+L_g]C}\,arctg[\frac{2}{R}\sqrt{\frac{L_s(\mathrm{N}_s)+L_g}{C}}]$$

The calculation showed that the optimal option is *Ns* = 6. The expansion of the laser plasma in an external HSMF leads to an additional collective acceleration of its components. The use of CMF increases the pulse duration to 4.8 ms, and the number of particles from 3x10^{11} to 2,3x10^{12}.

Literature

[1] Laser ion source with solenoid field / Takeshi Kanesue et al. // Applied Physics Letters. – 2014. – Vol. 105(19).
[2] K. Kozlovskiy, A. Shikanov et al. JPCS 941 (2017) 012016, doi:10.1742-6596/941/1/012016