DISCHARGE CHARACTERISTICS IN THE MPC CHANNEL IN PRESENCE OF EXTERNAL LONGITUDINAL MAGNETIC FIELD

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This paper reports the outcomes of recent experiments on the assessment of the external longitudinal magnetic field effect on the discharge characteristics and the main plasma stream parameters of the magnetoplasma compressor (MPC). The MPC device has been upgraded with the solenoid installed on the accelerating channel. Present experiments were carried out with helium as a working gas (P = 2 Torr) at a voltage up to 20 kV. The magnetic field varied up to 0.3 T. The additional longitudinal magnetic field exerts significant influence on the potential difference, the radial component of the electric field in the vicinity of the MPC electrodes and the electric currents that flow outside the MPC accelerating channel.

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INTRODUCTION

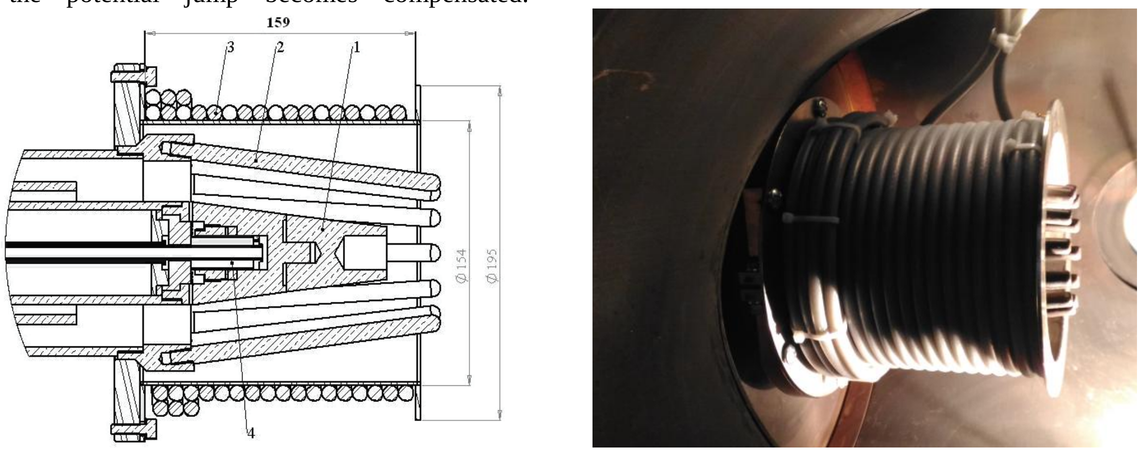
Quasi-steady-state self-compressed plasma flows were discovered theoretically [1-4] and observed experimentally [5-13]. The main fundamental principle of the quasi-steady-state plasma flows is a transition to the mode of operation when a discharge current is carried by ions in a profile channel. In that case, the current-carrying ions should be injected from an anode (outer electrode) surface into the accelerating channel to support discharge current and compensate an electric potential jump, and then they should be absorbed by a cathode (inner electrode) surface. The additional injection of the ions from the anode side for supporting the discharge current increases a total mass flow rate and, as a result, leads to a decrease in a plasma stream velocity.

One of the ways to avoid a potential jump formation in the near-anode region is to add an external magnetic field. Therefore, ions start to rotate such that they stay within the near-anode volume instead of moving away. Thus, the potential jump becomes compensated. The feasibility of the transsonic quasi-steady-state plasma flow without the potential jump formation has been shown [1-4]. A longitudinal magnetic field causes a rotational plasma motion gradually intensifying it; as a result, the plasma density increases near the outer electrode. An external magnetic field has a significant influence on the Hall Effect [4]. Therefore, the current crisis phenomenon in the plasma accelerator can be weakened.

This paper introduces the first stage of the experimental studies on the MPC operation with the external longitudinal magnetic field.

1. EXPERIMENTAL DEVICE AND DIAGNOSTICS

The MPC facility has been recently upgraded with a solenoid (Fig. 1). It is set up on the MPC accelerating channel and supplied by a capacitor bank with a total capacitance of 700 μF. Fig. 2 shows a schematic view of the MPC electrode system inside the solenoid where curves depict magnetic field lines.



a *b*

Fig. 1. Experimental device: schematic view of MPC accelerating channel with installed solenoid (a): 1 – conical part of cathode; 2 – conical part of anode; 3 – solenoid; 4 – gas valve. Picture of the MPC channel with the solenoid inside the vacuum chamber (b)

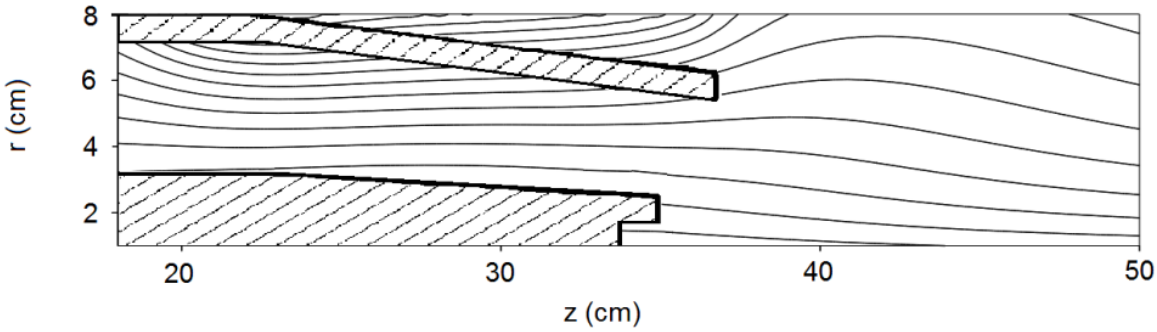


Fig. 2. Magnetic field lines of the solenoid inside the MPC accelerating channel

The MPC channel [5] is formed by a road-type cylindrical anode with an outer diameter of 8 cm and a solid conical cathode with an outer diameter of 3 cm. The solenoid, which produces a longitudinal magnetic field, is 17 cm in length with the inner diameter of 15 cm. The strength of the magnetic field is 0.05...0.25 T at the entrance of the MPC channel and decreases twofold at the channel output (Fig. 3). The magnetic field varied up to 0.3 T. The MPC is installed into the vacuum chamber that is 200 cm in length. The diameter of the vacuum chamber is 40 cm.

The MPC device operates under the mode with residual gas at different pressures. For the first experimental step, we chose the MPC mode of operation with helium as a working gas at a pressure of 2 Torr. This mode is thoroughly researched and well-established [5; 9-11]; moreover, the compression rate up to 200 has been obtained successfully.

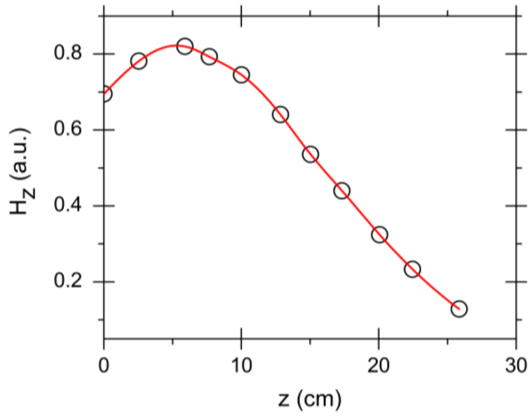


Fig. 3. Distribution of the external longitudinal magnetic field H_z along the axis z

The Rogowski coil and high voltage dividers were used for measurements of total current and a discharge voltage. We applied different probe techniques such as electric probes and internal magnetic probes to measure a local electric field radial component E_r and a self-induced magnetic field $H_φ$. The average statistical error of the probe measurements was up to 10…15 %. Present experiments were performed at a voltage up to 20 kV and a discharge current up to 400 kA.

2. EXPERIMENTAL RESULTS

We started by investigating the effect of the external magnetic field on the electric field radial component E_r in the plasma stream outside the MPC accelerating channel.

The signals were obtained at a distance of 9 cm and a radius of 1.5 cm from the MPC electrode system at a voltage up to 15 kV. Fig. 4 compares typical signals without external magnetic field with the signals obtained under conditions when the external magnetic field of 0.26 T was applied.

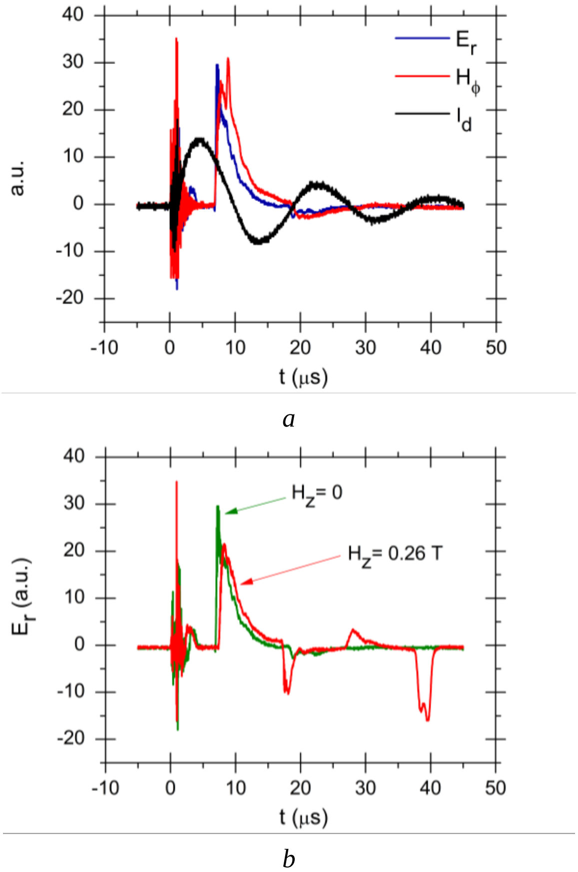


Fig. 4. Typical waveforms (a) of discharge current I_d, electric field radial component E_r and self-induced magnetic field $H_φ$ without external magnetic field; the E_r signals (b) with H_z=0.26 T and without external magnetic field

These experiments highlighted that the local characteristics of the plasma streams outside the MPC channel, such as the electric field radial component E_r and the electric currents, would be sensitive to the influence of the external magnetic field.

Fig. 5 shows a set of the typical signals of the electric field radial component E_r retrieved within the thin near-anode layer (z ≈ 1 cm) at a radius of 2 cm under different values of the external longitudinal magnetic field. In this case, the discharge voltage was 20 kV.

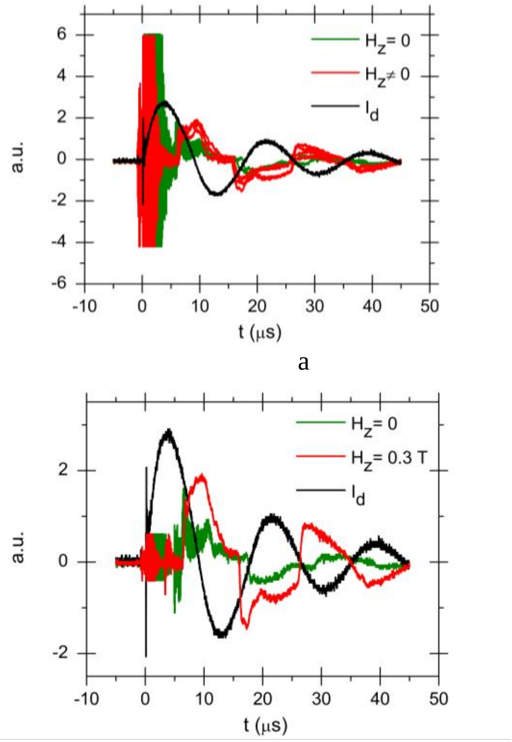


Fig. 5. Comparison of the typical E_r signals without external magnetic field to the signals with H_z varied up to 0.3 T (a) and H_z= 0.3 T (b)

The most remarkable result to emerge from the findings is that the increase in the external magnetic field strength can be considered to have contributed to the increase in the local electric field strength within the near-anode layer. As follows from the figures shown above, with the external magnetic field of 0.3 T, the local electric field radial component E_r is roughly 2 times higher. From this, we can conclude that the external longitudinal magnetic field may affect the plasma velocity. It remains to prove experimentally that such influence can lead to a rotational plasma motion within the outer electrode region of the MPC.

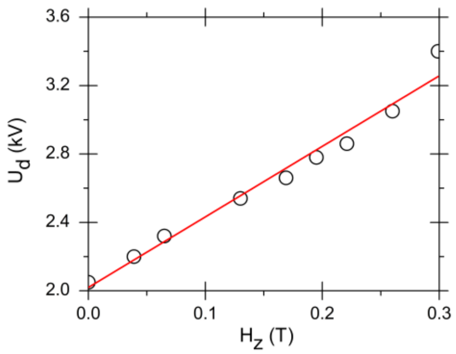


Fig. 6. Potential difference U_d increases with the external magnetic field

Consider Fig. 6, which plots the electric potential difference between the MPC electrodes U_d measured during discharge versus external longitudinal magnetic field. It is crucial to note that the U_d increases with the value of the imposed magnetic field. This lends support to previous findings in the investigation of the two-dimensional steady-state plasma flows [4].

CONCLUSIONS

1. As anticipated, our preliminary experiments demonstrate that the additional longitudinal magnetic field causes a noticeable influence on the processes near the MPC electrodes.
2. Inasmuch as this paper presents a pilot study to investigate whether the main discharge characteristics in the MPC channel change in the presence of the external magnetic field, particular attention is paid to the measurements of the electric field radial component, the discharge current, and the potential difference.
3. The potential difference U_d increases with the increasing of the external magnetic field (consistent with [4]).
4. The part of the discharge current that flows outside the MPC channel increases (good agreement with the QSPA operating with the discharge current less than 50 kA [6]).
5. In our future study, we intend to concentrate on the investigation of the MPC discharge characteristics under the conditions of the imposed longitudinal magnetic field.
6. Furthermore, the extensive research on the MHD parameters in the presence of the additional magnetic field is necessary to extend our knowledge of the dynamic processes in the plasma streams generated by the MPC.

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REFERENCES

1. A.I. Morozov, A.K. Vinogradova. Stationary compressed streams // *Physics and applications of plasma accelerator*s. 1974, p. 103-141.
2. A.I. Morozov and L.S. Solov'ev. *Reviews of Plasma Physics / Ed. by M. A. Leontovich.* Moscow: "Atomizdat", 1974; Consultants Bureau, New York, 1980, v. 8.
3. A.I. Morozov. *Introduction in Plasmadynamics*. Moscow: "Fizmatlit", 2006.
4. A.N. Kozlov. Basis of the quasi-steady plasma accelerator theory in the presence of a longitudinal magnetic field // *J. Plasma Physics*. 2007, v. 74, part 2, p. 1-26.
5. I.E. Garkusha, V.V. Chebotarev, V.I. Tereshin, et al // *Plasma Physics Reports*. 2011, v. 37, № 11, p. 948-954.
6. G.A. Dyakonov, V.B. Tikhonov. Experimental investigation of the influence of the accelerating channel geometry and external magnetic field on the plasma flow regimes in QSPA P-50a // *Plasma Physics Reports.* 1994, v. 20, № 6, p. 533-540.
7. A.Z. Giovannini, I. Barendregt, T. Haslinde, et al. Self-confined plasma in a magneto-plasma compressor and the influence of an externally imposed magnetic field // *Plasma Sources Sci. Technol.* 2015, v. 4.

8. T.N. Cherednychenko et al. Local magnetohydrodynamic characteristics of the plasma stream generated by MPC // *Acta Polytechnica*. 2013, v. 53(2), p. 131-133.
9. T.N. Cherednychenko et al. Creation of a compression zone in the plasma steam MPC under different initial conditions // *Ukrainian journal of Physics*. 2017, v. 62(4), p. 306-310.
10. V.V. Chebotarev, I.E. Garkusha, M.S. Ladygina, et al. // *Czechoslovak Journal of Physics*. 2006, v. 56. Suppl. B (335-341).
11. D.G. Solyakov, et al. Formation of a compression zone in the plasma stream generated by MPC // *Plasma Physics.* 2013, v. 39, p. 1099-1106 (in Russian).
12. L.Ya. Min'ko, V.M. Astashinskii, A.A. Man'kovskii. Compression of erosion plasma fluxes of given composition in air at atmospheric pressure (letters to the editor) // *Journal of Applied Spectroscopy*. 1991, v. 55(6), p. 1191-1193.
13. V.M. Astashynski et al. Choice of operating conditions and plasma parameters of a magnetoplasma compressor // *Journal of Engineering Physics*. 1992, v. 62(3), p. 386-390.

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ХАРАКТЕРИСТИКИ РАЗРЯДА В УСКОРИТЕЛЬНОМ КАНАЛЕ МПК В ПРИСУТСТВИИ ВНЕШНЕГО ПРОДОЛЬНОГО МАГНИТНОГО ПОЛЯ

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Представлены результаты новых экспериментов по изучению влияния внешнего продольного магнитного поля на характеристики разряда и основные параметры плазменных потоков в магнитоплазменном компрессоре (МПК). МПК модернизирован соленоидом, который установлен на ускорительный канал. Эксперименты проводились на гелии (Р = 2 Торр), разрядное напряжение достигало 20 кВ. Магнитное поле варьировалось до 0,3 Тл. Дополнительное продольное магнитное поле оказывает существенное влияние на разность потенциалов, радиальную составляющую электрического поля в окрестности электродов МПК и на электрические токи, протекающие вне ускорительного канала МПК.

ХАРАКТЕРИСТИКИ РОЗРЯДУ В ПРИСКОРЮВАЛЬНОМУ КАНАЛІ МПК ЗА ПРИСУТНОСТІ ЗОВНІШНЬОГО ПОЗДОВЖНЬОГО МАГНІТНОГО ПОЛЯ

Д.Г. Соляков, Ю.Є. Волкова, Т.М. Чередниченко, І.Є. Гаркуша, М.С. Ладигіна, А.Г. Марченко, Ю.В. Петров, В.В. Чеботарьов, В.О. Махлай, В.В. Стальцов, Д.В. Єлісєєв, С.А. Трубчанінов

Наведено результати нових експериментів з вивчення впливу зовнішнього поздовжнього магнітного поля на характеристики розряду та основні параметри плазмових потоків у магнітоплазмовому компресорі (МПК). МПК модернізовано за допомогою соленоїда, встановленого на прискорювальному каналі. Експерименти проведено на гелії (Р = 2 Торр), розрядна напруга сягала 20 кВ. Магнітне поле змінювалося до 0,3 Тл. Додаткове поздовжнє магнітне поле істотно впливає на різницю потенціалів, радіальну складову електричного поля поблизу електродів МПК та на електричні струми, що протікають поза прискорювального каналу МПК.