DISTRIBUTION OF THE MAGNETIC FIELD

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Abstract

Full Text

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PHYSICS

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DISTRIBUTION OF THE MAGNETIC FIELD IN A COAXIAL PLASMA INJECTOR

(Presented by Academician L. A. Artsimovich, 29 IV 1966)

The short discharge durations in ordinary coaxial plasma injectors (Marshall—KvartsKhava guns) (^{1}, ^{2}), on the one hand, hinder the study of the processes occurring during the discharge and, on the other, lead to the formation of clots that are nonuniform in velocity and density (^{4}). There is an unfounded opinion that the use of long discharge pulses, substantially exceeding the flight time, does not make it possible to obtain plasma flows with good parameters. In fact, when long pulses are used, i.e., in a quasi-stationary regime, it is possible to organize the supply of matter to the injector more carefully, to distribute the discharge current over a large surface, and to deliberately obtain an output of plasma uniform in velocity. Such systems, moreover, are very convenient for experimental investigation, and, in any case, an understanding of the processes in such systems will make it possible to clarify more deeply the specific features of ordinary pulsed injectors.

Fig. 1. Oscillogram of the H_φ-component of the field in the injector

In the present work experimental results are set forth concerning only the distribution of currents in a quasi-stationary system. The resulting picture of the currents clearly indicates the determining role of the Hall effect in the process of plasma acceleration. At the same time, the quasi-stationary injector with continuous electrodes studied in the present work proved, in some properties, to be similar to Marshall—KvartsKhava injectors and, in others, to Komelkov fountain pinches.

A coaxial system with cold electrodes was used as the injector. The outer electrode was weakly profiled in accordance with simple hydrodynamic considerations (^{5}). However, subsequent investigation showed that the profiling is not as essential as in an ordinary hydrodynamic nozzle.

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

The injector was powered from a capacitor bank producing a rectangular current pulse of up to 50 kA with duration $T = 1.5$ msec. For convenience in studying the acceleration process, operation was carried out in nitrogen, the supply of which was synchronized with the discharge by a pulsed valve. By the moment the discharge began, the pressure at the injector inlet varied in different experiments from 1 to 3 mm Hg. The preliminary vacuum in the chamber was 10^{-3} mm.

Measurements of the magnetic field were made with coils $d = 6$ mm and $W = 2000$ turns, placed in quartz tubes. Outside the injector these measurements were supplemented by measurements with Rogowski belts. The experiments showed the absence of a constant component of H_z and H_r, which indicates axial symmetry on the average over the discharge time.

A characteristic form of the oscillograms of H_φ is shown in Fig. 1. At the injector entrance the shape of the H_φ signal repeats the shape of the discharge-current signal I_0, while, as one moves toward the exit, at the beginning of the pulse there appears an overshoot of duration $100 \div 200$ μs, associated with the establishment of a steady-state discharge burning. On the flat part of the pulse, regular oscillations with frequencies of $15 \div 50$ kHz are observed (depending on the discharge-burning regime). The fraction of these oscillations increases as the exit is approached and, at the injector cut, amounts to $15 \div 25\%$ of the value of H_φ at this point. The oscillation amplitude, referred to I_0, remains practically constant over the entire length of the injector.

Fig. 2. Current distribution in the injector for different polarities of the central electrode (left—positive; right—negative)

Figure 2 shows patterns of current lines in the injector, averaged over the time interval ${}^{1}/{}_{3}\tau < t < {}^{2}/{}_{3}\tau$ of the discharge. The r axes correspond to the positions of the probes along z. Since in our case the constant components H_z and H_r are equal to zero, then the lines $H_\varphi r = \text{const}$ are current lines. Therefore, in this figure the plots of $H_\varphi r$ in the corresponding cross sections are shown, and the dashed lines are current lines. The presented patterns of current distribution correspond to a total discharge current $I_0 = 35$ kA and a pressure at the injector inlet of 3 mm. On the right is shown the case of negative polarity of the central electrode, and on the left, positive polarity. In both cases the current lines inside

Fig. 3. Central electrode after the discharge.

Figure 4

Figure 4: Figure 4

a —negative polarity; *b* —positive polarity

the injector are far from radial; a displacement of the current in the direction of motion of the plasma flow is observed.

This effect is especially pronounced near the anode, in the form of a peculiar “sliding” of the current along the anode, which leads to the current being carried out beyond the cut of the injector.

With a negative central electrode, the current carried out of the injector by the plasma jet at the cut amounts to 40% of I_0. At a smaller discharge current the pattern outside the injector remains almost unchanged, whereas the distribution inside changes. This change is expressed in the ionization front being shifted toward the exit; accordingly, the fraction of the current closing inside the injector decreases. Conversely, when the discharge current is increased, the ionization front shifts toward the inlet. The carried-out current is observed up to 50–60 cm from the injector cut. When the gas supply is reduced, some displacement of the ionization front into the injector is observed.

Fig. 4. Skewing of current lines in the injector, caused by manifestation of the Hall effect, for different polarities of the central electrode

With positive polarity of the central electrode, the carried-out current amounts to 5-7% of I_0. A considerable part of the current falls on the end face of the central electrode. In this case the plasma flow is poorly formed; current attachments are observed on the central electrode, leading to its severe erosion (Fig. 3).

The nature of the processes taking place—in particular, the strong influence of polarity on the carried-out current and on the structure of the outgoing flow—is associated with the manifestation of Hall currents. Indeed, if in the absence of the Hall current the conduction current must be directed along the normal to the surface of the elec-

of the electrodes, then the appearance of the Hall current

$$\mathbf{j}_{\text{Hall}} = -\frac{\sigma}{enc}[\mathbf{j}, \mathbf{H}],$$

directed opposite to the motion of the plasma, will lead to a skewing of the current lines. The total current will flow as shown in Fig. 4, which explains the qualitative features of the currents carried away.

In conclusion, the authors express their sincere gratitude to Acad. L. A. Artsimovich, on whose initiative and with whose active support the present work was undertaken and carried out, and also to Yu. P. Donkov, Yu. A. Zavenyagin,

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