

Membrane oscillations in SPT channel.

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Low frequency ($f \leq 1$ MNZ) oscillations in a channel of stationary plasma thruster (SPT) have axial symmetry [1,2]. So, equipotentials (not magnetic drift surfaces), when there are oscillations, may move either along a channel (along z - axis), or change its curvature along a radius r . The oscillations of the first type, "longitudinal" are usually considered. A.I. Morozov has paid attention in 1995 to the great influence of the second type of oscillations, he named them "membrane" oscillations. The membrane oscillations (MO) influence considerably the divergence of plasma flow and erosion of outlet part of insulators [3]. The appearance of MO is principally connected with electron temperature oscillations and the presence of transversal gradient of flow density. This statement follows from the expression for electric potential

$$\Phi(\bar{x}, t) = \Phi^*(\psi) - \frac{1}{e} \int \frac{dP_e}{n}$$

Here $\Psi(r, z)$ is magnetic flux function, $P_e = P_e(n, \Psi)$, other designations are conventional. For maxwellian electrons

$$\Phi(\bar{x}, t) = \Phi^*(\psi) - \frac{kT_e(t, \psi)}{e} \ln \frac{n(\bar{x}, t)}{n_0}$$

Although the change of a curvature of equipotentials may be connected with the disturbance of a density, but experimental measurements of ion current oscillations and electron temperature oscillations [4] show, that electron temperature oscillations are principal.

Fig 1 shows possible shapes of equipotentials at three values of T_e : optimal T_{e0} (fig 1a), maximal $T_{e,max}$ (fig 1b) and minimal $T_{e,min}$ (fig 1c). When the flow is divergent, the zone of crossover appears on the axis, this zone is characterized by complex superposition of fluxes, which depends greatly on the individual features of SPT and on the operation mode.

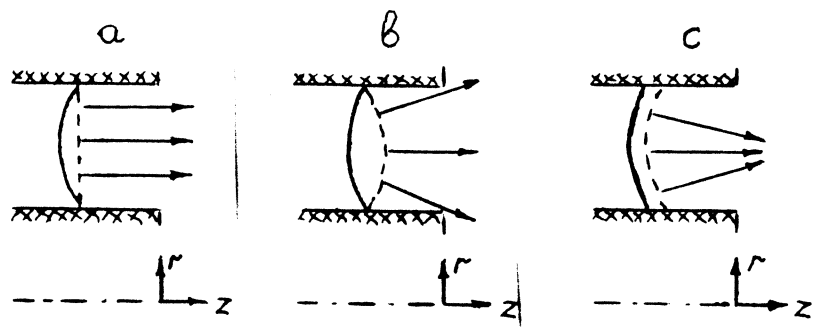


Fig.1a,b,c. The difference in the form of equipotential lines and magnetic force lines in SPT channel under different values of the electron temperature:

a - $T_e \sim T_{e0} \sim \epsilon^*/e$ ($\delta=1$), where ϵ^* - the value of electrons energy, under which the coefficient of the insulator secondary emission is equal 1;

b - $T_e \sim T_{e,max} > \epsilon^*/e$ ($\delta=1$);

c - $T_e \sim T_{e,min} < \epsilon^*/e$ ($\delta=1$).

Continuous lines - magnetic force lines;
dotted lines - equipotential lines.

Fig. 1d shows the distribution of flux density from SPT at $r > r_1$, where r_1 is the

radius of inner insulator.

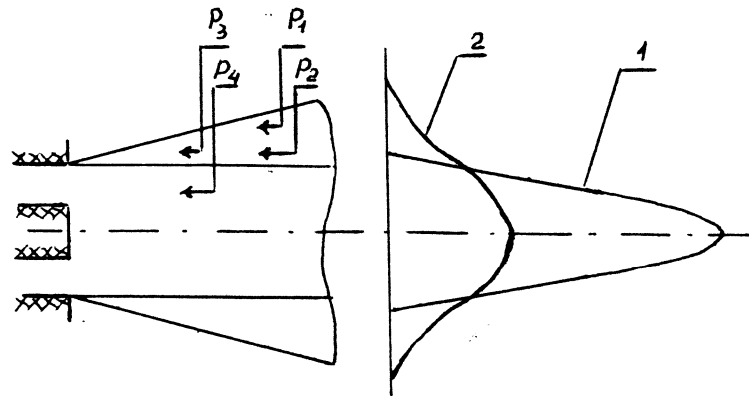


Fig.1d. The distribution of the ion flow density and the location of the probes with respect to the thruster outlet:

p_1, p_2 - the first pair of the probes;

p_3, p_4 - the second pair of the probes.

1-the distribution of the ion flow density for the time moment t_1 ;

2-the distribution of the ion flow density for the time moment t_2 .

If MO appear, then the flux density distribution will change temporarily, as it is shown on fig 1d. So, if one takes two pairs of the probes, p_1, p_2 and p_3, p_4 (see fig 1d), then one may expect, that ion signals on the probes p_3, p_4 would be opposite in phase. These signals would be accompanied by electron temperature oscillations in SPT channel.

The investigations, carried out with SPT-ATON [5], when $m = 2 \text{ mg/s}$, $U_d = 250 \text{ V}$ and the probes were used, confirmed these expectations exactly. The experiment was carried out with two flat probes, which had the

collecting surface $S = 60 \text{ mm}^2$, the distance between the probes was fixed, $d = 4 \text{ cm}$. The probes may move either longitudinally (along z -axis), or transversally (along r).

The negative potential $\phi = -21 \text{ V}$ was applied to the probes, so, ion component of a probe current were extracted, and the oscillogram of J_i oscillations was obtained. The frequency of LF oscillations was $\sim 35 \text{ kHz}$. The experiment revealed, that, when the probes move along r , the signals from the probes are either in phase, or opposite in phase (fig 2a).

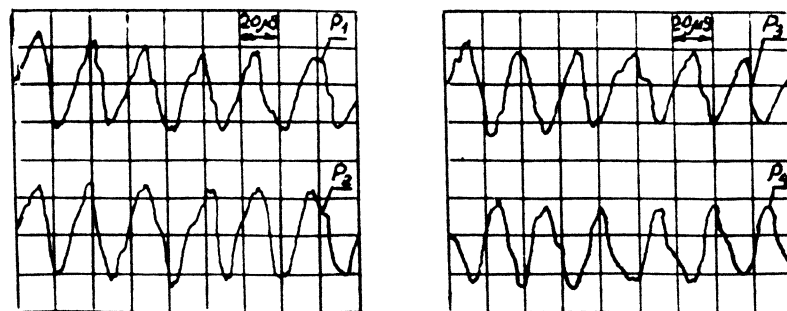


Fig.2a. The oscillations of the ion current on two pairs of the probes: p_1, p_2 and p_3, p_4 .

The more is z , that is, the farther we move from SPT outlet, then the farther from the axis of symmetry these positions are displaced. So, the experiment confirmed, that the regions boiled SPT outlet exist, where the oscillations are in synchronism, and the region between these regions exists, where these oscillations are opposite in phase.

If, as a result of the influence of electron temperature oscillations in the channel, the form of the plume, flowing out the thruster, becomes "tubular", "spoke", or "swallow-tail", then the characteristic regions (fig.2.2: 1,2,3) in plasma flow appear. In order to investigate ion current oscillations in various points of plasma flow we used "large" probe with collecting area $S = 60 \text{ cm}^2$. The probe was mounted on co - ordinate device, which displaced it axially (along z) and radially (along r). The thruster operated at optimal mode: $m_a = 2 \text{ mg/s}$ (Xe), $m_c = 0,4 \text{ mg/s}$, $U_d = 250 \text{ V}$, $J_d = 2,27 \text{ A}$.

The probe was installed at cross section $z = 20 \text{ mm}$ from thruster outlet, and then it was displaced radially from $r = 0$ (thruster axis) to $r = 12 \text{ cm}$. We applied negative potential ($\varphi = -21 \text{ V}$), relatively to the ground, to the probe, in accordance with the chart, shown on fig. 2.17. This potential allowed us to separate ion component of probe current and obtain the oscillogram of J_i oscillations on the screen of memorizing oscillograph.

It was revealed, that, in the region 1 of plasma flow, two types (two harmonics) of ion current oscillations exist ($f_1 = 25 - 30 \text{ kHz}$, $f_2 = 70 - 100 \text{ kHz}$), which may be either superimposed (fig.2.18), or alternate (fig.2.19,2.20). This region corresponds to $r = 0 - 2,5 \text{ cm}$. Crips LF ($f \sim 20\text{-}35 \text{ kHz}$) ion

Fig 2b represents the oscillograms of ion current oscillations on near- wall probe, installed in SPT channel and electron temperature oscillations, obtained from the probe VAC's. One may see from these oscillograms, that the presence of ion current

current oscillations (fig.2.21) exits mainly (are met much oftenly) in the region 2. This region corresponds to $r = 2,5 - 4,5 \text{ cm}$ (5 cm). HF ion current oscillations ($f \sim 70 - 100 \text{ kHz}$) are present in the region 3 at $r > 4,5 \text{ cm}$ (fig. 2.22), and LF oscillations are very rare here.

In all published papers, the mean current was measured in any event, and the temporary mean electron temperature was calculated. Our purpose was the determination of instantaneous (resolution up to $2 \mu\text{s}$) electron current on the probe at adjusted potential and calculation of the electron temperature. In order to carry out this problem, the chart, shown on fig.1.2.1, was established. The especial feature of this chart was synchronous measuring of constant probe component J_c , with aid of milliamperemeter, and alternating component J_a , with aid of oscillograph. The whole current on the probe was calculated as $J = J_c + J_a$.

It is necessary to have two values of electron current for two values of probe potential for calculation T_e . This problem was solved as below. We measured the probe current oscillations for various probe potentials, the probe were placed at various azimuths. It was shown that, in chosen frequency range ($-10 - 50 \text{ kHz}$), all oscillations had the same phase. Thus, we used double probes for measurements of instantaneous electron current. When z in the channel was fixed (8 and 18 mm from the anode), two double probes were mounted flush with outer insulator, having azimuthal shift 90° . We used two - conductor ceramics with W wire of the diameter $d = 0,3 \text{ mm}$, inserted into holes; the face of the wire was the working surface. Thus, we could obtain signals in series from four probes.

oscillations on near-wall probes is accompanied by electron temperature oscillations. So, the existence of membrane oscillations in SPT is confirmed experimentally.

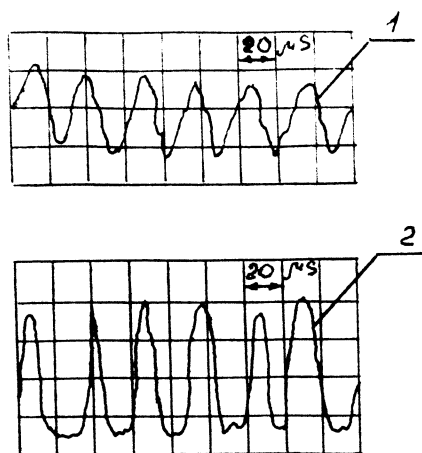


Fig.2b. The oscillations of the ion current (1) and the electron temperature (2).

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