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Electrostatic fluctuations in a Magneto-Plasma-Dynamics (MPD) Thruster

N.Vianello[§¶], V.Antoni[§¶], F.Paganucci[°],
G.Serianni[§], M.Zuin[§¶] , R.Cavazzana[§], M.Spolaore[§]
P.Rossetti[°], M.Bagatin [§], M.Andrenucci[°]
[§] *Consorzio RFX, Associazione Euratom-Enea sulla Fusione,*
C.so Stati Uniti 4, I-35127 Padova (Italy)
[¶]*INFM, Unità di Padova, sez.A Italy*
[°] *Centrospazio, Via A.Gherardesca 5, 56014 Pisa, Italy*

Magneto-plasma-dynamics (MPD) thrusters are currently under investigation as a possible high-power electric propulsion system for space missions. The addition of a magnetic field has proved to increase the performance [1]. However critical regimes observed when the power is increased limit at present the performance of these thrusters [2]. In the critical regime large fluctuations in the cathode and anode voltage are measured. In order to understand the origin of these large fluctuations, and their role in the degradation of the overall performance, an investigation of the mean and fluctuating plasma parameters such as electron density, temperature and floating potentials has been carried out, by means of arrays of electrical probes. The experimental apparatus is an axisymmetric MPD thrusters with an applied magnetic field called Hybrid Plasma Thruster (HPT), described in [3]. A Pulse Forming Network (PFN) configured to supply quasi-steady current pulse 2.5 ms long with plasma current up to 15 kA powers the HTP. In the data presented hereafter the propellant (Argon) is injected at a mass flow rate of 600 mg/s from the central cathode and at 60 mg/s from the peripheral cathode. Different values of V_{PFN} have been used from 800 up to 1400 V, corresponding to plasma current from 4 to 8 kA, and conditions without external magnetic field and with an applied field (with 3 different values 20, 40 and 80 mT) have been explored. Two different probe systems have been used. One, named ‘rake probe’, consists of 7 aligned electrodes, 8-mm apart from each other and housed in a boron nitride case. The probes were used in a five-pin balanced triple probe [4] configuration to obtain simultaneous measurements of electron density and temperature. The other system consists of a ring of 60 mm of diameter, placed coaxially with the thruster axis and opposite the outlet, where 16 equispaced electrodes for floating potential measurements were housed. Both systems were placed, in two different sets of similar discharges, at 80 mm from the thruster outlet along the thruster axis. A set of measurements has been done by placing the ‘rake’ probe so that the first electrode lied on the thruster axis, another set by moving the system 115 mm off axis the thruster. To relate the thrust performance to the main plasma parameters the electron density and temperature, averaged over a time interval of 0.1 ms around $t = 1$ms, during the ‘flat top’ phase of the discharge have been estimated for different values of applied voltage (different values of V_{PFN}) and different value of magnetic field. In figure *1(a)* the value of the density in two different radial positions ($r = 0$ (i.e. on axis) and $r = 115$ mm (off axis)) is shown for different values of applied voltage. Data refer to different shots with and without an external 40 mT magnetic field. The density is of the order of some 10^{20} particle/m^3 and tends to peak on the axis.

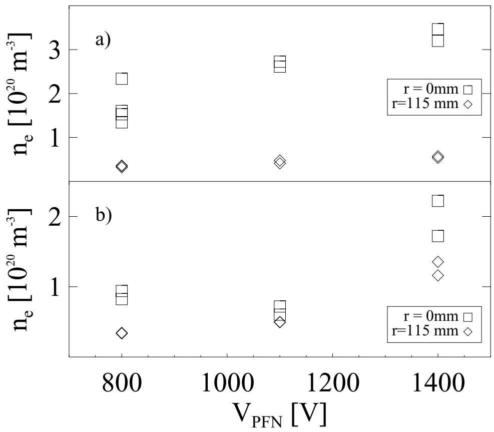

Fig 1: Density at different V_{PFN} for two different radial positions without external magnetic field a) and with an external magnetic field of 40 mT b) . Multiple points refer to different measures.

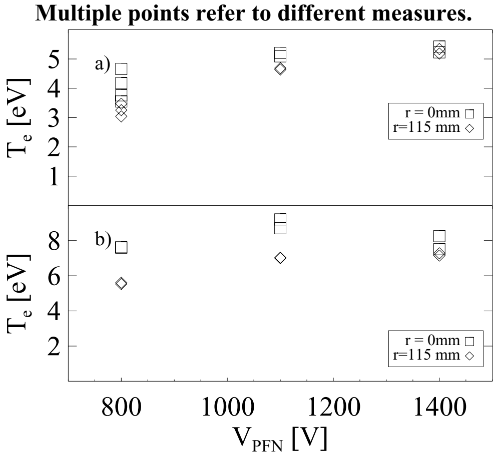

Fig 2: Temperature at different V_{PFN} for two different radial positions without external magnetic field a) and with an external magnetic field of 40 mT b) . Multiple points refer to different measures.

By increasing the input power, the difference between the values on axis and off-axis slightly increases. The application of external magnetic field (*fig. 1(b)*) reduces the value of electron density on axis and increases the same value at $r = 115$ mm, flattening the profiles. This flattening seems to increase with $V_{PFN.}$ The analysis of electron temperature has revealed different behaviour with B_{ext}. In normal condition the typical value spans from 3 to 5 eV (*fig 2(a)*) with the tendency towards a slight increasing with applied voltage. It has to be noticed that temperature profiles are rather flat with small difference between values on axis and off-axis. The application of external magnetic field causes an increase of the temperature that reaches value between 6 and 9 eV (*fig. 2(b)*) while the ratio between values on axis and off-axis seems not to be strongly affected. The analysis of the spectral properties has been focused on floating potential signals collected with the circular system of 16 probes for a more detailed spatio-temporal study. First of all, in normal condition without external applied magnetic field the signals show a clear peak (*fig. 3 (a)*) whose frequency location increases almost linearly with V_{PFN} (*fig. 3 (b)*) from about 40 kHz at $V_{PFN} = 800\ V$ up to 70 kHz at 1400 V. The application of an external axial magnetic field B_{ext} causes an increase of the dominant frequency although the dependence is not as clear as for the V_{PFN} one.

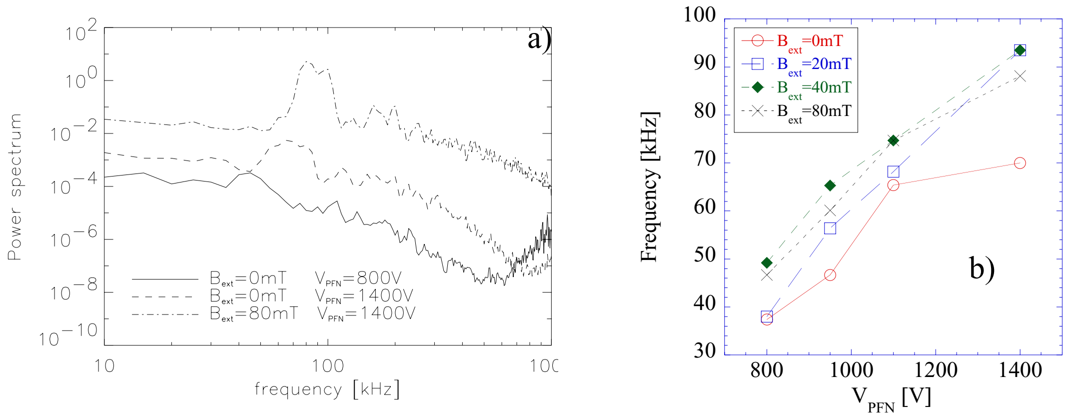

Fig. 3: a) Power spectrum of floating potential signals in 3 different conditions of external field and applied voltage b) Dependence of dominant frequency on the applied voltage and external magnetic field

Mode dynamics has been studied by Fourier decomposition of the fluctuating floating potential in the azimuthal direction. Without B_{ext} and at low V_{PFN} only a global $m=0$ mode has been identified (*fig. 4(a)*). With B_{ext} and $m=1$ mode appears (*fig. 4(b)*).

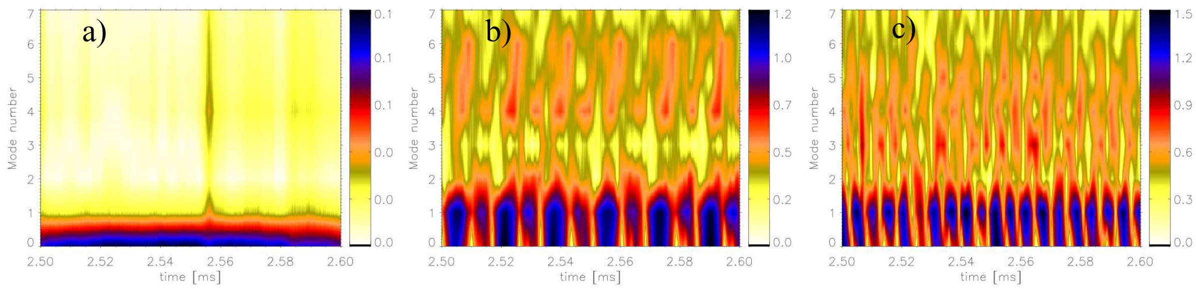

Fig 4: Mode amplitude for the probes located at *r* = 6 cm at: a) B_{ext}=0 mT , V_{PFN}=1100 V b) B_{ext}=40 mT , V_{PFN}=950 V c) B_{ext}=40 mT , V_{PFN}=1400 V.

Higher order modes (*m=3,4*) alternate in time with the *m =1* dominant mode at a frequency which increases with the applied voltage as can be seen by comparing figure *4(b)* and *4(c)*. The Fourier analysis applied to single mode allows to associate the frequency peak to the dominant *m=1* mode, while no clear frequency can be assigned to higher order modes. A simple phase velocity can be calculate as $v_{ph} = \omega/k$ where $k= m/r$ (*fig. 5*). As observed for the frequency there is no dependence on the applied magnetic field. We can also calculate a group velocity, i.e. the velocity that takes a defined potential peak to complete a circle and to be seen twice from a probe. As seen in fig. 5 this quantity doesn't show a linear dependence on V_{PFN} , and, for V_{PFN}=1100 V tends to decrease with the applied magnetic field. It has to be noticed that no propagation is seen at zero external field.

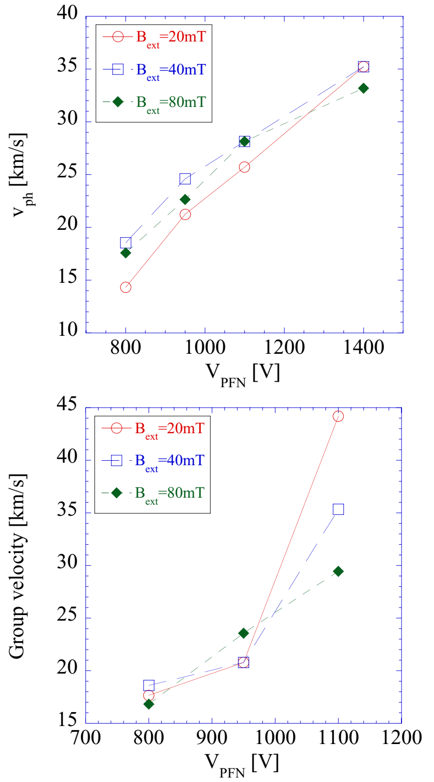

Fig 5.: Phase and group velocity at different values of V_{PFN} , and B_{ext}.

To summarize it has been observed that external magnetic field plays an important role on the modification of mean parameters, causing a flattening of the density profiles with a decrease of the average value and an increase of the temperature whose profiles appear instead almost flat independently of the applied magnetic field. The increase of the applied power and the application of B_{ext} results in the appearance of azimuthal modes with a dominant mode number $m=1$. This mode number is associated to a defined frequency that increases with the applied voltage and magnetic field. The associated phase velocity is in the range of 15-35 km/s and increases with the applied V_{PFN} : the group velocity spans in the range 10 – 45 km/s and tends to increase with the input power, while at higher value of V_{PFN} it decreases applying the external magnetic field. The results here presented confirm that fluctuations properties in MPD thrusters are very sensitive to applied power and magnetic field, fostering further investigation to access their role in the global performance of these devices.

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