# Impact of axial instabilities on ion energy distribution function in Hall thruster: time-resolved RPA measurements

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Hall thrusters are low-pressure cross-field plasma devices in which numerous instabilities can develop, making it challenging to track ion energy distribution functions (IDFs) over time. To overcome this issue, a technique based on the detection of similar events has been developed. The results presented at ESCAMPIG 2024 will show an experimental finding that reveals an evolution of the IDFs on two distinct time scales: firstly, a deceleration of the ions at the frequency of the breathing mode (BM) oscillations (≈ kHz), and secondly, an oscillation of the ion energy associated with the ion transit time oscillations (≈100 kHz).

In a Hall thruster (HT), an axial electric field **E** and a radial magnetic field **B** are imposed through an annular ionisation channel. Only electrons are magnetised, heavy ions are not. So, the application of these two fields perpendicular to each other generates an electron current in the **E**×**B** direction (the azimuthal direction). This important electronic current results from an efficient ionization of the gas, but is also a source of energy for the instabilities development in the plasma.

BM (~kHz) is described as an instability resulting from an enhanced ionization efficiency within the magnetic barrier [2], causing a violent ionization of the entire gas. The ionization front then moves down the channel towards the gas source, away from the magnetic barrier, reducing the efficiency of trapping and ionization. This allows neutrals to repopulate the channel, perpetuating the process.

Ion transit time oscillations (ITTO) are faster oscillations with a period equal to the ion transit time in the acceleration zone. They manifest as potential variations in the thruster channel and in the first few centimeters of the plume (plasma outside the channel) at frequencies around 100 kHz [3], [4], [5], These electric field fluctuations significantly impact ion acceleration, altering the ion energy distribution function (IDF), the ion current $I_i$ and consequently the discharge current ($I_d = I_i + I_e$, where $I_e$ represents the electron current from the cathode crossing the magnetic barrier). Figure 1 shows the temporal evolution of the IDFs over a time period corresponding to a BM oscillation. Oscillations in the hundreds of kHz are also visible, appearing as zig-zag patterns. These oscillations are characteristic of the ITTOs in the plasma and reflect a periodic variation in the ion energy at the ITTO frequency. This time-resolved IDF was obtained from simulations conducted using a hybrid model in which the electrons and neutrals are described as fluids, and the ions are described using the PIC method.

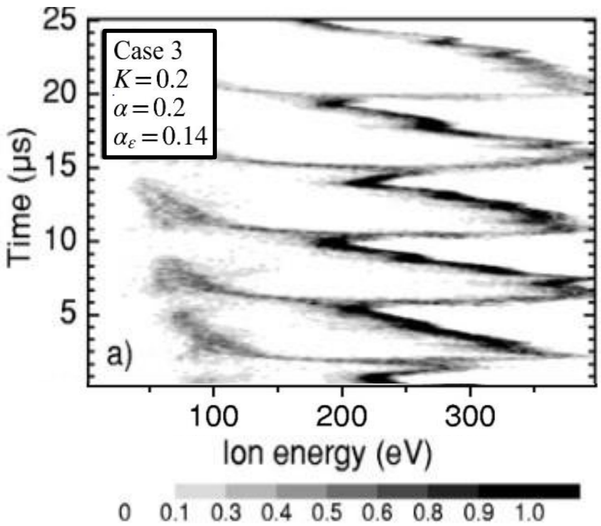


Fig. 1 Temporal IDF obtained for a simulated case with empirical anomalous transport and energy loss coefficients from Ref. [1].

In the literature, various techniques have been used with varying degrees of success to establish the TIDF. Techniques based on FFT, Empirical Transfer Function, and Shadow Manifold Interpolation [6], either require a huge amount of data and high regularity or are not robust against noise and discharge irregularities. One solution can be to stabilize the discharge by externally forcing BM oscillations. However, even if the discharge becomes more regular, it is not perfect, and we are no longer under the plasma's "natural" conditions. Although averaging the discharge (acquisitions) allows us to begin to discern the evolution of the IDF associated with BM, the irregularities of ITTO average out the faster evolutions than those attributable to BM. To our knowledge, there is no experimental evidence demonstrating ion energy variation at the ITTO scale.

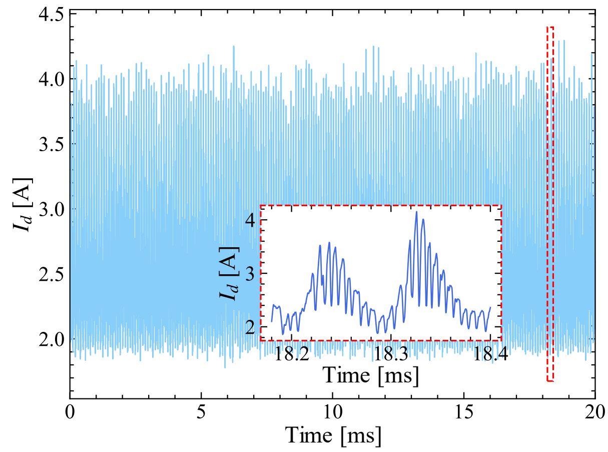


Fig. 2: Evolution and zoom on the discharge current.

Since the discharge always exhibits a certain degree of irregularity (amplitude, frequency, shape, number of sub-oscillations), as can be observed in *Fig.2*, we propose to identify, on a reference signal of the discharge (which does not vary with the modification of RPA settings), the oscillations that are most similar to each other. Here, the discharge current is chosen as the reference signal. This approach assumes that over a sufficiently long time, certain patterns repeat with a satisfactory degree of similarity.

Therefore, for each RPA ion filter voltage, the collected ion current and the corresponding discharge current are acquired over time. Once the pattern search has been performed on each series of discharge currents, families of oscillations with the most similar patterns can be created. The ion currents associated with the time coordinates of these most similar oscillations are then recovered. Subsequently, for each time, the corresponding IDF is calculated. Finally, the data can be assembled to reconstruct a time-resolved IDF. We will present with more details this process and a particularly compelling result at the ESCAMPIG 2024 conference in Brno.

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