Plasma Potential and Temperature Measurements of a thin Plasma by use of Langmuir-Probes*

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Abstract

Space charge compensated high perveance ion beams are of main interest for injection into RFQ-systems. To describe and understand the behaviour of compensated ion beams, it is necessary to know the space charge potential of the beam and the temperature of the confined electrons. For the low density beam plasma the use of Langmuir-probes is critical. We have developed different Langmuir-probes, allowing local investigation of the plasma. The evaluation and the comparision of different (due to size and shape) probe characteristics, will give a better comprehension of the perturbation of a thin plasma. Experimental results and preliminary theoretical descriptions will be given.

1. Introduction

The transportable current of a high perveance low energy ion beam can be enhanced by space charge compensation. To calculate the beam transport and the influence of space charge compensation on the beam quality, it is necessary to know the radial distribution of all beam components and from there on the potential distribution [1].

Langmuir-probes allow local measurement of electron density and temperature in one step. Another advantage of Langmuir probes is the possibility of high speed measurements for diagnostic of pulsed beams.

2. Theory

An idealized probe characteristic for thermalized electrons and ions can be devided into different parts [2]:

I) Ion saturation current: For sufficiently negative voltage in respect to the plasma the probe current is given by :

$$I_{+o} = \frac{1}{4} * N_i * q * \overline{v_{ion}} * A \ , \qquad (1)$$

with N_i the ion density, q the charge of the ions, $\overline{v_{ion}}$ the averaged ion velocity and A the probe surface area.

II) Exponential increasing part of the characteristic: By raising the probe voltage, more electrons are abel to overcome the retarding potential drop, simultaneously the sheath decreases. Because of the Maxwellian electron density distribution in the positive sheath the rising current is given by :

$$I_e = \frac{1}{4} * N_e * e * A * \overline{v_e} * \exp\left(\frac{eV_p}{kT_e}\right) \qquad (2)$$

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where e is the charge of the electron, V_p the probe potential referenced to the plasma potential, T_e the electron temperature and k the Boltzmann factor.

III) The plasma potential : When U approaches the plasma potential V_{pl} the sheath vanishes. There is no retarding field, therefore all electrons directed to the probe are able to reach the probe.

IV) Electron saturation : By raising Vp further a negative space charge sheath developes. If the dimension of the sheath S is large compared to the probe area A_p the electron saturation current is orbital motion limited (OML). With the impact parameter :

$$bg = rp * \sqrt{(1 - \frac{eU}{kT})} \ , \qquad (3)$$

the OML current for cylindrical probes is given by :

$$I_e = N_e * 2\,\pi\, r_p\, l_p * \sqrt{(\frac{kT_e}{M})} * \sqrt{1 - (\frac{eU}{kt_e})} \ . \qquad (4)$$

In thin plasmas the geometry of the sheath is responsible for the slope of the curve in the saturation part. To adapt the expression for the OML current to the given circumstances in praxi, Nuhn and Peter [3] established a general statement with parameter κ, which varies between 0.5(cylind.) and 1(sphere):

$$I_{NP} = \frac{1}{4} * N_e * e * A * \sqrt{8\frac{kT_e}{\pi m_e}} * \frac{2}{\sqrt{\pi}} * \left(1 + \frac{eV_p}{kT_e}\right)^{\kappa} . (5)$$

The theory, which is described above, is valid for thermalized electrons and ions. For using this theory to investigate ion beams, one has to notice that the beam ions are not maxwellian. Their distribution is determined by their high velocity parallel to the beam axis, thus nearly all ions directed to the probe are able to hit the probe, independent of the applied voltage. The secondary electrons emitted by the probe and the residual gas ions increase the ion current. The electron temperature can be changed by heating processes from the secondary electrons. Additionally for thin plasmas the thermal velocity distribution of the electrons can be disturbed by losses due to the electron current on the probe.

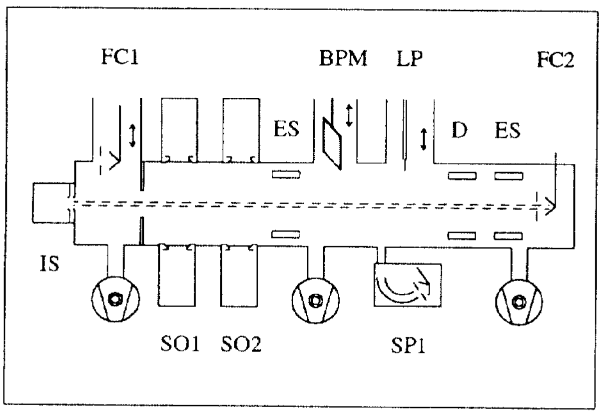
3. Data Interpretation

The break in the I-U-curve marks the point, where the exponential rising part changes into the saturation and indicates the plasma potential. For thin plasmas one can hardly find the break in the measured curve, because most characteristics have a flowing transition region. Therefore we use the first derivative to locate the transition point. The electron temperature (T_e) can be derived by the exponential ascent of the current. T_e is given by the slope of the curve $\ln(I_e)$ versus the probe potential V_p, with $V_p = U - V_{pl}$, where U is the applied voltage and V_{pl} is the plasma potential. The electron density N_e can be calculated from the electron temperatur and the probe current at plasma potential :

$$N_e = 4 \frac{I_e(V_{pl})}{e\,\overline{v_e}\,A} \qquad (6)$$

4. Experimental setup

The experiments have been done at a low energy beam transport line (LEBT, shown in fig. 1) consisting of a HIEFS ion source (IS) [4], two Faraday cups (FC1, FC2) for beam current measurements, two solenoids (SO1, SO2) for beam focusing, a diagnostic tank with a H. Rojanskji type spectrometer (SP1), a beam profile monitor (BPM) and the Langmuir probes. A decompensation electrode (D) could be biased to influence the degree of compensation. Secondary electrons have been suppressed by two electrodes (ES).



For the Langmiur-probe measurements we used two different cylindrical probes. One isolated probe and a shielded one. The isolated probe consists of a Tungsten wire (∅ 0.2 mm), which is covered by a ceramics tube (∅ 1 mm). The uncovered part was 5 mm long, which should lead to a cylindrical probe sheath. The shielded probe differs from the isolated one by covering over with a refined steel tube (∅ 2.5 mm). Both probes have the same length.

5. Experimental results

The results of the measurements are compared in the following plots. Fig. 2 shows the residual gas ion energy spectrum for different decompensation voltages. Without decompensation the maximun beampotential is appr. 18 V, which is similar to 92 % compensation. The other curves show the potential of a partly decompensated ion beam with beam potential slightly higher than the decompensating voltages.The BPM measurements have to be abelinverted [5] to gain the radial beam ion density distribution shown in fig. 3. The influence of the space charge forces for partly decompensation enlarges the beam radius compared to the compensated transport.

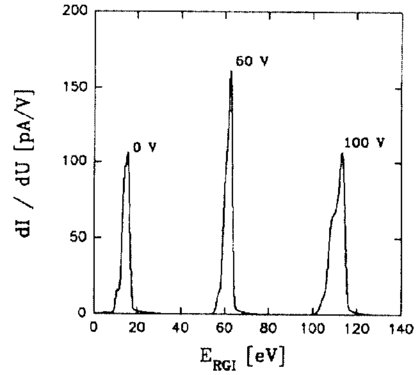


Fig. 2 : Residual gas ion energy spectrum for different dekompensation voltages.

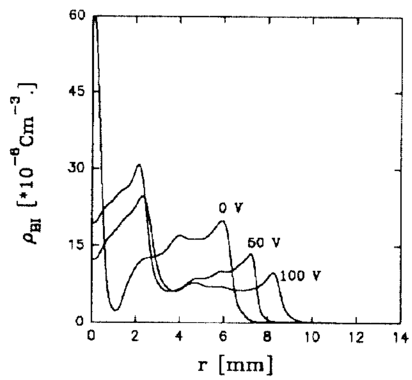


Fig. 3: Radial beam ion density profil for different dekompensation voltages.

Fig. 4 shows the data of a Langmuir-probe measurement. The total current on the probe is negative, because the probe was within the beam and therefore the beam ion current is dominant. Fig. 5 shows the first derivation of the same data. Therefrom we can determine the plasma potential V_{pl}, where the exp. raising changes into saturation, which is below the maximum of the first derivation.The logarithm of the Langmuir-probe datas is presented in fig. 6. The end of the linear rising part is another possible determination of V_{pl}. From the slope of the tangente we calculate the electron temperature.

Fig. 7 shows the plasma potential for different positions of the Langmuir-probes inside and outside the ion beam. Additionally the results of the RGI energy spektra are shown. The plasma potential at the beam edge is in good agreement with the RGI measurements but less on the beam axis. This could be the result of the influence of the probe on the beam.

Fig.8 shows the calculated (formula 6) electron temperature as a function of the position of the Langmuir-probe for different decompensation voltages. One should expect a constant temperature along the beam radius. The sharp change in temperature is supposed to be the result of secondary electrons produced on the outer shield of the probe. Fig. 9 shows the electron density as a function of the

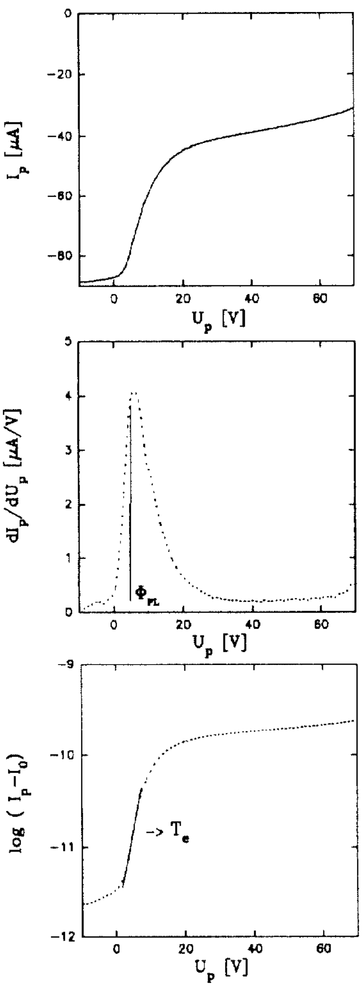


Fig.: 4-6 Langmuir probe measurement, first derivative and logarithmic presentation.

position for different decompensation voltages. The electron density on the beam axis for the compensated case is as expected appr. the same as the ion density on axis. Different other measurements not shown in this article have been made to investigate the influence of the Langmuir-probe on the beam and the compensation degree. Unshieded probes disturb the compensation and can not be used for measurements of compensated beams.

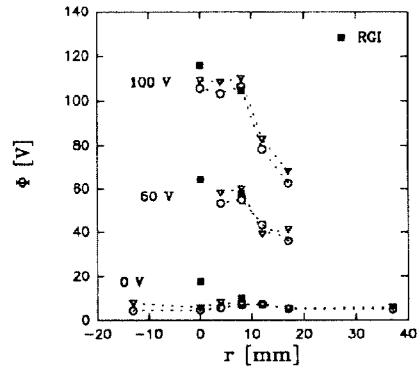


Fig. 7: Beam (plasma) potential as a function of probe position in comparison with the RGI measurements.

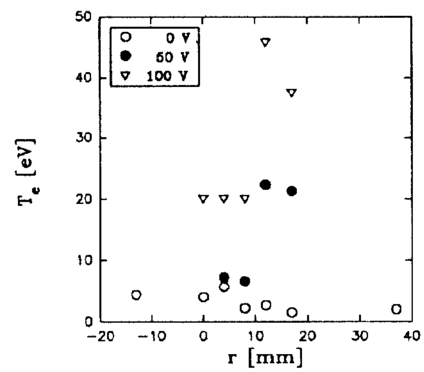


Fig. 8 : Electron temperature as a function of probe position for different decompensation voltages.

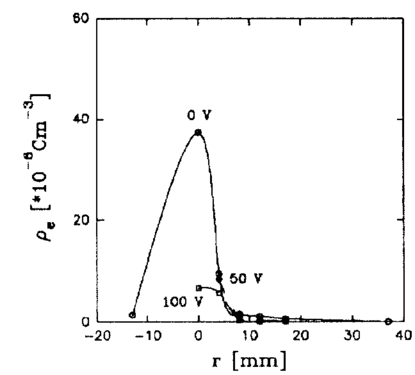


Fig. 9: Electron density as a function of the probe position for different decompensation voltages.

6. Conclusion

In principle shielded Langmuir-probes are suitable for local investigation of compensated ion beams. The determination of the plasma potential gives comparable results in respect to other methods, but still the influence of the probe itself on the beam is critical especially for determination of electron temperature and density. This is not valid for isolated probes, because the ceramics charges positive by the striking ions and disturbs the plasma and therefore the compensation essentially. Our next investigations will cover the influence of the probe on the ion beam plasma and time resolved measurements of pulsed beam operation.

7. References

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