AN ELECTRON BEAM PROBE FOR ION BEAM DIAGNOSIS*

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Abstract

An electron beam probe (1keV, 1μA) has been developed for the measurement of the space charge potential and charge density as a function of radius for intense ion beams The potentential is obtained from observed deflection characteristics of the electron beam for a variety of ion beam parameters. Steady state neutralization rates of the beams as well as rise times (5 μsec resolution) of the space charge compensation could be measured with high accuracy. Theory of the used technique and experimental results will be presented.

Introduction

The non disturbing diagnosis of space charge neutralized and not neutralized intense ion beams respectively is of common interest. Conventional methods , e.g. Langmuir electric probes, suffer from the interaction of the measuring devices with the ion beam, which leads to the creation of secondary electrons and/or capture of compensating electrons and hence a change in the space charge potential.

The electron beam probe (EBP) uses a transversal low-energy, low-current electron beam wich is deflected in the field of the ion beam without influencing the ion beam itself. This deflection provides information about the space charge distribution but is in general a highly nonlinear function of the ion beam parameters.

With the assumption of a cylindrical, infinite long ion beam in the center of a cylindrical beam pipe and small deflection angles of the probing beam, the deflection characteristic $\lambda(R)$ can be approximated by [1]:

$$\alpha(R)= \frac{e \cdot R}{W} \cdot \int_R^{r_D} \frac{E(r)}{\sqrt{r^2 - R^2}}\, dr \qquad (1)$$

Here α is the deflection angle, R the impact parameter (see fig. 1), W the kinetic energy of the probing electrons, r_D the beam pipe radius and E the electric field strength due to the space charge potential of the ion beam. Fig. 2 shows calculated deflection characteristics for different degrees of compensation for a 0.1 mA He^+ 10keV ion beam.

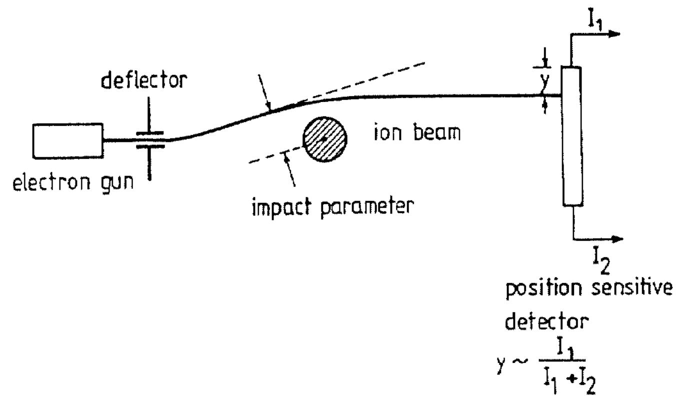

Fig 1 : Schematic layout of the experimental setup

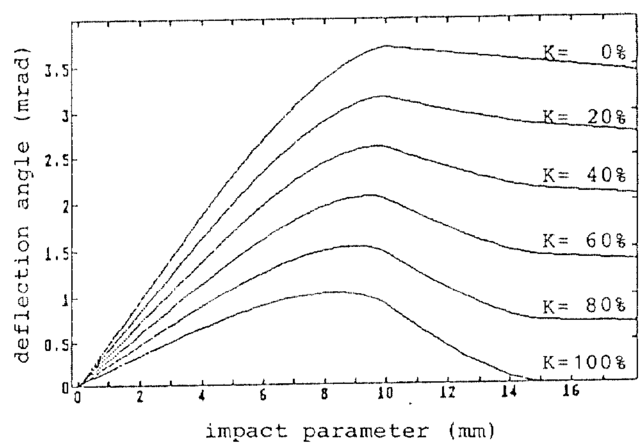

Fig 2 : Calculated deflection characteristics for different degrees of compensation.
Ion beam (KV-distribution) : radius 10 mm
Compensating e^- (homogenious) : radius 15 mm
0.1 mA He^+, 10 keV, EBP energy 1keV

For impact parameters larger than the ion beam radius, the deflection depends linearly on the net line charge $Q'=I/v_i$ (with ion beam current I and beam ion velocity v_i) and is given by

$$\alpha(R)= \frac{e \cdot Q'}{2 \cdot \pi \cdot \varepsilon_0 \cdot W} \cdot \arccos \frac{R}{r_D} . \qquad (2)$$

The degree of compensation therefore is a linear function of the large impact parameter deflection. With an Abel inversion of the integral equation (1) even the radial space charge potential distribution can be evaluated from the deflection characteristic

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$$V(r) = \frac{2 \cdot W}{e \cdot \pi \cdot r_{De}} \cdot \int_{r}^{r_D} \frac{\lambda(R)\, dR}{\sqrt{R^2 - r^2}} \,. \tag{3}$$

Here V is the space charge potential, r_{De} the distance from the detector to the beam axis and λ the deflection.

Electron beam probing can be an efficient and non destructive tool with a very good time resolution, which is in principle given by the time of flight of the electrons and is in the order of some ns.

In spite of this theoretical advantages the high sensitivity of the slow electrons concerning electric and especially magnetic fields has prevented a common use of this technique, although some tests have been successfully done previously [2,3].

Experimental Setup

A duopigatron ion source followed by a set of two electrostatic einzellenses has been used to provide a typ. Ar^+ beam at 10keV. The EBP was mounted between two negativ biased cylindrical electrodes (to prevent logitudinal loss of compensating electrons) together with a retarding field residual gas ion spectrometer and Langmuir electric probes.

Our EBP [4] consists of an electron gun , an electrostatic deflection system and a position sensitive detector (see fig. 1). The electron gun was designed to produce a 1keV, 1 μA beam with a diameter of $\approx$1.5 mm on the ion beam axis. By variing the potential of the deflection plates the impact parameter could be set in a range from $\pm$25 mm related to the ion beam axis. The probing beam is detected with a resistor coated plate of ceramics by analysing the two detector currents (position resolution: 0.2mm, time resolution : 5μsec). The measurement process is controlled by a PC, which is also responsible for the mathematical analysis of the deflection characteristics of typically 100-200 points.

Magnetic fields are reduced to $\approx$10mG by compensating coils and avoiding magnetic materials.

Experimental Results

A typical set of ion beam parameters are: 0.8 mA, Ar^+ , 10 keV , Φ20-40mm at the EPB, degree of compensation up to 90%, space charge potential 15 – 130V, residual gas pressure $5 \cdot 10^{-6}$- 10^{-4}mbar.

The deflection characteristics of a compensated and decompensated Ar^+ beam are shown in fig.3, both indicating the arccos-behaviour described by eq. (2) for large impact parameters. The calculated net charge distribution of the compensated ion beam (fig. 4) shows that the EBP is able to resolve a distorted beam (due to aberrations of the electrostatic einzellenses) and that there is a zero or even negative net charge density between the maxima. This can be explained theoretically, if one assumes a Maxwellian velocity distribution of compensating electrons, as proposed by Holmes [5].

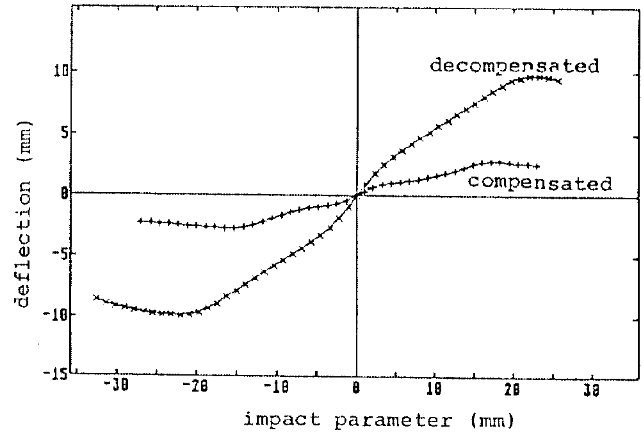

Fig 3 : Deflection characteristics of a neutralized and a decompensated Ar^+ beam (0.8 mA, 10keV)

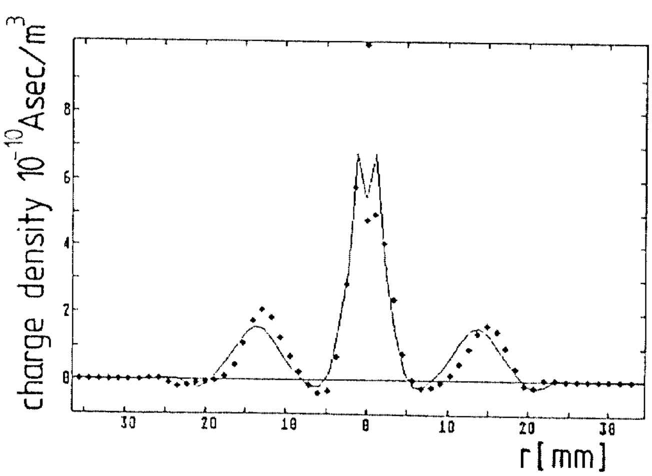

Fig 4 : Radial net charge density distribution of a compensated Ar^+ ion beam

Measurements at large impact parameters allow an easy and quick determination of the degree of neutralization K. K is independent of the actual net charge density distribution and is defined by $K = 1 - Q'_{comp}/Q'_{decomp}$. Fig 5 shows measured values of K versus residual gas pressure, indicating that K is as high as 90% for high pressures and decreases rapidly towards lower pressures, which is in good agreement with theoretical estimations given by [5].

The beam neutralization could be variied with a positively biased decompensating electrode. A reset time less than 1μs for this electrode allows the simulation of the compensation progress occuring at the front end of a macro pulse.

Time resolved measurements (see fig 6) with the EBP have shown that the rise of the compensation is linear in time at the beginning, indicating that all created electrons are trapped in the ion beam potential, and slows down for decreasing ion beam potential. This is due to electron losses caused by the non zero creation energy and the decreasing potential well. The minimum neutralization time τ_0 for neutralization by residual gas ionization is given by

$$\tau_0 = \frac{1}{\sigma_i \, v \, n_0} \; . \tag{4}$$

Here v is the ion beam velocity, n_0 the residual gas density. If the composition and the pressure of the residual gas is known, the ionisation cross section σ_i can be evaluated from the data of the time resolved measurements. Fig. 7 shows the measured minimum rise times of the neutralization of an Ar^+-beam in Ar residual gas in comparison with values obtained from literature. From the high pressure regime, where the argon partial presssure is more than 80% of total pressure, we estimate an ionization cross section of $\sigma_i \approx 4.2 \cdot 10^{-20}\ m^2$.

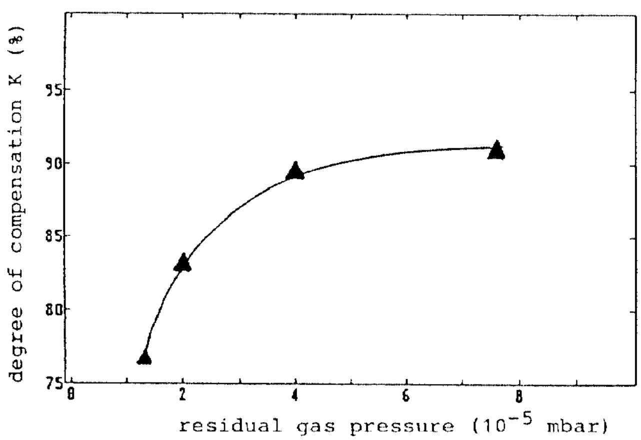

Fig 5 : Measured degrees of compensation versus residual gas pressure

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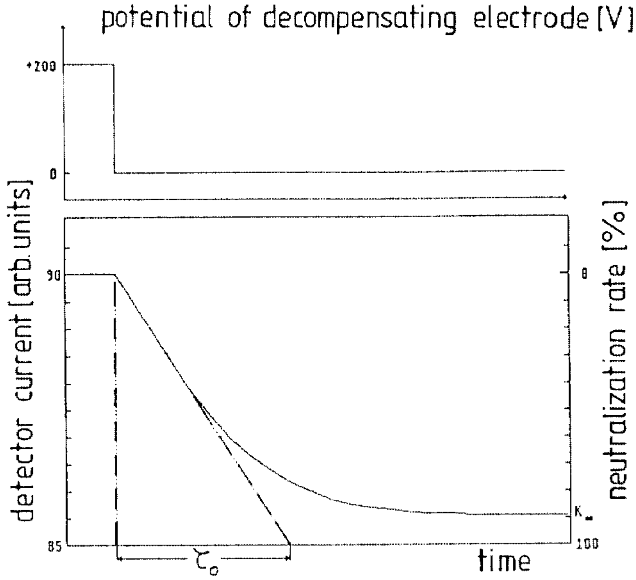

Fig 6 : Time evolution of the space charge compensation rate (schematic)

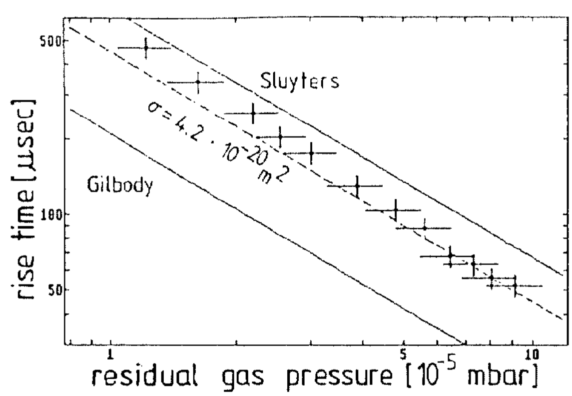

Fig 7 : Measured minimum rise times versus residual gas pressure for a 10 kev, 0.8 mA, Ar^+ beam. The dashed line corresponds to a σ_i measured at high pressure; the solid lines refer to values of σ_i from literature [6,7]. The decreasing cross section for low pressures is due to the increasing hydrogen component in the residual gas mixture.