THE EXPERIMENTAL STUDY OF NEUTRALIZED ELECTRON BEAMS FOR ELECTRON COOLING

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ABSTRACT

In this report we present the latest experimental results on electron beam neutralization. These experiments have been made at LEAR and on the JINR test bench. The main difficulty in obtaining neutralized beams resides in an instability which is dependent on the electron beam current. A number of methods have been developed in order to overcome this instability and have enabled us to further investigate the possibility of generating intense low energy electron beams for the cooling of Pb ions.

1. INTRODUCTION

The space charge of the electron beam used for cooling greatly influences the efficiency of the cooling process [1]. With neutralization, the gradient of the longitudinal velocity and the drift velocity are reduced [1,2] and in principle should improve the cooling when the electron current increases above 250 mA for a 2.3 keV, 5 cm diameter electron beam [3]. In fact, without neutralization, part of the ion beam can be lost due to the large electron longitudinal velocity gradient. All these undesirable effects with large electron currents have pushed us to look for methods to reduce the electron beam space charge.

2. EXPERIMENTAL RESULTS

Electron beam neutralization is obtained by trapping ions from the residual gas in a volume between two trap electrodes. These electrodes create a transverse electric field which causes the ions to be reflected at the level of the traps. The ions oscillate and accumulate between the trap electrodes while low energy secondary electrons created through ionization escape due to the crossed electric and magnetic fields. The experimental parameters for the LEAR machine setup are summarised in table 1.

At JINR, tests were made with electron energies up to 10 keV and currents of 2 A. The magnetic field used was between 400 and 500 G and the average pressure was 10^{-8} Torr.

Electron energy [keV]	27.5	11.5	3.2
Electron current [A]	1.5	0.5	0.12
Perveance [$\mu A/V^{3/2}$]	0.32	0.85	0.66
Neutralization factor η	0.9	0.85	0.75

Table 1. Parameters for the LEAR neutralized beam. The electron beam radius is 2.5 cm and the longitudinal magnetic field was varied between 300 and 600 G. Pressure = 10^{-11} Torr.

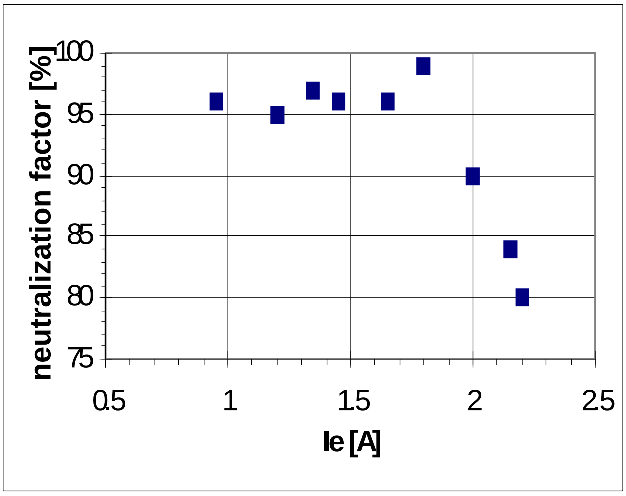


Figure 1. The dependence of the neutralization factor on the beam current at 27.5 keV.

It is shown that the neutralization factor η ($=Z_i n_i/n_e$,where n_i is the ion density and n_e is the electron density) decreases with larger electron currents (fig. 1) and increases with higher electron energies (table 1) or stronger magnetic field (fig. 2). On the JINR test bench, a logarithmic decay in η was observed as the average pressure in the system decreased from 10^{-7} Torr to 10^{-9} Torr.

Using the circulating ion beam as a probe [4] it was possible to measure the radial distribution of the electron beam potential. By displacing the ion beam horizontally in the cooling section, the change in electron energy needed in order to bring the circulating beam back to its original momentum was recorded. In this manner we were able to reconstruct the potential distribution within the electron beam. Figure 3a. shows a classical parabolic distribution which is measured when the electron beam is not neutralized. In figure 3b one sees that when neutralization is switched on, the potential is constant in the central part of the beam and increases abruptly on the edges. The radius over which the potential is constant depends on the degree of neutralization. Therefore the flatter the distribution, the greater the neutralization coefficient.

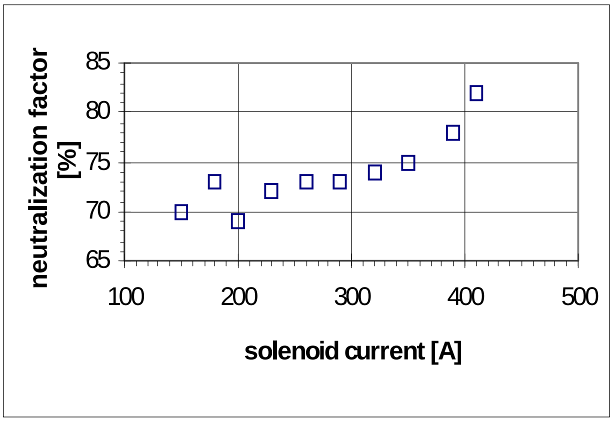
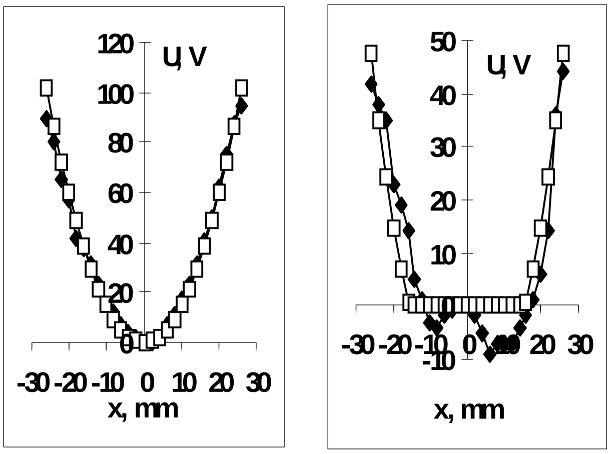


Figure 2. The dependence of the neutralization factor on the magnetic field in LEAR. E_e=12.5 keV, I_e=0.37 A, B(G)=1.57 I_{sol}.



(a) (b)

Figure 3. The radial electron beam potential distribution : (a) traps are OFF, (b) traps are ON. □ calculated points, ◆ measured points.

With this high degree of neutralization the variation of the electron current induced only a slight change in the revolution frequency of a circulating proton beam, as is illustrated in figure 4. This implies that the cooling rate can be varied without any significant shift in the circulating beam energy.

3. THE BEAM-DRIFT INSTABILITY AND ACTIVE METHODS FOR ITS COMPENSATION

The beam-drift instability, which restricts the formation of a dense neutralized electron beam, is caused by transverse electron-ion oscillations. It is a *two-stream* instability which exists due to some form of feedback. The main source of feedback is a flow of secondary electrons escaping from the collector and travelling along the beam in the opposite direction.

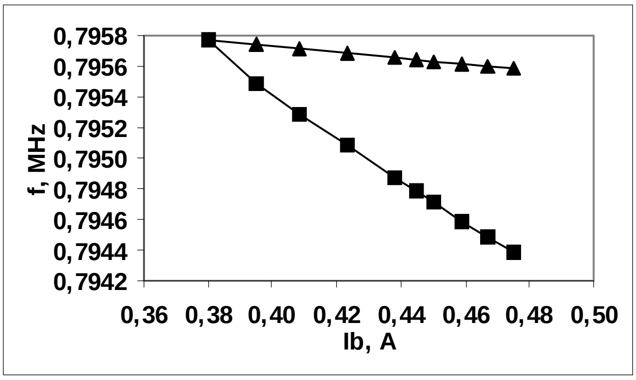


Figure 4. The dependence of the proton revolution frequency on electron beam current. E_e = 11 keV. ■ charged beam, ◆ neutralized beam.

To reduce this secondary electron flow, special clearing electrodes have been installed on the JINR test bench and on LEAR [5]. Their design is similar to that of the trap electrodes and in addition a coil produces a transverse magnetic field to compensate any deflection of the primary beam. At JINR the use of the clearing electrode has increased the instability threshold current by a factor of 1.5 (fig. 5) at fixed pressure. At LEAR no noticeable effect has been observed up to now.

A second source of feedback for the beam-drift instability is the sudden expulsion of ions due to heating by primary electrons. The neutralization reaches a stable level but after a certain time the neutralizing ions gain some energy from the primary electron beam and are lost. This partially destroys the neutralization but as the ions accumulate the neutralization factor goes up again until the next instability.

A way to overcome this is by exciting the ion column continuously such that there is a steady and controlled escape of neutralizing ions. This leads to a lower degree of neutralization [6], but as the polarization of the trap electrodes can be increased a greater control over the neutralization factor is obtained.

The external excitation was provided by a kicker with a transverse electric field. This so-called ‘*shaker*’ has been installed and tested on LEAR and on the JINR test bench. The optimal electron beam stabilization is obtained with a shaker frequency near to the incoherent ion frequency (f=200 to 400 kHz). When the shaker is used, the instability threshold increases 3 to 4 times (fig. 5) for η=0.4 to 0.6.

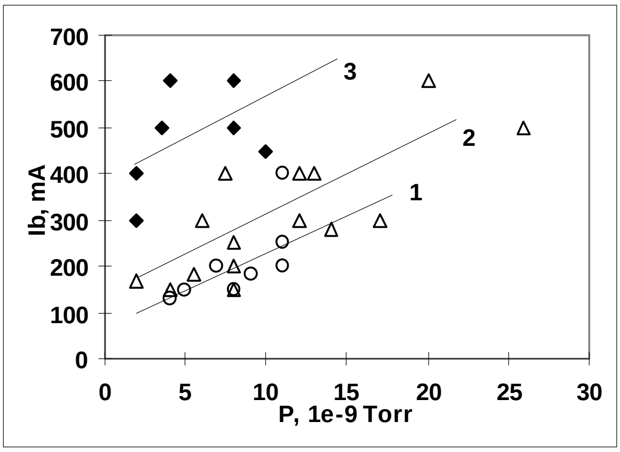


Figure 5. The dependence of the threshold current on the residual gas pressure on the JINR testbench. 1 (O) with traps, 2 (Δ) with traps and clearing electrode, 3 (◆) with traps, clearing electrode and shaker.

A similar stabilization effect is obtained if the electron beam intensity is modulated. This was observed on the JINR test bench but cannot be used on LEAR as the cooling will be greatly reduced. The modulation frequency is related to an excitation of longitudinal waves in the neutralized beam. When an ion interacts with a longitudinal wave, its longitudinal energy is increased. The reflection of an ion from an asymmetric potential barrier leads to a thermalization of its degree of freedom and hence the energy received in the interaction with the wave is translated into the transverse plane. This increase in the transverse energy leads to a stabilization of the beam with an instability threshold current increased by a factor of 2 to 3. The frequency used for electron current modulation is determined by the period of the ion longitudinal oscillations and corresponds to 16-25 kHz. The modulation amplitude used was in the range 20-40 V.

4. CONCLUSIONS

Neutralization of an electron beam can be achieved over a wide range of beam parameters. Under certain conditions the neutralization can become unstable, but this instability can be suppressed by the use of a shaker, clearing electrodes or by electron beam intensity modulation. In this manner the threshold for the beam-drift instability has been increased by a factor of 4 and stable neutralization of a high intensity electron beam has been obtained (η = 0.7 for E_e = 27 keV and I_e = 2.2 A).

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