Low-frequency transverse charge oscillations in an electron storage ring

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An experimental study has been made of the dynamics of the transverse motion of the center of the net charge of an electron beam and of the ions captured by the space-charge field of the beam.

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The collective interaction of relativistic electron rings with positive ions can drive electron-ion two-stream instabilities, as was shown by Budker[1] (see also the corresponding review article by Sarantsev and Perel'shteĭn[2]). In electron storage rings, in which intense electron currents ($I \gtrsim 100$ mA) circulate for rather long times ($\tau \gtrsim 100$ s), positive ions always accumulate, because the residual gas is ionized by the beam electrons, and the resulting ions are focused by the space-charge field of the beam near its orbit.[3] Accordingly, the necessary conditions for collective two-stream instabilities are satisfied automatically in these storage rings by the very system which is used to capture and confine the electron beam.

In this letter we are reporting an experimental study of low-frequency transverse oscillations of the net charge of a stored electron beam and of the ions captured by this beam in the N-100 storage ring of the Khar'kov Physicotechnical Institute.[4]

The transverse motion of the center of the space charge was studied with two pairs of differential electrostatic electrodes, which measured the vertical and horizontal displacements of the center of charge. The signals from each pair of electrodes were fed through broad-band amplifiers ($\Delta f = 10$ kHz–50 MHz) to the differential input of a dual-trace oscilloscope and to an S4-8 spectrum analyzer. In this manner we measured the current dependence of the temporal and frequency characteristics of the radial and vertical oscillations of the charge between the electrodes at several fixed energies of the electron beam, ϵ, and at several residual gas pressures in the chamber, p_0. The results of these measurements were reproducible well over the entire ranges of the external parameters studied [$\epsilon = 60$–130 MeV, $p_0 = (3$–$30) \times 10^{-8}$ Torr].

The current dependence of the signals from the electrodes exhibits a clearly defined threshold. The threshold current increases with increasing beam energy, from $I_{th} = 40$–50 mA at $\epsilon = 70$ MeV to $I_{th} = 70$–80 mA at $\epsilon = 120$ MeV. We found no dependence of the threshold current on the residual gas pressure in the chamber. At ring currents slightly above the threshold for the given energy, signals appeared sporadically on the electrodes. As the current was raised further, the signals appeared more frequently and more predictably. At currents on the order of 1 A, the signal repetition frequency was approximately 100 Hz. The signals on the vertical and horizontal pairs of electrodes appeared simultaneously and were similar in shape. Figure

FIG. 1. Oscilloscope traces of the radial (upper trace) and vertical (lower trace) oscillations. The sweep rate is 5 ms/div; $I = 100$ mA; $\epsilon = 70$ MeV, $p_0 = 5 \times 10^{-8}$ Torr.

1 shows some typical signals, photographed from the oscilloscope screen; Fig. 2 shows the corresponding frequency spectrum. We see that the transverse oscillations of the charge in the system are solitary pulses with rise times on the order of a few microseconds and decay times on the order of 10 ms (at $p_0 = 5 \times 10^{-8}$ Torr). The decay time of the oscillations does not depend on the current or energy of the beam, but it does fall off with increasing residual gas pressure. The frequency spectra of the horizontal and vertical motions of the net charge are identical: Both are line spectra, with characteristic frequencies f_1 = 100–130 kHz and f_2 = 180–230 kHz (the position of each line in the spectrum varies over the specified range from pulse to pulse; the heights of the signals do not remain constant). The intensity of the signals is negligibly low at frequencies of a few megahertz and above.

Taken together, these experimental results show that an instability on the position of the center of the net space charge (the charge of the beam and of the ions) with respect to the equilibrium orbit occurs in this system of an electron beam and background ions in a storage ring. This instability is not, however, accompanied by a

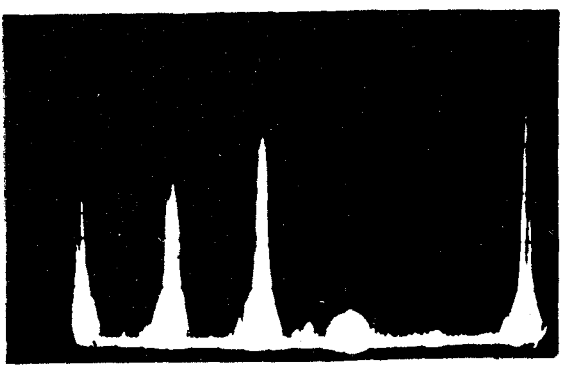

FIG. 2. Spectrum of low-frequency oscillations. Outer peaks–frequency markers corresponding to f_0 = 0 kHz (at the left) and f_{max} = 500 kHz (at the right).

loss of beam intensity. The measured dynamic characteristics of this instability show that the ions of the residual gas which are captured by the beam space charge play an important role in the onset and evolution of this instability. A quantitative comparison of the experimental data with the theoretical predictions[1,2] will require more-detailed measurements, primarily of the mass composition of the ions, the dynamics of the residual-gas ionization by electrons, the density distributions of the electron beam and of the ions over the cross section of the chamber, and the extent to which the beam space charge is not neutralized by the ions.

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