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Experimental studies of electrons in a heavy-ion beam

A.W. Molvik[a,b,*], M. Kireeff Covo[a,b], F.M. Bieniosek[a,c], R.H. Cohen[a,b],
A. Faltens[a,c], A. Friedman[a,b], S.M. Lund[a,b], L. Prost[a,c], P.A. Seidl[a,c]

[a] *Heavy Ion Fusion Virtual National Laboratory, USA*
[b] *Lawrence Livermore National Laboratory, University of California, PO Box 808, L-645, Livermore, CA 94550, USA*
[c] *Lawrence Berkeley National Laboratory, Berkeley, CA 9472-82010, USA*

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Abstract

We have measured electron and gas emission from 1 MeV K^+ impact on surfaces near grazing incidence on the High-Current Experiment (HCX) at LBNL. Electron emission coefficients reach values of 130, whereas gas desorption coefficients are near 10^4. Mitigation techniques are being studied: a bead-blasted rough surface reduces electron emission by a factor of 10 and gas desorption by a factor of 2. Diagnostics are installed on HCX, between and within quadrupole magnets, to measure the beam halo loss, net charge and expelled ions, from which we infer gas density, electron trapping, and the effects of mitigation techniques. Here we discuss a new diagnostic technique that measures gas pressure and electron ionization rates within quadrupole magnets during the beam transit.

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1. Introduction

Electron cloud effects (ECEs) [1] and beam-induced pressure rises [2], which are frequently observed to limit the performance of colliders and high-intensity rings, are normally a problem only in ring accelerators. However, the cost of future high-intensity accelerators for Heavy Ion Inertial Fusion (HIF) and High Energy Density Physics (HEDP) can be reduced by fitting beam tubes more tightly to beams. This places them at risk from gas desorption runaway, and from electron clouds produced by secondary electrons and ionization of gas [3]. We are engaged in an experimental and theoretical program to measure, understand, and model these effects in heavy-ion

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[*] Corresponding author. Lawrence Livermore National Laboratory, University of California, PO Box 808, L-645, Livermore, CA 94550, USA. Tel.: +1 925 422 9817; fax: +1 925 424 6401.

E-mail address: molvik1@llnl.gov (A.W. Molvik).

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accelerators [4,5]. In this paper, we review measurements of ion-induced electron emission and gas desorption for ions near grazing incidence, discuss a mitigation technique [6], and discuss measurements using diagnostics inside quadrupole magnets to measure local densities of gas, and the rate of electron generation from ionization of gas.

Residual-gas beam-profile monitors, which are related to our gas density diagnostic, have been demonstrated previously. Beam impact on residual gas produces ion–electron pairs and causes excitation of the gas molecules. Any of these interaction products can be measured to obtain the gas density; or by using multiple spatially distributed channels, the beam profile can be obtained. Many of these monitors use an electric field parallel to a dipole magnetic field (both normal to the beam) to direct electrons from residual gas to a multichannel plate (MCP) detector [7–9]. In these, the applied electric field dominates over the beam self-field, the magnetic field is large enough to confine electrons to orbits much less than the beam radius for adequate spatial resolution, and the MCP provides high gain enabling profiles of beams with low current (of order 1 mA or lower) to be measured in Ultra-High Vacuum (UHV). The beam profile is the main result; however, the peak of the profile or the integration of the signal over the beam profile can be calibrated to yield the residual gas density. Others have used fluorescence of excited residual gas [10] or of an injected gas sheet [11] to obtain the beam profile; the former could also determine the residual gas pressure.

Our device differs in several ways: (a) It depends on the positive beam self-field to expel cold ions from beam impact on residual gas, rather than using an applied electric field to drive electrons, from beam impact on residual gas, into a detector. Our technique has the advantage of not perturbing the low-energy ion beam, but it misses ~90% of the expelled ion current because the ions are expelled radially and our collector subtends only a small fraction of the circumference. (b) Our technique collects expelled ions directly rather than amplifying the electron current with an MCP in either an analog or counting mode—this restricts our operation to high vacuum rather than UHV but, for the beam parameters discussed below, provides response times of 0.5–1.5 μs. This is the time for the unneutralized beam potential of 300–2000 V to expel a cold oxygen ion. Hydrogen ions are expelled more quickly, in 0.1–0.4 μs. These times are substantially less than the beam FWHM of 5 μs, and so indicate the capability of measuring the time dependence of desorbed gas reaching the beam. (c) A consequence of (a) and (b) is that we measure the residual gas density, but cannot obtain the beam profile. (d) Our technique collects expelled ions across a quadrupole magnetic field rather than collecting electrons along a dipole magnetic field. This enables the magnetic field to suppress electron emission from the collector, while keeping the field low enough for ions to cross it. The requirement that expelled ions cross the quadrupole field restricts our technique to beams with relatively high space charge and low beam energy (for low quadrupole field strength), so that the beam potential provides sufficient energy to drive ions across the quadrupole magnetic field, and MCPs will not function in the transverse magnetic field. Item (d) is not essential to our concept: we are designing a retarding potential analyzer to be inserted into a magnetic-field-free drift region between magnets, where we could also relax feature (a) by applying an electric field to drive all ions from gas into the analyzer. This is intended to measure both the gas density, from the total current of expelled ions in the beam, and the beam potential, from the expelled-ion energy, as a function of time.

On the High-Current Experiment (HCX), we are using a 1 MeV, 180 mA, K^+ ion beam to study transport [12], beam-induced electron emission and gas desorption [6], and electron cloud and gas effects in magnetic quadrupoles [4,5]. The beam has a space-charge potential of ~2 kV, rise and fall times of 0.3 and 1 μs, respectively, and a flattop duration of 4 μs, and is pulsed at 10 s intervals. An aperture can be inserted at the diagnostic region immediately preceding the magnetic quadrupoles, to reduce the beam current to 25 mA and ~300 V space-charge potential. Electron transit times between walls are in the range of 7 ns (20 ns if apertured) for an unneutralized beam, almost 3 orders of magnitude shorter than the flattop duration. This enables exploration of

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