ISSN 0020-4412, Instruments and Experimental Techniques, 2006, Vol. 49, No. 3, pp. 446–448. © Pleiades Publishing, Inc., 2006.
Original Russian Text © V.V. Parkhomchuk, V.B. Reva, B.A. Skarbo, 2006, published in Pribory i Tekhnika Eksperimenta, 2006, No. 3, pp. 160–162.

Vacuum Pumping with an Electron Beam

V. V. Parkhomchuk, V. B. Reva, and B. A. Skarbo

Budker Institute of Nuclear Physics, Siberian Division, Russian Academy of Sciences, pr. Akademika Lavrent'eva 11, Novosibirsk, 630090 Russia

Received June 10, 2005

Abstract—The results of preliminary vacuum tests of an electron cooler with an electron beam that was designed for the LEIR lead-ion storage device (currently being built at CERN) are presented. The tests were performed at the Budker Institute of Nuclear Physics, Siberian Division, Russian Academy of Sciences (Novosibirsk, Russia). It has been shown that, after degassing the collector, injection of an electron beam improves the vacuum level in the setup.

PACS numbers: 07.30.-t, 29.27.a

DOI: 10.1134/S0020441206030274

INTRODUCTION

The luminosity of colliding ion–ion beams in a large hadron collider (LHC) will be governed by the quality of prepared lead-ion bunches. Every 3.6 s, the low-energy ion ring (LEIR) included in the injection system prepares 1.0×10^{10} ions of ^{54}Pb for subsequent acceleration and injection into the proton synchrotron (PS). The required values of the longitudinal and transverse emittances of the ion beam in the LEIR are ensured by means of the electron cooling system (electron cooler) installed in the storage [1, 2].

Acceleration of high-charge heavy ions imposes strong limitations on the amount of residual gases in the vacuum chamber of the storage ring. If such ions hit the wall of the vacuum chamber, they possess a very high desorption coefficient. One ion hitting the wall of the vacuum chamber can release up to 10^4–10^5 atoms of the absorbed gas. Deterioration of vacuum conditions in the ring reduces the ion lifetime and increases the particle flux toward the wall, which causes an "explosive" increase of losses in the beam.

It is required that the working vacuum in this setup be at least 10^{-12} Torr. Let our losses comprise 1% of the total number of injected particles. In this case, desorption of gas atoms from the walls of the vacuum chamber reaches 3×10^{10} s^{-1}. If the pumping rate is 10^3 l/s, this level of desorption increases the density of the residual gas by 3×10^4 cm^{-3} ($p = 10^{-12}$ Torr).

The presence of an electron beam in the electron cooler introduces an additional loading of the pumping system. At a desorption coefficient of 10^{-7}, absorption of a 1-A current in a water-cooled collector can release up to 6.7×10^{11} atoms. This amount is comparable or even exceeds the gassing level induced by the ion beam. The loss of electrons in the gun–collector space also deteriorates vacuum conditions. Though the absolute value of this loss is small (from 10^{-4} to 10^{-7} of the total current), the desorption coefficient of gases in the main vacuum chamber is substantially higher and can be as great as 0.01. The cause for this is that an intense electron flow in the collector allows the maximally rapid degassing of the collector and cleaning of its surface from the residual gas. Such a treatment of the entire surface of the pumped volume is technically impossible.

DESIGN OF THE VACUUM SYSTEM OF THE ELECTRON COOLER

The high-vacuum pumping system of the electron cooler consists of two ion pumps and a system of non-evaporable getters used for absorption of gases in the vacuum chamber [1]. According to the design specifications, two getters should be installed near the gun and the collector; two getters, in the toroid chambers; and two getters, in the 2.5-m-long straight cooling section. In the experiments described below, the vacuum system was not completely equipped. There were no getter pumps in the cooling section and getter units installed in toroids had a long service life before installation. In these experiments, we did not try to obtain a high vacuum but tested optics of the electron gun and collector. However, after the bake-out and activation of even the installed getter units, we could reach a vacuum level of 3×10^{-10} Torr. Here, the basic component of residual gases in the cooler's vacuum system is hydrogen. A typical spectrum of residual gases measured with the help of an RGA Prisma mass spectrometer (Pfeiffer Vacuum Technology) is shown in Fig. 1.

The use of electrostatic plates for deflecting the electron beam is a specific feature of this electron cooler. In this case, electrons not yet hitting the collector can travel from the cathode to the collector and backward, return to the collector, and deposit on it. This is impossible in the scheme with the deflecting magnetic field, where the motions of primary-beam elec-

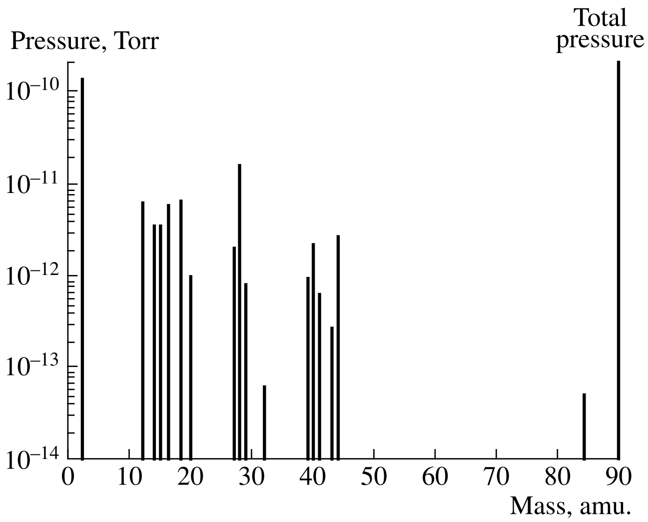

Fig. 1. Typical spectrum of residual gases.

trons and electrons reflected from the collector are substantially different. The latter electrons have time to substantially shift in the transverse direction as they cross the collector–beam space. The scheme described above allows us to almost completely eliminate losses of the electron beam due to deposition on the chamber walls [2, 3].

EXPERIMENTS ON THE EFFECT OF THE ELECTRON BEAM ON THE VACUUM LEVEL

Upon completing the bake-out and activation of the cathode, injection of an electron current caused a strong deterioration of the vacuum, even at currents of 5–10 mA. This was related to degassing of the inner surface of the electron-beam collector by this electron beam. At a current of 50 mA and a total pumping rate of ion pumps and getters of 1000 l/s, the pressure of the residual gas became 10^{-7} Torr, which corresponds to a collector desorption coefficient of 10^{-2}. The getters' pumping rate was estimated under the assumption that the gas flow was completely absorbed inside the absorber aperture with a diameter of 90 mm. After a two-week aging of the collector surface with an electron beam, this surface was cleaned to the degree at which injection of the electron current even improved the vacuum level. As shown in Fig. 2, injection of the electron current within a period of 0–100 s causes evacuation of the vacuum volume to a pressure of $p = 4 \times 10^{-10}$ Torr. After turning off the electron current at instant $t = 100$ s, pressure p increases up to 1.2×10^{-9} Torr over 150 s due to thermal desorption of molecules from walls of the vacuum chamber. Turning on the electron current at instant $t = 260$ s, we lower pressure p in the chamber to 4×10^{-10} Torr.

Such dynamic tests allow application of the simplest model for estimation of the vacuum system parameters.

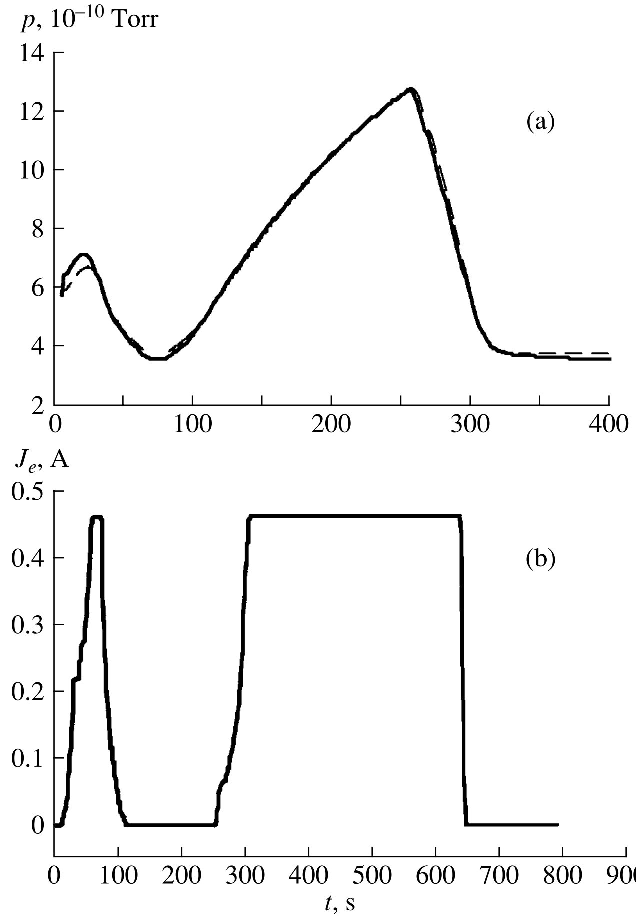

Fig. 2. Time dependences of (a) pressure p in the vacuum chamber (solid and dashed curves depict, respectively, measured values and values calculated from Eq. (1)) and (b) current J_e of the electron beam in the process of investigation of the effect of electron beam on the vacuum level in the electron cooler.

Let the gas in the device volume consist of two components: one component is well pumped by getters, and the other is pumped by ion pumps. Then, the dynamics of the pressure of the second component is described by the equation

$$\frac{dp_2}{dt} = -\frac{1}{V_0}\frac{dV_{\text{ion}}(t)}{dt}p_2(t) - \frac{1}{V_0}\frac{dV_e}{dt}\frac{J_e(t)}{J_{e_0}}p_2(t) + \frac{Q}{V_0}, \quad (1)$$

where Q is the gas inflow rate, $\frac{dV_{\text{ion}}(t)}{dt}$ is the pumping rate of ion pumps, $\frac{1}{J_{e_0}}\frac{dV_e(t)}{dt}$ is the normalized pumping rate by an electron beam with current J_{e_0}, and V_0 is the volume of the vacuum system. This equation is integrated with respect to time, taking into account measured values of the electron current ($J_e(t)$ in Fig. 2) and assuming that activation of the ion pump and reaching of the operating conditions occur instantaneously.

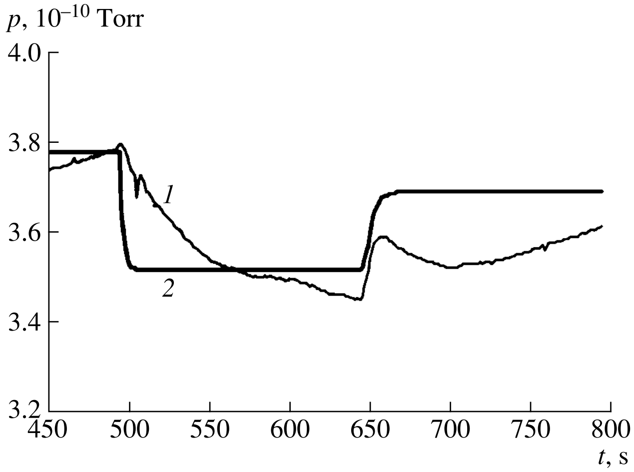

Fig. 3. Time dependence of pressure p: curves *1* and *2* depict, respectively, experimental and simulation results. Ion pumps were turned on at t = 490 c. The electron beam was initially injected at t = 650 s.

Pumping parameters and the gas inflow rate were chosen so as to ensure the best correlation between the measured and calculated pressure values. In this case, the pressure is written as

$$p(t) = p_1 + p_2(t),$$

where p_1 is the constant pressure for the component determined by the getter pumping and $p_2(t)$ is the pressure of the second component obtained from integration of Eq. (1).

Solving Eq. (1), we can estimate the system parameters. Pumping rate $\frac{dV_{\text{ion}}}{dt}$ of the component that is poorly pumped out with ion pumps is 2 l/s in the case of turned-off ion pumps and pumping with only getters and 80 l/s when ion pumps are on. The gas flow caused by thermal desorption is $Q = 3.2 \times 10^{-9}$ l Torr/(s cm^2), which corresponds to a value of 1.5×10^{-13} l Torr/s of the specific gas separation coefficient for this component (most probably, this component contains either inert gases or hydrocarbons). The pumping rate achieved with an electron beam was $\frac{1}{J_{e_0}}\frac{dV_e}{dt} = 140$ l/(A s).

Let us estimate the pumping rate with an electron beam by the ionization cross section of the residual gas. For the molecule destruction cross section $\sigma = 4 \times 10^{-17}$ cm^2, electrons with charge q moving in a beam of length $l_e = 5.5$ m produce the pumping-out effect determined by the formula

$$\frac{1}{J_{e_0}}\frac{dV_e}{dt} = \frac{1}{q}\sigma l_e = 140 \text{ l/(A s)}.$$

The energy of the electron beam was 2.3 keV and the ionization cross section, e.g., of a CO molecule is close to the value used in our estimate.

Figure 3 shows that, after turning on an ion pump, a low level of pressure is achieved for a substantially longer time than the time predicted by simulation. This is presumably related to slow activation of the ion-pump cells at a good vacuum. The step appearing after removal of the electron beam at a time of 650 s is simulated rather well. The drift that can be noticed in the experimental results is related to the fact that these changes comprise several percent and slow processes running in the vacuum system create a low-frequency “shift” of the total pressure of residual gas in this system.

CONCLUSIONS

It has been shown experimentally that, in an electron cooler with small losses owing to deposition of the electron beam on walls of the vacuum chamber, the vacuum level can be improved by injecting an electron beam. The rate of the additional evacuation by the electron beam approximates the ionization rate of the residual gas.

REFERENCES

1. Tranquille, G., *Nucl. Instrum. Methods Phys. Res., Sect. A*, 2004, vol. 532, p. 399.
2. Chanel, M., *Nucl. Instrum. Methods Phys. Res., Sect. A*, 2004, vol. 532, p. 137.
3. Bocharov, V., Bubley, A., Boimelstein, Yu., et al., *Nucl. Instrum. Methods Phys. Res., Sect. A*, 2004, vol. 532, p. 144.