EXPERIMENTAL PRESSURE DEPENDENCE OF THE ACCELERATED CURRENT IN THE CHAMBER OF THE SIRIUS SYNCHROTRON

I. P. Chuchalin and M. I. Dvoretskii

An experimental study of the dependence of the accelerated charge in the synchrotron on the vacuum-chamber pressure is reported. The results are compared with calculations; in the pressure range $5 \cdot 10^{-6}$-$2 \cdot 10^{-5}$ torr, the experimental and calculated results agree well.

As charged particles move in an accelerator chamber they are scattered by residual gas atoms, either elastically or inelastically. Both types of collisions deflect the particles from their direction, tending to increase the amplitude of the betatron oscillations. In addition, the particles lose some of their energy during inelastic collisions, so phase oscillations tend to be built up. After several interactions with gas atoms, the particles are lost to the acceleration process as they lose their phase (i.e., the phase of the particle exceeds a certain value $\varphi_{\text{max}}$, and the particles strike the wall of the vacuum chamber).

Particle loss due to scattering may significantly reduce the intensity of the accelerated beam in a synchrotron. This loss depends on many factors: the initial distribution, the injection energy, the rate at which the magnetic field increases, the rate at which the field decreases, the residual gas pressure, the dimensions of the vacuum chamber, and the radius of the accelerator. It is generally assumed that the electron loss due to scattering should not exceed 10-15% [1]; this is the case when the residual gas pressure in the chamber is $1 \cdot 10^{-5}$-$5 \cdot 10^{-6}$ torr. To reduce the loss to a few percent, the pressure must be reduced to $1 \cdot 10^{-6}$ torr and below.

The pressure in the vacuum chamber is given by

$$p = \frac{Q_{\text{des}} + Q_{\text{in}}}{S_{\text{eff}}} \cdot P_{\text{lim}},$$

where $Q_{\text{des}}$ is the total desorption flux; $Q_{\text{in}}$ is the total inleakage flux; $S_{\text{eff}}$ is the effective rate at which the chamber is evacuated; and $P_{\text{lim}}$ is the limiting vacuum achievable by the pump.

The flux $Q_{\text{in}}$ can be reduced to a minimum; $Q_{\text{des}}$ is governed by the structural materials, the seals, and the degassing capabilities of the entire system; while $S_{\text{eff}}$ and $P_{\text{lim}}$ are characteristics of the vacuum pumps.

If a pressure $P$ must be achieved in the vacuum chamber, $N$ pumps are required ($N$ is proportional to $Q_{\text{des}} + Q_{\text{in}}$) which are capable of achieving a total effective pumping rate $S_{\text{eff}}$ at a working pressure $P$ and having a limited vacuum of $P_{\text{lim}} \leq 0.1$ P.

In an electron synchrotron, the vacuum required is governed by the permissible particle loss due to residual-gas scattering and by the necessity to avoid hf breakdowns in the accelerating gaps. Reduction of the residual gas pressure in the vacuum chamber requires a reduction of the quantity $Q_{\text{des}}$, an increase in the number of pumps, or the use of fundamentally new pumping systems. Since this procedure involves a complication of the system and technology for producing the high vacuum and almost always leads to higher accelerator costs, it is not always economically wise to reduce the particle loss in this manner. It is a different situation if the conditions in the chamber at this vacuum level are not sufficient for normal operation of the accelerated system.


© 1972 Consultants Bureau, a division of Plenum Publishing Corporation, 227 West 17th Street, New York, N. Y. 10011. All rights reserved. This article cannot be reproduced for any purpose whatsoever without permission of the publisher. A copy of this article is available from the publisher for $15.00.
All these questions arise and are resolved during the planning of the accelerator; this planning requires the best possible estimate of the electron loss due to residual-gas scattering at the working pressure in the chamber.

The average vacuum in the chamber during the use of the accelerator may be worse than the working vacuum for a certain period of time for several reasons (the installation of new apparatus, the arising of small leaks, the increase in the temperature of the cooling water, etc.). In practice, therefore, there is considerable interest in the pressure dependence of the scattering loss; in this paper we report an experimental study of this dependence. The working vacuum in the chamber of the 1.5 GeV Sirius electron synchrotron is 5·10⁻⁶ torr, while the average pressure in the vacuum chamber may be 8·10⁻⁶ torr because of the factors cited above. Through the use of nitrogen traps, the vacuum in the accelerating cavities can be reduced to 3-4·10⁻⁶ torr.

To carry out these experiments, we had to degrade and reestablish the vacuum in the chamber repeatedly over a brief period of time. We did this by changing the effective pumping rate, by cutting off one or several of the oil-vapor diffusion pumps. For the pressure measurements, one of the LM-2 pickups was calibrated according to the average vacuum in the chamber for eight different combinations of pump cutoffs. Before an experiment, the accelerator was turned on in the usual manner, and a beam of electrons was accelerated to 700 MeV with an average of 7·10⁹ per pulse. The average vacuum in the chamber was ~5·10⁻⁶ torr.

The electron beam was detected and measured by a system of magnetic pickups [2] placed in one of the linear regions and by a dual-trace oscilloscope mounted on the control panel of the synchrotron. The signal from a ferrite pickup showed the time dependence of the beam intensity (curves 1 in Figs. 1-3).

The fraction of particles lost because of betatron and phase oscillations due to scattering of the electrons by the gas atoms is not known. By measuring the residual gas pressure at constant injection, acceleration, and adjustment conditions, one can follow the dependence of the electron loss on the chamber vacuum; the results are shown in Table 1.

The oscillograms of the accelerated current (Figs. 1-3) recorded at average vacuum of 4.8·10⁻⁶ and 1.8·10⁻⁵ torr clearly show a decrease in intensity with a degrading of the vacuum. Figure 4 shows the experimental dependence (I) of the relative particle loss in the Sirius synchrotron on the chamber pressure. The loss at pressure P is defined as

$$\eta = \frac{N_i - N_p}{N_i} \times 100\%,$$

where $N_i$ is the number of particles retained at pressure 4.8·10⁻⁶ torr; and $N_p$ is the number of particles retained at pressure P.

This figure also shows calculated curves (II and III). Curve II was constructed from calculations based on the Vlasov procedure [1] for the Sirius synchrotron and for the initial conditions $B_0/b = 0.3$, where $B_0$ is the initial amplitude of the betatron oscillations and $b$ is half the vertical chamber dimension.