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1958

SovietRxiv

Figure 1

Figure 1: Figure 1

Abstract

Full Text

PHYSICS

Academician of the Academy of Sciences of the Ukrainian SSR A. P. KOMAR and Yu. S. KOROBOCHKO

ON TWO PROCESSES THAT FACILITATE THE CAPTURE OF ELECTRONS INTO THE BETATRON MODE OF ACCELERATION

Various authors have proposed several mechanisms for the capture of electrons in a betatron ([1–4], etc.). In our opinion, attention should also be paid to two effects that can very substantially change the amplitudes of the radial oscillations of electrons, thereby facilitating the capture of some of them.

The first effect is illustrated in Fig. 1, which shows the trajectory of an electron beam in the chamber over one period of radial oscillations. The necessary explanations are given in the caption to the figure.

Fig. 1. r_0 –equilibrium orbit; a –trajectory corresponding to the axis of the electron beam; b and c –trajectories corresponding to the boundaries of the electron beam; r_0' and r_0'' –displaced instantaneous orbits; $F_e - F_e^0$ –the hypothetical curve of the electric force acting on electrons emerging from the injector along trajectory b.

It is obvious that an electron injected in the direction toward the outer wall of the chamber and moving along trajectory b will be acted upon by a force from the remaining part of the beam. During the first, as well as the subsequent odd half-periods of the radial oscillations, this force will act in the direction toward the outer wall of the chamber; during the second, as well as the subsequent even half-periods, it will act toward the inner wall. Accordingly, the effective instantaneous orbit for the odd half-periods will be shifted toward the outer wall of the chamber, and for the even ones toward the inner wall (Fig. 1). Thus the instantaneous orbit about which the radial oscillations occur will have the form of a periodic curve with a period equal to the period of the radial oscillations. Under these conditions the electron trajectory will be distorted, as shown in the figure (trajectory b'). In other words, the amplitude of the radial oscillations of an electron emitted in the direction toward the outer wall of the chamber will decrease monotonically.

It is easy to verify, by carrying out analogous reasoning, that for an electron emitted in the direction toward the inner wall, a monotonic increase of the amplitude will occur. A rough estimate of the relative change in amplitude in one revolution of the electron in the chamber leads to the result

$$\frac{\Delta^2 r}{\Delta r_0} = \alpha\,\frac{\delta\rho\Delta r_0}{\rho_2}\sqrt{1-n_i}\,\pi, \tag{1}$$

where Δr_0 is the initial amplitude, which we have taken equal to the half-width of the chamber; $\alpha = I_{\text{beam}}/I_{\text{lim}}$ is the ratio of the current in the beam to the limiting current; ρ is the width···

beam in the radial direction; $\Delta\rho$ is the distance from the electron under consideration to the beam axis (the last two quantities correspond to the position of the electron beam).

For $\alpha = 0.05,\ \Delta r_0 = 3$ cm, $\Delta\rho = \rho = 1$ cm, we obtain $\Delta^2 r/\Delta r_0 = 0.28$. Since an electron injected into the chamber, at $H = \text{const}$, makes on the average up to 4–5 revolutions ([4]), the decrease in amplitude may be quite considerable.

From the standpoint of the effect described, favorable conditions for capture occur for electrons emitted by the injector in the direction toward the outer wall of the chamber.

Along with the effect of interaction of electrons within the beam considered above, there must also be interaction between beams making successive revolutions. This interaction was pointed out in ([5]). Starting from the fact that electrons on the average make a considerable number of revolutions in the chamber ([4]), one may assume that the beam preserves its ribbon-like form over a number of revolutions. Under these conditions a force will act on an electron, varying in time in a very complicated manner and leading both to an increase and to a decrease in the amplitude of radial oscillations.

If it is assumed that $\overline{N}$ current turns exist simultaneously in the chamber, where $\overline{N}$ is the mean number of revolutions of an electron, then a rough estimate of the relative change in amplitude leads to the result:

$$\frac{\Delta^2 r}{\Delta r_0} = 4\pi k\alpha\sqrt{2(\overline{N}-1)}\sqrt{1-n}, \tag{2}$$

where k is a certain effective number of revolutions during which the indicated force acts.

Taking $\Delta^2 r/\Delta r_0 = 0.28,\ \overline{N} = 5,\ \alpha = 0.05$, and $n = 0.67$, we obtain $k = 0.27$. This result means that, for a substantial change in the amplitude of the radial oscillations of an electron, the existence of a sharp inhomogeneity in the volume-charge distribution over ~ 0.3 of an electron revolution, i.e. $\sim 120°$, is sufficient. Thus, the first effect amounts to a monotonic change in the amplitudes of the radial oscillations of electrons injected in the direction toward the outer wall of the chamber, due to the interaction occurring within the beam; while the second effect amounts to scattering of electrons by inhomogeneities in the volume-charge distribution arising because the beam retains an approximately ribbon-like structure over a number of revolutions.

Received
1 VIII 1958

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Note: Figure translations are in progress. See original paper for figures.