Influence of the self-acceleration effect on the phase span of a relativistic electron bunch in a storage ring

I.I. Koba, S.G. Kononenko, L.D. Lobzov, N.I. Mocheshnikov, and N.N. Naugol'nyi

Physico-technical Institute, Ukrainian Academy of Sciences

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We investigate the influence of self-acceleration on the phase span of a relativistic electron bunch in a storage ring. The experimental data are compared with the theory.

In connection with the method proposed in[1] for accelerating intense charged-particle beams, based on the use of passive resonant elements (self-acceleration), it is of interest to observe and investigate this effect in storage rings.

Of course, the current pulses presently obtained in storage ringe are of much lower intensity than the beams obtained by direct methods. However, the small relative energy scatter of the particles in the bunch in the presence of phase stability gives grounds for hoping to observe the self-acceleration effect at the present obtainable beam intensities in storage rings.

The interaction of the bunch with a passive low-Q resonant system is equivalent to the appearance of a certain additional accelerating field that leads to deformation of the potential well of the longitudinal motion, and consequently to a change of the phase span σ of the bunch.

Following the calculation method described in[1], we obtained for the normal distribution of the density $\rho = \pi^{-1/2}\sigma^{-1}\exp(-\phi^2/\sigma^2)$ in a bunch interacting with a resonant element of length h

$$\frac{\sigma^2}{\sigma_0^2} = 1 + JI\gamma^{-3}\left(\frac{\sigma}{h}\right)^{-1}\{1 - \exp(-h^2/\sigma^2)\}, \tag{1}$$

where σ_0 is the length of the bunch in the absence of space charge, in cm, I is the accumulated current in amperes, γ is the relative energy of the electron, and J is a coefficient that depends only on the transverse structure of the resonator and on the parameters of the storage ring. At energies above critical we have $J > 0$, corresponding to an increase of the phase span of the bunch.

Using the storage ring of the Khar'kov Physico-technical Institute of the Ukrainian Academy of Sciences,[2] we performed an experiment aimed at observing the self-acceleration effect. We used for this purpose a toroidal ferrite resonator with rectangular cross section, with inside and outside radii 5 and 9 cm, respectively, and with ferrite magnetic permeability $\mu = 60$. The experiment was performed at two values of the transit length, 2 and 4 cm.

Under the conditions of our experiments, we had $h\sigma^{-1} \ll 1$, so that in the comparison of the experimental data with the calculation we used instead of formula (1) the expression

$$\frac{\sigma^2}{\sigma_0^2} = 1 + JI\gamma^{-3}\frac{h}{\sigma}\ , \tag{2}$$

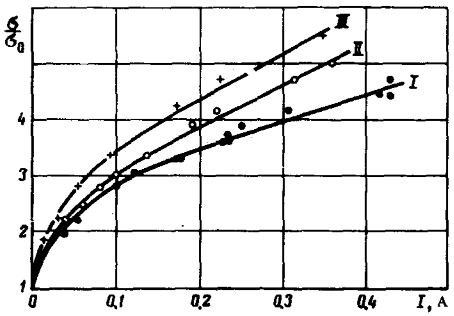

FIG. 1. Plot of σ/σ_0 against the accumulated current I: the curves were drawn through the experimental points: curve I—in the absence of a ferrite resonator, ●—experimental point; curve II—ferrite resonator installed with $h = 2$ cm; ○—experimental points; curve III—ferrite resonator installed with $h = 4$ cm, + – experimental points.

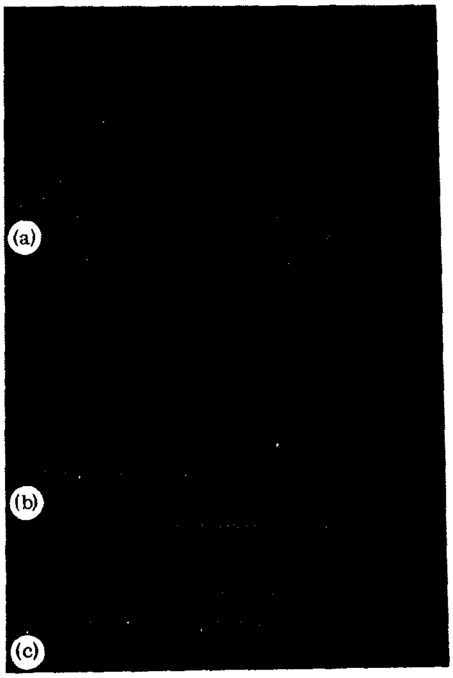

FIG. 2. Oscillogram showing the distribution of the electron density in the electron bunch with respect to the phase (in the absence of the ferrite resonator): a) $I = 0.23$ A; b) $I = 0.007$ A; c) calibration signal (distance between maxima 150°).

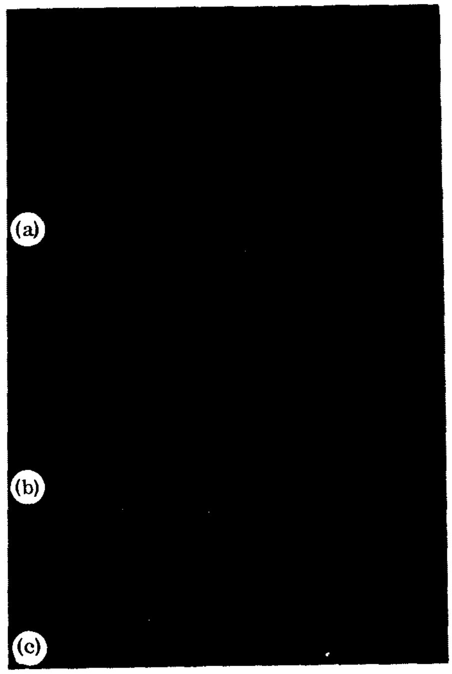

FIG. 3. Oscillogram showing the distribution of the electron density in the bunch with respect to phase (after introducing a ferrite resonator with $h = 4$ cm): a) $I = 0.35$ A; b) $I = 0.012$ A; c) calibration signal (distance between maxima 115°).

which agrees qualitatively with the result of[3]. The calculated values of the coefficient J for the indicated parameters of the resonator is equal to 1.3×10^9 A^{-1}.

The increase of the phase span of the bunch was observed against the background of the bunch elongation produced in the storage ring and apparently due to parasitic resonance elements of the chamber.[4] Figure 1 shows a plot of σ/σ_0 against the accumulated current.

The experimental relation agrees with formula (2) within the limits of the measurement accuracy. At large elongations of the bunch, an important role is played by the nonlinearity of the potential well, which leads to a noticeable change in the shape of the bunch. Figures 2 and 3 show oscillograms of the distributions of the particle density at different intensities of the accumulated bunch. It should be noted that the lifetime of the bunch, even at the maximum value of the bunch dimension, does not decrease in practice, thus indicating that there is no noticeable increase of the energy scatter of the electrons in the bunch.

We note in conclusion that the self-acceleration effect is based on the phenomenon of bunch elongation, observed in many storage rings and not connected with an increase of the beam temperature.[5]

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[4] Yu. N. Grigor'ev, I. A. Grishaev, *et al.*, "Élektronnye uskoriteli" Trudy VII mezhvuzovskoĭ konferentsii po elektronnym uskoritelyam (Electron Accelerators, Proceedings of Seventh Inter-University Conference on Electron Accelerators), No. 1, Atomizdat, 1970, p. 68.
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