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EXPERIMENTAL RESULTS ON BEAM-BEAM INTERACTION

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Effects of electromagnetic interaction between colliding beams ("Beam-beam phenomena") seem to place rather principles restriction on the achievable luminosity. Therefore, the experimental study of these effects appears to be of importance in the accelerating program of the storage ring investigation. In this connection, this report gives a survey of the preliminary results on beam-beam phenomena study obtained with the electron storage ring VEP-1. Beside this, are described the first notices about the behaviour on the positron beam in presence of the electrons in the storage ring VEPP-2. The description of the machine and the main beam parameters (stored current intensity, life time and beam dimensions) are given in (1).

Experiments at the storage ring VEP-1 were carried out mainly with beam energy of 43 MeV. For practical reasons the study of beam-beam phenomena was carried out by observing the beam behaviour in the upper ring, which will be called in what follows the first ring. Also, the magnetic field on this ring has the following nonlinearities, such as a quadratic $\partial\nu/\partial R = 1{,}5.10^{-2}$ l/cm and a cubic $\partial^2\nu/\partial R^2 = 4.10^{-2}$ cm^{-2}. In the storage of each beam the equilibrium orbit are separated at the collision point. After the storage of the current required, beams are matched by means of special arrangements (2). Beam-beam phenomena ambigously depend on the dimensionless frequency of betatron oscillations ν. Therefore beam behaviour in each ring depending on the ν value have been studies. The working region in our storage ring is the region from $\nu_z = 3/4$ to $\nu_z = 4/5$ (Fig. 1). It turned out that when beam passes through the nonlinear resonances $\nu_z = 3/4$; $4/5$; $\nu_r = 2/3$; $3/5$ within times of 1 sec order (radiation damping time) its axial or radial dimensions highly increase, and the beam is lost. For other values for $\nu_r = 0{,}792$ the increase of beam transverse size resonantly depending on the resonator voltage amplitude was obtained. The maximal "blowing-up" corresponds to ν shifted from the resonant value $\nu_z = 4/5$ by Ω/ω_0 were ω_0 is the revolution frequency and Ω is the frequency of synchrotron oscilla-

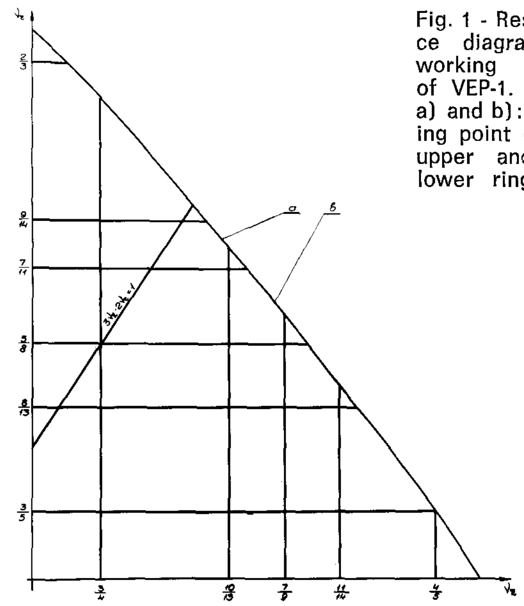

Fig. 1 - Resonance diagram in working region of VEP-1.
a) and b): working point of the upper and the lower rings.

tions. This, probably, indicates that synchrobetatron resonances may take place. For the other ν values in the working region, the beam conserves its « natural size » (1). The lifetime of the beam also depends on ν value (Fig. 4) and considerably decreases when approaching to $\nu_z = 3/4$; $4/5$; $\nu_r = 2/3$; $3/5$. Thus, the effects of synchrobetatron resonance-type are detected.

The action of the second beam results in the change of electron density distribution over the beam cross-section (the so-called "blowing-up") as well as in the decrease of particle lifetime. No phase effects were detected within our accuracy.

All the investigations were carried out at head-on collision (the crossing angle is less than 10^{-3} rad). The equilibrium orbit slope in the axial direction, as it is to be expected, had no remarkable influence on the results, since at crossing angles up to (10^{-2} rad) the relative transverse beam shift it the length of the interaction region is less than the corresponding bunch size.

The method of beam matching after storing (radial, axial or phase) has no effect on the steady beam-beam phenomena.

The existence of beam-beam phenomena highly depends on the second beam intensity and is very sensible to variations of the first beam ν values. The condition when blowing-up of the lifetime decrease can be observed in more intensive beam, is quite possible. The "beam-beam phenomena" do not depend or depend insignificantly on the first beam intensity, if the second beam is not "blown-up". Measurements of luminosity by a small angle e-e scattering indicated

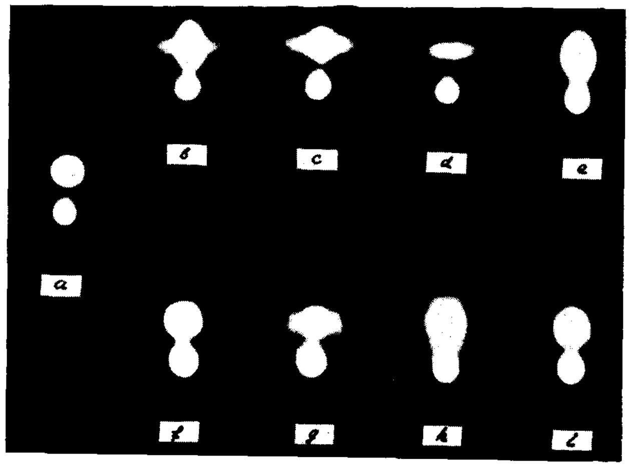

Fig. 2 Pictures of various types of "blow- up" of the first beam in the presence of the second one. (Beam images are separated by the optical system)
$J_1 = 5$ mA; $J_2 = 40$ mA.
a) beams dephased: b-i) beams phased:
b) $\nu_{z1} = 0{,}786$; c) $\nu_{z1} = 0{,}778$; d) $\nu_{z1} = 0{,}765$;
e) $\nu_{z1} = 0.782$; f) $\nu_{z1} = 0{,}768$; g) $\nu_{z1} = 0{,}792$.
h) $\nu_{z1} = 0.783$; i) $\nu_{z1} = 0{,}772$;

that beam size increase due to the beam-beam phenomena reduces luminosity. This reduction is uniquely by the changes in the transverse density distribution and may be easily taken into account. The external change of the transverse size also gave the coincidence between the reduction of luminosity and calculations (a transverse particle distribution was assumed to be gaussian) with the accuracy no worse than the accuracy of beam size measurements (statistical errors and the accuracy of beam size measurement were about 10%). These facts confirm the absence (in these case) of special coherent effects ("pass-by effects") in the presence of the second beam.

The pictures of various types of "blowing-up" in the working region of ν values are shown in Fig. 2. In Fig. 3 is shown transverse distribution of particle density measured by means of rotation slit (2). The blowing-up of the beam at different ν values differs in form.

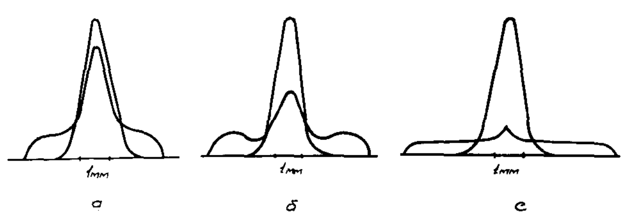

Fig. 3 - Density distribution in the first beam (with the second beam and without it).
a) $\nu_{z1} = 0{,}778$; b) $\nu_{z1} = 0{,}792$; c) $\nu_{z1} = 0{,}765$.

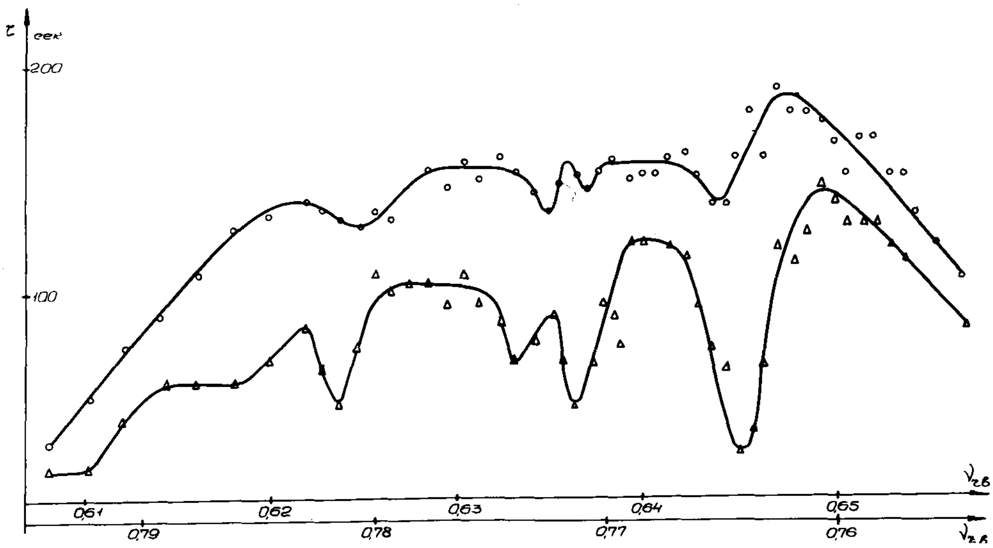

Fig. 4 - Lifetime of the first beam depending on ν

$J_1 = 5$ mA $J_2 = 0$

$J_1 = 5$ mA $J_2 = 40$ mA

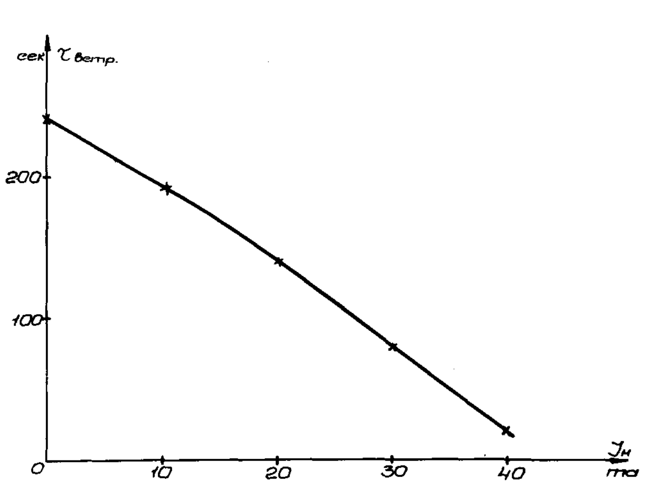

Fig. 5. - First beam lifetime depending in the second beam intensity.

$J_1 = 5$ mA $\nu_{z1} = 0{,}765$

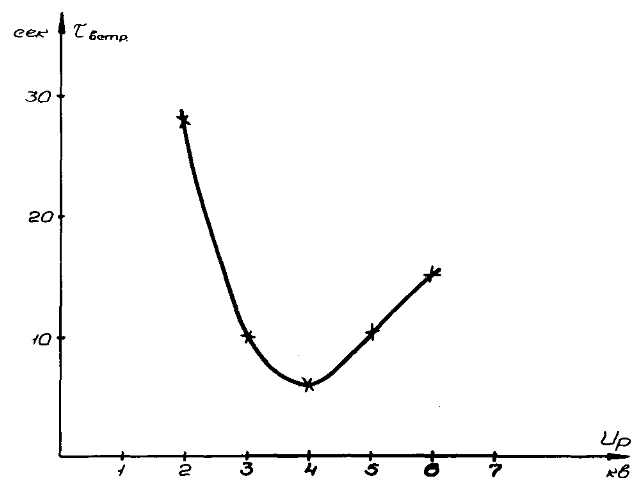

Fig. 6 - Partial life-time due to beam-beam phenomena depending on resonators voltage

$J_1 = 5$ mA $J_2 = 40$ mA $\nu_{z1} = 0{,}765$

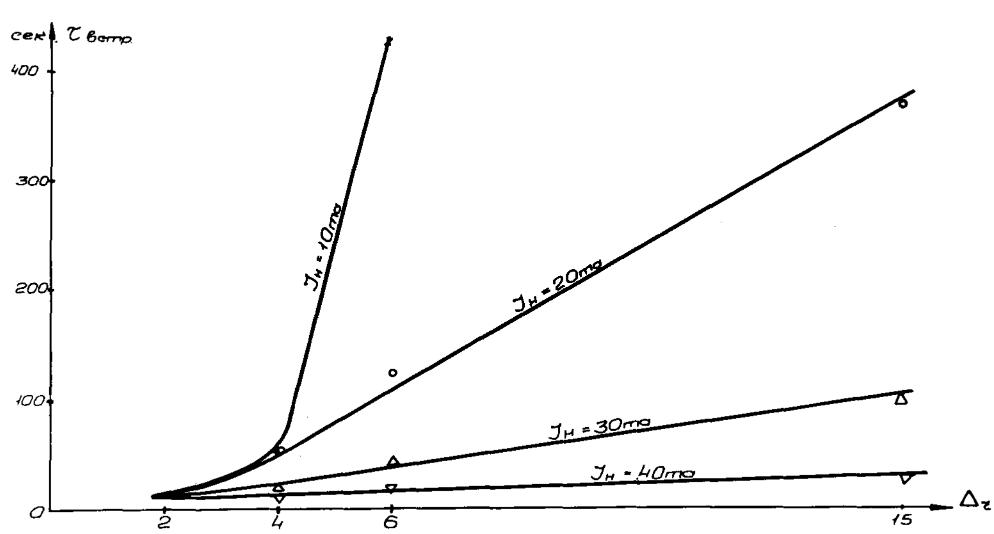

Fig. 7a - Partial lifetime due to beam-beam phenomena depending on z aperture.

$\nu_{z1} = 0{,}778.$

Thus, near nonlinear resonances $\nu_z = 7/9$ and $\nu_r = 5/8$ there takes place the growth of z oscillations at $\nu_z = 7/9 + \delta\nu$ or r oscillations at $\nu_r = 5/8 + + \delta\nu$ (ν values are measured for the first beam on the absence of the second one, but under the same conditions). The range in which there exists the growth seems to correspond to the frequency shift produced by the second beam. The blowing-up amplitude in this case is independent of the voltage on the first resonator.

The blowing-up at $\nu_z = 11/14$ has just same properties. In the vicinity of the other resonant ν-values such as $\nu_z = 4/5 - \delta\nu$ the amplitude of the blowing-up depends resonantly on the voltage on the first resonator, this blowing-up being maximal at synchrotron oscillation frequency equal to the detuning $\delta\nu\omega_0$.

The transition time of the establishment of the steady beam transverse size at collision, as estimated, is of the order of the time of betatron oscillation growth due to the single and multiple scattering from the residual gas.

Sometimes at high currents in the second beam (about 50 mA) the visible intensity of the beam size is diminished but other phenomenon, i.e. the reduction of the lifetime continues to grow.

In the presence of the second beam-beam lifetime for the fidex current I_1 strongly depends on the second beam intensity, as well as ν value and, sometimes, on the voltage on the first resonator. The corresponding relations are shown in Figs. 4, 5, 6.

One can see that the beam lifetime greately reduces in the vicinity of some nonlinear resonance, and effects of synchrobetatron resonance-type are also detected.

The time dependence of the beam lifetime in the presence of the second beam on the axial and radial apertures, shown in Fig. 7 confirms the loss of particles caused by the presence of the second beam, which occurs, in principle, due to the growth of betatron oscillation amplitudes.

We note that in these experiments we found no dependence of the lifetime and the established beam size on the ν values splitting of colliding beams.

Similar investigation of the collision effects was not so far carried out at other energies. One may note that the general nature of effects holds, and their strength decreases with the increase of energy (under similar conditions).

The following working points were chosen, as based on the above investigations for carrying electron-electron scattering experiments at 43 MeV energy: $\nu_z = 0{,}768$ at the upper ring, and $\nu_z = 0{,}776$ at the lower one. Under these conditions one succeded in maintaining the average current in each ring of about 30 mA without any remarkable increase of beam size and decrease of lifetime due to beam-beam phenomena. The average luminosity is of the order of 10^{27} cm^{-2} sec^{-1}.

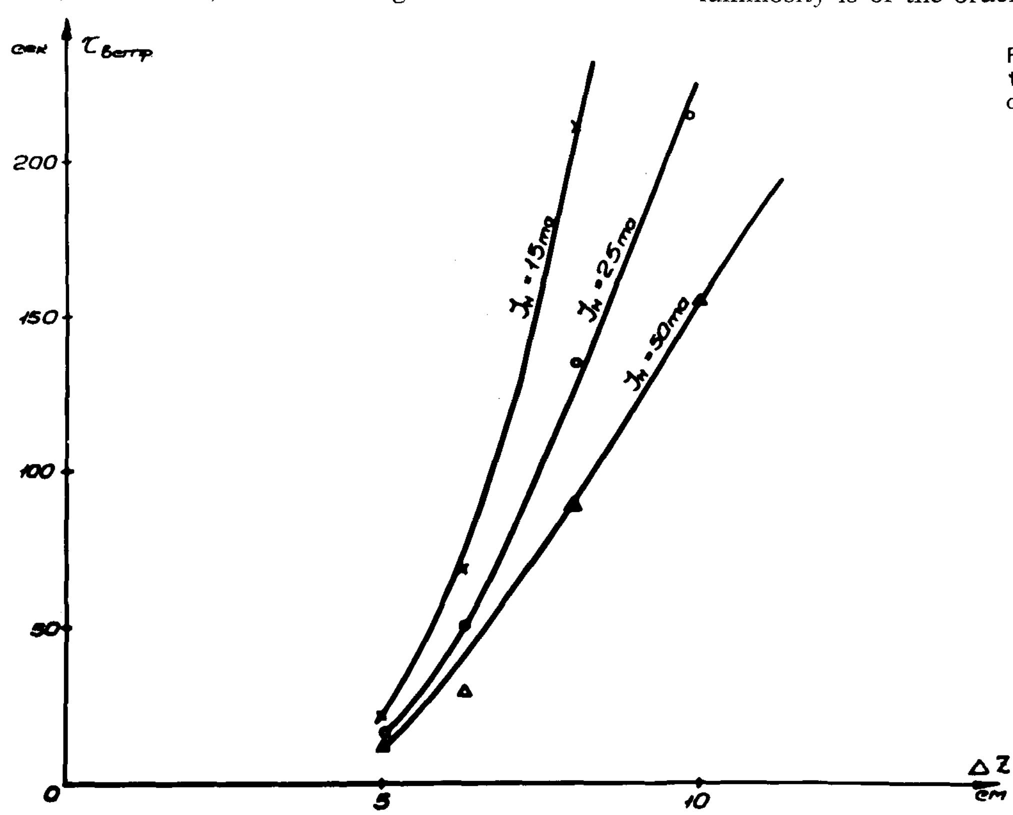

Fig. 7b - Partial lifetime due to beam-beam phenomena depending on r-aperture. $\nu_{z1} = 0.772$.

At the present time the first results on electron beam influence upon positron beam are obtained at electron-positron storage ring VEPP-I. At 100 MeV energy electron current up to 400 mA (10" particles) and positron current up to 0,5 mA (10^8 particles) can be obtained being stored separatly.

But at the presence of positron beam the effects of beam-beam interaction are already essential while storing electron current of the order of several mAs.

Every storing cycle exites the vertical betatron oscillations of electron bunch which gives growth of vertical positron beam dimension and that gives positron losses, it electron current is sufficiently high.

The effect can be avoided by means of non-uniform electric field, which splits the betatron frequencies of electrons and positrons. Besides this for reducing the growth of transverse dimensions of positron bunch and for increasing its lifetime the electron and positron orbits are also separated at the injection.

In this way electron current up to 50-60 mA can be stored without positron losses.

While the beams being intersected the transverse dimensions and lifetime of positron beam strongly depend upon electron current, upon frequency of betatron oscillations of positrons and upon the energy at wish the interaction is performed.

These effects are analogous to the effects observed in the machine VEP-1.

The main particularity in the observed effects is the ever present increasing of the radial dimension of the positron beam when there is a collision. This rise is of the order of a factor at the energy of 200 MeV and it is correlated, may be, with a presence of small coherent radial oscillations in the electron bunch (Fig. 8).

At the present time an intersection can be performed at an electron current up to 10 mA at 100 MeV energy and up to 50 mA at 200 MeV energy without essential roth of axial dimension of the positron beam and without essential lifetime reduction.

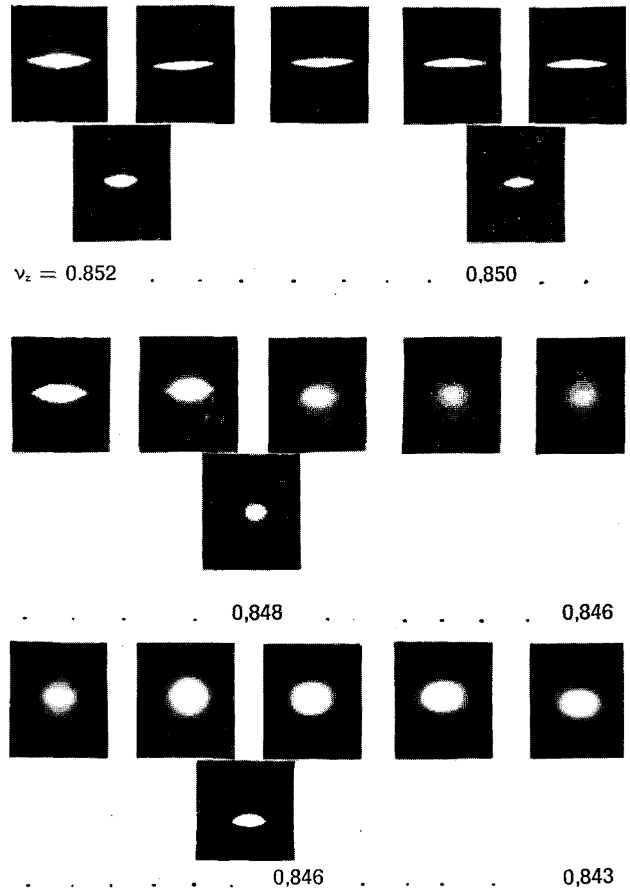

Fig. 8

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PHASE INSTABILITY OF INTENSE ELECTRON BEAM IN A STORAGE RING

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I. In working out the program of creating storage rings for carrying out colliding beam experiments a supposition was made by G. I. Budker and A. A. Naumov in 1959 that at high intensities phenomena of phase intability are possible due to the interaction between the beam and the accelerating cavities and other elements of vacuum chamber.

This topic was theoretically investigated by a number of authors. According to the stability conditions obtained in (3, 4, 6) it is sufficient to tune the accelerating cavities at a frequency