EXPERIMENTAL STUDY OF COLLECTIVE EFFECTS IN BEP STORAGE RING WITH HIGH STORED CURRENT

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Abstract

The results of extensive investigation of beam dynamics with high current in BEP booster are presented. Strong bunch lengthening due to the potential well distortion by the inductive impedance was observed on the background of the multiple intrabeam scattering and of the ion accumulation (in the e^- beam). The octupole and sextupole corrections enabled control of collective damping of the head-tail modes. Fast damping is also observed at zero chromaticity, this is attributed to the injection kickers acting as transmission lines. The proper tuning of the nonlinearity corrections cures the transverse instabilities and enables capability to store up to 0.8A current in a single bunch.

I. INTRODUCTION

The electron and positron accumulator ring BEP is recently built to upgrade performance of the e^+e^- collider VEPP-2M [1]. Electrons and positrons are accumulated alternately at the energy of 120 MeV. The injection repetition rate is 0.7 Hz, the machine is capable to capture 150 μA ($0.75 \cdot 10^8$) of positrons and 150 mA of electrons in a single-turn injection. The maximum accumulated currents are 0.2 A of positrons and 0.8 A of electrons.

Energy ramping time in BEP is about 8 s, its lower limit is mostly due to the effect of eddy-currents in the aluminum beam pipe. The maximum energy achieved is 775 MeV, and its upper limit currently results from shifting of the vertical betatron tune down to the integer resonance, while the available gradient correction strength is insufficient to oppose this tuneshift during the ramp.

The beam parameters were measured at the energies of 120, 360 and 510 MeV.

II. BEAM PARAMETER MEASUREMENT TECHNIQUES

For measurement of both transverse and longitudinal bunch dimensions we used the system of optical dissectors, as described in [2]. The resolution of the longitudinal dissector was ~ 2 cm, while the transverse dissector gave ~ 0.25 mm. In a series of measurements we also imaged the beam onto a CCD matrix, and obtained the same transverse resolution, which resulted from the realistic quality of the available mirror, window and lens optics, rather than from the image-scanning device.

Indirect measurements of the vertical beam size below that resolution were enabled by monitoring of the particle loss rate (from intra-beam scattering), which was performed with the scintillation counter and resulted in ~ 60 μm of the vertical beam size FWHM at the energy of 510 MeV. The count rate was calibrated against the vertical beam size directly measured with the dissector, when the machine was operated at the betatron coupling resonance, and the dissector could reliably resolve the enhanced beam height. Direct measurement of the beam energy spread is described in [2].

III. DYNAMIC APERTURE STUDY

The correct choice of the machine operating point is important for accumulation of intense beams. Due to low radiative damping at injection ($\tau_z \simeq 1$s) the particle motion is subject to influence of weak non-linear resonances, even those of the 6th order and above. Fig. 1 shows the positron beam capture efficiency as a function of the operating point. The injected positron beam has a large transverse emittance, so it is suitable for testing the dynamic aperture. The design operating point of $\nu_z = 3.18, \quad \nu_x = 3.61$ proved to be bad because of the neighbouring strong sum coupling resonances.

Changing the lattice for $\nu_z = 3.2, \quad \nu_x = 3.45$ resulted

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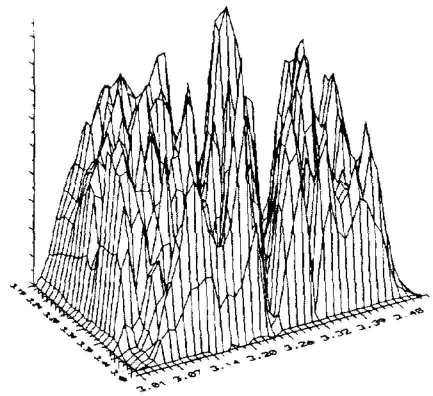

Figure 1: Positron beam capture efficiency.

in capability to use practically whole beam stay clear sizes of the vacuum chamber. For this lattice the horizontal injection kicker pulse lasts during two turns and serves as a pre-kicker at once. The lattice with $\nu_z \simeq \nu_x = 3.27$ also provides for a large dynamic aperture, however it requires a separate pre-kicker (which is also installed in BEP).

Scanning of the operating point in a wider range demonstrated relatively safe operation closely to the integer resonances $\nu_{x,z} = 3$, and revealed wide stopbands surrounding the resonances $\nu_{x,z} = 4$. The latter combine the effect of integer resonances with the non-linear 12/3 ones, which are enhanced in the 12-fold symmetry of the machine lattice.

IV. Ion Accumulation in BEP Beam

The positive ion accumulation in the electron beam of the BEP storage ring was mostly pronounced during the first days of the machine commissioning, resulting in the stored current limitation at a few milliamp level with the subsequent shift of this limit up to dozens of milliamps. With an upgrade of the vacuum in the machine due to cleaning the vacuum pipe walls by irradiation with the synchrotron light, the current limitation was no more imposed by the ions, other reasons were predominant, as outlined above. However, the presence of a small positive ion concentration in the electron beam trace can be detected even after a three-year period of practically continuous operation with the average pressure of $\sim 10^{-8} Pa$.

Fig. 2 shows the vertical beam sizes for electrons and positrons as functions of the operating point ν_z. The positron curve responds to the sum and difference resonances only, while the electron curve exhibits numerous one-dimensional resonances, which have a natural explanation in the framework of the ion accumulation hypothesis. With the current ramping the vertical beam size of the electron bunch grows much stronger than the positron beam size, the latter scales as $I^{1/6}$ due to the multiple intrabeam scattering effect. Above 300 mA the vertical beam size shrinks (see Fig. 3) that is likely to result from

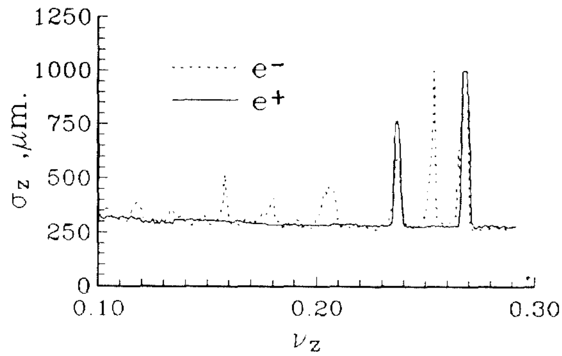

Figure 2: Vertical beam sizes for electrons and positrons.

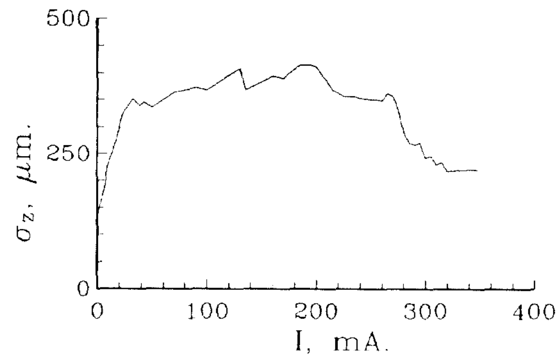

Figure 3: Current dependence of vertical beam size.

ion rejection out of the beam because of tresspassing the ion stability limit. This threshold current value agrees with the assumption that single charge Ar^+ or CO_2^+ molecules dominate in the ion contents.

The effect of ion rejection from the beam can also be observed when the resonance excitation of the vertical betatron oscillations is switched on with a certain small tune offset with respect to the exact resonance tune.

The estimate for the degree of the beam space charge compensation of $\sim 5 \cdot 10^{-3}$ at 20 mA current has been obtained from the measured coherent tuneshift of $\sim 2 \cdot 10^{-4}$ at the injection energy of 120 MeV. This corresponds to the ion Ar^+ partial pressure of $6 \cdot 10^{-7}$ Pa. At the energy of 510 MeV we did not observe any effect from ions on the beam dynamics.

V. Current Dependence of Bunch Dimensions in BEP

Experimental data on the current-dependent bunch dimensions in BEP at the energy of 360 MeV are presented in Fig. 4. We saw, that:

a) with ramping the current the longitudinal bunch profile was observed to deviate from the Gaussian and to approach the parabolic shape (Fig. 5);

b) the bunch length scaled as the 1/3 power of the beam current, while the beam energy spread scaled as the current to the 1/6 power (Fig. 4), the latter dependence was

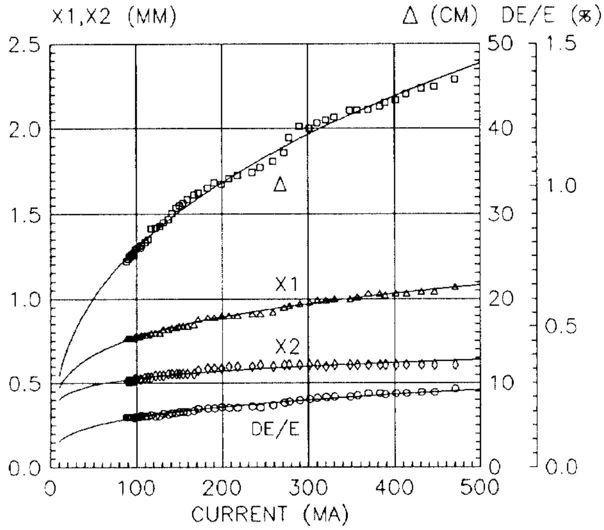

Figure 4: Current dependencies of total horisontal size $X1$, betatron size $X2$, beam energy spread DE/E and bunch length (FWHM) Δ; the curves are $I^{1/6}$ and $I^{1/3}$ fits to the mesured data.

due to the multiple intrabeam scattering effect (IBS);
c) the bunch equilibrium phase shift was small (practically undetectable);
d) the synchrotron tune shift with current was small ($\sim$ 10% at 300mA) if measured with the coherent excitation, but the *large incoherent tuneshift* was observed by a special technique [3] and proved to be in agreement with the longitudinal potential well flattening;
e) the longitudinal bunch size was independent of the revolution frequency displacement and insensitive to the position of the cavity higher order modes' tuners (apart from narrow bands where we had coherent longitudinal instabilities), so the multi-turn wakes were ruled out.

All this is consistent with the assumption of the static bunch lengthening due to the longitudinal potential distorted by the inductive wake. For a quantitative analysis we used the Haïssinski equation, and the inductance value deduced from these measurements was about 50 cm. The incoherent synchrotron tuneshift resulting from the longitudinal well flattening was measured for currents up to 470 *ma*. The data agree with the bunchlength behavior.

The data taken at the injection energy of 120 MeV showed that:
a) the bunch length below $\sim 10mA$ currents follows the $I^{1/6}$ relation, *i.e.* this lengthening results from IBS ;
b) at the currents of $\geq 150mA$ that slow energy spread blow-up due to IBS is negligible, and the bunch length scales with the beam current as $I^{1/3}$.

The collective damping rates $\propto I$ were measured [3] using the blinded PMT technique. At positive chromaticity the damping rate was proportional to its value. However at zero chromaticity the collective damping did not vanish at BEP, one should set $\partial\nu/\partial \ln\gamma = -0.3$ to eliminate the effect. At zero chromaticities it is due to the x' terms in the

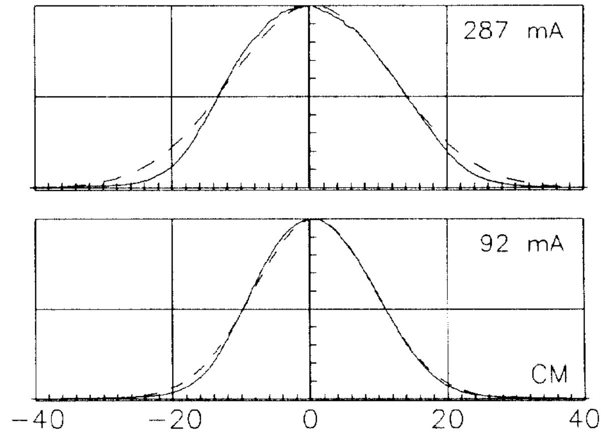

Figure 5: Evolution of the bunch longitudinal profile with current; solid line - the profiles from the dissector; dashed lines are the Gaussians with the same height and same FWHM.

transverse wake, resulting from the two injection kickers which are the transmission lines in their design. The reliable evidence for this was given by the two-fold reduction of the measured damping rates resulting from the elimination of one of the two kickers by a special mechanism envisaged in its design: the transmission line was grounded over its total length. This fast damping proved to be independent of the bunch length and the betatron tune.

At the energy of 510 MeV the measurements of transverse beam emittances gave $2.5 \cdot 10^{-8}$ cm·rad for the vertical emittance and $6 \cdot 10^{-6}$ cm·rad, which fairly well agree with their design values.

References

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