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CURRENT DEPENDENCE OF BUNCH DIMENSIONS IN VEPP-2000 COLLIDER*

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Abstract

The paper describes bunch dimension measurements in VEPP-2000 collider at energy 350 MeV. The three bunch dimensions (transverse sizes along with bunch length) was measured against bunch current to detect the energy spread growth. Emittance growth due to multiple intrabeam scattering was observed at bunch current below turbulence bunch lengthening threshold. The thresholds of these processes was used to estimate values of longitudinal impedance. Obtained values in a good agreement with predictions.

VEPP-2000 OVERVIEW

The VEPP-2000 is a small 24 m perimeter single-ring collider operating in the energy range below 1 GeV per beam [1] exploits the round beam concept (RBC) [2]. This approach, in addition to the geometrical factor gain, should yield the significant beam–beam limit enhancement.

Collider itself hosts two particle detectors [3], Spherical Neutral Detector (SND) and Cryogenic Magnetic Detector (CMD-3), placed into dispersion-free low-beta straights. The density of magnet system and detectors components is so high that it is impossible to arrange a beam separation in the arcs. As a result, only a one-by-one bunch collision mode is allowed. The layout of the VEPP-2000 collider is presented in Fig. 1.

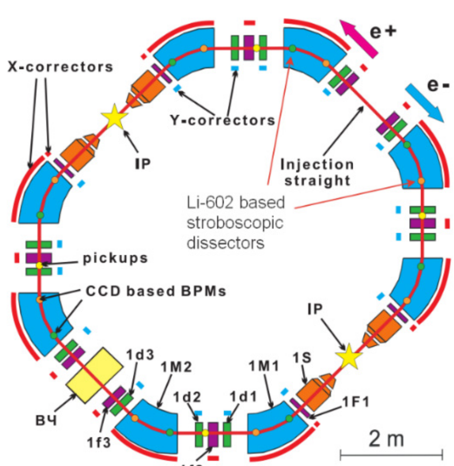

Figure 1: VEPP-2000 collider layout.

Beam Diagnostics

Diagnostics is based on 16 optical CCD cameras that register the visible part of synchrotron light from either end of the bending magnets and give full information about beam positions, intensities and profiles. In addition to optical beam position monitors (BPM) there are also four electrostatic pickups installed in the technical straight sections, two photomultipliers for beam current measurements via the synchrotron light intensity, and one beam current transformer as an absolute current monitor. Two phi-dissectors – stroboscopic image dissector [4] with electrostatic focusing and deflection that gives information about e+ /e− longitudinal distribution of particles and bunch length.

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BUNCH DIMENSIONS

At the end of the luminosity-taking run (May 2018) a series of machine learning experiments was done – all thee bunch dimensions was carefully measured in wide range of bunch currents (1-100 mA) while RF cavity voltages changes around the values used in operations – U_{rf} = 18.5 / 49.5 / 38.5 / 9.3 / 4.7 / 4.6 / 18.6 / 68.5 kV (text colors corresponds to the line colors in pictures below). Measurements have been carried out for single bunch without collisions (i.e. 8 observation points for transverse sizes of electron bunch) which decays with time naturally.

The control system of the VEPP-2000 collider allow us to measure and even store (for offline analysis) almost all parameters of magnetic system, RF system, timings and measured beam parameters. The most of these parameters can be measured with effective frequency 1-5 Hz. The resolution of bunch current measurement is equal to 0.1 mA; bunch sizes – 5-10 um in transverse and 2-3 mm in longitudinal direction; RF cavity voltage – 0.2 kV.

The VEPP-2000 lattice was the same as for the data taking regimes at E=350 MeV and was carefully measured and corrected to be consisted with the machine model [5].

Horizontal bunch sizes shown for the places with significantly different dispersion function (see Fig. 2) and shows the growth with intensity variation.

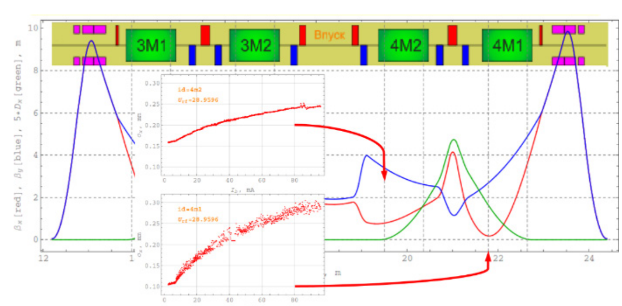

Figure 2: VEPP-2000 lattice functions for the luminosity-taking regime at E=350 MeV.

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For the simplicity, the transverse bunch sizes shown only for the 4M1L observation point (shown in Figs. 3, 4), but transverse sizes saved for all 8 available locations along the ring. Throughout the experiment, σ_x remained constant below certain threshold, while σ_y increases continuously from the low bunch intensities.

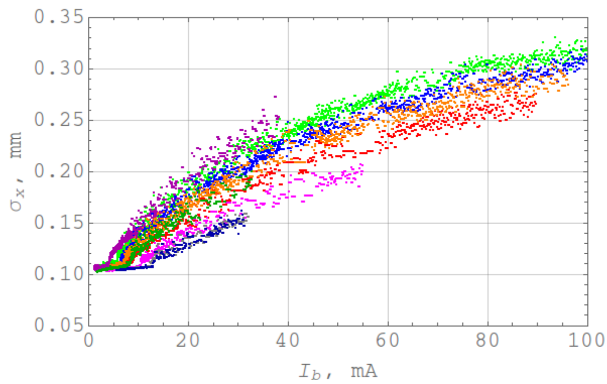

Figure 3: Horizontal beam size at 4M1L.

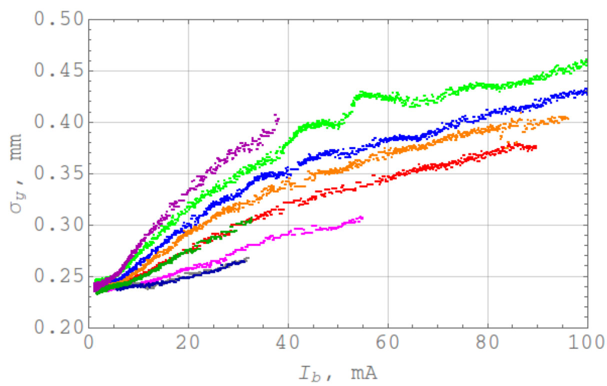

Figure 4: Vertical bunch size at 4M1L.

The variation of the bunch length with the beam current is given in Fig. 5.

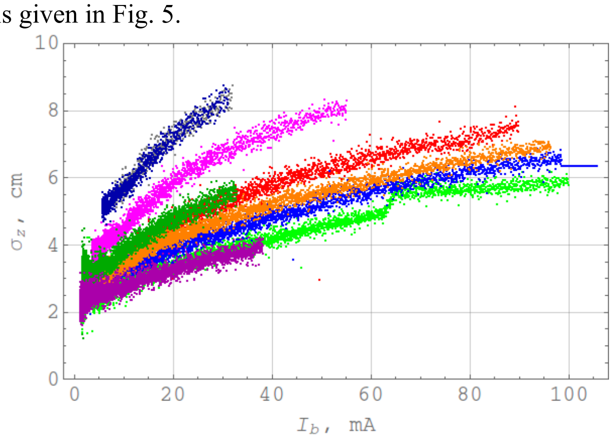

Figure 5: Bunch length at different RF voltages.

PARAMETERS ESTIMATIONS

The length of an electron bunch in a storage ring depends on the peak current of the bunch. The two effects that alter the length are potential well distortion and microwave instability. For potential well distortion, bunch length varies due to the electro-magnetic fields induced by the electrons that modify the RF voltage seen by the bunch. This effect is present even at very low currents. The second effect, microwave instability (MWI), is only observed after a certain threshold current has been reached. Above this threshold energy spread of the beam increases until the peak current of the bunch reduces to equal the threshold current again.

The bunch length variations below threshold described by equation:

$$\sigma_z^3 - \sigma_z^2\sigma_{z0} = \frac{\alpha_p |Z/n|_{eff} R^3}{\sqrt{2\pi}(E/e)\nu_s^2} I_b, \qquad (1)$$

where I_b is the average beam current, e is the electron's charge, R is the ring average radius, E is the beam energy, ν_s is the synchrotron tune and σ_{z0} is the bunch length at infinitesimal low intensity (say well below 1 uA) which is fully determined by the quantum excitation by synchrotron radiation.

Since the instability increases the bunch energy spread the horizontal bunch size σ_x is also increased. The dependence of energy spread – σ_E:

$$\sigma_x^2 = \varepsilon_x \beta_x + (D_x \sigma_E)^2, \qquad (2)$$

where ε_x is the horizontal emittance, β_x is the horizontal betatron function, D_x is the horizontal dispersion function. The bunch size in vertical direction does not depend on σ_E:

$$\sigma_y^2 = \varepsilon_y \beta_y = \varepsilon_x \beta_y \qquad (3)$$

where $\varepsilon_{x/y}$ is the horizontal/vertical emittance, β_y is the vertical betatron function. Here we assume equal beam emittances $\varepsilon_x = \varepsilon_y$ – demands of RBC [2], and it was tuned so (the betatron tunes chosen at the main coupling resonance). It should be noted that transverse bunch size depends not only on energy spread but on emittance as well. The latter grows with bunch intensity due to multiple intra-beam (IBS) scattering.

Equation (2-3) can be used for the bunch parameters estimation – emittance and energy spread – from the fitting measured bunch sizes to those one known from the optical model. In Figs. 6 – 8, one can find beam emittance and energy spread is estimated in such a way.

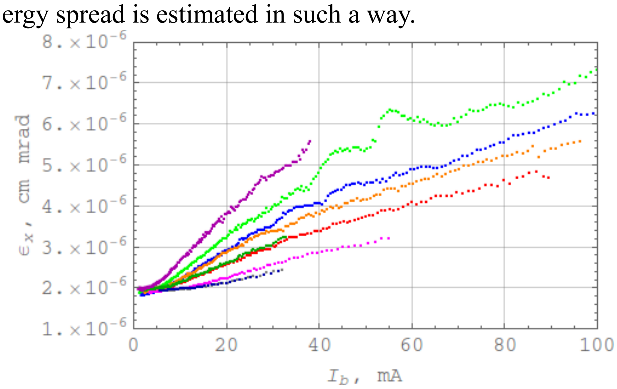

Figure 6: Estimated horizontal emittance for different RF cavity voltages as a function of bunch intensity.

The exact values of these parameters obtained from the VEPP-2000 model is equal: $\varepsilon_x = \varepsilon_y = 2\ 10^{-6}$ cm mrad, $\sigma_E = 2.5\ 10^{-4}$. The bunch volume as a simple product of bunch rms. dimensions shows the linear growth with different slope blow and above MWI threshold. Exact bunch intensity at MWI threshold (shown in Figure 9) gives Z_{BB} estimation according Keil-Schnell-Boussard criteria.

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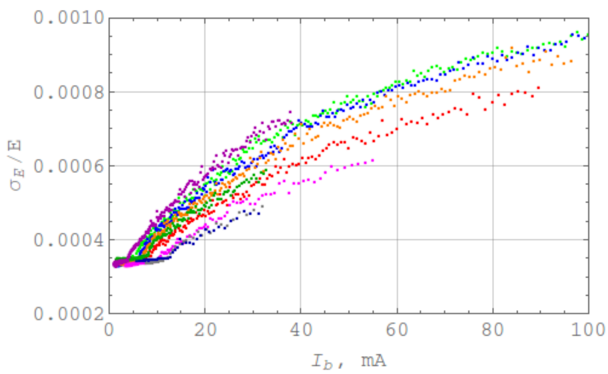

Figure 7: Estimated energy spread for different RF cavity voltages as a function of bunch intensity.

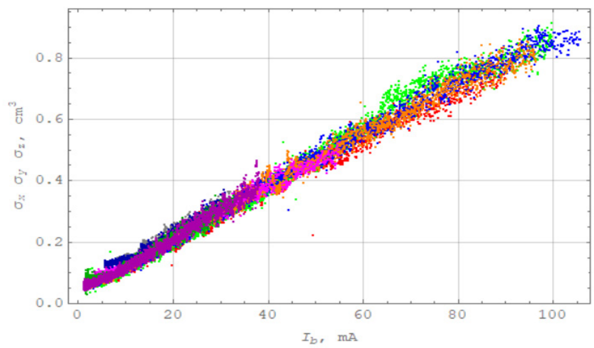

Figure 8: Bunch volume vs. bunch intensity.

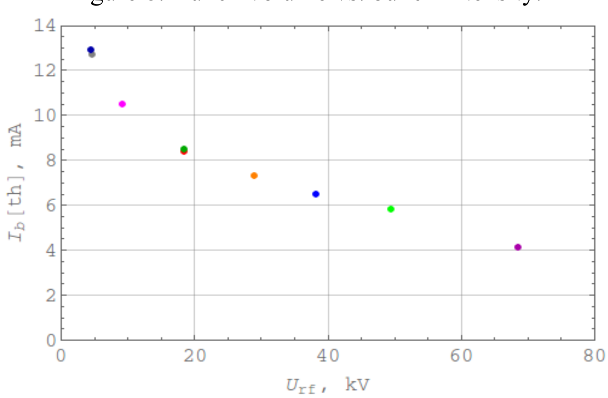

Figure 9: MWI threshold for different RF cavity voltages.

Comparison with CBS system

Visible cross-sections reduction at narrow resonances φ(1080), ω(782) depends quadratically on c.m. energy spread, and achieve values of ~5%. To measure real cross-sections with accuracy better then 1% the energy spread control needed at level of at least 10% [6]. During the routine luminosity-taking runs bunch energy and energy spread measured by Compton backscattering method [7] which require relatively high bunch intensities or long measurement time. Special experimental run was carried out in parallel with bunch sizes measurements: measurement time equal to 30 min for high and low bunch intensities. Bunch energy spread estimations compared with CBS results is shown in Fig. 10. At low currents CBS measurements became inconclusive.

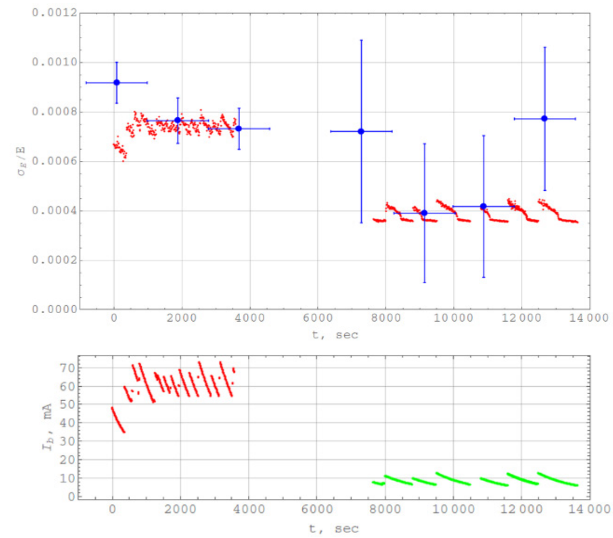

Figure 10: CBS comparison with estimations.

CONCLUSION

Bunch dimensions changes with bunch current due to: emittance growth caused mainly by IBS (continuously); energy spread growth caused by MWI (threshold). Bunch volume increases linearly with bunch current. MWI has been observed over a wide range of U_{rf} values and estimated Z_{BB} is about 2-2.5 Ohm. Energy spread can be estimated quite accurate from transverse bunch profile(s) for single bunch. Such “online” estimation should be used for routine operation during luminosity-taking runs with further modifications in presence of opposite counter bunch.

ACKNOWLEDGEMENTS

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