ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPA18

DEVELOPMENT OF LONGITUDINAL BEAM PROFILE DIAGNOSTICS FOR BEAM-BEAM EFFECTS STUDY AT VEPP-2000

M. Timoshenko*, V. Borin, V. Dorokhov, O. Meshkov, Yu. Rogovsky, D. Shwartz, Yu. Zharinov
BINP SB RAS, Novosibirsk, Russia

Abstract

The comprehensive development of beam longitudinal profile measurement systems based on stroboscopic optical dissector has started at VEPP-2000 electron-positron collider complex. The dissector was setted and commissioned at booster ring BEP that was deeply upgraded (2013-2015) to achieve top energy of 1 GeV. Bunch lengthening with current was studied at BEP with its new RF-cavity. In addition the method of synchrotron frequency measurement by dissector was applied. After dissector checkouts at BEP the similar studies were carried out with a single beam at VEPP-2000 storage ring in parallel with streak-camera measurements. Good agreement of results was observed. Series of single-turn longitudinal and vertical bunch profiles snapshots was made by streak-camera with respect to delay after counter beam injection. The unexpected longitudinal beam dynamics was observed for intensities above the beam-beam threshold. These studies together with beam-beam coherent oscillations spectra seen by pickups are of a great interest for understanding of flip-flop phenomenon which establish a fundamental luminosity limit at VEPP-2000 operating with round beams.

INTRODUCTION

The VEPP-2000 is a collider complex which mean parts are electron-positron booster BEP and collider VEPP-2000 with two detectors CMD-3 and SND [1]. After modernization BEP energy range began to be from 200 MeV to 1 GeV. It and BEP parameters are described in [2]. The experiments at the collider VEPP-2000 has become possible in this energy range without acceleration.

To achieve luminosity project value 10^{32} cm^{-1} s^{-1} the comprehensive beam monitoring system is required. There was no longitudinal beam distribution monitoring system. Its observation gave more full understanding of colliding beams nature.

MEASUREMENT SYSTEM AT BEP

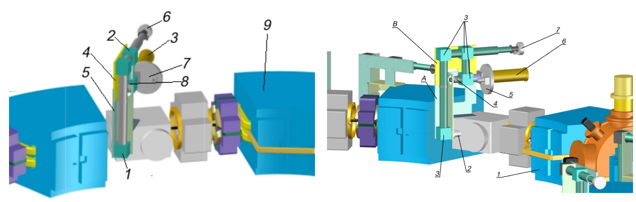
Electron and positron booster BEP are needed for portioned storaging of particles supplied by Injection complex VEPP-5 [3] at 395 MeV energy. After storaging enough intensity of beams following accelerating (changing beam energy) and injection at collider VEPP-2000 occur. At the accelerating regime BEP work at the energy range from 200 MeV to 1 Gev. Operating with different sort of particle is possible due to polarity reverse of magnet systems.

BEP synchrotron radiation spectrum contains optical range and its spectrum power maximum is around 30 nm. Beam motion is strictly periodical. These factors allow to use synchrotron radiation in optical diagnostic system. BEP have several outputs of synchrotron radiation but all are used. For these reason one of it was upgraded.

The system of longitudinal charge distribution of beam (dissector) was set and tested at BEP at first.

Optical Table Modernization

The task of modernization conclude in to save current beam transverse position monitor (CCD-camera) functional. For realization it and duplicating light of synchrotron radiation semitransparent mirror was setted in optical table tract. Yellow part of table and mirrors at the Fig. 1 is added in the modernization.



a) b)

Figure 1: Concept of modernization. Optical table before modernization a), and b) — after modernization.
1— bending magnet, 2— sync. rad. output, 3— cubes with moving mirrors, 4— calibration light source, 5— light filters, 6— dissector, 7— CCD-camera.

Alignment of Optical Table

After production necessary details and realization of optical table concept it was aligned outside BEP room with using portable CCD-cameras. The task was to pointing and focusing precisely simulation of synchrotron radiation light on the places where the real devices (CCD-camera and dissector) should be setted.

After preliminary alignment the optical table with both devices was installed to BEP synchrotron radiation output Fig. 2 and the final tuning was completed with very low intensity beam (around 100 μA) in the BEP.

DISSECTOR

Dissector is a optical stroboscopic device. One of the way of applying it is registration longitudinal distribution of beam charge in a circular accelerators where the beam motion is strictly periodical. The synchrotron radiation light

* email address: tim94max@gmail.com

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPA18

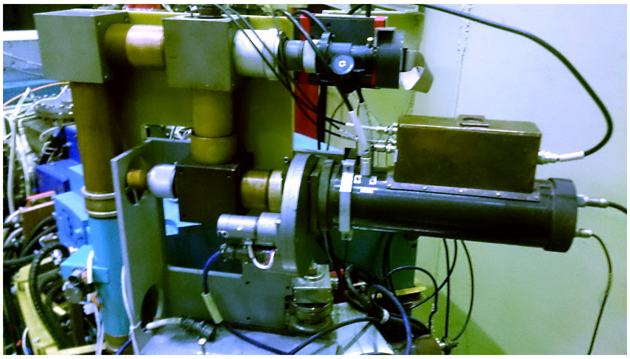


Figure 2: Optical table on the BEP

from beam is focused and pointed at the dissector photo-cathode by optical table systems of mirrors and lenses.

Operation Principles

Dissector is the vacuum tube consisting of mean components:

- imagine section
- slit
- multiplier section

Behind photo-cathode in the imagine section focusing, accelerating and deflecting of photo-electrons take place.

Photo-electron cloud emitted from photo-cathode is focused and accelerated by potential differences between a slit plane, photo-cathode and focusing electrode. Then the cloud transform to narrow electron beam.

Photo-electrons beam can be deflected by electrostatic fields between pare of deflection plates. Sum of two voltages are applied to the plates. One of them is sinusoidal *RF sweep voltage* and other is *scan voltage*. RF sweep voltage forms photo-electron image which duplicates temporal distribution of synchrotron radiation light pulse created by circulated beam in accelerator. Scan voltages slowly shifts the image across the slit consistently cutting different narrow part of image from turn to turn of beam.

After transitions over the slit photo-electrons are multiplied by system of dynodes and form output signal at anode of multiplier.

Calibration of dissector is implemented by calibration source of permanent light. Scaling factor and estimation of resolution can be found.

Final formula of input pulse duration is

$$\Delta l = \frac{D}{q}\frac{\sqrt{t^2 - t_0^2}}{T_s}, \tag{1}$$

where $D = 2R$ — average diameter of accelerator, q — ratio RF sweep frequency to revolution frequency, t_0 — width of dissector apparatus function, t — output electrical pulse duration.

You can look for description of dissector principles and calibration more detailed in [4, 5].

For dissector installed at the BEP resolution is 26 ps (or 0.8 cm in spacial dimension).

The Dissector Used at BINP

As the dissector, electron-optical converter LI-602 is used. The voltage divider of multiplier is compactly realized in adapter 2. The oscillatory RF-circuit 5 is necessary because transporting clear sinusoidal harmonic signal with high amplitude through long wire without distortion is impossible task. Furthermore electrical breakdowns in the wire connectors take place. The signal with low amplitude (~50 V) is generated at circuit and there signal with high amplitude (~1 kV) is swung and applied to deflection plates.

Parameters of LI-602: Voltage slit — photo-cathode 10 kV; Voltage slit — focusing electrode 10±1 kV; Max. voltage at deflection plates 2.5 kV; Max. spectrum sensitivity 440 – 470 nm; Multiplier voltage −1.5 – −2.0 kV; Slit width 50 mkm.

BEAM LENGTH

For dissector testing the model of potential well distortion has been selected. The nature of this process is in process of introduction between bunches and accelerator vacuum chamber and all its components (RF-cavity, bellows and other). In this model it was considered that energy spread change insignificantly versus beam intensity.

Distribution of bunch charge is Gaussian for electron-positron accelerators. The bunch length is dispersion of this distribution and is defined in [6] by following formula:

$$\left(\frac{\sigma}{\sigma_0}\right)^3 + \left(\frac{\sigma}{\sigma_0}\right) = -A \cdot \Im\left(\frac{Z}{n}\right)_{\text{eff}}, \; A = \frac{(2\pi R)^3 I_b}{3h\sigma_0^3 U_0 \cos\phi_s}. \tag{2}$$

Software

For measurements by dissector it was necessary to develop software. This program has developed at C++ language in QT — cross-platform application framework and widget toolkit. This program allows to operator of VEPP-2000 complex calibrate dissector and observe results of measurements. Program read data from ADC, operate it and calculate bunch length and also visualize results of calculating values of length and of longitudinal bunch profile registration.

Layout of it is showed at Fig. 3 where there are examples of beam profile and history of length measurements with decreasing of beam intensity.

In realization of program we uses library GSL for automatic fitting of data by Gaussian function and bunch length calculating. Also there is length averaging over time periods and writing them to VCAS — system of data storage at VEPP-2000 complex [7].

MEASUREMENTS AT THE BEP

Three identical dissector measuring systems have been installed at the VEPP-2000 complex. One of them has been installed on the booster BEP and two others have been installed on the VEPP-2000 collider singly for electron and positron beams.

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPA18

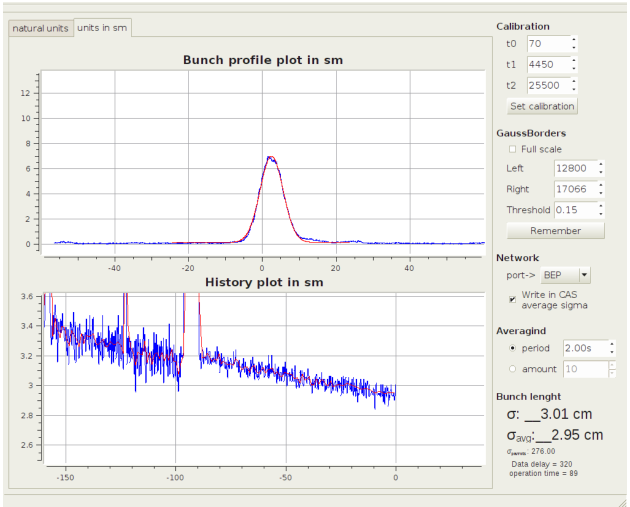


Figure 3: User interface of program

The complex tests of dissector have been done at BEP. Measurements at the BEP:

- Measurement of normalized synchrotron frequency (ν_{s0}) with low intensity of bunch versus RF-cavity voltage has been done (Fig. 4).
- Measurement of bunch length (σ_0) with low intensity of bunch versus RF-cavity voltage (Fig. 5).
- Measurement of bunch length σ versus its intensity with different values of RF-cavity voltage (Fig. 6).

Bunch intensity in the first two measurements is less 100 mkA and we consider that at this intensity measuring synchrotron frequency was $\Omega_{s0} = \nu_{s0} f_0$ (f_0 — revolution frequency) and bunch length was σ_0 (at "null" intensity).

Method of measuring of synchrotron frequency is concluded in switching-off the scan voltage. Then the photoelectron image inside dissector on the slit plane is static but small synchrotron oscillation of bunch causes output signal modulation. In this process distribution slope of photoelectron image should be located opposite slit for better sensitivity. There is function of oscillogram saving by the software and synchrotron frequency is less than ADC speed (around 0.04 MHz versus 2 MHz). These factors allows to make this measurements.

All results are presented at following plots. Theoretical curves are calculated with using known formulas for synchrotron frequency and equilibrium bunch length and also using calculated project parameters of BEP. At the each step little deviations of project parameters are admitted and are corrected according to fitting.

MEASUREMENTS AT THE VEPP-2000 COLLIDER

We has made one series of measurement of bunch length versus bunch intensity by dissector and streak-camera at the same time. The measuring has been done at 387.5 MeV energy which is energy of last approach for experiments at CMD-3 and SND detectors.

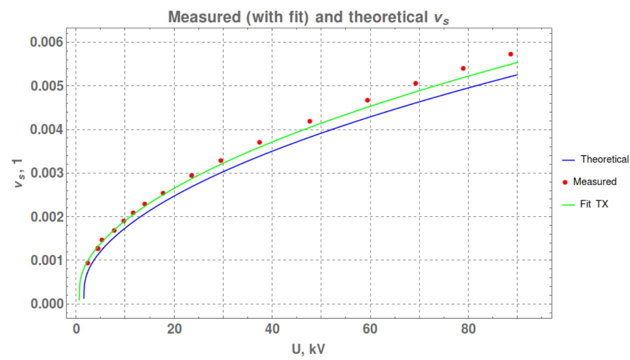


Figure 4: $\nu_{s0}(U)$

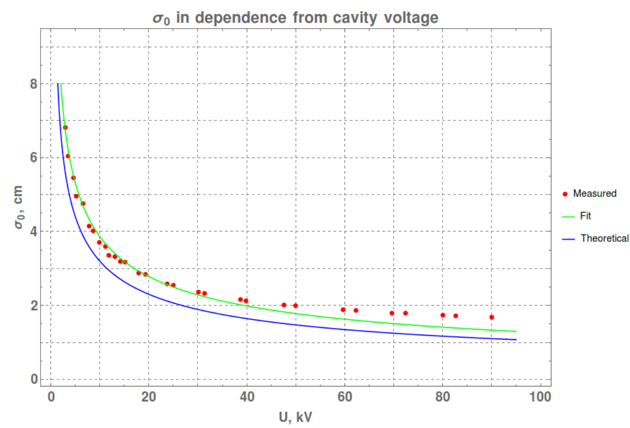


Figure 5: $\sigma_0(U)$

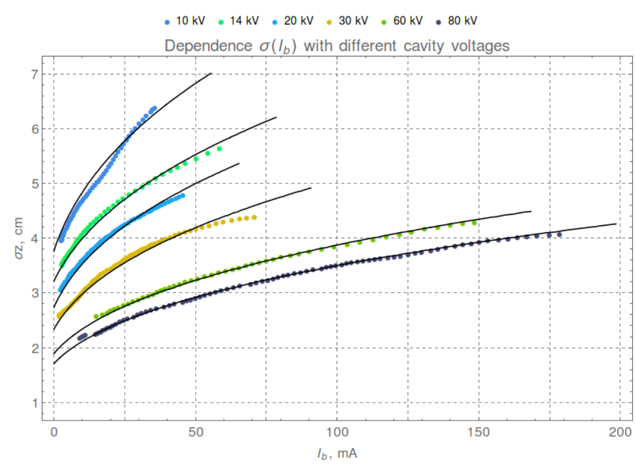


Figure 6: $\sigma(I_b)$

Streak-camera

Streak-camera is useful for observing of dynamical processes through making single-turn snapshot of bunch charge profile in plane ZS (longitudinal and vertical coordinates). The distributions of charge can be obtained by snapshot post-processing.

Principles of streak-camera are similar to dissector and the detailed description you can see in [8]. There are photocathode and deflection plates as in the dissector but instead of multiplier section streak-camera has phosphoric screen

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPA18

and CCD-camera behind it for registration image on screen made by photo-electrons.

Results of it is dependence showed at the following plot at Fig. 7 where the agreement is observed.

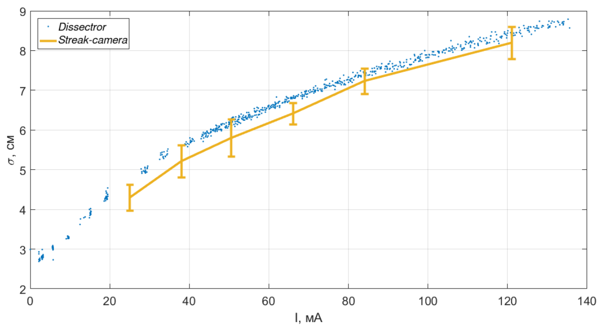


Figure 7: $\sigma(I_b)$

Injection Process Observed by Streak-camera

The number of measurements was made for the observation of the injection processes for the single bunch and for colliding bunches over subsequent 20-80 turns.

Vertical oscillation and size increasing are observed for single electron bunch with bunch intensity I_b 40 mA. Longitudinal shifts are connected with instability of streak-camera starts.

Unexpected results have been obtained at snapshots with different combination of conditions. The snapshots of electron bunch have been made at different turn after injection from the BEP and different intensities of electron and positron bunches (I_{e^-} and I_{e^+}). The head of electron bunch is on the left side of snapshot.

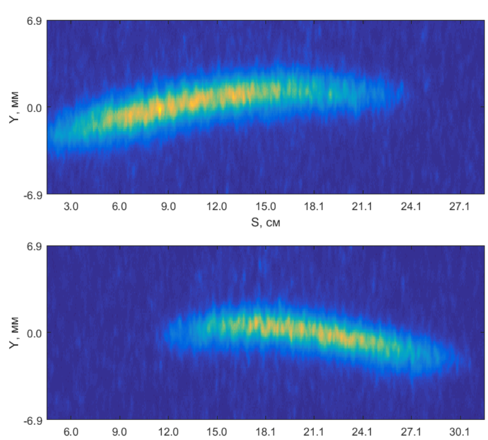


Figure 8: 40th turn, I_{e^-} = 66 mA, I_{e^+} = 45 mA (up), 80th turn, I_{e^-} = 50 mA, I_{e^+} = 40 mA (down).

Injection of the positron bunch has occurred when the electron bunch has circulated (Fig. 8). Almost total loss of injecting positron bunch took place and the intensity of the electron beam did not change significantly.

Injection of the electron bunch has occurred when the positron bunch circulated (Fig. 9). The same problem that the injecting bunch is lost took place.

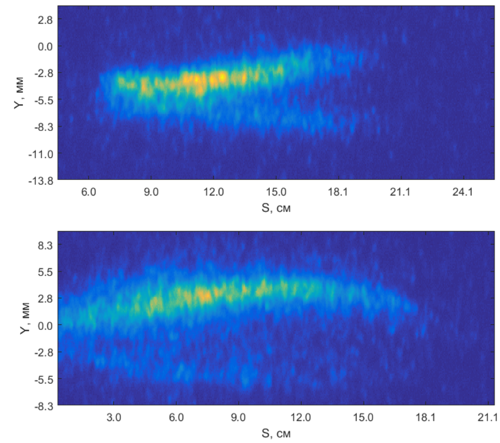


Figure 9: 40th turn, I_{e^-} = 30 mA, I_{e^+} = 66 mA (up), 60th turn, I_{e^-} = 30 mA, I_{e^+} = 64 mA (down).

At the figures we can see vertical tilt of electron bunch influenced interaction with injected positron bunch. After around 40 turns the slope changes its direction. Electron bunch separates to two parts influenced interaction with circulated positron bunch. The current series of measurements is limited by capabilities of time synchronization impulse system.

CONCLUSION

In work season 2017-2018 the longitudinal beam profile diagnostic get comprehensive development. Dissector has been installed at the BEP. For this task optical table at the synchrotron radiation output has been upgraded and aligned. Two more identical dissectors has been installed to VEPP-2000 collider. All dissectors has been calibrated. For using them the special software has been developed. After that these systems has been commissioned by operators of complex VEPP-2000. Also the streak-camera has been installed at VEPP-2000 collider.

Results of joint measurements of bunch length by dissector and streak-camera at the VEPP-2000 collider and comprehensive measurements of bunch length in the BEP in model of potential well distortion show than work of dissector is correct.

Some interesting snapshots of bunch profile showed that streak-camera is very useful device for studying of processes near injection.

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPA18

REFERENCES

[1] D. Shwartz, D. Berkaev *et al.*, "Recent beam-beam effects and luminocity at VEPP-2000", in *Proc. 5th International Particle Accelerator Conference (IPAC'14)*, Dresden, Germany, June 2014, pp. 924–927. doi:10.18429/JACoW-IPAC2014-TUOBA03

[2] D. Shwartz, D. Berkaev *et al.*, "Booster of electron positron (BEP) upgrade to 1 GeV", in *Proc. 5th International Particle Accelerator Conference (IPAC'14)*, Dresden, Germany, June 2014, pp. 102–104. doi:10.18429/JACoW-IPAC2014-MOPRO018

[3] Yu. Maltseva, A. Andrianov *et al.*, "VEPP-5 injection complex: new possibilities for BINP electron-positron colliders", in *Proc. 9th International Particle Accelerator Conference (IPAC'18)*, Vancouver, BC, Canada, Apr. 2018, pp. 371-373. doi:10.18429/JACoW-IPAC2018-MOPMK011

[4] E. I. Zinin and O. I. Meshkov, "Optical dissector for longitudinal beam profile measuremen", *Journal of Instrumentation*, vol. 10, p. 10024, Oct. 2015, doi:10.1088/1748-0221/10/10/P10024

[5] O. I. Meshkov, E. I. Zinin *et al.*, "Development, calibration and application of new-generation dissector with picosecond temporal resolution", in *Proc. 7th International Particle Accelerator Conference (IPAC'16)*, Busan, Korea, May 2016, pp. 251–254. doi:10.18429/JACoW-IPAC2016-MOPMR013

[6] B. Zotter, "The effective coupling impedance for bunched beam instabilities", CERN, Geneva, Switzerland, Rep. CERN-ISR-TH-78-16, Jul. 1978.

[7] A. Senchenko, D. Berkaev *et al.*, "VEPP-2000 collider control system", in *Proc. 9th International Workshop on Personal Computers and Particle Accelerator Controls (PCaPAC'12)*, Kolkata, India, 2012, Dec. 2012, paper FRCB04, pp. 263-274.

[8] A. Chao and M. Tigner, *Handbook of accelerator physics and engineering. 2nd Printing*. Singapore: Mainland Press, 1999.