LONGITUDINAL BEAM PROFILE DIAGNOSTIC SYSTEM AT BOOSTER OF ELECTRONS AND POSITRONS BEP

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Abstract

The longitudinal beam profile measurement system based on optical dissector was upgraded at booster synchrotron BEP during VEPP-2000 collider complex 2017/2018 data taking run. New RF cavity of 13-th harmonic was installed during the booster upgrade in 2013-2015 to increase top energy to 1 GeV. The complex work on synchrotron radiation output modernization was performed, and measurement system was commissioned. The system was tested and calibrated, the resolution was studied. The bunch length dependence was measured for different RF cavity voltages while beam current changes and compared with the potential well distortion model. Good agreement with theory proved system operability. In addition the results of bunch length current dependence obtained by dissector at VEPP-2000 collider were compared with streak-camera measurements being in a good agreement. The synchrotron tune dependence on RF cavity voltage was measured both at BEP and VEPP.

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 at this energy range without energy increasing in it.

Before this work longitudinal beam distribution monitoring system wasn't used. Observation of this distribution can give more full understanding of beams nature in the booster and collider of VEPP-2000 complex.

MEASUREMENT SYSTEM AT BEP

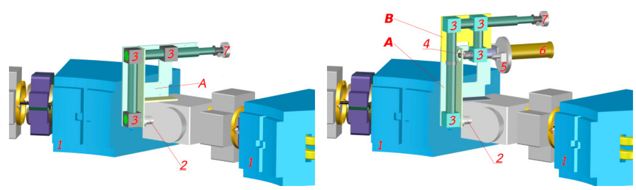
Electron and positron booster BEP are needed for portioned storaging of particles supplied by Injection complex VEPP-5 [3] at 395 MeV energy. At the accelerating regime BEP works at the energy range from 200 MeV to 1 Gev. Operating with different sort of particle is possible due to polarity reverse of magnet systems.

BEP synchrotron radiation spectrum contains optical range and 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 of them are used. For this reason one of them has been upgraded.

The longitudinal beam charge distribution measurement system (dissector) has been installed and tested at BEP at first.

Optical Table Modernization

The task of modernization concluded in to save current beam transverse position monitor (CCD-camera) functional. Duplication light of synchrotron radiation has been applied by semitransparent mirror set in optical table tract. Yellow part of table (with some mirrors cube and dissector components) at the Fig. 1 has been added during modernization.



a) b)

Figure 1: Concept of modernization. Optical table before a) and after b) modernization.
1 – bending magnet, 2 – sync. rad. output, 3 – cubes with moving mirrors inside them, 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 has been aligned outside BEP room with using portable CCD-cameras. The task was to precisely pointing and focusing[1] of light from simulation of synchrotron radiation source on the places where the real devices (CCD-camera and dissector) should be set.

After preliminary alignment the optical table with both devices have been installed to BEP synchrotron radiation output and the final tuning has been 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 of longitudinal distribution of beam charge in a circular accelerators.

Operation Principles

Dissector is the vacuum tube consisting of mean components:

- photo-cathode

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[1] There are system of lenses in the optical tract

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- imagine section
- slit
- multiplier section

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

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

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

Scaling factor between dissector output signal and input light pulse and also resolution can be found analyzing of output signal from permanent light source.

Final formula of input synchrotron radiation pulse duration is

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

where t - output electrical pulse duration, $D = 2R$ - average diameter of accelerator, q - ratio RF sweep frequency to revolution frequency, t_0 - width of dissector apparatus function, T_s - width of output signal from calibration light source [2].

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

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

Alternative way of dissector using is synchrotron radiation measurement. This measurement may be possible if to turn off scan voltage. Then the synchrotron oscillations produce modulation of output signal.

The Dissector Used at BINP

As the dissector, electron-optical converter LI-602 was used (1 at Fig. 2).

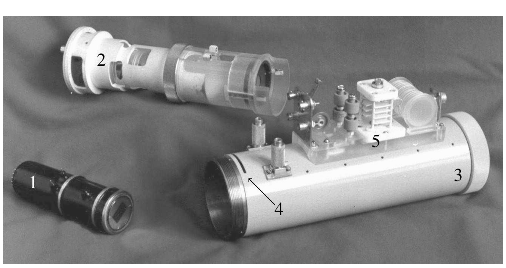

Figure 2: Dissector LI-602 used in BINP

[2] formula (1) is for case when dissector apparatus function and beam charge distribution are Gaussian functions

The resistive voltage divider of photo-electrons 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 tripled revolution frequency ($q = 3$) signal with low amplitude ($\backsim 50\ V$) is generated at circuit and there signal with high amplitude ($\backsim 1\ kV$) is swung and applied to deflection plates.

Parameters of LI-602: Voltage slit – photo-cathode 10 kV; Voltage slit – focusing electrode $10 \pm 1\ kV$; Max. voltage at deflection plates 2.5 kV; Max. spectrum sensitivity $440 - 470\ nm$; Multiplier voltage $-1.5 \div -2.0\ kV$; Slit width 50 μm.

BEAM LENGTHENING

For dissector tests 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 accepted that energy spread is constant when beam intensity varies.

Charge distribution of one bunch is Gaussian for electron-positron accelerators. The length of a bunch is understood as the standard deviation σ of the distribution and is defined in [6] by following formula:

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

where R - is average orbit radius, I_b - bunch intensity (average current), U_0 - RF cavity voltage, ϕ_s - equilibrium phase of bunch longitudinal motion in RF cavity, h - RF cavity harmonic of revolution frequency f_0. $sigma_0$ - bunch length when the intensity is very low and described effect is significant (at "null" intensity).

MEASUREMENTS

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 application allows operator of VEPP-2000 complex to calibrate dissector and observe results of measurements. Application operates data from ADC, calculates bunch length and visualizes results of longitudinal bunch profile registration and also writes the history of bunch length measurements.

In realization of application we used library GSL for automatic fitting. Also there is writing bunch length values to VCAS — system of data storage at VEPP-2000 complex [7].

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Measurements at the BEP

The complex tests of dissector have been done at BEP. Measurements have been made at 395 MeV energy in single-bunch mode:

- normalized synchrotron frequency (ν_{s0}) versus RF cavity voltage (Fig. 3).
- bunch length (σ_0) bunch versus RF cavity voltage (Fig. 4).
- bunch length σ versus its intensity with different values of RF cavity voltage (Fig. 5).

Bunch intensity in the first two measurements is less then 100 μA (7.5 nC) and we consider that measured synchrotron frequency was $\Omega_{s0} = \nu_{s0} f_0$ and bunch length was σ_0 (at "null" intensity).

Theoretical curves are calculated with using known formulas for synchrotron frequency and equilibrium bunch length and also using calculated project parameters of BEP. Little deviations of project parameters were admitted and were corrected according to fitting.

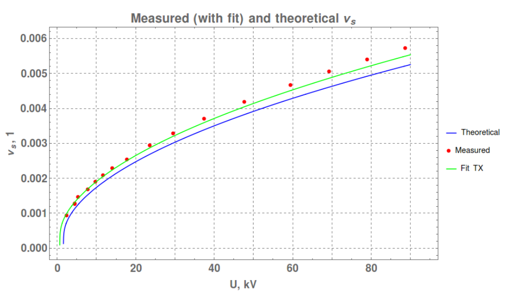

Figure 3: $\nu_{s0}(U)$

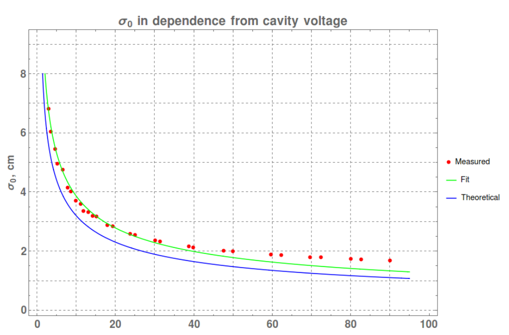

Figure 4: $\sigma_0(U)$

Measurements at the VEPP-2000 collider

Two the same measurement system with using dissector have been installed at VEPP-2000 collider. And the same results of measurements of synchrotron radiation and bunch length has been obtained.

We has made one series of measurement of bunch length versus bunch intensity by dissector and streak-camera at the same time [9]. The measuring has been done at 387.5 MeV energy.

Streak-camera is useful for observing of dynamical processes through making single-turn snapshot of bunch charge profile. The distributions of charge can be obtained by snapshot post-processing.

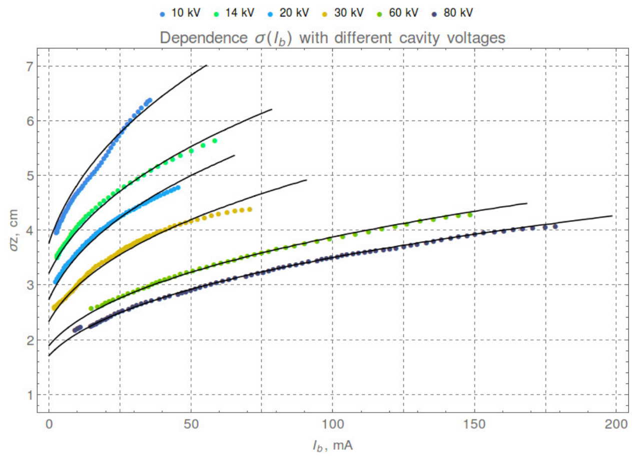

Figure 5: $\sigma(I_b)$

Principles of streak-camera are partly similar to dissector and the detailed description you can see in [8]. Instead of multiplier section as in dissector streak-camera has phosphoric screen and CCD-camera behind it for registration image on screen made by photo-electrons.

Results of measurements of single electron bunch length in VEPP-2000 collider are showed at the following plots at Fig. 6 where the agreement is observed.

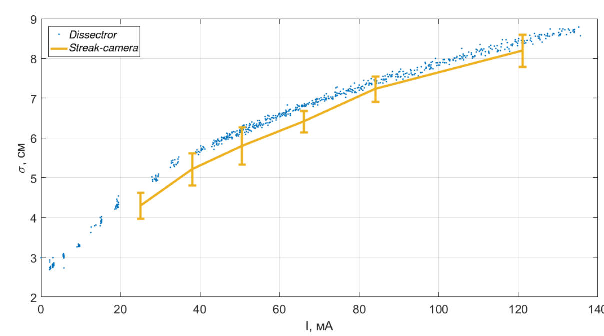

Figure 6: $\sigma(I_b)$

CONCLUSION

In work season 2017-2018 the longitudinal beam profile diagnostic get comprehensive development. Dissector has been installed at the BEP. Two more identical dissectors have been installed to VEPP-2000 collider. All dissectors have 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.

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 have been done.

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