TRANSVERSE BEAM PROFILE MEASUREMENT AT THE VEPP-4M COLLIDER

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Abstract

A visible part of the synchrotron radiation from the bending magnets is used at the VEPP-4M collider to control the radial and vertical sizes of the electron and positron beams. The light density distribution is measured by the digital CCD camera. It is created on the basis of SONY ICX084AL CCD sensor and 14 bit signal processor AD9822 and equipped with fast 100M ethernet interface, allowing to connect a set of devices to a host computer. The distance between a host computer and CCD camera may reach 200 m. One frame readout takes about 0.08 s. Developed software works under Linux OS and provides constant monitoring and recording of the beam profile and position.

1 INTRODUCTION

The electron-positron collider VEPP-4M [1] consists of 2 semi-rings with the average radius $R = 58.3\ m$ and two straight sections (see Figure 1). Together with the KEDR [2] detector the VEPP-4M complex operates now in the energy range 1500-1850 MeV, performing the presize mass measurement of $J/\psi(1S)$, $\psi(2S)$ mesons [3].

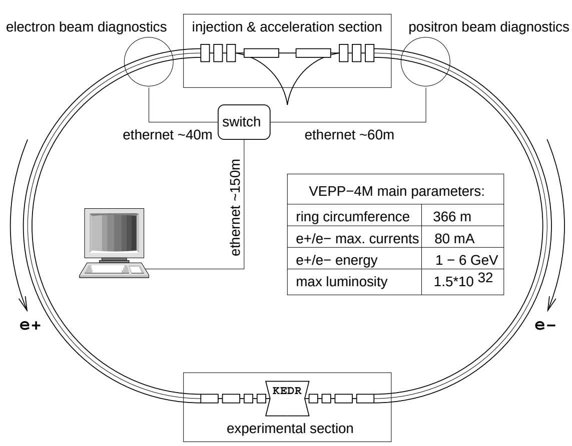

Figure 1: Layout of the VEPP-4M complex with main operation parameters. The placement of the optical diagnostics areas (Figure 2) are shown with circles.

2 LAYOUT OF THE OPTICAL SYSTEM

The optical beam diagnostic system [4] provides the information about the beams dimensions, controls the relationship of the bunch currents and is employed for studying the coherent oscillations of the beams. Two channels of the synchrotron radiation (SR) output are located in the bending magnets of the semi-rings (Figure 1), each channel outputs a radiation of the electron or positron beam only. Both channels are equipped with practically identical diagnostic systems, shown on Figure 2.

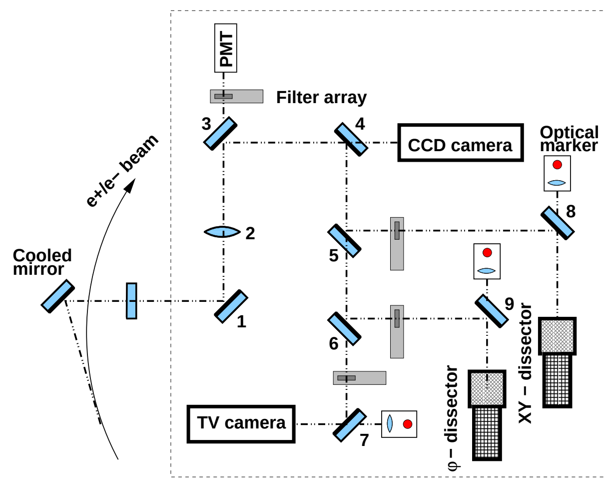

Figure 2: Layout of the optical diagnostic system.

A visible part of the SR is reflected from the cooled metallic mirror and leaves the VEPP-4M vacuum chamber through a glass window. Mirror 1 matches the SR ray with an optical axis of the system. The beam image is formed by lens 2. Remotely controlled neutral filter arrays expand the dynamic range of the system. The XY-dissector with electromagnetic focusing and deflection is used for radial and vertical beam dimension measurements and fot studing the collective effects in the beam. A part of the light, passing through the semi-transparent mirror 5, is used for measurement of the longitudinal size of the beam by the φ-dissector. The radial and vertical beam sizes at the point of the measurement, obtained by simulations for the electron beam energy $E = 1550\ MeV$, are: $\sigma_Y = 0.1\ mm$, $\sigma_X = 0.5\ mm$, $\sigma_S = 35\ mm$.

3 DIGITAL CCD CAMERA WITH FAST ETHERNET INTERFACE

Recently, the diagnostic was supplemented by the digital CCD camera with fast 100M ethernet interface. It is based on Sony ICX084AL CCD sensor and 14 bit signal processor AD9822. ICX084AL has progressive scan that

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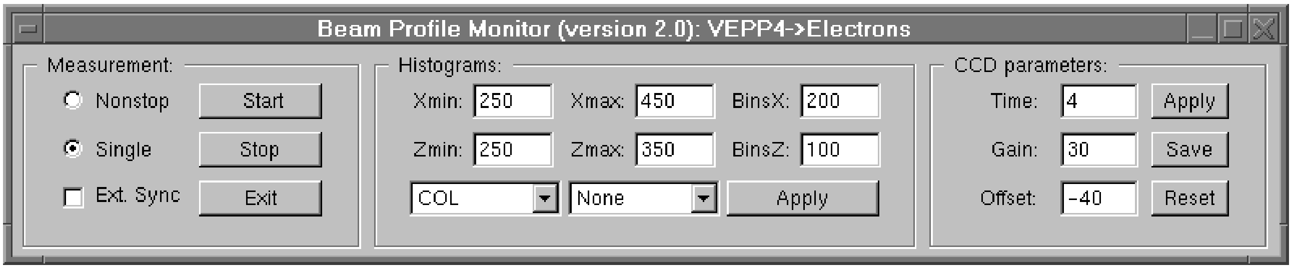

Figure 3: The mesurement program control window.

allows all pixels signals to be output independently within approximately 1/30 second, it also features an electronic shutter with variable charge-storage time. As a result we have the device with the following parameters:

Table 1: The CCD camera main parameters

Parameter	**Value**
Dimensions	$125 \times 92 \times 35$mm box
Image size	diagonal 6mm
Effective pixels	659×494
Total number of pixels	692×504
Chip size	5.84 mm $\times$ 4.94 mm
Unit cell size	7.4 μm $\times$ 7.4 μm
Charge storage time	1/10000 s up to 1/30 s
Output	digital, 14 bit
Interface	100M twisted pair ethernet
Frame readout time	80 ms (approx)
Operation modes	continuous, single frame
Synchronization	internal or external
Power supply	+8V; +20V; -12V

3.1 *Low level communication protocol*

The devices are connected to the ethernet card in a host computer via a hub, forming a stand-alone LAN. Each device has unique network address, a simple communication protocol was developed and now it possesses the following basic functions:

Packets to the device may contain the following instructions:

- modification of the charge storage time and the AD9822 signal processor parameters (operation mode, gain, offset, etc.);
- request for a frame with an internal or external synchronization.

3.2 *Software*

The designed software works under Linux OS. It uses low-level sockets to communicate with the CCD devices and CERN GUI libraries of the ROOT system [5]. It possesses an interactive interface to control the CCD camera operation, and graphical visualisation of the results of the measurements. The view of the measurement program control window is shown on Figure 3, and the example of electron beam SR light density distribution is shown on Figure 4.

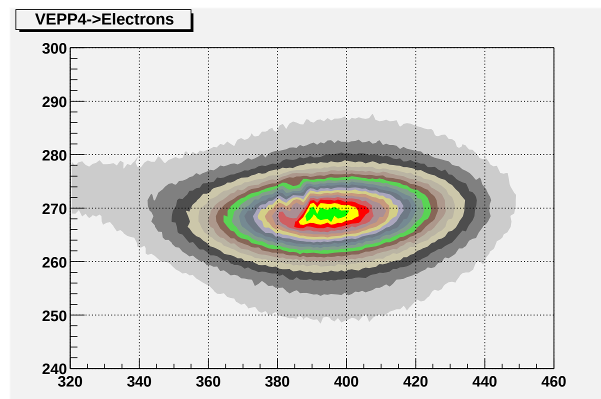

Figure 4: Light density distribution from the CCD camera.

The visualization is also provided for the radial and vertical projections of the beam image and the numerical values of FWHM and fitting parameters.

4 SPATIAL RESOLUTION

Accuracy of the transverse beam size determination is restricted by the angular divergency of SR at the wavelength of the measurement ($\lambda \approx 5000$Å) [6]: $\sigma_{X,Y}\ [mm] \approx 0.3 \cdot 10^{-4} \cdot \lambda^{2/3}\ [\text{Å}] \cdot R^{1/3}\ [m] \approx 0.03\ mm$. The distance between the radiation point and the lens 2 (Figure 2) is equal 3210 mm, thus the lens aperture should exceed 40 mm, in order to neglect the diffraction contribution to the spot size. The optical slit of $0.05\ mm$ width, illuminated by the white light, was applied as a test object. The R.M.S. of the instrumental function of the optical system, excluding the components located inside the vacuum chamber, was found to be $\sigma = 0.06\ mm$ (Figure 5). The scale factor of the optical system was determined by applying the rectangular grid as the test object and was found to be $d_p = 0.0225 \times 0.0225\ mm$. The FWHM of the instrumental function covers nearly 7 pixels, hence the instrumental error of the diagnostic can be estimated as $\Delta\sigma \approx d_p/\sqrt{7} \approx 0.007\ mm$. Apparently, if required, the spatial resolution can be approved through using the components with the better optical quality. Nevertheless, the available value is sufficient to control the beam dimensions and to tune the accelerator.

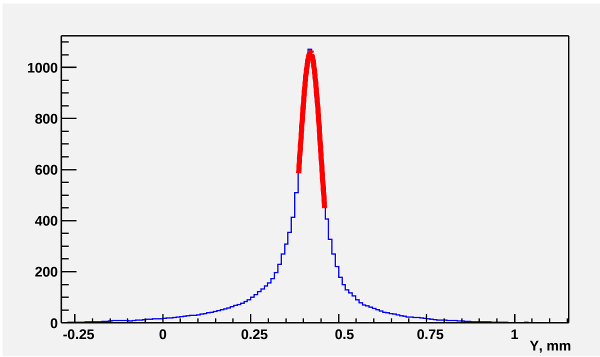

Figure 5: The image of the optical slit of 0.05 mm width.

5 THE DIAGNOSTIC APPLICATION FOR THE COLLIDER TUNING

The distinguishing feature of the VEPP-4M collider is the non-zero dispersion function ($D_X \approx 70cm$) in the interaction point, so that the radial beam size is mostly determined by the energy spread in the beam. The pair of gradient wigglers are symmetrically located in the injection and acceleration straight section (Figure 1), where the dispertion function $D_X \approx 80\ cm$. Alteration of the wigglers currents allows to redistribute the damping partitions between the radial and longitudinal oscillations in the beam, that influence the ratio of the synchrotron and betatron components in the radial beam size at the interaction point. For the wigglers current of $WG = 940\ A$ the radial and longitudinal damping partitions are $J_X = 2$ and $J_S = 1$, respectively, and the beam size in the interaction point increases, raising the luminocity and the critical current, restricted by the beam-beam effects.

For the presize measurement of the $J/\psi(1S)$ and $\psi(2S)$ mesons masses, the accelerator is set up to operate with the reduced energy spread in order to minimize the systematic errors in the mass measurement [3], originating from the D_X and β_X functions chromaticities ($WG = 620\ A$, $J_X = 1$, $J_S = 2$).

The presize measurement of the radial beam size by the CCD camera allows to control the collider tuning by comparing the measured parameters with the simulation. Figure 6(A) represents the measured radial beam size σ_X versus the beam energy shift (the circulation frequency was varied) at two different values of the wigglers current. The same dependencies for the energy spread $\sigma_{E,\delta}$, measured by the φ-dissector [4], are shown on Figure 6(B). Figure 6(C) represents the behavior of the radial emittance ε_X, restored from the known values of D_X and β_X in the point of measurement, and measured values of σ_X and $\sigma_{E,\delta}$. The results are in a good qualitative agreement with the simulation predictions for the enrgy dependencies of $\sigma_X, \sigma_{E,\delta}, \varepsilon_X$.

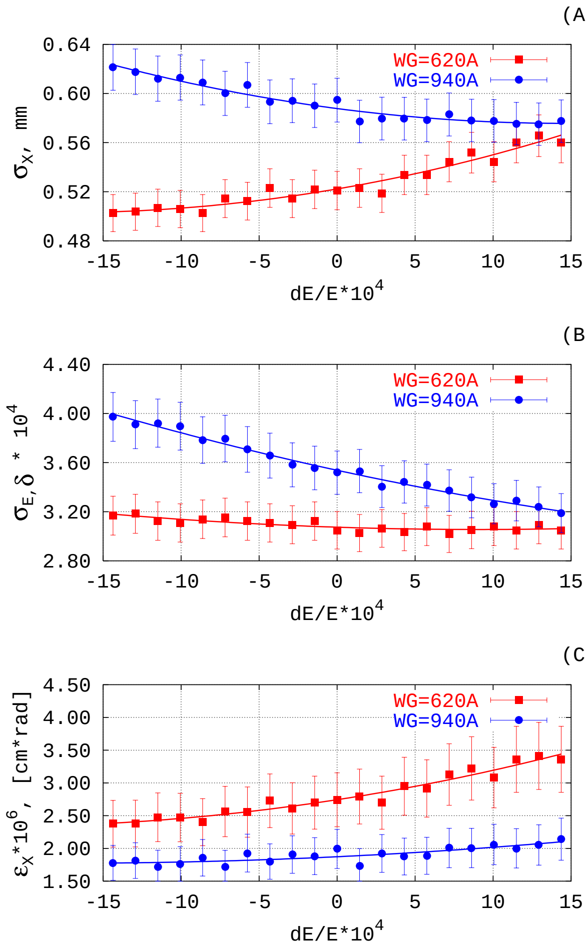

Figure 6: Experimental results.

6 CONCLUSION

The transverse beam profile diagnostic is described. The spatial resolution and the sensitivity of the diagnostic satisfy the experimental requirements. The diagnostic provides on-line information about transverse electron and positron beams dimensions and their centre of gravity. These data are effectively applied for tuning and studying the machine.

7 REFERENCES

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