MULTI-PINHOLE CAMERA FOR BEAM POSITION AND VERTICAL ANGLE STABILIZATION

O.I. Meshkov[#], A.N. Zhuravlev, Budker Institute of Nuclear Physics, Novosibirsk, Russia
[#]Novosibirsk State University, Novosibirsk, Russia

Abstract

The VEPP-4M electron-positron collider is now operating with the KEDR detector for the experiment at the energy area between 1100 – 3000 MeV. In these experiments, monitoring of beam coordinates and angles at the interaction point is important for energy stabilization. BPM system of VEPP-4M doesn't provide the reliable information about beam orbit when machine operates as a collider. The diagnostics, described in this paper, is a good supplement for BPM data. The vertical coordinate and angle of the beam can be measured and stabilized at two points that are placed symmetrically relative to the beam interaction point. The precision of the measurements and the collider energy accessible for the diagnostics are discussed.

INTRODUCTION

The basic physical program of the VEPP-4M collider [1] consists in precise measurements of mass of $J/\psi, \psi', \psi''$ narrow resonances and $c-\tau$ lepton mass on the threshold production. Besides it, the nearest experimental program of the collider includes the scanning of the area from 1100 to 3000 MeV for measurement of the cross section $e^+/e^- \to$ hadrons.

All these experiments require the precise control of the collider energy. Compton Back Scattering (CBS) [2], Fig.1 is applied on VEPP-4M for this purpose.

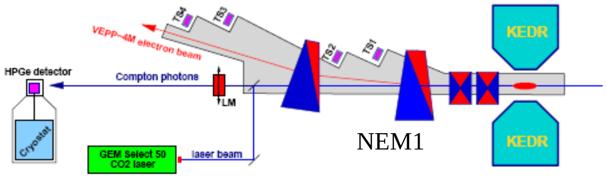

Figure 1. Experimental setup of CBS. The distance of the HPG detector from the interaction point is about 16 m. NEM1 – the bending magnet. The SR of electron beam from this magnet is used for the pinholes. The distance from NEM1 to the interaction point is about 7 m.

The stabilization of the bunch on the x, y coordinates and vertical angle at the segment of the orbit, where laser interacts with the particle beam, is necessary for the reliable operation of the CBS. BPM system operating on VEPP-4M doesn't provide the required accuracy when the accelerator operates as a collider. It is connected with outdated electronics of the pick-up electrodes, which doesn't separate e^+ and e^- beams precisely.

Multi-pinhole camera, described in this paper, is able to stabilize the orbit on the x, y coordinates and the vertical angle. The synchrotron radiation from two bending magnets placed symmetrically relative to the interaction point at the distance of 7 m is applied for that (Fig. 1). Only the "electron shoulder" of the diagnostics is under operation now.

BASIC PRINCIPLES OF THE DIAGNOSTICS

Functional concept of the camera obscura is known from the 18th century. This diagnostics is widely applied on the electron/positron ring accelerators for measurement of the beam dimensions [3], Fig.2.

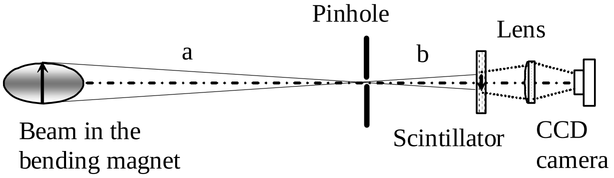

Figure 2. Typical layout of the pinhole camera; a – the distance between the beam and pinhole; b – the distance between pinhole and scintillator.

Pinhole lets the X-ray part of the SR through and CCD camera records the image of the beam created on the scintillator.

Camera obscura gives the possibility to determine the inclination of a beam relative some reference position also; but few vertically aligned pinholes, separated at the distance of about $3\sigma_y$, should be applied for that. The distance between exterior pinholes should be about $3a\psi$, where ψ is the divergence of SR. Both the shift and the inclination of the beam can be determined from the shift of the single beam image relative to the reference position and the shift of the envelope of all of the beam images (Fig. 3).

Let d be a vertical shift of a beam (Fig. 3, case *II*) and $e = a \cdot \varphi$ be a shift of the SR cone on the multi-pinhole caused by the inclination of the beam by a vertical angle φ (Fig.3, case *III*). Overlay of the beam images created by the pinholes provides the distributions presented in Fig. 4. Merely vertical shift of a beam without the inclination results in the shift as images as the envelope of them at the distance of $d1 = -d\frac{b}{a}$ (Fig.4, case *II*).

The inclination of a beam merely in the vertical plane without the vertical shift ($d = 0$) will lead only to the shift of the envelope of the beam images by value $e1 = a \cdot \varphi$; the images of the beam will not shift (Fig.4, case *III*). Hence, the algorithm for determination of the angle of inclination and linear shift of a beam is the following:

- The shift of the beam images is determined: $d1$
- The shift of the envelope of the beam images is determined: $e1$

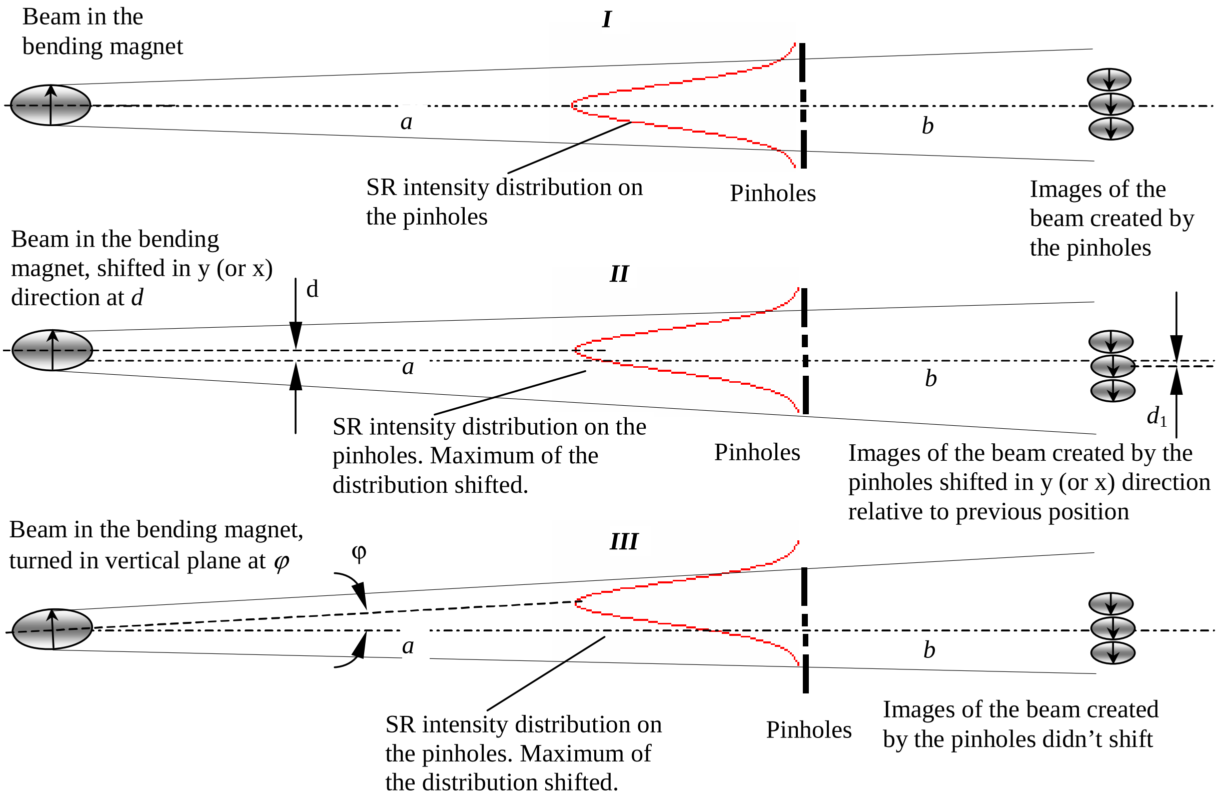

Figure 3. Three cases of the illumination of the multi-pinhole camera are presented. ***I*** – the reference position. The SR cone is symmetrical relative to the central pinhole and the central image is the most bright. ***II*** – the beam is vertically shifted about *I* at the distance *d*. ***III*** – the beam is inclined about *I* by the angle φ, but the shift $d = 0$.

- The linear shift of the beam is determined: $d = -d1 \cdot a/b$
- The inclination of the beam is determined: $\varphi = (e1 \pm d)/a$

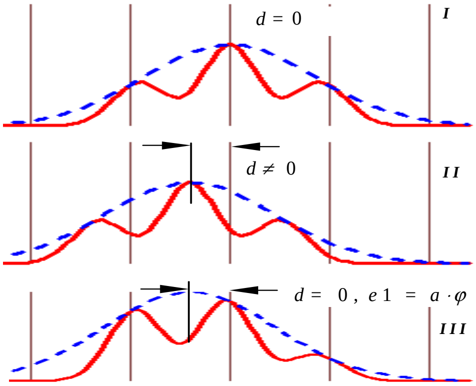

Figure 4. Distribution of the beam profiles, corresponding to the cases *I*, *II*, *III* in Fig. 3.

Sign "+" corresponds to case $e1 < d$, sign "-" corresponds to case $e1 > d$.

ACCURACY OF THE MEASUREMENTS

Accuracy of the determination of *x*, *y* coordinates of the beam depends on the precision of the CCD camera measurements.

If the beam image on the CCD matrix has a size σ_y and this value corresponds to *N* pixels so the accuracy is $\sigma_0 \approx \sigma_y / \sqrt{N}$ for Gaussian beam distribution $n(y) = n_o \exp(-(y/\sigma_y)^2)$.

The size d_p of the pinhole should be taken into account as well. It corresponds to the size of $d_p' = \frac{a}{b} d_p$ at the radiation point.

For VEPP-4M we have $\sigma_y \approx 150$ mkm, $N \approx 30$, so $\sigma_0 \approx 30$ mkm and $d_p \approx 30$ mkm, so $d_p' \approx 60$ mkm. As a result, the precision of the beam shift measurement is about 40 mkm. It corresponds to the accuracy of $7 \cdot 10^{-6}$ rad for measurement of the inclination of the beam, $a = 6$ m, $b = 3$ m.

ENERGY AREA, ACCESSABLE FOR THE MEASUREMENTS

Synchrotron radiation from the bending magnet leaves the vacuum chamber of the collider through the beryllium foil with thickness of 200 mkm. It means, that only γ-quanta with the energy over 3 keV can be registered. It restricts the energy area in which the diagnostics can be applied. Fig. 5 demonstrates the SR spectra from the bending magnet NEM1 calculated with account of the transparency of beryllium foil. The diagnostics provides the reliable measurements at the energy over 1800 MeV because of a small solid angle of the pinhole ($\Omega_p \approx 6 \cdot 10^{-6}$ sterrad).

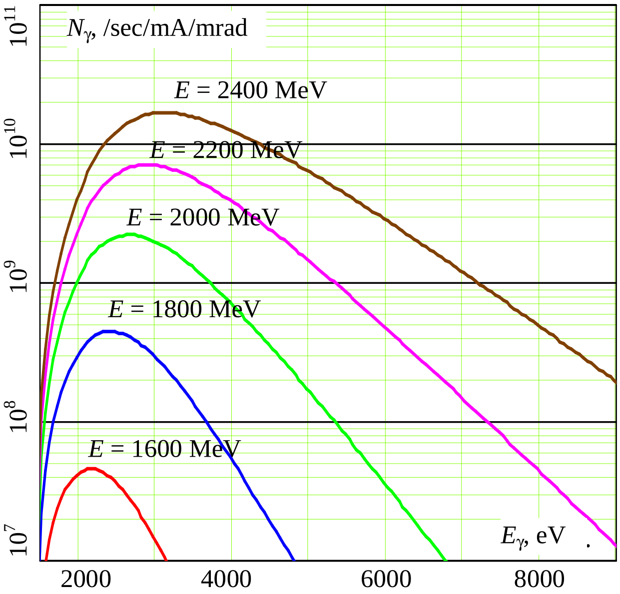

Figure 5. The computed SR spectra for different energies of VEPP-4M. The bandwidth is 0.1 %. The radius of the beam orbit in the bending magnet NEM1 is $R = 18$ m. The transparency of the separating beryllium foil is taken into account.

EXPERIMENT

At the present time the diagnostics is assembled at the “electron” direction of VEPP-4M and the first images of the e^- beam are recorded (Fig. 6).

Synchrotron radiation from the bending magnet has such a spectrum that it is absorbed in the air at the distance of about 1.5 m. Because of that we apply the vacuumed tube to deliver the radiation to the pinholes and *ZnS* scintillator.

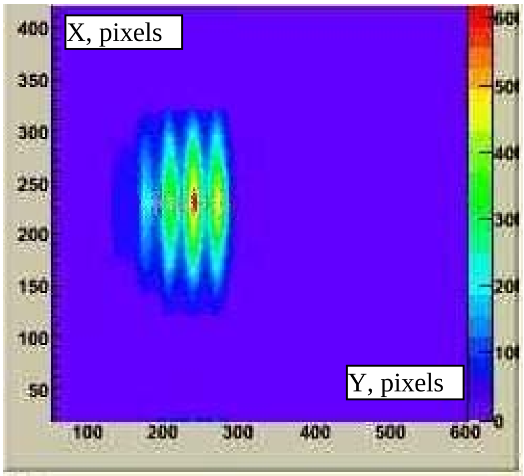

Figure 6. The images of the beam created with the multi-pinhole camera. $E_b = 1852$ MeV, beam current $I_b = 2$ mA.

Beam images from the scintillator are recorded with the CCD camera. Software of the diagnostics enables determination of the local maxima of the image and the envelope of them.

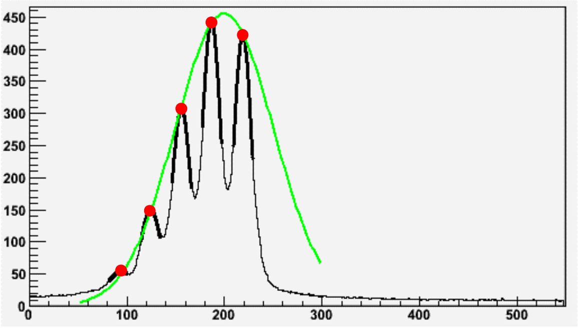

Figure 7. Integral projection of the beam images on the Y axis. The maximum of each image determined with the software is marked with the filled circle. The envelope of the maximums is shown.

Long-term measurements of the stability of the beam coordinates and inclination will be taken during the nearest collider run.

REFERENCES

[1] V.Anashin e.a VEPP-4M Collider: Status and Plans //Proc. of the 6-th European Particle Accelerator Conference, Stockholm, 22-26 June, 1998, vol.1, p.400-402

[2] N. Muchnoi, S. Nikitin, V. Zhilich. Fast and Precise Beam Energy Monitor Based on the Compton Backscattering at the VEPP-4M Collider//. *Proceedings of EPAC 2006*, Edinburg, Scotland, TUPCH074

[3] CERN Accelerator School «Synchrotron radiation and free electron lasers», CERN 98-04, p. 303.