BEAM MEASUREMENTS WITH VISIBLE SYNCHROTRON LIGHT AT VEPP-2000 COLLIDER*

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Abstract

This paper describes beam diagnostics at VEPP-2000 collider, based on visible synchrotron light analysis. These beam instruments include: SR beamline and optics; acquisition tools and high resolution CCD cameras distributed around the storage ring to measure the transverse beam profile and its position in vacuum chamber; photomultiplier tubes (PMT) which enables beam current measurements; video system. Some applications of these measurement systems and their measurement results are presented.

INTRODUCTION

The new electron-positron collider VEPP-2000 ring is a part of VEPP-2000 complex [1, 2] at BINP has been successfully commissioned and has been delivering luminosity at energy close to 508 MeV since June 2007. VEPP-2000 is a new machine with luminosity up to 10^{32} cm^{-2}s^{-1} and the beam energy from hadron production threshold up to 2×1 GeV. Small ring size and sophisticated optics lay on limitation on beam quality and operations. Therefore such modern machines requires various beam diagnostics for perfect tuning and ask us to monitor the beam status quickly and accurately.

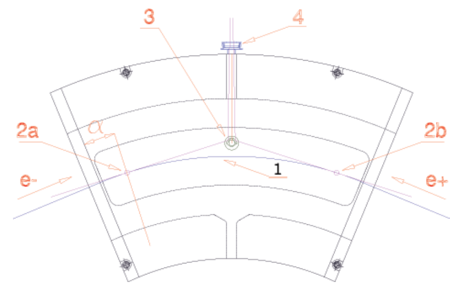
The measurement and control of the closed orbit is one of the basic functions of any accelerator beam instrumentation and control systems. A beam position monitor (BPM) system is operated for two kinds of orbit measurements, a relative measurement and an absolute measurement. The VEPP-2000 optical BPM system equipped with 16 CCD cameras registering beam synchrotron radiation have high precision of 1 μm, and used to monitor the beam orbit and correct the closed orbit distortion (COD), but hasn't absolute calibration.

BEAM ORBIT AND PROFILE MONITOR

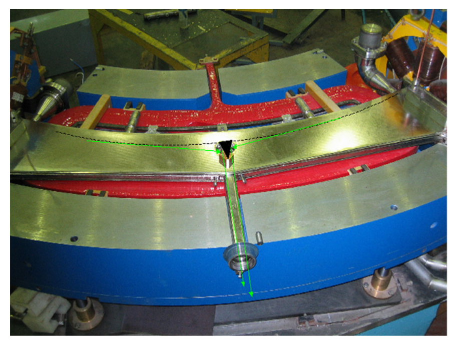
SR Acquisition System

Beam parameters in the VEPP-2000 collider measured by the Synchrotron Radiation (SR) at 8 points along the ring for both (e^+e^-) directions. Polished copper plates installed in the vacuum chamber, are used for output the SR from the bending magnets. The SR after passing through vacuum glass window comes to the optical diagnostics station and then is distributed by the half-transmitting mirrors Figs. 1-2.

Each station equipped with two CCD cameras (for positron and electron beams) for measurements the beam size and position. Because the SR outputs are located in orbital positions with very small dispersion function, four additional places are foreseen for dispersion and its symmetry control, and the beam position is measured in these points with pick-ups.



(a) 1-beam orbit, (2a, 2b)-radiation point of e^+e^- beams, 3-copper mirror, 4-output window, $\alpha = 4°47'$.



(b) Vacuum chamber and mirror after assembling. Additional mirror is placed in the center for comparison.

Figure 1: SR output in bending magnet.

In some stations the SR are used for beam current measurement (by the PMT) and will be used for the longitudinal beam sizes control in future (by the dissectors).

CCD Camera

Processing of optical part of the SR in circular accelerators allows one to obtain various beam parameters – vertical and radial sizes, axes tilt, position in a vacuum chamber. There is non-perturbative diagnostics that can work with super small beam currents. The essential nonlinearity (gamma correction) and low spatial resolution put some limitations on "TV camera + videograbber" system. In the case of a cheap digital TV camera the limitations appear due to space between camera and a computer. Typical values for this distance are about 100 m. Therefore the decision of development special camera based on b/w CCD of the type *ILX084AL* was taken from the very beginning. This CCD in 1/3-inch format has in working area

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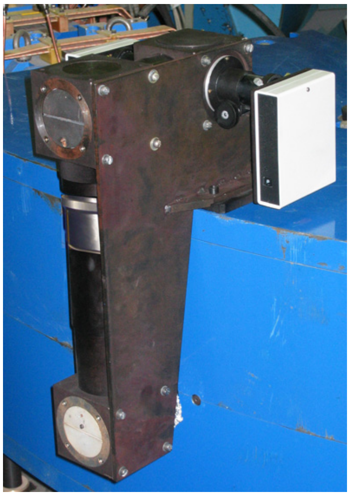

Figure 2: Optical bench with system of movable mirrors and SR diagnostic station with two CCD cameras.

494 rows of 659 elements (i.e. about 330,000 active diode target cells) and uses so-called line-to-line transfer, when diode columns alternate with light-proof vertical storage registers. For high sensitive to obtain a matrix of light-collecting microlenses is placed on the CCD surface. Saturation charge of the cell is about 40000 carriers, a noise charge is about $30 - 40$ carriers.

The camera structure is developed under Ethernet 100 MHz standard. Usage of this standard allows one not to have in the camera internal memory unit and to real-time transfer the information from the camera to a computer. Reading rate is about 1/12 sec per frame. It is possible to install in the camera 3-channel ADC AD922. This 14-bit ADC has a double correlated sampling regime as well as independent correction of sensitivity and offset for each channel. In a standard configuration only one ADC channel is connected to the main CCD, but it is possible to use two channels as is needed in case of VEPP-2000 collider (electron and positron monitors is placed together).

Software

The subsystem software is based on client-server model over TCP/IP protocol. All cameras have own unique MAC addresses and are connected to the special private subnet, because of traffic limitation. It may be more than 150 Mbytes/sec, so CCDs subnet is insulated to another subnets (control room private net). Only a special program, "CCD-server" has immediate access to CCD cameras; all other programs, "clients", sent their measure requests to the server; and the server provides for requests optimal execution and primary development of CCDs frames. Elliptical beam profile model is fitted to the real data - and position, axes main sizes and axes tilt are calculating. For the optimized algorithm it takes about 10 mksec to approximate a frame (300000 pixels $\times$ 16 bits) on (Athlon 64, 1.8 MHz) machine. Also, the server provides clients for more detailed information, such as beam profiles, along X,Y-axes; or a compressed picture with level lines marked by pseudocolors. According their purposes, clients may request any type of data. The user interface is developed under X-Windows/Motif/Qt environment.

Applications

The system widely used for routine operations: common control, measurement and correction of closed orbit (CO) distortions, specific beam measurements. More precise experiments of solenoid position determination with respect to CO was done in regular "round beam" optics also with use of ORM measurements [3]. There is regime for the system with external synchronization to perform some specific measurements. Synchronization of the system with beam injection gives the possibility of the beam position measurements for the first turn after injection or external signal.

Transverse Profile Monitor application, providing to the operator online picture of the beam, presented at Fig. 3. The program can store pictures in different formats and allows online hardware configuration.

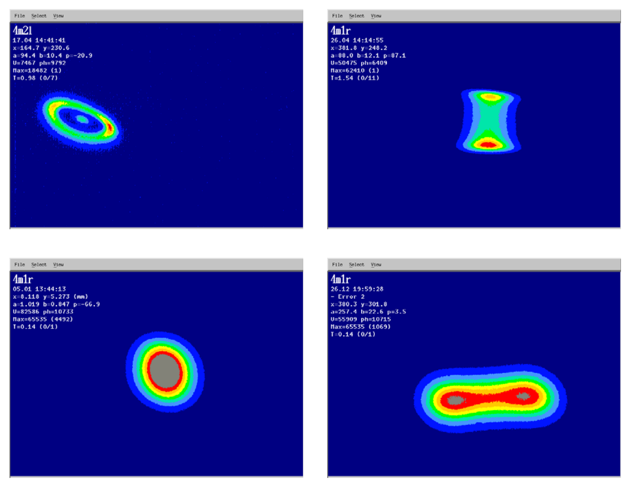

Figure 3: Beam profile at different moments.

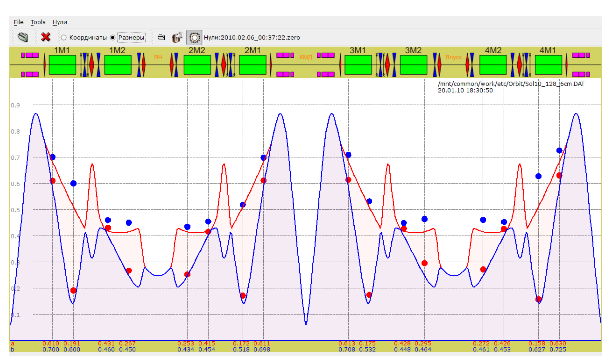

Figure 4: Beam sizes along the ring vs. lattice model.

Special code was written for online luminosity measurement which takes data about e^+, e^- beam energy, beam currents, beam positions and transverse profiles along the

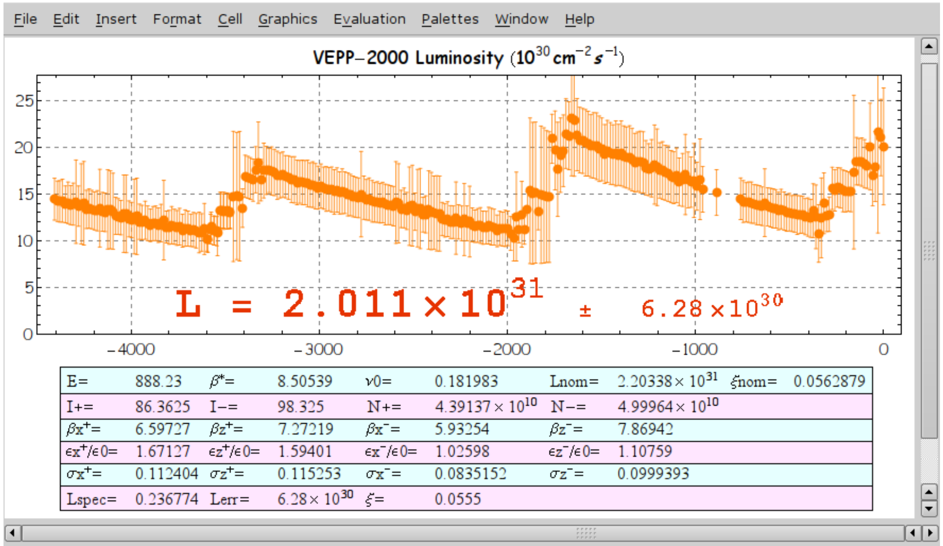

Figure 5: Online Luminosity calculations based on beam sizes measurements along the ring.

ring from different parts of control system Fig. 5. Then lattice model is fitted to satisfy the real measurements and beam cross section at IP is calculated.

LIFETIME MONITOR

A DC Beam Transformer (DCBT) is used to measure the bunched or unbunched circulating beam current. As mentioned above the SR intensity measurement is used for beam current measurements in case of low beam intensity. Signal from PMT measured by the integrating 8-bit ADC is proportional to the real beam current. So the DCBT values with sufficient electron beam are used to cross-calibrate the low intensity PMT-based measurement system. If there are

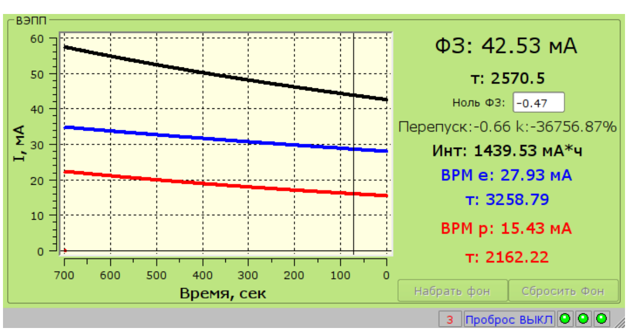

Figure 6: Beam currents and life time monitor.

two beams with different charge rotating together the additional information about relative beam intensities which can be obtained from the BPM system, because DCBT can measure only total charge amount and sum. signal from all BPM's tablets is proportional to the beam current.

OTHER SYSTEMS

There are a number analog TV cameras distributed around the ring for both e^+, e^- beam diagnostics. The cameras and display monitor are connected through a matrix video switcher, which can be control either local, or by the control system. Video switch also provides stamped title for each video signal. Since the title display is synchronized with incoming video signal, it is also often used for simple and fast diagnostics. Figure 7 shows positron vertical beam size blow up in the presence of strong electron beam. There are couple scintillation screens in the VEPP-

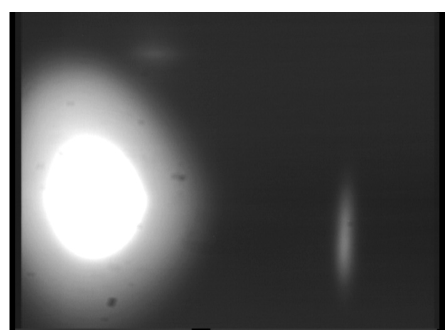

Figure 7: Both colliding beams beams: electron - left, positron - right.

2000 injection channels, used for beam observation with TV cameras. For specific tune measurements the swept Beam Transfer Function (BTF) measurements is used. All systems are integrated in common VEPP-2000 Collider Control System.

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