BEAM MEASUREMENT SYSTEM OF VEPP-2000 INJECTION CHANNELS

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Abstract

The paper presents single-flight beam diagnostic system for VEPP-2000 injection channels. The system includes two types of beam position monitors: secondary emission monitors and image current monitors. Tuning of the system, calibration of monitors, hardware and software of the diagnostic system are described.

Main goal of the beam diagnostic system is providing lossless beam transport. To solve such problem one needs to tune up as guide fields as focusing fields of transportation channels. First task - trajectory correction - is solved with response matrix inversion by SVD method. Second task - optic function reconstruction - is solved with help of multidimensional fitting of channel magnet structure parameters with minimization mean-square deviation of modelled response matrix from measured one.

The paper presents results of practical experience with automated beam transfer and optic functions tuning of injection channels of VEPP-2000 complex.

OVERVIEW

Tuning of transportation channels and beam injection system was an important stage of commissioning of the new accelerator complex VEPP-2000. Injection channels have complicated 3-dimmensional geometry (fig.1). They have 15 m length and 6 mm vertical physical aperture. The beams, stored in the booster, are injected to the collider by the one-turn injection method in horizontal plane to the straight section with zero dispersion function. Both DC (big dipoles of achromatic rotations) and pulsed (lenses and inlet/outlet dipoles) magnets (fig.2) are used in channel's optics.

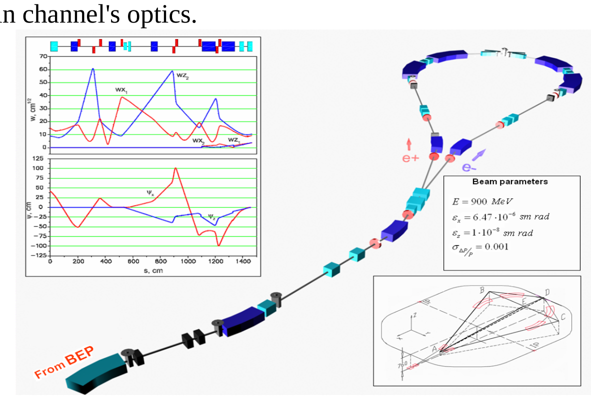

Figure 1: Injection channels of the VEPP-2000 accelerator facility. On the left insets amplitude Floquet functions (top) and dispersion functions (bottom) are shown. On the right insets beam parameters and the wire frame model of the channel's geometry are shown.

The work on lossless beam transport through the channels was closely related to commissioning of the single-turn beam position monitors in the channels. The system of beam diagnostics consists of secondary emission monitors (SEM) and image current monitors (ICM) (fig.2).

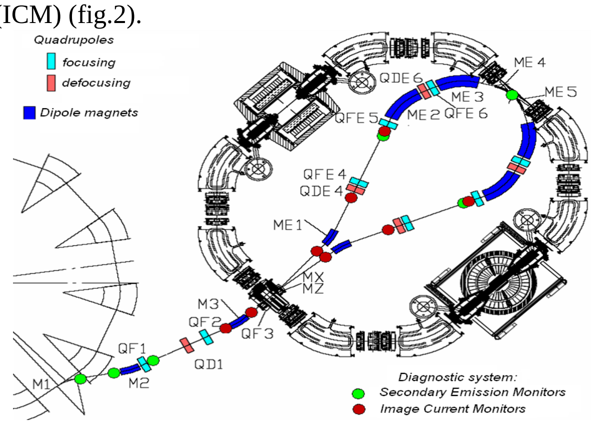

Figure 2: Magnetic system and beam diagnostic system of VEPP-2000 injection channels.

SECONDARY EMISSION MONITOR

The secondary emission monitor (SEM) is a set of thin tungsten wires (diameter of wire is 28 mkm and step between wires is 1 mm). Passing through the monitor beam emits out the secondary electrons from the wires making it positively charged. The wires are connected to the inputs of the integrating amplifiers. The amplified signal digitized by the multi-channel 14-bit ADC [1].

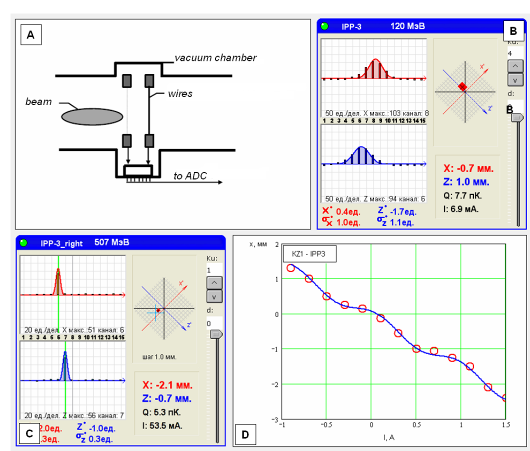

Figure 3. Secondary emission monitors. A) Schematic of monitor; B) The beam profile at the beam energy of 120 MeV; C) The beam profile, energy - 507 MeV; D) The dependence between current of some steering dipole and measured beam position. Picture demonstrates typical systematic error of the SEM - "staircase" effect.

The time of discharge of the wire is about 10 ms because of the connecting cable capacity (200 pF/m). It allows having SEM start time shift about several milliseconds to avoid the influence of pulsed systems.

Secondary emission sensors have a good protection to the pulse influence and low level of noise, but the precision of the measurements decreases dramatically if the beam size is comparable to the step of sensor wires [2]. In process of tuning the magnetic system one interests not of the absolute beam position but dependence between tuning parameter and beam position. This dependence could be measured very precisely by scanning beam position dependence on the tuning parameter and fitting procedure.

IMAGE CURRENT MONITOR

Image current monitors (ICM) measure pulses of current which induced by the beam in image current lines placed in the insulator gap of conducting vacuum chamber. These lines are connected through 1:20 increasing transformers by 50 Ohm cables to the inputs of special peak detectors. Beam position determines by proportion between amplitudes of pulses on different image current lines. Sum of these amplitudes gives total current of the beam. The algorithm of normalization on doubled own sums leads to purely radial distortions of coordinate grid of the monitor, which could be calculated analytically [3]. Analogous part of each detector includes the shaper made from section of long line, which splits input signal onto two antipodal ones digitized separately. Use of such shaper allows solving a set of problems with the noise stability [3].

Image current monitors of this type were used on VEPP-2000 for the first time, and they had demonstrated good performance during facility commissioning.

HARDWARE AND SOFTWARE

Every secondary emission sensor is served by Beam Position Monitor (BPM) station [1]. Image current monitors are connected to Pickup (PU) stations [3]. BPM and PS have unified interface and could be connected serial way to the BPM-standard line. To connect BPM-line to PC one needs to use some interface module. On VEPP-2000 facility CAN-BPM interface modules are used, which connect BPM-lines to PC through a CAN-bus interface. Software of the beam diagnostic system is based on client-server architecture over TCP/IP protocol and is integrated with the software of the facility. Figure 5 shows up-to-date graphical user interface of beam channel diagnostic system.

The experimental investigation of the properties of both sensors types was carried out. Noise levels of measurement of coordinate and current were determined. Systematic errors of secondary emission sensors, which are defined by the discrete properties of the set of sensitive elements (wires), were carefully studied also. Image current monitors have demonstrated coordinate measurement noise level about 50 mkm, and nearly zero relative error due to nonlinearity in the aperture of the monitor (see fig.4,D).The determined noise level of coordinate measurement of secondary emission sensors is about 60-70 mkm (with correction of “staircase” effect shown in fig 3,D) .

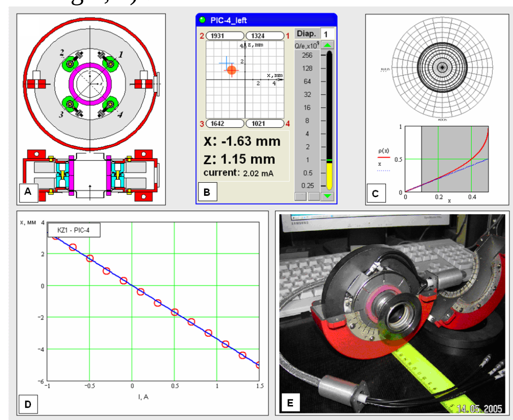

Figure 4: Image current monitors. A) Monitor schematic (vertical and horizontal sections); B) Signal from ICM. Amplitudes from four image current lines and a level of a signal in a logarithmic scale are shown; C) Typical distortions of a coordinate grid and the physical aperture of the channel in comparison with the linear diapason; D)The dependence between current of correcting dipole magnet and measured beam position; E) ICM picture.

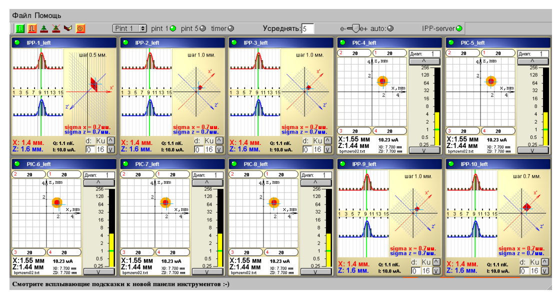

Figure 5: Graphical user interface of client program for beam diagnostic system.

LOSSLESS BEAM TRANSPORTATION

The task of tuning lossless beam transport through the injection channels comes to the task of finding an optimal set of magnetic system parameters, which provide high-quality beam transport and injection to the VEPP-2000 collider ring. This task could be divided on two stages:

1) Trajectory alignment (dipole magnets tuning)
2) Optic alignment (quadrupole magnets tuning)

The most common way to solve the first task is inversion of trajectory response matrix. Response matrix element A_{ij} is coordinate response on i-th monitor with respect to current change of j-th correction. As response matrix is usually singular or nearby so, one needs to use singular value decomposition to find unique rms-solution [4].

The automated system of response matrix measurement and trajectory correction for VEPP-2000 injection channels were developed. It allows measuring the response matrix in automatic mode, invert it with control of singular values spectrum, and propose a set of corrections to reach a needed trajectory. Response matrix elements are measured by monitor's aperture scanning. It allows solving a problem of precision loss due to SEM systematic errors. The measurement of every matrix element is accompanied by the measurement of its relative error. The level of cutting off matrix singular values is determined by the square relative noise level of the monitors.

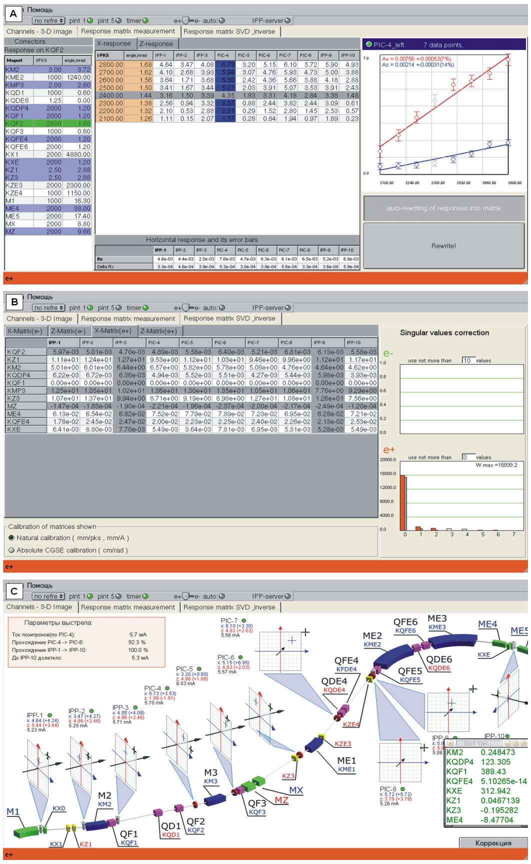

Figure 6: Graphical interface of trajectory correction program. A) Measurement of the response matrix's lines; B) Response matrix processing; C) Trajectory correction (graphical representation on the channel's)

RESULTS

To get a required phase ellipse of the beam at the end of injection channel one needs to restore the design optics of the channel. It could be achieved by studying the individual calibrations of the quads and some typical features of real optic system, defined by edge fields, vacuum chamber influence, etc. To solve this problem one needs to find a set of fit parameters (quadrupole gradients, focus length of effective thin lenses, geometric parameters etc.), which give the closest coincidence between model and experimental data. The most complete available data set, which characterizes the magnetic system of a channel, is a trajectory response matrix. Thus, the problem reduces to minimization of the deviation between model and measured response matrix by fitting the model parameters. Supposing the linear dependence between set of deviations and fit parameters we reduce problem to the system of linear equations. This system is over determined because the number of data in response matrix is much more than number fit parameters. Inversion of this system using SVD allows effective usage the data contained in response matrix and to get statistically reliable solution [5].

The investigation of the injection channels had allowed to improve calibrations of quadrupole magnets, and also discovered some specific features of the magnetic system (edge focusing of septum magnet and weak gradients in big DC magnets).

Knowing the real optic properties, one can change individual calibrations of the quads and come close to design optics. Manual step-by-step tuning of the channel (coarse tune), and multidimensional fit (fine tune), have allowed to get practically lossless beam transportation through the channels. Further tuning of injection system gave 80-90% injection of electron and positron beams to the VEPP-2000 collider ring.

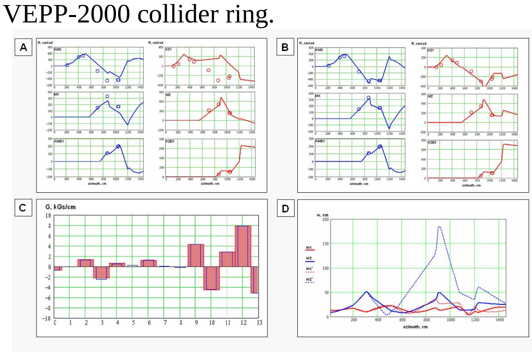

Figure 7: Offline response matrix processing: A) Difference between measured and modelled response vectors before fit; B) Measured and modelled responses after fit of the model's parameters; C) Changes in the gradients of 14 elements of the magnetic system (solid bars - gradients before fit, transparent bars - after fit); D) Distorted real amplitude Floquet function of the electron channel (dashed lines) and corrected ones (solid lines).

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