

# APPLICATION OF MODEL INDEPENDENT TECHNIQUES AT VEPP-2000 AND SIS100

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## Abstract

In order to exploit an accelerator successfully all parameters should be set correctly. To check and fix errors in the accelerator lattice measurements of parameters of the betatron motion and measurements of optical functions of the accelerator lattice are used. Due to Model Independent Analysis it is possible to carry out measurements of the beta-function and the phase advance fast. Using NAFF technique lets us compute betatron tune with good precision. Limiting capabilities of the MIA at SIS100 project are discussed, implementation of the MIA and the NAFF techniques at booster VEPP-5 and at collider VEPP-2000 are shown.

## INTRODUCTION

In order to receive the information about settings of an accelerator we can use MIA (Model Independent Analysis) [1] and NAFF (Numerical Analysis of Fundamental Frequencies) [2]. These techniques demand beam histories — arrays of data from BPMs (Beam Position Monitors), which have the information about the betatron motion of the beam. We don't have enough possibilities to describe these methods, but full specification you can find in the references.

## SIS100. THE RESULTS OF SIMULATIONS

SIS100 is a future synchrotron for acceleration of high intensity and high energy ion beams with primary significance in the FAIR project. In its design the synchrotron has six equivalent sectors and is served by 84 BPMs.

To examine the limiting capabilities of the future diagnostic system of SIS100 and the MIA technique, numerical simulations were applied. At first, particle tracking with MADX [3] was used, then simulated "beam histories" were filtered and analyzed with MIA. Received results (shown on Figure 1 and 2) were compared with the beta-function and the phase advance, that are calculated using MADX. For all these calculations parameters were applied:  $n = 200$  turns, the level of the noise  $\Delta x = 100 \mu m$ ; amplitudes of the simulated betatron oscillations were  $\approx 1 mm$ . The error of MIA calculations is determined as:

$$\delta = 100\% \cdot \frac{1}{m} \sum_{i=1}^m \left| \frac{f_i^{MADX} - f_i^{MIA}}{f_i^{MADX}} \right| \quad (1)$$

where  $f$  is  $\beta$  or  $\phi$ ,  $\phi_i = \Psi_i - \Psi_{i-1}$ . The difference between the model beta-function in positions of BPMs and measured by MIA is less than 2 %. For the phase advance precision is better than 1 %. Also the relative error of calculations raises almost linearly in the observed

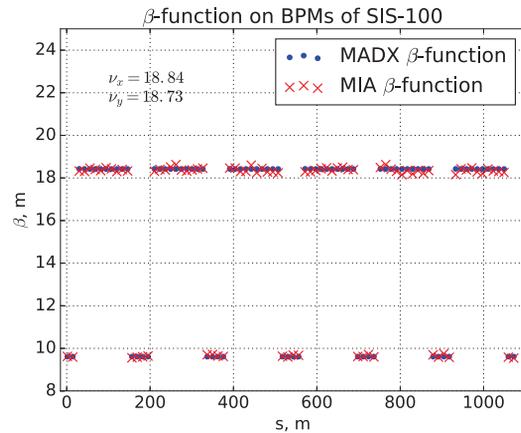


Figure 1: Values of  $\beta$ -function at BPMs for SIS100.

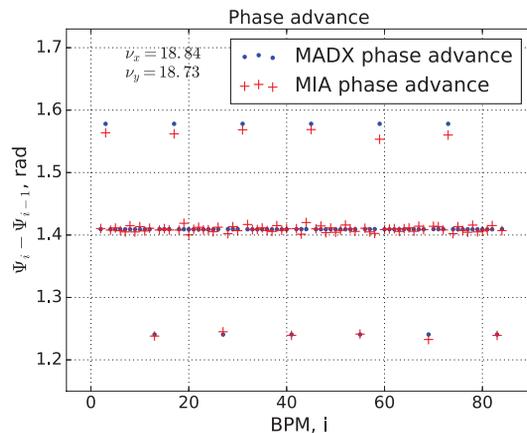


Figure 2: The phase advance between neighboring BPMs.

range of noise-amplitude ratio. Furthermore the MIA error decreases when  $n$  raises. These results are shown on the Figure 3.

Finally, we tested limiting capabilities of MIA using the "beta-beating" task. We applied the unrealistically big gradient error at the level equal to 5%. Results are shown on the Figure 4. Green triangles are the distorted beta functions at the BPMs, blue points are the ideal beta-functions at the BPMs, red crosses are  $\beta$  calculated by MIA. Here we found that calculations of the  $\beta$ -function are very sensitive for varying scaling factor ( $J^{-1}$ ).

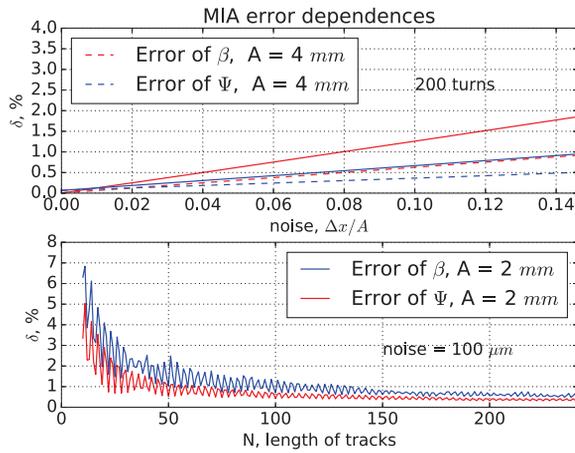


Figure 3: MIA error dependence: a) on the number of turns b) on the noise-amplitude ratio.

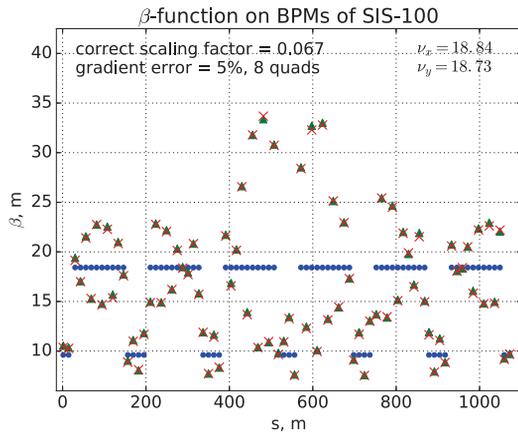


Figure 4: Beating of the beta-function of the SIS lattice.

## THE RESULTS OF MEASUREMENTS AT VEPP-5 AND VEPP-2000

### VEPP-5 Damping Ring

The damping ring of Injection Complex (VEPP-5 at BINP) is an accelerator which stores and cools down both of electron and positron beams. The accelerator ring consists of four cells, each cell includes: two dipole bending magnets, five quadrupole lenses and sextupole lenses between bending magnets. The circumference of the ring is 27.4 meters, the project energy is 510 MeV, the detailed description is given in [4]. The damping ring is served by 16 beam position monitors as the main tool of diagnostic system.

The number of experiments with electron bunch with different initial states was carried out. The bunch of electrons had the betatron oscillations which were implemented by the horizontal kick excitation. The intensity of the bunch was varied in the range from 1 mA to 25 mA. The amplitude of the kick was chosen to produce betatron oscillations with an amplitude  $\approx 5$  mm. Simultaneously with

the kick recording at the BPMs was initialized. The energy of the beam was 390 MeV, betatron tunes were calculated using NAFF and they corresponded to their project values:  $\nu_x = 4.44, \nu_z = 2.65$  (the fractional part of  $\nu_x = 0.43794 \pm 9 \times 10^{-6}$ ).

However several BPMs for the some reasons aren't able to be used in the experiment. The 13-th and 15-th BPMs have problems with the ADC and the line delay, 5-th and 14-th monitors had strong a electromagnetic noise in the signal.

After preliminary analysis the phase advance and the beta-function were computed using MIA. Results obtained with different beam intensities differ less than experimental error (as the results of MIA and NAFF for the phase advance), thus 4 mA results are shown at the Figure 6 and 5. The difference between the model and experiment might be described: the model of the damping ring was made in 2015, but then values of magnetic fields were significantly changed in order to obtain a successful injection of the electron bunch into the damping ring from linac.

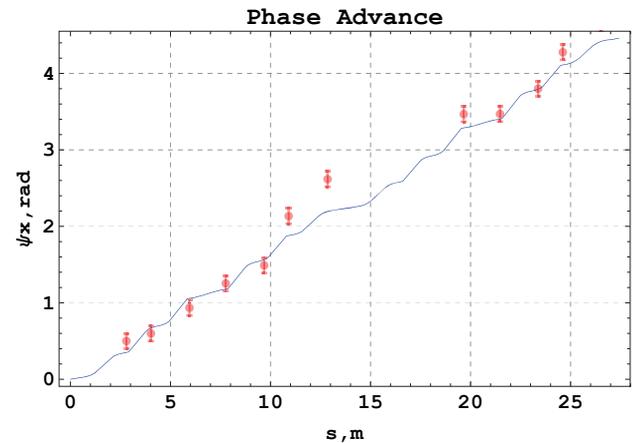


Figure 5: The horizontal phase advance at the damping ring.

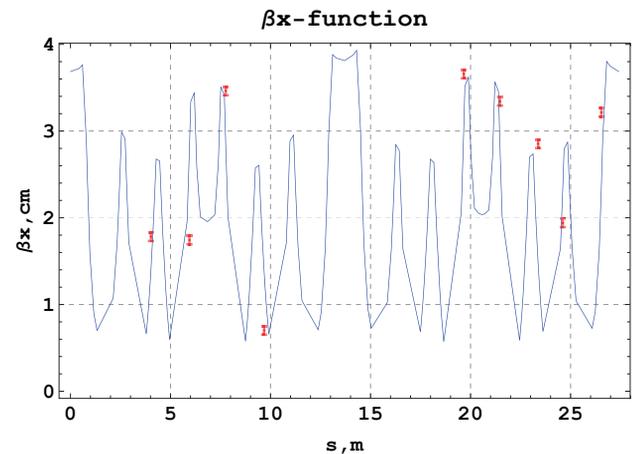


Figure 6: The horizontal beta-function at the damping ring.

## VEPP-2000

Collider VEPP-2000 at BINP is an accelerator with a symmetric magnet structure which is divided on four sectors. The sector consist of two bending magnets, five quadrupole lenses and few sextupoles. As well there are superconductive solenoids for the final focusing and the realization of the round beam concept of the machine. The circumference of the collider is 24.38 meters, the project energy is 1 GeV, full description of the accelerator see here [5]. To obtain data about equilibrium orbit and to carry out turn-by-turn measurements four electrostatic BPMs are used.

This experimental work has been done directly after the modernization of the booster (BEP) and VEPP-2000. In order to set all systems of the accelerator correctly using the beam, the magnet system of the collider was changed to the "warm optics" mode, which means that solenoids of final focusing were switched off and the gradients of all lenses were reduced.

The range of experiments with electron bunch was carried out. The intensity of the bunch was varied in the range from 1 mA to 3 mA. In order to excite betatron oscillations with the variable amplitude the horizontal kick with suitable amplitude was implemented. The amplitude of betatron oscillations was varied in the range from 1 mm to 5 mm. Simultaneously with the kick beam histories at the BPMs were recorded. Computed by NAFF the value of the fractional part of  $\nu_x = 0.431876 \pm 4 \times 10^{-6}$

Results obtained with varied intensities and amplitudes differ less than experimental error, thus results of the experiment where intensity was 1 mA and amplitude of betatron oscillations was 1 mm are discussed below.

For the sake of computing the phase advance between BPMs MIA was applied, results are shown on the Figure 7. Red dots are the array of the experimentally measured betatron phase, the blue curve is the model phase advance for "warm optics" mode. Next result is beta-function which is shown on the Figure 8. As for the phase advance red dots is the array of the experimentally measured beta-function at BPMs, the blue curve is the model beta-function for "warm optics" mode.

## CONCLUSIONS

Beta-function at the BPMs and the phase advance was measured at the collider VEPP-2000 and the damping ring of VEPP-5 during the experimental research. Also simulations for SIS100 were made, there is the result — MIA is available for applying at SIS100. Aims of further studies are: to measure the optic functions with better accuracy at the damping ring, to reduce different noises and to improve the diagnostic system of accelerator. Now on-line measurements of the optic functions are available at VEPP-2000 and next step is to calculate the beta-function and the phase advance in "hard focusing" mode with turned solenoids on.

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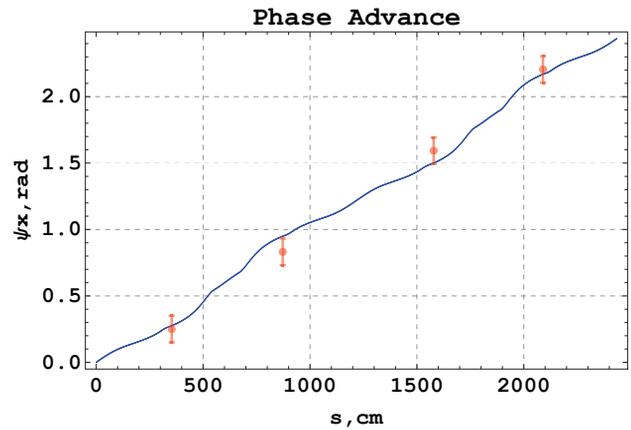


Figure 7: The horizontal phase advance at the VEPP-2000

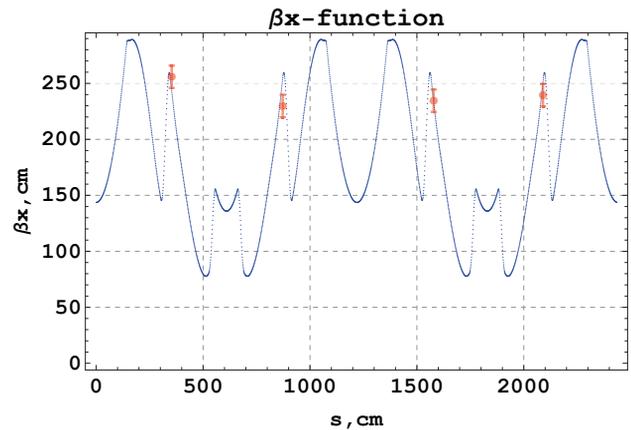


Figure 8: The horizontal beta-function at the VEPP-2000

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