# SURVEY AND ALIGNMENT OF VEPP-4M

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## 1. INTRODUCTION

VEPP-4, a 6 GeV electron-positron collider, has been operated since 1980 [1]. The magnetic system of VEPP-4 was modified a few years ago to increase luminosity and extend possibilities for experiments in nuclear physics and synchrotron radiation (SR) researche. The new magnet lattice is fully symmetrical with respect to the interaction point (IP). Two regular cells in the center of both half-rings are replaced by special insertions accommodating 14 SR-beamlines. A new superconducting detector is under assembly now. Figure 1 shows the layout of VEPP-4M.

The alignment system of VEPP-4 has been changed on the basis of the experience and a new apprehension of alignment goals. This paper describes the alignment concept and instrumentation used to position VEPP-4M components. Main parameters of VEPP-4M are summarized in Table 1.

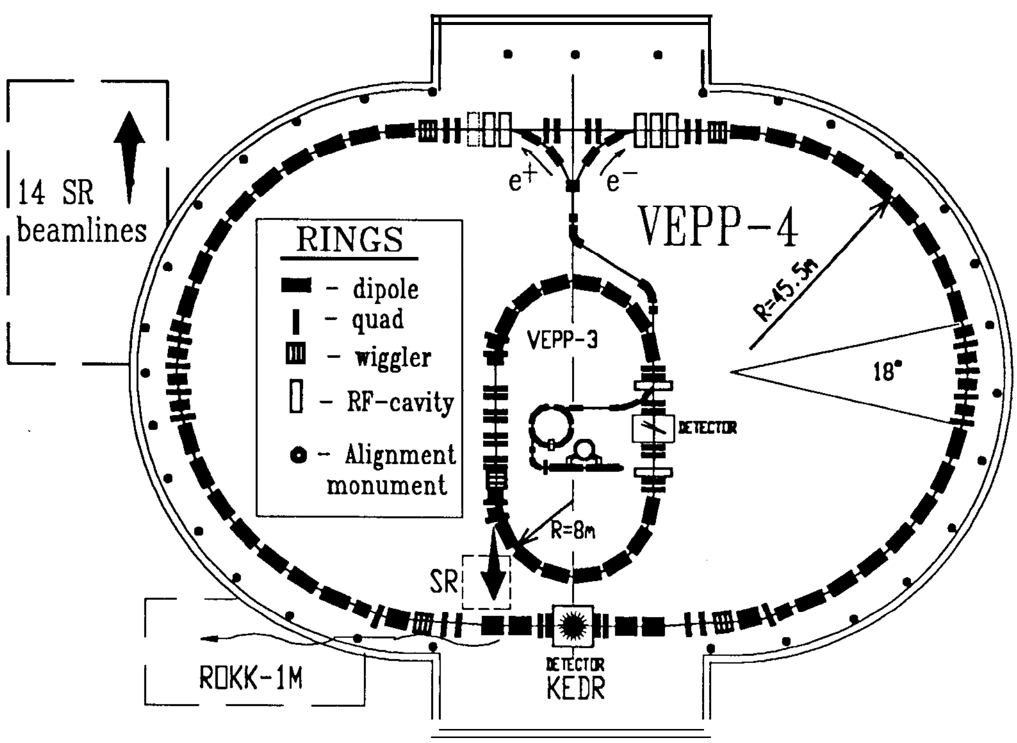


Figure 1. Layout of the VEPP-4 complex

**Table 1**
Main parameters of VEPP-4

| | |
|---|---|
| Energy | 6 GeV |
| Luminositv | $7*10^{31}$ |
| Beam current | 50 mA |
| Circumference | 366m |
| Average arc radius | 45.5m |
| Horizontal aperture | 60mm |
| Vertical aperture | 27mm |
| Number of blocks(dipole-quad) | 70 |
| Number of dipoles | 14 |
| Number of quads | 26 |
| Number of RF-cavities | 6 |

## 2. TOLERANCES

The accuracy required in the positioning of VEPP-4M components is typical for circular accelerators. Table 2 shows detailed tolerances for the elements. They are calculated assuming that the orbit distortion caused by misalignment does not exceed one-tenth of the vacuum chamber size all around the ring (allowing for magnet measurement errors, dynamic aperture, long term deformations, etc.). This guarantees the injection of beams into the storage ring without turning on any correctors and their lifetime long enough to activate beam position monitors (BPM) and perform precise orbit corrections with the use of correction magnets.

**Table 2**
VEPP-4m alignment tolerances

| Magnet | Radial(mm) | Vertical(mm) | Along orbit | Angles(mrad) |
|---|---|---|---|---|
| Quad | 0.2 | 0.2 | 1.0 | 0.1 |
| Dipole | 1.0 | 0.2 | 0.5 | 0.1 |
| Block(quad part) | 0.2 | 0.2 | 0.5 | 0.1 |
| (dipole part) | 1.0 | 0.2 | 0.5 | 0.1 |

## 3. ALIGNMENT CONCEPT

There are a few specific details to be taken into consideration in developing the alignment system:

i) The beam orbit is 2.3 meter high over the floor level. Figure 2 shows the cross section of the ring tunnel. There is no room to place measurement devices at the orbit level.

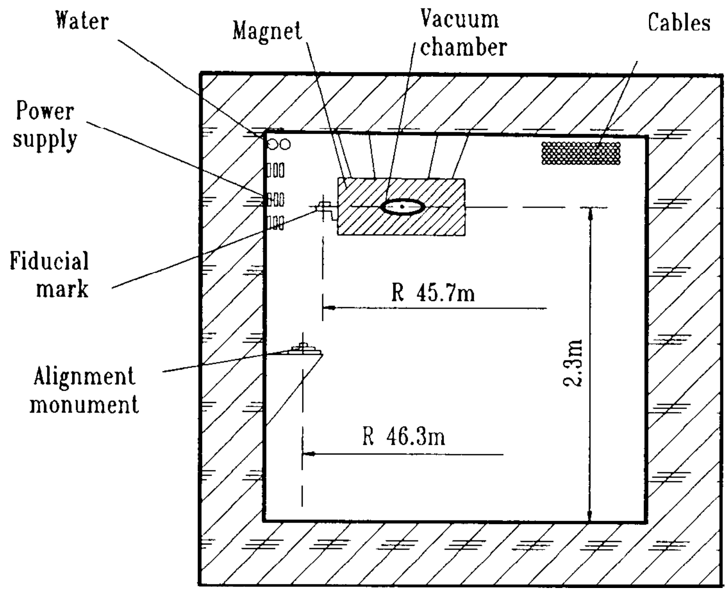


Figure 2. Cross section of the VEPP-4 ring

ii) A regular cell consists of two blocks. Each block includes bending and quadrupole magnets. Conventionally, it is divided into dipole and quad parts which can be aligned with different accuracy.
iii) The VEPP-4M tunnel is located close to the surface on soils which tend to subside. Any variations in environments, i.e. a new construction sites close to the tunnel, additional experimental equipment to be installed, heavy rain and snow, summer-winter temperature changes, etc., result in significant deformations of the tunnel and, respectively, in misalignment of the components. VEPP-4m has to be realigned annually.
iv) Due to the tight conditions for the measurements and a side refraction in the tunnel it is not desirable to perform measurements by theodolite.

The alignment system is based on a monumented network and distance measurements. A precise survey of the monument positions is performed separately for horizontal and vertical directions. Thereafter, the positions of the monuments are corrected into ideal ones and a control survey is carried out. This process is repeated until1 the necessary accuracy tolerances are met. Usually it needs one iteration.

VEPP-4M components are aligned with the use of a jig-plate, invar rods and a bubble level without any additional measurements.

## 4. FIDUCIAL REFERENCES AND MONUMENTS

Each component of the magnet system has at least two fiducial marks, which are accurately mounted on the side surface at the orbit level relatively to the mechanical reference with the use of a jig-plate. The reference is a precise 25.4mm socket settled vertically. Usually fiducial marks are a reference for magnetic measurements. The upper surface of elements is well machined for setting a bubble level.

The network monument has exactly the same reference socket for housing either a calibrated dowel pin or a tooling ball as that used in the fiducial mark. It is possible to adjust the socket axis vertically and move it in horizontal plane within ±5mm range in both directions.

## 5. NETWORK

The network consists of 94 permanent monuments (3-D), fixed on the tunnel wall by brackets. In the half-rings the monuments are placed exactly opposite to the fiducial marks on the blocks. The distances between monuments are mainly equal. Both planimetric and altimetric networks are free, which means they have no permanent origin and orientation.

### 5.1 Planimetric network

This network is simple and fully homogeneous. Measurements are performed according to the scheme shown in figure 3. The coefficient of redundancy is 2.0 [2].

Simulations show that the sagitta should not exceed 0.25mm.

The deviation from ideal values of distances and offsets are measured, as the monuments are placed close to their ideal positions. The accuracy for the distance measurements is 0.04mm, for the offsets it is 0.015mm.

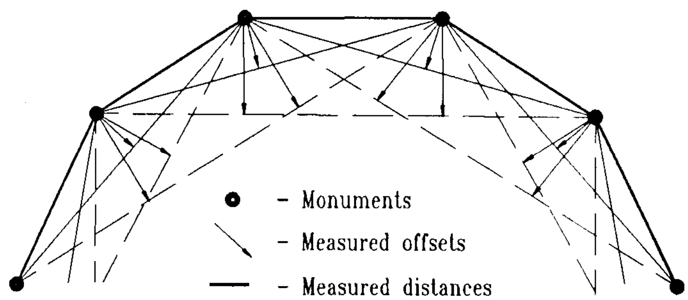


Figure 3 Scheme of measurements

Redundant measurements provide an efficient control of the measurement accuracy. If a “local” residual exceeds a certain limit, it indicates that the measurements used for the calculation of the residual have a gross error. This measurements have to be repeated or eliminated from adjustment. It is possible to calculate systematic errors caused by calibration errors of instruments and subtract them from measurements.

The least square fitting is applied to analyze measurements and compute deviations of monument positions from their ideal values. An optimal rotation and a parallel translation in the horizontal plane without contortion of the geometry are calculated so that the total square sum of displacement of monuments is minimal.

The Fourier analysis of the deviations is performed and harmonics of up to 3-rd order are eliminated since they do not affect the orbit distortion [3]. Figure 4 shows the displacement of the monuments in the radial direction before and after the elimination of these harmonics. Only a few monuments have to be corrected.

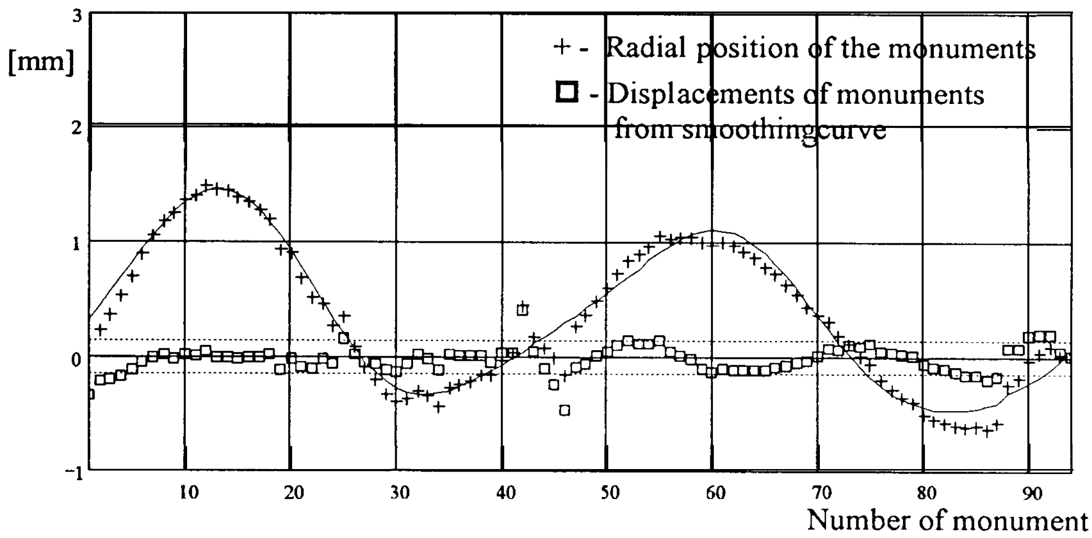


Figure 4 Positions of the VEPP-4M network monuments in radial direction

### 5.2 Altimetric network

The altimetric network uses the same monuments. The scheme of measurements consists of 13 closures to provide the measurement control. If a relative position of a group of monuments has no variation for a few sessions of leveling, it is chosen as an immobility group. An average altitude of such a group of monuments is taken as an origin in the vertical direction.

A sight level and invar staffs are settled upon the monuments to guarantee a high stability of the instrument during the measurements and equal distances from the sight level to the staffs. The measurement accuracy is 0.12mrn/km.

## 6. INSTRUMENTATION

The distance measurements are performed with the use of a distancemeter (Figure 5) and two invar tapes. The invar tapes have perforated holes which allow us to measure any distance within a 0.5-25 meter range. The measurement accuracy is 0.04mm.

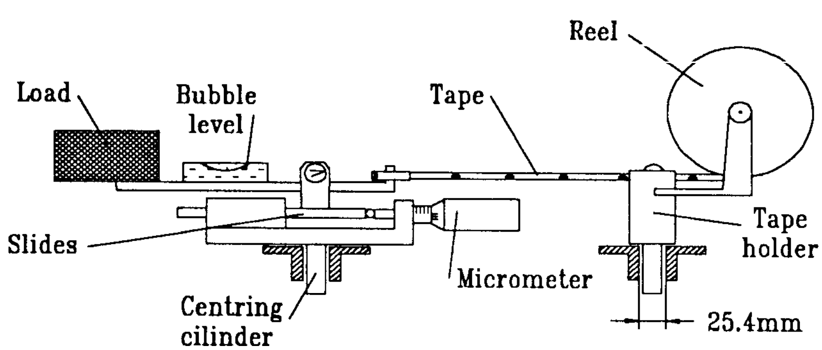


Figure 5 Distancemeter with perforated invar tapes

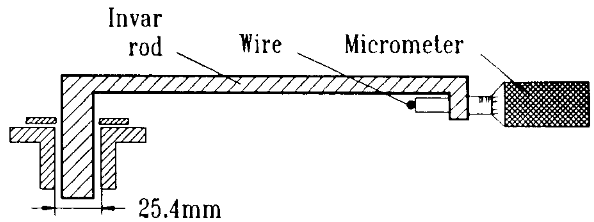


Figure 6 The offset measurement device

The offsets are measured with the use of calibrated invar rods equipped with a micrometer (Figure 6). The accuracy of the offset measurements is 0.015mm.

The calibration of instruments is performed at a standardization bench equipped with a laser interferometer. The leveling is carried out using a Koni-007 sight level and double scaled invar staffs.

## 7. RESULTS

A successful commissioning of VEPP-4M is the main result of our alignment efforts. An annual realignment due to a continuous deformation process of the tunnel still remains the main problem of positioning of VEPP-4M components. Usually the realignment takes 1.5 months for a team of one surveyor and two technicians. It is carried out during the summer shutdown.

The deformations in the vertical direction have the largest amplitude. Figure 7 shows the deviation of monument altitudes for the last 7 years. A new building and the construction work are the main reason of the tunnel subsidence. The most essential movement occurs at the moment when the load changes, and after that the subsiding is slowing down.

In horizontal directions the deformations are about 1mm/year. A season (summer-winter) deviation of the radius of the tunnel with an amplitude of 0.5mm has been detected. The large amplitudes of deformations results in many cracks on the concrete walls. Figure 8 shows the correlation between the deviation of the crack gaps and the air temperature in the tunnel.

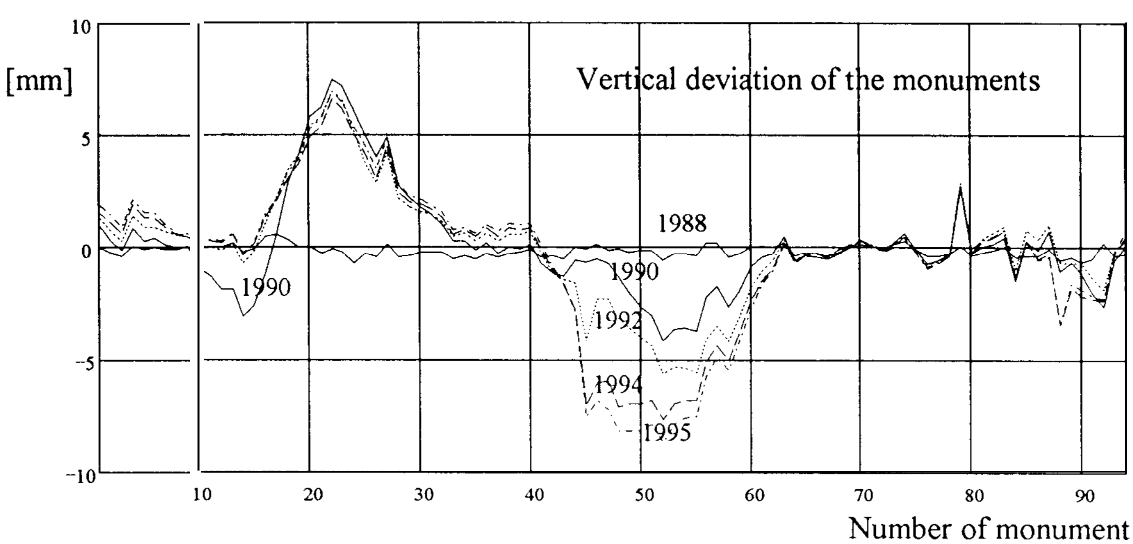


Figure 7 Deviation of the VEPP-4M network monuments in vertical direction

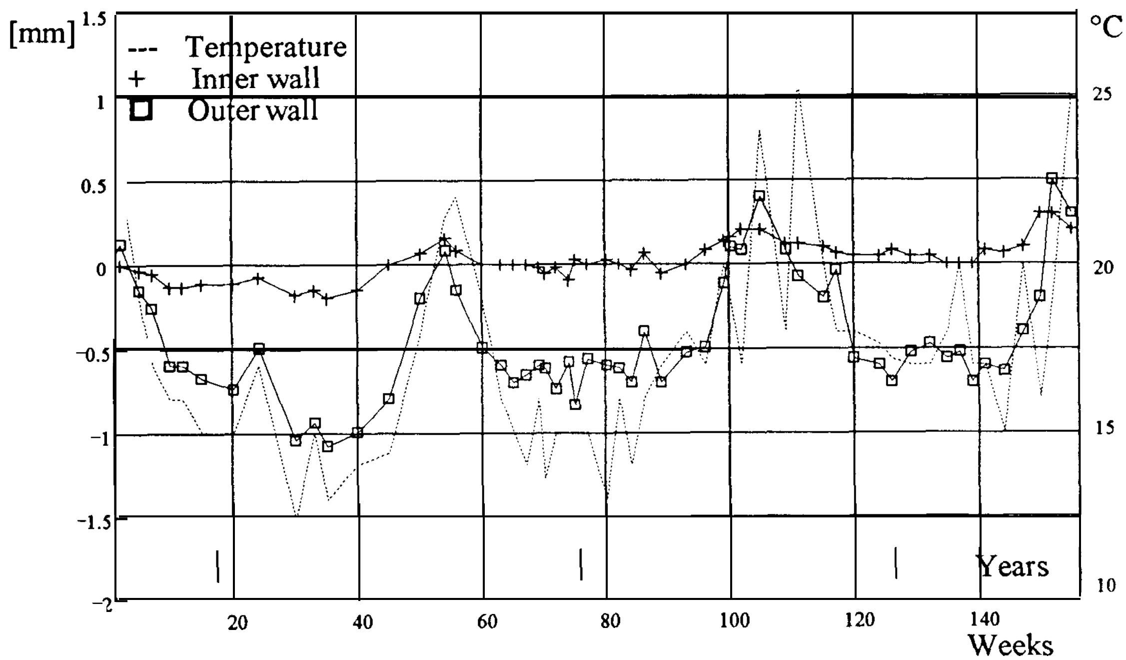


Figure 8 Correlation between deviation of the crack gaps and the air temperature in the tunnel

Amplitudes of the crack disclosures on the inner and outer walls of the tunnel are different, which indicates the disproportionate deformations.

## 8. CONCLUSION

Though the described alignment system does not seem to be very modern, it is rather attractive due to its simplicity and low cost. We use the general ideas in the development of the alignment system for the C-Z factory which is currently under construction at BINP.

## REFERENCES

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