Results of Long-Term Observations of Deformations of the VEPP-4 Storage Ring Constructions, BINP

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Key words:

SUMMARY

This paper presents results of more than thirty years long study of settlements and deformations of support structures of the electron-positron collider VEPP–4 at Budker Institute of Nuclear Physics (BINP). First results of this work were presented at the XVI FIG Congress, Switzerland in 1981.

The VEPP-4 complex is a racetrack facility with 40 m long straight sections and circular sections with a radius of 45 m (the perimeter is 366m). The straightforward sections are situated in an industrial building and the circular ones are in a tunnel. There are over 100 units of physical equipment installed (the dipole and multipole magnets, detector , RF cavities etc). They must be aligned with accuracy of fractions of millimeter.

A distinctive feature of VEPP-4 is that it was designed and built in an earlier-existing industrial area of the Institute. In contrary to a common practice of accelerator construction the site was not specially chosen; the tunnel has no strong foundation; magnets in the tunnel are fixed on the ceiling. The internal cross-section of the tunnel is 3m*3m; the reinforced concrete walls are 0,5 m thick. The tunnel bases on a thick layer of sedimentary rocks – sand loams, loams and clays.

Geodetic network used for alignment pupposes consists of 94 monuments located almost uniformly along the collider circumference. Their design together with special measurement methods let one to determine the geometrical parameters of the complex with an accuracy of 0.1 mm. Scheduled observation sessions (about 50 sessions have been performed) allowed one to perform a study and prediction analysis of settlements and deformations of the construction which exceeded 15 mm for last 30 years long period.

Since no special reference monuments were available, a method to determine a stable group of the monuments have been developed and applied for the deformation analysis.

The presented materials can be useful for a similar constructions design.

Index Terms **–** Accelerator, collider, electromagnet, absolute and relative positioning, alignment, tunnel, deformations, smoothing curve.

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1. INTRODUCTION

The experiments on physics of elementary particles are carried out routinely on the research facilities whose sizes are ranging from hundreds of meters up to tens kilometers in length. These facilities have various spatial configurations: the linear - (SLAC, 3.2 km); ring - (VEPP-4 with the circumference of 366 m, LHC CERN of ~30 km in circumference). The basic systems of these accelerator facilities are magnetic systems, which include up to several thousands electromagnets of different types. The particles are traveling in vacuum chambers of the magnets in bunches. Cross section of the bunch is typically a few tens of millimeter. Casual displacements of electromagnets from the due positions are resulted into the transverse displacement of a trajectory of particles with a factor 10 - 100. Therefore, there are both the direct problem of precise installation of elements of the accelerator magnetic systems, and related problems of their time-space stability. It results in the necessity of a choice of the site area, development of special building designs, etc., that considerably affects the cost of complexes.

At first, requirements to the accuracy of the accelerator electromagnet positioning have been formulated by experts when the accelerators had the sizes of a few tens of meters as follows [1]:

Table: The tolerances on elements positioning

Magnets	σR(mm)	σZ(mm)	σL(mm)	$\sigma\alpha,\omega,\psi$ (mrad)
Quadrupole	0.1-0.2	0.2	1.0	0.1
Dipole	0.5	0.2	1.0	0.1
Other elements	0.5	0.5	1.0	1.0

where σR, σZ are the mean square values of casual displacement of elements across a trajectory, σL – the same along the trajectory of particles from the design position, $\sigma\alpha,\omega,\psi$ - tilting angle of elements.

These requirements were used for many years and were referenced for experts in the field of the engineering geodesy. They did not take into account some possible correlations in positions of the adjacent magnetic elements, correlations between their displacements, and distortions of the particle trajectories.

When sizes of accelerators have reached hundreds of meters and a few kilometers, it became clear, that required accuracy in the former form cannot be met physically due to limitations on accuracy of engineering - geodetic methods of measurement. Differential settlements and deformations of constructions were presented practically in all grounds and at any areas. It was necessary to carry out repeated sessions of measurements and repositioning of the equipment.

It was required to reconsider physical aspects of requirements in a new fashion. The studies have shown [2], that it is enough to comply with the requirements given in Table not for the complex as a whole, but only at any part of it of a certain extent – the so-called wave-length of a betatron oscillation λ. These values are specific for each accelerator and lay in a range from 10 to 200 meters (~40 meters for VEPP-4). There was made a shift from absolute positioning requirements to relative positioning ones; it means that it is enough to provide the accurate and stable positioning for neighboring magnets only at any place of length ~ λ.
The efficiency of such approach is proved by long-term alignment works at the electron-positron storage ring (collider) VEPP-4 of the Budker Institute of Nuclear Physics (BINP), Novosibirsk, Russia.

2. THE DESCRIPTION OF VEPP-4M

The VEPP-4 collider (after 1987 VEPP-4M) was built on the territory of already existing Institute. The earlier constructed buildings were used also. Therefore, the geomorphological conditions (geotechnical conditions) for the project construction were determined unambiguously. The civil works were completed in 1970; the physical experiments have been carried out since 1977 [3].

The VEPP-4M was designed to operate at particle energy of 6 GeV. The particle trajectory consists of two semi-circles, each 45.5 м in radius, and connected by two 40 m long straight lines. Along the trajectory, various electromagnets and other equipment are placed. The VEPP-4M particle beam orbit (see Fig. 1) is located 6 meters below the ground surface. In the circle sections, the magnets (80 units) are placed in a concrete tunnel reinforced by iron bars. The rectangular tunnel has a cross-section 3x3 meters, the wall thickness is 0,5 meter (see Fig. 2). Each semi-ring is structurally divided into 5 blocks with expansion gaps between them. The magnets in the tunnel are fixed to the ceiling, so the plane of the particle orbit is at the level of 2.3 meters from the tunnel floor. The technical straight section is housing 8 quadrupole lenses and 6 RF cavities. In the experimental straight section, there are 10 quadrupole lenses, 6 dipole magnets and the superconducting detector "KEDR" of ~1000 tons in weight.

Magnetic elements in the straight sections are installed on the support structures fixed to the floor. Each magnet has adjustment mechanisms. The top surface of the magnets is reference surface for alignment. Each magnet has two combined horizontal and vertical fiducial marks. They are fixed to the outer part of the magnets in the plane of the particle orbit. The spatial position of the fiducial marks is strictly determined by the ring geometry. The magnets are aligned by placing their fiducial marks into the given design position [4].

The alignment is made with respect to the basic geodetic network, monuments of which are placed nearby of each magnet.

The VEPP-4M basic network consists of 94 monuments located in semi-rings – on the external wall; in the technical section - on columns; in the experimental section – on the internal wall.

The general view of the monument is shown in Fig. 3. The horizontal position of a monument is determined by an axis of a one inch diameter socket. A forced centering technique allows the positioning of alignment instruments on the monument with an accuracy of ±0,006мм. The top surface of the socket was taken as a vertical reference point. The monument design allows to displace the socket axis in the horizontal plane in two coordinates in a range ±10 mm with an accuracy of 0,01mm and to incline the axis at ± 40 '. The monuments are settled down almost in regular ~3.6 m intervals along the circumference of VEPP-4.

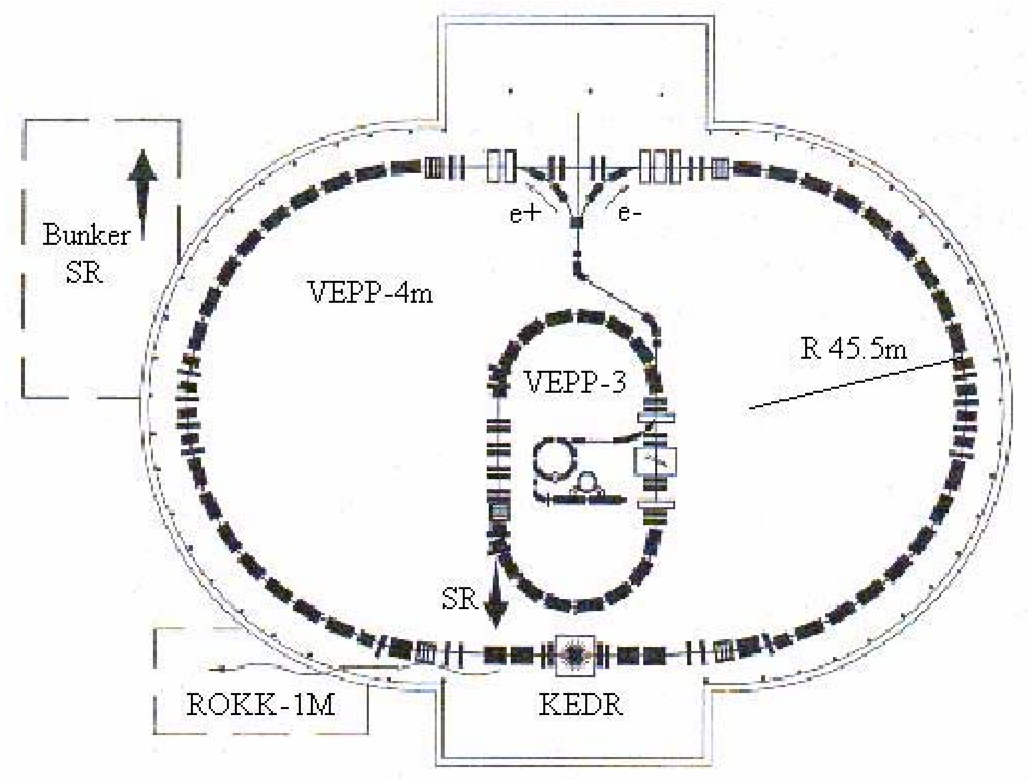

Fig. 1: Layout of VEPP-4M

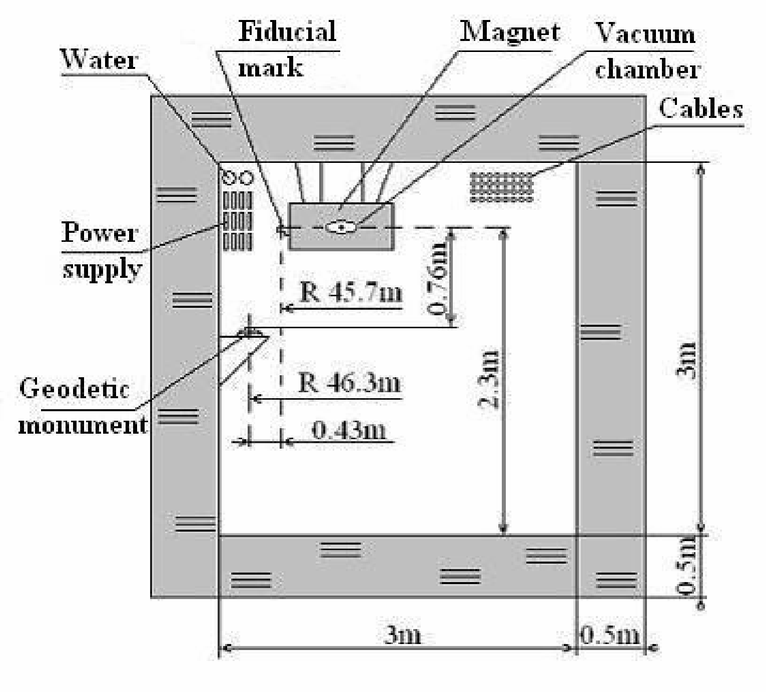

Fig. 2: Cross-section of VEPP-4M tunnel

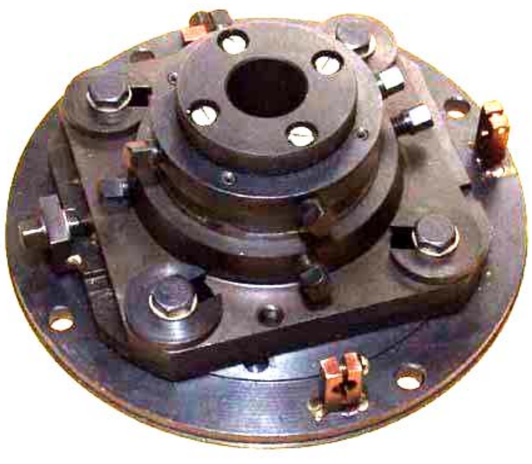

Fig. 3: Geodetic monument

Measurements in a horizontal and a vertical geodetic networks are performed separately. For the horizontal network an off-set measurements method was chosen, with additional measurements of distances between the neighboring monuments. The precision of measurement of distances is σ = 0,04 mm, off-set measurements up to 0,5m σ =0,015mm, off-set measurements from 0,5m up to 2 m σ = 0,030*L (m) mm.

The method of geometrical leveling is chosen for the vertical geodetic network. The leveling is made by short collimating ray from the middle, with the use of precision levels, such as Ni-007 and special scales. The precision of the measurements could be evaluated by σ=(0.016+0,002*L(m))mm, where L - a length of the collimating ray.

After the measurement result analysis, the monument coordinates are calculated with the following precision:

- Absolute positioning σR=0.6mm;
- Positioning with respect to a σR=0.06mm;
- Along the beam path σL=0.1mm;
- In vertical direction σZ=0.06mm.

3. THE GEOLOGICAL STRUCTURE OF THE SITE AREA

The accelerator complex is located in the region of the right-bank of the Ob - river plateau. The natural relief of the site was broken during various construction works, but the bias of district in the western direction was kept. The absolute elevations in the direction of the district bias is ranging from 178,0 up to 173,0.

The geological structure of the territory is built of the middle-overburden - loamy sands, loams, and clay sand.

The earth thickness from the surface to depth 0,2-2,5m is combined by a bulk ground (loamy sand, light loam). Under the bulk ground down to depth 6,0-10,0m (a.m. 164,0-168,0) sandy loam (light and heavy) with layers of sand, less often than the loam is deposited. Sandy loam does not contain impurities of organic, it is nonswelling, nonsubsidence, not salted.

Under a layer of sandy loam from depth 6,0-10,0m down to depth 15,0-17,0m (a.m. 160,0-162,0m), a loam with lenses of the sandy loam, water-sated is deposited. From depth 15,0-17,0m down to depth 25,0 and deeper, the dust sand with lenses of fine sand, from depth 18,0-20,0m passing to the fine sand is deposited.

The level of subsoil waters in March, 1991 was opened at a.m. 153.9m. The average size of seasonal fluctuations of a level of subsoil waters is 0,5-0,6m .

Major factors breaking mutual stability of the construction parts are:

- Change of a mode of humidity of substrates as a result of a filtration of the storm and spring waters. For example, in 1984 after a strong downpour, the active water inflow in a tunnel through expansion gaps and cracks with significant carrying out of a ground was observed. It testifies that the tunnel is a dam on the way of land water which bends around it from below and accumulates, at the external wall and takes out spreading ground from under a tunnel.

- Change of a seasonal temperature in the tunnels in a range ±10°C.
- Change of a specific loading on the soles by the complex physical equipment. For example, installation of detector "KEDR" (1000 tons), installation of a concrete wall served as a protection from the radiation.
- Destruction of the ground nearby the soles as a result of a construction of a synchroton radiation facility, and a tunnel for a linear accelerator.

4. THE SELECTION OF A STEADY GROUP OF MONUMENTS IN THE VERTICAL NETWORK

In local leveling networks used for a study of deformations of large engineering constructions, which differ by the increased requirements to the measurement accuracy, frequently, there is a necessity of a selection of the coherent group of geodetic marks. The estimation of stability generally consists of separation of the actual displacement and mistakes of their estimation and of comparison of these values. The criterion of a choice of a steady group, as a reference, is determined as a result of the analysis of changes in elevations values, in view of a physical nature of the phenomenon, real factors. The initial hypothesis, for example, can be the statement that the monuments can only go down (or only go up) or the average level remains constant.

Upon the completion of construction of the VEPP-4M tunnel, its deformations are being observed regularly. The analysis of the measurement results for the period from 1973 to 1975 had shown that acceptance for a reference an average level of all monuments of a network was not correct since the determined tendencies of monument motions exclude their casual character. Having the determined character of deformations, it was required to choose the reference more appropriate to real conditions. Since 1976, at VEPP-4 a different method was applied. A local group of monuments have been chosen as a stable one, if it forms a surface, which would not change its shape from one session of leveling to another one within the limits of measurement accuracy. Invariance of the surface shape means that there are no ground deformations.

The number of marks in a group should cover the area larger in size than that of a of a zone of essential deformations of the construction base. The maximal number of marks in the group is not limited. The first group of marks is formed from the chosen minimum of marks and subjected to the stability study. Then the neighboring mark from a leveling network is added to the group, and the conventionally accepted as the first mark is removed from the group. This results in the formation of the second group of marks, etc. So all the marks of the network are sorted. By the initial data for each group we evaluate the value of D_j by the following formula:

$$D_j = \sqrt{\frac{\sum_{k=2}^{m}\sum_{i=1}^{n}[(H_{ji}^{k} - H_{jav}^{k}) - (H_{ji}^{1} - H_{jav}^{1})]^2}{(m-1)n}}$$

where j – the number of a group;
i – the mark number in the group;
n – the number of marks in the group;
k – the number of measurement session;
m – the total number of measurement session;
H^k_{ji} – the height of the mark in the k_{th} session;
$H^k_{j\,av}$ - average marks in the k_{th} session.

The value of D_j characterizes the group stability. The least value of D_j specifies the stable group of marks and altitudes of the remained marks of the network should be referred to an average mark of this group. For stable group with probability ≥ 95 % is satisfied ratio $D_j \leq 1.7*\sigma_H$.

If some marks are included into the adjacent steady groups, it is necessary to increase the number of marks in the group and repeat the calculations. As the practice has shown, there is a destruction the earlier existing groups and occurrence of new steady groups of geodetic marks.

The given method can be applied under the following conditions: changes of mark altitudes correspond to deformations of a surface under study (a layer of ground, the base, etc.); distances between the neighboring marks are comparable with the sizes of a zone of essential deformations of bases; the grades of marks are obtained with approximately identical accuracy.

The principle of an invariance of a relative positioning of marks within the limits of accuracy of the distance and angular measurements can be put in a basis of a method of definition of the steadiest group of spacial marks.

5. VERTICAL AND HORIZONTAL DEFORMATIONS OF THE VEPP-4M STORAGE RING TUNNEL

Since 1973 about fifty sessions of measurements in a vertical geodetic network was carried out. On the diagram, Fig.4, some results are shown

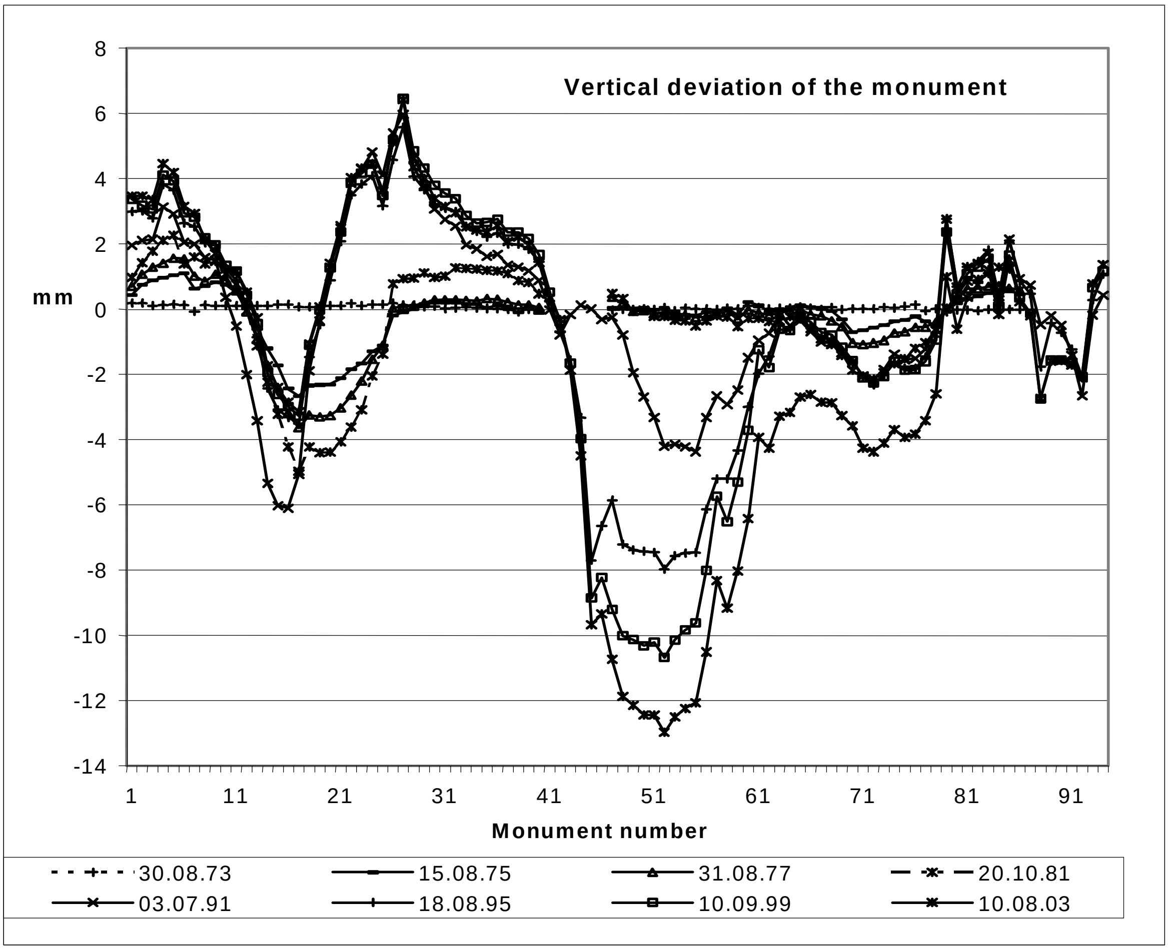

Fig. 4: Vertical deviation of the monument

The schematic diagram can be divided into three time periods.

In the first period from 1973 to 1977, the steady group of 47-53 marks was kept, the non-uniform subsidences in this group were not observed. But since 1977, the group stability began to break down. The reasons of this violation was not found out, but, as a probable reason it could be a laying of two cable lines with excavations on the surface and a transport activities occurred, in despite of the prohibition. The subsidence in a zone 12-25 marks caused by filling of a blanket of ground in 1973, continued later. The rise in an area of 1-10 marks can be explained by loading of the experimental section with protective concrete walls and a 400 ton magnetic detector. The subsidence of the section itself caused a wave buckling up in the neighboring areas. The non-uniform subsidence in a zone of 69-81 marks is a consequence of a storage of the equipment in gross weight of 15-20 tons at the surface above the ring. Buckling up in a zone of 25-40 marks began after carrying out of excavation and waterproofing works with opening the tunnel in a place of an adjunction of a tunnel to the building 15. The given steady group was used until 1988.

The second period was from 1988 to 2000. During this time, a new steady group in area of 65-75 marks was chosen. This time interval is marked by a number of construction works and modernization of the complex. One of the essential changes on the complex was the replacement of the detector. The weight of the new one was 1000 tons that has resulted in the further deposits of the experimental section and buckling up in the neighboring areas. During the construction of the bunker of the Synchrotron Radiation facility in 1989-1990, the ground was excavated in the area of 20-30 marks that has resulted in buckling up of this part of the ring . When making the LINAC tunnel in 1993-1995, subsidences in areas of 45-46 and 87-88 marks were clearly registered. During the period of 1988-2000, it was observed an intense deposit in the area of 46-60 marks. By the hydrological expertise, in 2000, soaking a southern semi-ring has been revealed and the decision to construct the drainage network was made. In 2000-2001, the drainage has been built. The latter might probably be a cause of a destruction of the steady group in the area of 65-75 marks.

Since 2000 to the present time, supervisions are carried out and research of a network on stability proceeds.

Measurements of the horizontal position of the monuments, unlike the high-altitude, is a cumbersome and time consuming procedure. Therefore, these measurements were carried out two times in a year at a stage of installation and commissioning of the complex, and once a year thereafter. The small volume of the information has allowed to reveal only some regularities in scheduled deformations of the tunnel:

- In practice, horizontal deformations of the tunnel independent of high-altitude deformations;
- A seasonal change of an average radius of the tunnel from winter to summer was observed to be 0,5 mm;
- On these seasonal deformations casual, irregular deformations in a range of ±0,5 mm were imposed.

The weekly measurements of a divergence of expansion gaps between blocks of the tunnel, temperature of air inside the tunnel, external temperature and temperature of a concrete wall of the tunnel were carried out. The temperature sensors of the wall were deepened in the concrete by 150 mm. Sensors of a divergence of expansion gaps are installed at external and at internal walls of the tunnel, at the wall surface. The seasonal nature and correlations between temperatures changes and behavior of expansion gaps were traced. Fig.5 shows the behavior of one expansion gap and temperatures of air for a few years.

Consideration of factors of a pair correlation and particular factors of a correlation has shown that the main reason of a divergence of expansion gaps is the change of the tunnel air temperature. The influence of the concrete temperature was insignificant.

As is seen in Fig.5, divergences of expansion gaps located at the external and internal walls of the tunnel had essentially different values. From this and a weak dependence of a divergence of expansion gaps on temperature of the concrete it follows, that a temperature regime change in the tunnel results in unequal deformations of various layers and parts of concrete blocks, there is no similar change of its form, and, hence, there are non-uniform scheduled deformations.

On the basis of these research works, some measures for stabilization of the temperature regime of the tunnel have been undertaken.

Long-term observation of deformations has shown, that the maximal strain rate run up ~ 1 mm per one year. Therefore they have, mainly, smooth character and can be interpolated by a smooth curve.

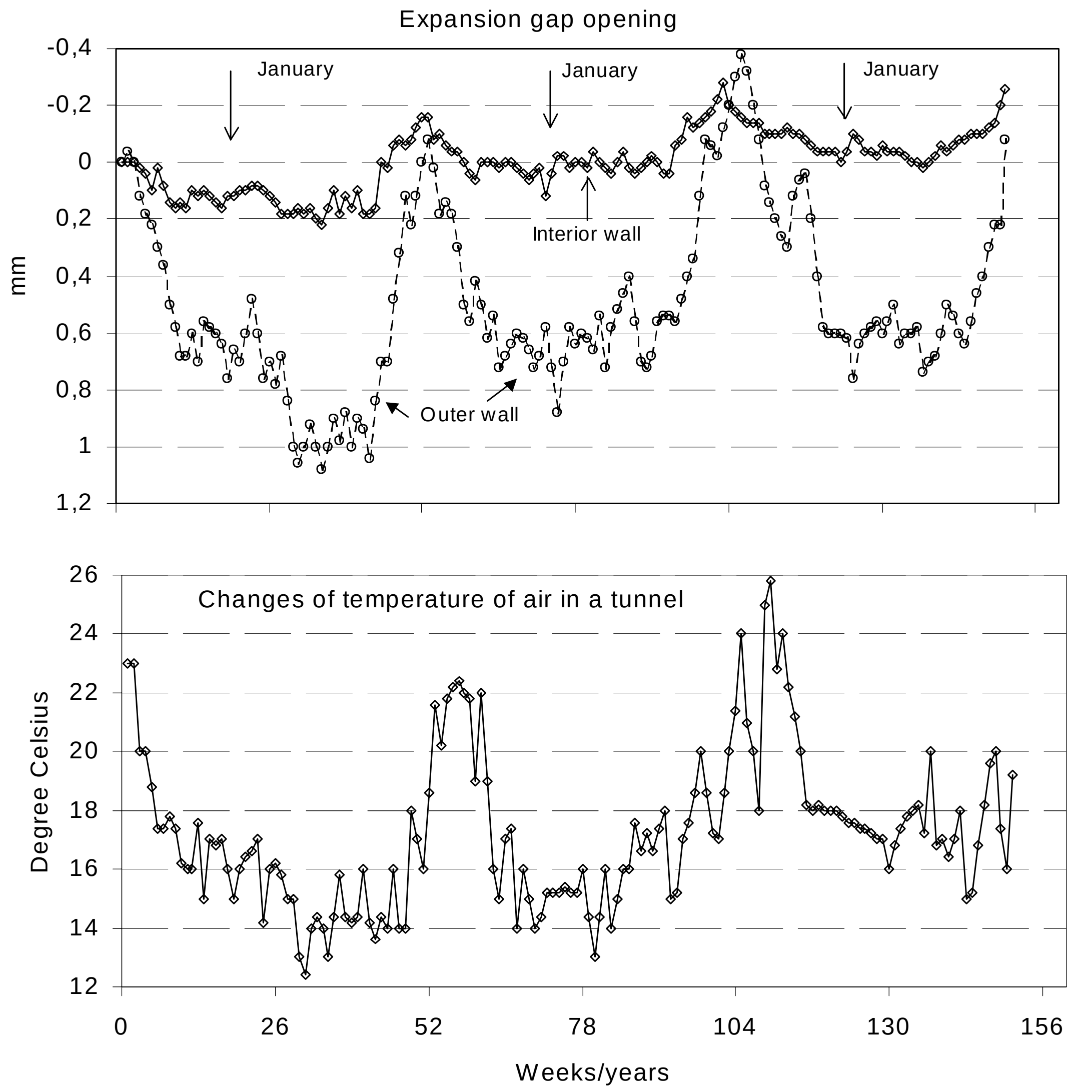

Fig. 5: Expansion gap opening

6. ADJUSTMENT OF THE EQUIPMENT POSITION WITH RESPECT TO A SMOOTHING CURVE

Measurements of magnet positioning in the tunnel have shown that there were no displacements occurred with respect to the tunnel base structures. Therefore, all the tunnel deformations correspond to deformations of the magnetic system. In order to satisfy the requirements of Table, once a year, during the prophylactic shutdown of VEPP-4M, the magnetic system elements are readjusted.

The executive surveying of monuments positions is made. To determine a smoothing curve, a curve, closed along the circumference representing the radial (vertical) position of geodetic marks is divided into the spatial harmonic components. The wavelengths Λ_n of these components are P/N, where P is the trajectory circumference, N is the integer number. Displacements of magnets due to harmonic components with the wavelength < $2*\lambda$ have insignificant affect on the particle trajectory. Therefore, the smoothing curve is determined as a sum of harmonic components with $\Lambda_n< 2*\lambda$, where λ is the earlier mentioned wavelength of betatron oscillations. The smoothing curve can differ significantly (up to a few millimeters) from the design curve of particle motion. For example, transformation of the circle into ellipse (N=2) has no effect on the accelerator performance. For VEPP-4M, the harmonic components with N=1,2,3,4 are summed. After that, adjustment is performed only for those components whose deviations from the smoothing curve exceed the tabular values (Table). The number of adjusted elements is much smaller than that at the "absolute" adjustment see Fig.6.

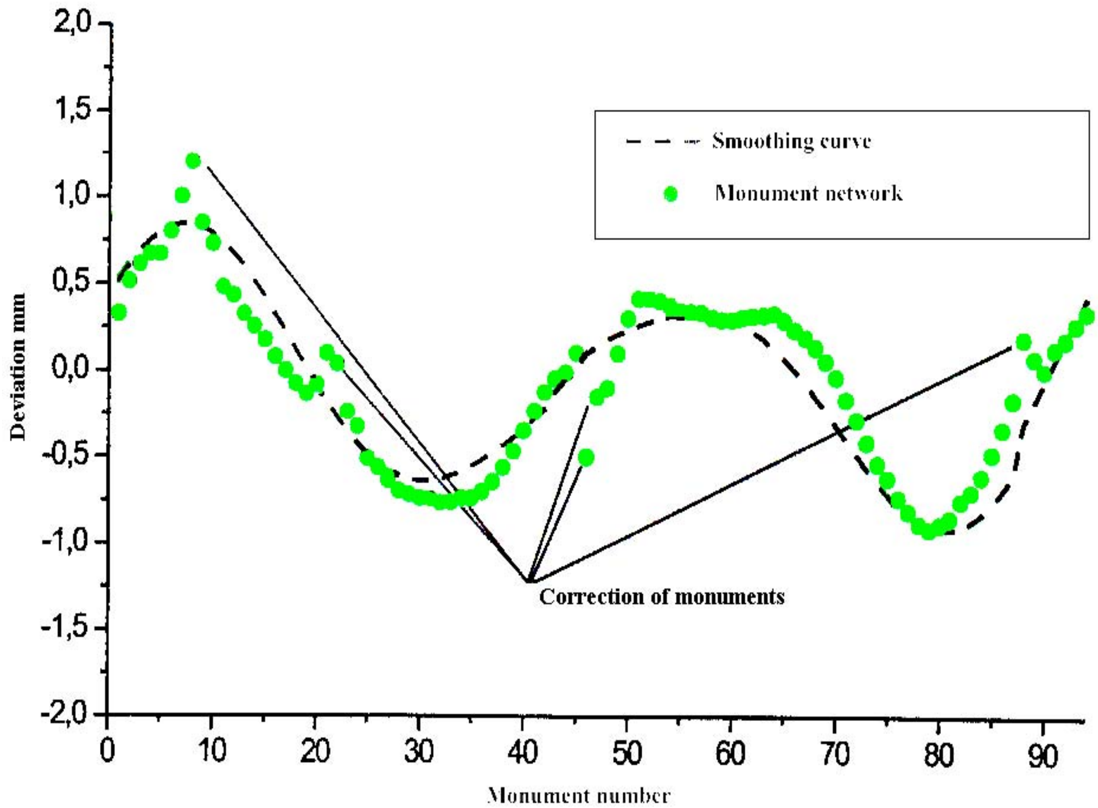

Fig. 6: Position of the VEPP-4M network monument in radial direction

Such an approach to the adjustment of magnetic systems enables one to eliminate the influence of smooth components of the tunnel deformations on the operablility of accelerators. The harmonic components with small N show the accuracy of the “absolute” geodetic measurements also. For example, elimination them from monument position enables one to determine the distance between the opposite points within accuracy of a few millimeters (and within a few centimeters in large storage rings as LHC CERN).

7. CONCLUSION

Experience of the long-term maintenance of the VEPP-4M complex has shown that on the base of correct physical prerequisites it is possible to provide the successful operation of the storage ring constructed under unfavorable geological-morphological conditions. This experience can be used by specialists in engineering research for the choice of the sites for the future accelerators and specialists who are responsible for the maintenance of the existing accelerators, specialists in geodetic engineering working at the accelerator centers.

REFERENCES

Courant E.& Snyder H. Handbuch der Physik, band XLIV, Instrumentelle Hilfsmittel der Kernphysik, Springer-Verlag, (1959), s. 439; Bruck H., Accélérateurs circulaires de particules, PUF, Paris, (1970)

Протопопов И. Я., Пупков Ю.А., Скринский А. Н., A system of tolerances for positioning magnets of the high energy storage rings. Geodetic works during the mountage and maintenance of technological equipment. Proceedings of the All-Union scientific technical conference, Moscow Система допусков на установку магнитов ускорителей на большие энергии, Геодезические работы при монтаже и эксплуатации технологического оборудования, Материалы Всесоюзной научно-технической конференции, М., ГУГК, ЦНИИГАиК, (1980),стр.99; Gervaise J. and Wilson E.J.N., High precision geodesy applied to CERN accelerators, Proc. CERN accelerator school. Applied geodesy for particle accelerators, CERN 87-01. Geneva (1987) p.128; Mayoud M., Applied metrology for LEP, ibid., p.248; Levashov Yu.I.,Pupkov Yu.A, Matrix method for analysis of network accuracy based on the beam dynamic theory. Proc. of 4-th International Workshop on Accelerator Alignment, KEK, JAPAN, (1995), p.--; Levashov Yu.I., Pupkov Yu.A., A smoothness criteria for trend curves used in accelerator alignment. Proc. of XVII International Conference on High Energy Accelerators - HEACC-98, 1998, Dubna. ОИЯИ, Дубна. 1999.

Анашин В. В. и др. VEPP-4: commissioning and first experiments, Proceedings of the 7th All-Union Workshop on charged particle accelerators, V.1, Dubna. запуск и первые эксперименты, Труды 7 Всесоюзного совещания по ускорителям заряженных частиц, Том 1, Дубна, (1981); V.V.Anashin at al., 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.

Bokov M.A., Levashov Yu.I.,Pupkov Yu.A., Survey and alignment of VEPP-4M. Proc. of 4th International Workshop on Accelerator Alignment, KEK, JAPAN, (1995), Боков М. А., Подойников А.А.,Пупков Ю.А., Determinin of the steady group of leveling marks. Geodesy and cartography N2 (1977)Определение устойчивой группы нивелирных знаков, Геодезия и картография. №2, (1977)

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