THE GENERAL PRINCIPLES OF SURVEY FOR UNK-1.

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INTRODUCTION

The ring electromagnet of the UNK will be located in the underground tunnel with a diameter in its regular part of 5.1 m. in the matched straight sections (MSS) - 7 m and the total length of more than 20 km. The tunnel installation depth reaches 54 m. The orbital plane of the future accelerator for providing favourable geological conditions for tunnelling has been designed with the 0.6 mrad inclination. The ring electromagnet consists of about 3000 units of the equipment - bending magnets (dipoles) and focusing lenses (quadrupoles).

Particular attention is given to the ideal maintenance of the UNK geometry. The most stringent demands are imposed on the accuracy of the mutual position of the quadrupoles, their total number is 456 units. According to the physical task, r.m.s. error of radial position of each quadrupol relative to the neighbouring ones must not be more than 50 μm, the r.m.s. height, error between the neighbouring ones must not exceed 60 μm. The quad-to-quad distance, 45.9 m or 47.5 m in MSS's, must be kept with the ±2mm accuracy. The permissible r.m.s. error of radial and height position of the dipoles relatively to quadrupoles is equal to ±1mm.

It is necessary not only to guarantee such a unique precision, but also to fit the accelerator orbit into the limited space of the tunnel. Therefore the precise tunnelling is one of the most important construction problems. According to the mechanical task requirements, variations of the tunnel axis around its theoretical position must not be more than 10 cm.

The high precision of the UNK equipment installation, the large orbit length, the large number of components, all that complicates the geodetic work, requires the new forms of this work based on its automatization, elaboration of new instruments, use of more advanced commercial geodetic tools.

1.1. The Surface Geodetic Network.

The tunnel is oriented in the Earth body by the geodetic network developed on the surface. The surface and underground geodetic networks are connected through the 19 vertical shafts of the UNK. The maximum distance between shafts is 1.5 km. Taking into account the wooding of the UNK construction site, the method of polygonometry has been chosen as the most economical for geodetic surface network. The position of the points of the so-called tunnel polygonometry is determined most exactly (see Fig. 1.1.). These points form a polygon on the surface, approximately corresponding to the underground location of the future accelerator orbit. The points situated on the periphery are connected by the tunnel polygonometry traverse built along the diameter. The distances between the points vary from 624 to 1916 m.

To decrease the errors caused by the instability of the geodetic centres, their coordinates are controlled by periodic network measurements. The accuracy of measuring the network elements has been chosen proceeding from the tunnelling precision and with due regard for modern geodetic Instrument capabilities. In particular, the r.m.s. error in measuring the distances is determined as ±5 mm, and that for measuring the angles as ±1."5.

There are 6 points in the surface network where the astronomic azimuths are measured in order to determine the network orientation in space. The r.m.s. error in azimuth determination is ±O."7. The azimuths measured accurately allow one to decrease the accumulation of the errors in the angle measurements, to obtain the co-ordinated results from one measurement cycle to another. The closed polygons and astronomic aximuths lead to the appearance of geometrical conditions, allowing one to adjust the network by the least squares method and to obtain the most probable corrections to the-elements measured.

The network geometry and the measurement accuracy have been estimated with the help of the covariation matrix of the vector of points coordinates. The r.m.s. errors of points coordinates calculated from the diagonal matrix terms are presented in table 1.1. Point 0003 is taken as the reference one. As is seen, the r.m.s. errors of the coordinates of the points most distant from the reference one do not exceed ±16 mm along Y and 19 mm along X. This corresponds to a relative error of the diameter of $4 \cdot 10^{-6}$.

Table 1.1.

The r.m.s. errors in the coordinates of the points of the surface network

Point name	M_x (mm)	M_y (mm)	Point name	M_x (mm)	M_y (mm)
0004	6	6	0033	13	16
0005	11	8	0032	13	15
0007	14	10	0030	12	13
0008	14	11	0029	10	11
Kalinovo	16	12	0028	8	8
0009	16	14	0027	5	5
0010	16	15	0031	12	14
0011	16	16	0017	13	15
0012	15	19	0021	12	15
0013	15	18	0023	13	15
622	15	19	0025	14	15
0014	15	19	0026	15	15
0015	14	17			

The adjustment of the measurement results yields the normalized matrix for the correlation coefficients for adjusted coordinates of the coordinates errors, suggesting that the errors in the position of the neighbouring points of the ring polygonometry traverse have a sufficiently close correlation (r_{min}=0.68). The r.m.s. error in the mutual position of the neighbouring points does not exceed ±9 mm.

To specify the tunnelling direction the surface geodetic network should be connected with the underground geodetic marks. The majority of the fundamental surface network marks is located far from the vertical shafts, through which the coordinates and direction are transferred to the tunnel horizon. Therefore in order to determine the coordinates of the geodetic marks, located directly at the vertical shafts, the polygonometry network is thickened. To make this operation more precise, it is executed many times and with redundant measurements.

The height geodetic network on the ground surface is developed on the plane network points with the accuracy, corresponding to the State First-Class Levelling: ±0.5 mm r.m.s. per 1 km of the levelling traverse. The bench-marks group near U-70 is taken as the reference one.

The high precision of the geodetic work required a more accurate account of the factors influencing it. In particular, in the construction region the gravimetric survey has been carried out in order to reveal the anomalies of gravity forces which can distort the results of the geodetic measurement. Table 1.2 shows the correction values taking into account the anomalies of the Earth gravity field for the construction region [1].

As is seen, these corrections into the values of angles and distances are negligible in comparison with measurement errors. The smooth nature of the correction variations along the whole UNK circumference allows one not to take them into account during the equipment adjustment. The accuracy of determining the astronomical azimuths corresponds to the correction value. Therefore it should be taken into account.

1.2. The Underground Geodetic Network

Tunnelling is done from every vertical shaft in two faces. As noted before, the maximal distance between shafts is 1.5 km. Hence, the counter-faces will meet at a distance of 750 m from the transfer of the coordinates and orientation directions into the shaft. However, for different reasons there is no timing of the beginning of tunnelling in different faces and the length of one face may reach 1.5 km. At this distance the tunnel axis must be no farther than 10 cm away from its theoretical location.

Table 1.2.

The corrections due to the anomalies of the Earth gravity field

Element	Correction value	
	maximum	average
Horizontal direction ($z>80^{o}$)	0."11	0."00
Mutual position of points at a distance of 100 m in the plane	0.05 mm	0.00 mm
Mutual inclination for plumb line orientation at a distance of 100 m	0."67	0."05
Astronomical azimuth	-	0."81
Mutual position of height points at a distance of 100 m	0.03 mm	0.02 mm

This strict tolerance requires the constant tunnelling control and that the tunnelling survey should be supplied with qualitative geodetic data. This is provided by the high precision geodetic surface network, its careful connection with the underground polygonometric points, the independent azimuth determination in the tunnel by means of gyrotheodolites.

For further utilization of the underground polygonometry marks it is expedient to arrange them at a distance of 45.9 m in the regular part of the machine and at a distance of 47.5 m in MSS, according to the position of the quads.

For tunnelling survey the polygonometry traverses are thickened to distances of 22.9 m and 23.7 m between the points.

Each polygonometry traverse is developed along the face advance and has the form of a "hanging" geodetic system with the measured angles, distances and gyroscope azimuths (see Fig 1.2.). As is seen, one can single out of this system an independent gyroscope traverse with 90-m lines, which is important for the tunnelling accuracy. In the traverse beginning, the orientation direction transferred from the surface is used.

Taking into account that the turning angles are close to 180°, one can consider this traverse to be a stretched one with the support on the reference point. In this case the tunnelling accuracy is dependent mainly on the errors in measuring the angles and gyroscope azimuths. As estimated from the observation conditions in the tunnel and also from the accuracy of the independent orientation instruments, the r.m.s. error in angle measurements should not exceed 5". and those of gyroscope orientation - 10". The organization of the accurate gyroscope observations being difficult under the tunnelling conditions, another version of high precision underground geodetic network was proposed. In this version the azimuth is measured not at every line of the gyroscope traverse but at every second one.

For both versions the covariation matrices for the vector of the transverse displacements of the gyroscope points have been obtained. The length of the "hanging" traverse is equal to 1.5 km. Table 1.3. shows the transverse standard deviations of the points for the two versions considered.

The table suggests that both versions satisfy the tunnelling accuracy required. The second traverse version is more preferable as it requires less measurements of the gyroscope azimuth. If it is realized, the probability of the tunnel axis deviation from the design position by more than 100 mm at a distance of 1.5 km from the face beginning is less than 0.01%.

These conditions can be regarded as quite acceptable. Moreover, the tunnelling accuracy will be verified by coordinates transfer through the trunk holes to be drilled from the surface to the tunnel horizon within every 400 m of advance.

Table 1.3.

The standard radial deviations for gyroscope traverse points due to the geodetic measurement errors.

N°N° points	Standard deviations (mm) 1	Standard deviations (mm) 2	N°N° points	Standard deviations (mm) 1	Standard deviations (mm) 2
1	0.0	0.0	18		
2			19	9.7	11.6
3	2.4	2.3	20		
4			21	10.3	12.2
5	3.7	4.6	22		
6			23	11.1	13.1
7	4.7	6.2	24		
8			25	11.8	14.1
9	5.4	7.3	26		
10			27	12.6	14.8
11	6.4	8.2	28		
12			29	13.4	15.6
13	7.2	9.1	30		
14			31	14.1	16.4
15	8.3	10.2	32		
16			33	14.6	17.2
17	9.2	11.1	34		
			35	15.0	18.4

1.3. The Connection between the Surface and Underground Geodetic Measurements

The determination of the reference coordinates and underground geodetic network orientation in the beginning of the tunnellling is a most important stage in geodetic work. The coordinates and directions are transferred through the vertical shaft by the method of joining triangle, i.e. by simultaneous measurements of the directions from the points of the surface and underground networks to two plumbs cast into the shaft. The altitudes of the geodetic points at the shafts are transferred to the shaft bottom with the help of steel tape-measures. These procedures are described and stipulated in the instructions and manuals of the construction firms. Practically, the r.m.s. error of orientation with the method of joining triangle is l0"- 12". which corresponds to the gyroscope orientation precision. The accuracy of transferring the coordinates with the help of the plumbs is 2- 3 mm. Special attention should be attached to the coordinates transfer, because the underground polygonometric points at the vertical shafts will be regarded as the reference ones in the future adjustment of the UNK equipment.

Through the trunk holes, located between the vertical shafts, there will be the coordinates and altitudes transfer down in order to specify the tunnelling direction.

As soon as separate sections of the tunnel are over, the connection between the surface and underground networks will not be needed any longer and when the whole tunnel is completed, the surface network will not be needed either.

1.4. Geodetic Instruments and Equipment Used in the Construction of the UNK Tunnel

One of the factors which guarantees the high quality of the geodetic work is the utilization of the reliable and precise geodetic instruments and the double measurements by different instruments.

In particular, the distances of the surface and underground polygonometry are measured by EDM apparatus AGA (Sweden), ELDI2 (West Germany), Mekometer Me-3000 (Switzerland), SM2 (USSR). The r.m.s. error in measuring the distances after the least square adjustment is ±5 mm.

The angles of the surface network formed by the adjacent points are measured according to a special programme by such theodolits as Theo-010, Theo-010A(E.Germany), 0T-02(USSR). The r.m.s. error in measuring the angles after the network adjustment is ±1."3. Independent orientation in the tunnel is carried out by the gyrotheodolites GiB-2, GIB-21, GiB-3 manufactured by a Hungarian company MOM.

The position of the bored tunnel intervals with respect to the design one is checked by the photogrammetry method. For the distance measurements to have the same scale, the linear measures are compared periodically at the IHEP comparator. The cyclic errors of the EDM devices are also studied here. The constant corrections of the EDM devices are determined on the 150-m and 1-km bases.

2. THE SURVEY METHODS FOR INSTALLING THE UNK EQUIPMENT

2.1. The Choice and the Estimation of the Survey Methods for the Installation of the UNK Equipment

The stringent requirements imposed on the accuracy of the mutual position of the UNK magnets, a large scope of this unique work, the limited tunnel cross-section space have established the underlying principles for the choice of the installation method:

1. This method must be simple, excluding any extra measurements and, if possible, even some stages of measurements. This will make it possible to avoid additional errors and also to provide favourable conditions for the measurements automatization.
2. The method should make the maximal use of the results of the previous measurements.
3. The geodetic work must occupy the minimum space in the tunnel cross-section.

The geometric axis of the future accelerator orbit has a closed ellipsoid form, close to the circumference (see Fig. 1.1.). The tunnel, where the accelerator ring must be located, is divided by the shafts into separate sections. As soon as separate tunnel sections are commissioned, they will be filled in with the equipment. The schedule of commissioning different sections may vary strongly. Therefore it may well happen that the equipment will be installed in the sections remote from each other and connected only by the surface geodetic network. In that case the high precision of the mutual position of the equipment elements comes in conflict with a worse accuracy of the determination of the underground geodetic points on the joints of the sections. In this connection after the final precise adjustment of all sections of the ring and orbit closing, it will be necessary to repeat the adjustment, correcting the inaccurate knowledge of the geodetic point position on the joints of the sections. In this case the equipment of some whole sections must be displaced by a few tens of mm. In addition, to make the final adjustment of the equipment, it will be necessary to await the tunnelling completion. In order to eliminate this disadvantage, the 1st phase of the machine is planned to be assembled on the basis of the following procedure.

The reference marks located underground along the circle perimeter on the section joints serves as the basis for installation. Each pair of the neighbouring marks sets the beginning and the end of the magnet structure section, which is aligned independently of other sections. The main factors influencing the value of the closed orbit distortion are:

a) errors in the position of the reference marks:

b) errors in quadrupole installation.

2.1.1. The Determination of the Position of the Reference Marks

The coordinates of the reference marks are determined from the measurements of the surface geodetic network (see Section 1), which are then transferred through the vertical shafts to the tunnel horizon. The r.m.s. errors in the mutual position of the neighbourlng points of the surface network in radial and tangential directions to the accelerator axis after the adjustment do not exceed $m_R=m_T=\pm 9$ mm (see Subsection 1.1.).

The r.m.s. error of the coordinates transfer to the tunnel horizon is not more than $m_{tr}=\pm 3$ mm. Then the accuracy of the plane position of the underground reference marks is as follows:

in the radial direction

$$M_R=\sqrt{m_R^2+m_{tr}^2} = 10 \text{ mm:} \qquad (2.1.)$$

in the tangential one

$$M_T = \sqrt{m_T^2 + m_{tr}^2} = 10 \text{ mm}. \qquad (2.2.)$$

If the accuracy of the mutual height position of the neighbouring surface network marks is defined as $m_H = 2$ mm, the accuracy of altitudes transfer to the tunnel bottom as $m_{H_{tr}} = 2$ mm, then the r.m.s. error of the position of the neighbouring underground reference marks is

$$M_H = \sqrt{m_H^2 + m_{H_{tr}}^2} = 3 \text{ mm} \qquad (2.3.)$$

As a result of the numeric simulation the following stochastic relation between the r.m.s value of the closed orbit distortion in the quadrupole centre of the normal period and the error in the mutual position of the reference marks has been obtained:

$$M_{x_1} = \sqrt{0.13 \cdot M_R^2 + 2 \cdot 10^{-4} \cdot M_T^2} \qquad (2.4.)$$

$$M_{z_1} = 0.5 M_H \qquad (2.5.),$$

where M_{x_1}, M_{z_1} are the r.m.s. orbit distortions in radial and vertical directions, respectively. All the coefficients are dimensionless.

After the substitution into equations (2.4.), (2.5.) of the values of M_R, M_T, M_H determined in (2.1.), (2.2.), (2.3.) the following r.m.s. orbit distortions are obtained:

M_{x_1} = 3.6 mm;

M_{z_1} = 1.5 mm.

2.1.2. The Quadrupole Installation

The specific feature of installation is its realization not on the basis of the fundamental geodetic network, but on the basis of the geodetic measurements on the geodetic marks located directly on the equipment to be adjusted [2]. This will help avoid errors of the whole stage of the geodetic work usually carried out during the accelerator installation, i.e. surveying the geodetic marks on the equipment to the fundamental high precision geodetic network. The absence of the network will decrease considerably the scope of the geodetic work and the space occupied by it.

The quadrupoles are installed in each section in the following way. For radial adjustment each quadrupole has two geodetic marks: the main and additional. The main mark on the 1st quadrupole is surveyed to one of the reference marks near it at the bottom shaft. Then the following measurements are made on the geodetic marks fixed on the quadrupoles: the measurements of the offsets of two marks on each quadrupole from the line defined between the main marks on two neighbouring quadrupoles and those of the distances between the neighbouring main marks (Fig. 2.1.).

At the same time the height quadrupoles position is determined by consecutive levelling. The levelling is carried out on the geodetic marks fixed to the quadrupoles from below. After the last quadrupole is surveyed to the second reference mark, the discrepancy is determined and distributed evenly among the network elements. Then the displacements of the quadrupoles are computed.

The connection between the r.m.s. orbit deviations and the installation errors is determined by the following equations:

$$M_{x_2} = 77\ m_h\ ;$$

$$M_{z_2} = 27\ m_z\ ,$$

where m_h is the r.m.s. error in the offsets measurement,

m_z is the r.m.s. error in the levelling of the neighbouring quadrupoles.

If $m_h=5\cdot 10^{-2}$ mm and $m_z=6\cdot 10^{-2}$mm, the following r.m.s. orbit distortions are obtained:

$$M_{x_2} = 3.8 \text{ mm}$$

$$M_{z_2} = 1.6 \text{ mm} .$$

2.1.3. The Estimation of the Orbit Distortion due to Survey Errors

In 99.94% of all the cases the maximum closed orbit deflection from the axis of the vacuum chamber of the machine is equal the following values:

$$M_{x_{max}} = 3.4 \ M_x \qquad (2.6.)$$

$$M_{z_{max}} = 3.4 \ M_z \qquad (2.7.)$$

where

$$M_x = \sqrt{M_{x_1}^2 + M_{x_2}^2} \qquad (2.8.)$$

$$M_z = \sqrt{M_{z_1}^2 + M_{z_2}^{\ 2}} \qquad (2.9.)$$

Putting the values of $M_{x_1}, M_{x_2}, M_{z_1}, M_{z_2}$ evaluated above into formulas (2.8)-(2.9) one obtains:

$M_x = 4.5$ mm; $\qquad M_{x_{max}} = 15.5$ mm

$M_z = 2.2$ mm; $\qquad M_{z_{max}} = 7.5$ mm.

Table 2.1. shows the r.m.s. closed orbit distortions for the first and the second phases of the UNK versus the magnet and the geodetic measurements errors, the errors in surveying the quadrupole marks to the magnetic axis and also the magnetic field quality.

Table 2.1.

The closed orbit distortions for the first and the second phases of the UNIX

Distortion cause	Perturbation value	1-st phase M_x (mm)	1-st phase M_z (mm)	2nd phase M_x (mm)	2nd phase M_z (mm)
1.The effective dipole field spread with account of errors in magnet measurements	6×10^{-4}	3.3	3.2	3.3	3.2
2. The errors in quadrupole marks surveying	0.1 mm	3.4	3.4	3.2	3.2
3. The quadrupoles adjustment errors R	0.05 mm	3.85		2.8	
Z	0.06 mm		1.62		1.6
4. The reference marks determination errors R	10 mm	3.6		-	
Z	3 mm		1.5		-
The resultant effect of factors		7.1	5.2	5.4	4.8
The max.orbit distortion due to systematic dipole fields spread (mm)		2	-	2	-
The max.orbit deflection (mm)		±24	±18	±19	±15

2.2. The Main Stages of the Equipment Installation in the 1st Phase of the UNR

2.2.1. The Measurement of the Additional Network

The equipment of the 1st phase of the UNK will be installed in the tunnel on special supports furnished with adjustment gears. For its preliminary installation the geodetic network developed during tunnelling will be used. The versions of the network development and the estimate of their accuracy were considered in Subsection 1.2. After the tunnelling of the section is over this network will be supported by two reference marks located on both ends of the interval bored. The discrepancy obtained in this case by introducing the corrections into all measured elements of the network will be distributed over the coordinates of the marks between the reference ones.

In the places, where the network marks are not preserved or are inconvenient for utilization, the additional network will be built, its marks will be placed in the floor in the central part of the tunnel near the quadrupoles. The r.m.s. errors in measuring the elements of the additional network are ±1."5 for angles and ±2 mm for distances. Table 2.2 gives the r.m.s. transverse deviations for the underground network points from the line defined by two reference marks on both ends of the section. It also gives the r.m.s. deviations for the additional network, for both network versions developed during tunnelling and also the high precision network to be measured directly on the quadrupole marks with the following r.m.s. errors: +50 μm for the offset, and ±1 mm for distances. The high precision network will be used in the final equipment adjustment. The table indicates that the maximum errors in the points position are in the middle of the traverses. The accuracy of the three types networks for the supports installation is of about the same order.

There will be a close correlation between the errors in the transverse position of the neighbouring points of the installation networks. Table 2.3 contains a block of the normalized matrix for the correlation coefficients of the errors in the transverse position of the points of the additional network. One can see that the correlation coefficients of the errors of the neighbouring points are close to unity. Therefore the networks points due to measurement errors will be located relatively to its true position on a smooth curve passing through both reference marks.

2.2.2 The Preparatory Geodetic Work

The installation geodetic network serves for plotting on the tunnel floor the line corresponding to the orbit axis of the future machine. The experience in assembling the booster-accelerator in 1979-1980 showed that such a line raises the efficiency of preparatory assembling work.

Table 2.2

The r.m.s. transverse deviation of the points of the installation networks in the UNK tunnel

$N^{o}N^{o}$ point	r.m.s. deviations (mm)				$N^{o}N^{o}$ point	r.m.s. deviations (mm)			
	network type					network type			
	additional	1 version	2 version	precise		additional	1 version	2 version	precise
1	0.0	0.0	0.0	0.0	18	9.0			2.7
2	1.1			0.3	19	8.9	5.8	7.8	2.7
3	2.0	2.0	2.2	0.6	20	8.8			2.6
4	3.0			0.9	21	8.6	5.7	7.6	2.6
5	3.8	3.3	4.0	1.2	22	8.3			2.5
6	4.6			1.4	23	8.0	5.5	7.3	2.4
7	5.3	4.1	5.2	1.6	24	7.6			2.3
8	6.0			1.8	25	7.1	5.2	6.8	2.2
9	6.6	4.7	6.2	2.0	26	6.6			2.0
10	7.1			2.2	27	6.0	4.7	6.2	1.8
11	7.6	5.2	6.8	2.3	28	5.3			1.6
12	8.0			2.4	29	4.6	4.1	5.2	1.4
13	8.3	5.5	7.3	2.5	30	3.8			1.2
14	8.6			2.6	31	3.0	3.3	4.0	0.9
15	8.8	5.7	7.6	2.6	32	2.0			0.6
16	8.9			2.7	33	1.1	2.0	2.2	0.3
17	9.0	5.8	7.8	2.7	34	0.0			0.0

The points characterizing the position of the electromagnet elements, i.e. their geometrical axes are marked on the line. The r.m.s. error of the marking-out must not exceed ±5 mm relatively to the geodetic network. The vertical distances from these points to the orbit axis are determined by the levelling.

The equipment supports are installed relatively to the marking-out with account of the measured vertical distances with the help of plumbs, installation staffs and clinometers. In this case the adjusting gears on the supports are put into their medium position. The preliminary installation of the equipment placed on the supports is also carried out relatively to the floor marking-out. The installation accuracy is ±3 mm r.m.s.

The mutual longitudinal position of the electromagnet elements versus the distances is controlled by the EDM instruments of type DK-001, by tape-measures and the steel staffs to an accuracy of ± 2 mm. This stage of the longitudinal equipment installation may be considered as final.

Table 2.3

The block of the normalized covariation matrix for the vector of the transverse deviations of the additional network

1.00	0.99	0.97	0.96	0.94	0.93	0.91	0.90	0.88	0.87	0.85	0.84
0.99	1.00	0.99	0.98	0.97	0.95	0.94	0.92	0.91	0.89	0.88	0.86
0.97	0.99	1.00	1.00	0.99	0.97	0.96	0.95	0.93	0.92	0.90	0.89
0.96	0.98	1.00	1.00	1.00	0.99	0.98	0.96	0.95	0.94	0.92	0.91
0.94	0.97	0.99	1.00	1.00	1.00	0.99	0.98	0.97	0.95	0.94	0.93
0.93	0.95	0.97	0.99	1.00	1.00	1.00	0.99	0.98	0.97	0.96	0.94
0.91	0.94	0.96	0.98	0.99	1.00	1.00	1.00	0.99	0.98	0.97	0.96
0.90	0.92	0.95	0.96	0.98	0.99	1.00	1.00	1.00	0.99	0.98	0.97
0.88	0.91	0.93	0.95	0.97	0.98	0.99	1.00	1.00	1.00	0.99	0.98
0.87	0.89	0.92	0.94	0.95	0.97	0.98	0.99	1.00	1.00	1.00	0.99
0.85	0.88	0.90	0.92	0.94	0.96	0.97	0.98	0.99	1.00	1.00	1.00
0.84	0.86	0.89	0.91	0.93	0.94	0.96	0.97	0.98	0.99	1.00	1.00
0.82	0.85	0.87	0.89	0.91	0.93	0.95	0.96	0.97	0.98	0.99	1.00
0.81	0.83	0.85	0.88	0.90	0.91	0.93	0.95	0.96	0.97	0.99	0.99

2.2.3. The Final Equipment Adjustment.

The precise adjustment of the equipment is carried out after its preliminary installation. First, the quadrupoles are adjusted. The offsets of the geodetic marks fixed on the quadrupoles are measured from the alignment line defined between the main marks on the two neighbouring quadrupoles (Fig. 2.1.). The measurements are made with the help of the steel string and the invar staffs.

Taking into account that the equipment of the first phase is placed high (Fig. 2.2.1, the dedicated precise zenith-apparatuses will be used as microscopes.

At the same time the height position of the quadrupoles is determined by the levelling on the geodetic marks fixed from below on every quadrupole. For this purpose the precise levels with selfsetting sight line as Ni-005B, Ni-002, Ni-005 (East Germany) or N-05K(USSR) are used [3].

The measurements are made in the specially chosen zone (Fig. 2.2.). which must not be occupied by other services. This zone will be kept in the accelerator exploitation period.

As mentioned above, the geodetic network on the equipment is supported by two reference quadrupoles, installed from the reference geodetic points on both ends of the section. From the measured data the discrepancy is obtained and distributed among it. Then the necessary radial and vertical displacements of the quadrupoles are determined and they are installed in their design position with the help of gears and mechanical indicators.

Let us estimate the r.m.s. value of the expected displacements. This value consists of the errors in the position of the geodetic network points used for marking-out (see Table 2.2), errors in the marking-out, those in the initial equipment installation above the marking-rout and the errors in the position of the points of the high precision network on the equipment (see table 2.2.). Using the above data on the values of the enumerated errors we obtain the following r.m.s. value for the radial displacements:

$$m_{disp} = \sqrt{9^2+5^2+3^2+2\cdot7^2} = \pm 11 \text{ mm.}$$

This means that the displacement value in the central parts of the 1.5-km section will be in the ± 25 mm interval with the probability 97%. Therefore the adjusting gears must be operable within this range. A similar value for the interval of the vertical equipment displacement is ±10 mm.

The quadrupoles are displaced with the help of special devices with indicators. After displacement the survey is taken for the second time. Its results allow one to judge whether the second displacement is required. After the quadrupoles are installed. their geodetic marks will serve as the basis for the dipoles installation. The radial one will be carried out with the help of the theodolit and special sight mark placed on the geodetic marks of the neighbouring quadrupoles. They specify the alignment line for the adjustment of the dipoles placed between these quadrupoles. (see Fig. 2.1).

One can adjust a large number of the equipment (about 3000 units) timely and accurately only on the basis of the automatization and computerization of the adjustment process. In particular, to displace the elements it is planned to use the computer-connected servodrives, the displacement indicators and electronic clinometers. The lazer system with the remote data read-out will be used to adjust the dipoles. The primary processing and storing of the measurement data will be done by a field computer. Other aspects of high precision geodetic measurements will also be automized and computerized.

After the 1st phase of the machine is assembled, the necessity of the local additional displacements of the equipment will be determined from the data on the second survey of each section.

2.3. The Observation of the Stability in the Position of the Tunnel Structures and Equipment

Instability in the position of the tunnel structures and equipment can violate the high precision attained during adjustment. The major factors affecting the stability are the load values and the geological environment conditions. Presently, the work on detecting the UNK areas, where deformations may occur, is carried on. For this purpose the geodetic observations of the tunnel stability are made on the geodetic network marks in the tunnel. They make it possible to trace the deformation nature in time and to estimate the critical deformations corresponding to the hazardeous harmonics of the machine and also to determine the moments of deformation stabilizaton. Taking into account a large scope of work the stability observations are to be automized.

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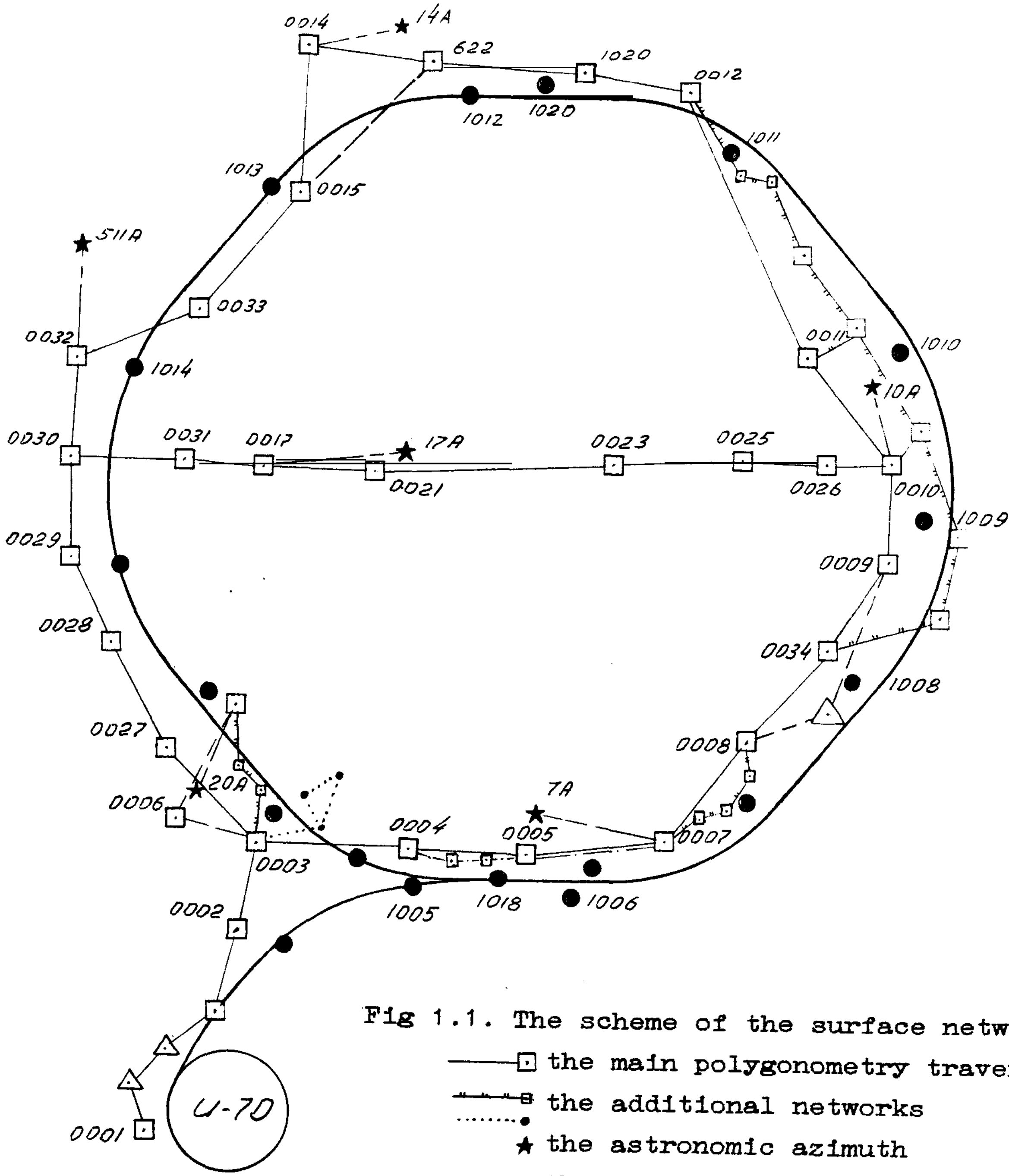

Fig 1.1. The scheme of the surface network

the main polygonometry traverse

the additional networks

the astronomic azimuth

the microtriangulation points

the shaft

the point of the State Network

the temporary polygonometry

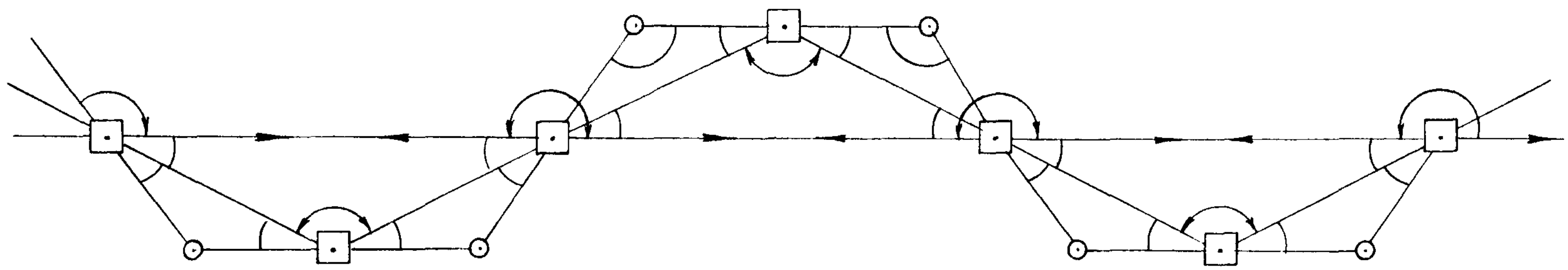

Fig. 1.2. The scheme of the underground geodetic network

- the main polygonometry points
- the tunneling network points
- the hyroscope azimuthes
- the meazured angles
- the measured distances

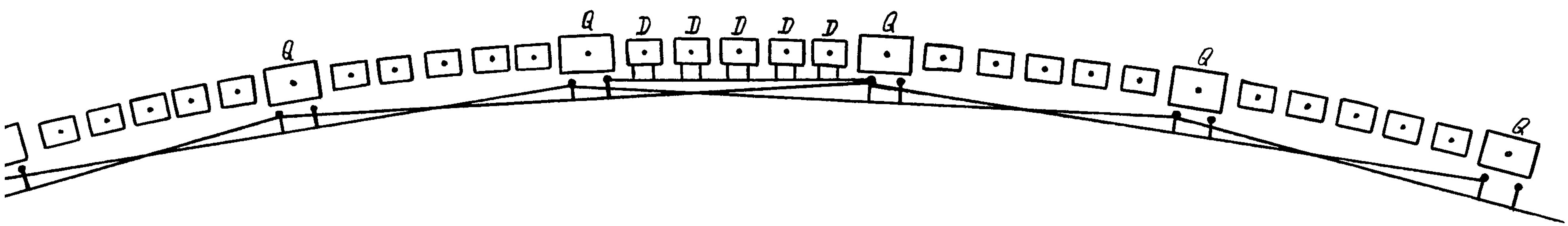

Fig. 2.1. The scheme of the offset measurements of the geodetic marks on the quadrupoles

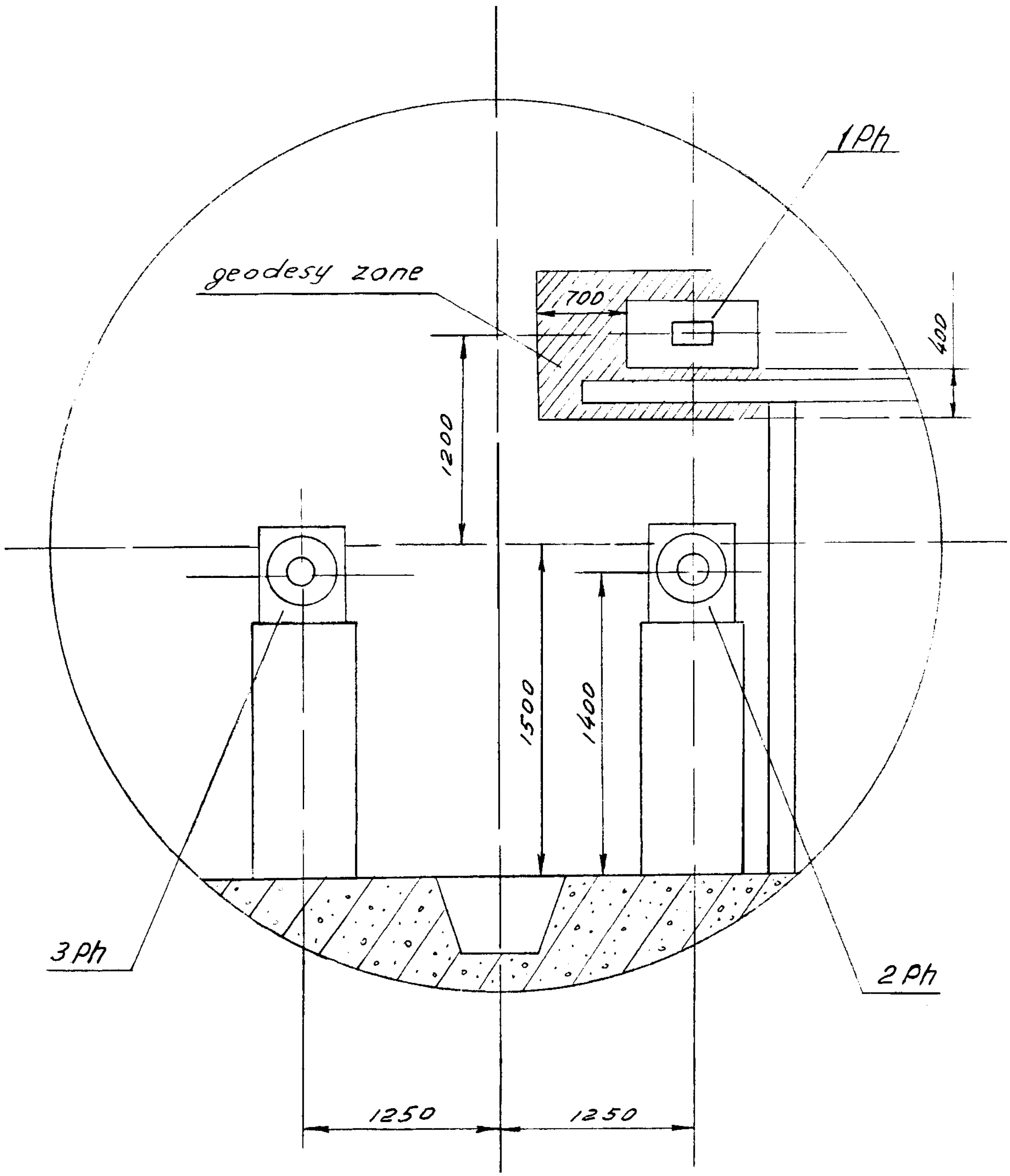

Fig. 2.2. The scheme of UNK equipment disposition in the tunnel section