THE PRECISE ALIGNMENT OF THE INJECTION BEAM LINE FOR THE UNK

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The injection beam line for the UNK will be used to transport the particle beam from the operating accelerator U-70 to the electromagnets of the 1st phase of the UNK 21 km in circumference.

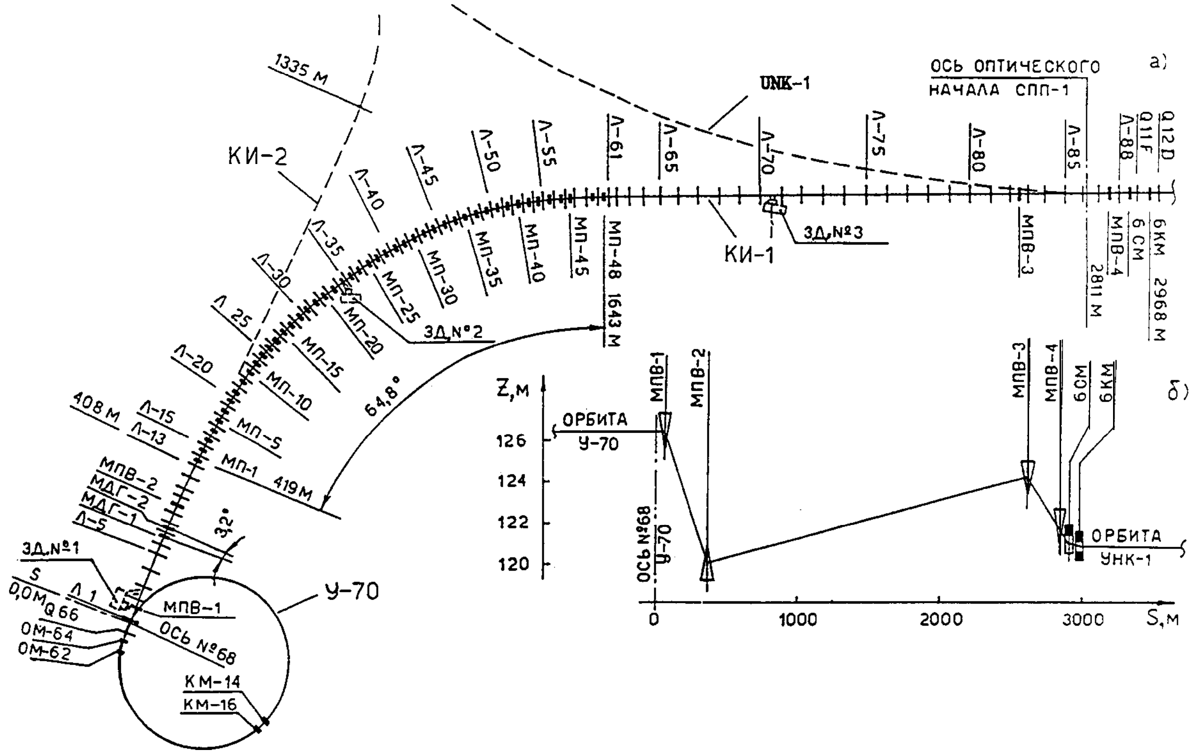

Fig. 1 The scheme of the injection beam line for the UNK

The beam line orbit is more than 3 km long (Fig. 1). The beam line equipment includes 188 main magnet elements. There are 89 quadrupoles, 62 bending dipoles and 37 correction dipoles. The distance between the quadrupoles is 25-51 m. The height of the vacuum chamber centre above the tunnel floor is 1.1 m. The relative position error of the neighbouring quadrupoles in the lateral directions must not exceed ± 0.2 mm r.m.s.. The precision of the dipoles positioning with respect to the quadrupoles is ± 1.0 mm r.m.s.

The problem of the beam line equipment alignment was settled successfully using the technology designed at IHEP. Some single parts of the technology may be distinguished from the known methods. One of them is the geodetic network, developed in the period of boring the main ring tunnel during the early step of the adjustment.

The network had two parts : surface and underground. The surface part was included into the general surface geodetic control for the UNK. It was the traverse (see fig. 2), where the comers and distances were measured to a precision of ± 1.5” and ± 5 mm r.m.s.

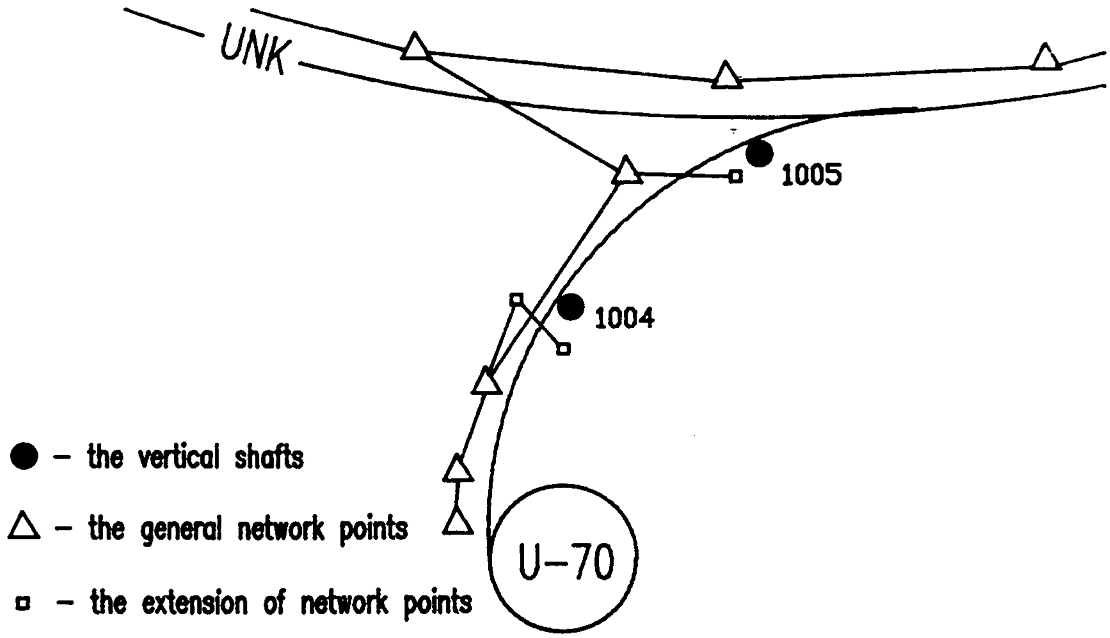

Fig. 2 The scheme of the surface network for the injection beam line

The points of the surface network were fixed with help of metal tubes. Each 80 mm diameter tube had its concrete anchor placed below the soil freezing level. The tube top had a shape of a half-sphere with a cross mark. It was 20-30 cm below the surface and was used as a co-ordinate storage.

The altitudes of the points were measured by levelling to a precision off 5 mm r.m.s. per 1 km. The network points were referenced to the network of the operating accelerator U-70.

The underground part of the geodetic network supported the tunnel boring. It was referred to the surface part through the vertical shaft and ventilation wells placed in every 400 m. For this purpose, the co-ordinates and altitudes of the surface points were passed by the extension of the network immediately to the shafts and wells.

The underground network included 51 points, anchored to the concrete floor in every 60 m along the tunnel. The corners and distances between the neighbouring points were measured to a precision of ± 5” and + 5 mm. To increase the precision of the boring direction, the network was oriented additionally through the azimuth measured by gyrotheodolite with ± 10” r.m.s.

According to the estimates, the final precision for the plan lateral position of the network point, placed in the middle of the beam line, relative to the points in its beginning and end was ± 5 mm r.m.s. The precision of the height position of the middle point was ± 1.5 mm.

The sufficiently high precision of the network allowed us to use it at the fist stage of the equipment alignment. First, for the marking-out on the tunnel floor of the main geometrical axes of the supports under the magnets. This marking-out decided the problem of the preliminary installation of the equipment. The point is that the adjustment screw-jacks on the supports are connected geometrically with main axes of the magnets. If one installs the support according to marking-out, sets the adjustment screw-jacks in the middle position and after that places the magnet on the support, then the magnet will go automatically to the initial position for the precision adjustment.

The supports were installed using the ordinary devices, including the plumb bobs, rods, and clinometers. This work was done by the construction firm experts during the mounting activities. At this stage, the magnets were installed at their design longitudinal position to a precision of ± 5 mm. Later on, this position was left unchanged, and during calculations the design distances between the magnets was used.

For the precise alignment, the magnet structure was divided into nine approximately equal sections. Each section was aligned independently of others. The section borders were determined by tow magnet elements, selected as initial ones. There were two quadrupoles with correction dipoles placed near them.

The second aspect of the applying the saved geodetic network was the installation of the initial quadrupoles at the design position. The alignment order of each section was the following :

- the installation of the initial elements from the geodetic network points (the precision was ± 1 mm);

- the alignment of the quadrupoles, placed within the section. The quadrupoles were aligned on the design trajectory, run along the initial magnets. The precision of the relative positioning of the neighbouring quadrupoles was ± 0.2 mm;

- the beam line geometry smoothing at the section joints with the help of cubic spline-functions. This operation allowed us to avoid the sharp comer bends at the sections joints through the accumulation of the measurement errors;

- the bending and correction dipoles alignment relative to the already adjusted quadrupoles (the precision was ± 1.0 mm).

The exposed surfaces, formed from the edges of lamellae making the magnet body, were chosen as the base surfaces for alignment. The base surfaces were located on the sides, top and bottom of each magnet. They were referred to the main longitudinal magnet axis.

The relative lateral plan position of each three neighbouring quadrupoles was measured according to the following scheme (see fig. 3). The theodolite Wild T-2002 on the tripod was placed at a distance of about 2-3 m from one of the two outer quadrupoles. The rod with the invar scale for levelling 400 mm long was placed on the longest from the theodolite base surface of the opposite quadrupole. The theodolite was sighted with comer reading on one of the lines on the rod scale. This was the initial direction. Then instrument was sighted on other five positions of the rod, in every case on the rod line, the nearest to the initial direction.

The measured corners between the initial direction and the directions to the other positions of the rod, the measured distance from the theodolite to the nearest quadrupole, the known distances between quadrupoles presented an opportunity to determine the position of the quadrupole centres relative to the initial direction. As the comer values were small, then all distances had to be known to a precision of 5 cm.

For example, position of the middle quadrupole centre was calculated by formula :

$$\Delta = \frac{B_3 \cdot s_3 + B_4 \cdot s_4}{2 \cdot \rho}$$

where ρ is equal to 1 radian in the degree measure.

After that it was not difficult to determine the position of the middle quadrupole centre relative the outer ones.

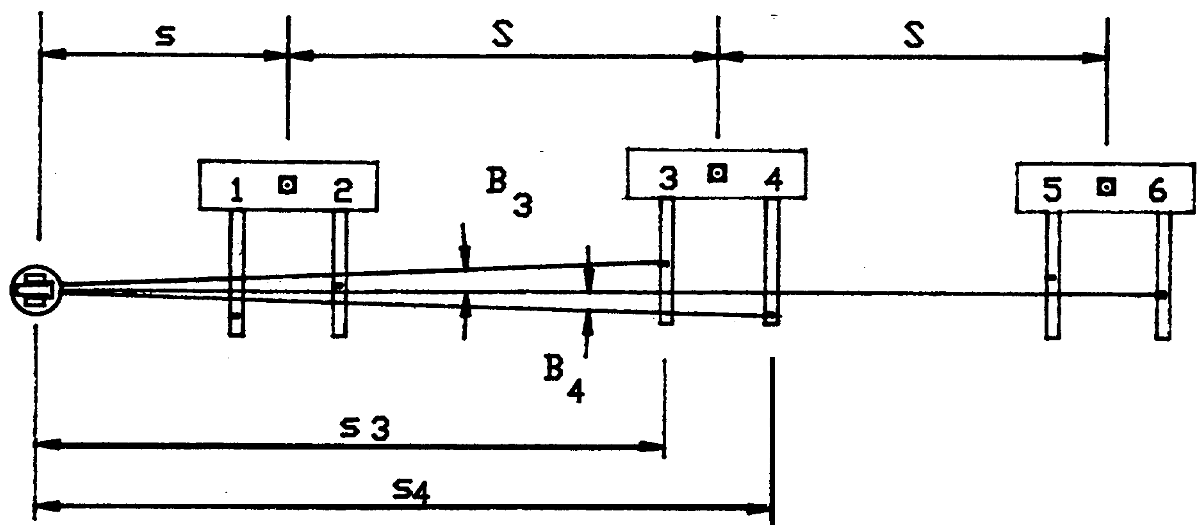

Fig. 3 Measurement scheme of the three quadrupoles relative position

The place for the theodolite installation was chosen to a certain extent arbitrarily. But it was made so that the theodolite sight axis during the measurements would constantly be within the range of the rod scale. This provided the sufficient parallelism of the initial sight direction to the straight line, joining the outer quadrupoles centres.

One measurement procedure was made at each side of the quadrupole triplets. The error in determining the middle quadrupole position was not more than ± 0.10 mm r.m.s., and the capacity was ten triplets per shift.

The results of plan and height surveying were used for calculation of the magnet motions to the design trajectory.

The motions were made with the help of the screw-jacks. In order to track the magnet displacement two specially designed devices were used. There were stable metal tripods about 70 cm high. The top part of each tripod held the two precision indicators of the linear displacements. There were indicators of the clock type with the division precision 0.01 mm and measurement interval 10 mm. The rods of the indicators were directed at an angle of 90º with respect to one another.

During the work each device was placed at the magnet side. The indicator rods contacted the magnet body at its side and beneath it (see fig. 4).

The magnet was moved by the screw-jacks to the necessary interval until the indicators showed the readings calculated in advance. The precise adjustment of one magnet took l0-15 minutes.

After the section alignment, the plan and height survey of the magnets was made again. Judging from their results, the errors of the magnet positioning were estimated. If the error values did not exceed the theoretical ones calculated in advance, then the adjustment was completed.

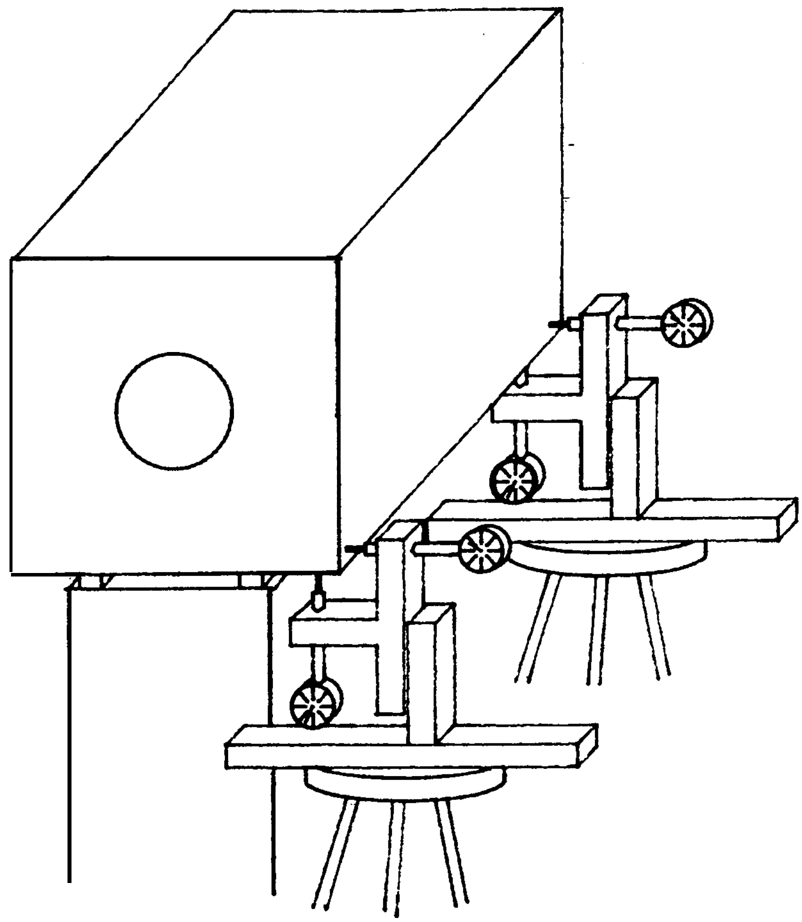

Fig. 4 Mechanical system for the magnets precise adjustment