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UNDERGROUND LASER TACHEOMETRIC NAVIGATION SYSTEM OF A TUNNELING COMPLEX WITH A SOIL LOAD "HERRENKNECHT"

Sayyidksimov S., Khakimov A.
Tashkent State Technical University named after Islam Karimov
Email: abdubokikhakimov277@gmail.com

Abstract– This article discusses the basic principles and implementation of innovative technologies of the latest underground laser navigation system of the Herrenknecht tunnelling complex in the field of underground construction of the second Yunusabad line of the Tashkent metro.

Key words– navigation, tacheometer, mechanized tunnel-boring achines (TBM), tubing ring, polygonometry.

I Introduction

In present days, surveying services of mining enterprises are trying to introduce GPS/GNSS equipment and other modern measuring instruments into their work. From October 2018 to May 2019, the construction of the second Yunusabad Line marked a new stage in the development and transformation of the Tashkent Metro. The utilization of the mechanized tunnel boring system manufactured by the German company "Herrenknecht" has led to effective results in tunnel construction [1]. It should be noted that the mechanized tunnel-boring complex (TBC) performs not only tunneling work, but at the same time strengthens the underground passage, leaving behind a ready-made reinforced concrete tunnel. This complex operates in difficult engineering and geological conditions. The tunnel boring machine is equipped with state-of-the-art navigation electronics developed by the German company VMT GmbH and is capable of excavating a maximum of 12 meters of tunnel per day [3].

GPS/GNSS certainly greatly simplifies the work of a surveyor on the surface, where there is a signal from satellites, but what about specialists in the field of construction and mining underground?

The essence of inertial underground navigation is to determine the acceleration of an object and its angular velocities using instruments and devices installed on a moving object. The advantages of inertial navigation methods are autonomy, noise immunity and the possibility of automating all navigation processes. Due to this, inertial navigation methods are becoming more and more widely used in solving the problems of navigating underground works [5].

Currently, in the construction of tunnels for various purposes, automatic navigation systems are widely used. They allow you to determine the spatial position of the tunneling complex in real time, which significantly increases the speed, accuracy, quality and analysis of the structure under construction [4].

The SLS-SL (Space Launch System) system was developed by specialists of the German company VMT GmbH based on the space system and includes:

- "Robotic total station Leica TS15-1" with built-in laser, automatic aiming at the reflector;
- Prism reflector;
- Active laser target, Electronic Laser System (ELS);
- Radio modem #1 (mobile) and Radio modem #2 (fixed);
- Power cables;
- Central distribution radio modem (switch);
- Industrial computer with original «Tunis» software.

The navigation system SLS-SL is designed for tunneling shields of tunnels with tubing lining, the principle of operation of the system: when the Tunnel Boring Complex is moving, the current position of the target is continuously read from the system automatic total station and, by means of its correlation with the design axis of the tunnel, the exact position of the machine is displayed.

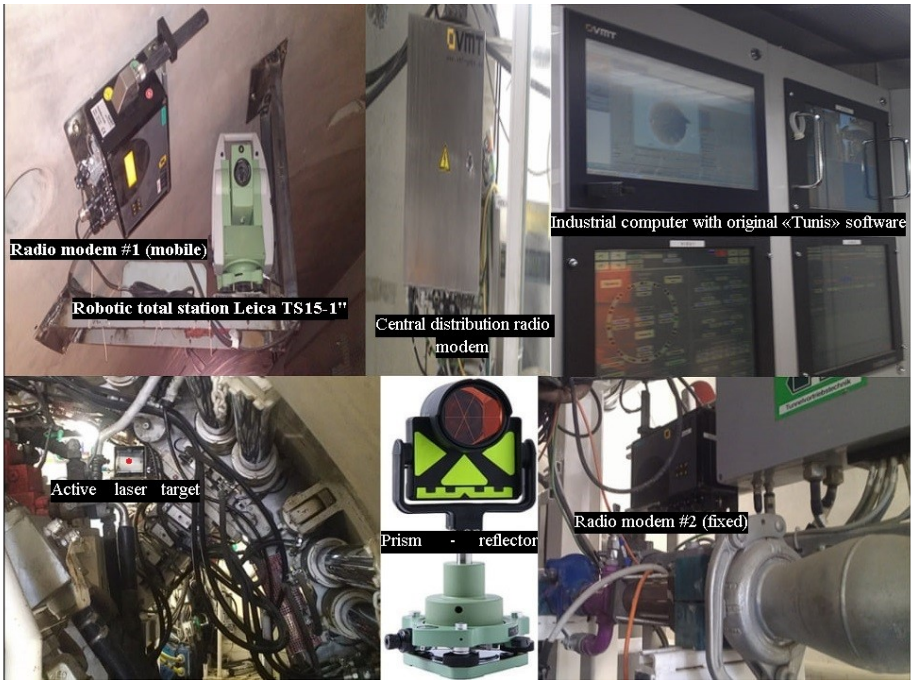

Fig. 1: Technical means of navigation equipment of the SLS-SL system by VMT GmbH

The next step in the construction of tunnels with tubing lining is the construction of the tubing ring itself in the tail of the TBM. The choice of the most suitable ring is of great importance, which determines the quality of the entire tunnel structure in the future. When the machine deviates from the design axis, the program automatically calculates the appropriate correction curve, which ensures that the machine is brought to the planned design axis. In addition to calculating the position of the rings and the order of their construction, as work progresses, the construction of a tunnel with a tubing lining to ensure high quality construction and guarantee its safety [2].

The modern technical means of equipping the navigation system are illustrated in Fig.1. The SLS (Space Launch System) navigation system by VMT, which transmits all the information necessary to move the TBM along a given route at high speed, was designed specifically for this purpose. In addition, it gives out full documentation describing the movement of the shield and a lot of additional information, for example:

- Calculation and representation of the position of the TBM in graphical and digital form;
- Calculation and image of the installed rings, showing the position of the ring after its installation;
- Calculation and display of trends in the movement of TBM (shield diagram);
- Calculation of a correction curve that tangentially brings the TBM back to a given track;
- Preliminary calculation of tubing rings to be installed in the future (based on the route and correction curve);
- Management of system elements from an industrial computer;
- Complete documentation of the shield progress (database, log files, etc.) [2].

Fig.2.depicts the schematic representation of the installation, devices, and equipment of the underground navigation system for the tunnel boring machine "Herrenknecht".

The operation of the system is based on the determination of the active target by electronic pallets relative coordinates of the point of the laser beam, using "Tunis" software which converting them into absolute coordinates and determining the offset from the design positions of the knife, tail and front base point of the shield [8].

"Tunis" is an embedded software platform for data preparation and analysis in tunnel construction projects.

"Tunis" stands for Tunnel and Underground Integrated Software Structure.

"Tunis" includes software modules for any task related to tunnelling, for example:

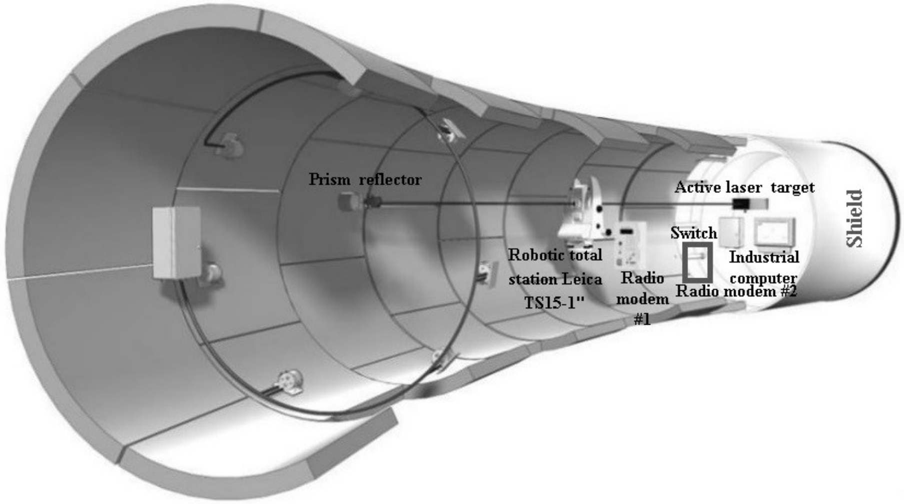

Fig. 2: Schematic diagram of the installation of the SLS-SL navigation system from VMT GmbH

- Registration and preparation of navigational data for far-sighted and reliable navigation of the tunnel-boring mechanized complex;
- Until documentation of all received data.

Tunis is distinguished primarily by a holistic interface and a harmonious concept of data processing.

- Single design and consistent management;
- Documentation of data following general instructions;
- Standard protocols;
- Ability to adapt to customer requirements;
- Tunnel-suitable, rugged and proven hardware security.

Mine surveyors are involved in all stages of tunnel construction, from surveying, designing and ending with construction, operation of an underground structure, which means that a mine surveyor is required to have solid experience in performing surveying work. In Fig.3., surveyor data of the last installed reinforced concrete ring is visible. It is impossible to judge the accuracy of measuring angles and the distance of underground mine surveying points by the result of the TBM navigation system, since it makes a hanging move [7]. The big disadvantage of an inertial navigation system is that its error accumulates over time. This is due to the integrating action of the system itself. Therefore, the results of measurements of the inertial system require periodic corrections. Before starting work, the SLS-SL navigation system is tied to points of the underground mine surveying network with known coordinates using traditional measurement methods using a high-precision electronic total station. The so-called external orientation is measured. In the process of field measurements, spatial information obtained by means of navigation is recorded in the permanent memory of an industrial computer. Surveying work must be carried out in such a way that reliable control is exercised in the process of surveying measurements [6].

The principle of operation of the navigation system "SLS-SL - Tubing" is as follows: when the tunneling complex moves, the current position of the target is continuously read from the automatic total station and by correlating it with the design axis of the tunnel, the exact position of the machine is displayed. The next step in the construction of tunnels with tubing lining is the construction of the tubing ring itself in the tail of the TBM. The choice of the most suitable ring is of great importance, which determines the quality of the entire tunnel structure in the future. However, even experienced tubing teams often cannot predict the situation more than one ring ahead [10]. Each calculation must take into account such parameters as: the translational movement of the tunneling complex, the liner clearance, the type of ring, the location of the machine in relation to the design axis of the tunnel, etc. For these purposes, VMT has developed a special program: "RMP - Program for calculating the position of the tubing ring and the order of building rings". This development allows you to calculate the laying order for several rings ahead, as well as for the entire length of the tunnel. The values obtained during the calculation are documented and stored in the database. When the machine deviates from the design axis, the program automatically calculates the appropriate correction curve, which ensures that the machine is brought to the planned design axis. When constructing a chain of triangles that ensures the construction of this subway line, as a rule, city triangulation signs were used. The

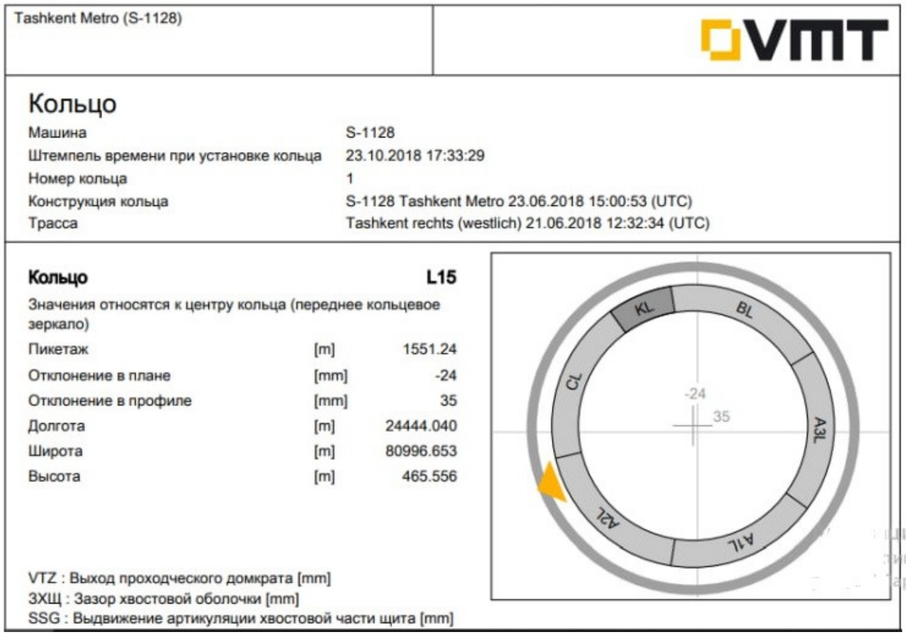

Fig. 3: Displaying the information of the last constructed reinforced concrete ring

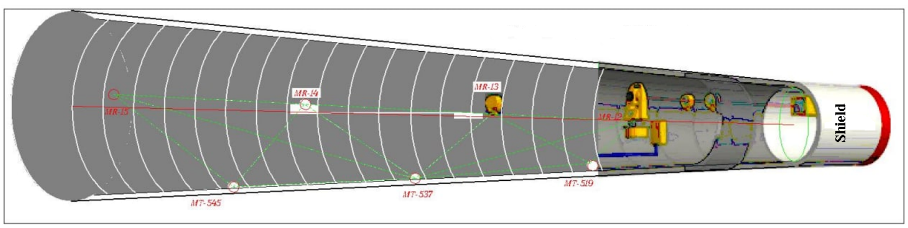

Fig. 4: Installations and application of linear-angular networks in the construction of tunnels

development of underground polygonometry was carried out through a vertical shaft by direct adjacency to the points of the ground geodetic base. After each successive orientation, all measurements by underground polygonometry were repeated again and the necessary calculations were made. The length of one-way tunneling was 1.5 km. , therefore, the underground polygonometry was laid in the form of triangles, with such a system, the working underground polygonometry with sides from 25 to 50 m was observed, the main underground polygonometry with sides from 50 to 100 m, and the main underground polygonometry with sides 150-200 m. [6]. Improved consoles for forced centering of points of the main and main tunnel polygonometry are for the installation of a robotic electronic total station TBM. The proposed design is designed for a rational location along the design metro route. Creation of a geodesic-surveyor linear-angular network for underground construction of the subway to provide TBM navigation. In Fig.4., a diagram of the linear-angular network is presented, which is used for the surveyor justification of tunnel construction. The control over the geometric parameters of the structure has to be carried out throughout the entire movement of the TBM, starting from the ground support geodetic-surveying base [9].

The CREDO DAT and CREDO NIV software was used to facilitate and improve the work for pre-calculation, processing and adjustment of the linear-angular network of the underground main and main polygonometry and leveling. Office processing was performed by the specialists of the State Unitary Enterprise "O‘zGASHKLITI".

An optimal linear-angular network for laying the underground main and main polygonometry has been created to introduce a correction in the coordinates and elevations of the console with forced centering of the TBM. Estimates of the accuracy of the positions of points based on the results of the adjustment are given in Table 1.

The most accurate point among those presented in Table is MT193 in terms of $(M_x; M_y)$, while in terms of height (Mh), it is MK309.

The vertical transmission of marks to the horizon of the subway penetration was applied with a Leica DISTO laser

Survey points	**Root Mean Square (RMS) error of point measurements** (M)**,** m	**Root Mean Square Errors of Point Position along Coordinate Axes,** m		**Correction Equation Coefficients,** m		**Directiona Angles** (α)**,** $deg., min., sec.$	**Mean Square Error of Elevation,** $(Mh), m$
		M_x	M_y	**a**	**b**		
1	2	3	4	5	6	7	8
MK309	0.008	0.005	0.006	0.007	0.004	129°34’27”	0.010
MR-16-302	0.007	0.005	0.005	0.006	0.004	128°31’08”	
MR-17-333	0.009	0.006	0.007	0.008	0.004	130°37’11”	0.016
MR15	0.006	0.004	0.004	0.005	0.003	127°16’39”	0.017
MT93							0.046
MT123							0.040
MT158							0.036
MT193	0.002	0.002	0.001	0.002	0.001	31°57’36”	0.034
MT226	0.003	0.002	0.002	0.002	0.002	122°44’30”	0.027
MT258	0.005	0.003	0.004	0.004	0.003	123°38’15”	0.023

TABLE 1

rangefinder twice and with two compared steel tapes. The main technical effect of the practical application of the developed methods for substantiating the technological parameters of transferring marks to the horizon of the metro mine with a high-precision electronic-laser rangefinder "Disto", development and practical application of forced centering consoles, as well as the method of a linear-angular network with processing in the Credo.Dat software during the construction of the metro in Tashkent, is to increase the productivity of penetration, the safety of mine surveying [11].

Fig. 5: Successful exit of the TBM into the dismantling chamber

When the tunneling is completed, surveyors and builders demonstratively excavate the final centimeters of the tunnel. This event, depicted in Fig.5. is referred to as "finishing" or "completing the tunnel.".During the excavation of workings in the Quaternary loam zone, the developed soil was pressed in the TBM screw conveyor into large blocks, which ultimately led to an emergency stop of the conveyor. The experience gained showed the need for a more thorough study of mining and geological conditions along the subway tunnel route for the timely determination of conditioning compositions. The developed methods have been fully applied and used in the sinking of the "Second stage of the Yunusabad line of the Tashkent metro". In the future, it is planned to develop it and increase the functionality during the construction of the metro. The complex of these methods made it possible to control with high accuracy and introduce timely amendments to the navigation of a robotic laser electronic total station, which made it possible to enter the closure chamber at PK 29+43.30 with a plan error of +3 mm. and 0 mm in height. Modern underground navigation technologies, high-tech equipment and ambitious projects, which are often on the verge of the possible - all this leads to the emergence of new developments that make the construction of subway tunnels safer, more economical and of higher quality.

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