Areas of research on the construction of tunneling underground machines of the Geokhod class

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Abstract. The article presents the features that characterize the complexity and novelty of the main functional systems of underground machines of the “Geokhod” class as an object of design and production. The authors discuss the problems that developers encountered at all stages of creating test models and prototypes of a new class of underground machines “Geokhod”. The lack of special scientific and methodological support is a deterrent to the creation of a new class of underground vehicles. Taking into account the peculiarities of work, interaction with the geo-environment of tunneling underground machines of the “Geokhod” class, the need arose to create a scientific specialty that will be associated with the design and construction of tunneling underground equipment. Thus, by analogy with the aircraft industry, the support for the creation of underground machines interacting with the geo-environment should be assigned to a new scientific profile and the scientific specialty “Construction of underground machines that interact with the geo-environment”. A new scientific direction is considered as a key element of an advanced technological structure for the development of underground space on the basis of advanced development and new approaches in construction geotechnology and geotechnics.

1. Introduction

Currently, with the active participation of OOO “Sibirskoye SPA”, a Concept for creating an advanced industrial structure based on the rapid development of key engineering components has been formed and is being implemented. One of the approaches of the Concept is the thesis [1]:
“It is difficult to enter the industrial structure formed by global corporations with standard products, but you can set a goal to replace this structure to the maximum extent. If we propose more economical technologies, we can significantly expand our participation in the international division of labor, as well as secure a priority for ourselves in creating more advanced mechanisms and machines”.

The team of OOO “Sibirskoye SPA” Research Center is working on the creation of Geokhod – a new class of tunneling underground machines (UM) moving in the bowels of the Earth using an edge rock mass (geo-environment) [2–6]. One example of a “Geokhod” class UM is shown in figure 1. In contrast to existing approaches, the authors consider underground mining as a process of movement of a solid body (underground vehicle) in a solid medium (geo-environment) [4–19].

Figure 1. The prototype UM model "401" with a diameter of 3.2 m: a) on the assembly slipway, b) bottom-hole area in tests.

2. Main part
The UM of the “Geokhod” class so far have no analogues among existing mining systems (MS). Distinctive features of the “Geokhod” class UM and the advantages arising from them are given in [4, 6, 9, 10]; here we indicate only the main ones:

– The presence of an external (contour) musculoskeletal system, including new functional and structural elements that interact with the geo-environment.
– The use of the rock massif to form traction and pressure forces (using the geo-environment), while the massif is a kinematic link, is meshed with the marginal musculoskeletal system.
– Possibility of horizontal and vertical maneuvering with a turning radius commensurate with the diameter of the output.
– Versatility in tilt angles in a wide range.
– Exclusion of the weight of the machine from the process of forming traction and pressure forces.
– To create on the executive body of the destruction of the slaughter of UM sufficient pressure without artificial weight gain UM.

As part of the “Geokhod”, new functional systems have appeared that are absent in serial MS:
– marginal elements: external mover (EM), counter-rotation elements (CRE) [8, 14–19];
– executive parts (EP) of contour elements – EP EM and EP CRE [8, 14–19];
– unit (module) for pairing sections [20];
– a rotating shell [12, 21];
“steering” system [7, 8, 15–19]. Other “Geokhod” systems have undergone changes that practically exclude the borrowing of ready-made aggregates from serial tunneling equipment.

Signs characterizing the complexity and novelty of the main functional systems of the UM class “Geokhod” as an object of design and production [2, 3, 21–26]:

Common to all systems and user agents in general:
– lack of analogues among existing MS;
– there are no methods of calculation and design;
– the combination of rotation (movement) and the performance of the functions of temporary support;
– placement of working mechanisms in a confined space;
– placement of working mechanisms on a rotating supporting structure;
– the need to transfer energy from a non-rotating stabilizing section to consumers located on the rotating section;
– the need to manufacture parts and assemblies of large sizes with high accuracy;
– the need to ensure the possibility of modification in mining;
– ensuring the performance of all operations of the driving cycle with their combination in time;
– providing the possibility of horizontal and vertical maneuvering;
– performance at any angles of inclination of the production;
– the possibility (feasibility) of reducing metal consumption due to the exclusion of weight from the number of useful and necessary parameters;

Specific to individual systems:
– peripheral placement of power elements of the transmission with the possibility of multi-threaded power transfer;
– significant torque and axial force on the housing and interface module;
– the complex nature of the movement of destructive elements of the AI to the face;
– a different approach to rock destruction in the central and peripheral parts of the face;
– the need to coordinate the parameters of the EM and the main EP, due to the rigid kinematic connection of their movements;
– the formation of EP EM and EP CRE of the deep channel with a complex profile.

When creating experimental models and prototypes of a new class of UM “Geokhod” [2, 3] at the design stage, developers were faced with the problem of the lack of methodology for determining the parameters of the main elements and systems of the UM interacting with the geo-environment during its movement: the main face [9, 11]; UM case [12]; marginal elements (external mover, anti-rotation elements and their EP) [8, 14–19], etc.

At the production stage, they faced the problem of the lack of a methodology for ensuring the accuracy and manufacturability of specific UM systems [21–25]. The problem of the scientific and methodological “deficit” was also present at the testing stage [27, 28].

The lack of special scientific and methodological support is a limiting factor [9, 23–30] on the way to creating a new class of UM.

New scientific and methodological problems arose at all stages of creating a new generation of UM: design, manufacturing and testing.

And if there are separate guidelines for designing mining machines, textbooks and educational disciplines, then production is based on the general technology of mechanical engineering, and tests are based on operating experience and bench tests of individual elements. While in the aircraft industry there are scientific and engineering specialties that are “tailored” to each of the stages of creating a new aircraft: there are research institutes and design institutes that accompany the process of creating new equipment at each stage, there is a “test pilot” profession, testing grounds and full-scale laboratory facilities (wind tunnels, etc.).

Papers [31–35] describe the concept of creating an advanced technological structure for the formation (development) of underground space on the basis of the advanced development of new approaches in
construction geotechnology and geotechnics. Figure 2 presents the structure of the proposed technological structure of the development (formation) of the underground space.

![Diagram](image_url)

**Figure 2.** The structure (Paradigm) of an advanced technological structure for the development (formation) of the underground space on the basis of the advanced development of new approaches in construction geotechnology and geotechnics.

All the key structural elements of the technological structure have their own special purpose, are closely interconnected and together form a technical and economic paradigm [36]. The construction of UM interacting with the geo-environment is the main structural element of the technological structure of the development (formation) of the underground space. When creating a promising technological structure, the experience and advantages of the through technological structure created in the aircraft industry were fully taken into account [31, 35].

One of the key structural elements of the technological structure in the aircraft industry is aircraft construction (helicopter construction, rocket construction).

The term “Aircraft industry” has two closely related meanings:
1) Scientific discipline related to the design and construction of aircraft.
2) Aircraft manufacturing industry.

It should be specially noted that aircraft construction at one time initiated the need for industrialization of the country, and also became one of the main consumers of the created components of mechanical engineering: materials; bearings, mechanisms, etc.

The name of the science supporting aircraft industry is 05.07.02 “Design, construction and production of aircrafts”.

From the specialty formula 05.07.02: “A distinctive feature of the specialty is that its main content is a systematic study of the design, construction and production of engineering objects taking into account economics and automation, an analysis of the experience in creating samples of rocket and space and aviation equipment, and conversion use of the abovementioned methods and works. The importance of solving the scientific and technical problems of this specialty lies in improving the theoretical, methodological, experimental and production base, which can improve the quality (reliability, maintainability, carrying capacity, etc.) and reduce the cost of developing, manufacturing and operating aircraft (reduce metal consumption, power consumption, etc.). This area of science is complex, covering the
identification of physical, chemical, mechanical and other laws with the aim of using in practice the most efficient and economical design and technological processes that require the least time, human and material resources."

In mining, there is a science “Mining machines” described as “a field of science and technology, including research, development and operation of machinery and equipment (units and apparatuses) of the main and auxiliary industries in the mining industry and engaged in the study of relationships and patterns in order to create new and improvement of existing mining machines and equipment and their elements, which have increased productivity (efficiency), durability (reliability), safety and environmental friendliness.”

Taking into account the peculiarities of work, interaction with the geo-environment of tunneling UMs of the “Geokhod” class, the best approach to the formulation of research areas for the scientific specialty “Construction of UMs, interacting with the geo-environment”, in our opinion, is shown by the specialty 05.07.02 “Design, construction and aircraft manufacturing.”

We propose the following research areas for the scientific specialty "Construction of UMs interacting with the geo-environment":

- Development of design and construction methods, mathematical and software-algorithmic support for choosing the optimal look and parameters, layout and structural power scheme, units and systems of UM.
- Development of assessment methods and research of the organization and management of design and design work of design bureaus with a high level of application of CALS-technologies.
- Development of search methods for optimal design and technological solutions in the early stages of designing a UM.
- Research and analysis of ways to intensify the design and modernization of existing UMs, taking into account the experience gained.
- Creation and development of fundamentally new design solutions for the implementation of nodes, systems and user agents as a whole. Study of their characteristics and assessment of application prospects.
- The study of the dynamics (changes) in the reliability of systems and UM in the process of the life cycle in order to form an optimal plan for their development.
- Study of the impact on the technical characteristics of systems and the structural design of the UM body of geodynamic processes in the designed structure.

Development of methods of model and mathematical support for solving (research) of functional problems:

- selection of the optimal composition of UM;
- selection of the trajectory of movement, etc.

- Development of methods, models and software for making optimal decisions in order to study design problems under given restrictions, taking into account their compromise nature, risk and distinguishability of compared product options (processes).

- A study of the economic feasibility of creating UMs with a multi-purpose purpose (for example, civil and military), as well as the effectiveness of using existing products and ground complexes for the same purposes.

- Technological preparation for the production of UMs and their systems, including:
  - constructive and technological solutions that allow for advanced preparation of production;
  - manufacturability of structures;
  - directive technological materials for the production of new UM structures, their systems and assemblies;
  - systems and means of automated production preparation;
  - other methods and means of development and implementation of technological processes of production.

- Technological processes, special equipment for the manufacture of UM parts, including technology:
- manufacturing of cast parts;
- manufacturing of parts by pressure treatment (forging, stamping, etc.);
- manufacture of parts using beam energy beams and other physical and physico-chemical methods;
- manufacture of parts from liquid, powder or fibrous materials; - manufacturing of parts from non-metallic materials, including parts of thermal protection;
- coating;
- manufacture of parts from composite materials; - manufacture of parts by galvanic plastic;
- thermal, thermomechanical and chemical-thermal treatment of parts;
- metal cutting;
- manufacturing of parts by combined and complex methods, including in flexible production systems.

– Technological processes, special and specialized equipment for assembly, installation and testing, repair of UM, their systems and units, including technology and tools:
- nodal, modular and general assembly;
- the formation of detachable and one-piece joints during the assembly of UM using bolted joints, welding, soldering, riveting, gluing and their combinations, including using robotic systems;
- cleaning the internal and external surfaces of assembly units and UM as a whole;
- installation and testing of on-board systems in workshop conditions;
- performance of newly developed compounds specific for the production of UM.

– Technological processes for monitoring, testing and metrological support in the production of UM, their systems and units, including technology and tools:
- control of geometric parameters; surface quality control;
- functional control and testing (pneumohydraulic, vibroacoustic, electrophysical, force impacts);
- control of physical and technical parameters;
- non-destructive testing of parts, assemblies, products and integral joints, as well as other types of control;
- metrological support of controlled quality indicators of production facilities.

– Technological processes of designing, programming and information support in the production of UM, including technology and tools:
- computer-aided design of technological processes and their management;
- mathematical modeling of technological processes;
- dimensional linking of aggregates;
- control of the shape, size and relative position of the surfaces of the units;
- manufacturing of technological surfaces, equipment and parts, including machines with CNC;
- control of technology and programs for the manufacture of parts and assembly units.

– Organization and economics of manufacturing UM, including:
- the production structure of the enterprise and the features of the organization of technological processes in pilot, single, small-scale and mass production;
- enlarged methods for calculating material consumption, labor and cost of products;
- methods for evaluating the manufacturability of products;
- methods for calculating the technical and economic efficiency of technological processes, equipment and organizational and technical measures.
- Study of the process of introducing scientific, technological and technical achievements in the design and construction of UM in other areas of science, engineering and technology.

In the direction of creating and practicing fundamentally new design solutions for the implementation of nodes, systems and UM as a whole, the first studies were performed and the results obtained [9, 10, 19, 26]. But these results, as experience shows, can generally be regarded as obtaining “intelligence”
data for making decisions on the choice of areas for further research and development of experimental samples of UM.

With regard to the creation of a new class of user agents, priority tasks are:
- Creation (improvement) of the general layout of the "Geokhod" class UM.
- Creation (improvement) of UM body.
- Creation (improvement) of UM transmissions.
- Creation (improvement) of external movers for UM.
- Creation (improvement) of counter-rotation elements for UM.
- Creation (improvement) of executive bodies for destruction of the face of UM.
- Creation (improvement) of the paramount executive bodies of the UM.
- Creation (improvement) of UM controls along the route of development.
- Creation (improvement) of UM loading modules.
- Creation (improvement) of transport systems for UM.
- Creation (improvement) of power plants for UM.
- Creation (improvement) of UM starting devices.
- Creation (improvement) of UM mounting hardware modules.

3. Conclusion
The need to develop the provisions of a new scientific direction and scientific specialty “Construction of underground machines interacting with the geo-environment” is based on the distinctive features of the “Geokhod” class UM with the ensuing advantages, as well as highlighted features that characterize the complexity and novelty of the main functional systems UM. By analogy with the aircraft industry, the authors of the article have proposed research areas for the scientific specialty "Construction of underground machines that interact with the geological environment."

Currently, work is underway to create new elements and systems of the “Geokhod” class UM. The existing scientific and methodological support for the development and construction of mining machines basically does not meet the requirements and features of the new class of “Geokhod” UM. For most systems and elements of a new class of UMs for which there are no calculation methods and a reasonable choice of rational parameters. The lack of scientific and methodological support hinders the creation of new elements and systems of UM "Geokhod", which dictates the need to expand the areas of research areas of the passport of the specialty "Mining machines".

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