Research areas of the scientific specialty “Geodynamics of underground machines”

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Abstract. At all stages of creating experimental models and prototypes of a new class of underground machines "Geokhod", developers faced problems. At the design stage the problem was the lack of methods for determining the parameters of the main elements and systems of underground machines that interact with the geo-environment during their movement. At the production stage, they faced the problem of the lack of a methodology to ensure the accuracy and manufacturability of specific systems of underground machines. In addition, the problem of scientific and methodological “deficit” was present at the test stage. The development of systems of a new class of underground machines is constrained by the lack of special scientific and methodological support. When creating a new class of underground devices moving in the bowels of the Earth and using the geo-environment, there is an urgent need to study the effects of the geo-environment on bodies moving in the geo-environment. In the aircraft industry there is a fundamental science that studies the forces arising on the surface of a solid body moving in the air - aerodynamics of aircrafts. Thus, by analogy with aircraft construction, studies of the effects of the geo-environment on bodies moving in the geo-environment should be assigned to a new scientific direction and the scientific specialty “Geodynamics of underground machines”. The article proposes a draft passport of the specialty and a field of research in the new direction “Geodynamics of underground machines”. This scientific direction is one of the basic elements of an emerging advanced technological structure for the development of the underground space, based on new approaches in construction geotechnology and geotechnics.
1. Introduction

To develop and implement new approaches and projects in any engineering industry, the Concept of creating an advanced industrial structure based on the rapid development of key engineering components has been formed and is being implemented. OOO “Sibirskoye SPA” took an active part in developing the provisions of this concept, one of which 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 sophisticated mechanisms and machines.”

One of the R&D directions pursued by the team of OOO “Sibirskoye SPA” Research Center is the creation of a new class of tunneling underground machines (UM) named “Geokhod” that move in the bowels of the Earth using an edge rock mass (geo-environment) [2–5]. The sample of the new “Geokhod” class is presented in figure 1. When developing the UM, the authors rely on a new approach to the tunnel work and consider it as a process of movement of a solid body (underground apparatus) in a solid medium (geo-environment) [4–6].

![Figure 1. The prototype UM model "401" with a diameter of 3.2 m.](image)

Distinctive features of the “Geokhod” class UM [7–10]:

– The principle of operation is based on the use of a contour massif of rocks for the formation of traction and pressure forces (use of a geo-environment).

– The presence of an external (marginal) musculoskeletal system, including new functional and structural elements that interact with the geo-environment.

– General functional layout.

– Qualitatively new functionality: horizontal and vertical maneuvering, versatility in the angles of inclination of the mine in a wide range.

In this case, the near-mass array (geo-environment) is a kinematic link, is meshed with the UM running system and is used [4, 7–10]:

– as a supporting element involved in the creation of traction of the UM and the formation of pressure on the executive body;

– for the perception of reactive efforts when driving a driving unit (underground unit);

– to perform basic technological operations, including securing the mine with a permanent support.

Using the geo-environment allows you to:

– Exclude the weight of the machine from the process of forming traction and pressure forces.

– To carry out the movement of UM in any direction of the bowels of the Earth.

– To create on the executive body of the destruction of the slaughter of UM sufficient pressure without artificial weight gain for UM.
2. Main part

At the stage of designing experimental samples and prototypes of a new class of UM “Geokhod” [2, 3], the developers faced the problem of the lack of a methodology for determining the parameters of elements and UM systems that interact with the geo-environment during its movement. The main such systems are: executive bodies (EB) of the main face [9–11]; UM case [11]; external mover, counter-rotation elements and their EB (edge elements) [8,12–18], etc. At this stage of development, it is possible to modernize the existing calculation methods presented in the guidelines, textbooks and educational disciplines on mining machines, to the requirements of “Geokhod” class UM.

The problem of the lack of a methodology to ensure manufacturing accuracy and manufacturability of original UM elements and devices arose at the stage of production of a new “Geokhod” class UM [19–23]. At this stage of the development of experimental and prototypes, production is based solely on the general principles and approaches of mechanical engineering technology.

In addition, at the test stage, the problem of the lack of scientific and methodological support for testing new equipment [24, 25] was especially acute. In this case, the developers are based on the experience of operating mining machines and bench tests of individual elements.

The indicated problems arising during the creation of a new “Geokhod” class UM create an urgent need to develop and justify special scientific and methodological support [9, 21, 24–27].

At the same time, in the aircraft industry, in the development of experimental aircraft models and prototypes, there are scientific and engineering schools and specialties, “sharpened” for each of the stages of creating a new aircraft. To accompany the process of creating new technology, at each stage we can see research and design institutes, test sites, and full-scale laboratory facilities (wind tunnels, there is the profession of a test pilot, etc.).

To form a new scientific structure, the papers [28–31] developed and presented the concept of creating an advanced technological structure for the formation (development) of underground space on the basis of the accelerated development of new approaches in construction geotechnology and geotechnics. The structure of the proposed technological structure for the development (formation) of the underground space is shown in figure 2.

![Figure 2](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.
The key structural elements of the technological structure located on the tops of the tetrahedron have their special purpose, they are closely interconnected and form the techno-economic paradigm [32]. Geodynamics of UM is one of the main structural elements of the technological structure of the development (formation) of the underground space. When developing the provisions of the new technological structure, the experience and advantages of the end-to-end technological structure created in the aircraft industry [29, 31] were fully taken into account.

One of the key structural elements of the technological structure in the aircraft industry is fundamental science, which studies the forces arising on the surface of a solid body moving in the air – Aerodynamics of aircraft [33–38].

The very same role of fundamental science in the new technological structure of the development (formation) of the underground space should be played by the new scientific direction “Geodynamics of UM”. But, at present, there is no science with that name!

To formulate a definition of a new term, we turn to the established terminology in aircraft construction and shipbuilding. For convenience, we will present the existing formulations of the variants of terms in binding to the medium in the form of a table.

| Term                      | Definition                                                                                                                                  | Notes                                                                                     |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Aerodynamics (from classical Greek ἀηρ – air and δύναμις – power) | – A science that studies the movement of air masses and their effect on bodies in a stream.  
|                           | – The science of air movement and its effect on the bodies streamlined by it [38].                                                            | It originated in connection with the first attempts to create aircraft. Aerodynamics is the theoretical basis of aviation and rocket and space technology [37]. The main task of aerodynamics [33] is the choice of the rational form of aircraft in order to obtain the specified flight performance, as well as determine the aerodynamic loads and heat fluxes acting on the surface of the aircraft for strength calculations. |
| Hydrodynamics (from classical Greek ὕδωρ «water» + dynamics) | – A branch of continuum physics that studies the motion of ideal and real liquids and gas and their force interaction with solids.  
|                           | – The science of the movement of fluids under the influence of external forces and the mechanical interaction between a fluid and bodies in contact with it during relative motion; is part of hydromechanics.  
|                           | – Section of hydromechanics, in which the motion of incompressible liquids and their interaction with solids or interfaces with other liquids (gas) are studied. | As a science began to emerge in the 16th-17th centuries from experimental studies of the resistance of a mobile medium to the movement of a rigid body (Leonardo da Vinci, Galileo Galilei, E. Toricelli, I. Newton, etc.). In the 18th -19th centuries the science obtained analytical, empirical and methodological foundations with the participation of the most prominent researchers of that time (L. Euler, J.L. Dalamber, John, Jacob and Daniel Bernoulli, O. Reynolds and others). It formed the basis of Aerodynamics [33, 34]. The main task of hydrodynamics is the selection of rational geometric parameters of hydraulic units with the aim of obtaining the given characteristics [39-41]. |
| Geodynamics               | – A branch of geology that studies the nature of deep-seated forces and processes that arise as a result of the planetary evolution of the Earth, and which determine the movement of matter inside the planet. | Geodynamics as science began to isolate itself from other Earth sciences in the 1950s. Objects of the study of geodynamics are not accessible to direct study and they can be judged by indirect signs, theoretical constructions and the results of their manifestation on the surface of the Earth [42]. |
| Term                        | Definition                                                                                                                                                                                                                                                                                                                                 | Notes                                                                 |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| —                           | The science of the deep forces and processes arising as a result of the evolution of the Earth as a planet and determining the movement of the masses of matter and energy inside the Earth and in its outer hard shells. Objects of geodynamic research are inaccessible to direct study and they can be judged by indirect signs, theoretical constructions and the results of their manifestation on the Earth's surface. |                                                                      |

From the above definitions, it becomes clear that in relation to the air and water environment, the corresponding sciences (aerodynamics and hydrodynamics) study not only the movement of the environment itself, but also **its effect on bodies located in the environment under consideration**.

As for the term geodynamics, such a scientific direction — the **study of the effects of the geo-environment on bodies located (moving) in the geo-environment** — does not exist at the moment.

This situation is a consequence of the fact that in underground conditions external movers (tracked, wheeled, wheel-rail or spreader-walking) were used and used to move the tunneling apparatus, which showed themselves well when working on the earth's surface, and to create the traction force of the UM and pressure effort on the executive body in no way involved the surrounding geo-environment, but only the solid surface of the mine at the contact of the geo-environment and the air, or with the shield method of penetration - a powerful permanent lining. For this class of mining machines, the corresponding scientific and methodological support was created, but which cannot provide the design of new UM.

When creating a new class of UM moving in the bowels of the Earth using the geo-environment [7–18], there was **an urgent need to study the effects of the geo-environment on bodies that are (moving) in the geo-environment**.

The solution to this problem by analogy, for example, with aircraft construction should be assigned to the **“Geodynamics of UM”**.

At the initial stage, for the preliminary formulation of the passport of the specialty “Geodynamics of underground machines”, the passport of the specialty 05.07.01 “Aerodynamics and aircraft heat transfer processes” was adopted as an analogue.

### 3. Conclusion

**The authors of the article propose the following:**

**Geodynamics and heat transfer processes of underground machines (UM)** is a field of science that studies the laws of interaction between UM and their parts with various geo-environment, including the development of theoretical and experimental methods for studying stationary, unsteady force and thermal effects of these geo-environments on UM.

**Research areas of the scientific specialty "Geodynamics of UM":**

— Geo-environment, geodynamic parameters. Formulations (terms), parameters, systematization.
— Theoretical and experimental studies of the interaction of UM and their elements with various geo-environments.
— Computational and experimental studies of the geodynamic parameters (characteristics) of UM and their elements.
— Development of methods for determining geodynamic parameters, including algorithms and software for CAD UM.
— Studies of the influence of various geo-environments on the geodynamic characteristics of UM.
— The geodynamic calculation of the UM motion controls.
– The geodynamic characteristics of UM and surface heating under conditions of interaction with the geo-environment.
– Studies of the impact of UM on the environment (deformation, displacement).
– Development of tools and methods for experimental geodynamic and thermal studies (methods, installations, full-scale underground studies).
– Experimental and theoretical studies of the force, thermal and physico-chemical interaction of various geo-environments with the surfaces of structural elements from various structural materials.

If we compare the air environment (aerodynamics of the aircraft) and the geomedium (geodynamics of the UM), then the geo-environment is much more diverse and multifaceted in its properties and manifestations in comparison with the air environment.

The indicators of physical and mechanical properties of rocky and non-rocky soils (rocks), and there are only twenty of them by name [43], differ quite significantly among themselves.

With regard to the creation of a new class of user agents, the priority ones in terms of solving the problems of geodynamics of user agents are:
– Development of geodynamic forms of UM elements.
– Development of geodynamic forms of supporting elements of the geo-environment
– Definitions of geodynamic resistance, power, strength parameters of UM elements interacting with the geo-environment.

In the direction of developing the geodynamic forms of UM elements, the first studies were performed and the results were obtained [9–11, 14–18].

The development and construction of the “Geokhod” class UM allows solving the problems that arise during the construction of underground structures of various directions in the bowels of the Earth. The lack of scientific and methodological support for the development of UM elements and systems interacting with the geological environment inhibits the creation of new machines. Such a basis should be a new scientific direction "Geodynamics of underground machines." Obtaining and systematizing new knowledge in the presented research areas is a priority.

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