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Multifunctional mobile complex of transport-technological machines for the Arctic

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Abstract. The development of the Arctic shelf and the Far North is hampered by severe natural and climatic conditions, remoteness from the places of permanent human habitation, lack of infrastructure and vehicles adapted to such conditions. Taking into account the need to create new models and types of transport-technological machines, the unification of the structure is rational. The article briefly presents the essence of the concept of creating a mobile complex of transport-technological machines for the Arctic with a unified platform. To create this complex, the need for key types of transportation and technological works in the Arctic was analysed. The design of machines from the complex was carried out taking into account the functional designations, ergonomic requirements and technological features of structural materials. For the development machine construction were used the methods of computer modelling and finite element analysis. The article describes an experimental sample of a technological machine created using the unified platform. The presented results of experimental studies confirm the validity of the selected solutions, the feasibility of creating a complex of machines on a unified platform and the validity of the concept as a whole.

1. Introduction

1.1. The richness of the natural resources of the Arctic

The total land area of the Arctic zone occupies about 15 million square kilometers. The Arctic zone includes the territories of 8 countries: Russia, USA (Alaska), Canada, Iceland, Denmark (Greenland and Faroe Islands), Norway, Sweden and Finland. The Arctic is extremely rich in almost all types of natural resources. About 35% of the oil and 32% of the gas produced in the world fall on the offshore fields [1]. In connection with the reduction of oil and gas reserves in continental deposits, the development of offshore deposits is inevitable [2]. About a third of the Arctic zone accounts for a huge part of Russia (4.4 million km^2), where live about 2 million people. Accelerated and large-scale development of the Arctic is important for increasing the economic potential of the Russian Federation. The development of the Arctic is associated with the extraction of oil and gas from the continental deposits of the Barents, Pechora and Okhotsk seas. The economy of the Russian Arctic produces more than 10% of the country's GDP, approximately 70% of the entire GDP of the Arctic zone, and provides more than 20% of exports (gas, oil, non-ferrous metals, fish) [3]. On the Russian territory there are more than 250 million barrels of oil and gas in the oil equivalent, which is 60.1% of the entire Arctic reserves. The Russian Arctic shelf may become the main source of hydrocarbon raw materials for Russia and the world market in the 21st century.

1.2. Difficult natural and climatic conditions of the Arctic

The development of the Arctic and the Arctic shelf is impeded by natural and climatic conditions: a difficult snow and ice situation, prolonged low temperatures, severe erosive effects of sea water, storms, a strong gusty wind, poor visibility conditions, etc.

The natural and climatic conditions of the Russian Arctic have the following characteristics:

- the average annual air temperature is below 0 ° C, falling in winter to minus 50 ° C;
- the water temperature can reach minus 2 ° C, and the flow speed is 1 m / s;
- storms (September-November) with wave height up to 12.5 m and wind speed over 40 m / s;
- significant sea level fluctuations (up to 5 m over a 100-year period);
- ice thickness up to 3 m and ice formations (hummocks, icebergs, etc.) with a height of up to 5 m;
- icing of surface and underwater structures;
- extremely complicated navigational situation: frequent long fogs and snowstorms; continuous polar night up to 150 days; the drift of ice fields and icebergs;
- the ground coldness.

The development of natural resources is also constrained by the lack of infrastructure, considerable distance to the nearest human habitats and a small number of transport-technological machines.

1.3. Key types of transport and technological work in the Arctic

At present time the following types of transport and technological works are being carried out for the development of the Arctic:

1. Geological prospecting;
2. Unloading of vessels on unequipped coast;
3. Organization of pontoon crossings;
4. Laying and maintenance of oil and gas pipelines;
5. Preparation of aerodrome runways;
6. Liquidation of emergency oil spills;
7. Release of objects from ice captivity;
8. Carrying out sea and land rescue operations;
9. Posting of sea vessels along the Northern Sea Route;
10. Performance of public functions in hard-to-reach regions.

Despite the different purposes of each of the works presented, they are largely similar in composition of their operations: transportation of people, cargo and equipment by land / water; bulldozer work; Excavation work; ice-cutting works; snow-removal works; loading and unloading operations; installation / deployment of residential modules; power supply; welding works; positioning on the ground; drilling work; urgent repair of equipment; work on hardening the ice surface; collection of oil from the surface of water / ice / snow / soil; setting boom barriers; provision of funds for the provision of medical assistance; communication.

2. Mobile complex of transport-technological machines for the Arctic

2.1. The key element of the mobile complex

The presented transport-technological operations are carried out using specialized Arctic types of equipment, which is adapted to the conditions of the Arctic in varying degrees. A significant part of the ground transportation of the Arctic was created on the basis of ready-made serial assemblies and components designed for operation in a milder climate. This borrowing is reflected in the low efficiency and reliability of existing equipment, which is a deterrent to the development of the Arctic.

Arctic vehicles should not only withstand low temperatures, but also easily overcome off-road. Work in the coastal part of the northern seas requires machines to have amphibious properties and the ability to leave water for ice. Performance of work in the swampy terrain requires all-terrain movement and stability.

The use of a common universal base chassis is rational for the creation of new transport-technological machines for the Arctic and reducing the costs of its production. Such an approach will allow to maximally unify the technique, which will ensure high maintainability, interchangeability and modularity of the transport and technological complexes being created.

Since the movement in the Arctic is mainly carried out in several environments (ice, snow, water and their combinations), it is important to use amphibious vehicles with high cross-country terrain. In the line of all-terrain vehicles, a special place is occupied by machines with a rotary-screw propeller. Like any other machine, they also have their advantages and disadvantages. Rotary-screw propeller provides the vehicle the following advantages [4, 5]:

- particularly high cross-country capability of the vehicle;
- creating very low ground pressure (0.004-0.01 MPa);
- movement along various weakly bearing bases, including their combinations: bogs, silted fields, snow virgin soil, water and ice obstacles, etc.;
- greater traction force than any other type of ground propulsors.

The disadvantages of rotary-screw machines include:

- unsuitable for driving on hard and abrasive substrates: public roads, sand, stone;
- large friction forces with a support base.

Arctic conditions allow to fully use the advantages of the rotary-screw propeller, and the effect of its shortcomings is minimized. Areas of rational use of vehicles with rotary-screw propeller are difficult-to-reach land areas and transitional zones from land to water [6]. The low development of infrastructure in the Arctic and the properties of the rotary-screw propeller system make it possible to widely use it in the real sector of the economy. One of the ways to solve the transport-technological problem for the Arctic can be the use of a unified platform with the rotary-screw propeller (Figure 1). This platform has the following main structural elements: frame-boat, rotary-screw propellers, ship engine, hydraulic transmission, deck with fences and fuel tanks.

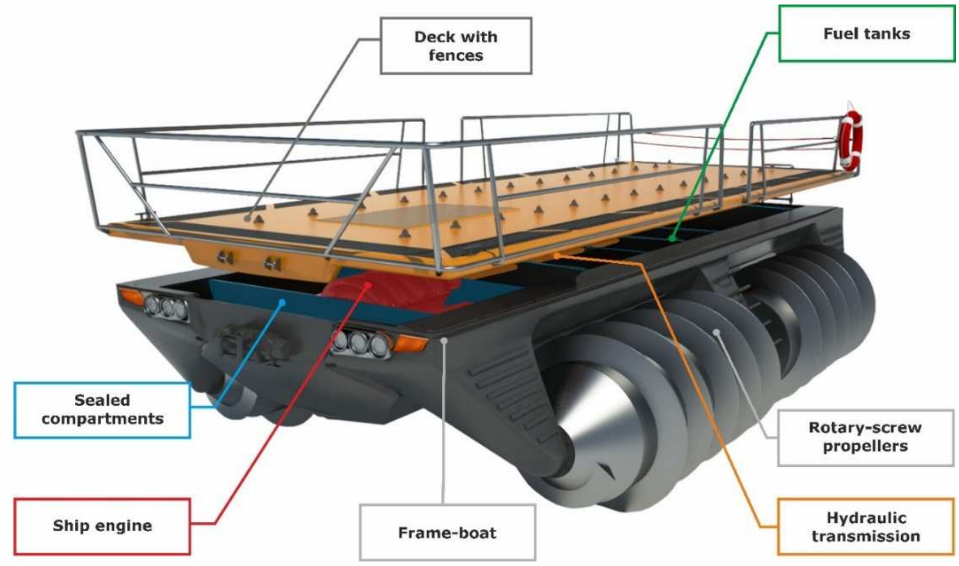

Figure 1. Unified platform with rotary-screw propeller.

2.2. General description of the complex

The concept of creating a multifunctional mobile complex of transport-technological machines for the Arctic is based on the following principles:

The principle of universality is aimed at the use of serially produced and widely used equipment without any modifications. This principle provides for a simplified implementation of the complex in the real technological process, reducing the financial costs associated with the need to expand the fleet of equipment.

The unification principle is aimed at achieving the highest level of unification and ensuring complete interchangeability of the units of the machines being developed. The result consists in reducing the costs associated with the operation and repair of machines from the complex.

The principle of variability ensures the availability of standard series of equipment of various capacities used in the complex. The result is variability in the composition of the complex for the performance of a specific task, which in turn will increase mobility.

The modular design of the complex provides significant flexibility in the formation of a group of machines of the required functionality. The unified platform will allow the installation of various operating units, for example, a drilling rig (Figure 2), a shift module (Figure 3), oil spill response equipment (Figure 4), a crane installation (Figure 5), a cargo container, construction equipment (bucket, manipulator, dumps), etc.

The design of the machines was carried out taking into account the anthropometric properties of man. The maximum possible dimensions of a tall man in Arctic clothes were used (Figure 6). According to the principles of universality and variance, it is necessary to organize various combinations of component parts of the complex for performing typical transport and technological operations. The formation of rational combinations can be ensured by structuring the composition of the complex and constructively ensuring the interfacing of its constituent parts in various combinations (Figure 7).

The functional structure of the complex divides the nomenclature of structural units of the complex into three functional blocks:

- technological blocks are technological equipment provided for use in the complex;
- transport blocks represent the entire standard range of unified rotary-screw chassis;
- auxiliary blocks represent various blocks that ensure the functioning of the complex (parts and assembly units for interfacing individual blocks or software).

Figure 2. Unified rotary-screw platform with drilling rig.

Figure 3. Residential vehicle based on unified rotary-screw platform.

Figure 4. The unified platform with oil spill response equipment.

Figure 5. Unified platform with crane.

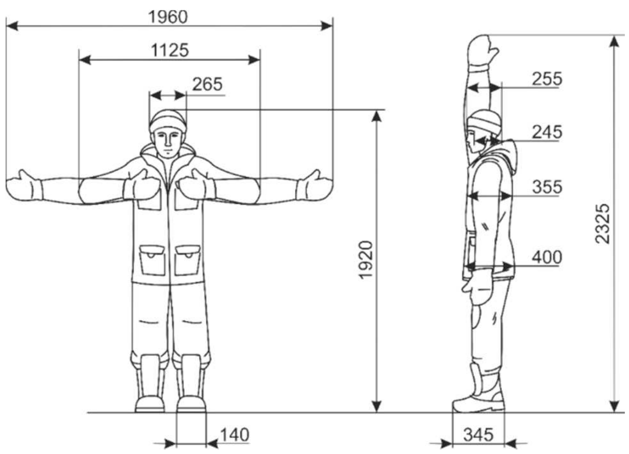

Figure 6. Conditional designation of the operator in overalls in a standing position (dimensions are in millimeters).

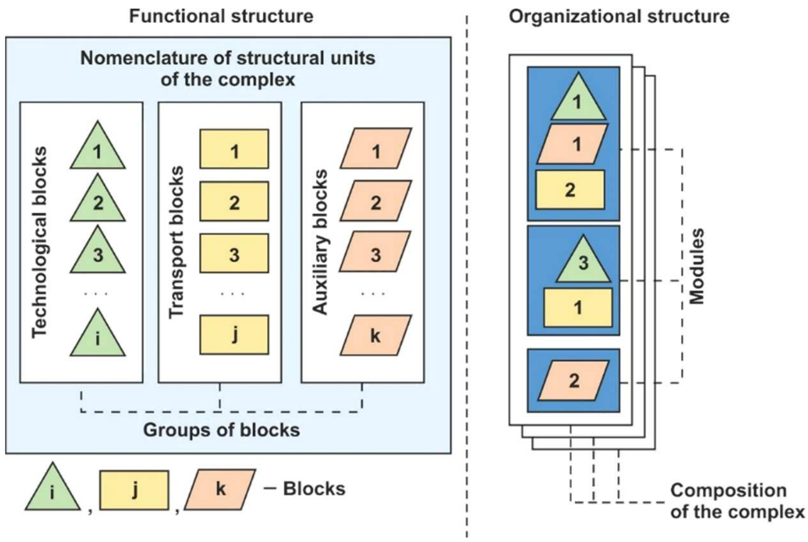

Figure 7. Structure of the multifunctional mobile complex of transport-technological machines for the Arctic.

The technological group should include equipment that is produced serially and widely used at present in real economic activities. A typical range of equipment should not exceed three positions, and generally should include light, medium and heavy equipment. The length of the standard size row can be reduced to two positions, where appropriate.

The transport group will be designed and will be able to fully comply with all three previously stated principles. The typical range of the chassis will correspond to the equipment from the technological group. Auxiliary blocks are a minor component of the complex and include the necessary minimum equipment for interfacing blocks in the construction of various module configurations.

The organizational structure of the complex determines the combination of individual blocks from different groups of functional structures to perform specific practical tasks. These combinations of blocks form the modules of the complex. The module can include blocks from all three groups of the functional structure, and only from one group. The set of modules forms the composition of the complex.

3. Designing an experimental model of a lightweight class vehicle

In the scientific and educational center "Transport" an experimental model of a light-weight vehicle was developed and created from the mobile transport-technological complex for the Arctic.

3.1. General description of the experimental model

The experimental model of a lightweight vehicle was chosen for testing and verifying technical solutions. The machine is a rotary-screw floating amphibian with a small drilling rig installed on the frame, designed for exploratory drilling of wells up to 100 m deep (Figure 8). Overall dimensions of the machine: length (frame / protruding parts) 6044/6676 mm; height of the cabin is 2232 mm; width 2626 mm. The total weight of the machine is 4.5 tons.

Figure 8. Computer 3D model of an experimental model with a small drilling rig.

3.2. Mathematical modeling: stability, all-terrain movement, strength

At the first design stage, a simplified model of the machine was used to determine the rational spatial arrangement of the main elements. The search was carried out based on calculations of the draft,

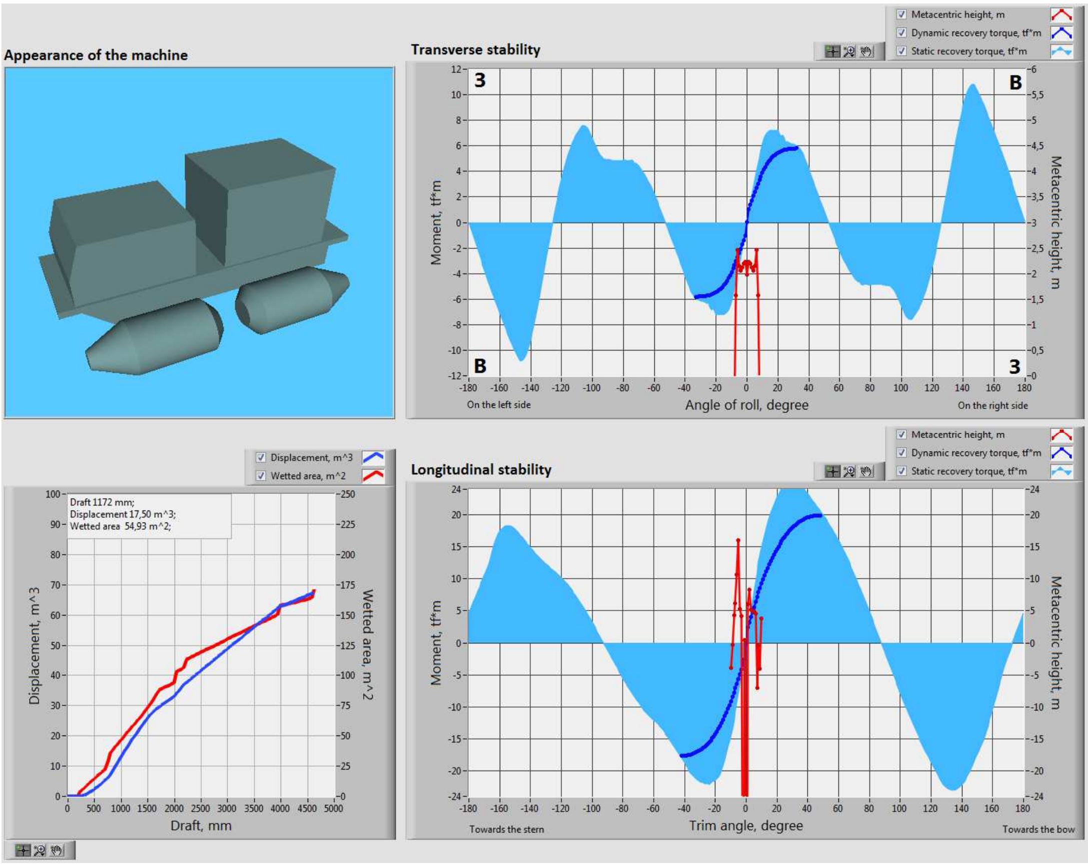

Figure 9. The stage of determining seaworthiness, based on a simplified model.

displacement, wetted area, longitudinal and transverse stability for static and dynamic loading, metacentric height (Figure 9). Calculations were carried out in the LabVIEW software package in accordance with the generally accepted calculation methods in shipbuilding theory [7].

The result of the search studies was the determination of the most rational proportions and sizes of the new machine, which allowed us to proceed to the next stage of design. Were determined rational shape and dimensions of the helical blade for the specified overall dimensions of the rotary-screw propeller. Determination of the parameters of the helical blade was carried out by the method of choosing rational parameters of the rotary-screw propeller [8]. Modeling the motion of different types of snow (from freshly fallen to dense and caked) made it possible to determine the achievable value of the traction force and the necessary torque for the propeller. As expected, the greatest impact on the traction force of the machine was made by a helical blade (Figure 10). Increasing the height of the blade leads to an increase in the resistance to movement, which is expressed in the significant torque that must be created on the output shaft of the transmission (Figure 11).

Studies on the experimental model of the machine showed good convergence with the results of calculations. The comparison was made for cases of immersion of the rotary-screw propeller in the snow and for the maximum value of the developed traction force for different types of snow (Figures 12 and 13). The discrepancy between the calculations and the experimental data for immersing rotary-screw propeller in snow is 13%, for the traction force of the experimental model is 17%. This confirms the reliability of the main theoretical assumptions and hypotheses in the compilation of mathematical models. Computer 3D models of the rotary-screw propeller with rational geometric parameters and frame-boat are presented in Figures 14 and 15 respectively.

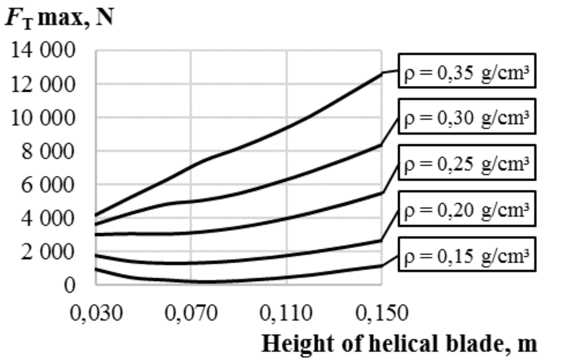

Figure 10. Dependence of the traction force on the height of the helical blade.

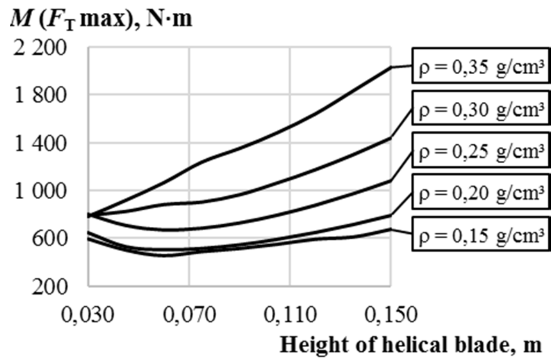

Figure 11. The dependence of the torque on the height of the helical blade.

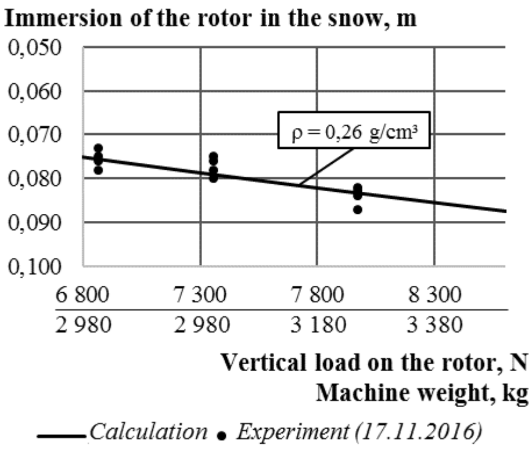

Figure 12. Dependence of the traction force on the height of the helical blade.

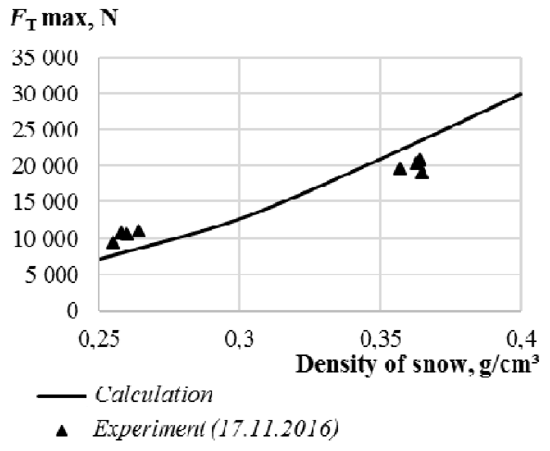

Figure 13. The dependence of the torque on the height of the helical blade.

Figure 14. Computer 3D model of rotary-screw propeller.

Figure 15. Computer 3D model of frame-boat.

The strength calculations were performed by the finite element method in the Autodesk Simulaton Mechanical environment. The calculations took into account the degradation of the physical and mechanical properties of the material in the Arctic climate.

Calculations showed that the greatest load on the amphibious chassis occurs when the vehicle is diagonally twisted (Figures 16 and 17). This load occurs when the vehicle leaves the water on ice or when one of the propulsion units hits the obstacle.

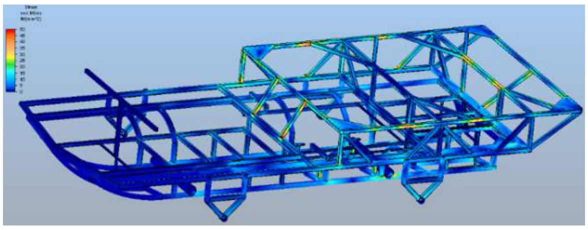

Figure 16. Stress distribution in the frame construction.

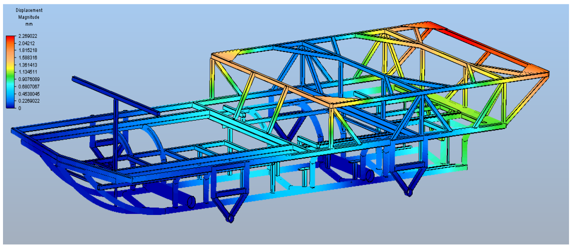

Figure 17. Distribution of deformations in frame construction.

The maximum values of stresses and deformations in the frame from diagonal twisting were 128 MPa and 2.27 mm, respectively. The maximum stresses did not exceed the yield strength of stainless steel (345 MPa), so the resulting stresses and strains are acceptable. For the rotary-screw propeller, the most critical load occurs when the obstacle is struck by the inter-turn space, when it is not supported by the inner frame (Figures 18 and 19). The maximum values of stresses and deformations in the propeller construction were 273 MPa and 4.25 mm, respectively. These stresses exceed the yield strength of stainless steel by 31.7%, but they do not destroy the propulsion shell and only slightly deform it. The calculation confirmed the efficiency of the rotary-screw propeller, and also showed the need to fill the internal cavity with a rigid material. Conducting experimental studies aimed at verifying the results of strength calculations is planned for the end of 2018.

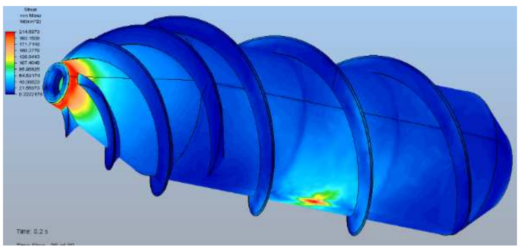

Figure 18. Stress distribution in the rotary-screw propeller construction.

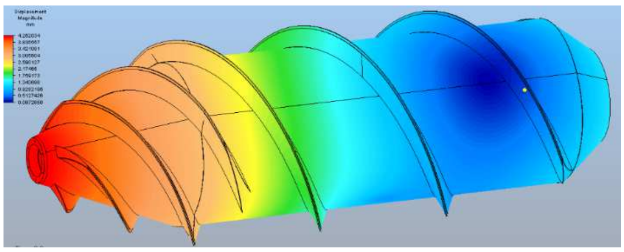

Figure 19. Distribution of deformations in the rotary-screw propeller construction.

4. Conclusion

The result of the creation of this universal mobile complex will be the expansion of the field of human economic activities in the Arctic shelf zone by increasing the efficiency of geological, seismological, prospecting, mining and other technological operations. A positive economic effect can be achieved thanks to the year-round operation of the complex, the use of serially produced samples of technological equipment, the unification of the carrier chassis to perform any role in the complex, improve the level of automation of work.

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