Comparative Structural Analysis of Hydrodynamic Interaction of Full-Submerged Tandem Archimedes Screws of Rotary-Screw Propulsion Units of Snow and Swamp-Going Amphibious Vehicles with the Water Area in Running and Mooring Modes

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Abstract: The paper deals with the issues of analysis of thrust and torque of structural elements of rotary-screw propulsion units of snow and swamp-going amphibious vehicles of tandem design when operating on water. For a wide range of propulsors with three variants of the helix angle, the contribution of various elements of Archimedes screws to the overall efficiency of the propulsor is analyzed. A comparative analysis of the hydrodynamics of rotary-screw propulsion units in running and mooring modes is given.

1 INTRODUCTION

Nowadays, there is a clear tendency to explore the regions of the Arctic, Siberia and the Far North in connection with the active extension of the sphere of subsoil use and the development of gas and oil fields. In these territories, there are mainly such supporting bases as snow, ice, water, sludge, broken ice in the water, as well as swamp, silt, etc. Rotary screw propulsion units are the best suited for such operating conditions due to the low pressure they exert on the support base by virtue of the specifics of the design.

The features and parameters of the motion of rotary-screw propulsors on the water are extremely little known, and therefore it is important to study the hydrodynamics of these propulsion units in order to ensure an optimal ratio of overwater and overland characteristics when designing them.

Earlier, the authors carried out studies of the hydrodynamics of single rotary-screw propulsion units, as a result of which dependencies of a similar nature were obtained, as given in this work. The results of the structural analysis of the hydrodynamic interaction of such Archimedes screws with the water area are given in the paper (Karaseva, 2022).

2 DESCRIPTION OF COMPUTER SIMULATION

To solve the problems, computer simulation methods were used at constant values of the flow velocity v = 4 m/s in the running mode and 0 m/s in the mooring mode; the values of the rate speed of propulsor varied in the range n = 200 ... 600 rpm.

Figure 1 shows the image of the three-start models of tandem Archimedes screw propulsors used. The geometric characteristics of all three models, with the exception of the angles of inclination of the helix, are

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identical and are the most typical for rotary-screw propulsion units of snow and swamp-going vehicles (Kulyashov, 1993; Danilov, 2011; Kolotilin, 2015; Shapkin, 2017). The values of the helix angles are, respectively, 24, 30 and 39 degrees: smaller angles of inclination correspond to typical values for traction vehicles, large ones – for transport vehicles.

As a result of computer simulation of the hydrodynamics of the models, a large amount of data was obtained. As a graphical representation of the simulation results, some of the visualization patterns shown in Figure 2 can be considered.

The analysis of these patterns confirms the complexity of the hydrodynamics of the interaction of tandem Archimedes screws with the water area. For the possibility of structural analysis, the entire propulsor was divided into logical elements, namely: front cowl, rear cowl, input and output helixes divided into three elements each, as well as cylindrical parts of the helixes of the fore and aft Archimedes screws in the amount of 8 elements – 4 elements per Archimedes screw (Figure 1). Averaged values of thrust in the longitudinal direction and torque with respect to the axis of rotation of the propulsor were monitored on each of these elements. In addition, the base cylinders of both Archimedes screws themselves were also divided into 4 elements each; however, these elements practically do not participate in the creation of thrust or resistance, therefore they are not shown in the diagrams.

It is also worth noting separately the fact that the distribution of loads is non-uniform for the remaining elements of the screw propulsion unit.

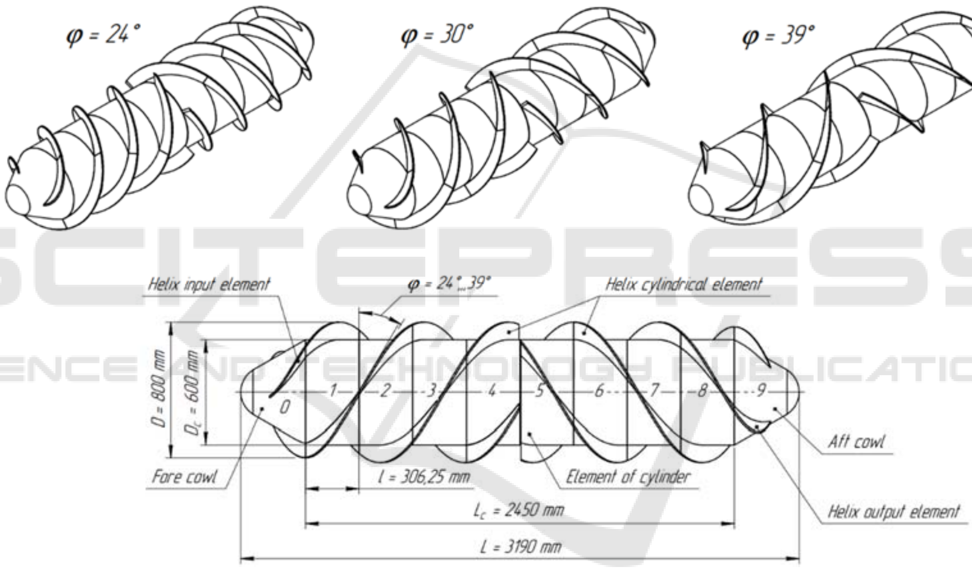

Figure 1: Images of rotary-screw propulsor models used for computer simulation.

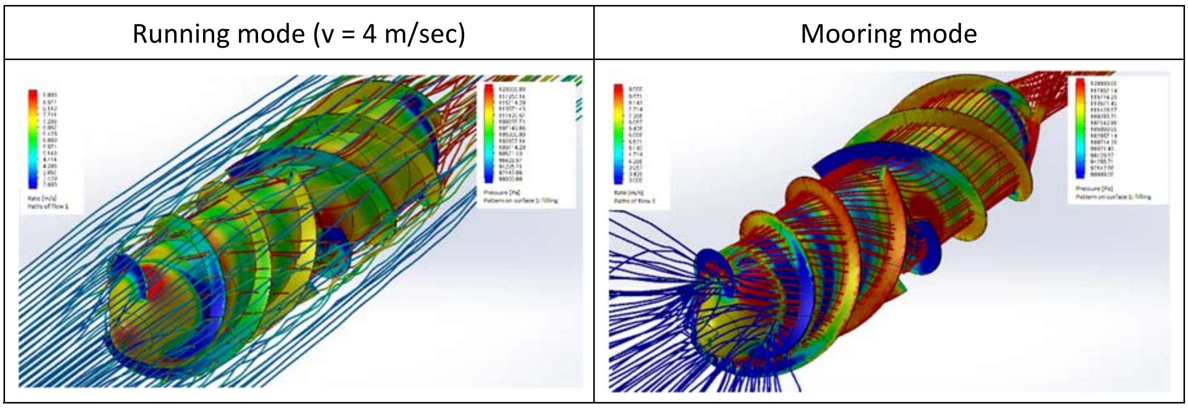

Figure 2: Examples of patterns of interaction between Archimedes screw and water area (helix angle 30°, n = 400 rpm).

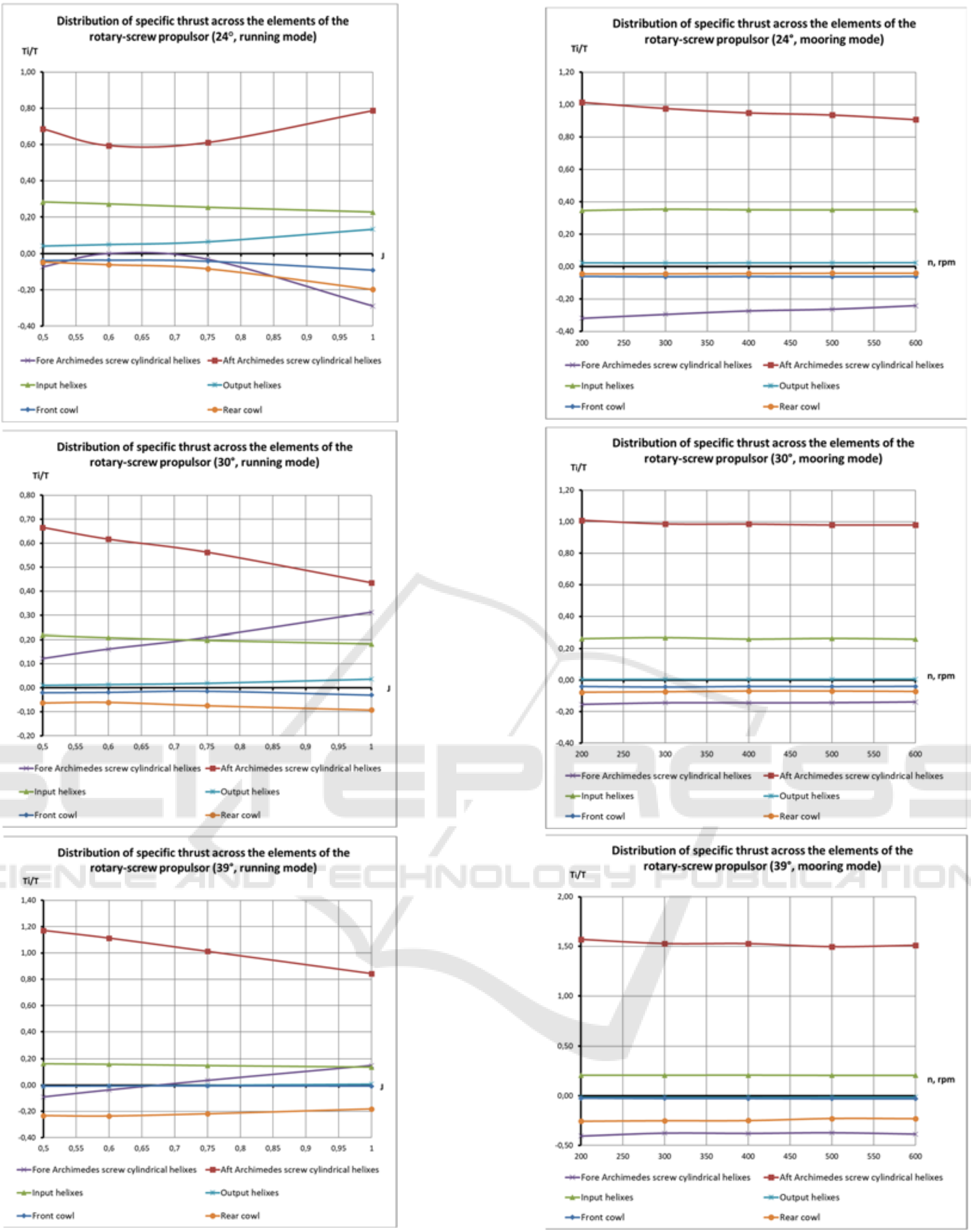

Figure 3: Distribution of specific thrust across the elements of the rotary-screw propulsor in running and mooring modes.

3 ANALYSIS OF THE ELEMENT-BY-ELEMENT DISTRIBUTION OF SPECIFIC THRUST AND SPECIFIC TORQUE

Figures 3 and 4 show the specific thrust and specific torque curves on the main elements for three propulsor models in running and mooring modes. For the running mode, the curves are presented in the traditional dimensionless form, depending on the advance ratio. For the mooring mode, in which the speed of the frontal incoming water flow is zero and the advance ratio, respectively, is also zero, a slightly different principle is used, namely, dependence on the number of revolutions of the propulsor.

Figure 4: Distribution of the specific moment across the elements of the rotary-screw propulsor in running and mooring modes.

On the diagrams, T_i is the thrust of the propulsor certain element, Q_i is the corresponding torque, T is the total thrust of the mover, Q is the total input moment, J is the advance ratio equal to

$$J = \frac{v_a}{n \cdot D}, \qquad (1)$$

where V_a is the water flow velocity (m/sec), n is the speed of rotation of the propulsor (rpm), D is the diameter of the Archimedes screw (m) (Basin, 1977).

As can be seen from the diagrams, the elements of the rotary-screw propulsor can create both thrust and resistance, which is manifested in positive and negative values on the diagrams, respectively.

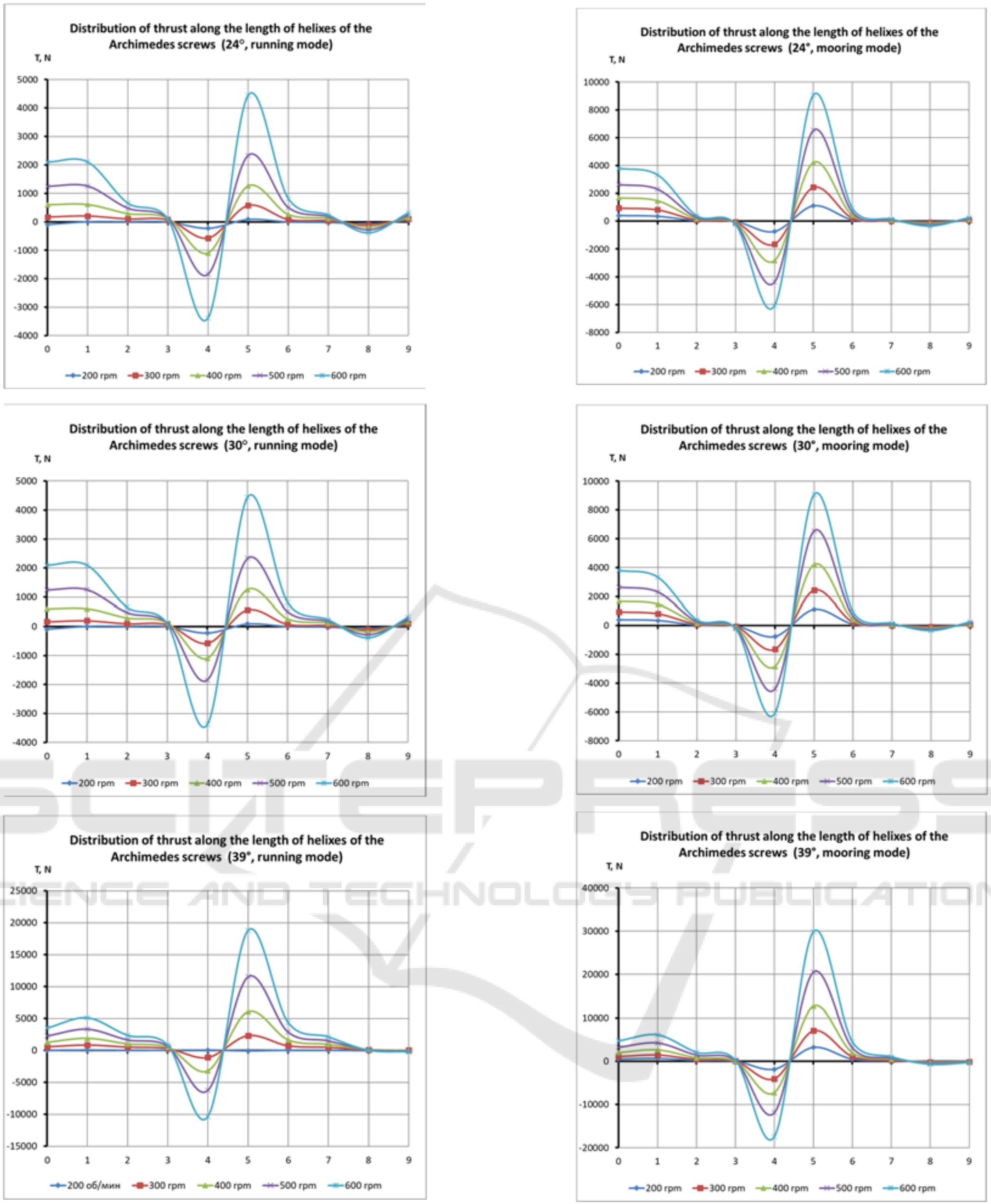

Figure 5: Distribution of thrust along the length of helixes of the Archimedes screws in the running and mooring mode.

When analyzing the data on the parameters of movement in the running mode, it can be seen that the greatest contribution to the creation of thrust is made by the helixes of the aft Archimedes screw located on the base cylinder (Figure 3). In addition, the input helixes are also quite actively involved in this process, although for transport vehicles with a propulsor with the helix angle approaching to the upper limit of the range of typical values the efficiency of the input part of the helixes decreases a bit, and the efficiency of the cylindrical part increases. Output helixes are practically not involved in the creation of thrust. The greatest contribution to the creation of resistance is made by the rear cowl, its resistance is least for vehicles with average values of helix angles. In addition, the resistance is also created by the front cowl, but it is a bit smaller and not for all models: for traction machines with small helix angles the resistance of the front cowl is greater, while for transport vehicles it is practically zero.

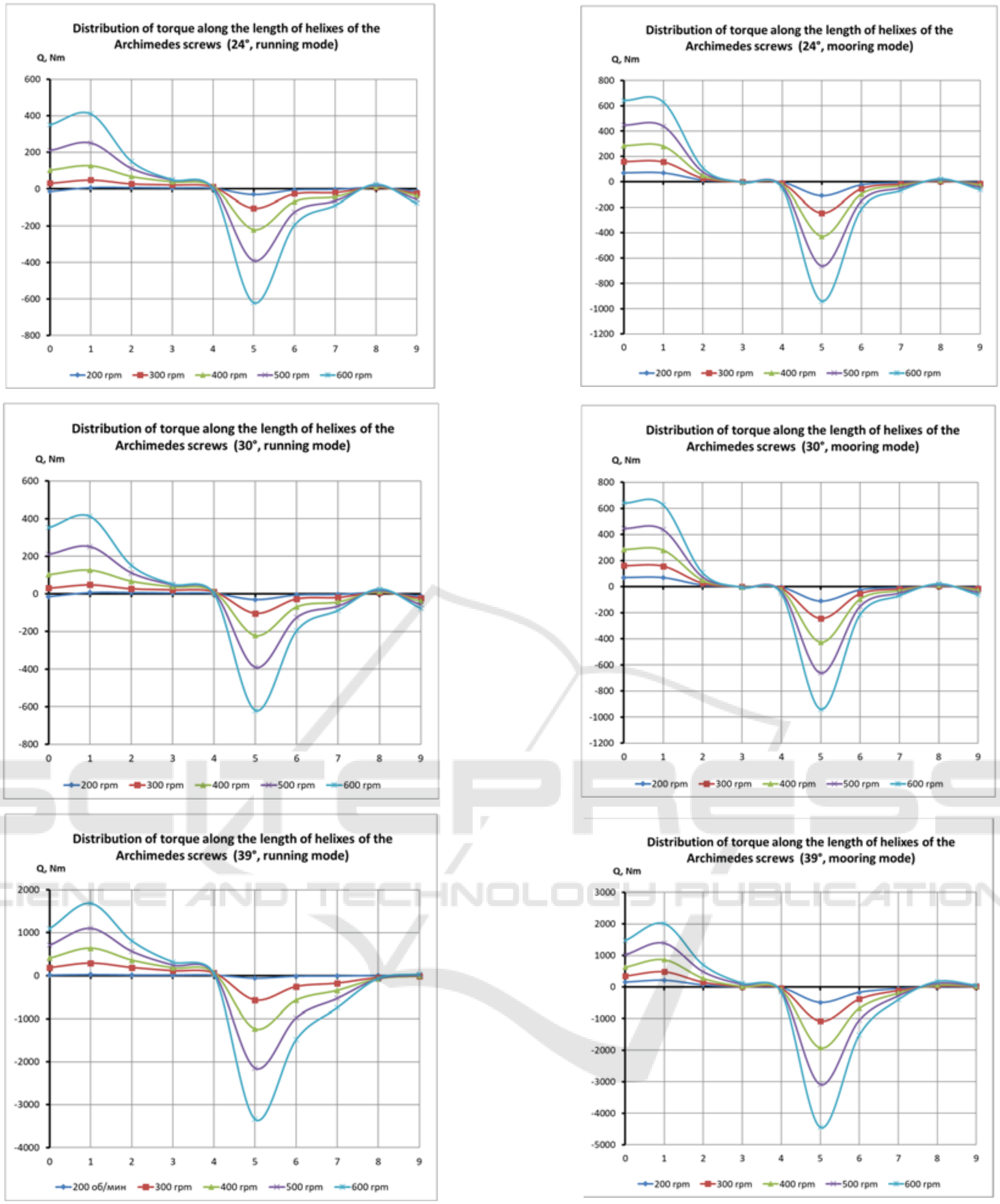

Figure 6: Distribution of torque along the length of helixes of the Archimedes screws in the running and mooring mode.

The behaviour of the cylindrical part of the helixes of the fore Archimedes screw is most interesting, since at small helix angles they create resistance, at medium – they participate in thrust creation on a par with the input helixes, and at large – they create both resistance and thrust depending on the value of the advance ratio.

In the mooring mode, an almost identical pattern of the nature of the curves is observed, with the exception of the behaviour of the helix cylindrical part of the fore Archimedes screw, which create resistance for all three models, and their contribution to this process is the greatest in comparison with other elements.

When analyzing the distribution of specific torque across the propulsor elements in the running mode, it is possible to note the characteristic similarity of most curves with the thrust distribution curves (Figure 4). The cylindrical part of the helixes of the aft Archimedes screw contributes the most to the creation of the turning torque as well as to the creation of thrust; the input helixes also participate in this process. The rear cowl creates neither turning nor braking torque, its participation is minimal. The greatest braking torque is created by the front cowl; the output part of the helixes also creates a slight braking at small and medium angles of inclination of the helix, however, with an increase of this angle, the value of the braking torque drops to zero at 39 degrees.

One of the main differences from the formation of thrust is the fact that the behaviour of the cylindrical part of the helixes of the fore Archimedes screw in this case is practically unchanged for all three models studied. The values of the specific moment on these elements are 2…3 times more than those on the input helixes.

When comparing the behaviour of the propulsor elements and their participation in the formation of the torque in the mooring mode it can be concluded that the overall picture, as in the case with thrust, is almost identical to the running mode.

4 ANALYSIS OF THE DISTRIBUTION OF THRUST AND TORQUE ALONG THE LENGTH OF THE HELIXES

Of particular interest is the distribution of thrust and torque along the length of the helixes of the rotary-screw propulsor shown in Figures 5 and 6. For graphical representation, the helixes are divided into 10 elements, numbered in order from fore to aft (Figure 1). So, the value "0" corresponds to the input element of the helixes, and "9" corresponds to the output one. These values on the diagrams are postponed along the abscissa axis.

When analyzing the patterns of thrust distribution in the running and mooring modes, we can note their fundamental similarity for all models in both modes. The nature of the curves is exactly the same for the certain elements of the helixes. The front part of the aft Archimedes screw (element "5") takes the greatest part in creating thrust, which is presumably explained by the work in the flow twisted in the opposite direction by the fore Archimedes screw. In addition, a significant contribution is made by the front part of the rotary-screw propulsor, namely, the input part of the helixes and the front part of the fore Archimedes screw (elements "0" and "1"). A small thrust is created by the middle parts of the Archimedes screws. The greatest resistance is created by the rear part of the fore Archimedes screw, although the rear part of the aft Archimedes screw together with the rear cowl makes a small contribution to this process. The patterns are identical for both running and mooring modes.

The torque distribution also has a similar character (Figure 6). As it can be seen, the greatest contribution to the creation of the torque is also made by the front part of the propulsor helixes. The middle and rear parts of the fore Archimedes screw in the running mode create very little torque, but in the mooring mode they practically do not participate in this process, as well as the rear part of the aft Archimedes screw in all modes.

An interesting thing is the transition of part of the elements to the "turbine mode", that is to the operating mode when the element creates a negative braking torque. To simplify the perception of such a mode, a picture can be conditionally imagined when the water flow is not twisted by the propulsor, but vice versa. A low turbine mode is observed on the output part of the helixes, but a much larger braking torque is created by the front and middle part of the aft Archimedes screw or, to be more precise, almost its entire cylindrical part. This can be explained by working in a stream of water twisted by the front screw, and, characteristically, this behaviour is manifested for all the considered helix angles in all modes, which allows us to assume quite confidently that such a picture will be typical for Archimedes screws with other parameters.

5 CONCLUSIONS

Based on the analysis of the above patterns, it can be concluded that the obtained dependences illustrate stable trends in the behaviour of specific elements of tandem rotary-screw propulsors of snow and swamp-going vehicles with typical parameters, regardless of the speed and number of revolutions, including mooring mode. Taking into account the stability and generality of the nature of the thrust and torque curves, it is safe to assume that the data obtained can be used to study the hydrodynamic interaction of tandem rotary-screw propulsion units with the water area also with other parameters of the geometry of the Archimedes screws and the working area.

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REFERENCES

Basin, A.M., 1977. Propulsion and course-keeping qualities of ships: study guide for higher educational establishments of water transport. “Transport”, Moscow.

Danilov, R.G. et al., 2011. The off-road crossing: studies of SKB ZIL. Svitok, Smolensk.

Karaseva, S.A. et al., 2022. Structural analysis of hydrodynamical interaction of full-submerged Archimedes screws of rotary-screw propulsion units of snow and swamp-going amphibious vehicles with water area by methods of computer simulation / S. Karaseva, A. Papunin, V. Belyakov, V. Makarov, D. Malahov // 15-th International Conference “Intelligent Systems” (INTELS’22).

Kolotilin, V. E. et al., 2015. Statistical model of selection geometric parameters, mass-inertia and power characteristics of transport-technological machines with rotary-screw propellers. N. Novgorod, Transactions of NNSTU, Issue 3 (110), pp. 156-208.

Kulyashov A.P., Kolotilin V.E., 1993. Ecological safety of propulsion units of transport and technological vehicles. Mashinostroenie, Moscow.

Shapkin, V.A. et al., 2017. Introduction to dynamic of systems snow-covered area – rotary-screw vehicle: monograph. The Russian Presidental Academy of National Economy and Public Administration, Nizhny Novgorod.