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Proceeding Paper

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 via Methods of Computer Simulation †

Svetlana Karaseva [1,*], Aleksey Papunin [1], Vladimir Belyakov [1], Vladimir Makarov [1] and Dmitry Malahov [2]

[1] Department of Construction, Road and Carrying-and-Lifting Machines, Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Minin Str., 24, Nizhny Novgorod 630092, Russia; lexa-lenia@rambler.ru (A.P.); belyakov@nntu.ru (V.B.); makvl2010@gmail.com (V.M.)

[2] Department of Tow Trucks and Amphibious Vehicles, Moscow Automobile and Road Construction State Technical University, Leningradsky Prospect, 64, Moscow 125829, Russia; malahow_dm@mail.ru

* Correspondence: geliosveta@gmail.com; Tel.: +7-985-413-3988

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Abstract: The paper considers the problems of estimation and provision of efficiency of rotary-screw propulsion units (RSP) for snow and swamp-going amphibious vehicles. The performance curves of fully submerged Archimedes screws of RSP are presented with parameters typical for snow and swamp-going amphibious vehicles. These parameters were obtained from the results of computer simulation. For a wide range of performance modes, the impact of particular elements of Archimedes screws on the general efficiency of the propulsion unit is analysed. According to the results of analysis of data received, lines of further research will aim to increase the efficiency of RSP when moving afloat.

Keywords: rotary-screw propulsion units; amphibious vehicles; Archimedes screws

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1. Introduction

Taking into account the ongoing reclamation of the Arctic, Siberia and the Far North, there is an increasing requirement for vehicles that can achieve high flotation over bearing surfaces such as ice, snow, water, brash ice and broken ice on water, and also over the low-load-bearing capacity soils, for example, over swamps, silt, liquid mud, etc. [1,2]. In such exploitation conditions, the snow and swamp-going amphibians with rotary-screw propulsion units prove themselves to be the best. When designing them, it is crucially important to define the optimal proportion of overwater and overland characteristics depending on the aim of the vehicle, the area of application and the planned region of operation to provide effective and rational use of it. The overland characteristics of RSP Archimedes screws are rather well researched. Meanwhile, there are very few data about the overwater characteristics and optimal geometrical parameters for water movement [3–5]. At the present time, research works on hydrodynamical characteristics of rotary-screw propulsion units are conducted in the department "Construction and road-building equipment" of Nizhny Novgorod State Technical University n.a. R.E. Alekseev and department "Truck tractors and amphibious vehicles" of Moscow Automobile and Road Construction State Technical University. The research on propulsive characteristics of RSP Archimedes screws with typical geometrical parameters for snow and swamp-going amphibious vehicles previously conducted by authors revealed the correspondences of thrust, torque and performance indicators for cruising and mooring modes [6–9]. These correspondences are shown in Figure 1.

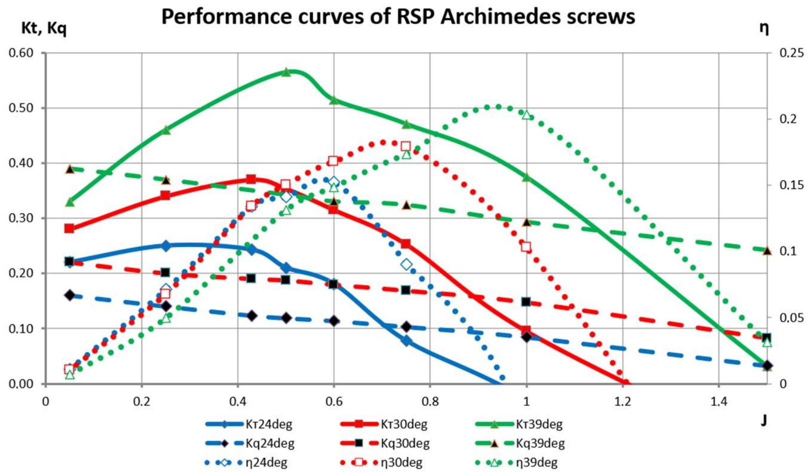

Figure 1. Performance curves.

Thrust coefficient

$$K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$$

Torque coefficient

$$K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$$

Propulsive coefficient

$$\eta = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$$

Advance ratio

$$J = \frac{v_a}{n \cdot D}$$

Here, T is the propeller thrust (N), Q is the torque of the propeller shaft (N•m), n is the propeller rotational speed (rpm) and v_a is the speed of water flow (m/s). The analysis of visualization patterns of computer simulation results of Archimedes screws hydrodynamics proved the difficulty of the nature of their interaction with the water area and showed the essential non-uniformity of load distribution over particular elements. The results of quantitative analysis of pointed non-uniformity can be seen below. These allow us to estimate the contribution of Archimedes screw elements to useful thrust and structure of power loss to Archimedes screw rotation while moving afloat.

2. Representation of Geometrical Models and Statement of the Problem

Figure 2 shows the schemes of simulation objects. The research was conducted for three models of a three-start Archimedes screw with helix angles 24, 30 and 39 degrees. The other geometrical characteristics are identical. To determine the possibility of structural analysis of hydrodynamic interaction with the water area, the surfaces of Archimedes screw models were separated into elements. During simulation over each element, we registered the averaged values of thrust in the longitudinal direction and torsion torque, respectively, to the rotation axis. As a result, the Archimedes screw models consist of eight parts of helixes located on the basic cylinder of Archimedes screw, as follows: cylindrical helixes; eight parts of basic cylinder of the Archimedes screw; fore and aft cowls; three input and three output elements of helixes.

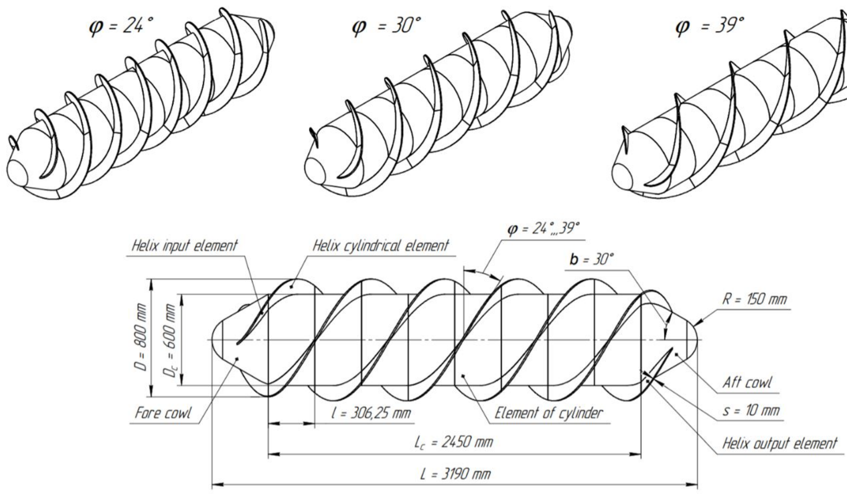

Figure 2. Schemes of researched models of Archimedes screw.

3. Results of Computer Simulation

These problems were solved with the aid of a computer simulation at the fixed value of flow speed v = 4 m/s and various values of rotation speeds of the Archimedes screw in the range n = 200. . . 700 rpm. As a result, the essential dataset was received. Some visualization patterns of the results of computer simulation are shown in Figure 3.

Figure 4 presents the correspondences of thrust T_i and torque Q_i of basic elements thoroughly brought to the thrust of the entire Archimedes screw and torque, due to the advance ratio. Different elements can create either thrust or resistance. Because of this, the values of specific force factors shown in the diagrams in the first case can exceed one. In the second, the negative quantity is obtained.

Naturally, the main element generating the thrust is the cylindrical part of the helixes of Archimedes screws. In the entire range of helix angles, their thrust is close to the total thrust of the Archimedes screw. Meanwhile, with the increase in the advance ratio, the specific thrust and the torque of the cylindrical part of helixes simultaneously increase. The second element generating the thrust is the input helixes. On the ascending branch of efficiency of the Archimedes screw (see Figure 1), their stake in general thrust does not depend on an advanced ratio and varies in the range 0.5. . . 0.8 (fewer values conform to the higher values of helix angles). Specific torque lies in the range 0.2. . . 0.3, which reduces with the increase in the advance ratio. The main factor reducing the hydrodynamical efficiency of Archimedes screws is the resistance of the aft cowl. Its stake in general thrust increases with the reduction in the helix angle and the increase in the advance ratio. The critical excursion of specific resistance of the aft cowl is on the descending branch of efficiency of the Archimedes screw. The contribution of this element to power loss to Archimedes screw rotation is insignificant. The correspondences provided show that other structural elements slightly affect the general efficiency of fully submerged Archimedes screws in a frontal approach flow.

The results received for thrust and torque distribution in relation to the length of spiraling of Archimedes screws (Figure 5) are of particular interest. For clear presentation, the elements of helixes are numbered from fore to aft (the abscissa axis). The values “0” and “9” correspond to input and output helix elements.

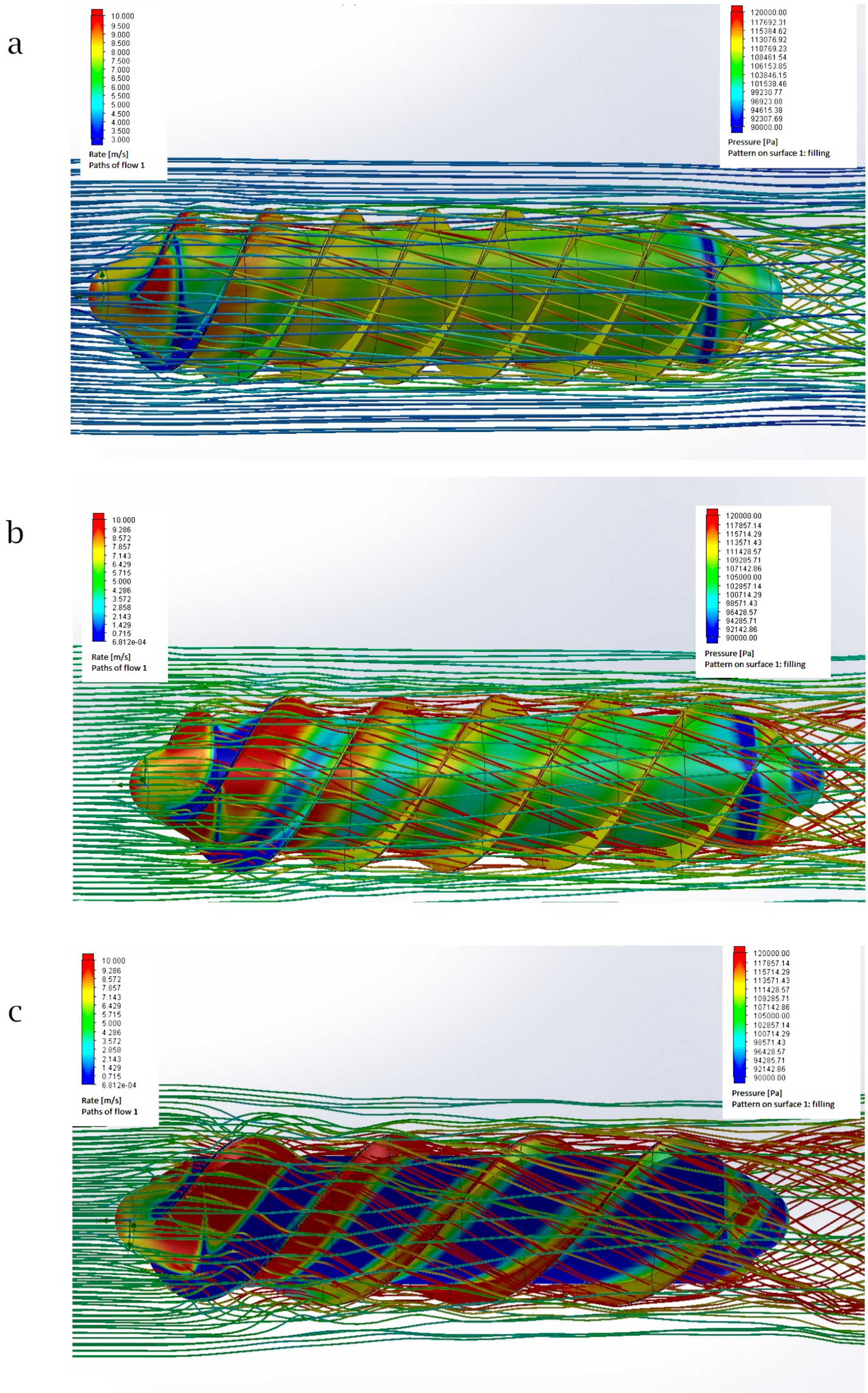

Figure 3. Visualization patterns of computer simulation of hydrodynamics of fully submerged Archimedes screw of RSP (v = 4 m/s, n = 500 rpm): (**a**) helix angle 24 deg; (**b**) helix angle 30 deg; (**c**) helix angle 39 deg.

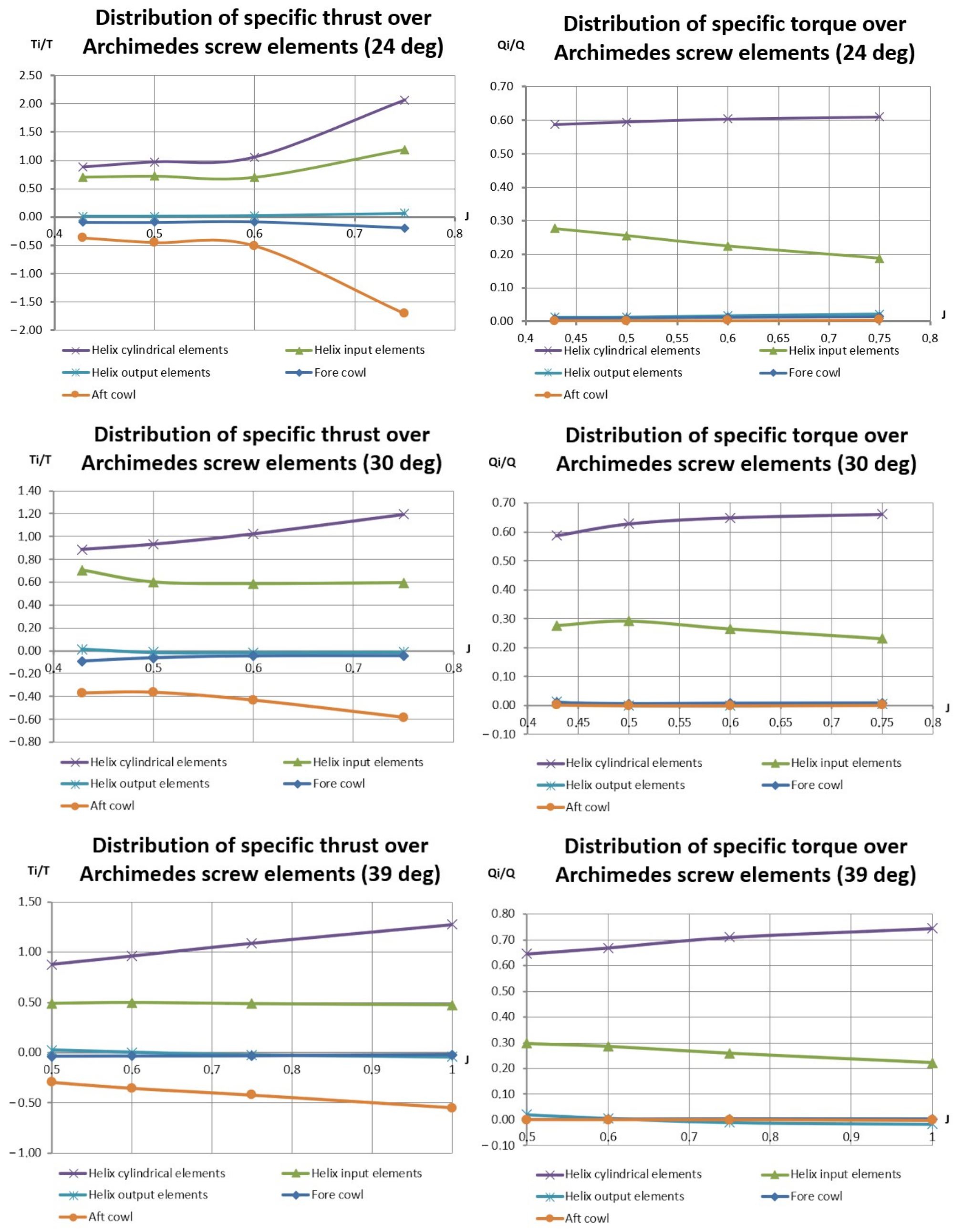

Figure 4. Impact of advance ratio on specific thrust and specific torque for frontally approaching flow to fully submerged Archimedes screw.

The correspondences given show that in the full range of helix angles, there is a conceptually identical pattern of distribution. In fact, the efficiency area is limited by the first four elements of helixes, including the input one. The contribution of the other parts to thrust and useful power is inessential, particularly at high rotation speed (for low values of advance ratio). The intriguing point is also the discovered effect of changeover of some helix parts (elements 5…8) to "turbine operation" appearing for high angles of spiraling (39 degrees).

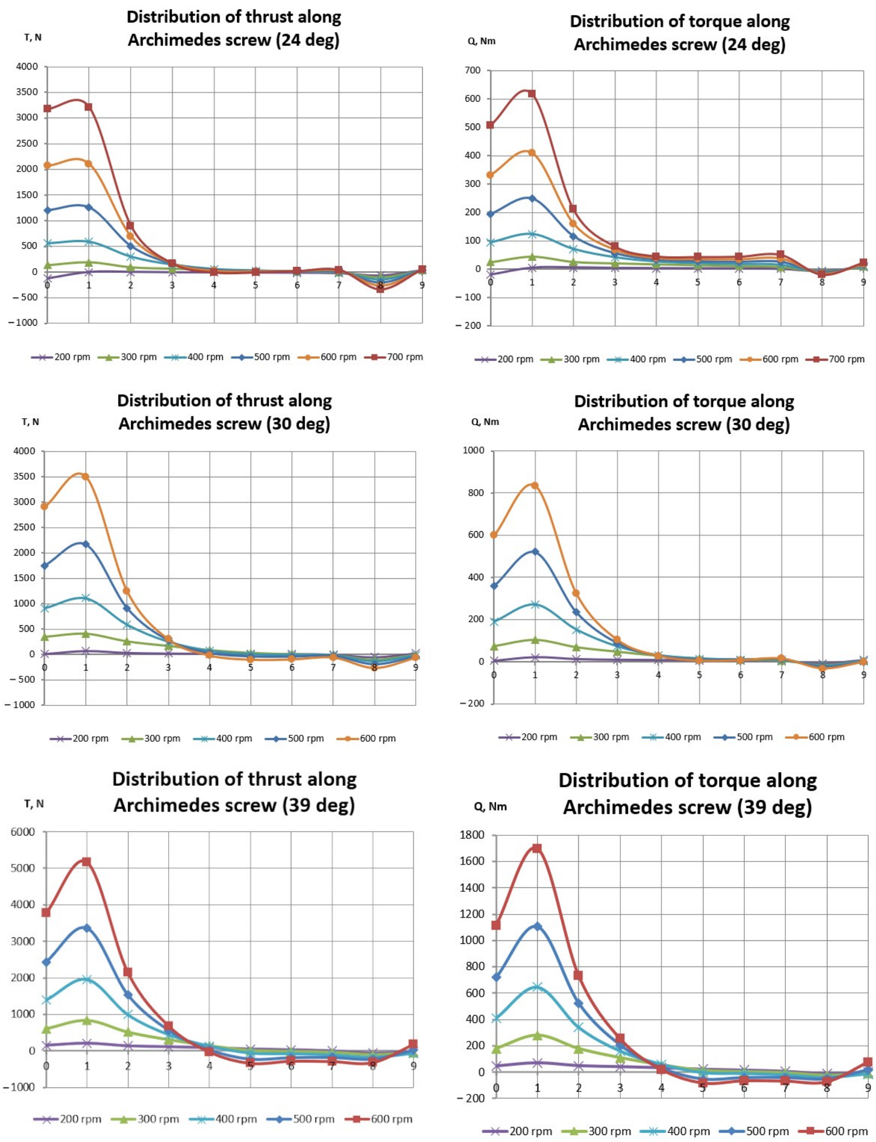

Figure 5. Thrust and torque distribution over the length of one helix of Archimedes screw.

4. Summary

According to the results of research on models of fully submerged Archimedes screws with the most typical geometrical characteristics for snow and swamp-going amphibious vehicles with rotary-screw propulsion units, the following main conclusions can be drawn:

- In the analyzed typical range of advance ratio J for frontally approaching water flow, the thrust is generated by input and cylindrical elements of Archimedes screw helixes. The fore cowl, output elements of helixes and cylindrical part (basic cylinder) of the Archimedes screw play a small part in thrust generation and input power costs. The main negative influence on the general thrust of the Archimedes screw has the resistance of the aft cowl.
- The input power and effective thrust are practically realized only on the input part of helixes and on the front part of cylindrical helixes with a length approximately equal to Archimedes screw diameter D.
- Archimedes screws in combination with their high hydrodynamical efficiency give evidence of the necessity of paying special attention to the construction development of these elements during the design process.

5. Conclusions

The observations about the contribution of Archimedes screw elements to its propulsive characteristics allows us to consciously form variants of design concepts targeted at increasing the hydrodynamical efficiency of RSP. As concepts, we can consider the mounting of optional equipment (deflectors, shrouds etc.) changing the behavior of flow around the particular parts of Archimedes screw and the shaping of cowls, input and output elements of helixes. While adding the optional equipment to Archimedes screw structure, it is necessary to design it in such a way that the application of equipment does not disimprove the overland characteristics of the rotary-screw propulsor. At the present time, the relevant research continues and the study of hydrodynamics of tandem Archimedes screws with counterrotation is being conducted.

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