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# THE STRAIN-STRESS STATE OF THE ROTOR DURING ENTRANCE OF THE ROTOR-SCREW VEHICLE FROM WATER TO ICE

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**ABSTRACT**

A rotor is the main element in a construction of rotor-screw vehicle. Accordingly, the durability of the whole vehicle is in direct connection with the durability of a rotor. The loading mode in the case of the vehicle's entrance from water to ice is viewed in this work. The paper contains the computational scheme developed for the loading mode. The rotor of the universal Arctic rotary-screw rescue vehicle was chosen as an object of the research. This rescue vehicle is being developed in NNSTU named after R.E. Alekseev. The simulation model of the rotor was created in accordance with the computational scheme and technical characteristics of the vehicle. The strength calculation of the computer model was carried out by finite-element analysis with Autodesk Simulation Mechanical 2016. The paper shows the strain-stress state of the rotor as a result of the calculation. The influence of the reviewed loading mode to the rotor's construction is described in the conclusion.

**Keywords:** rotor-screw vehicle, finite elements method, strain-stress state, strength calculation, arctic.

## 1. INTRODUCTION

The most important feature of rotor-screw vehicles is their amphibiousness. Rotor-screw vehicles can move in water, on land and get out from water to ice (or to nature shore) (Figure-1) [1]. This fact makes rotor-screw vehicles universal all-terrain vehicles.

**Figure-1.** The entrance of GPI-72 (developed in NNSTU) from water to ice.

The case of rotor-screw vehicle entrance from water to ice is the extreme mode of rotor's work, because the biggest part of traction force is on the blade, which contacts with a solid ground (ice). The estimation of the accurate amount of the traction force, which is produced by the mentioned above part of the blade, is the difficult issue. Other parts of blades are immersed in water and they produce the traction force, but not so efficiently, because bearing capacity of water is less than bearing capacity of ice.

The case when only one rotor contacts with ice in the initial time of the entrance, was chosen like the case for calculation. There is an extremely high possibility of appearance of this situation in the real exploitation conditions, because usually there is no opportunities for the vehicle to approach the ice perpendicularly. In this situation, the vehicle's weight is distributed to the one side of the vehicle.

Figure-2 displays forces, which affect the rotor's blades from the ground during the motion. [2].

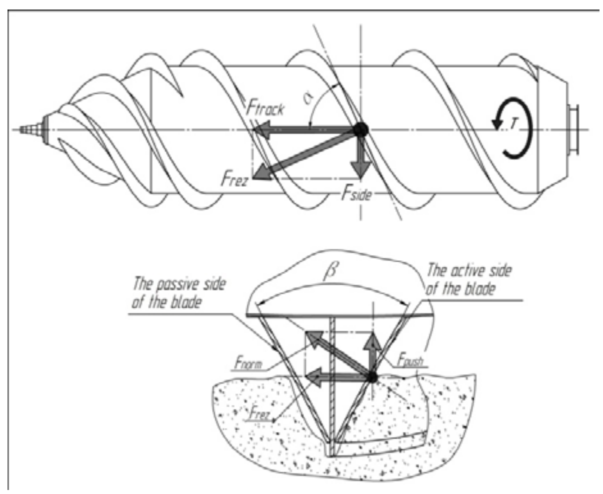


**Figure-2.** Forces affecting rotor's blade during the motion.

Where: $F_{norm}$ – normal force; $F_{push}$ – vertical force; $F_{rez}$ – resultant moving force; $F_{tract}$ – traction force; $F_{side}$ – side force; T – torque on a rotor; α – tilt angle of helix; β – angle of blade's crest.

The rotor of the universal Arctic rotary-screw rescue vehicle [3] was chosen like an object of the research. This rescue vehicle is being developed in NNSTU named after R.E. Alekseev (Figure-3).

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**Figure-3.** Universal Arctic rescue vehicle with rotor-screw mover.

The values of forces for the calculation of the rotor is presented in Table-1.

**Table-1.** The values of the forces, which affect to the rotor of the universal Arctic rescue vehicle.

| **Quantity** | **Value** |
|---|---|
| Torque T, kN·m | 9 |
| Weight of the vehicle G, N | 127,530 |
| The force from the vehicle's weight affected to one rotor $F_{wt}$, N | 31,882.5 |
| The force from the vehicle's weight affected to one rotor $F_{wt}$**, N | 63,765 |
| Side force $F_{side}$, N | 15,000 |
| Traction force $F_{tract}$, N | 29,440 |
| **the force from the vehicle's weight in the case of the vehicle's weight is distributed to one side | |

## 2. CALCULATION SCHEME

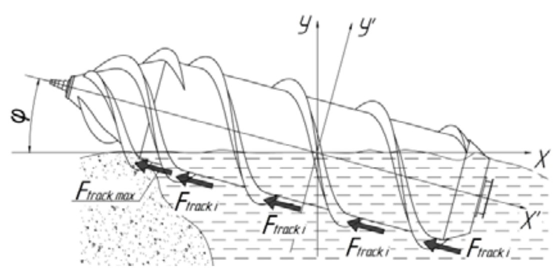
70% of $F_{track}$ is on the part of the blade ($F_{track,\ max}$) was decided, which contacts the ice. The other 30% are distributed equally among active sides of the blades immersed in water ($\sum F_{track,i}$) (Figure-4a).

The values of the forces are: $F_{track,\ max}$ = 20608 N; $\sum F_{track,i}$ = 8832 N.

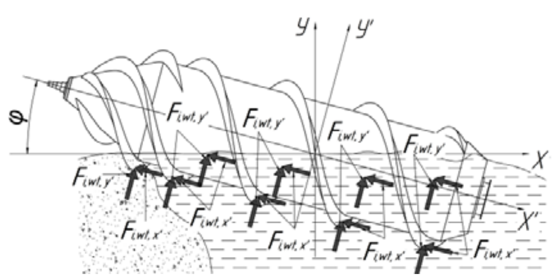
For further calculations, the canting angle φ during the vehicle's entrance from water to ice is considered to be 15°. Horizontal and vertical components $F_{wt,x'}$ and $F_{wt,y'}$ of the ground reaction force from the vehicle's weight are distributed among the immersed part of the rotor (including the blades) (Figure-4b). The values of the forces are: $F_{wt,x'}$ = 16500 N; $F_{wt,y'}$ = 61500 N.

The side force is distributed among the immersed part of the rotor (including the blades) (Figure-4c). The total value of the side force is: $F_{side}$ = 15000 N.

The constraints applied to the rotor are shown on Figure-4(d). Both bearing supports of the rotor are fixed.




(a)




(b)

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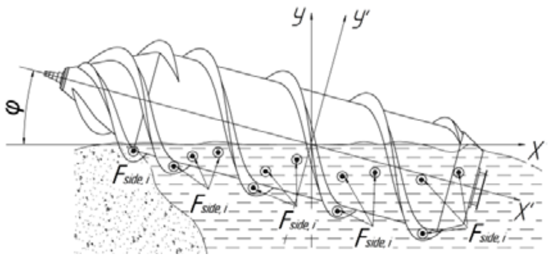


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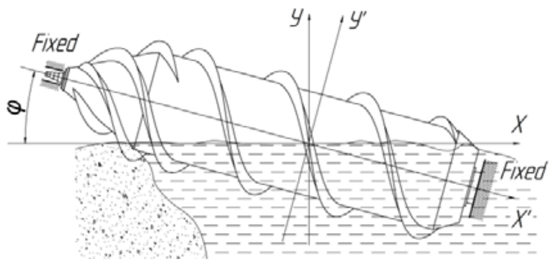


(d)

**Figure-4.** Loads and constraints.

(a) the traction force distribution; (b) the distribution of the components of the ground reaction force from the vehicle's weight; (c) the distribution of the side force; (d) constraint.

**3. SIMULATION MODEL**

Autodesk Simulation Mechanical 2015 was used for mesh building and further calculation of the simulation model. The mesh of the rotor's simulation model is displayed on Figure-5.

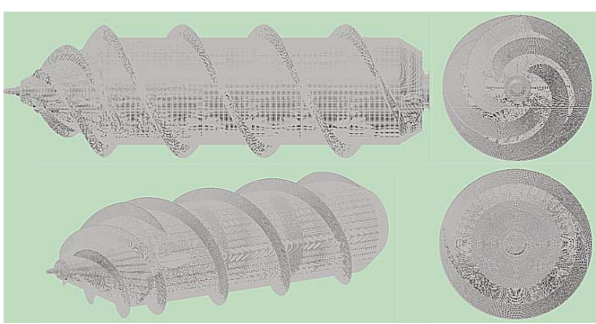

**Figure-5.** The mesh of rotor's computer model.

Short characteristics of the mesh are displayed below in Table-2.

**Table-2.** Short characteristics of the mesh.

| | |
|---|---|
| Fixed element's size, mm | 9 |
| Element's type | Solid (Brick and tetrahedral) |
| Amount of nodes | 1,237,140 |
| Amount of elements | 3,015,473 |

Figures 6 and 7 display rotor's computer model with loads and constraints for the calculation. All loads and constraints are distributed as it's shown on Figure-4.

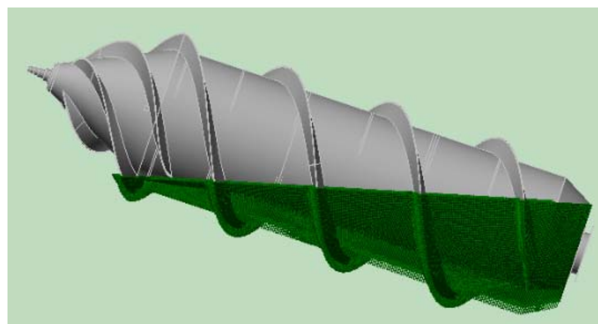

**Figure-6.** The computer model with distributed loads.

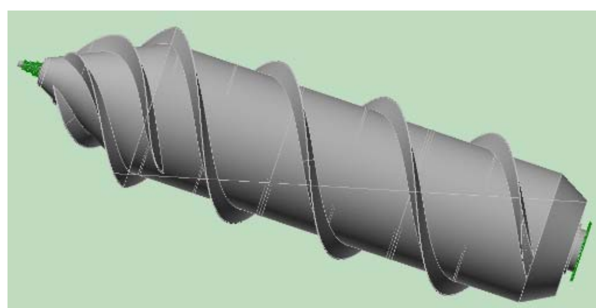

**Figure-7.** The computer model with distributed loads.

The rotor for the special Arctic rescue vehicle is made of stainless steel 12X18H10T (analogue AISI 304). The simulation model contains characteristics of the chosen material. They are presented in Table-3 [4].

**Table-3.** Short characteristics of the stainless steel 12X18H10T.

| Density, kg/m$^3$ | Young's modulus E, GPa | Poisson ratio | Yield stress $\sigma_{0,2}$, MPa | Resistance to rupture $\sigma_B$, MPa |
|---|---|---|---|---|
| 7920 | 198 | 0,3 | 225-315 | 550-650 |

**4. RESULTS OF THE CALCULATION**

Figure-8 displays views of the rotor's strain-stress state and distribution of the von Mises stress. The most loaded zone of the rotor is the zone on the nose area of the rotor, namely, is in the peak of the blade (Figure-9). The maximum value of stress von Mises in this zone reaches 244.98 MPa.

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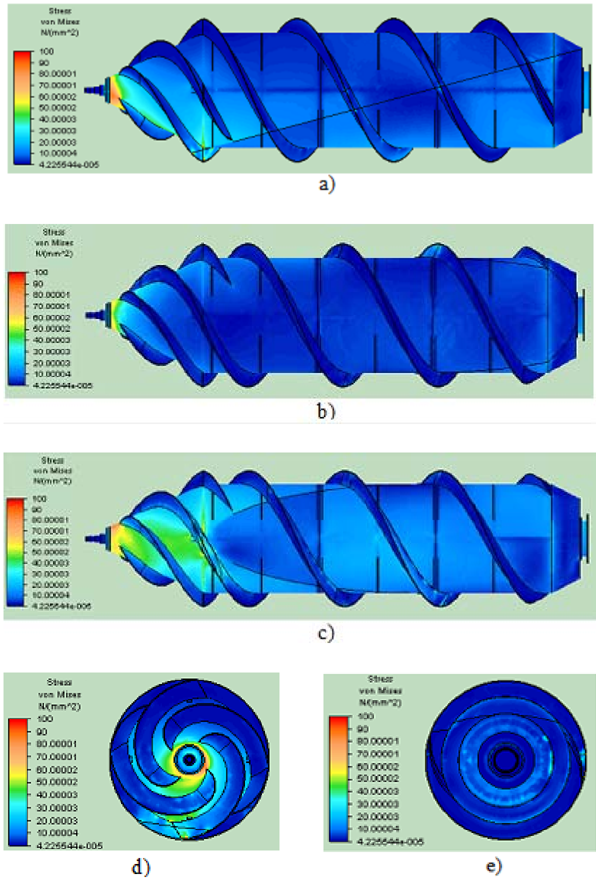


**Figure-8.** Stress von Mises in the rotor (scale of deformation 1x1) a) left; b) top; c) bottom; d) front; e) back.

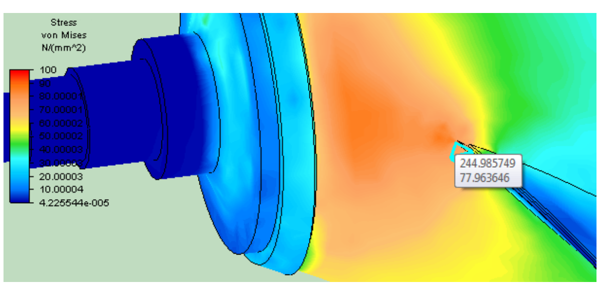


**Figure-9.** The most loaded zone of the rotor.

Figure-10 shows displacements arising in the rotor.

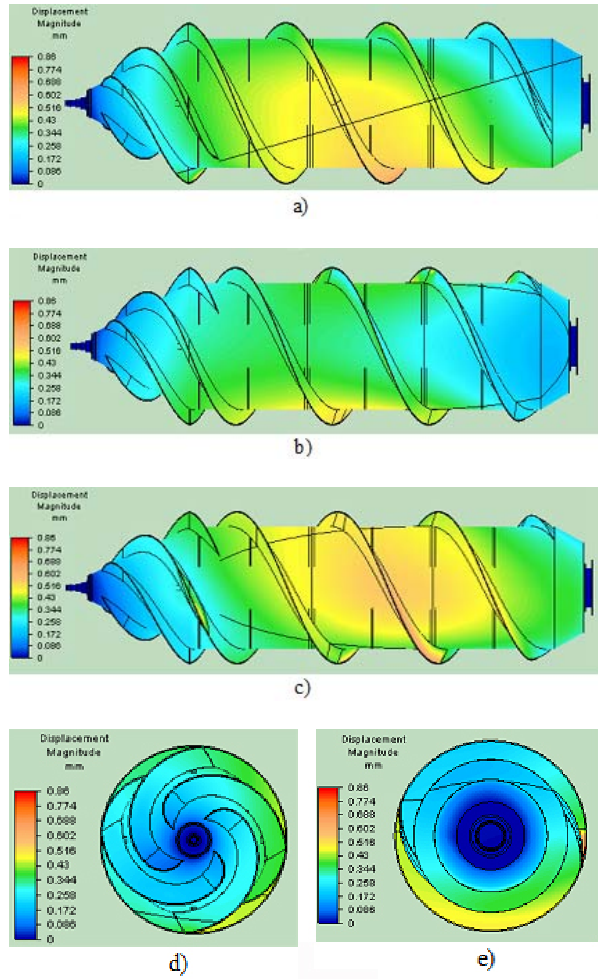


**Figure-10.** Displacements in the rotor (scale of deformation 1x1) a) left; b) top; c) bottom; d) front; e) back.

The zone of the rotor, which has the maximum displacements, is the zone on the peak of the blade in the middle area of the rotor (Figure-11). The maximum value of displacement in this zone reaches 2.24 mm.

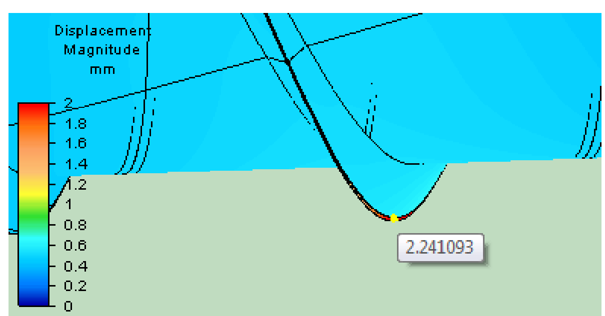


**Figure-11.** The zone of the rotor with the maximum displacements.

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## 5. CONCLUSION

The yield stress for stainless steel 12X18H10T is $\sigma_т$ = 300 MPa and resistance to rupture is $\sigma_в$ = 650MPa. It means there will be allowable values of stress in the rotor during the vehicle's entrance from water to ice, because $\sigma_{мах}$= 244.98 MPa < $\sigma_т$ = 300 MPa.

In addition, displacements in the rotor can be considered allowable as well, because all deformations are in the limit of yield stress.

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