Determining friction coefficient between the base cylinder of rotary screw propulsion unit and various ice types in different daylight surface

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Abstract: Statistical data processing results of friction coefficient change between steel base cylinder of rotary screw propulsion unit and ice of different surface roughness are considered in the article. Experimental values of ice surface roughness complex criterion are given. It is also established that in actual operating conditions the basic factor affecting the friction coefficient change of the base cylinder on ice is represented by the processes connected with the plastic yield of the ice daylight surface irregularities. At this the adhesive component of friction force while operating on rough ice did not exceed the 20% value.

To improve social and economic standards and to carry out projects of transport infrastructure development in the Arctic zone, it is necessary to create new as well as modernize current all-terrain vehicles as far as underpopulation and thus low cargo traffic makes the road network development in this region unprofitable.

Nowadays over 100 kinds of special-purpose snow and swamp-going vehicles are produced worldwide, capable of performing transportation and processing operations in swam and snowscape area. Herewith, in order to cut the production costs most of these vehicles are manufactured on the basis of production cars. Despite the fact that these vehicles passed certification tests during production, including the ones measuring the amount of noise in the vehicle, the noise impact on the driver in operating all-terrain vehicles created on their basis, frequently exceeds the established norms and can reach 90 to 100 dB. Thus we can make a conclusion that all-trailer propulsion unit interaction with the supporting medium is the source of excessive noise when snow and swamp-going vehicles are in motion. Consequently studying the interaction of different propulsion unit types with the supporting medium in order to decrease the noise level in the vehicle and operating medium is an important scientific problem.

It should be noted that unlike cars, all-terrain vehicles move over surfaces having high diversity of physical and mechanical, strength and geometry parameters. Hence the most rational approach to simulate the noise level is to develop several models of its appearance for each propulsion unit type interaction with the given supporting medium. The article considers one of the most widespread types of motion – the interaction of rotary screw propulsion unit with ice. In this case the noise level will be determined solely by the results of friction of the base cylinder and screw blade on the ice surface as shown in Fig.1.
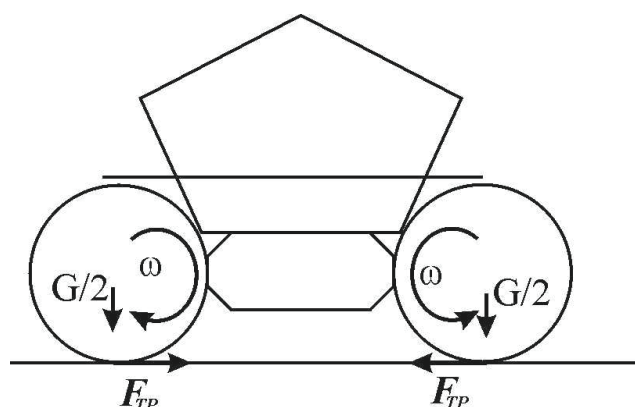
Figure 1. The chart determining the noise level created by the base cylinder at its friction on ice.

The noise when the rotary-screw machine is in motion appears due to the interaction of the rotor and the supporting medium and depends on the contact surfaces motion speed. This noise is caused by the base cylinder hitting the ice microroughness. Friction force on each peak of contact surfaces according to [1-2] can be presented by 2 summands: a molecular (adhesive) and a mechanical component. Thus the total friction force depends on the contact surfaces actual field of contact. The surface roughness is characterized by the complex roughness index Δ. At its low values, i.e. at a high class of surface smoothness, the dominant factor is a molecular component; and at increasing Δ in the contact zone plastic yield prevails [6]. Determining the value of the complex index Δ is a complicated applied research task which involves determining both the ice surface roughness height and the radius at their asperity summits. This is possible only by statistical processing of test data carried out within the framework of federal task program «Research and development in priority development fields of Russia's science and technology sector for the period of 2014-2020 » № 14.577.21.0222 its subject being «Creating a test sample of amphibious stand-alone transport and technological complex with intelligent control and navigation system for carrying out all-year-round exploratory drilling operations on the Arctic shelf». According to the research the dependency of Δ index and the maximum surface roughness height can be approximated by the dependency:

$$\Delta = 0{,}038h_{MAX} - 0{,}05$$

For the circuit load, equal to 1 rotor load rate ratio to the rotor area of contact with ice surface, equal to the ice compression strength HB 3-6 MPa [3], elasticity modulus E, ranging from 4 to 8 MPa, and Poisson's ratio of 0,31 the contact index value of rotary screw propulsion unit equal to:

$$\frac{p_c(1-\mu)}{E} = \frac{(3 \div 6) \cdot 0{,}68}{4 \div 8} = 0{,}50 \div 51$$

can be obtained.

As soon as this index exceeds the contact index value of the rotary screw propulsion unit with the supporting medium equal to 0,06· $\sqrt{\Delta}$ [7] or 0,1, it is possible to make a conclusion that the contact of the rotary screw propulsion unit with ice is of intense yielded type. For this interaction type the friction coefficient value of these surfaces is calculated by the equation [7]:

$$f = \frac{\tau_0}{HB_C} + \beta + 0{,}9\sqrt{\Delta \frac{HB_\Pi}{HB_C}}$$

where τ_0 — is the observed tangential strength at the adhesive bond section; β — the observed pressure-coefficient of molecular friction component, HB_Π and HB_C – are ice and steel indices in MPa

respectively. In the case of ice plastic contact with steel, index τ_0 is determined by value 10-15 MPa, and β=0,0072. Then the friction coefficient of the steel base cylinder on the ice surface is determined by the expression:

$$f = \frac{\tau_0}{HB} + \beta + 0,9\sqrt{\Delta\frac{HB_{Л}}{HB_C}} = \frac{10}{2500} + 0,0072 + 0,01\sqrt{0,038h_{MAX} - 0,05}$$

$$f = 0,0112 + 0,01\sqrt{0,038h_{MAX} - 0,05}$$

Thus, the dependency which considers not only steel characteristics and ice temperature data, but also ice roughness, while determining steel friction coefficient upon ice, was obtained.

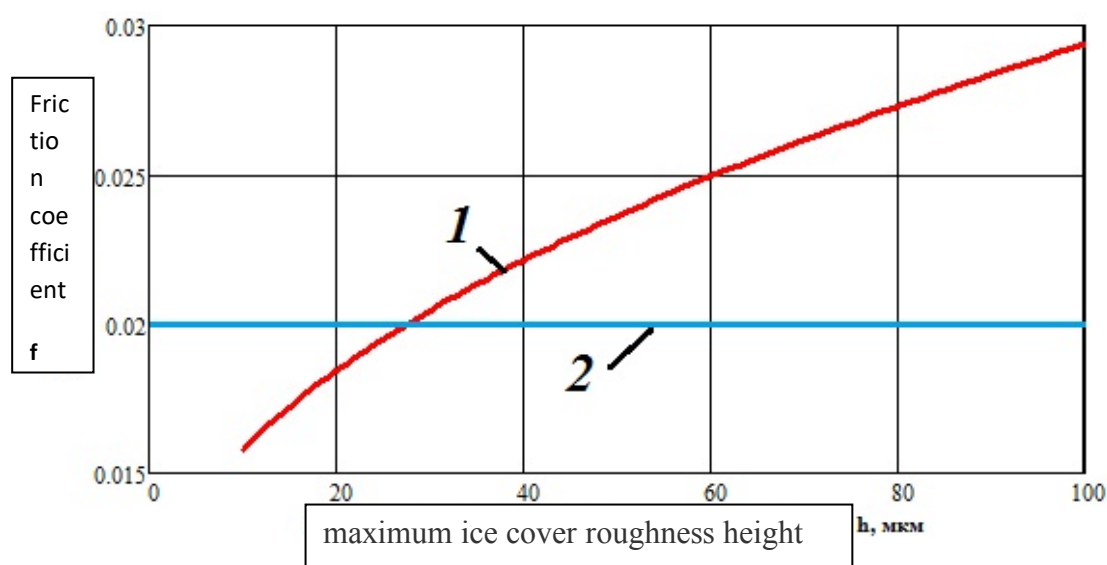The value of correlation coefficient with the test data is 0,996. The data obtained are shown in Fig.2.

Figure.2. Calculation data of steel on the ice friction coefficient considering. roughness parameters of ice; 1 – dependency obtained; 2 – previously applied dependency

Calculation data show that the calculation method used up to now had a calculation error of over 60% when describing the machine operation on rough ice as it did not consider ice surface roughness parameter. The research shows that this parameter is crucial. The newly obtained dependency allows to improve calculation accuracy when determining both motion resistance force and noise level, created by the rotary screw propulsion unit.

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