Simulation of noise generated by a rotary-screw mover as a result of friction

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Abstract: The article describes the theoretical study of the noise generation parameters under friction of a base cylinder of a rotary-screw mover. The analysis of the influence of parameters of the base cylinder (diameter, angle of winding of the helical blade, length) and the vehicle motion parameters (speed, mass) on the noise level arising from mover interaction with a single obstacle is presented in the paper. The conditions for the occurrence of sound vibrations are shown. Analysis of the research results allows us to conclude that a significant noise level generated by the rotary-screw mover can take place only when the vehicle is moving on ice. The created model and the obtained results can be applied by developers of all-terrain vehicles.

1. Introduction.
Analysis of the efficiency of transport and technological operations on ice performing by various types of vehicles shows that in some cases rotary-screw vehicles are more effective in comparison with wheeled and tracked vehicles. These vehicles provide the necessary force to supply working equipment that meet the requirements of performance and flotation. One of the disadvantages that prevent the widespread of rotary-screw vehicles is the high level of vibrations and, as a result, the generation of various noises, the overall level of which adversely affects the working conditions of operators.

2. Background.
In current times, there is a steady tendency to simulate the movement of rotary-screw vehicles using generalized mathematical models of motion under steady-state motion, acceleration, deceleration and turning modes [1-7]. Moreover, the determination of resistance force to uniform straight motion needs a large number of calculations with an approximation of the exponential dependences of the rotor slipping and the total immersion force, which depends both on the vertical load and on the amount of material carried out during the slipping. In this case, the maximum value of the resistance forces of movement is formed when the base cylinder slips along the support surface [1-5].

Friction is generally a complex dynamic occurrence. Therefore, the continuous measurement of the friction coefficient shows that this characteristic of the friction pair is not a constant value even under the steady state process, but changes periodically, reaching maximum and minimum [17]. The occurrence of acoustic vibrations is the manifestation of the dynamic nature of the friction is also. The vibrations play an important role in the behavior of interacting bodies, including their wear [18]. Based on the results presented in [17], a sinusoidal signal was used as a source of elastic waves, which changed both the pressure on the cylinder and the speed of its rotation.

At present, the nature of the occurrence of nonfunctional noise remains poorly understood, nevertheless, there are two established signs of an assessment of the propensity of materials to arise in friction [17,18,19,20]:
(A) – positive difference between the static friction coefficient \( \mu_s \) and sliding friction \( \mu_d \), i.e. \( \mu_s > \mu_d \);

(B) – the falling dependence of the dynamic coefficient of friction \( \mu_d \) on the sliding velocity \( V \), which is mainly approximated by the dependence:

\[
\mu_d = \mu_s - kV
\]

where: \( m_0 \) – constant; \( k \) – curve slope of dependence \( \mu_d = f(V) \).

According to the data given in the work “All-terrain transport and technological vehicles. Fundamentals of the theory of motion” [8], the friction of metals over snow and ice is fully consistent with the stated parameters. In [17], it was established that a clearly audible sound is born at a certain value of the magnitude of the coefficient of friction for a single “jump” \( \Delta \mu \). When \( \Delta \mu > 0.08 \), there is a clearly audible sound in the form of a “click with a creak”; at \( 0.08 \geq \Delta \mu \geq 0.06 \) - audible sound is at the background level; when \( \Delta \mu < 0.06 \) - the sound does not exceed the background or is not emitted. The maximum range of \( \Delta \mu \) changing, in case of non-functional noise, in the experiments was \( 0.11 < \Delta \mu < 0.06 \). In addition to the above, when a sound is emitted, there is a “triangular sawtooth” type of change in the dependence \( \mu(t) \) for “jump”; in the absence of sound, there is a “triangular equilateral” type of dependence \( \mu(t) \) for “jump”. The normalization of the dependence \( \mu(t) \) in the form of the parameter \( s = \Delta \mu / (D_1 / D_2) \), reflecting the “jump” type, makes it possible to increase the range of variation of the estimated parameter 2.8 times compared with the parameter \( \Delta \mu \), since the range of variation of the parameter \( s \), which reflects the “jump” type when non-functional noise occurs, is \( 0.52 < s < 0.1 \) — for the same experimental data.

Thus, for the parameter \( s \), we obtain the following ranges: \( s > 0.24 \) for the audible sound; with \( 0.24 \geq s \geq 0.1 \) - audible sound is at the background level; when \( s < 0.1 \), the sound does not exceed the background.

Analysis of the parameters of friction between ice and rotor materials, such as steel, aluminum, etc. shows that for the occurrence of an audible sound, the rate of slip change in the contact pair to achieve a value \( \Delta \mu = 0.06 \) should change in 0.1 s 4 times, which is an impossible event for a rotary-screw vehicle. Increasing the sliding speed 4 times is possible only when the vehicle starts to move, however, even in this case, the time required for acceleration is more than 5 seconds. At sliding speeds greater than 0.2 m/s, the friction coefficient are not changed (see the results of the studies shown in Figure 1).

![Figure 1](image-url)

**Figure 1.** The dependence of changing of the friction coefficient on ice of steel (1) and aluminum (2) on the sliding speed with a specific load value of 100,000 N/m² [8]

Verification the hypothesis of the dependence of the sound radiation power on the power expended on friction of surfaces was carried out in the framework of experimental studies. Studies have shown that under actual operating conditions, a change in the friction coefficient by an amount equal to 0.06 is not a real event, since the total range of change in the friction coefficient on all kinds of ice does not exceed a value equal to 0.04.

Figures 2 and 3 show the spectograms of noise arising from the friction of steel plates on ice at a temperature of 0°C, at different friction rates, loads and specific pressures. It can be seen from the figures that when the interaction parameters were changed within the widest possible limits, the change in the noise level did not exceed 1 dB, that is, it was within the measurement error of the instrument. Thus, it can be concluded
that the friction force of the base cylinder on the ice itself does not have a practical effect on the acoustic radiation that occurs during the rotary-screw mover operating.

It should be noted that in real operating conditions, the movement of all-terrain vehicles on clear ice is an unrealistic event. At least ice is usually partially or completely covered with snow. If the coefficient of friction of steel on ice is 0.01-0.04, then on snow this coefficient is from 0.1 to 0.2 [8]. That is, the difference in friction coefficients can reach values from 0.09 to 0.16.

The power spent on the rotors rotation can be defined as the product of the friction force and the speed of rotation of the rotors. At the same time, the speed of the rotors will have longitudinal and transverse components, interconnected by the ratio:

\[ v_x = v_y \tan \varphi \]  

where: \( \varphi \) - the angle of winding of the screw blade, while the total speed of the rotors will be determined by the dependence:

\[ v = \sqrt{v_x^2 + v_y^2} = v_x \sqrt{1 + \tan^2 \varphi} \]

\[ (2) \]

\[ (3) \]

Figure 2. Spectrogram of sound vibrations that occurs when a steel plate interacts with ice at a temperature of 0°C, a sliding speed of 0.1 m/s, a load of 1 newton and a specific pressure of 100 KPa
The power expended on such movement of the rotors can be found by the equation:

$$N_Z = vGg\mu = \mu gGv_x\sqrt{1 + \text{ctg}\varphi}.$$  \hfill (4)

Then the maximum power generating sound waves in the audible range will be equal to:

$$N_Z = (\mu - \Delta\mu)gGv_x\sqrt{1 + \text{ctg}^2\varphi}.$$  \hfill (5)

Taking into account that only 20% of the power generating sound waves is converted into sound vibrations, and also taking into account that a change in the friction coefficient by up to 0.06 does not result in audible noise, the maximum noise level emitted due to friction of the cylinder of ice and snow is determined from the expression:

$$L_P = 10\log\left(\frac{\mu - \Delta\mu - 0.06}{5} gGv_x\sqrt{1 + \text{ctg}^2\varphi}\right).$$  \hfill (6)

The solution of this equation is shown in Figures 4 and 5.

**Results.**

Obtained data indicate that the noise level emitted from friction of the cylinder of ice and snow weakly depends on the design of the mover. The degree of variation does not exceed 10% and is associated only with a change in the wound angle of the helical blade. But it is in general a function of the state of the surface of motion.
Figure 4. The dependence of the noise generated by the vehicle on ice with snow; 1 – the vehicle with mass of 500 kg; 2- the vehicle with mass of 2500 kg; 3 – the vehicle with mass of 5000 kg

Figure 5. The dependence of the level of generated noise from the angle of winding of the helical blade; 1 – the vehicle with mass of 500 kg; 2- the vehicle with mass of 2500 kg; 3 – the vehicle with mass of 5000 kg

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