Ways of decreasing noise impact on operator by changing rotary-screw propulsion units natural frequency of vibration

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Abstract Calculation results of rotary-screw propulsion units’ natural frequency of vibration in order to lower structure-borne noise level at the operator’s workplace are presented in this article. One of the most effective ways of noise-reduction is changing base cylinders length. Also, the base cylinder diameter has a considerable impact on natural frequency of vibration – and its wall thickness has the minimal impact. A design solution is suggested using four independent rotors instead of two, allowing to decrease three-times the vehicle natural frequency of vibration.

Transport and technological problems solution under off-road conditions, lack of developed road network, underpopulation is laid upon cross-country vehicles and in particular those equipped with a rotary-screw propulsion unit. When interacting with such kinds of bearing surface as snow, ice and water having no environmental requirements, vehicles with a rotary-screw propulsion unit are widely used in the Extreme North, Siberia, Russia’s Far East, as well as on the ice fields of the Arctic Ocean. Such vehicles have shown high-performance results when solving various national economy problems. They provide the necessary force on the working units (technological equipment), meet the efficiency and floatation requirements, even the ones of getting out of the ice hole onto the ice [1-5].

One of the drawbacks hindering the widespread use of special TTV with RSPU, is high vibration and noise level, and as a result, short service life, unfavourable operators’ working conditions, which become more acute when moving along typical for these vehicles routes – ice and snow covered surface of frozen water bodies [6].

Internal noise, having a negative impact on the cross-country vehicle operator consists of structure-borne noise appearing as a result of trim panels resonant vibrations and aerodynamic noise, transmitted through air from independent noise sources, located outside the transport or technological vehicle. Structure-borne noise sources are vibrations from the engine operation, components, containing toothed gearing, torsional oscillations of engine shaft system and transmission, bending and torsional vibrations of the frame or load-carrying body. Vibrations from the source are transmitted to body parts and then to frame construction. One of structure-borne noise sources is rotary oscillations of rotary-screw propulsion unit. One of the directions of reducing noise impact on the operator is changing vibration system natural frequency in such a way that the propulsion unit natural frequency exceeds the frame construction oscillation frequency of a cross-country vehicle in the maximum speed mode.

Natural frequencies magnitude is a critical parameter in conditions of dynamic loading and when modelling noise impact of the vehicle in motion. Determining natural frequencies is the first step of
parts and mechanisms analysis. Meeting the conditions of low noise impact on the operator is non-coincidence of natural frequencies with operational range of effective external loads [7-10].

\[ F_{\text{собств}} \leq F \ast 0.7 \text{ или } F_{\text{собств}} \geq F \ast 1.3 \]

where \( F_{\text{собств}} \) - natural frequency of the construction being studied, \( F \) - mechanism operational frequency.

If this condition is not met, measures are taken to bring natural frequencies out of the structure operational range. It is achieved by changing the geometry of the structure and its other parameters. Also hazard assessment of resonant vibrations is carried out by the value of deformations and strains appearing in the structure. [7]

The purpose of this work is to study rotary-screw propulsion unit vibrations. The basic method to determine RSPU natural vibrations is equations of circular cylindrical shell oscillations. [11,12] This approach is a limited one as it leaves out all rotary-screw propulsion unit engineering specifics connected with both screw blade on its surface and rotor head design.

In general, rotor has a lot of natural vibrations frequencies, however when estimating them from the point of view of determining its acoustic characteristics, rotor speed is of primary importance. In theoretical calculations rotary-screw propulsion unit was presented as a cylindrical shell, tightly fixed on both ends.

This assumption is justified as the length of the front and rear parts is little compared to the rotor length. Mistakes introduced by such simplification will be of the same magnitude as measurement errors. Under this approach rotor minimum natural vibrations frequency \( \omega_r \) can be determined from the expression:

\[
\omega_r = \omega \sqrt{\frac{R_p \left( \frac{\rho_P (1 - \upsilon_P^2)}{E} \right)^{0.5}}{q}} \]  

where: \( R_p \) - base cylinder radius, \( \rho_P \) - rotor material density, \( \upsilon_P \) Poisson’s ratio, \( E \) – material elasticity modulus, \( n \) – number of waves rotationally, \( h_P \) - rotor wall thickness, \( L_P \) - rotor length, \( q \) – coefficient, depending on rotor geometrical dimensions ratio [3].

\[
\delta^2 = 0.083h^2_PR_p^{-2} .
\]

A relative change of rotor natural vibrations frequency by such basic parameters of propulsion unit as base cylinder diameter, rotor length and rotor wall thickness is shown in Figure 1, 2 and 3.

![Figure 1. Propulsion unit natural frequency change depending on rotor diameter](image-url)
As can be seen from the above results base cylinder length has a maximum impact on rotor natural frequency change, and the minimal one – rotor wall thickness. It has been noted that the absence of resonance condition was fulfilled not for all propulsion units. At this, the most promising direction of noise and vibrations reduction is changing the base cylinder length.

The research results allowed to develop and practically apply a currently operating cross-country vehicle as an engineering prototype not using a standard fit with two long rotors along the vehicle sides, but with four pairwise mounted rotors able to move on side balance-beams towards the vehicle body. This took place within the Federal Target Programme «Research and development of priority areas of Russia’s science and technology sector for 2014-2020 » № 14.577.21.0222 on the subject «Creating an experimental model of amphibious stand-alone transport and technological complex with intelligence control and navigation system for all-year-round exploratory drilling operations on the Arctic shelf». Patent certification of these decisions is proved by registered utility models № RU 516 990 U1 and RU 15 185 U1 [13,14,15], and the general view of the produced vehicle is given in Fig.4.

![Figure 2. Propulsion unit natural frequency change depending on rotor length](image1)

![Figure 3. Propulsion unit natural frequency change depending on rotor wall thickness](image2)

**Figure 2.** Propulsion unit natural frequency change depending on rotor length

**Figure 3.** Propulsion unit natural frequency change depending on rotor wall thickness

![Figure 4. Realized concept of using two separate shortened rotors on either side, instead of two long ones](image3)

**Figure 4.** Realized concept of using two separate shortened rotors on either side, instead of two long ones
The analysis of rotor natural vibrations frequency has shown that by changing rotor length it is possible to decrease considerably structure-borne noise level, emerging when a cross-country vehicle is in operation. This work is one of the recent studies of Nizhny Novgorod Scientific School of Cross-country Vehicles [16-20]

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