Case Study: Regulation of Noise Produced by a Rotary-screw Propulsion Unit in an All-terrain Vehicle

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Keywords: Rotary-screw Propulsion Unit, Ice, Interaction, Noise Level.

Abstract: The study presents methods developed to calculate permissible level of acoustic radiation produced by a rotary-screw propulsion unit on ice. The study is based on the papers of the researchers who studied acoustic waves generated by construction and road vehicles. The authors of the study applied the aforementioned theories to the case of interaction between a rotary-screw propulsion unit and ice. The paper provides general measuring methods and evaluates how every type of interaction between propulsion unit components and ice affects overall level of generated acoustic pressure. The results and conclusions obtained during the research can be used to help manufacturers select the parameters of the rotary-screw propulsion unit which contribute to reduction of noise inside the cabin of an all-terrain vehicle.

1 INTRODUCTION

One way to increase population mobility and transport accessibility in less-populated regions is to develop all-terrain vehicles. However, there is one issue that remains unresolved, and challenges the development of such vehicles: poor ride comfort due to high noise and vibration levels [Shashurin, 2010].

Multiple research papers studying technical condition of all-terrain vehicles have established that acoustic impact on vehicle drivers considerably exceeds permissible values reducing efficiency of all-terrain vehicles and affecting the occupants [SanPiN 2.2.4.3359-16, SN 2.2.4/2.1.8.562-96, SP 51.13330.2011].

2 THEORETICAL RESEARCH

Noise generated by all-terrain vehicles has three main sources: engine and transmission, vibration fluctuations caused by uneven road surface, and a rotary-screw propulsion unit. Design of most all-terrain vehicles is currently based on wheeled vehicles permitted to participate in road traffic, suggesting that cabin, engine, transmission units and assemblies comply with enforceable requirements to

Figure 1: Noise level measured in the cabin of snow and swamp-going vehicle “Uzola” manufactured by LLC “All-Terrain Vehicles Plant” in Zavolzhye. [https://zvm-nn.ru].

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Vahidov, U., Belyaev, A., Makarov, V., Mokerov, D. and Molev, Y.
Case Study: Regulation of Noise Produced by a Rotary-screw Propulsion Unit in an All-terrain Vehicle.
DOI: 10.5220/0009570605480551
In *Proceedings of the 6th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2020)*, pages 548-551
ISBN: 978-989-758-419-0

Figure 2: Noise level measured in the cabin of a multi-functional rescue vehicle with a rotary-screw propulsion unit produced by Research and Education Centre “Transport”, Nizhny Novgorod State Technical University n.a. R.E. Alekseev.

noise level on the road. Also, perfectly smooth ice rules out noise caused by deformation, and bending of body and rotary-screw propulsion unit components [Nikitin, 2004, Abramova, 2018, Erasov, et al. 2019]. Considering the abovementioned, overall level of noise generated by the rotary-screw propulsion unit in an all-terrain vehicle cabin can be calculated from the following overall noise level equation [SN 2.2.4/2.1.8.562-96]:

$$L_{\Sigma} = 10\lg \sum_{i=1}^{n} 10^{0,1L_i}$$
$$L_{\Sigma} = 10\lg(10^{0,1L_K} + 10^{0,1L_P}) \qquad (1)$$

where L_K is overall noise level in the all-terrain vehicle cabin with rotary-screw propulsion unit switched off, and LP is the sought-for noise level produced by the rotary-screw propulsion unit. From which we obtain the following:

$$L_{\Sigma} - L_K = 10\lg\left[1 + 10^{0,1(L_K - L_P)}\right] \qquad (2)$$

or:

$$10^{0,1(L_{\Sigma} - L_K)} - 1 = \left[10^{0,1(L_P - L_K)}\right]$$
$$\lg(10^{0,1(L_{\Sigma} - L_K)} - 1) = 0,1(L_P - L_K) \qquad (3)$$
$$L_P = 10\lg(10^{0,1(L_{\Sigma} - L_K)} - 1) + L_K$$

In his paper “Measurement of noise in the cabins of construction and road vehicles” [Shashurin, 2010], A.E. Shashurin states that equation for cabin noise level generated by a linear source of acoustic vibrations, i.e. by a rotary-screw propulsion unit, can be sought from the following equation:

$$L_D = L_P - 10\lg arctg\frac{L}{2r} + $$
$$+ \Theta - 10\lg\frac{S}{A} + 10\lg\frac{r}{r_0} + \qquad (4)$$
$$+ 10\lg(1 - \alpha_K) + 10\lg\Psi + 2,$$

where *L/2r* – ratio of the noise source length to the distance from the source to the cabin (for rotary-screw propulsion units, this ratio equals to 3), Ψ - diffuse field approximation factor, r_0 – distance from the cabin floor to the ground surface (r/r_0 ratio for rotary-screw propulsion unit vehicles is 1, because noise is generated at the point where rotary-screw propulsion unit has contact with the ground surface) S – total area of the all-terrain vehicle cabin, which can vary from 10 to 50 square meters depending on the design; *A* – equivalent sound absorption surface of the cabin, which equals to the total area of the cabin multiplied by sound absorption factor **α** (0,3 [11] for low-frequency acoustic vibrations produced by a propulsion unit), **Θ** – cabin sound insulation factor, when critical sound insulation frequency for the walls (f_{gr}), equal to 100-200 Hz, is lower than the sound frequency *f* (up to 500Hz) calculated from the following equation:

$$\Theta = 20\lg\left(\frac{\pi f M}{\rho r}\right) + 5\lg\frac{f}{f_{gr}} + \lg\eta + 3 =$$
$$= 20\lg\frac{3,14 * 500 * 1000 * 0,01}{1,2 * 1,0} + 5\lg\frac{500}{136} + \qquad (5)$$
$$+ \lg 0,25 + 3 = 15 - 30dB$$

where *M* is a factor equal to the ratio of the acoustic blanket weight (blanket density multiplied by its thickness) to the air weight between the driver and the cabin walls (air density multiplied by the distance from the driver to the cabin wall), and η - loss factor equal to 0,25 [Shashurin, 2010];

According to [Shashurin, 2010] 10lg(S/A) ratio varies from 20 to 12dB, 10lg(1-α_K) ratio from 0 to 4 dB varies from 20 to 12dB. Therefore, maximum sound level generated by a propulsion unit in the ground surface contact area shall be calculated according to the following formula:

$$L_D = 10\lg(10^{0,1(L_\Sigma - L_K)} - 1) + L_K + 19, \quad (6)$$

Minimum sound level shall be as follows:

$$L_P = 10\lg(10^{0,1(L_\Sigma - L_K)} - 1) + L_K \quad (7)$$

The 19 dB difference indicates that current cabins reduce sound level generated by propulsions units of all-terrain vehicles approximately by 19 dB.

Solution of these equations is presented in Figure 3.

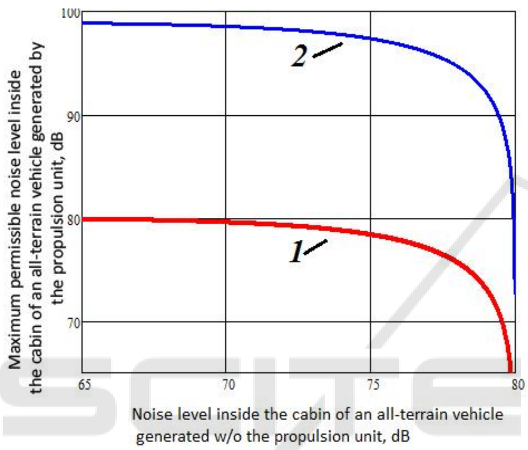

Figure 3: Relationship between the maximum permissible sound level produced by a propulsion unit and the sound level inside the all-terrain vehicle generated w/o the propulsion unit with no sound insulation of the cabin (1) and with standard sound insulation (2).

3 EXPERIMENTAL RESEARCH

Research conducted on various propulsion units of all-terrain vehicles shows that current design of the propulsion units does not always keep the generated sound within the acceptable limits.

4 CONCLUSIONS

The results show that propulsion units with acoustic radiation under 70dB have almost no effect on the sound level in the cabin. Propulsion units with acoustic radiation of 90-100dB produce the noise which considerably influences acoustic comfort in the cabin, and those with radiation level over 105 dB become the only source of noise around the driver.

Figure 4: Sound level generated by a rotary-screw propulsion unit on the concrete.

Figure 5: Sound level produced by a rotary-screw propulsion unit on marsh.

Figure 6: Sound level generated by a rotary-screw propulsion unit on water and sand.

Since the technical regulations in force [GOST 23941-79, GOST 27408-87, GOST P 51401-99] stipulate a 80 dB limit for the permissible noise level in the cabin. We can use the obtained data to develop requirements to a rotary-screw propulsion unit installed in various types of vehicles.

ACKNOWLEDGEMENTS

This study was conducted in continuation of the research conducted in the "Nizhny Novgorod scientific and practical school of transport snow" in the framework of cooperation between the Nizhny Novgorod state technical University. R. E. Alekseeva and LLC All-Terrain Vehicles Plant.

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