Measurement and Analysis of the Noise of Off-Road Vehicles

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ABSTRACT

Being assembled of many moving parts, every vehicle is a source of harmful noise. Total vehicle noise is a sum of noise contributions produced by parts that appear as noise sources. The most important noise sources seem to be the vehicle driveline system parts, i.e. engine, transmission, axles and tires - see Fig.2. However, total noise indication by itself is not sufficient and detailed signal analysis is necessary to be performed so as to identify individual noise sources.

This paper presents methods of measuring noise emitted by heavy off-road vehicles, which is used by Tatra Company in the early stage of truck development, in particular, external noise investigation and introduction of measures regarding noise emissions in production are mentioned.

Figure 1: Tatra off-road vehicle model 6MWR27

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1.0 INTRODUCTION

The effort to make vehicles more silent imposes a significant technological and economical burden on vehicle manufacturers. In the last 20 years the vehicle noise levels have dropped by almost 10 dB(A), which means that the absolute sound pressure has decreased by 1/3 of the original level. The following table shows European noise limits of the N3 class of vehicles powered by engines over 150 kW, i.e. the category of Tatra vehicles.

1972	91 dB(A)
1984	88 dB(A)
1988	84 (86)* dB(A)
1995	80 (82)* dB(A)

* Valid for off-road vehicles

What makes the situation even more difficult is the fact that the development of new vehicles is becoming increasingly dominated by necessary reduction of cost, as well as by the lowest possible time-to-market requirement. For this reason precise noise measuring methods and analysis are necessary disciplines allowing carry out effective steps for achieving required noise levels as fast as possible.

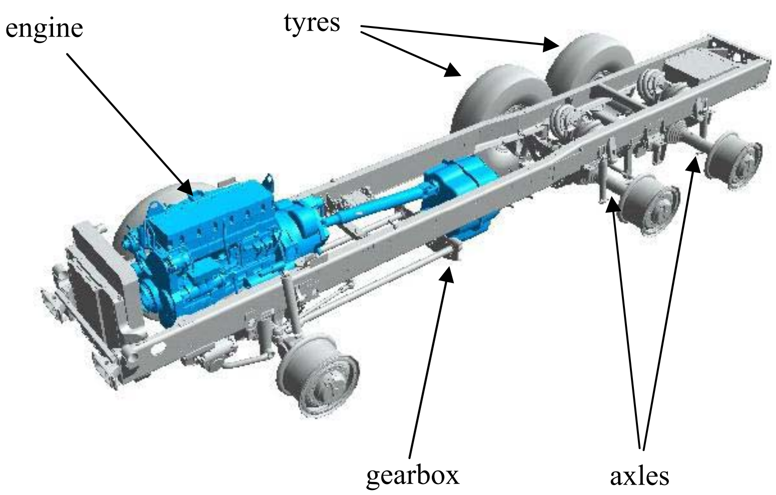

Figure 2: Main off-road vehicle noise sources

The noise reduction methods have been developed from theoretical studies, finite element calculations and experimental investigations both on test benches, and on vehicle prototypes. Potential modifications of vehicle components are basically focused on form and shape of parts, production accuracy improvement, change of technology in production, and applying acoustic shields over noise sources. Interior noise reduction is conducted in the same way as on other vehicle components, since the noise sources are identical. However, special attention is paid to improving absorption capacity of cab surfaces and to the properties lining and coating beneath the engine cover.

2.0 NOISE MEASUREMENTS AND ANALYSIS

External noise test is performed according to ISO 362 as a pass-by test. The vehicle approaches the measuring area at a constant speed and in the beginning of the test the truck accelerates at full throttle. Measuring microphones are located in the middle of the testing track in the distance of 7.5m along both sides of the vehicle path. External noise measurement as per American standard SAE J 366 is similar to ISO 362 including the vehicle acceleration procedure. The main difference between these standards is the distance of measuring microphones from the vehicle path, which according to SAE is 15.2 m (50 ft). An external noise value of vehicles over 4.536 kg of GVW (gross vehicle weight) in accordance with MIL-STD-1474D FEB97 is 80 dB(A).

Measured noise is evaluated with the Sound Level Meter set at “FAST” time constant and A-correction during homologation testing of the vehicle. Maximum noise level obtained during the pass-by is regarded as the test result. Sound Level Meters are equipped with maximum level indication for this purpose.

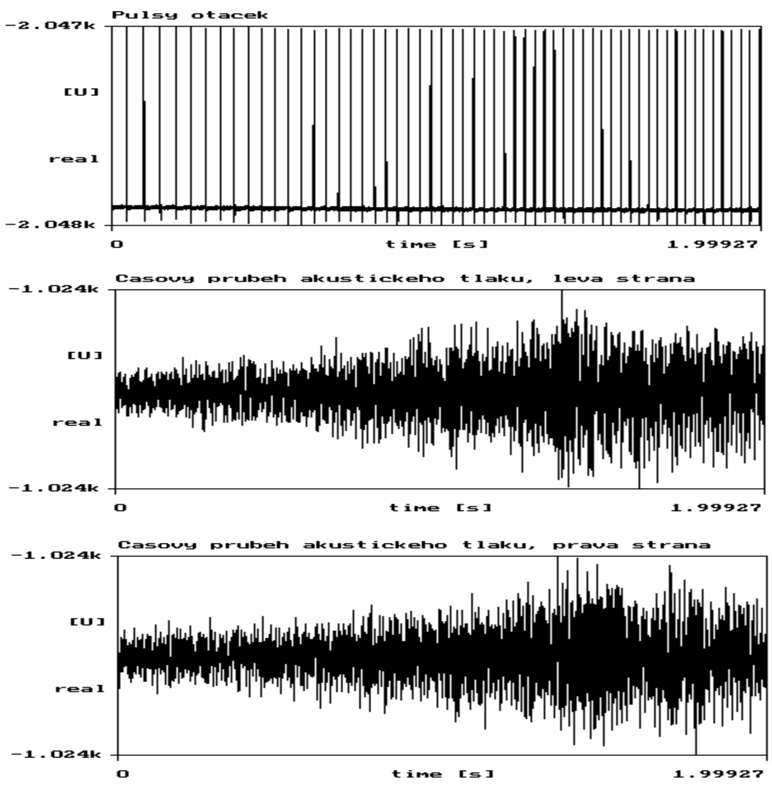

Figure 3: Time history of recorded RPM pulses and noise pressure levels

Detailed noise analysis of the vehicle is necessary to determine important noise sources. One of noise analysis methods is a Fast Fourier Transformation (FFT). Noise signal is recorded together with engine speed during the whole acceleration procedure in order to obtain sufficient number of the frequency spectra - see Fig.3. Engine speed is a very important quantity since it allows identification of frequency components within these spectra. Seeing that the vehicle acceleration procedure is a rather fast process, frequency analysis with FFT calculation is not usually performed in real time but is a subject of a follow-up evaluation. The result of this is an exterior vehicle noise multi-spectrum, which consists of hundreds of partially overlapped simple frequency spectra - see Fig.4. Next task is to identify noticeable discrete components through the spectra and to assign them to the relevant vehicle noise sources. Most significant discrete components, which form typical heavy off-road vehicle noise frequency spectra, match up with tooth-mesh frequencies of gearwheels under load and their multiples. Assignment of noise sources is feasible because of the fact that all tooth-mesh frequencies are derived from the actual engine speed.

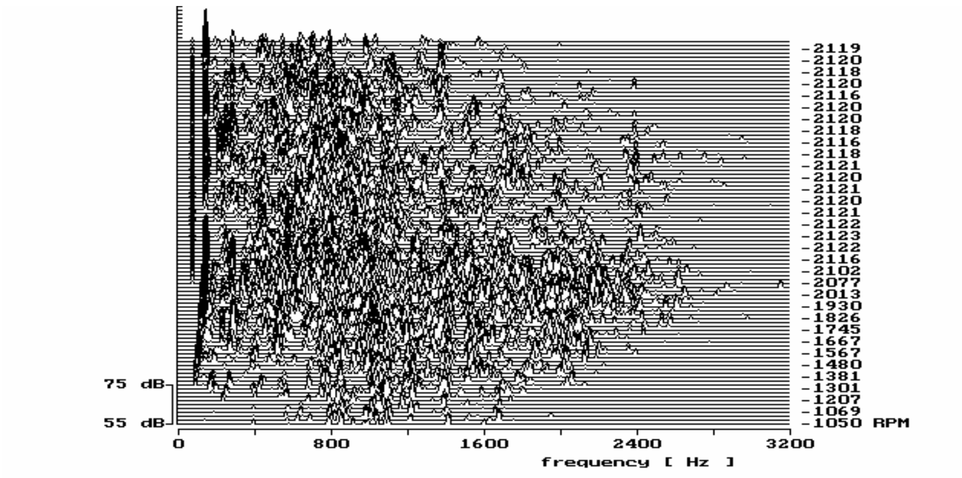

Figure 4: Multi-spectrum of external off-road vehicle noise

Tooth-mesh frequencies are determined by the formula:

$$f_K = k \cdot Z \frac{n}{60}$$

Where: f_k – tooth-mesh frequency or their harmonic [Hz]
Z – number of teeth
n - revolutions of the relevant shaft [min^{-1}]
k – 1, 2, 3, … order of harmonic frequency

Engine valve-gear mechanism, transmission, axle and other tooth-mesh frequencies, as well as harmonic frequencies of compression ignition and combustion cycles depend on engine speed.

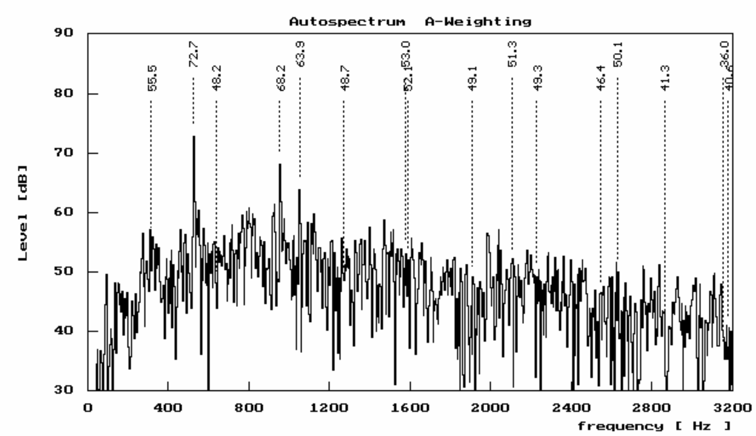

Figure 5: Single frequency spectrum of off-road vehicle transmission

Another significant noise contribution is produced by rolling of tires. But since the number of tire tread grooves around wheel circumference is known, determination of tread groove frequency according to the wheel speed is quite simple.

Fig. 5 demonstrates one of transmission noise frequency spectra with indication of two groups of harmonic components belonging to two different noise sources, i.e. to two loaded couples of gears.

In order to be able to take measures for reduction of the total external noise it is essential to know contributions of individual noise sources in the vehicle. A contribution of a particular noise source is calculated as a sum of all harmonic frequency components contained in the frequency spectrum. It is performed by means of special software, which enables to determine contributions of all selected vehicle noise sources throughout vehicle acceleration including the Doppler phenomenon correction.

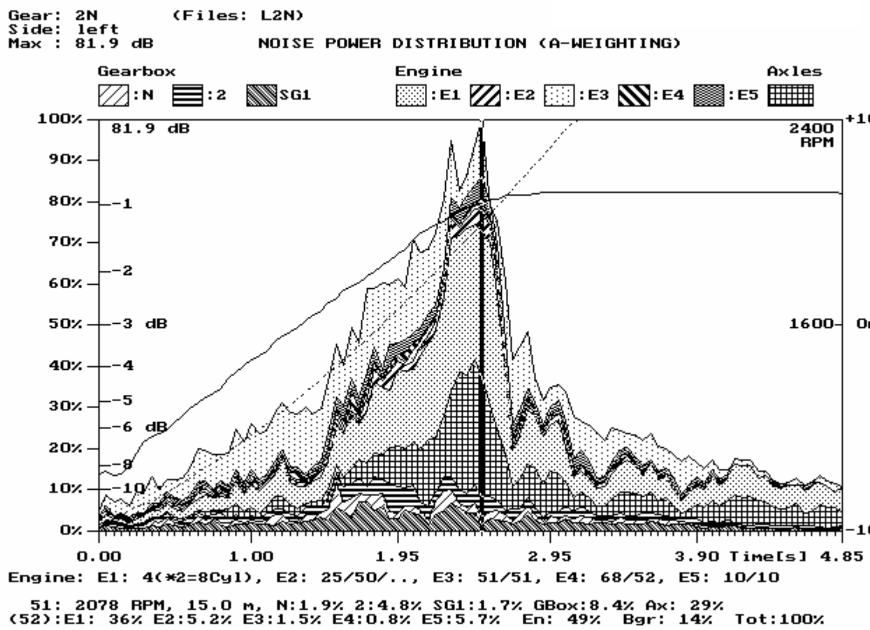

Figure 6: Noise power distribution of off-road vehicle

The above-mentioned vehicle noise analysis results in a noise power distribution diagram - see Fig.6. The scale of the diagram has been selected so that the measured peak of the total vehicle noise (dB) corresponds to the 100 % noise power (W) - see the scale at the left side of the diagram. The maximum measured total noise (Max) in dB(A), speed gear (Gear) and measured vehicle side (Side) are indicated in the top left corner of the diagram. The double scale at the right-hand side serves for reading of engine speed (RPM) and vehicle position on the testing track (DIST). Above the diagram there are squares with different shadings used in the diagram to illustrate contributions of analysed noise sources. Instantaneous per-cent contributions of the particular noise sources are stated at the bottom of the diagram. The difference between the sum of noise shares from the main vehicle sources and the total measured noise level is the "background", which is created by less significant noise sources.

3.0 CONCLUSION

The methods presented in this paper demonstrate the system of noise testing and following checking of production of Tatra vehicles and their main components.

Measures for the vehicle noise reduction are basically focused on optimisation of parts of the main vehicle noise sources. Changes and modifications are experimentally verified by bench tests and, finally, on vehicle prototypes.

More than 30 types of off-road vehicles and 10 on-road models successfully certified for the noise limit of 82 dB(A) or 80 dB(A), respectively, in the last 7 years illustrate a high level of knowledge and experience of Tatra in this field.

4.0 REFERENCES

[1] Kuběna R.: Influence of Doppler Phenomenon on External Noise of Off-Road Vehicles, 64th Czech Acoustical Meeting of AES, Vysoké nad Jizerou, May 2003.

[2] Tůma J.: Introduction of Narrow Frequency Analysis of External Vehicle Noise, H 000/060.95, Kopřivnice, July 1995.

Detailed Analysis or Short Description of the AVT-110 contributions and Question/Reply

The Questions/Answers listed in the next paragraphs (table) are limited to the written discussion forms received by the Technical Evaluator. The answers were normally given by the first mentioned author-speaker.

P5 M. Krizek, R. Kubena 'Measurement and Analysis of the Noise of Off-Road Vehicles' (TATRA a.s., CZ)

The author presented the method that Tatra company uses for measuring, according to the similar ISO362 or AE J 366 standards, the external noise levels of off-road trucks and to extract from the global spectrum the contribution of the noise sources (engine (35 %), axles (25%), transmission (20%) and tyres (15%) have been mentioned as typical values . He concludes on the large experience acquired by the company and the successful design of off-road vehicles whose the global noise level doen'nt exceed the European noise limits of the N3 class of vehicles powered by engine with a minimal power of 150 kW (82dBA)

Discussor's name: M.C. Tse
Q. How do You separate the noise components accurately and how do You calculate the noise % contribution?
R. We can use two methods: (1) covering some vehicle parts, which are noise sources. Results are measured as noise differences between non covered and covered parts (engine, transmission,..) (2) using special softwares. The software separates rows of discrete components of the frequency multi-spectrum and summarises them as elements of the vehicle noise sources

Q. Why the new fan rotor has less blades than the original one?
R. The new fan wheel was calculated by the FE (Finite Element) method. New blades are larger and have new shapes. The goal of the redesign were (1) to reduce the noise (2) improve the parameters of the air flow. The number and shape of the blades is the result of an optimisation.

Discussor's name: J. Blankenship
Q. What type of surface did you run your test on?
R. The standard surface, according ISO, is asphalt.