

Tytskyi O.Yu.

National Transport
University,
Kyiv, Ukraine,

E-mail:

alexander.tytskyi@scania.com

**METHODS OF ANALYSIS
OF OUTPUT DATA FOR TRUCK ENGINE
DIAGNOSTICS**

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Tytskyi O.Yu. Methods of analysis of output data for truck engine diagnostics.

Abstract. *The article presents a new method for solving the scientific and practical problem of forming a functional dependence for determining methods of analyzing the initial data of diagnosing truck engines. Applied methods and means of studying the initial data of diagnosing truck engines have been developed, which allow minimizing the resource characteristics at the early stages of product design and modernization. In the course of the research, a method of setting the spatial impact is presented, which consists in the fact that statistical characteristics using known methods are converted into mutual characteristics taking into account the correlation of profiles. At the same time, accounting for the initial data allows for the process of forming the efforts that fall on each parameter of the technical condition of the truck engine and to bring it as close as possible to the real one.*

Key words: *data network, diagnostics, truck, method.*

Тицький О.Ю. Методи аналізу вихідних даних діагностування двигунів вантажних автомобілів.

Анотація. *У статті представлено новий метод для вирішення науково-практичної задачі сформуванню функціональну залежність для визначення методів аналізу вихідних даних діагностування двигунів вантажних автомобілів. Розроблено прикладні методи та засоби дослідження вихідних даних діагностування двигунів вантажних автомобілів, що дозволяють на ранніх стадіях проектування та модернізації виробів мінімізувати ресурсні характеристик. У ході досліджень представлений спосіб завдання просторового впливу, полягає в тому, що статистичні характеристики за допомогою відомих методів перетворюються на взаємні характеристики з урахуванням кореляції профілів. При цьому облік вихідних даних дозволяє провести процес формування зусиль, що припадають на кожний параметр технічного стану двигуна вантажного автомобіля та максимально наблизити до реального.*

Ключові слова: *мережа даних, діагностування, вантажний автомобіль, метод.*

Introduction

All trucks in international and national classification systems are divided according to their purpose, consumer properties and requirements [1]. According to the classification developed by the Inland Transport Committee of the United Nations Economic Commission for Europe (UNECE) and adopted by the Geneva Agreement of 1958, there are 3 categories of trucks, presented in Table 1.

When assessing the consumer properties of a truck [2], the following concepts are used in accordance with UN/ECE No. 68 No. 101. The load capacity of a truck is the largest

number of goods or passengers that a truck can simultaneously transport based on its strength and body dimensions, while complying with the permissible values of loads on the supporting surface of the road [3]. The mass of a fully equipped truck is the mass corresponding to its own mass, i.e. includes tools, a spare wheel and all provided equipment, but does not include the mass of the driver, crew, passengers and cargo [4]. The total mass is the mass of a fully equipped truck, which includes the mass of the driver, crew, cargo, passengers and luggage [5]. The load capacity of a truck is the largest mass of cargo that can be transported while complying with the permissible values of loads on the supporting surface of the road [6].

Table 1

Classification of trucks		
Vehicle category	Gross weight, t	Vehicle type
N_1	$m_a \leq 3.5$	Trucks
N_2	$3.5 < m_a < 12$	
N_3	$m_a > 12$	

The truck moves on different types of roads, which, as is known, are the main source of disturbances and vibrations that negatively affect both the truck in general and the passengers and cargo transported in particular [7]. It is practically impossible to accurately assess such a large number of influences, since the condition of the road surface depends not only on the terrain, but also on weather conditions and the specifics of the region. However, to assess and analyze the operational properties of the vehicle, a simplified classification of road surface types is used. According to [8], as well as [9], highways are divided into five categories (Table 2).

Table 2

Characteristics of road operating conditions			
Road category	Road clothing	Main types of coatings	Estimated speed*, km/h
1	1 – a	Capital Cement concrete monolithic; reinforced concrete or reinforced concrete prefabricated; asphalt concrete	100
	1 – b		
	2		
3			
4	Lightened	Tar concrete, paving stones, made of crushed stone, gravel and sand, treated with binders	60
	Transitional	Crushed stone and gravel, made from soils and local low-strength stone materials treated with binders.	
5	Lower	From soils fortified or improved with additives	40

* For this task

The realization of a random surface of a specific section of the road surface is called the road relief and is the most general model of the roadway. The road profile is the section of the relief in the direction of traffic [10]. The section of the surface of a specific section of the road is a realization of profile, and the set of such realizations is the road profile as a random process.

The road profile is distinguished by three components:

- Macroprofile – long smooth irregularities with a wavelength of 100 m or more, which cause minor vibrations of the truck on the suspension, but significantly affect traction and dynamic performance;
- Microprofile – irregularities with a wavelength of 0.1 to 100 m, which cause significant vibrations of the truck on the suspension, determine the load on the components and assemblies, and are one of the main factors determining the speed of movement, maneuverability, and load capacity;
- Roughness – irregularities with a wavelength of less than 0.1 m, which are smoothed out by the tires and do not cause noticeable vibrations of the truck, but significantly affect the operation of the tires, their grip on the road surface and wear.

Analysis of recent researches

EU Directives 85/3, 86/360, 88/212, 89/338 set the maximum values of axle loads depending on the design and number of wheels of each axle. The maximum loads must not exceed the following values: on driving axles: with single wheels – 92kN; with twin wheels – 115kN; on driven axles: with single wheels – 71.2kN; with twin wheels – 101.7kN.

In the CIS countries, road trucks are divided into 2 categories depending on the axle load (Table 3): category A includes vehicles with an axle load not exceeding 100 kN per axle or 180 kN per bogie; category B includes vehicles with an axle load not exceeding 60 kN per axle or 100 kN per bogie.

Table 3

Distribution of axle loads in trucks and coupling weight coefficient

Vehicle group and axle/bogie load, kN	wheel formula	Load per axle of a full-weight vehicle, %		Load per axle of equipped vehicle, %		Gross vehicle weight, t	k_m		
		front	back	front	back		With full load	Without cargo	
B	60	4 × 2	24...30	70...76	45...49	51...55	8	0.75	0.55
	110	6 × 4	25...28	72...75	42...47	53...58	15	0.73	0.55
D	80	4 × 2	25...31	69...75	46...53	47...54	12	0.67	0.47
	140	6 × 4	22...24	76...78	33...44	56...67	18.5	0.76	0.57
	100	4 × 2	33...38	62...67	51...58	42...49	16	0.62	0.41
	180	6 × 4	23...29	71...77	53...59	41...47	24	0.75	0.54

Table 4

Truck layout parameters

Vehicle layout diagram	Gross vehicle weight,	$L_{n,n}/L$
Cab over the engine	up to 6.5	1.3...1.5
	6.5 - 12.0	
	12.0 - 16.0	
	more than 16.0	

In all-wheel drive vehicles, uniform distribution of the load on the axles leads to increased operational efficiency, while in non-all-wheel drive vehicles, the load should be

distributed slightly differently, according to Table 3, since it is this distribution that leads to satisfactory traction and coupling properties and improved cross-country ability. In this case, the assumption is made that the load is distributed throughout the body volume with the same density and the center of gravity of the load coincides with the geometric center of the body volume.

Those trucks whose gross weight, overall dimensions, or load distributed over the axles exceed the maximum permissible standards established in the relevant documents are classified as off-road, and their movement on highways is not allowed.

Table 4 shows the main dimensional parameters of the layout of trucks.

The wheel formula is also determined based on the operating conditions and purpose of the vehicle while ensuring reliable starting and movement without slipping of the driving wheels.

The aim and objectives of research

The purpose of the study is to form a functional dependence to determine methods for analyzing the initial data for diagnosing truck engines.

Research results

The condition of the vehicle moving without skidding $G_{зд} \varphi \geq G_a \Psi$ allows us to determine the coupling weight coefficient, which characterizes the part of the total vehicle load on the road that falls on the driving axle and can be used to ensure coupling qualities and overcome road resistance (Table 3).

$$k_\varphi = \frac{G_{зд}}{G_a}, \quad (1)$$

where $G_{зд}$ – the towing weight of the vehicle (weight on the driving axle),

φ – coefficient of adhesion of tires to the road;

G_a – total weight of the vehicle;

$\Psi = f + i$ – coefficient of total road resistance;

f – rolling resistance coefficient;

i – the angle of elevation of the road.

Therefore, to reduce the probability of loss of vehicle cross-country ability in specific road conditions, with a higher gross vehicle weight, there should be a greater load on the driving axle or, taking into account the limitations for the maximum axle load, there should be a greater number of driving axles. The number of driving axles is determined taking into account the purpose of the vehicles under the conditions of ensuring satisfactory traction and coupling properties of the vehicle. The minimum permissible value of the coupling weight coefficient for category A vehicles is calculated from the condition of reliable starting from a standstill and movement on a slippery road ($\varphi = 0.2$) at the rolling resistance coefficient $f = 0.008 \dots 0.012$ on the rise with the largest permissible slope for roads with a capital coating $i = 0.05$.

$$k_{\varphi \min} = \frac{f+i}{\varphi} = 0.29 \dots 0.31, \quad (2)$$

For group B vehicles, the towing weight coefficient is determined taking into account more difficult road conditions: $\varphi = 0.2$, $f = 0.02 \dots 0.03$, $i = 0.06$, $k_{\varphi \min} = 0.40 \dots 0.45$.

Table 3 shows the optimal values k_φ , that exceed the value $k_{\varphi \min}$, which indicates the possibility of using these vehicles as tractors in a road train, and their passability will be ensured even when driving without cargo on a slippery road.

Smoothness of movement - a set of potential properties of a vehicle that characterize its ability to move in a given speed range without exceeding the established norms of vibration load of the driver, passengers, cargo and structural elements of the vehicle. To assess the smoothness of movement of road trucks, there are methods based on the principle of eliminating, firstly, unpleasant sensations and rapid fatigue during vibrations of the driver and passengers, and secondly, damage during vibrations of the cargo and structural elements.

The method of assessing the smoothness of a vehicle's ride, consists in analyzing the oscillations of the body vibration frequency range of 0.9-2 Hz. This is due to the fact that with oscillations with such a frequency, a person will not feel discomfort. From the analysis of the accelerations of a person's head in different driving modes, he proposed the limit values $\sqrt{D_z}$, $\sqrt{D_y}$, $\sqrt{D_x}$ which are given in Table 5. However, the intensity of oscillations also plays a great role, which is not taken into account in this method.

Table 5

Limit values of root mean square accelerations

Driving mode	, m/s ²	, m/s ²	, m/s ²
Jog	1.0	0.6	0.5
Normal walking	2.5	1.0	0.7
Short run at a speed of 8-9 km/h	4.0	2.0	1.0

There is a technique that takes into account the intensity and power of vibrations at different frequencies and directions, but people perceive vibrations differently, and the technique does not take this fact into account.

The methodology for assessing vibrations from vehicle body jolts assumes that these jolts have a greater impact on human performance and health than harmonic vibrations. At the same time, the speed and acceleration of the jolts are not taken into account.

The following method is based on experimental data. The study analyzes the acceleration of vertical and horizontal harmonic vibrations. Vibrations are divided into levels: imperceptible, barely perceptible, well perceptible, strongly perceptible, conditionally harmful and harmful. However, the disadvantage of this method is the artificial nature of the vibrations.

It is also possible to assess vehicle vibrations using control parameters in certain frequency ranges. Based on this technique, the Geneva standards for comfort assessment were adopted (Table 6).

Table 6

Assessment of ride smoothness

Frequency range, Hz	Parameters	Valid parameter values
1 – 6	Rate of change of vibration acceleration	12.6 m/s ²
6 – 20	Vibration acceleration	0.33 m/s ²
20 – 60	Vibration speed	2.7 m/s ²

Thus, in the course of various studies, standards were developed for assessing and normalizing the smoothness of motor vehicles.

International standard ISO 2631 “Guide to the assessment of the effects of general vibration on the human body”, as well as 12.1.012 “System of occupational safety standards. Test methods for smoothness of movement take into account the same physical factors, except for the duration of vibration exposure. The assessment of sensations is carried out in the

frequency range of 1-90 Hz, which can be represented in octave or third-octave bands. For the octave band there are upper and lower limits and an average frequency, with the upper limit frequency being twice the lower.

Human sensations during vibrations are estimated by accelerations during large-amplitude vibrations and frequencies of 0.5-5 Hz and by velocity during small-amplitude vibrations and frequencies of 15-80 Hz. Each octave or third-octave band corresponds to a weighting factor necessary to bring the root mean square value of vibration acceleration to the frequencies at which the human body is most sensitive to vibrations: 4-8 Hz – for vertical vibrations, 1-2 Hz – for horizontal vibrations.

Table 7

Characteristics of octave frequency bands

Geometric mean frequencies of octave bands, Hz	Octave band cutoff frequencies, Hz		Sensitivity weighting factors		, dB	, m/s ²	, dB
	lower	upper	Z ₀	X ₀			
1.0	0.8	1.4	0.50	1.0	-6	1.10	121
2.0	1.4	2.8	0.71	1.0	-3	0.79	118
4.0	2.8	5.6	1.00	0.5	0	0.57	115
8.0	5.6	11.2	1.00	0.25	0	0.6	116
16.0	11.2	22.4	0.50	0.125	-6	1.13	121

Table 8

Characteristics of third-octave frequency bands

Geometric mean frequencies of one-third octave bands, Hz	Band cut-off frequencies, Hz		Sensitivity weighting factors		, dB	, m/s ²	dB'
	lower	upper	Z ₀	X ₀			
0.8	0.70	0.89	0.45	1.00	-7	0.71	117
1.0	0.89	1.12	0.50	1.00	-6	0.63	116
1.25	1.12	1.41	0.56	1.00	-5	0.56	115
1.6	1.41	1.80	0.63	1.00	-4	0.50	114
2.0	1.80	2.25	0.71	1.00	-3	0.45	113
2.5	2.25	2.81	0.80	0.80	-2	0.40	112
3.15	2.81	3.55	0.90	0.63	-1	0.355	111
4.0	3.55	4.50	1.00	0.50	0	0.315	110
5.0	4.50	5.60	1.00	0.40	0	0.315	110
6.3	5.60	7.07	1.00	0.315	0	0.315	110
8.0	7.07	9.00	1.00	0.25	0	0.315	110
10.0	9.00	11.2	0.80	0.20	-2	0.40	112
12.5	11.2	14.1	0.63	0.16	-4	0.50	114
16.0	14.1	18.0	0.50	0.125	-6	0.63	116
20.0	18.0	22.4	0.40	0.10	-8	0.80	118

Vibration intensity is determined using the root mean square value of the vertical vibration acceleration or controlled parameter $\sigma_{\bar{z}}$ and its logarithmic level.

$$L_{\sigma_{\bar{z}}} = 201g \frac{\sigma_{\bar{z}}}{\sigma_{\bar{z}0}}, \quad (3)$$

where $\sigma_{\bar{z}0}$ is the limiting root mean square value of the vertical vibration acceleration m/s.
 $\sigma_{\bar{z}0} = 10^{-6}$.

When analyzing vibration exposure to humans, the indicators that are normalized are single-digit parameters – integral assessment, or the vibration spectrum - frequency-separated assessment.

Integral assessment refers to the frequency-adjusted value of the controlled parameter, which takes into account the heterogeneity of human perception of vibrations with different frequency spectrum.

The frequency-adjusted value of the controlled parameter and its logarithmic level are calculated as follows:

$$\overline{\sigma_z} = \sqrt{\sum_{i=1}^n (k_{zi} \sigma_{zi})^2}, L_{\overline{\sigma_z}} = 101g \sum_{i=1}^n 10^{0.1(L_{\sigma_{zi}} + L_{k_{zi}})}, L_{k_{zi}} = 201g k_{zi}. \quad (4)$$

where σ_{zi} , $L_{\sigma_{zi}}$ – the root mean square value of the parameter being adjusted and its logarithmic level in the i-th octave or third-octave frequency band;

k_{zi} , $L_{k_{zi}}$ – weighting factor for the root mean square value of the controlled parameter and its logarithmic level in the i-th frequency band;

n – number of bands in the normalized frequency range.

Thus, Table 9 shows the maximum technical standards for the smooth running of trucks, i.e., the root mean square values of vibration accelerations operating in the frequency range of 0.7-22.4 Hz are indicated. In this table, the road sections correspond to the following coatings:

- I – cement concrete, dynamometric with a mean value of irregularities of 0.6 cm;
- II – cobblestone paved without potholes (special paved road) with a mean value of irregularities of 1.1 cm;
- III – cobblestone with potholes (special section) with a mean value of irregularities of 2.9 cm.

Table 9

Maximum technical standards for smooth running of trucks

Road section number	Corrected values of vibration accelerations on the seat, m/s ² , not more than			RMS of vertical vibration accelerations at characteristic points of the sprung part, m/s ² , slightly more
	$\sqrt{D_{\ddot{x}}}$	$\sqrt{D_{\ddot{y}}}$	$\sqrt{D_{\ddot{z}}}$	
I	1.00	0.65	0.65	1.30
II	1.50	1.00	0.80	1.80
III	2.30	1.60	1.60	2.70

In frequency-separated assessment to determine the vibration load on a person, the normalized indicator is the root mean square value of the vibration acceleration or its logarithmic level in octave or third-octave frequency bands.

Due to the fact that different methods yield different results, it is recommended to use frequency-separated estimation as more accurate results.

To assess the vibration loading of sprung masses of trucks, tractors, and dump trucks, acceleration is measured at characteristic points of the left side member: above the front axle; above the rear axle of a two-axle vehicle and midway between the middle and rear axles of a three-axle vehicle.

For a two-axle trailer, the characteristic points are the points on the left side member above both axles; for a semi-trailer, the points on the floor of the body platform, to the left of the vertical axis passing through the fifth wheel coupling at a distance equal to half the track of the rear wheels of the tractor, as well as on the left side member of the frame above the rear axle. For trailers and semi-trailers with two or more rear axles, the characteristic points are

midway between the extreme axles of the rear track of the bogie. In special vehicles designed for trucks and passenger trucks, acceleration is measured on the floor of the cargo platform or the frame above the rear axle.

Conclusions

To analyze the process of vehicle movement on roads of various types and develop a methodology for selecting design parameters of the suspension system, it is necessary to compile a mathematical model of the oscillatory process, which will allow using mathematical dependencies to describe the action of a technical object in the environment. According to the definition, mathematical modeling is an indirect practical and theoretical study of an object, in which not the object of interest to us is directly studied, but some auxiliary artificial or natural system, which:

- 1) is in some objective correspondence to the cognitive object;
- 2) capable of replacing them in certain respects;
- 3) when studying it, it ultimately provides information about the modeled object.

Thus, to build a mathematical model, we first need to determine the scheme that most accurately characterizes the process of truck movement, and then compile a series of mathematical dependencies that describe its operation.

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