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THE METHODS OF QUALITY ASSESSMENT OF THE TRACKED SUSPENSIONS OF THE COMBAT VEHICLES

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Abstract:

The extortions that result in the vibrations of a hull of the combat vehicle have an impact on the tracked combat vehicle during the off-road driving. They may have a negative impact on the crew, internal equipment, shooting accuracy. A level of the hull loads depends on quality of the suspension system, which main responsibility consists in minimising an amplitude of the vibrations. Therefore, it is necessary both to improve a structure of the suspension system, and its components, as well as their optimisation.

The tests of the driving smoothness of the vehicle and quality of the suspension elements can be realised both within a frame of the model tests and while driving in the real conditions. The assessment criteria of the driving smoothness are directly related to the negative influence of the vibrations to the human body. The suspension quality should be assumed both upon an execution of the vehicle prototype, and during the design or modernisation phase. It results both in reducing the time, and minimisation of the costs and risk related to the structure development. The model tests enable to evaluate the driving smoothness and comfort prior to an execution of the prototype. The tests on the test tracks in the final phase of the development are carried out in order to evaluate the driving smoothness.

Keywords: *tracked combat vehicle, suspension, driving smoothness, test track*

1. Introduction

The extorsions from the ground influence on the tracked combat vehicle during both during the typical, and in the complex off-road conditions. The larger the field irregularities are met by the vehicle on its way and the higher velocity it moves, the extorsions are greater. A shape of the irregularities and their distribution cause the vibrations of the vehicle hull, as the sensored mass, which intensity depends on the properties of the suspension system. These vibrations are transferred to the human and have the negative consequences in a form of the general fatigue, lowering the psychophysical capabilities, slowing of the reactions, reducing a visual acuity and the other. The vibrations of the vehicle hull can be reduced or their form can be modified by a proper selection of the suspension parameters in order to reduce their negative impact. You should evaluate a fulfilment of the requirements imposed on the suspension compounds, the suspension system, and an impact of the system on the driving smoothness of the vehicle during a design phase, upon completing its construction, after making the suspension elements and an execution of the vehicle prototype.

2. Methods of assessment of the driving smoothness

The tests of the vehicle driving smoothness and the quality of its suspension compounds are conducted while using the computer methods, bench testing, as well as when driving in the real vehicle operating conditions. This process can be in simple terms reduced to the following stages:

- an assessment of the vehicle driving smoothness on the basis of the known suspension parameters such as: maximum clearance, minimum clearance, static and dynamic travel of load-bearing wheels, potential energy of suspension, characteristics of resilience and damping,
- a mathematical model of the vehicle. The above-mentioned parameters can be assessed both individually and collectively compiling them with the vehicle parameters that have a direct

impact on the vibrations. They are substituted in the motion equations solved by a software that supports required by the design calculations. The Motor Vehicle and Transport Institute of the Mechanical Department in the Military University of Technology developed and tested an original computer software intended for an analysis of the dynamic loads that have an impact on the multi-axle vehicles with the independent suspension. It was validated and verified experimentally within a process of its development. It enables to determine the displacements, velocities and accelerations of the significant vehicle elements such as the load-bearing wheels, the hull and the driver's seat. The software allows also for changing the suspension characteristics, mass parameters, vehicle velocities and a type of the extorsions, its shape and dimensions, single field irregularities of the slope and reverse slope;

- the tests that use the advanced computer methods (e.g. the Adams' methods);
- a strength test of the elements by means of the finite element method (e.g. LS-DYNA®);
- the bench tests, upon completing the suspension prototype can be, and sometimes even should be, conducted in the stationed conditions in order to determine the actual characteristics of resilience and damping;
- a test of driving smoothness on the test track with a design that allows for generating loads with a high amplitude;
- a test of driving smoothness in the actual operating conditions.

2.1. Experimental test tracks of the tracked vehicles

The studies of the vehicles on the test tracks are performed in order to verify and assume mobility, strength and resistance of the elements and traction properties of the vehicle. The test tracks are intended for conducting the qualification or certifying tests of the subassemblies, assemblies or complete vehicles, as well as the environmental tests or the field tests realised according to the requirements and conditions of the entry into service. The test tracks are equipped with a different road infrastructure, including artificial and natural obstacles.

The types of the obstacles:

- natural: sandy roads, muddy roads, fords, roadless tracks, sand dunes, natural sandy elevations,
- artificial: prismatic and trapezoidal obstacles, hard-paved elevations: 150 mm, 200 mm, 250 mm, 300 mm,
- a track with the artificial obstacles: trapezoid obstacle, wall, ditch, embankment, logs, road unevennesses,
- a pool for conducting the fording and buoyancy tests,
- a station for the static test, a practical lateral inclination angle and a position of mass centre of the vehicles.

The artificial obstacles can have the different dimensions, geometry and shapes. The obstacles in the form of the various unevennesses with a height of h_i and a distance between them of l_i equal approximately to an arrangement of the neighbouring wheels at one side is presented in fig. 1.

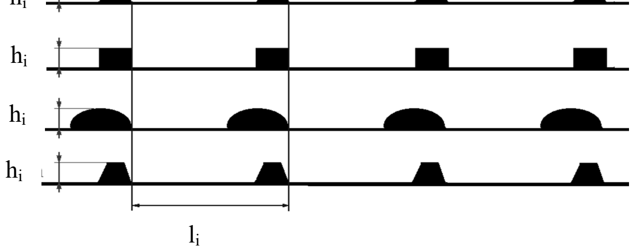


Fig. 1. The exemplary shapes of the field obstacles, where h_i – obstacle height, l_i – obstacle spacing

While driving on this type of the track a maximum vertical acceleration that has an impact on the driver should not exceed 5 m/s^2 (0.5g) regardless of the driving velocity. In case of driving on the elevated unevennesses, e.g. to a height of 0.15 m, the vertical accelerations acting on the driver should not exceed 30 m/s^2 (3g).

The Motor Vehicle and Transport Institute of the Mechanical Department in the Military University of Technology has at its disposal the original overrun obstacles with a triangle profile with the different heights designed and executed for the needs of the driving smoothness tests of the combat vehicles. In fig. 2 a and b are the photographs presented of the obstacles.

In fig. 3 are presented the sequences from the Leopard 2 tank tests during its drive with a high velocity (V>50 km/h) on the track with the trapezoidal obstacles featuring a height of 0.15 m. These obstacles are distant from each other for a distance two times greater that a length of the resistance surface of the caterpillar track. At these velocities, the great dynamic extortions have an impact on the vehicle suspension and hull. The caterpillar track of the vehicle while driving on the trapezoidal obstacle mitigates a trajectory of the load-bearing wheel therefore the trajectory is approximate to the sinusoidal one, at the same time reducing the loads that act on the hull.

In fig. 4 are presented the excerpts from the driving smoothness tests of the other tracked combat vehicles, respectively: in fig. 4a, the K-2 Black Panther tank (South Korea) on the track featuring the triangle cross-section obstacles, in fig. 4b, the T-90 tank (Russia) on the track featuring the square cross-section obstacles, in fig. 4c the AMX-56 Leclerc tank (France) on the track featuring the flattened rectangle cross-section, in fig. 4d the BWP-3 infantry fighting vehicle (Russia) on the track featuring the tubular obstacles. In case of unavailability of the track with the presented obstacles, the suspensions of the combat vehicles for the tests, you can use the appropriately spaced out logs of the cut down trees or in the winter season, the frozen furrows of the ploughed field.

a) height h_1

b) height h_2 – before and after tests (h_1<h_2)

Fig. 2. The overrun obstacles intended for the driving smoothness tests of the combat vehicles

In fig. 5 are presented the excerpts of the tests of the permitted lateral inclination of the M1 Abrams tank (U.S.A.) presented on fig. 5a, and a fulfilment of the requirement related to the approach angle by the Anders light tank (Poland) presented on fig. 5b.

Fig.3. The Leopard 2 tank – the sequences of driving on the transverse unevenesses with a trapezoidal outline with a high velocity [1], four shots that show an operation of the suspension and the caterpillar mechanism.

2.2. Assessment criteria of the driving smoothness

The basic parameters, which characterise the mechanical oscillations, constitute an amplitude and a frequency. A vibration amplitude as a value of the deflection from an equilibrium point can be described by a displacement, a velocity and an acceleration. The most frequently, while evaluating an impact of the vibration on the human at the workstation, the acceleration time-courses are used. This value characterises the vibration in terms of their energy. The national and international standards that determine the permissible vibration exposure limits at the workstation refer just to it. Due to an unfavourable impact of the vibrations on the human body, the Minister of Economy and Labour in [4] specified the maximum permissible concentration and intensity of harmful factors in the work environment (MPI), which are describe by the following values:

- a value of the daily exposure to risk arising from vibrations referring to eight hours,
- a short-time exposition of 30 min or shorter,
- an operating threshold.

Depending on a degree of the vibration, transfer to the human body there are distinguished the following ones:

- local vibrations transmitted by the upper extremities (hand-arm vibration),
- whole-body vibration.

The ways of calculating the vibrations at the workstations are determined in the standard [5], but the permissible values of the vibration amplitude are summarized in table 1.

a) MBT K-2 Black Panther *b) MBT T – 90*

c) MBT AMX-56 Leclerc *d) CV BWP-3*

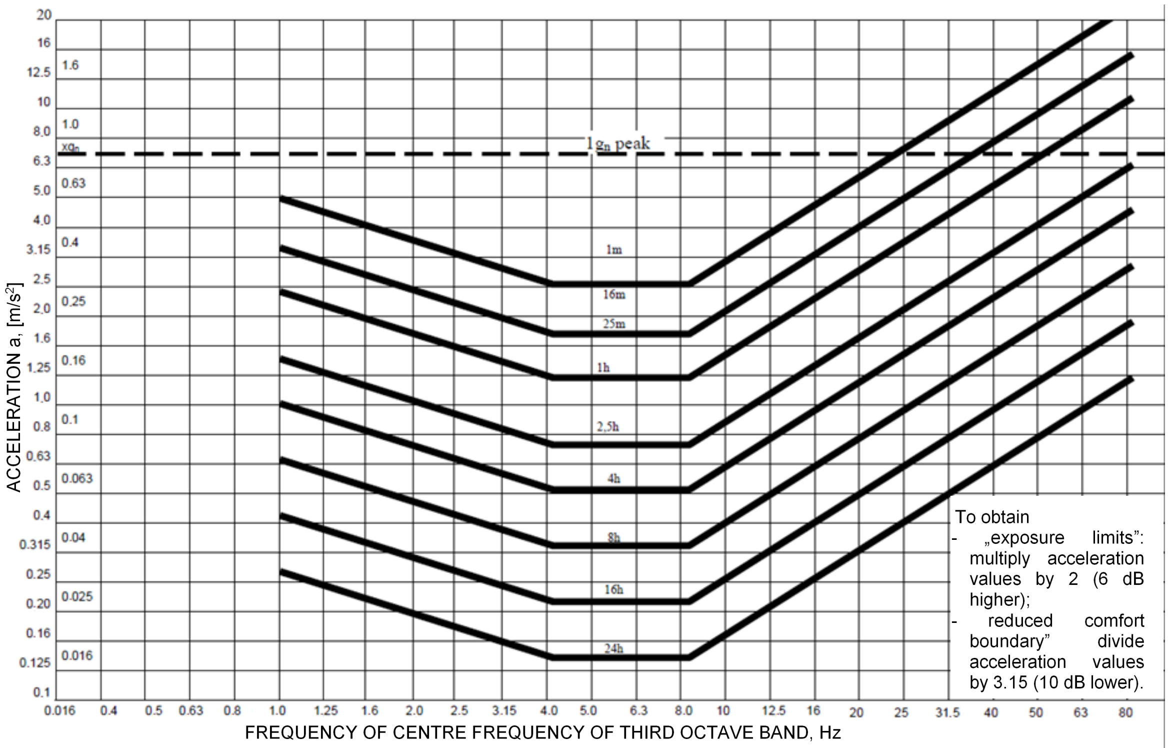
Fig. 4. The experimental test of the tank suspensions on the test tracks [1]

Fig. 5. The test station a) lateral inclination angle (M1A2 Abrams tank) [2], b) approach angle (ANDERS platform) [3]

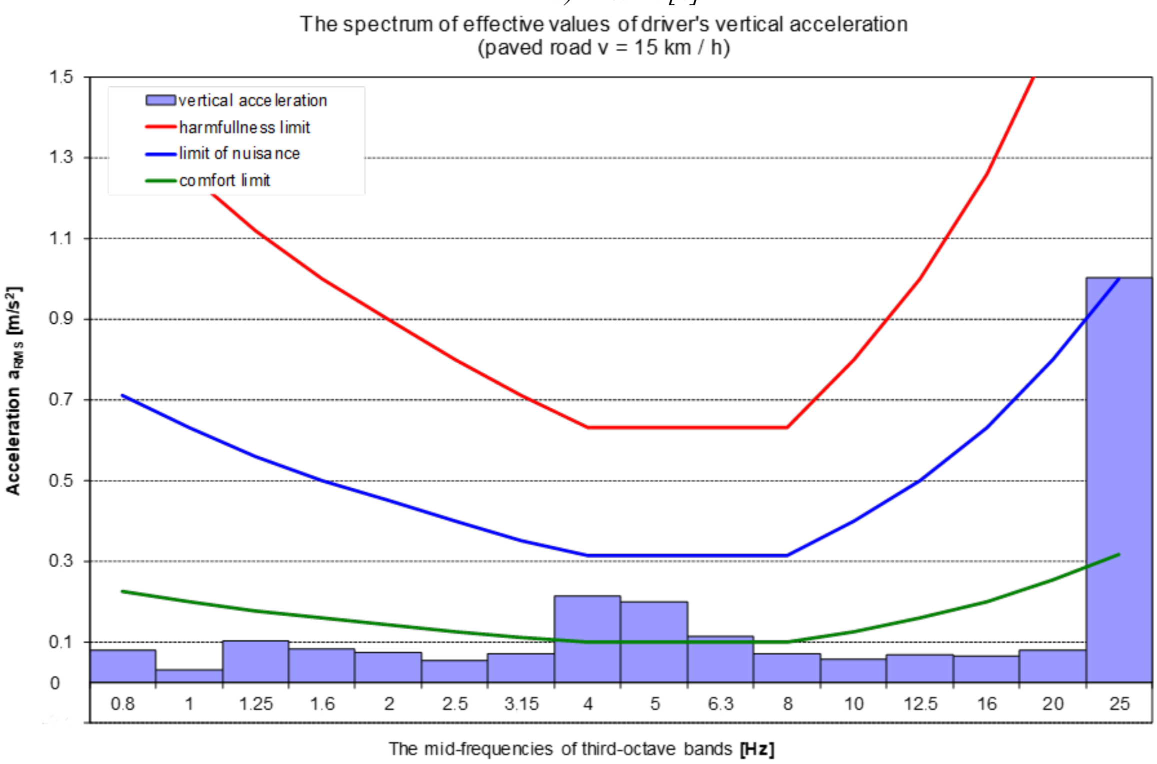
Tab. 1. Limit values for exposure to mechanical vibrations [5]

Type of vibrations	Daily exposure limit for mechanical vibrations (NDN)	Permissible values for short-term exposure to mechanical vibrations (NDN)	Operating thresholds for mechanical vibrations
Hand-arm vibration	A(8) = 2.8 m/s^2	$a_{hv,30min}$ = 11.2 m/s^2	A(8) = 2.5 m/s^2
Whole-body vibration	A(8) = 0.8 m/s^2	$a_{w,30min}$ = 3.2 m/s^2	A(8) = 0.5 m/s^2

A reaction of the human body to the vibration impact depends also on their frequency. The human body is the most sensitive to vibrations with a frequency up to 35 Hz, in particular within a range between 4-10 Hz. In fig. 6a are presented the permissible exposure times to the vibrations with the individual centre frequencies in the one-third octave bands. Whereas in fig. 6b are presented, the permissible exposure Times to the vibrations in the frequency one-third bands obtained from the experimental tests conducted with regard to the high-speed tracked vehicle.



a) Norm [6]



b) results of the experimental tests related to the tracked vehicle on the dirt road [7]

Fig. 6. The dependency graphs of the value of the effective acceleration that has an impact on humans on the frequency or the centre frequencies in the one-third octave band with the marked lines of the exposure limit time.

The most hazardous for the human body is a stimulation of the internal organs to the resonance vibrations. It occurs as a result of the whole-body vibrations that correspond to the resonance frequencies of the organs. Furthermore, the accelerations that exceed the threshold value may cause the vibrations with a hazardous amplitude, which in turn can result in the organ disorders, internal haemorrhages, and in the extreme cases, it may lead to a mechanical damage of the internal organs. The natural vibration frequencies of the most organs in the human body are presented in table 2.

Tab. 2. The range of resonance frequencies of human organs [8]

Name of the authority	**Resonance frequency [Hz]**
Head	4-5 and 17-25
Eyes	60-90
Jaw	6-8
Larynx, trachea, bronchi	12-16
Chest organs	5-9
Upper limbs	3
Spine	8
Abdominal organs	4,5-10
Liver	3-4
Bladder	10-18
Pelvis	5-9
Lower limbs	5
Sitting man	5-12
Standing man	4-6

3. Summary and Conclusions

The advanced computing systems enable to assume (in a multi-variant manner) the driving smoothness and comfort of the vehicle already at the design phase or in the phase of the modernisation proposals. Nevertheless, quality of the suspension solutions (due to a range of uses) used in the tracked combat vehicles is verified and assumed during the experimental tests. It is possible to assume the driving smoothness and a level of the oscillations and vibrations transferred from the hull to the human body. A change of the design parameters and the vehicle suspension parameters enables to reduce the accelerations that have an impact on the hull and the unfavourable influence of the vibrations, what allows for increasing a level of comfort in work.

The experimental test tracks enable to assume a fulfilment of the tactical and technical requirements, inter alia, such as the approach angle, lateral inclination, permissible accelerations that act on the crew while riding, acceleration time, braking distance. During the long-term running, they also allow for verifying a strength of the vehicle and its systems and subassemblies.

The tests conducted on the test tracks enable to compare the properties of the different types of the vehicles subjected to the repeatable loads.

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