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Original article

The analysis of conditions for testing mileage of military vehicles

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ABSTRACT

The study discusses the issue of determining the conditions for testing the mileage of a vehicle. Lifetime tests are the crucial element of qualification tests. This type of research verifies the resistance of vehicles and elements of their on-board equipment to vibrations and shocks resulting from the interaction of uneven surface during the movement. Certain test conditions can be straightforwardly determined and verified e.g. weather conditions or a type of the road/surface. The problem appears when the tests are to be conducted in field conditions (off-road). At the set driving speed, the level and frequency structure of dynamic loads of elements of a vehicle drive system depend mainly on a surface profile and its viscoelastic conditions. Either the profile or the characteristics of ground foundations change over the time depending on various factors. The paper attempts to assess the interaction of a ground surface of selected field roads on a vehicle. The result of direct measurement of the vertical acceleration captured on a drive axle and on a vehicle's frame above the axle was addressed. The measurement results were analyzed within the context of possible planning of vehicle test requirements with the application of the method of testing mileage under the field conditions.

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KEYWORDS

mileage tests, special purpose vehicles, dynamic loads

Introduction

While conducting mileage tests the wheels of the vehicle are subjected to kinematic input from random changes of the road profile altitude. They are specific inputs that destructively affect the vehicle components during its operation [Kosobudzki 2014; Rybak 2014; Jacenko 1975]. The parametrization of unsurfaced roads, including field test tracks, is necessary due to the fact that basic requirements used in vehicles' service life testing programs are relatively vague. The existing requirements set before off-road vehicles, in particular military ones, contain general statements such as: 'a vehicle should be able to move on ground roads and sideways'. This type of the statement is ambiguous for a constructor, a producer, a researcher and an administrator. In fact, nobody knows on which unevenness and with which speed a given vehicle is supposed to move. Unsurfaced roads are characterized by an unstable profile changing under influence of various factors such as:

– weather conditions,
– incidence of road usage,
– type of a vehicle moving on a road (mass of a vehicle, type of a drive system).

In literature as well as in everyday lifetime tests practice methods characterizing unsurfaced roads through the root mean square value (RMS) of profile altitude variations can be found. However, taking into account variability of ground-surfaced profiles it is allowed to state that such the measure is not constant and, simultaneously, does not account mechanical properties of ground foundation material [*Endurance testing*… 1981; Johannesson et al. 2014; Loprencipe and Cantisani 2013; Ojeda et al. 2006]. Distinct measures are used as well e.g. International Roughness Index IRI [Sayers et al. 1986]. This coefficient is mainly applied while characterizing the variability of surfaced roads profiles.

The tactical-technical criteria regarding high mobility vehicles frequently assume that a vehicle should be able to move on surfaced and unsurfaced roads and sideways. The criteria do not impose any average speed of a vehicle nor include a single parameter characterizing an alignment of the road itself. These parameters characterize the conditions of a vehicle movement, which influence the level and frequency structure of dynamic loads of elements of a vehicle drive system. Matching the driving speed to a relevant surface's type and profile may affect the lifetime testing results.

The attempt to evaluate the features of ground foundations as a source of dynamic loads of drive system elements was undertaken within the framework of the study. Various types of foundations were benchmarked through a force applied to a vehicle during movement. This interaction was determined with the use of an indirect method. The variation of flow acceleration measured on a drive axle and on a vehicle's frame as well as the deflection variation of the front drive axle moving on ground surfaces were achieved. The values of comparative indicators and comparative characteristics of dynamic loads combinations of a vehicle drive system elements were determined based on the obtained mileages.

1. Conditions set before wheeled vehicles of military purpose

Vehicles used in the Polish Armed Forces (WP) are divided into 7 groups. Among them there are the vehicles designed for off-road use which were classified as [*Instrukcja*… 2013]:

– high mobility vehicles,
– extended mobility vehicles.

Various conditions are set before these vehicles. For example, a high mobility vehicle is supposed to keep pace with tracked vehicles, that is either equal them with the speed or with the ability to cross terrain obstacles. Whereas extended mobility vehicles are exempt from the requirement regarding the speed but they must be able to follow tracked vehicles [*Instrukcja*… 2013].

Definitions related to off-road vehicles are very general and only specify the possibility of moving in certain conditions. The average mandatory value of speed nor are indicators characterizing a surface not provided. Due to the lack of the precise conditions of vehicles movement, the problems with establishing the criteria for vehicles' designing as well as conducting service life and mobility tests arise, particularly during movement on ground roads and sideways.

2. Experimental research

The experimental research was conducted on the test track in the Military Institute of Armoured and Automotive Technology in Sulejówek. The characteristics of individual road sections were presented in Table 1 and Figure 1. The all-terrain truck (Fig. 2), which was equipped with independent suspension and off-road tires, was used for the research. During the tests the tires pressure was in line with the recommendations formulated by the producer. The vehicle was not extra loaded. The selected ground road sections were diversified as for amplitude and length of the profile unevenness. The surfaces differed also with respect to physical characteristics. In particular it referred to S1 sideway whose ground surface was packed which hindered plunging the drive wheels and S4 gravel road whose surface covered with packed slag was hard and relatively flat, therefore, basically with the characteristics of a surfaced road. In turn, tank roads marked as S2 and S3 were covered with the loose sand layer which makes the drive wheels of a vehicle plugging into surface's foundation and causing clear ruts during movement.

The vehicle moved along presented sections with the speeds of 12 and 6 km/h. The basic speed of 12 km/h was picked as the maximum speed with which it is possible to move without exposing a driver to a health risk and a vehicle to a failure on the surface with the highest amplitudes of the profile unevenness (S3 surface, Table 1).

The speed of 6 km/h constituted a half of the basic speed. Additionally, along the sections on which the possibility of safe movement at higher speed existed, it was increased by 6 km/h.

Table 1. Designation and characteristic data of test sections

Designation of surface type	Characteristic features
S1 – sideway (Fig. 2a)	– sand ground surface, packed – RMS of the profile on representative section of the surface 0.04 m – a lack or shallow rutting by the vehicle's drive wheels – unevenness of significant length exceeding axle base of a vehicle

S2 – smooth tank road (Fig. 2b)	– sand ground surface, loose – RMS of the profile on representative section of the surface 0.05 m – possible rutting by a vehicle's drive wheels – unevenness of length exceeding the axle base of a vehicle
S3 – tough tank road (Fig. 2c)	– sand ground surface, loose – RMS of the profile on representative section of the surface 0.09 m – deep rutting by a vehicle's drive wheels – unevenness comparable axle base of a vehicle
S4 – gravel road (Fig. 2d)	– gravel surface, packed – unevenness of low altitude and considerable length – short unevenness, including those in the form of randomly placed stones

Source: [Own study].

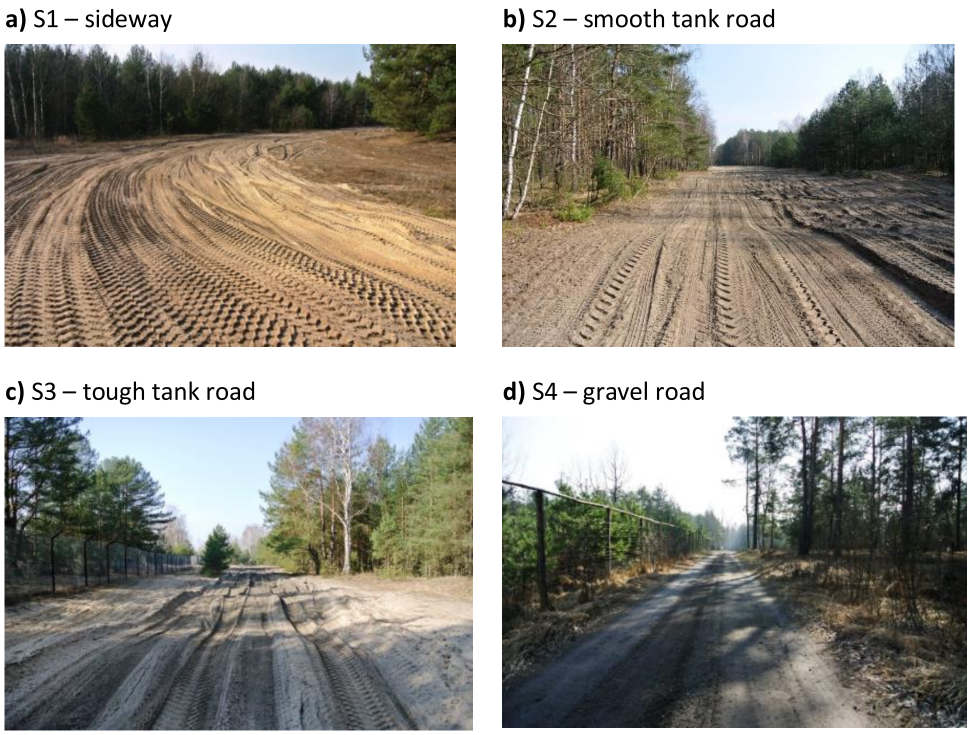

Fig. 1. View of the individual field surfaces sections
Source: [Own study].

The following physical quantities were registered during experimental research (Fig. 3):

– vertical acceleration of the vehicle drive axle,

– vertical accelerations of the vehicle frame over the front drive axle,

– deflection of suspension.

The listed physical quantities were registered at the left and right sides of the tested vehicle. However, the study presents only exemplary measurement results obtained on one side of the vehicle. The authorial program for data processing and visualization in the Matlab environment was developed for the purpose of the analysis of measurement results.

Fig. 2. View of the all-terrain truck during tests
Source: [Own study].

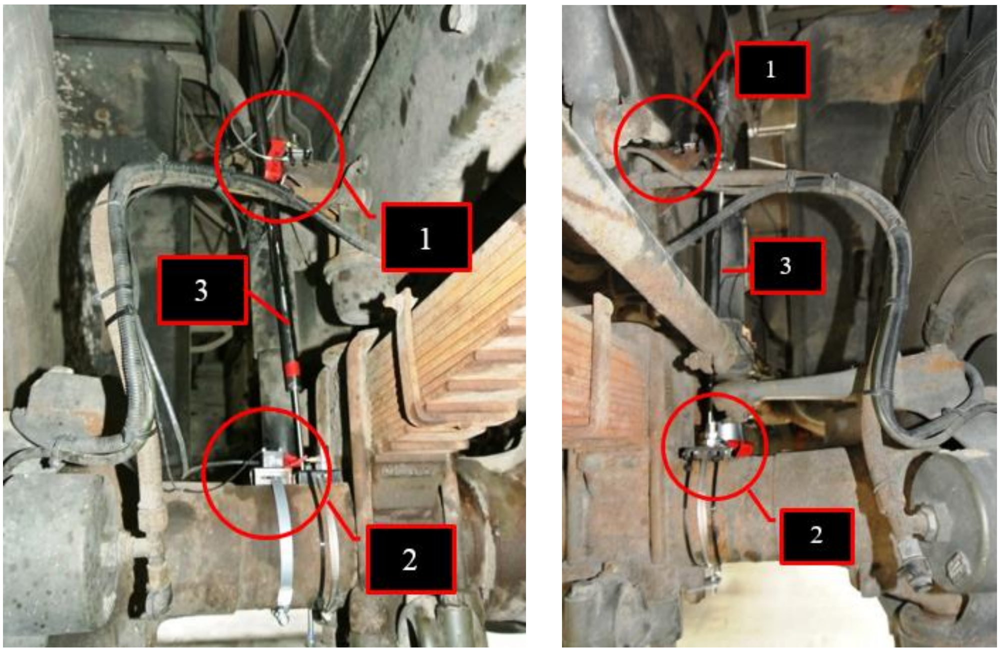

Fig. 3. View of measuring probes mounted on the vehicle.
1 – acceleration probe on the vehicle's frame; **2** – acceleration probe on the front drive axle;
3 – accelerations probe/deflection of suspension)
Source: [Own study].

3. Results of the tests performed

The values of comparative indicators and the characteristics achieved based on the experimental research were correlated in the subsequent figures. Consecutively, they are as follows:

- average values of 10 maximum acceleration amplitudes measured on the vehicle's frame and the beam axle as well as the deflection of suspension in the function of driving speed (Fig. 4),
- RMS effective values of acceleration measured on the vehicle's frame and the beam axle as well as the deflection of suspension in the function of driving speed (Fig. 5),
- the characteristics of power spectral density (PSD) of measured accelerations and deflection of the drive axle (Fig. 6).

a) Acceleration on vehicle's the drive axle [m/s^2]	**b)** Acceleration on the vehicle's frame [m/s^2]	**c)** Deflection of suspension [mm]

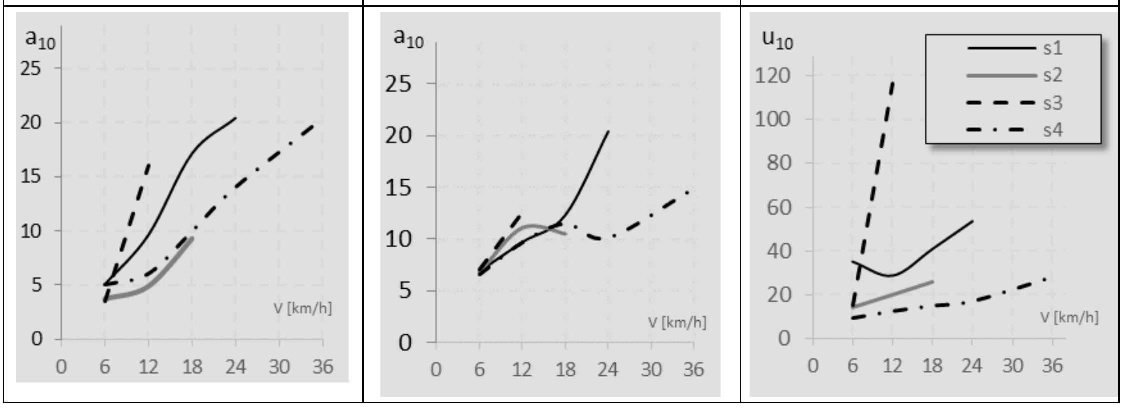

Fig. 4. Influence of types of driving speed and surface on the extremes of achieved accelerations a_{10} and deflection of suspension u_{10} of the drive axle
Source: [Own study].

a) RMS of acceleration on the vehicle's driver axle [m/s^2]	**b)** RMS of acceleration on the vehicle's frame [m/s^2]	**c)** RMS of deflection of suspension [mm]

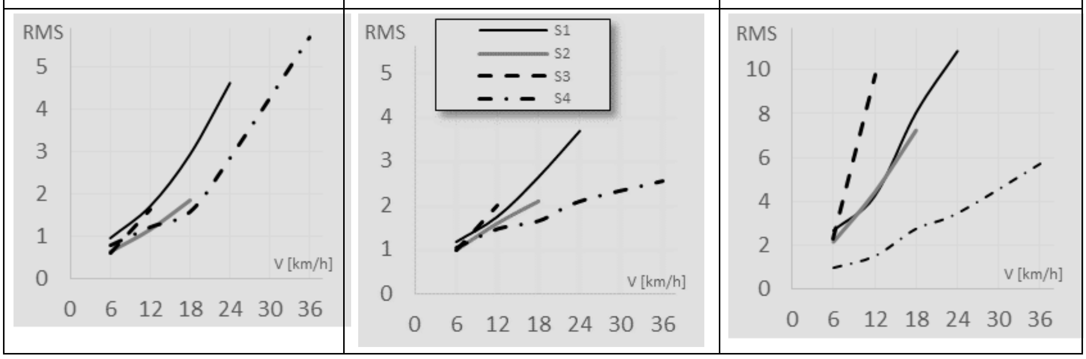

Fig. 5. Influence of driving speed and type of the surface on RMS effective values of acceleration and deflection of the drive axle
Source: [Own study].

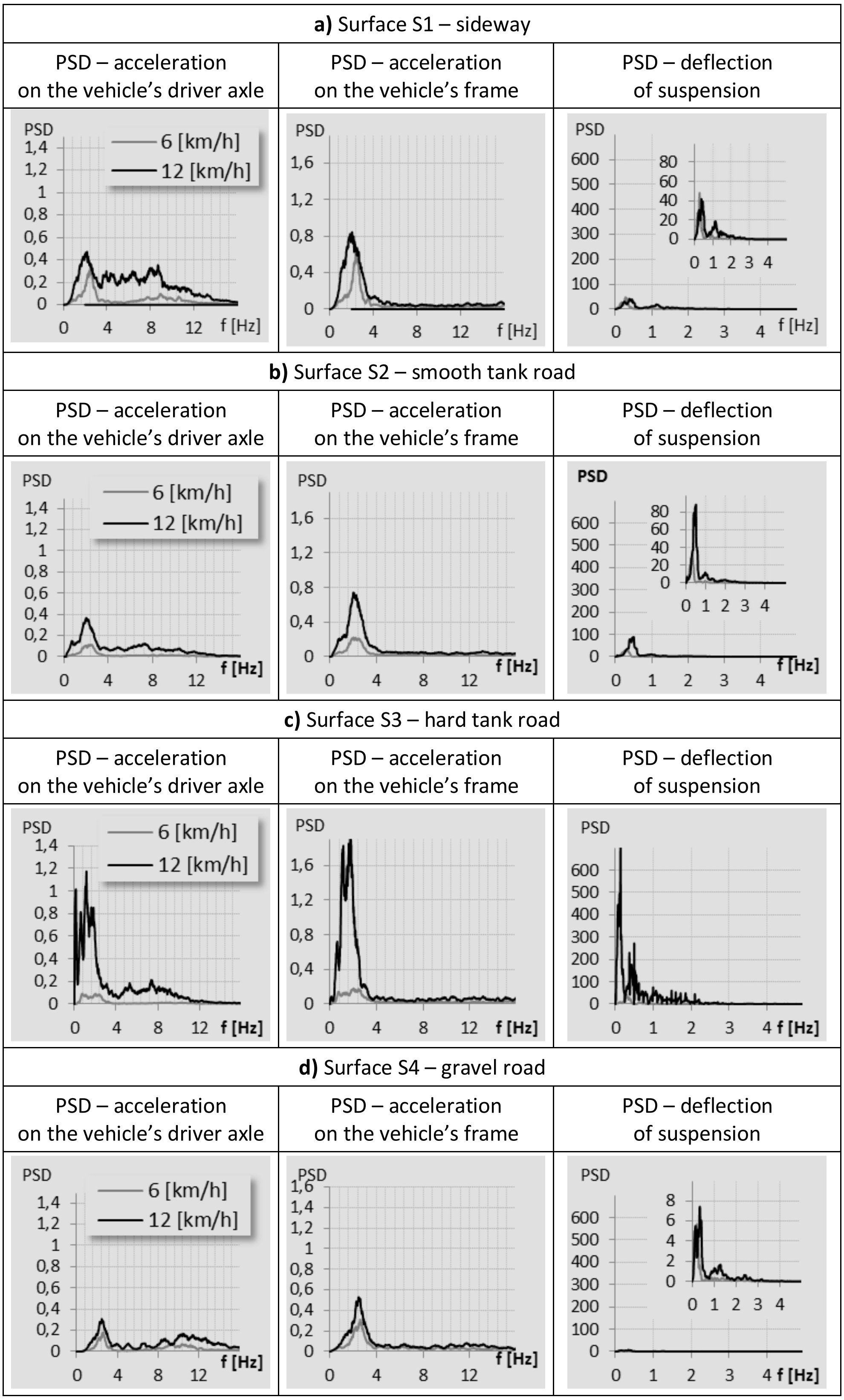

Fig. 6. Power spectral density PSD characteristics of measured accelerations and deflection of suspension of the drive axle during the movement on selected types of the ground surface

Source: [Own study].

The results of the experimental research revealed significant influence of the surface and driving speed on the representative indicators values and the characteristics determined. However, it is visible that the surface with the highest RMS effective value of the profile variations (S3) does not prompt the highest values of the acceleration measured on the drive axle and the frame of the vehicle, particularly in terms of low driving speed (Figs 5 and 6).

The influence of the ground surface on the obtained results of the measurements is marginal in terms of low driving speed, nonetheless, it increases following the growth of the speed. Namely, similar level of ad hoc and effective values of vehicle drive system dynamic loads is possible to be selected on each of the ground surfaces through choosing the appropriate driving speed.

Power spectral density characteristics of measured physical quantities also demonstrate that the adjustment of driving speed on ground surfaces can may lead to the significant change of mode values mainly in the sphere of natural frequency of the drive axle mass and the bodywork in vertical movement. However, the frequency structure of vertical vibrations of the drive axle and the frame over the drive axle practically do not change. Thus, it can be stated that from perspective of determination of the vehicle's mileage testing in off-road conditions the selection of appropriate driving speed is of the utmost importance. The appropriate driving speed guarantees obtaining the required level of ad hoc and effective dynamic loads of the vehicle drive system elements on each type of the surface, by maintaining similar frequency structure of these loads. These are the relevant conclusions from the point of view of formulating criteria and planning tests of vehicles with the use of the method of service life in terrain conditions.

Conclusions

Based on the presented test results following conclusions can be formulated:

- ground surfaces trigger vibrations of the drive axle in the low frequency range, mainly below the natural frequency vibrations of the sprung mass,
- indicators of ground profile variations, e.g. RMS do not guarantee obtaining the required level of dynamic loads of elements of a vehicle drive system during mileage tests,
- the required level of dynamic loads of elements of a vehicle drive system on the specific ground surface can be achieved practically only through the selection of driving speed,
- selection of the driving speed appropriate for a specific surface constitutes the essence of choosing the driving conditions of a vehicle during lifetime tests – it is necessary to suggest a method for determining conditions of a vehicle mileage testing for each type of ground surfaces.

Hence, a question arises: how and based on which criteria the value of the average driving speed of a vehicle during mileage tests under terrain condition can be determined. The possible scenarios of scheduling testing conditions of wheeled vehicles' service life were developed on the basis of gained experiences.

Scenario 1

The criterion of the ability to follow fighting vehicles

This case seems to be the simplest one. The test conditions can be established based on the required ability to follow fighting vehicles of a specific type – the condition is to be determined as per the technical-tactical criteria (ZTT) or in the research agenda. The essential elements of lifetime tests method include:

- determination of a fighting vehicle's driving speed which assures effective and safe movement in given field conditions for the vehicle itself and for the crew – determination of required values of driving speed for selected sections of the field road,
- conducting the mileage tests of the vehicle under examination on the individual field roads sections with the previously established values of average speed,
- the lifetime compatible with the research agenda or established based on the required driving time and determined average speed.

Scenario 2

The criterion of maximum level of RMS ad hoc or effective acceleration values of designated drive system elements or deflection of suspension

This case is based on the driving speed determination enabling obtaining the values of defined indicators on distinguished types of surfaces. Research conditions (the speed on the defined type of the surface) cane be established based on the level of maximum values or RMS of acceleration of designated drive system elements or deflection of suspension provided in the ZTT or in the research agenda. The essential elements of mileage testing method include:

- driving tests on selected sections of ground roads (with distinct RMS profiles) with various speeds – the measurements of acceleration or suspension deflection,
- determining the driving speed on designated sections of ground roads which assure obtaining the required level of dynamic loads of elements of a vehicle drive system,
- conducting the lifetime tests of a vehicle on individual sections of field roads with determined values of the average speed.

Scenario 3

The criterion of a driver's comfort

This case is based on determination of the driving speed which assures obtaining the values of defined indicators of a driver's/crew's comfort on designated surface types. Such the procedure of movement condition establishment comes from the assumption that a vehicle ought to last the exposure on shocks when a man is able to endure them of a definite level of nuisance. The research conditions can be determined based on the required level of a driver's, a crew's or passengers' driving comfort specified in the ZTT or the research agenda – for example in the range between the comfort and the nuisance, between the nuisance and the harmfulness or below the nuisance level (in the continues exposure time). The essential elements of mileage tests method include:

- driving tests on selected sections of ground roads (with distinct RMS profiles) with various speeds – the measurement of the acceleration components on a driver's, a crew's or passengers' seats,
- determining the driving speed on the distinguished sections of ground roads which assure achieving the required level of driving comfort of a driver, a crew or passengers,
- conducting the mileage tests of a vehicle on individual sections of field roads with determined values of the average speed.

The proposed scenarios enable systematizing the issue of scheduling the conditions of vehicles' service life tests in off-road terrain. They can be useful either in the process of formulating the criteria for the vehicles or establishing the conditions during the industrial and qualification research. Adopting one of the proposed scenarios may facilitate the communication between an entity procuring the equipment, a producer and a research agency.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

ORCID

Witold Luty – The author declared that he has no ORCID ID's

Marcin Mieten – The author declared that he has no ORCID ID's

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Witold Luty – D.Sc Eng., Head of the Laboratory of Armoured Fighting Vehicles in the Military Institute of Armoured and Automotive Technology; his research interests cover inter alia: vehicle dynamics, testing vehicles, studying and modeling properties of tires of vehicles' road wheels, military vehicles and specialized vehicles. Number of publications – 51, patents – 1, monographies – 1, participation in monographs – 7 and scientific edition of monographs – 2.

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