TRACKED VEHICLE MOVEMENT MODELLING

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Abstract. Vehicles in civilian sector are mostly designed to provide maximal comfort and safety to the vehicle crew. On the other hand, there are also military vehicles on wheeled or tracked undercarriages. Secure maximum mobility, fire power and good resistance are the main tasks of these vehicles. Capability to fulfil all these requirements can positively or negatively affect the design and control of the vehicle. Although crew safety (vehicle resistance) is one of the priorities of a combat vehicle, but in combination with maximum cross-country capability and manoeuvrability, the crew comfort is greatly overlooked. Vibrations directly affect the systems and properties of combat and special vehicles. These vibrations occur, when the vehicle is operated - movement of tank treads, shooting, ride in complex terrain at high speeds, etc. Vibrations are transmitted from its sources to the hull area, where they have a direct impact on the vehicle crew, its health and fatigue. The incidence of motion sickness or disorders of organisms may occur in the worst cases, where the body is exposed to the effect of vibrations. Individual factors that influence the formation of vibrations in the field of tracked combat and special vehicles (e.g. APC, MBT) are analysed in the article. Operation of these military vehicles is financially demanding and in the peace period characterized by very small annual run. Therefore, a sophisticated model of a combat tracked vehicle has been supposed in multibody system MSC Adams and used to simulate the impact of vibrations on tracked vehicle crew. The model will also make it possible to replace real-world experiments of tracked vehicle dynamics with simulations and offer a wide range of uses, not only for subsequent investigation of vibration impact on human body. Partial results and evaluation of vibrations in relation to human health are mentioned in the final part of the article.

Keywords: tracked vehicle, vibration, human, modelling.

Introduction

Tracked vehicles are not only the priority of armies, (MBT – Main Battle Tank, APC – Armored Personnel Carrier, Fig. 1), but we can also find them in special rescue units and agricultural machinery (Fig. 2) all around the world. Combat tracked vehicles have very different requirements than civilian ones - higher maximum speed, weight, resistance and firepower.

Fig. 1. **BMP-2**

Fig. 2. **Tracked tractor**

Crew of a combat vehicle is constantly exposed to negative effects that arise when operating the vehicle – microclimate in the vehicle, vibration etc. The problematics of the influence of vibration to human body is a very complex matter. Human body as the receiver and the machine itself as the source of vibration have to be taken into account for solving this problem. Sciences such as biology, anatomy, biomechanics and psychology can be also included in the field of impact of vibration on a human body, Fig. 3 [1].

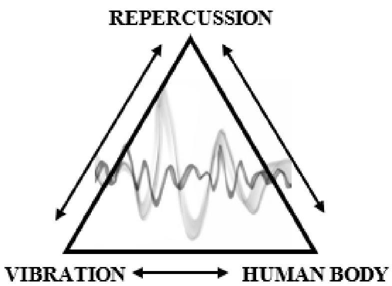

Fig. 3. **Human response to vibration dependency**

Vibration reduction methods in combat tracked vehicle

Vehicles in the civilian sector are developed and produced much faster than in the military sector, moreover, the acquisition costs of combat vehicles also exceed the cost of civilian vehicles several times. In addition, combat vehicles are characterized by their specific features, which have to be respected; therefore, comfort of the crew is not a first-class affair. However, elements, which reduce the effect of vibration of the vehicle to the crew, are used in modern construction. There are several ways to reduce vibration that spreads thru the vehicle:

1. Source approach
   - Rubberized road, specked, guide wheels; rubber tank tread.
2. Patch approach
   - Reinforcement of the hull structure – ribbing etc. (change of vibration frequencies outside the operating speed).
3. Receiver approach – separation of human body from the vehicle hull
   - Cushioned seats, suspended seats, rubberized floor of the vehicle.

Vibration with respect to human health

Vibrations in combat tracked vehicles are much more pronounced than in civilian vehicles. This is due to the construction itself – higher running speeds, track motion, but also the place of movement of vehicles (rugged terrain). All the facts mentioned above lead to generation of vibrations that affect the crew. Human body responds to mechanical vibrations differently, depending on the frequency and acceleration magnitude.

Effect of mechanical vibration on human body can be divided into three basic groups, which are mechanical damage, physiological and subjective reactions of the human body. Mechanical damage is represented by WBV (Whole Body Vibration) and HTV (Hand Transmitted Vibration) – for frequency ranges see Fig. 4. As an example, WBV may pose an increased risk of degenerative spine changes, especially for crane operators, tractor drivers, and drivers in transportation industry. On the other hand, HTV vibration can cause chronic hand injury – especially for handheld operators with power tools (e.g., drills, pneumatic hammers, etc.) [1; 2]. However, the human body can also react to vibration physiologically. Reaction is manifested by increased heart rate, accelerated breathing and increased blood pressure – human stability may be impaired as a consequence. Whole-body vibration of extremely low frequency, such as occurs in many transportation vehicles and ships, may also cause kinetosis (motion sickness) [2].

Subjective responses to vibration are when human feels discomfort. The extent of discomfort depends on the size, frequency, direction and duration of exposure to vibration. In general, subjective responses to vibrations can be divided into three broad categories – the threshold of perception, the onset of unpleasant feelings, and the margin of tolerance [2].

The basic approaches to evaluating vibrations with respect to WBV were published in [3-5].

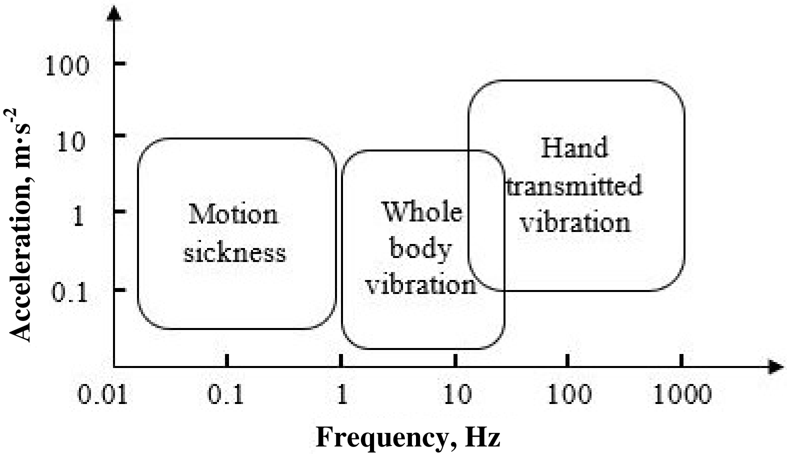

Fig. 4. **Frequency ranges of vibrations according to human health**

Numerical simulation using MBS software

Mechanical properties of shock absorbers and suspension part of a tracked vehicle are important factors in modelling the vehicle undercarriage. Hydraulic shock absorbers and torsion bars are generally used in modern constructions. These features have their characteristics that are used in a virtual model. The virtual model was made in MSC ADAMS (Automated Dynamic Analysis of Mechanical Systems) [6].

The software is based on a multibody system that, when properly configured, allows you to fully replace an actual experiment and thereby reduces financial costs associated with it. However, much input information is needed to complete the model, some are mentioned below.

One of the kinds of input information is the characteristic of suspension of the road wheel and the torsion bar characteristic. Calculation is based on Hooke's law and after editing is got the equation:

$$F_k = \frac{\pi \cdot d^4 \cdot G \cdot \gamma}{32 \cdot L \cdot r \cdot \cos(\alpha_0 - \beta)}, \tag{1}$$

where F_k – force acting on the wheel, Pa;
d – diameter of the torsion bar, deg;
L – length of the torsion bar, Pa;
r – arm length, deg;
α_0 – mounting angle of the arm, Pa;
β – overall angle of the arm movement, Pa;
γ – angle of twist, deg;
G – Shear modulus, Pa;

The displacement of the road wheel is given by the equation:

$$f_k = r \cdot (\sin(\alpha_0) - \sin(\alpha_0 - \beta)), \tag{2}$$

The resulting suspension characteristic – dependence of the acting force and displacement of the road wheel is shown in Fig. 5 according to the values shown in Table 1.

Reduced stiffness of the torsion bar is calculated according to the equation:

$$c_k = \frac{dF_k}{df_k}, \tag{3}$$

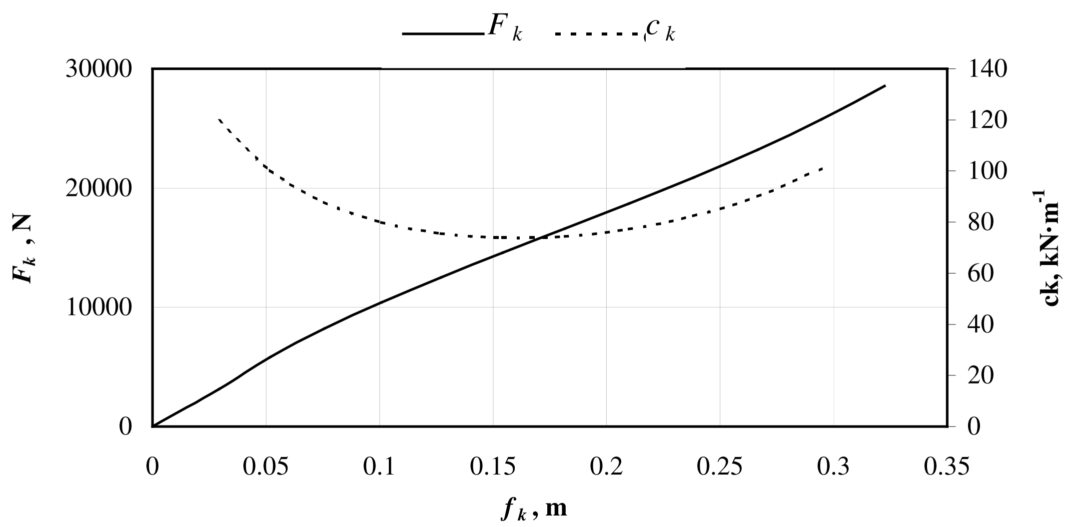

Fig. 5. **Suspension characteristics of one wheel of BMP-2**

Table 1

Suspension characteristic parameters

Parameter	Value
d	38 mm
L	1920 mm
r	325 mm
α_0	40 deg
G	81 GPa

Stiffness of suspension of individual wheels depends on the material properties of the torsion bars, their working length and diameter. Proper tuning of the chassis is an important feature – different montage angles are used to achieve different stiffnesses of the torsion bar. Montage angles are also influenced by the position of the torsion bars. Each of the twelve road wheels has its own torsion bar and these bars had pitch of 90 mm. Simplification for Adams model has been done – the mean torsion bar position was calculated, see Fig. 6. The second torsion bar is 20 mm lower than the other one shown in Fig. 6.

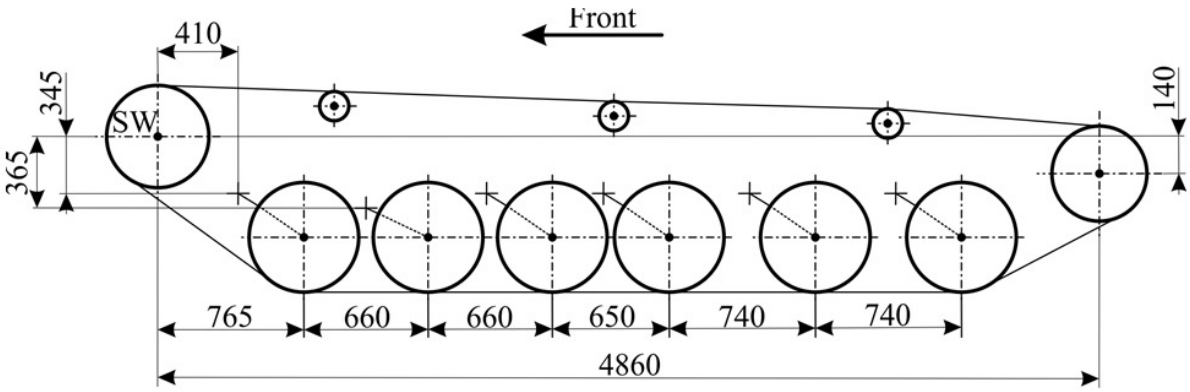

Fig. 6. **Dimensions of BMP undercarriage model**

Adams multi-body simulation represents a virtual vehicle model of BMP-2, which crosses over standardized obstacles – trapezoidal, perpendicular, trenches, field waves. The most important thing is the actual construction of the model relative to the actual vehicle – dimensions, weights, moment of inertia, damping characteristics, stiffness characteristics etc.

The basic geometric dimensions and weights were measured or obtained from the BMP-2 vehicle documentation. In addition, complete 3D model was created in Autodesk Inventor, which provided additional input parameters.

MSC Adams template for each part has been designed – whole vehicle assembly. Static analysis is one of the most important parts, where the value of error, stability and imbalance should not exceed the limit value 1. Precise static analysis will cut down the probability that the calculation model fails or the results will be inaccurate.

Obstacle of trapezoidal shape can be an example of an obstacle, which can be mathematically described by means of equations (4), depending on time:

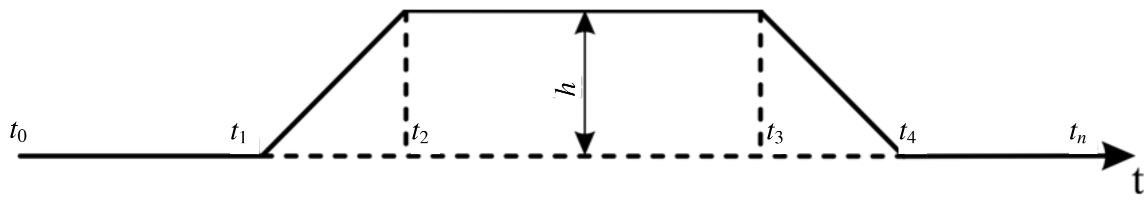

Fig. 7. **Obstacle of trapezoidal shape**

$$y(t)=\begin{cases}0, & t_0 \le t \le t_1 \\ \left(\dfrac{h}{t_2-t_1}\right)\cdot(t-t_1), & t_1 \le t \le t_2 \\ h, & t_2 \le t \le t_3 \\ h-\left(\dfrac{h}{t_4-t_3}\right)\cdot(t-t_3), & t_1 \le t \le t_2 \\ 0, & t_4 \le t \le t_n\end{cases}, \tag{4}$$

where $y(t)$ – vehicle position, m;
h – height of the obstacle, m;
$t_1 - t_n$ – time slots, s;

Results

The simulations were made for the trapezoidal obstacle with a height of 0.3 m and a vehicle speed of 30 and 40 km·h^{-1}. Sensors for acceleration measuring were situated in the crew compartment in the back part of the vehicle and in the place of the driver – front part of the vehicle. Calculation outcomes for the vehicle speed of 40 km·h^{-1} are shown in Fig.10 and for speed of 30 km·h^{-1} in Fig. 11.

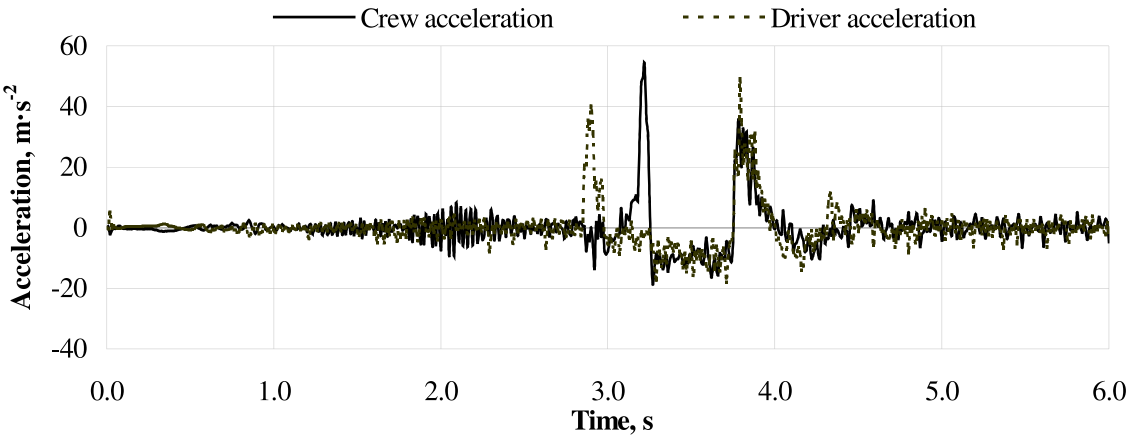

Fig. 10. **Vehicle vibration at 40 km·h^{-1} – crew and driver position**

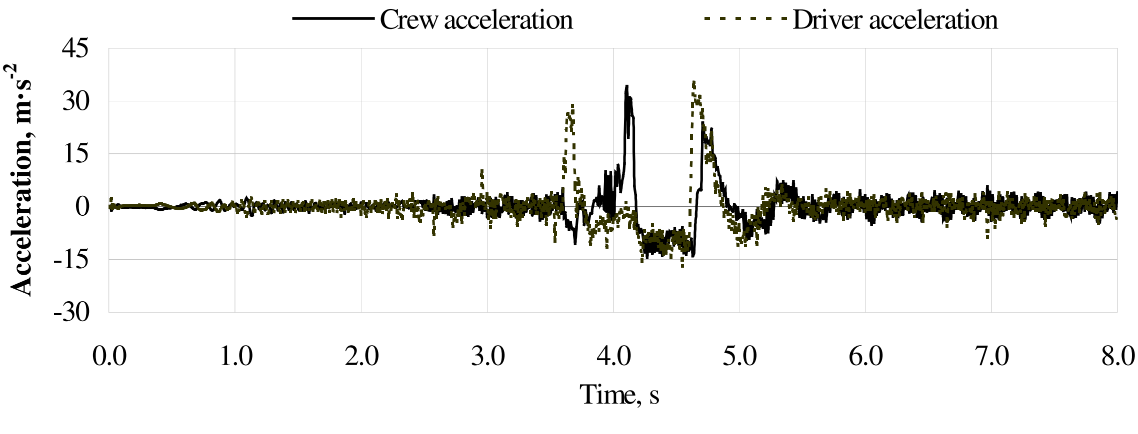

Fig. 11. **Vehicle vibration at 30 km·h^{-1} – crew and driver position**

The Fourier transform of the measured data was performed to evaluate the simulation results. Outcomes together with the areas of the whole body vibration (fatigue and disorders in organisms) are shown in Fig.12. Areas of rapid fatigue and disorders of organism are generated according to literature [7].

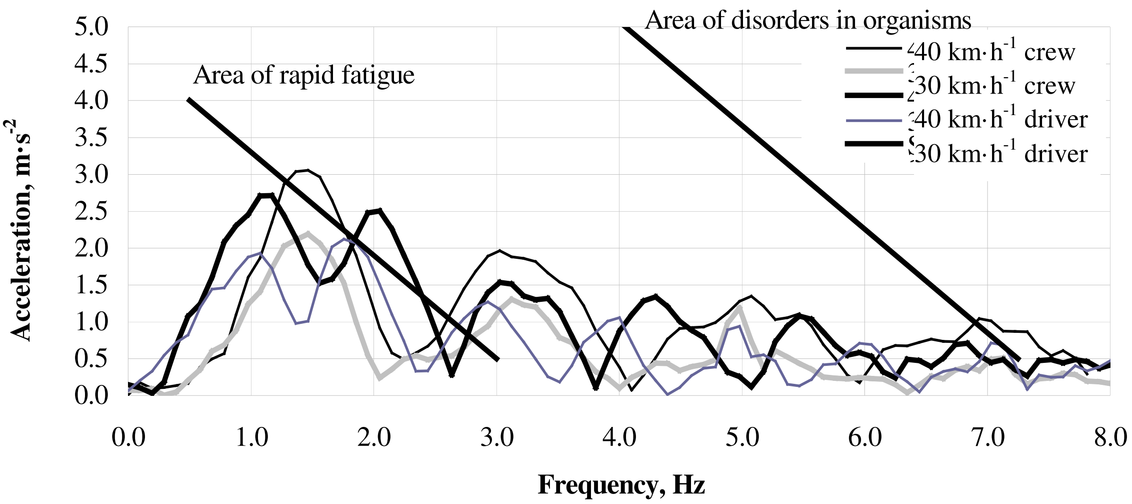

Fig. 12. **FFT and areas of WBV**

Conclusions

The article summarizes the knowledge of creation of asimulation model for tracked vehicle vibration. Vibrations from different sources are acting on the vehicle crew - the most important source is the undercarriage and running track system. Consequently, the suspension and torsion bar characteristics were used as inputs for the simulation model.

In the result, vibrations are assessed against the crew's health – fatigue and damage to human body. Simulation outcomes show that the frequency range of vibrations is up to 15 Hz, and therefore motion sickness and WBV are considered. In the case of controlled elements examined directly, the frequency could reach the HTV area. Simulations were performed for a trapezoidal shape obstacle of height 0.3 m, where the simulated vehicle started at a constant speed of 30 and 40 km. $h^{-1}$and overcame the obstacle. The frequency spectrum shows that vibrations exceed the rapid fatigue value. If these obstacles were placed much more behind, there would be accelerated fatigue of the crew - the ability of combat activities could be reduced. In the spectrum there are also frequencies above 7 Hz, where acceleration amplitudes are relatively small, but can cause damage to human body during prolonged exposure. For all cases, the human body will be trying to prevent exerting excessive acceleration by alternately stretching the muscles. These muscle functions will also increase the crew fatigue.

Acknowledgements

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