TRACKED VEHICLE ANALYSIS WITH SIMULATION TECHNOLOGIES SUPPORT

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Abstract: *The paper is focused on the analysis of tracked vehicle propulsion mechanism during a movement of the vehicle. Propulsion mechanisms of tracked vehicles are highly loaded by dynamics stress. This stress arises by vehicle movement on a terrain and by vibration of tracks. Analysis of this stress is essential in the process of development or optimization (modernization) of the vehicle. Simulating technology was chosen for analysis of selected vehicle, because analysis of propulsion mechanism stress of tracked vehicle is complex process. Utilization of simulating technologies enables extensive analysis of vehicle behaviour including analysis of stress of main parts of the vehicle.*

Keywords: TRACKED VEHICLE, SIMULATION, MOVEMENT, STRESS, DANAMICS

1. Introduction

Lethality, protection, mobility and communication are the general capabilities of the combat vehicle. Nowadays conflicts and military missions require different types of vehicles. Improving of the lethality and protection is current trend. Both these capabilities affect vehicle weight and its mobility.

Combat tracked vehicles are constructed for movement in a heavy terrain. Movement in this terrain increases requirements on chassis and whole propulsion mechanism. Especially transmission, sprocket wheels, idler mechanism and track elements are highly load by dynamic stress.

It is essential to analyze the stress of the main elements of transmission, its control mechanism and main parts of chassis for development of lifetime and reliability of propulsion system of the vehicle. This analysis is essential in process of vehicle optimization (usually weight increasing), too.

2. External load

We can divide external load of the propulsion mechanisms of the tracked vehicles into two groups – stress from track lines and stress from vehicle movement on the ground. The 1st group represents difference between wheeled and tracked vehicles. Utilization of the track lines arises additional forces. The 2nd group represents vehicle movement and its vibrations.

- stress from track lines:
  - by track tightening
  - by centrifugal force
  - by propelling force
- stress from vehicle movement on a terrain:
  - by vehicle vibration
  - track vibration

Track tightening F_t

Weight of the track lines affect magnitude of track tightening force. Track tightening is different for each vehicle. Track tightening influences possibility of track falling and magnitude of friction forces between track elements. Decreasing track tightening increases possibility of track falling and decreases friction forces. Optimal tightening of track line depends on character of a terrain.

Expressing magnitude of F_t by track line bend f is advantageous, because track tightening is characterized by track line bend on defined track part (Fig.1). Magnitude of f is possible to measure on standing vehicle.

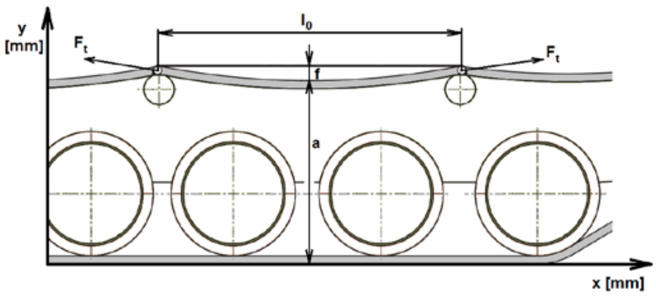

Fig. 1 *Track tightening*

We can mathematically express f by next equation[2]:

$$(1)\quad f = \frac{1}{2} \cdot \frac{x^2}{a} = \frac{1}{8} \cdot \frac{l_0^2}{a}$$

where l_0 is distance between support rolls, x - distance in x axles, a - vertical distance between the bend track element and the ground.

Magnitude of track tightening can by expressed by next formula[2]:

$$(2)\quad F_t = m_{te} \cdot a = \frac{m_{te} \cdot g \cdot l_0^2}{8 \cdot f}$$

where m_{te} is weight of the track element.

Centrifugal force F_c

Track line is during track rewinding loaded by centrifugal forces. These centrifugal forces arise additional load of the track line. Magnitude of this force can be expressed by next formula:

$$(3)\quad F_c = m_{te} \cdot v^2$$

where m_{te} is weight of an track element, v - relative speed of the track.

Propelling force F_p

Part of the track is loaded by propelling force. Length of the loaded part depends on a position of the sprocket wheel. This stress affects load if idler mechanisms, too. Dependency of sprocket wheel position and length of loaded part is shown in the Fig. 2. Magnitude of this load can be expressed by following formula:

$$(4)\quad F_p = \frac{T_{sw}}{r_{sw}}$$

where T_{sw} is sprocket wheel torque, r_{sw} - radius of a sprocket wheel.

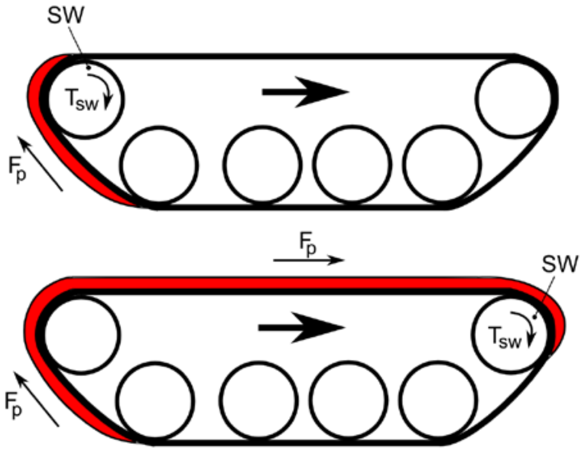

Fig. 2 *Propelling force – up - sprocket wheel in the back, down - sprocket wheel in the front*

Stress from vehicle vibrations F_v

Vehicle vibrations which are produced during vehicle movement over rough ground depends on vehicle speed, terrain geometry surface and dynamic characteristics of suspension system. A good insight into the effect of these characteristics can be gained by considering a simple, single degree of freedom model of a vehicle moving over a surface with a sinusoidal profile (Fig. 3)[1].

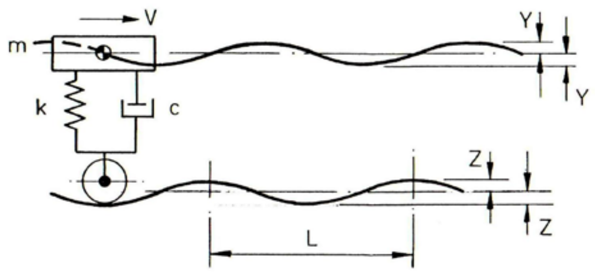

Fig. 3 *Simple, single degree of freedom model of a vehicle moving over a sinusoidal surface[1]*

Vehicle is represented by a mass *m* connected by a linear spring of stiffness *k* and a damper with damping coefficient *c* to a wheel of negligible mass which follows the profile of the surface. If the vehicle is moving with a constant horizontal velocity *v*, the amplitude of its vertical oscillation Y is given by the following solution[1]:

$$(5)\quad \frac{Y}{Z}=\frac{\sqrt{1+4\xi^2\left(\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2+4\xi\left(\frac{\omega}{\omega_n}\right)^2}}$$

where Z is amplitude of sinusoidal surface profile, ω_n - natural frequency of vehicle, ω - forcing frequency, ξ - damping ratio.

Vehicle vibration analysis is a complex process, especially for vehicle movement on the undefined terrain. Vehicle behaviour depends on the suspension system parameters and its interactions. Analysis of vibrations of the track lines is more complicated process because vibrations and movement of the vehicle have an influence on the track line vibrations. The next parameters mainly affect track lines vibration:

- vehicle vibration – defined by suspension system
- vehicle speed
- terrain surface
- kinematics of the track moving mechanism
- type of a track and connectors
- characteristics of road wheels

Basic bonds, parameters and degrees of freedom of the track line are shown in the next picture (Fig. 4).

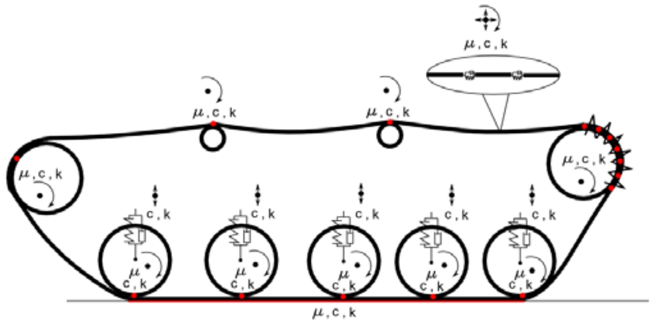

Fig. 4 *Kinematic schema of a track moving mechanism*

Vehicle movement and vibrations and track vibrations affect additional load force. This track force has highly dynamics character. Its magnitude depends on a lot of parameters and it is very difficult to mathematical express their dependency. From this point of view it is very efficient to use mathematic modeling and simulations for their analysis.

Simulating technologies are widely spread in all of spheres of industry. Possibility of complex analysis of stress of defined part of a system is first advantage of this methodology. We can record defined parameters (e.g. position, speed, stress) of defined element during whole process of simulation. Next benefit is that this manner enables not only assessment and evaluation of fixed vehicle configuration, but also enables assessment and evaluation of various vehicle modifications (e.g. chassis, main body, power units, protection systems, etc.) without necessity for real vehicle manufacturing. It is possible to compare different construction ideas in same operational environment and under the same conditions. Simulation of various critical states and behavior of vehicle (e.g. destruction of wheel, main body, etc.) is another benefit.

3. Utilization of simulating technology

I have used Multibody Dynamics (MBD) software ADAMS for creating of mathematic model of a tracked vehicle. This software enables to create complex model with full range of motion and operating environments. Optional modules available with Adams allow users to build and test virtual prototypes that accurately account for the interactions between main subsystems. Along with extensive analysis capabilities, Adams is optimized for large-scale problems, taking advantage of high performance computing environments[3].

I have selected vehicle BMP-2 for application of simulation technology. The BMP-2 is amphibious infantry fighting vehicle introduced in the 1980s in the Soviet Union. Picture of this tracked vehicle is shown in the next picture (Fig. 5).

Fig. 5 *Vehicle BMP-2[4]*

Chassis of BMP-2 consists of 12 road wheels, 2 sprocket wheels, 2 idler mechanism, 6 support rolls, 2 track lines (85 track segments) and suspension system (torsion bars + hydraulic dampers on the 1st, 2nd and 6th road wheels). Sprocket wheel is located in front part of the vehicle.

Basic parameters of the vehicle BMP-2 are[5]:

- length with gun forward 6735 mm
- max. width 3180 mm
- max. height 2450 mm
- combat weight 13900 kg
- max. engine power 221 kW
- max. engine torque 980 Nm
- track lines distance 2550 mm
- track width 300 mm
- length of track surface in touch with ground 3600 mm
- max. speed 65 km/h
- 5 gears forward, 1 gear backward

Mathematic model of BMP-2 was created according to basic parameters and kinematics of BMP-2 chassis. Created model is shown in the next picture (Fig. 6).

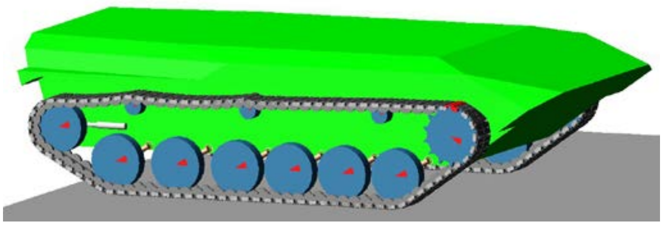

Fig. 6 *Mathematic model of the vehicle BMP-2*

One part of the model is ground. Physical parameters of the terrain meet the requirements of strengthened road → minimal deformations of the road → stress of the main parts of the chassis is maximal on this type of the ground.

For the basic analysis of the stress of main parts of track line were selected 4 types of the surfaces - straight road (Track A) and 3 types of a sinusoidal surface (according to theory) (Track B – D). Comparison of these sinusoidal surfaces is shown in the next picture (Fig. 7).

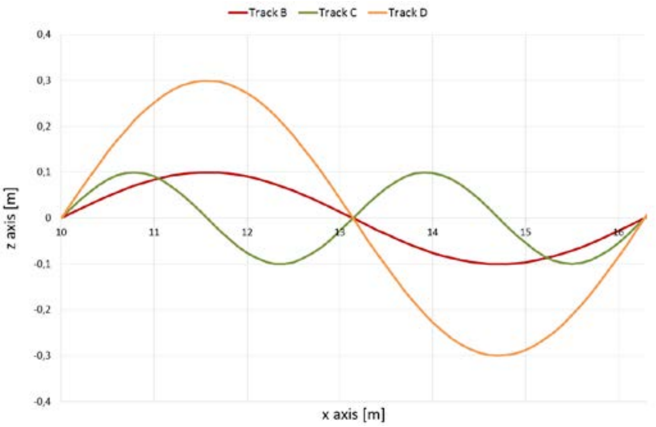

Fig. 7 *Surfaces of track B - D*

Propulsion mechanisms of the model is active → keeps defined vehicle speed by torque change. Maximal magnitude of the torque was counted for each gear (according to gear ratio – Table 1).

Table 1: *Overall gear ratios*[5]

no of gear	1st	2nd	3rd	4th	5th
gear ratio [-]	28,875	15,631	10,516	7,062	4,719

Basic parameters of simulations were set:

- vehicle speed was 20 km/h a 40 km/h for each type of terrain
- vehicle overcame each type of terrain forward and backward – for analysis of influence of position of sprocket wheel into track and idler mechanism stress
- length of the simulations for 20 km/h was 6,5 s
- length of the simulations for 40 km/h was 3,2 s

4. Results

Stress of the idler mechanism and torque of sprocket wheel of the vehicle were selected as basic outcomes of proceeded simulations.

Magnitude of the idler mechanism stress can confirm theory of influence of position of sprocket wheel into overall track stress. There are shown courses of idler mechanism stress in the next graphs (Fig. 8 and 9). Track A – D forward movement, Track A r – D r backward movement.

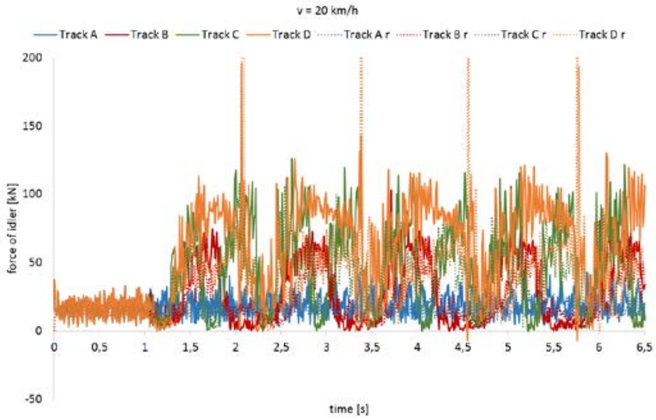

Fig. 8 *Stress of idler mechanism, speed 20 km/h*

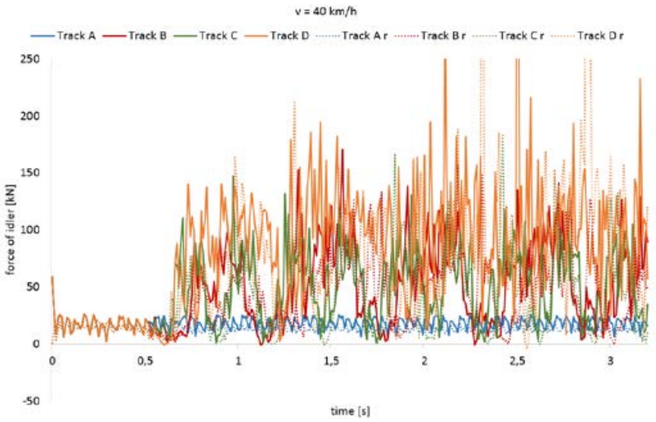

Fig. 9 *Stress of idler mechanism, speed 40 km/h*

From the courses of the force of idler mechanism we can find dependency of force course on the terrain surface. We can find that force of the idler mechanism has highly dynamics character, too. For better comparison of the force courses I have done linear extrapolation of these forces (Fig. 10 and 11).

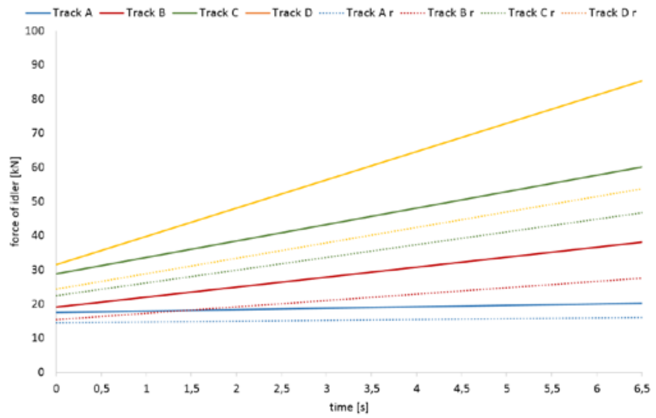

Fig 10 *Linear extrapolation of the idler mechanism stress, speed 20 km/h*

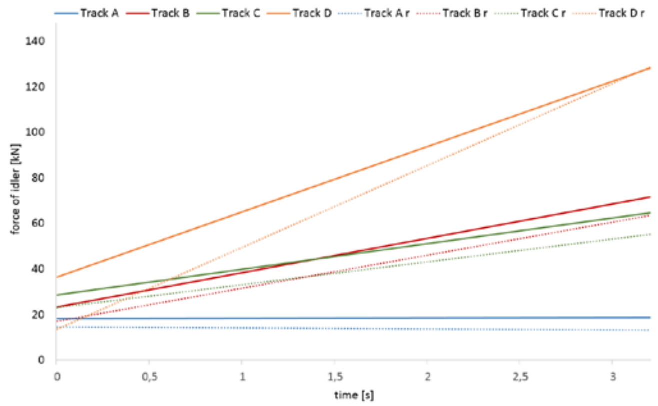

Fig 11 *Linear extrapolation of the idler mechanism stress, speed 40 km/h*

From the graphs (Fig. 10 and 11) it is clear that stress of the idler mechanism with sprocket wheel in front of the vehicle is higher. Proceeded simulations has confirmed the theory.

Torque of the sprocket wheel (transmission) is the next outcome of the simulations (Fig. 12 and 13).

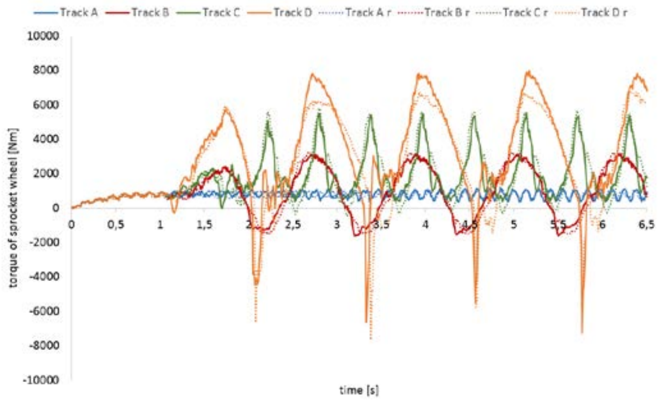

Fig. 12 *Torque of the sprocket wheel, speed 20 km/h*

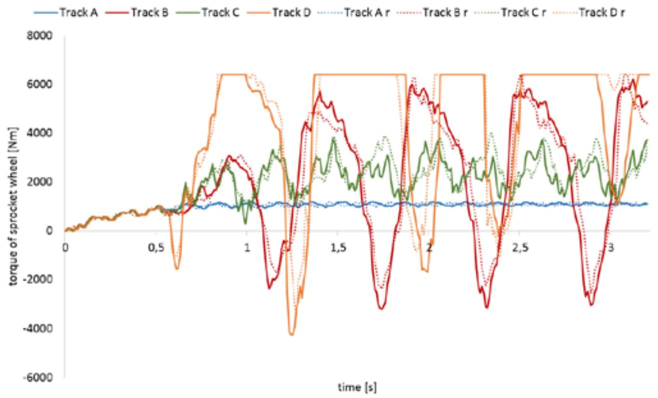

Fig. 13 *Torque of the sprocket wheel, speed 40 km/h*

Simulations confirmed that terrain surface affects stress of the sprocket wheel (track vibrations). We can find changes of the stress magnitude according to the sinusoidal course of the terrain in the graphs (Fig. 12 and 13).

We can find that magnitude of the engine torque on the tracks D and D r got to maximal value. Vehicle speed 40 km/h was too high for overcoming track D and D r and the vehicle was "jumping" on these types of the terrain (Fig. 14).

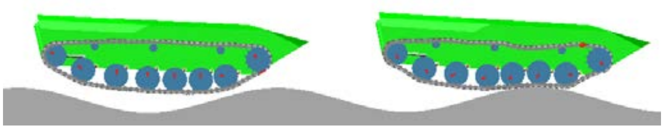

Fig. 14 *Vehicle "jumping", track D, speed 40 km/h*

5. Conclusion

Sprocket wheel of tracked vehicles is loaded by forces arising by track tightening, by centrifugal force, by propelling force and by vibration of track lines. Position of sprocket wheel affects stress from propelling force. Track line vibrations affect vehicle vibrations, vehicle speed, terrain surface, parameters of the chassis, type of a track and connectors and parameters of road wheels. All these stresses highly dynamically load transmission mechanism.

The vehicle consists of a lot of movable parts, attachments and contacts defined by stiffness, damping and friction coefficients. It means that vehicle is complicated mechanism and the analysis of the stress of the main parts of the chassis is a complex process. Simulation technologies are very efficient manner for analysis of this complex system.

I have used Multibody Dynamics software ADAMS of MSC Software for application of simulating technologies. The vehicle BMP-2 was selected for this type of analysis. Mathematic model of BMP-2 was created according to basic parameters and kinematics of BMP-2 chassis.

Model analysis was performed during the model movement on the 4 types of terrain – A – flat; B, C and D – sinusoidal. Sinusoidal courses of terrain were selected for verification of theory of vehicle vibrations influence. Vehicle was moving by speed 20 and 40 km/h, forward and backward.

Proceeded simulations has confirmed the theory that stress of the idler mechanism with sprocket wheel in front of the vehicle is higher than with sprocket wheel in the back of the vehicle. Top branch of the track is loaded by this additional force, too. And this force has highly dynamic character.

Simulations confirmed that changes of the torque of the sprocket wheel depend on the course of the terrain. We can find sinusoidal course of this stress, too. Torque of the sprocket wheel has highly dynamic character.

Speed 40 km/h was inappropriate for terrains D and D r, because the vehicle was "jumping" on these types of the terrain. Engine torque got to maximal value on this terrain by speed 40 km/h.

Simulating technologies are appropriate for vehicle movement analysis and for analysis of the stress of the main parts of the chassis and transmission mechanism.

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