Assessing load on support rollers of the tracked load-transport timber harvesting vehicle through simulated mathematical modeling

V E Klubnichkin¹, G O Kotiev¹ and V S Makarov¹,²

¹Bauman Moscow State Technical University, 2º Baumanskaya str., 5/1, 105005, Moscow, Russia
²Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Minin str., 24, 603950, Nizhny Novgorod, Russia

E-mail: vklubnichkin@gmail.com

Abstract. The article describes a process of simulated mathematical modeling of movement of a tracked load-transport vehicle in the applied software package followed by output of the results of the loads acting on the portside and starboard support rollers during movement at different speeds on flat surfaces, over single 100 to 400 mm obstacles located at a certain distance from each other, on sinusoidal unevenness and along a preset microprofile of the bearing surface. It also describes conditions of the virtual tests conducted.

1. Introduction
At the designing stage it is crucial for the manufacturers and customers to determine the service life of the structural elements of the tracked load-transport timber harvesting vehicles, including the support rollers. With that it is required to maintain the optimum ratio between the initial cost of the support rollers and maintenance and repair expenditures during the entire service life. Timber harvesting vehicles operate in hard climate-production conditions. During their operation they regularly meet variable obstacles like stumps, stones, fallen trees, pits etc. which in their turn negatively affect the life of the support rollers [1].

The movement dynamic of a tracked load-transport vehicle (LTV) has been modelled in the “Universal mechanism” package in accordance with the program and research method [2] and is based on the system of tests including equilibrium test, initial speed calculation, linear movement at different speeds on a flat surface, over single obstacles from 100 to 400 mm high, on sinusoidal unevenness and along a present microprofile of the skid roads [3 – 9].

To start modeling of the LTV movement it is necessary to conduct auxiliary tests including equilibrium tests and initial speed calculation. The aim of the auxiliary tests is to determine initial state of the LTV with due consideration for all forces acting on it in a static state. Then the main tests (rectilinear movement) are carried out which allow for calculation of the dynamic indicators of the LTV undercarriage during movement on the bearing surface unevenness [10, 11].

To carry out the tests an LTV simulated model was generated comprising a vehicle frame with installed process equipment, undercarriage, cabin, power plant, etc. [12, 13]. All model components were manufactured in accordance with the real geometrical and physical parameters of timber harvesting vehicle LZ-11.
2. Conditions of Virtual Tests
An equilibrium test was conducted to determine position of a static equilibrium to verify a model against the experimental data. Figure 1 shows a simulated model of LTV before a test and after a test.

During the test loads were determined which are applied to the starboard and portside support rollers of the LTV, from the side of the bearing surface with due consideration for a mass of the loaded vehicle, as well as the tracks which interact with the upper side of the support rollers at the beginning of modelling that leads to the track strike against the rollers. The analysis of the modelling processes demonstrates that it takes 3 s for the intensive transition processes in the LTV simulated model to pass and a model takes a state of equilibrium. The tests are interrupted when values become stable. During this test the highest load was noted at the beginning of the modeling process and was applied to the third support roller on the starboard and portside as the vehicle faces forward. The maximum peak load on a roller stood at 61 KN. By the end of the test when an LTV reached a state of complete equilibrium the total load applied to all portside support rollers was 138 KN, and 144 KN to all starboard support rollers.

The second test was a rectilinear movement on hard bearing surface. This test is among the main ones and allows for assessment of the LTV running gear dynamic. The LTV rectilinear movement is simulated in accordance with the given profile of the driving sprocket speed which is a relation between speed and time or passed way with due consideration for the preset profiles (unevenness) of the left and right track.

The tests to determine loads applied to the LTV support rollers were carried out in the following conditions (cases):
Case 1. LTV driving sprocket speed: \( V = 3 \) m/s. Surface profile characteristics: flat surface. Mass of transported assortment - 12 t.
Cases 2 and 3. LTV driving sprocket speed: \( V = 1 \) m/s; \( V = 2 \) m/s. Surface profile characteristics: single 100, 200, 300 and 400 mm obstacles located at an interval of 8 m. Assortment mass of 12 t.
Cases 4 5. LTV driving sprocket speed: \( V = 1 \) m/s; \( V = 2 \) m/s. Surface profile characteristics: sinusoidal unevenesses with the following parameters: \( A = 200 \) mm, \( L = 8 \) m, \( x0 = 2 \) m. Assortment mass - 12 t.
Cases 6 and 7. LTV driving sprocket speed: \( V = 1 \) m/s; \( V = 2 \) m/s. Surface profile characteristics: path profile unevenness for the starboard and portside tracks obtained during measurement of microprofile of the skid road in Murashinsky forestry of Kirovsk oblast [14]. Assortment mass of 12 t.

3. Results of Virtual Tests
The first case modeling results found that maximum loads on the support rollers were up to 40 KN.
during the LTV movement on a flat surface and were applied to the sixth starboard and portside rollers as the vehicle faces forward. Minor sudden variations of the support rollers’ load were caused by interaction of the roller with a track which design includes an open hinge \[15, 16\].

In the second case the speed of the LTV driving sprockets was \( V = 1 \, \text{m/s} \). The surface profile featured single 100, 200, 300 and 400 mm obstacles located at a distance of 8 meters. Assortment mass was 12 t.

During its operation the timber harvesting vehicle meets variable single obstacles like stumps, fallen trees, pits etc. that is why it is important to research load on the support rollers during movement over single obstacles. Conducted were experimental researches of the LTV movement over single obstacles to generate a respective loading mode \[17 – 20\].

The second case modeling results have found that during the LTV movement at a driving sprocket speed of \( V = 1 \, \text{m/s} \), over single obstacles of variable height and located every 8 meters, the loads applied to individual support rollers were up to 48 KN with a vehicle moving over a 100-mm obstacle, up to 60 KN with a vehicle moving over a 200-mm obstacle, up to 123 KN with a vehicle moving over a 300-mm obstacle and up to 132 KN with a vehicle moving over a 400-mm obstacle. The maximum loads occurred in the second carriage and were applied both to the starboard and portside 3\textsuperscript{rd} support rollers as the transport-load vehicle faces forward. Figure 2 shows a fragment case when a load-transport vehicle is overcoming single obstacles simulating a fallen tree.

![Figure 2. A fragment case of an LTV simulation model overcoming single obstacles](image)

In the third case during an LTV movement at a driving sprocket speed of \( V = 2 \, \text{m/s} \), the loads applied to individual rollers were up 52 KN with a vehicle moving over a single 100-mm obstacle, up to 94 KN with a vehicle moving over a single 200-mm obstacle, up to 132 KN with a vehicle moving over a 300-mm single obstacle and up to 160 KN with a vehicle moving over a single 400-mm obstacle, however peak loads up to 232 KN were applied to the front support rollers of the first carriage which briefly occurred during the rollers’ interaction with a 400-mm obstacle which is unlikely during movement at such a high speed. In a real-life operation an operator slows down a vehicle during movement over such a high obstacle.

Fourth case. The LTV driving sprocket speed was \( V = 1 \, \text{m/s} \). Surface profile characteristics: sinusoidal unevenness with the following parameters: amplitude \( A = 200 \, \text{mm} \), wave length \( L = 8 \, \text{m} \),
phase displacement for the portside track $x_0 = 2$ m. Assortment mass of 12 t. In this case the maximum loads applied to the support rollers reaches maximum values of 110 KN.

Fifth case. LTV driving sprocket speed $V = 2$ m/s. Surface profile characteristics: sinusoidal unevenness with the following parameters: $A=200$ mm, $L=8$ m, $x_0=2$ m. Assortment mass of 12 t. The loads applied to the support rollers under such conditions reached 122 KN.

Sixth case. LTV driving sprocket speed $V = 1$ m/s. Surface profile characteristics: unevenness of the path profile for the portside and starboard tracks obtained during measurement of the microprofile [21 – 24]. Assortment mass of 12 t.

The virtual tests used data obtained during measurement of the skid road microprofile presented in the work [14]. Figure 3 shows fragment characteristics of the path unevenness for the portside and starboard tracks.

![Figure 3](image)

**Figure 3.** A fragment of the path unevenness for the portside and starboard track. Red for the portside track; blue for the starboard track.

The sixth case modeling results have demonstrated that when an LTV moves along a microprofile, the maximum loads applied to the support rollers reach 106 KN.

The seventh case modeling results have found that the maximum loads applied to the support rollers during movement along a preset microprofile are single and reach 152 KN.

4. Conclusion

Two directions were employed in this research to justify experimental estimated data. The first one was based on that a real profile of a cutting area was composed of single unevennesses that is why the LTV undercarriage was designed by examining an LTV movement over single unevennesses. The second direction was based on experimental data and results of theoretical research demonstrating usefulness of using a path microprofile and harmonic shape path to design the LTV undercarriage.

It has been found that during the LTV steady movement along a periodic, close to harmonic path profile, the body angular oscillations are practically harmonic by their shape even in case of the undercarriage “breakthrough” causing acceleration of up to (4-5) g at the operator’s workplace.

It has been found that the resonance characteristics of the LTV body oscillations are by their shape not corresponding to the nature of nonlinearity of characteristics of the elastic element in the undercarriage (track tension device).
It has been found that the LTV undercarriage may be considered as close to linear in practical estimates even during movement in the modes accompanied by hard strokes of the undercarriage beams against the restraints (frame).

The fundamental advantage of the conducted research of the LTV support rollers’ loading is that it allows for a number of important practical general recommendations relevant not just for this LTV but the entire class of the vehicles featuring certain common properties.

It has been found that the 3rd and 6th support rollers of the vehicle undercarriage experience loads 1.5 times the loads applied to the rest rollers of the LTV undercarriage when the LTV is moving over the path microprofile unevenness and overcoming single 200, 300 and 400 mm obstacles.

References
[1] Klubnichkin E E, Klubnichkin V E 2015 Service life of track rollers of tracked forestry machines Polytthematic network electronic scientific journal of the Kuban State Agrarian University 112 1016-1026
[2] Klubnichkin VE, Klubnichkin EE, Kondratyuk DV, Beketov SA 2017 Program and methodology for experimental studies of a loading and transport machine in the applied software package Forestry journal T 7 No. 4 (28) 175-182
[3] Klubnichkin E, Klubnichkin V 2017 Theoretical foundations of preliminary assessment of the impact of the timber harvesting vehicles on forest soils in the course of logging. Proceedings of the 19th International & 14th European-African Regional Conference of the ISTVS
[4] Klubnichkin V, Klubnichkin E, Kotiev G 2017 Developing a method of theoretical evaluation of the tracked timber harvesting machine undercarriage element loading. Proceedings of the 19th International & 14th European-African Regional Conference of the ISTVS
[5] Cambi M, Certini G, Neri F, Marchi E 2015 The impact of heavy traffic on forest soils. Forest Ecology and Management 338 124-138
[6] Horn R, Vossbrink J, Peth S, Becker S 2007 Impact of modern forest vehicles on soil physical properties. Forest Ecology and Management 248 (1–2) 56-63
[7] Kotiev G, Padalkin B, Kartashov A, Dyakov A 2017 Designs and development of Russian scientific schools in the field of cross-country ground vehicles building. ARPN Journal of Engineering and Applied Sciences 12 (4) 1064-1071
[8] Rakhjea S, Afonso M, Sankar S 1992 Dynamic analysis of tracked vehicles with trailing arm suspension and assessment of ride vibrations International J. of Vehicle Design 13 (1)
[9] Bekker M G 1969 Introduction to Terrain-Vehicle Systems (Ann Arbor: The University of Michigan Press)
[10] Pogorelov D J 2005 Computer simulation of the dynamics of technical systems using the software package "Universal mechanism". J. of Computer and Information Technologies 4 27-34
[11] Bodin A 1999 Development of a tracked vehicle to study the influence of vehicle parameters on tractive performance in soft terrain J. Terramechanics 36 (3) 167-181
[12] Dhir A, Sankar S 1994 Analytical track models for ride dynamic simulation of tracked vehicles J. Terramechanics 31 (2) 107-138
[13] Dmitriev A A, Savochkin V A 1993 Statistical dynamics of transport and traction tracked vehicles (Moscow Mashinostroenie)
[14] Klubnichkin V E 2012 Improvement of design models of loading of transmissions of tracked logging machines depending on external traffic conditions diss. Cand. tech. Sci. Moscow State Forest University
[15] Goberman L A, Goberman V A, Ksenevich I P 2003 Ground trailer transport systems Technical and economic bases of designing machines and processes Methodological aspects of project activities and decision making 3 Moscow Encyclopedia
[16] Kochnev A M, Anisimov G M 2008 Tests of harvesting machines St Petersbourg State Forest Technical University
[17] Said Al-Milli, Lakmal D, Kaspar Althoefer 2010 Track–terrain modelling and traversability prediction for tracked vehicles on soft terrain *J. Terramechanics* **47** (3) 151-160

[18] Wong J Y 2001 *Theory of Ground Vehicles* 3 (NY: John Wiley & Sons) ISBN 0-471-35461-9

[19] Wong J Y 2009 *Terramechanics and Off-Road Vehicle Engineering* 2 488

[20] Klubnichkin V E, Klubnichkin E E, Kotiev G O, Beketov S A, Makarov V S 2018 Interaction between elements of the track ground contacting area with the soil at curvilinear motion of the timber harvesting machine *IOP Conference Series: Materials Science and Engineering* **386** 012016

[21] Kotiev G, Sarach E, Beketov S 2018 Methods for road microprofile statistical data transformation *MATEC Web of Conferences* **224** 02096

[22] Klubnichkin E E, Klubnichkin V E, Kotiev G O 2018 Theoretical research of soil packing by timber harvester running gear *IOP Conference Series: Materials Science and Engineering* **386** 012025

[23] Alyabiev A F, Kотов A A, Klubnichkin V E, Klubnichkin E E, Bykovskiy M A 2019 Experimental determination of soil shear force by track model depending on track surface to soil friction coefficient *IOP Conf. Series: Journal of Physics: Conf. Series* **1177** 012033

[24] Klubnichkin V et al. 2019 Researching rolling resistance of the wheeled forestry tractor at skidding *IOP Conference Series: Materials Science and Engineering* **695**(1) 012003 doi: 10.1088/1757-899X/695/1/012003

[25] Makarov V S et al. 2019 Study of uneven surfaces distribution on forestry roads *Journal of Physics: Conference Series* **1177**(1) 012041 doi: 10.1088/1742-6596/1177/1/012041