Evaluation of small-sized skidders performance

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Abstract. The aim of the work is to further develop theoretical description of interaction between small-sized forestry vehicles and soils, to study productivity and indicators of interaction of wheeled and tracked vehicles with weaker forest soils. According to the calculation results it was established that the LMT-3 wheeled skidder when working on weakly-bearing soils is able to provide productivity when skidding trunks within 43 m$^3$ per shift, with the trunks to be skidded for the tops. Productivity of small-sized tracked vehicle LMT-6 is slightly lower and makes up to 39 m$^3$ per shift when trunks are skidded for the tops. For both tractor models, the productivity of skidding is reduced by approximately 5 m$^3$ per shift when the trunks are to be skidded for the bottoms.

1. Introduction
When working on low-bearing soils, small-sized skidding tractors with wheeled and tracked mover are used for skidding. The weight of such machines is approximately 4-6 tons, the volume of skidded timber packs does not exceed 2 m$^3$. Geometric parameters of the mover and the ratio of sides of the contact patch with the ground in such machines differ from the heavier equipment, which used to be considered in research on cross-country ability and rutting of forest machines [1-5]. Among the modern studies related to determination of tractive performance of small-sized forestry machines, note the work [6]. In [6] there have been developed mathematical models predicting the rut depth and tractive performance of a small-sized wheeled vehicle working in conditions of a swampy ground, the interaction of the propulsor with turf cover lying on a deformable base of unlimited thickness has been considered.

The purpose of our study is the further development of the theoretical description of the interaction of small-sized forestry vehicles with soil, the study of productivity and tractive performance of wheeled and tracked vehicles with weaker forest soils.

2. Results and Discussion
Let us consider tractive performance of two small-sized tractors - universal tracked skidder LMT-6 and universal wheeled skidder LMT-3.

Universal small-size skidder LMT-6 is designed for skidding trees, trunks and assortments. LMT-6 tractor is operated on low-bearing capacity soils during forest harvesting, development of clearings during construction of roads, communication lines and power lines, oil and gas pipelines, cleaning of territories from bushes, during forest park operations [7]. Technical characteristics of the tractor are presented in Table 1. Universal small-sized wheeled skidder LMT-6 is designed for skidding trees and trunks during forest harvesting, development of clearings during the construction of roads,
communication lines and power lines, oil and gas pipelines, cleaning up areas from forest vegetation, in conditions of man-made pollution of forests and in areas of natural disasters [7].

Table 1. Technical characteristics of the universal small-sized tracked skidder LMT-6 and wheeled skidder LMT-3 [7].

| Parameter                        | LMT-6       | LMT-3       |
|----------------------------------|-------------|-------------|
| Engine power, kW (HP)            | 18.7 (25)   | 18.7 (25)   |
| Speed of movement, km/h          | up to 9.0   | up to 25.0  |
| The pulling force of the winch, kN | 16          | 20          |
| Operating weight, kg             | 2 610       | 3 400       |
| Overall dimensions, mm           |             |             |
| - length                         | 3 100       | 5 450       |
| - width                          | 1 925       | 2 215       |
| - height                         | 2 350       | 2 350       |

To calculate the tractive performance of the tractors, first it is necessary to determine the depth of the rut \( h \), formed when the tractor passes through the forest soil, for this purpose we use following equation, obtained on the basis of [5, 8-10]:

\[
h = \frac{JpaBp_s}{(p_s - p)(E(E - Jp))^0.5} \arctan \left( \frac{E(H - h)}{aB(E(E - Jp))^{0.5}} \right),
\]

(1)

where \( J \) is a parameter that takes into account the ratio between the length and width of the tractor mover's contact with the ground, \( a \) is a parameter that takes into account the thickness of the soft soil layer, \( H \) is the thickness of the soft soil layer, \( B \) is the width of the tractor mover, \( p \) is the pressure of the tractor mover on the ground (average), \( E \) is the general deformation module of the ground, \( p_s \) is the bearing capacity of the ground.

Parameters \( J, a \) we will find by formulas [5, 8-10]:

\[
J = \frac{0.03 + LB^{-1}}{0.6 + 0.43LB^{-1}},
\]

(2)

\[
a = 0.64 \frac{B + H}{H},
\]

(3)

where, \( L \) is the length of the contact patch.

For wheeled tractor [4]:

\[
L = \frac{d}{2},
\]

(4)

where, \( d \) is the diameter of the wheel.

For a tracked tractor the length of the contact spot is approximately equal to the length of the track's supporting surface.

The bearing capacity of the soil is calculated using the formulas [1, 10]:
where $p_{s0}$ is the bearing capacity of the ground at the unlimited thickness of the soft layer, $\alpha_s$ is the coefficient of the soft layer of the ground, $K_1$, $K_3$ are the coefficients of the ratio of the length and width of the contact spot of the mover with the ground, $N_1$, $N_2$, $N_3$ are the coefficients of the internal friction angle of the ground, $C$ is the specific adhesion of the ground, $\gamma$ is the specific weight of the ground, $S$, $H^*$ are auxiliary designations.

Force of soil resistance to tractor movement is calculated according to the formula [9, 10]:

$$ F_r = B \int_0^h p dh. \quad (6) $$

The mover's adhesion force to the ground is based on the formula [9]:

$$ F_r = \frac{B G^2 L (p \tan \varphi + C)}{(G - C)^3} - S \cdot \frac{B C G L^2}{2 t_g (G - C)} - \frac{1}{S} \cdot \frac{(p \tan \varphi + C)^3 B G^2 t_g}{(G - C)^3} \cdot \ln \left(1 + S \frac{L (G - C)}{t_g (p \tan \varphi + C)}\right) \quad (7) $$

where $S$ is the slipping ratio, $t_g$ is the grouser spacing.

Let us calculate the coefficient of resistance to tractor movement by the formula [9, 10]:

$$ \varphi_r = \frac{F_r}{BL}. \quad (8) $$

Find the tractor's coupling factor with the ground using the formula [9, 10]:

$$ \mu = \frac{F_r}{BL}, \quad (9) $$

and in determining $F_r$, the slipping ratio $S$ is a variable.

At calculation the following characteristics of weakly bearing soil [11, 12] are accepted: the module of general deformation $E = 0.4$ MPa, specific adhesion of soil $C = 0.005$ MPa, angle of internal friction of soil $\varphi = 12^\circ$, specific weight of soil $\gamma = 0.0075$ MN/m$^3$, thickness of soft layer $H = 0.73$ m, the module of shift $G = 0.22$ MPa. The parameters of the mover are as follows: wheel width or track width of small tractor $B = 0.3$ m, track support length $L = 3$ m, wheel diameter $d = 1.2$ m. Maximum ground pressure of the mover was limited to $p_{max} = 0.045$ MPa.

The procedure for calculation is as follows. The program Maple 2017 has been used to solve the problem. When the initial data are received, the pressure range is set into intervals with the specified step (0.0045 MPa). At each value of pressure $p$ the system of equations (1) - (4) is numerically solved (command $fsolve$). As a result we get the table of correspondence of pressure $p$ and track depth $h$. According to the table, using the trapezium method, we find an approximate value of the integral by
formula (6), then we calculate the resistance coefficient $\varphi_r$ by formula (8). Then, for each value of $p$, we determine the maximum function (7) by means of the Maximize command of the package of built-in commands Optimization and the corresponding slipping factor value $S$. We find the coefficient of adhesion by the formula (9).

The results of the calculation of the traction and coupling properties of tractors are shown in figures 1 and 2 and in table 2.

![Figure 1](image1.png)

**Figure 1.** Rutting and tractive performance of small-sized wheeled skidder.

![Figure 2](image2.png)

**Figure 2.** Rutting and tractive performance of small-sized tracked skidder:
1 – rut depth; 2 – rolling resistance coefficient; 3 – net thrust coefficient; 4 – slip ratio.

Basing on tables 1,2 at the accepted initial data we shall establish, that average pressure of a small-size tracked tractor LMT-6 on a ground makes $p = 0.015$ MPa, small-size wheeled tractor LMT-3
makes \( p = 0.02 \) MPa. The numerical results of calculation of tractive performance for two considered models of tractors are summarized in Table 2.

**Table 2.** Traction-coupling properties of small-size tractors LMT-3 and LMT-6 at work on weaker forest soil.

| Tractor model | Rut depth \( h \), m | Rolling resistance coeff. \( \phi_r \) | Net thrust coeff. \( \mu \) | Slip ratio \( S \) |
|---------------|------------------------|-----------------------------------|-----------------|-------------|
| LMT-3         | 0.046                  | 0.047                             | 0.316           | 0.127       |
| LMT-6         | 0.045                  | 0.009                             | 0.376           | 0.023       |

The results of calculating the productivity of LMT-3 and LMT-6 skidders are presented in Table 3 (the method is described in detail in [13], the initial data concerning tractors are presented in Tables 1-2).

**Table 3.** Results of calculating the productivity of LMT-3 and LMT-6 skidders.

| Parameter                                      | Dimension | LMT-3 | LMT-6 | LMT-3 | LMT-6 |
|------------------------------------------------|-----------|-------|-------|-------|-------|
| Tractor speed at II gear                       | m/sec     | 1.48  | 1.48  | 1.48  | 1.48  |
| Tractor speed at III gear                      | m/sec     | 1.87  | 1.87  | 1.87  | 1.87  |
| Permissible load on the cone                   | kN        | 9     | 9     | 7     | 7     |
| Towing force of the winch                      | kN        | 20    | 21    | 16    | 16    |
| Skidding method                                | by the   |       |       |       |       |
|                                               | tops      |       |       |       |       |
|                                               | bottoms   |       |       |       |       |
| Weight distribution coefficient of the        |           |       |       |       |       |
| skinned pack between the tractor and the      |           | 0.41  | 0.73  | 0.41  | 0.73  |
| ground                                        |           |       |       |       |       |
| Average skidding distance                      | m         | 250   | 250   | 250   | 250   |
| Number of hours per shift                      |           | 8     | 8     | 8     | 8     |
| Average picking rope feed distance             | m         | 20    | 20    | 20    | 20    |
| Average trunk volume                           | m\(^3\)   | 0.15  | 0.15  | 0.15  | 0.15  |
| Total weight, limited by the tractive force.   | kN        | 25.70 | 48.84 | 28.89 | 60.26 |
| Total weight, limited by the grip              | kN        | 24.21 | 48.84 | 28.89 | 60.26 |
| Total weight, limited by the load capacity     | kN        | 21.72 | 12.40 | 16.89 | 9.64  |
| Total weight, limited by the pulling force of  | kN        | 20.92 | 21.96 | 16.73 | 16.73 |
| the winch                                      |           |       |       |       |       |
| Calculated pack weight                         | kN        | 20.92 | 12.40 | 16.73 | 9.64  |
| Weighted average wood density                  | kg/m\(^3\)| 859.00| 859.00| 859.00| 859.00|
| Volume of wood in skidded bundle               | m\(^3\)   | 1.70  | 1.01  | 1.36  | 0.79  |
| Tractor average speed                          | m/sec     | 1.68  | 1.68  | 1.68  | 1.68  |
| Driving time in the workplace and at idling    | sec       | 149.25| 149.25| 149.25| 149.25|
| speed e.g.                                     |           |       |       |       |       |
| Bundle forming time                            | sec       | 590.97| 438.24| 515.98| 388.85|
| Bundle bounce time                             | sec       | 128.04| 90.55 | 109.63| 78.43 |
| Bundle skidding cycle time                     | sec       | 868.27| 678.04| 774.86| 616.54|
| Hourly skidding performance                    | m\(^3\)/hour | 6.01 | 4.56  | 5.38  | 3.90  |
| Skidding performance per shift                 | m\(^3\)/shift | 43.25| 32.82 | 38.77 | 28.08 |
3. Conclusion

According to the calculation results it has been established that the LMT-3 wheeled skidder is able to provide the productivity with the stems skidding within 43 m³ per shift while the stems should be skidded for the tops. Productivity of a crawler small-sized tractor is slightly lower and makes 39 m³ per shift when whips are skidded behind the tops. For both tractor models, the capacity per lump of skidding is reduced by approximately 5 m³ per shift.

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