The forecast of forestry tractor speed with mechanical transmission

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Abstract. One of the most energy-intensive logging processes is skidding of trees. The correct choice of engine and transmission system parameters significantly affects the efficiency of forest machine use. The article suggests the method of determining the optimal range for mechanical transmission of skidders, which are widely used in skidding of log the logging area to the upper warehouse. This technique allows considering properties of fiber (rolling resistance, drag part of the forest pack and the slope of the fiber), truckload and parameters of the motor installation. It should be also noted that the coefficient of adaptability of the diesel engine (the coefficient of engine torque loading) and the engine loaded at crankshaft speed are taken into account. Results of experimental researches that have shown good convergence with theoretical calculations are presented.

1. Introduction
Currently about 40% of the world's timber is logged using whole tree technology, and these operations are mainly carried out with the use of machines with a classic mechanical transmission. These transmissions have a number of advantages over hydrodynamic and hydrostatic. They are easy to maintain and operate especially at low temperatures, do not require expensive synthetic hydraulic fluids, they have higher efficiency (no double conversion of energy), and therefore lower fuel consumption.

It should also be noted that there are conditions at the logging site where it is not feasible, and sometimes even impossible, to use modern logging complexes with hydrostatic transmissions. Classic skidder tractors for forestry, reforestation and firefighting operations are indispensable in the forest.

Therefore, increasing the efficiency of the forestry tractor with mechanical transmissions is a task of current interest.

The aim of the research is to increase the traction and velocity properties of the skidder and to reduce the energy consumption of the skidder process by determining the optimal parameters of the engine and transmission unit.

2. Methods and Materials
The proposed method allows to evaluate the parameters of powerpack unit at the design stage. The formula (10) shows that the accuracy of the results is influenced by the engine torque factor (\(K_{lo}\)), which in its turn is significantly influenced by the adaptability coefficient of the diesel engine torque (\(K_{lo}\)) [1, 2]. This is very important due to the increased use of Common Rail diesel engines, which have increased torque reserves.
The results of the study can also be used in the development of test programs and the calculation of the strength of components.

3. Results and Discussion

One of the main criteria for evaluating the efficiency of work is the transport capacity of the skidder system consisting of a skidder and a trawl bundle of wood. This criterion essentially depends on the time of $T_i$ operation of the system at the $i$ front and on the number of switching operations.

Each gear ratio $i$ determines the lower and upper limits of the velocities used at $\mathbf{U}_i^{\text{min}}$ and at $\mathbf{U}_i^{\text{max}}$. The velocity of $\mathbf{U}_i^{\text{max}}$ is determined by the operation of the engine on the velocity characteristic regulator branch and $\mathbf{U}_i^{\text{min}}$ by the crankshaft velocity $n_{\text{en}}$ corresponding to the maximum engine torque.

Time $T_i$ of tractor operation at $i$ gear is determined by the formula:

$$T_i = T \int_{\mathbf{v}_i^{\text{min}}}^{\mathbf{v}_i^{\text{max}}} f_v(v) dv,$$

where, the $T$ – full time skidding, $f_v(v)$ – the density of the random velocity distribution of the tractor $V$.

When skidding, the skidding velocity of the skidding system $V$ is a function of the skidding resistance coefficient ($f_x$), the skidding slope ($\alpha$) and the radius $R$. These values of the trail properties can be considered as random values determined by the movement of the tractor and the slip of the packs ($X_1$), the slope of the trail ($X_2$) and the slew resistance of ($X_3$), and besides

$$X_k = A_kV^{-1} + B_k$$

where, the coefficients $A_k$ and $B_k$ ($k = 1, 2, 3$) are determined by the parameters of the engine and the skidding system [3-7].

In the given work, the technique of direct determination of density $f_v(v)$ is offered that simplifies calculation of time $T_i$ of system work on separate transfers.

At the same time, no special assumptions are made regarding the type of distribution of resistance forces $X_k$, which is quite important, since the laws of distribution $X_2$ and $X_3$ significantly differ from normal. The developed scheme is based on the possibility to rearrange the operations of addition of independent random values of one dimension and calculation of their distribution densities.

Suppose there is a functional dependence of $Y = t(X)$ between random variables $X$ and $Y$. The distribution densities $f_x(x)$ and $f_y(y)$ of these random variables are related by the ratio [6, 7]

$$f_y(y) = \int_{-\infty}^{+\infty} f_x(x) \delta[y - t(x)] dx,$$

where, $\delta$ is a Dirac function belonging to many broad functions.

If $t(x)$ has no multiple roots, the generalized function $[y - t(x)]$ can be represented as a linear combination of broad functions $\delta(x - x_m)$ [5]:

$$\delta(y - \varphi(x)) = \sum_{m} |\tau'_m(y)| \delta[x - \tau_m(y)],$$

here, $\tau_m(y) = x_m$, where $x_m$ form a set of equation solutions

$$y = t(x)$$

Therefore, the non-negative number $m$ depends on $y$, i.e. $m = m(y)$. Let us denote by $\Phi$ set of all $t(x)$ values at $-\infty < x < +\infty$. If $y \notin \Phi$, then $m(y) = 0$, equation (5) has no solution and sum (4)
turns to zero. We will further assume that (5) is a monotone function. Then there is an inverse function with respect to (5) \( x = \tau(y) \) defined for all as \( y \in \Phi \). Hence \( m(y) = 0 \) if \( y \in \Phi \) and \( m(y) = 1 \) if \( y \notin \Phi \) and according to (4) we have:

\[
\delta(y - t(x)) = \begin{cases} 
0 & \text{if } y \notin \Phi; \\
|\tau'(y)| \delta[x - \tau(y)] & \text{if } y \in \Phi. 
\end{cases} 
\] (6)

By virtue of (3) and (6) we find:

\[
f_Y(y) = \begin{cases} 
0 & \text{if } y \notin \Phi; \\
|\tau'(y)| f_X(\tau(y)) & \text{if } y \in \Phi. 
\end{cases} 
\] (7)

Formula (7) allows to pass from the distribution density \( f_X(x) \) of a random variable \( X \) to the distribution density \( f_Y(y) \) of random variable \( Y = t(X) \) if the function \( \tau(y) \) inverse to the monotonic function (5) is known.

If \( f_Y(x) \) is the density of the generalized law of distribution of the properties of the skidding wire corresponding to a random value:

\[
\psi = f_c + i + f_t,
\] (8)
where \( f_c, i \) and \( f_t \) are dimensionless analogues of resistance forces \( X_1, X_2 \) and \( X_3 \) then according to (2) we obtain:

\[
\psi = AV^{-1}(A + A_1 + A_2 + A_3),
\] (9)

because \( B_1 + B_2 + B_3 = 0 \). Coefficient \( A \) is found by the formula [6, 7]

\[
A = 0.377M_{en}K_{lo}^i\eta_{ir}\eta_{en}K_n^i(G + Q)^{-1},
\] (10)

where, \( M_{en} \) is the motor torque at rated crankshaft speed; \( K_{lo}^i \) is an coefficient of the engine torque load; \( \eta_{ir} \) is a transmission efficiency; \( \eta_{en} \) is a nominal engine speed; \( K_n^i \) - speed utilization factor at \( i \)-th gear; \( G \) is a tractor weight; \( Q \) is a weight of the forest pack.

According to (7) by replacing (9) the following formula is obtained

\[
f_Y(v) = \begin{cases} 
0 & \text{if } v \leq 0; \\
(Av^{-1} f_Y(Av^{-1})) & \text{if } v > 0.
\end{cases} 
\] (11)

May \( MX_k = \alpha_k \) (mathematical expectations); \( DX_k = \sigma_k^2 \) (dispersion) and \( \alpha_k \) (asymmetry coefficients) are parameters of the random components \( X_k \). In real situations, the asymmetry coefficient \( \alpha_1 \) is statically insignificant and therefore we will assume \( \alpha_1 = 0 \). Using the transition formulas (11) we can show that the distribution density \( f_Y(v) \) is set in the form:

\[
f_Y(v) = \frac{A}{\sigma v^2} \exp \left( -\frac{v^2}{\sigma} \right) \left[ 1 + \frac{\alpha}{6} H_3(t) + \frac{\beta}{720} H_6(t) \right];
\] (12)

where,

\[
H_3(t) = t^3 - 3t; \quad H_6(t) = t^6 - 15t^4 + 45t^2 - 15
\] (13)

- Chebyshev-Ermita polynomials [8, 9].

Bcisults and discussion concrete calculations will be carried out with reference to the tractor TLT-100M with rated power of the engine \( N_{en} = 72 \text{kW} \). Let us consider two variants of the travel loads \( Q = 5.0 \text{m}^3 \) and \( Q = 6.5 \text{m}^3 \) at different values of the adaptability coefficient of the diesel engine \( K_{lo} \). For characteristic operating conditions of tractors OTZ in the region of Karelia these loads correspond to the total factors of resistance to movement \( \psi_1 = 0.221, \psi_2 = 0.230 \) and average square deviation \( \sigma_1 = 0.032, \sigma_2 = 0.034 \).
Table 1. Use of tractor transmission time TLT-100M.

| Q, m³ | Transmission number | \( \nu_i^{\text{min}} - \nu_i^{\text{max}} \), km/h | T,T⁻¹, % | \( K_{lo} = 1.15 \) | \( K_{lo} = 1.30 \) | \( K_{lo} = 1.40 \) | \( K_{lo} = 1.50 \) |
|-------|---------------------|---------------------------------------------|--------|-------------|-------------|-------------|-------------|
|       |                     |                                             |        | 5.0         | 6.5         |
|       |                     |                                             |        |             |             |             |
|       | I                   | 2.88                                        | 1.98–2.71 | 2.27        | 2.47–3.39  | 2.47–3.39  | 2.47–3.39  | 2.47–3.39  |
|       | II                  | 2.14                                        | 2.66–3.65 | 1.57        | 3.57–4.89  | 3.57–4.89  | 3.57–4.89  | 3.57–4.89  |
|       | III                 | 1.64                                        | 3.47–4.76 | 1.03        | 5.44–7.46  | 5.44–7.46  | 5.44–7.46  | 5.44–7.46  |
|       | IV                  | 1.06                                        | 5.38–7.37 | 0.69        | 8.12–11.13 | 8.12–11.13 | 8.12–11.13 | 8.12–11.13 |
|       | V                   | 0.65                                        | 8.77–12.02| 0           | 0          | 0          | 0          | 0          |

Figure 1 shows the results of experimental studies of TLT-100M tractor transmissions with DPM \( (K_{lo} = 1.40) \) at the Onega Tractor Plant test site. Results of researches show good convergence with theoretical calculations (table 1).
Figure 1. Use of tractor’s TLT-100M gearboxes with CDA ($K_{lo} = 1.40$) and five-speed gearbox on the FFW polygon. a) $Q = 5.0 \text{ m}^3$, b) $Q = 6.5 \text{ m}^3$.

References

1. Ivanov G A 1982 Influence of the engine adaptability factor on the choice of the number of gears in the tractor transmission (in Russian – Vliyanie koeffizienta prisposoblyaemosti dvigatelya na vybor chisla peredach v transmissii traktora)/ Tractors and agricultural machines, 8, 12-13
2. Izvekov V S 1980 About efficiency of use on the skidding tractor of the engine with the increased correcting factor of a reserve of torque (in Russian – Ob effektivnosti ispolzovaniya na trelevochnom traktore dvigatelya s povyschennym korrekturmnym koeffizientom zapasa krutyaschtgo momenta)/ Collection of data from Moscow State Forestry Engineering Institute. Issue 126, 104-109
3. Anisimov G M 1975 Operating conditions and load of the skidder transmission (in Russian - Usloviya ekspluatacii i nagrugennosti transmissii trelevochnogo traktora) (Moscow: Forestry industry) 165
4. Anisimov G M and Pustoshny P A 1981 Prediction of the skidder gear use (in Russian – Prognozirovanie ispolzovaniya peredach trelevochnogo traktora) - Ex. higher education institutions. Forestry Magazine (Lesnoy Zhurnal), 2, 55-58
5. Antipin V P, Durmanov M Yand Mikhailov O A 2019 Choosing Transmission Gearset for Agricultural Aggregates Based on Energy Consumption eds. Radionov A, Kravchenko O, Guzeev V and Rozhdestvenskiy Y Proceedings of the 4th International Conference on Industrial Engineering. ICIE 2018. Lecture Notes in Mechanical Engineering. Springer,
6. Mikhailov O A, Spiridonov S V, Taradin G S and Durmanov M Ya 2018 Prediction of the time of use of transmission transmission numbers taking into account the random nature of the weight of the pack» (in Russian – Prognozirovanie vremen i ispolzovaniya peredatochnykh chisel transmissii s ucheton sluchainogo haraktera vesa pachki) / Forests of Russia: politics, industry, science, education / materials of the third international scientific and technical conference. Volume 2 / ed V M Gedjo (St. Petersburg: SPbFTU) 195-197

7. Mikhailov O A, Martynov BG , Durmanov M Ya and Taradin G S 2018 Efficiency of the use of diesel engines with high adaptability on the harvesting machines (in Russian – Effektivnosti ispolzovaniya dizelei s vysokoi prisposoblyaemostyu na lesosechnyh maschinah)/ Forests of Russia: politics, industry, science, education / materials of the third international scientific and technical conference. Volume 2 / ed by V M Gedjo (St. Petersburg: SPbFTU) 197-199

8. Gelfand I M and Shilov G E 1958 Generalized functions (in Russian – Obobschennye funkzii) Issue. 1 (Moscow: Science) 439

9. Pugachev V S 1968 Introduction to probability theory (in Russian – Vvedenie v teoriyu veroiatnosti) (Moscow: Science) 368