Models for the determination of basic parameters of tracked feller buncher machines

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Abstract. Models for the determination of basic parameters of tracked feller bunchers are presented. A statistical analysis has been carried out and the normal law of distribution of the main technical characteristics of the most common models of machinery has been established. Both univariate and multivariate regression equations of the main parameters of the machines have been obtained, depending on the main parameter characterizing the load transmitted from the object of labour, which is cut and packaged by the machine - load capacity.

1. Introduction

The whole tree logging technology currently maintains a strong position both in Russia and around the world. In 2013, in the Russian forest complex about 26% of the total volume of logging was harvested using the whole tree technology [1-10]. The most common system of machines for the whole tree harvesting is: a feller buncher (FB), a skidder and a delimbing machine. The main machine in this system is the FB equipped with a hydraulic manipulator with a gripping-cutting device, a rotary platform with an operator's cabin and a power generating unit mounted on it, and a tracked undercarriage.

The main parameters of the FB are engine power, vehicle mass, and ground pressure. In order to establish the optimal values of the main parameters of any FB, one has to know the nature and strength of influence of the load factor on them.

The purpose of the study was, by means of statistical analysis, to establish the optimal parameters of a FB, an indicator reflecting the load transmitted from a tree to the metal structure of a manipulator and to the whole machine is used as a load factor - load capacity.

2. Methods and Materials

2.1. Object of the Study

Generally speaking, a tracked feller buncher is an excavator type machine. The undercarriage is of a track type, consisting of a track belt equipped with lugs and support rollers. Most modern FBs are equipped with a full-rotary platform, which makes it possible to pack trees behind the machine, thus protecting the undergrowth. Also, some models of machines are equipped with a platform equalizer which allows the machine to work on slopes or uneven ground. An operator’s cabin, a power unit...
building construction, etc.). Technical characteristics of thinning machines are also used in selective cuttings with a share of the cut component around 0.7, clear fellings, and other types of felling (deforestation for power lines, building construction, etc.). Technical characteristics of the most common FBs are given in Table 1.

| Company  | Model     | Power, kW | Mass, kg | Energy saturation, kW/t | Ground pressure, kPa | Load-carrying capacity, kg | Max. manipulator reach, m |
|----------|-----------|-----------|----------|-------------------------|----------------------|---------------------------|--------------------------|
| John Deere | 803M      | 224       | 28250    | 7.93                    | 57.7                 | 5520                       | 8.49                     |
|          | 853M      | 224       | 30170    | 7.42                    | 57.7                 | 6860                       | 8.49                     |
|          | 859M      | 224       | 35450    | 6.32                    | 68.0                 | 6860                       | 8.49                     |
|          | 903M      | 224       | 31590    | 7.09                    | 60.4                 | 7680                       | 8.88                     |
|          | 909M      | 224       | 36660    | 6.11                    | 70.4                 | 7680                       | 8.88                     |
|          | 953M      | 246       | 33210    | 7.41                    | 63.5                 | 10260                      | 8.88                     |
|          | 959M      | 246       | 37740    | 6.52                    | 72.4                 | 10260                      | 8.88                     |
| Tigercat | 845E      | 210       | 26760    | 7.85                    | 57.3                 | 5760                       | 8.53                     |
|          | L845E     | 210       | 34925    | 6.01                    | 74.8                 | 5760                       | 8.53                     |
|          | 855E      | 212       | 27600    | 7.68                    | 59.1                 | 8440                       | 8.46                     |
|          | L855E     | 212       | 35600    | 5.95                    | 75.1                 | 8440                       | 8.46                     |
|          | 860C      | 224       | 29260    | 7.65                    | 62.6                 | 6080                       | 8.46                     |
|          | 870C      | 224       | 31300    | 7.16                    | 66.1                 | 8435                       | 8.46                     |
|          | L870C     | 224       | 35600    | 6.29                    | 75.1                 | 8435                       | 8.46                     |
|          | LX870C    | 224       | 35600    | 6.29                    | 75.1                 | 8435                       | 8.46                     |
| Caterpillar | 511      | 184       | 24363    | 7.55                    | 38.6                 | 7100                       | 8.1                      |
|          | 521       | 212       | 27084    | 7.83                    | 40.8                 | 7100                       | 8.1                      |
|          | 522       | 212       | 30410    | 6.97                    | 45.8                 | 7100                       | 8.1                      |
|          | 532       | 212       | 31620    | 6.71                    | 46.8                 | 7100                       | 8.1                      |
|          | 541       | 227       | 30191    | 7.52                    | 38.4                 | 9400                       | 8.6                      |
|          | 551       | 227       | 31057    | 7.31                    | 39.4                 | 9400                       | 8.6                      |
|          | 552       | 227       | 35680    | 6.36                    | 45.3                 | 9400                       | 8.6                      |
|          | 541-2     | 226       | 30826    | 7.33                    | 39.2                 | 9400                       | 8.6                      |
|          | 552-2     | 226       | 35816    | 6.31                    | 45.4                 | 9400                       | 8.6                      |
|          | 521B      | 226       | 37501    | 8.22                    | 41.1                 | 6100                       | 8.1                      |
|          | 522B      | 226       | 32528    | 6.95                    | 48.5                 | 6100                       | 8.1                      |
| Komatsu  | XT450L2   | 224       | 31545    | 7.10                    | 64.0                 | 5216                       | 8.18                     |
|          | XT445L3   | 224       | 30926    | 7.24                    | 61.4                 | 5216                       | 8.18                     |
|          | XT430L3   | 224       | 29239    | 7.66                    | 57.9                 | 5216                       | 8.18                     |
|          | XT460L3   | 224       | 33710    | 6.64                    | 68.0                 | 6121                       | 8.18                     |
| Valmet   | 475FXL    | 246       | 35951    | 6.84                    | 73.1                 | 5988                       | 9.49                     |
The main parameters of an FB are in the following ranges of values:

- Power $N_e$ is from 184 to 246 kW;
- Mass $M_m$ from 24.363 to 35.951 kg;
- Energy saturation $N_e/M_m$ from 5.95 to 8.22 kW/t;
- Ground pressure $P$ from 38.4 to 75.1 kPa;
- Load capacity $M_g$ from 5.216 to 10.260 kg;
- Maximum reach $L$ from 8.1 to 9.49 m.

Caterpillar machines produce the lowest pressure on the ground (from 38.4 to 48.5 kPa), despite the standard mass (from 24.363 to 35.680 kg) of modern FBs; this is due to the fact that they have the longest track length compared to models of other companies. The greatest ground pressure is produced by machines with a larger mass.

A wide range of load capacities can be explained by the design features of machines and technological equipment, such as wall thickness and the type of material of the metal structure of the manipulator, the use of a reinforced frame of machines, etc.

The values of power, mass, energy saturation and maximum reach for all machines differ slightly from one to another.

2.2. Research Methods

To assess the reliability of the considered values of the characteristics of feller bunchers, we carried out a statistical analysis. The minimum sample size was 112. It was obtained with a Student criterion of 1.96, a coefficient of variation of 11%, and an accuracy of 2%.

3. Results and Discussion

The results of the statistical analysis are summarized in table 2. The statistical analysis was performed using Statgraphics 18 software.

| Key Statistics | Power $N_e$, kW | Mass $M_m$, kg | Energy saturation $N_e/M_m$, kW/t | Ground pressure $P$, kPa | Load capacity $M_g$, kg | Maximum reach $L$, m |
|----------------|----------------|---------------|---------------------------------|-------------------------|-------------------------|-----------------------|
| Mathematical Expectation $m(X)$ | 223.4 | 31904.9 | 7.04 | 57.4 | 6958.3 | 8.47 |
| Standard deviation, $\sigma$ | 11.56 | 3858.2 | 0.56 | 13.02 | 1597.05 | 0.33 |
| Distribution law | Normal | Normal | Normal | Normal | Normal | Normal |
| Coefficient of variation $C_v$, % | 5.2 | 12.1 | 7.9 | 22.7 | 22.9 | 3.9 |
| Criterion $\chi^2$ (Chi-Square) and its significance level $p$ | 12.8 | 14.4 | 14.8 | 11.4 | 12.4 | 9.4 |
| | 0.23 | 0.42 | 0.19 | 0.25 | 0.26 | 0.49 |
According to the data presented in table 2, the values of $\chi^2$ for all parameters $p = 0.19 – 0.49$ were above 0.05. Consequently, the distribution of parameter samples does not differ from the normal distribution. Figure 1 is an example of a graphical representation of the normal energy saturation distribution of a modern tracked FB.

![Normal distribution of energy saturation values of modern tracked feller bunchers.](image)

**Figure 1.** Normal distribution of energy saturation values of modern tracked feller bunchers.

Given the values of the coefficient of variation $C_p = 22.7 – 22.9\%$, the values of mathematical expectation of ground pressure $m(P)$ and load capacity $m(M_g)$ have noticeable fluctuations. Mathematical fluctuations in power $m(N_e)$, energy saturation $m(N_e/M_m)$, mass $m(M_m)$ and maximum reach $m(L)$ vary only slightly. Noticeable fluctuations in ground pressure and load capacity can be explained by the design features of the machines.

One can evaluate the effect of a machine’s load capacity $M_g$ on its power $N_e$, mass $M_m$ and ground pressure $P$ using figures 2 – 4, respectively. These relationships are estimated by linear regressions. The values of the coefficient of determination $R^2$ of the presented relationships are 0.83, 0.93 and 0.96; therefore, the linear regressions explain 83%, 93% and 96% of variation in power, mass and ground pressure, respectively. The significance levels of the $t$-test and $F$-test statistic for all three equations are less than 0.05, i.e. the coefficients of the equations and the regressions themselves are 95% reliable. The correlation coefficient between the arrays amounted to $r = 0.91; 0.96; 0.98$. 
Figure 2. Change in the power of an FB depending on its load capacity.

\[ N_e = 171.1 + 0.0066M_g \]

Figure 3. Change in the mass of an FB depending on its load capacity.

\[ M_m = 15232 + 2.1928M_g \]
Figure 4. Change in the ground pressure of an FB depending on its load capacity.

Thus, the obtained regression equations show that with an increase in carrying capacity $M_g$ by 1.000 kg, power $N_e$, mass $M_m$, and ground pressure $P$ will increase by 7 kW, 2200 kg and 5 kPa, respectively. The given regression equations make it possible to evaluate the main parameters of an FB at the design stage based on the required carrying capacity. Also, these regression equations $N_e = f(M_g)$, $M_m = f(M_g)$ and $P = f(M_g)$ make it possible to determine the values of these parameters for operation depending on the load capacity.

Together with the analysis of univariate regressions, an analysis of multiple linear regressions was also carried out; the equations of multiple regressions have the form:

$$N_e = 133.7 + 0.0036M_g + 0.0027M_m,$$

$$M_m = 5508.1 + 49.89N_e + 2M_g,$$

$$P = 10.35 + 0.093N_e + 0.0038M_g.$$  

The values of the coefficient of determination $R^2$ for expressions 1 – 3 are equal to 0.84, 0.97, and 0.96, respectively. The significance levels of the $t$-criterion for the coefficients of all three equations are less than 0.05, therefore, the coefficients of the multiple regressions obtained are 95% reliable. Significance levels of the $F$-test statistics were less than 0.05 for the three equations; therefore, the regression equations themselves are 95% reliable.

4. Conclusion

1. The obtained regression equations made it possible to describe the nature and strength of the main acting factors. Using the obtained equations, it is possible to approximately determine the values of the main parameters of tracked FBs, i.e. power, mass and ground pressure, both at the design stage and when choosing a machine for operation in various natural and industrial conditions, depending on the requirements for load capacity.

2. The resulting multiple regression equations $N_e = f(M_g, M_m)$, $M_m = f(M_g, N_e)$, $P = f(M_g, N_e)$ allow us to estimate the combined effect of the load capacity and mass on the FB power; the effect of the load capacity and power on the mass of the machine; and the effect of the carrying capacity and power on the ground pressure. Thus, these equations make it possible to comprehensively evaluate and select the main parameters of tracked feller bunchers.
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