JOURNAL OF FOREST SCIENCE, *57*, 2011 (1): 34–40

Energy consumption of a chipper coupled to a universal wheel skidder in the process of chipping wood

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ABSTRACT: The chipper for chips is an energy consuming machine. Many factors influence the result of chipping which influence the whole process. The paper deals with the process of wood chipping by a chipper in order to determine its energy consumption. The main purpose was the determination of input power and comparison of revolution frequency on the outlet shaft of a skidder regarding the dimension of the torque depending on variable parameters which characterize the process of wood chipping during the measurement and the analysis of energy consumption of a chipping machine was carried out.

Keywords: chip; chipper; chipping; energy consumption; power of cutting

Chipping machines are used for the processing of inferior wood and wooden waste like waste from sawing which are produced by the processing of whole tree stems for assortments in the forest or main wood stocks and waste from timber production (e.g. branches, tree stumps, coniferous topwood, etc.) Output products of these machines are small particles of wood called chips. Chip production can run directly in the scrub, on the skid road and in the factory. These are input materials for subsequent industrial delimbing, e.g. in chemical industry for the production of cellulose and paper, in wood-processing industry for the production of chipboards and fibreboards and in power industry biomass (fuel) is used for the production of heat (2001).

According to the purpose the chip will be used for it must have required dimensions and shape. For the production of fibreboards the fibres should be from 20 to 30mm in length and from 3 to 5 mm in width. For the production of brown coal the chips should have the length from 80 to 120 mm. The length of chips is given by the type of grate in the furnace and stoking equipment in automatic burning machines. If the chips are blown, the required length is from 6 to 10 mm. If there is a mechanical transport of chips, the required length is from 12 to 20 mm. In the chemical processing of chips by a sulphite process the length of chips from 20 to 30 mm and the thickness from 3 to 6 mm are recommended. In a sulphate process the length of chips is from 10 to 25 mm and the thickness from 3 to 5 mm (STN 48 0057; STN 48 0058).

In practice we can find more names of these machines like chipper, cutting machine and grinder of wooden mass. All these names are characteristic of a machine which uses mechanical way of cutting knives for taking small particles from wood and it is called a chip. Chipping machines are machines for the chipless cutting of wood by a knife across the fibres and also for necessary thickness along the fibres. Nowadays, there are more and more people who know that chipping is a real way of wooden mass utilization and that it enables to obtain the pureness of forest.

Technological operations which prevent waste wood utilization involve timber production, concentration into lines, skidding to transporting places, its dimensional homogenization, e.g. chipping, grinding, etc. Wood for energy production can come from either waste from technological processes of wood production and primary wood processing or goal-directed production of fuel wood.

Theoretical principles of wood chipping by a chipper

First, we have to say that wood chipping is a very difficult process. This is the reason why simplifying assumptions are used for its solution. This method is also used for chipping by disc and drum chippers. As mentioned above, it is about combined cutting by a flat knife with one cutting edge. The principle and the scheme of cutting by a disc chipper are shown in Fig. 1. The knife with cutting edge angle β, which is fixed on a rotating disc, cuts from wood the layer of thickness a. The slotted hole is leaned against the second knife during cutting. The cut layer is disintegrated into chips of required dimensions (of length *l* and thickness *h*).

The basic factors which influence the properties of chips and specific consumption of energy in the process of chipping wood, except technical parameters, are also the type, moisture and quality of wood, lock and cutting angle of knives, angle of the contact, cutting speed, length of the slotted hole and feeding speed of wooden mass at chipping (Bučko 2001).

The cutting tools, i.e. knives in chippers, work discontinuously and are much stressed. The quality and efficiency of chip production depend directly on the state and hardness of their cutting edges. The cutting knife is characterized by the material and by an angle of the cutting edge β. Very important is also the value of overhang from the plane of the disc in the process of step on the disc and work with a gradual change of the radius for the cutting edge of the knife. Knives for chippers should be made explicitly from homogeneous and unclad material. Steel for the production of cutting tools must have mainly high hardness, stability of the cutting edge regarding the abrasive action and blunting and it should have adequate toughness. These properties are fulfilled by some types of tool steels (19,132; 19,559; 19,732). When the cutting angle is decreased, the number of thin, long and undersized chips is lower. When the angle of blunting is increased, there is a higher share of dust and the sharpness of cutting is decreased. The overhang of knives from the plane of the disc defines the predetermined length of chips, which directly influences the length of chips (Štempel et al. 1964).

According to Lisičan there are ordinary values of angular knife parts (α, β, δ) defined from the following criteria:

– kinematic (α)
– technological (β)

The kinematic point of view defines a possibility of the log feed to the disc also during the activity of the knife, i.e. not only in the position of a log situated between two knives. This is the reason why the cutting clearance angle α should be minimum:

$$\alpha_{\min} = \text{arctg}\ \frac{z \times h_1}{2\pi \times R_{\text{str}}} \qquad [°] \qquad (1)$$

where:

z – No. of knives,

h_1 – overhang of the cutting edge from the plane of the disc (mm),

R_{str} – distance from the disc rotation axis to the half length of the cutting edge of the knife (mm).

The technological point of view (disintegration of wooden mass into "chips") is defined by the thermal state and type of wood. Approximately:

$\beta_{\text{optim}} \cong 37° \Rightarrow$ in summer time

$\beta_{\text{optim}} \cong 39°–40° \Rightarrow$ in winter time

The incorrect setting of knives, i.e. the distance between knives is too big (3–5 mm), can cause that cutting is not smooth but in the place of cut-

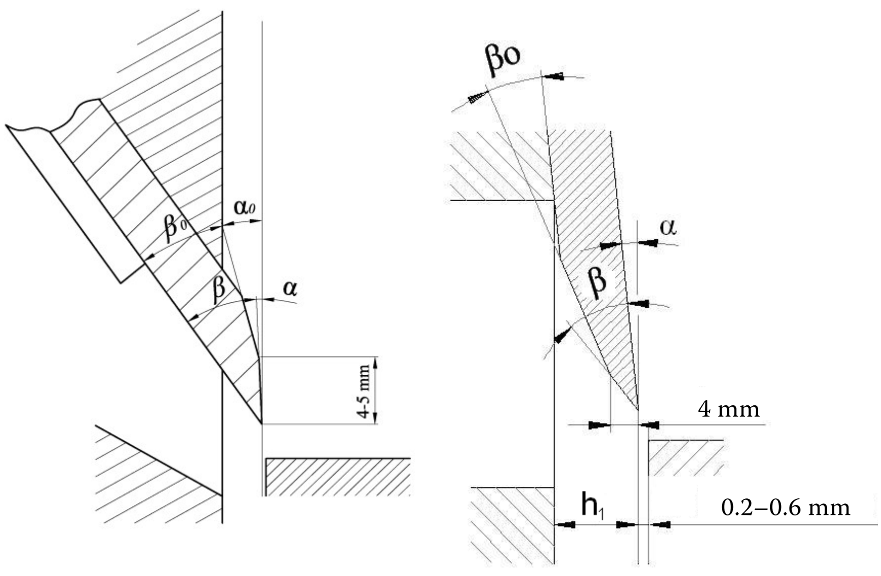

Fig. 1 The tilt-angle of a knife in a chipper disc at high and low number of revolutions in a chipper (Lisičan et. al 1996)

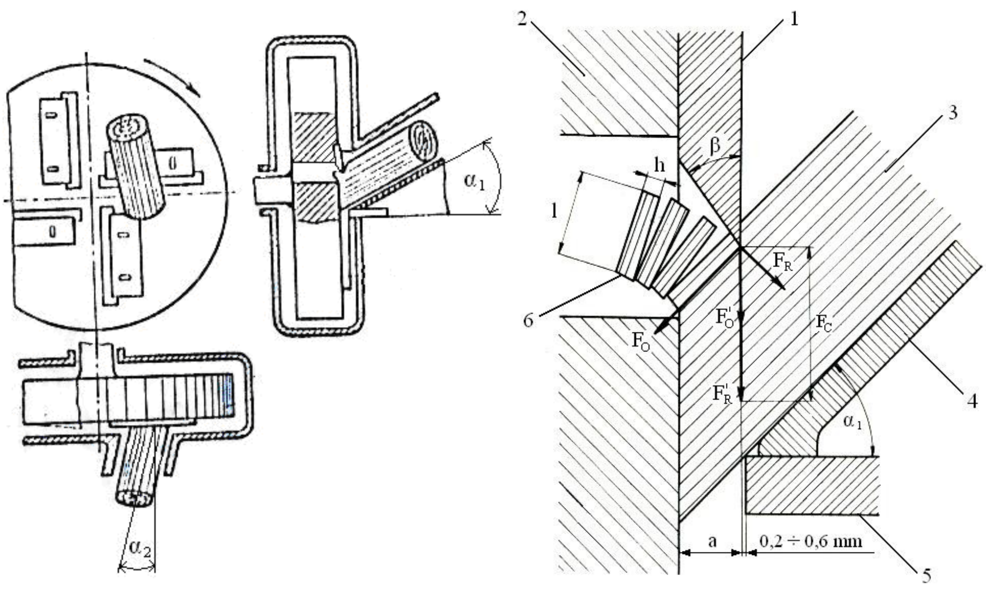

Fig. 2. The scheme of wood chipping by a disc chipper (Štempel 1964)
1 – chipping knife; 2 – disc; 3 – chipped section; 4 – down-gate; 5 – counter knife; 6 – chip

ting there are bend and drafting between knives and it leads to the production of too big chips. If the distance between knives is defined correctly (0.2÷0.6 mm), then the knives work like scissors and clean cut is produced (Lisičan 1996).

If the cutting out a layer occurred, the knife would have to act on wood by total force F_c. This force acts in the trajectory of the knife movement and it is defined by the sum of forces F'_o and F'_R. The part F'_o creates the force F'_o, which acts in the direction of wood fibres. It is necessary for the separation of chips from the wood layer. The part F'_R creates the force F_R acting perpendicularly to the fibres and because of this action the cut of wood fibres occurs. In Fig. 2 the decomposition of force F_R is shown. The friction between a slotted hole and a loading inlet is caused by the force F_R. The part F''_R presses the slotted hole to the knife. Its course is opposite to friction. It is caused by a feed effect, it means that the stem is pressed to the disc by itself (Očkajová 1996).

To separate the chips the condition that $\alpha > \beta$ must be met, it means that the force FT is positive. Otherwise if $\alpha < \beta$, the chips will be pressed to the part of the stem which was cut. The angle α is the final angle of the loading inlet, which is defined by angles α_1 and α_2 (Mikleš et al. 2004).

There are many factors influencing the result of chipping, e.g. the shape and position of a loading inlet, shape and setting of knives, number of knives on a disc and also the shape of a disc. This is the reason why the optimal dimensions are looked for from the aspect of correct chipping and they are looked for experimentally and the machines are constructed according to experimental conditions (Štempel et al. 1964).

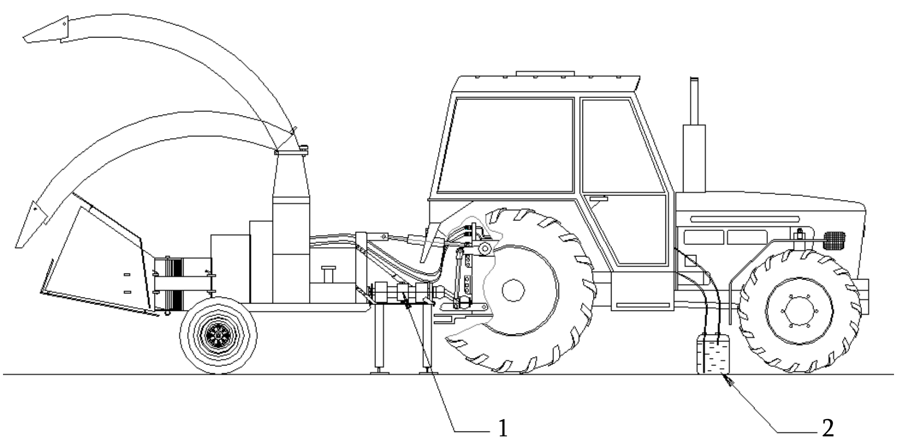

Fig. 3 Connection of the chipper Pezzolato H 780/200 to the skidder Zetor 5341
1 – torque sensor;
2 – gravimetric measurement of fuel

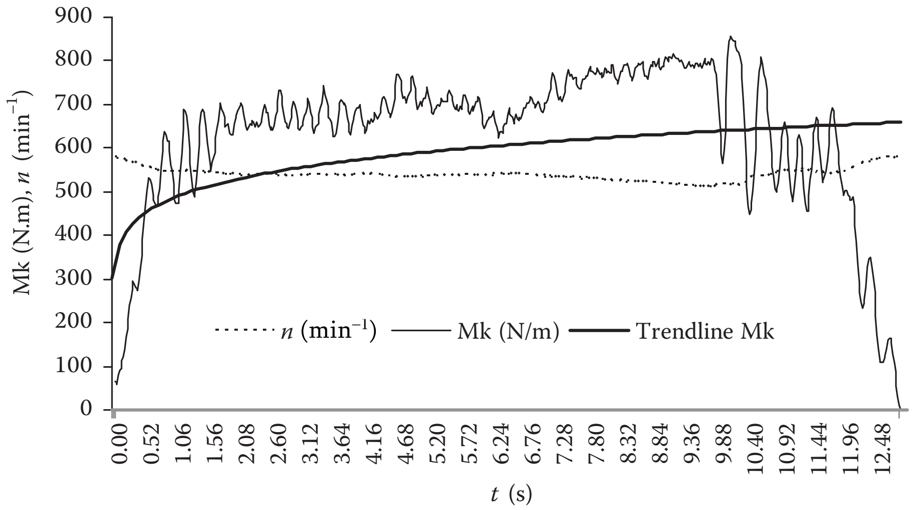

Fig. 4. The course Mk and n at chipping where the thinner part of a branch was used (beech)

The chipper for chips is a machine with high energy consumption. This is the reason why it is necessary to use the kinematic energy of flywheel mass for overcoming the resistance of wood and to choose a higher number of knives on the disc (two knives in work at the same moment) to decrease impacts in electrical network or to eliminate them only for breaks during chipping between two logs. During breaks kinematic energy is accumulated in the rotor of a chipper (this is called START), it relieves the work of the motor, i.e. revolutions decrease during the cutting of a log from n_1 to n_2 and during the break between two logs revolutions increase again to n_1. This effect is used for constructing the whole power of the motor (Lisičan et al.1996).

Table 1. Technical parameters of the chipper Pezzolato H 780/200

Loading inlet dimensions (mm)	860 × 630
Disc diameter (mm)	780
No. of knives (pcs)	3
Max. No. of disc revolutions (min^{-1})	1,000
Length of chips (mm)	6–18
Flywheel diameter (mm)	200
Max. inlet dimensions (mm)	230
Required power (kW)	min. 30
Shaft revolutions (min^{-1})	540
Power of a motor (kW)	37
Performance of a machine per hour ($m^3 \cdot h^{-1}$)	14–18
Dimensions with a shaft [w × l × h]* (mm)	2,900 × 1,800 × 2,750
Weight with a shaft (kg)	850
Dimensions of discs	5.5 J × 13
Dimensions of tires	175/70 – R13
Pressure in tires (bar)	3.0
Max. transport velocity ($km \cdot h^{-1}$)	20

*with an exhaust pipe in transport position

MATERIAL AND METHODS

A Pezzolato H 780/200 overhung chipper coupled to a three-point linkage Zetor 5341 skidder (Fig. 3) was used for the research of parameters. The chipper is driven from the output shaft of the skidder. This version of the machine is equipped with sequentially driven horizontal hydraulic cylinders which are secured by a hydraulic security system against impacts. The maximum diameter of disintegrated material is 200 mm. The other basic characteristics of this material are shown in Table 1. The Zetor 5341 skidder was equipped according to the chipper producer's instructions. The minimum required power of the motor is 30 kW. The power of the skidder is 47 kW at 2,200 min^{-1}. The revolutions on the outlet shaft are $n = 580$ min^{-1} without loading.

Two types of wood in three assortments were used which are widely used and spread in the Slovak Republic. Softwood (spruce) and hardwood (beech) were used. Three types of assortments were used for measurements, i.e. brushwood (branches up to 5 cm in diameter), wood up to 8 cm in diameter and 2 m in length and round timber 12 cm and 20 cm in diameter and 2 m in length. The samples for chipping were directly cut from intermediate

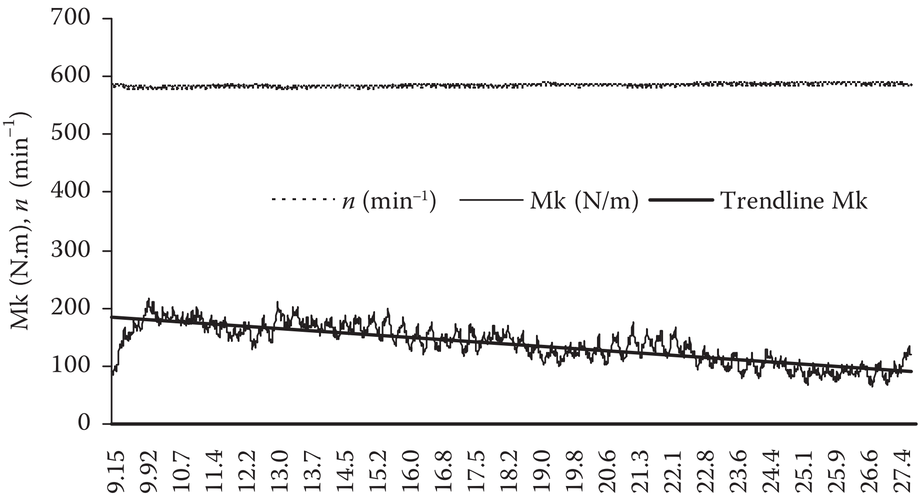

Fig. 5. The course Mk and n at chipping where the thicker part of a branch was used (spruce)

or removal felling. The moisture was measured by a weight method. The moisture of spruce was 61% while the moisture of beech was 44%.

The measurement consisted in scanning the torque and revolutions on the outlet shaft with an HBM T10 scanner with output to the evaluation device SPIDER 8 and this information was recorded to the computer hard disc using the software program Conmes Spider. The measured results were statistically processed on a personal computer which was equipped with the statistical programme STATISTICA and fuel consumption was determined by a weight method (Krilek 2008).

RESULTS AND DISCUSSION

The main objective of the experiment was to determine power and to compare the frequency of rotation on the outlet shaft of the skidder in the process of chipping regarding the torque depending on measurement parameters characteristic of the process of cutting wood (Krilek 2009).

The energy used for cutting wood was supplied by the motor during caracole and by the rotor in consequence of the revolution decrease. The torque of the rotor consists of the disc torque, shaft torque and cardan shaft torque. The other rotating parts are not important due to low weight. The average no-load input of the chipper was established as 4.09 kW. The no-load input was evaluated and controlled individually before each attempt in the experiment. Then the no-load input before each attempt has the value of 4.09 kW.

The value of the torque varies during the chipping process along the stem of the tree. It increases or decreases with the frequency of chipping disc revolutions. The values Mk and n increase

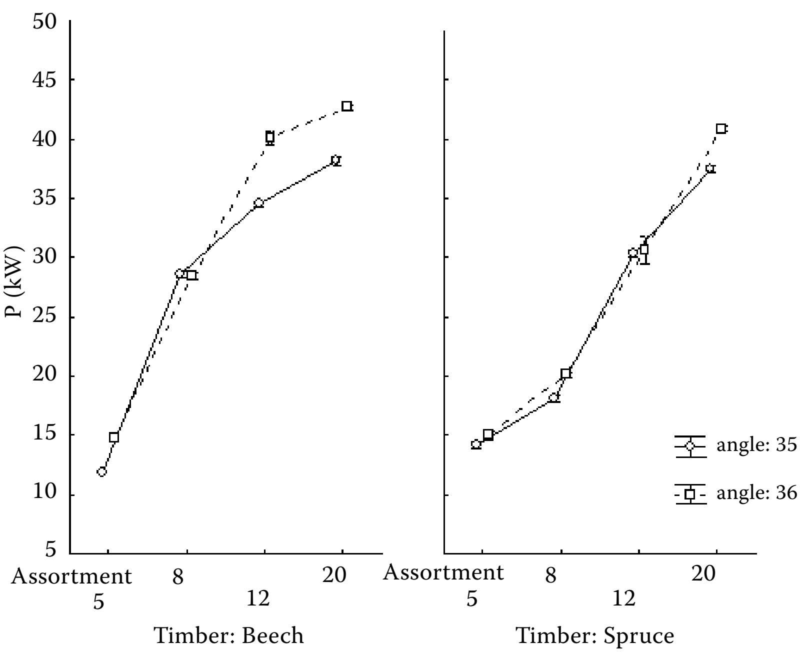

Fig. 6. 95% of dependability intervals for mean values of power for all factors which influences of angles are emphasized

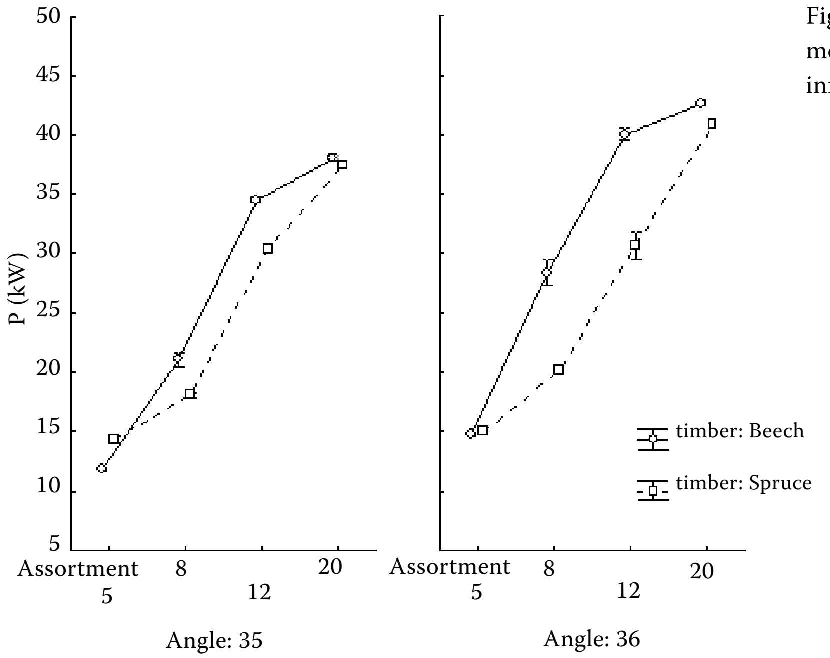

Fig. 7. 95% of dependability intervals for mean values of power for all factors which influence of wood is emphasized

or decrease according to the way of putting stems into the chipper, i.e. if thick (Fig. 4) or thin ends (Fig. 5) are introduced to the loading inlet hole. This change is proportional to a change in diameter along the treated assortment and presence of wood defects. Power parameters were tested in connection with the type of wood, assortment and the angle of the clearance face. The energy consumption was analyzed from two measurements (two types of chipping knives) after realization and analysis of preparatory measurements. The power found out on the output shaft of the Zetor 5341 skidder with Pezzolato H 780/200 chipper varies linearly with the change in the assortment and it has the highest influence on power. The power varies from 9 kW to 47 kW (these maximum values are calculated from the measurement record).

ANOVA (multifactor analysis of variance) was used for finding out the interaction of several factors with energy consumption of the chipping process. The criteria used for the analysis were maximum torque, maximum revolutions and maximum power. As criteria of statistical significance (P) F-test was used and it is probability of the fact that the factor does not have a statistical influence. A reciprocal statistical dependence was found out between the maximum power (dependent variable) and wood, assortment and knife angle (independent variables). There was an assumption that the particular parameters influenced each other. For the test generalization Duncan's test was used.

For each variation of three-factor levels (4 assortments × two types of wood × two different knives = sixteen variations) there was filtered out representing interval of values tested items (n, Mk, P). For each physical item the results were statistically evaluated by three-factor analysis of variance (Krilek, Mikleš 2008).

Based on the monitored factors, the following results were obtained: the assortment has the statistically most significant influence, followed by the type of wood and knife angle. It is documented in Figs. 6 and 7, where 95% reliability intervals for medians of power take place.

Based on the statistical interpretation, maximum average energy consumptions in beech and spruce assortments are visible which were calculated from the measured physical parameters of torque and revolutions on the outlet shaft. In the statistical interpretation the maximum average value of power is 42.43 kW (beech – round timber up to 20 cm, the cutting clearance angle is 36°) and the minimum is 11.85 kW. The graphs illustrate that the maximum energy consumption of the chipper was determined when assortments up to 20 cm in diameter were used. We can state on the basis of maximum average values that the power-driven means (skidder) is suitable for a certain adapter (chipper) and for the chipping process of nonstandard wood.

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Received for publication March 4, 2010
Accepted after corrections July 2, 2010

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