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THE RESISTANCES OF THE WOOD SUBDIVISION IN THE DRUM CHIPPER

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SYNOPSIS. The analysis of the forces acting on the wood in a process of its subdivision in a drum chipper as well as on the stresses in the wood was performed. The effects of various factors are discussed, among other things the efficiency of the chipper on the separation of the chips from the rest of wood, thus on their quality.

KEY WORDS: drum chipper, subdivision resistances, wood subdivision

INTRODUCTION

In the plants producing wood fibreboards the wood raw material is being subjected to a preliminary subdivision in order to form the chips in the disc- or drum--chippers The drum chippers that are considerably cheaper, smaller and working at low noise level find more and more applications. They are often used in the pulp and paper industry as secondary chippers for disintegration of the slivers or oversize chips. If, however, the conditions of wood subdivision by means of the disc chippers have been exactly analyzed and described (Kawka et al. 1980, 1987-1997), the drum chippers, as up till now, are given in this respect short shrift.

The aim of this paper is to fill this gap in respect of the resistances appearing at the subdivision of wood in the drum chippers. The author expresses hope that the results of this analysis will make it possible to rationalize the operation of the discussed equipment and especially to cut down the consumption of energy for subdivision of wood. The analysis will take into consideration the drum chipper of the design shown diagrammatically in Figure 1.

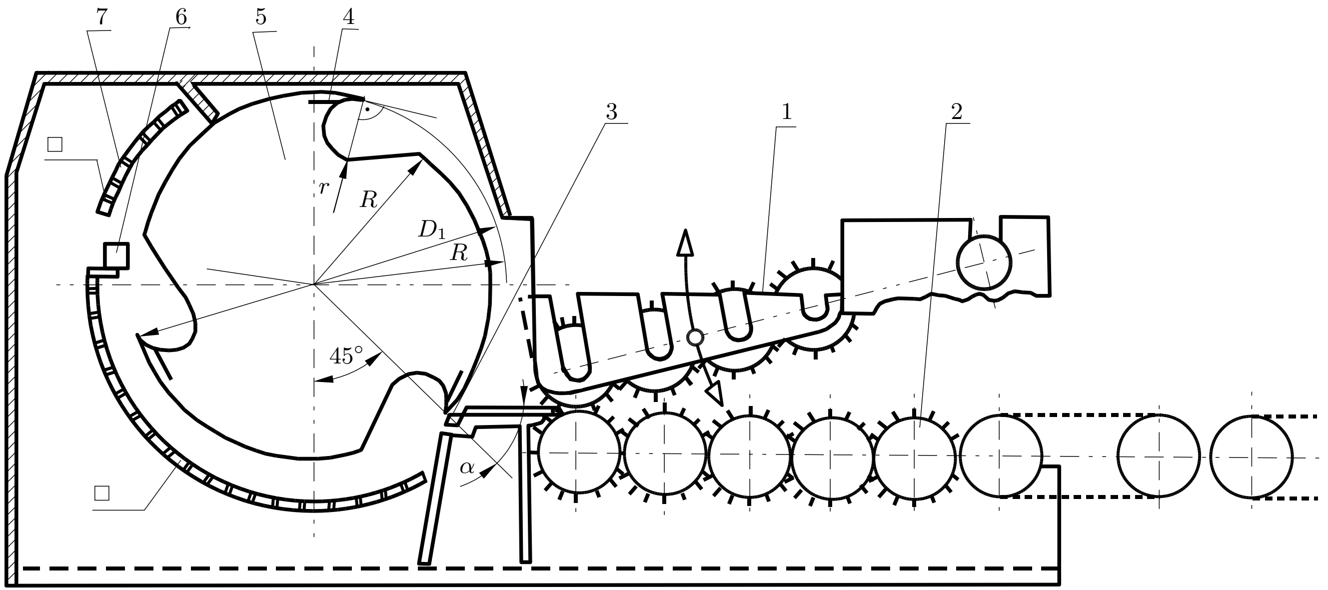

Fig. 1. Schematic diagram of the drum chipper: 1, 2 – the elements of the wood feeder, 3 – bed knife, 4 – shear knife, 5 – knife drum, 6 – auxiliary bed knife, 7 – sieve

Rys. 1. Schemat ideowy rębaka bębnowego: 1, 2 – elementy podajnika drewna, 3 – przeciwnóż, 4 – nóż skrawający, 5 – bęben nożowy, 6 – dodatkowy bęben nożowy, 7 – sito

ANALYSIS OF THE RESISTANCES AT WOOD SUBDIVISION

The process of wood subdivision into chips in a chipper of this type depends mainly on the system of forces that are used by a knife for acting on the wood. Good chips are formed in case when we have to do with the so-called clean cutting of the wood that occurs when the inequity $\tau > R_{t\parallel}$ is satisfied (τ – shear stress in the wood, $R_{t\parallel}$ – immediate strength of wood against shearing parallel to the grain). If the discussed inequity does not take place then division of the chips from the rest of wood appears as a result of the accidentally happening phenomena of breaking and crushing the wood. The quality of the chips undergoes considerable deterioration (Kawka et al. 1980, 1987-1997).

Acting of the knife on the wood may be presented with the following system of the forces (Fig. 2):

F_S – force with which the knife has to act in order to cause the cutting of the fibres in the wood (it has been assumed that this force is perpendicular to the grain),

F_{N2} – usual (normal) force with which the knife face acts on a chip,

F_{T2} – force of mitigated solid friction $= \mu_2 \cdot N_2$ on the surface of the knife face,

F_{N1} – usual (normal) force with which the chipper drum acts on the wood,

F_{T1} – force of mitigated solid friction $= \mu_2 \cdot N_1$ on the surface of knife application.

Reaction of the bed knife (counter – knife) comes down to the normal reaction N_3 and to the force of friction $F_{T3} = \mu_3 \cdot F_{N3}$. In order for simplification, the dead weight of the wood as insignificant, in relation to the existing forces, has been neglected.

The projection equations (Fig. 2) of the forces acting on the wood on the perpendicular and parallel axis to the surface of the knife application are given as follows:

$$\begin{aligned} F_{N1} \cdot \sin(\gamma - \beta) &- \mu_1 \cdot F_{N1} \cdot \cos(\gamma - \beta) - F_{N2} \cdot \sin\gamma - F_{N2}\mu_2 \cos\gamma + \\ &- F_S \cdot \cos\delta + F_{N3} \cdot \cos\delta + F_{N3} \cdot \mu_3 \cdot \sin\delta = 0 \\ F_{N1} \cdot \cos(\gamma - \beta) &+ \mu_1 \cdot F_{N1} \cdot \sin(\gamma - \beta) - F_{N2} \cdot \cos\gamma + F_{N2}\mu_2 \sin\gamma + \\ &+ F_S \cdot \sin\delta - F_{N3} \cdot \sin\delta + F_{N3} \cdot \mu_3 \cdot \cos\delta = 0 \\ \sin(\gamma - \beta) &\approx 0 \end{aligned} \tag{1}$$

After transformations we get:

$$\begin{aligned} F_{N2} &= \frac{F_{N3}\left[\dfrac{\cos\delta}{\mu_1} + \left(\dfrac{\mu_3}{\mu_1} - 1\right)\sin\delta + \mu_3 \cdot \cos\delta\right]}{\left(\dfrac{\mu_2}{\mu_1} + 1\right)\cos\gamma + \left(\dfrac{1}{\mu_1} - \mu_2\right)\sin\gamma} + \\ &+ \frac{F_S \cdot \left(\sin\delta - \dfrac{\cos\delta}{\mu_1}\right)}{\left(\dfrac{\mu_2}{\mu_1} + 1\right)\cos\gamma + \left(\dfrac{1}{\mu_1} - \mu_2\right)\sin\gamma} \end{aligned} \tag{2}$$

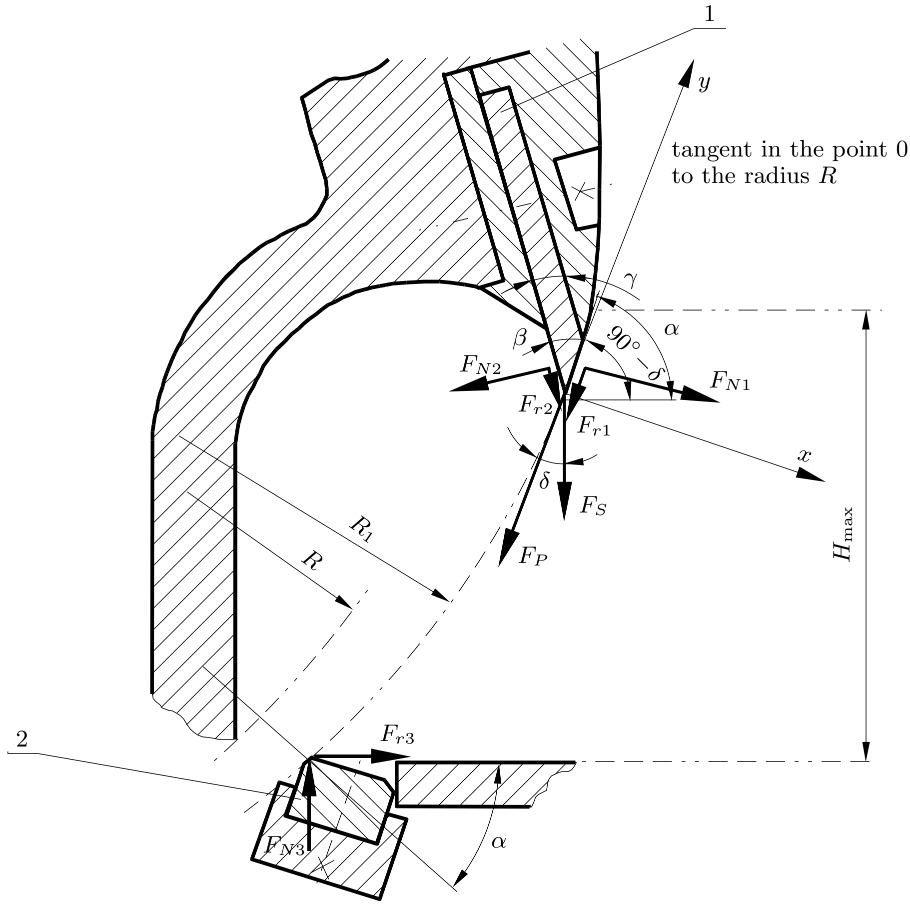

Fig. 2. The forces acting on the wood being subdivided in the drum chipper: 1 – shearing knife, 2 – bed knife
Rys. 2. Siły działające na drewno w rębaku bębnowym: 1 – nóż skrawający, 2 – przeciwnóż

As it is shown in Figure 2 the hoop force P is balanced by the reaction appearing on the bed knife (the resultant of the forces F_{N3} and F_{T3}).

$$F_P = F_{N3} \cdot \cos\delta + F_{N3} \cdot \mu_3 \cdot \sin\delta \tag{3}$$

Using the relationship (3) in the equation (2) the following is obtained:

$$F_{N2} = \frac{F_P \left[\dfrac{\cos\delta}{\mu_1} + \left(\dfrac{\mu_3}{\mu_1} - 1 \right) \sin\delta + \mu_3 \cdot \cos\delta \right]}{(\cos\delta + \mu_3 \sin\delta) \left[\left(\dfrac{\mu_2}{\mu_1} + 1 \right) \cos\gamma + \left(\dfrac{1}{\mu_1} - \mu_2 \right) \sin\gamma \right]} +$$

$$+ \quad \frac{F_S \cdot \left(\sin\delta - \dfrac{\cos\delta}{\mu_1}\right)}{\left(\dfrac{\mu_2}{\mu_1} + 1\right)\cos\gamma + \left(\dfrac{1}{\mu_2} - \mu_2\right)\sin\gamma} \tag{4}$$

where: μ_1 – coefficient of friction of the wood against the surface of the knife application,
μ_2 – coefficient of the friction of the wood against the knife face,
μ_3 – coefficient of the friction of the wood against the bed knife,
γ – the angle of the knife setting in the knife holder.

The angle δ can be determined from the following relationship:

$$\delta = \arcsin\left(\sin\alpha - \frac{H}{R_1}\right)$$

The resultant F of the forces F_{N2} and F_{T2} occurring on the surface of the knife face (Fig. 3) can be divided into the force $F_{\|}$ that is parallel to the grain and the force $F_{\perp}$ that is perpendicular to the grain. The analysis of these forces shows that the chips separated from the wood are being formed by their cutting off (Kawka et al. 1987-1997), since normal (usual) force F_{N2} is the compressive force. The magnitude of the forces used by the knife action on the wood is increasing as the cutting edge of the knife goes deeper into wood up to the moment when the value of the resisting force against wood cutting Ff is reached and exceeded. Then the wood breakage takes place and the separated part of wood (chip) is shifted along the OA line and comes off the rest of the wood. This is the classical case of shearing the wood, detachment of the chips as a result of their cutting off the rest of wood (Kawka et al. 1980, 1987-1997).

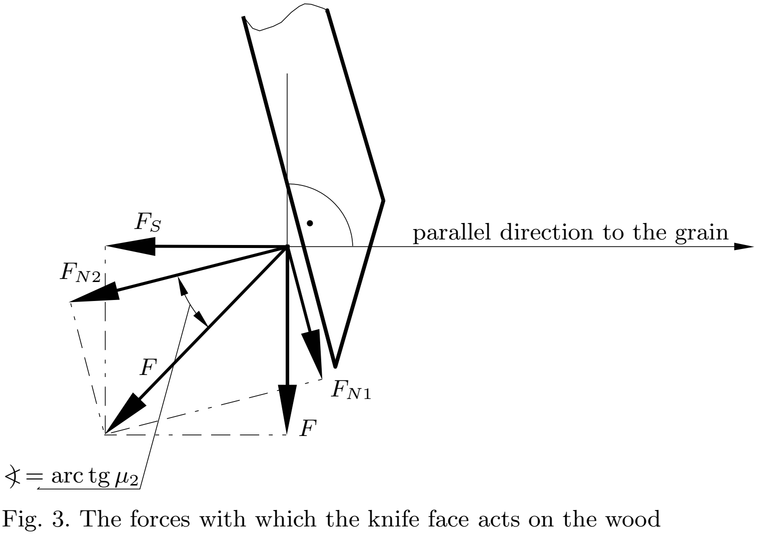

Fig. 3. The forces with which the knife face acts on the wood
Rys. 3. Siły, którymi działa powierzchnia noża na drewno

After the detachment of the chip the value of the forces with which the knife is acting on the wood, including the force F_{N1} drops considerably and afterwards it increases again as the knife edge goes deep into wood and the successive chip is being formed.

The system of forces acting in this way on the chip being detached is depicted in Figure 4. The chip being cut off moves along the plane AO in the direction out from the knife and is pressed against this plane by the knife. Thus one should take into consideration at the load on the chip the resistance against the shear force F and the force of mitigated solid friction $F_{T4} = F_{N4} \cdot \mu_4$ (F_{N4} = pressure of the wood log on the chip, μ_4 – coefficient of the internal friction in the wood, parallel to the grain).

The equations of the forces projections, acting on a chip, on the parallel and perpendicular axis to the OA line (Fig. 4) are as follows:

$$\begin{aligned} F_f &+ F_{N4} \cdot \mu_4 - F_{N2} \cdot \cos(\gamma - \delta) + F_{N2} \cdot \mu_2 \sin(\gamma - \beta) = 0 \\ F_{N4} &+ F_{N2} \cdot \sin(\gamma - \beta) - F_{N2} \cdot \mu_2 \cdot \cos(\gamma - \delta) = 0 \end{aligned} \tag{5}$$

After the transformation the value of the force F_f can be determined.

$$F_f = F_{N2} \left[\cos(\gamma - \delta)(1 - \mu_4 \cdot \mu_2) - \sin(\gamma - \beta)(\mu_4 - \mu_2)\right] \tag{6}$$

The dependence of the hoop force F_P on the F_{N2} and F_S forces has been determined with the formula (4). The value of the force F_S that is necessary

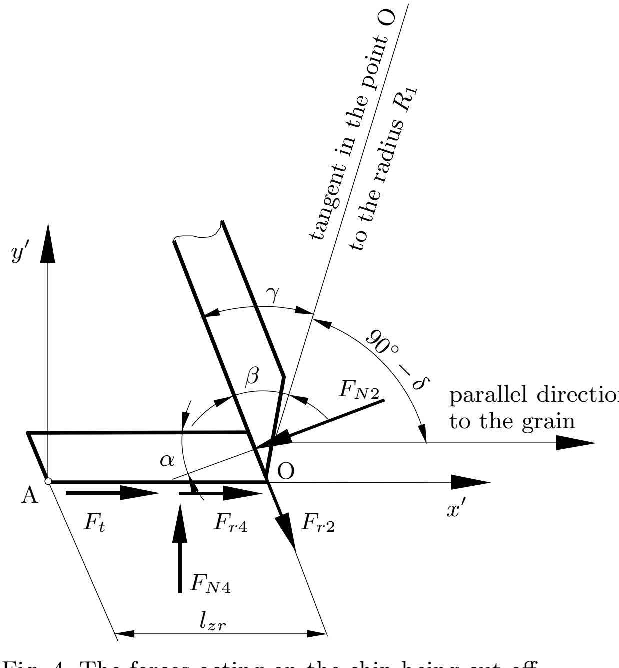

Fig. 4. The forces acting on the chip being cut off
Rys. 4. Siły działające na zrębek w trakcie rozdrabniania

for cutting the fibers in the wood depends in a considerable degree on the knife sharpness. This force can be expressed with the formula:

$$F_S = F_{RK} \cdot b_s$$

where: F_{RK} – the force that should be used at the unit of the knife edge length in order to cut through the thin fibers which are perpendicular to the knife edge,

b_s – the length of the wood area that is being cut with the knife.

Because the value of the F_{RK} force is difficult to be determined and to take into consideration the resistances at cutting through the fibers in the formula (5) can be defined by means of the coefficient $\varphi = 1.12$ basing on the literature data (KAWKA et AL. 1980, 1987-1997) which show that for cutting through the fibers in the wood the consumption of the energy amounts to about 12% of this energy which is necessary for the wood subdivision. Taking into consideration the above assumption the value of the force F_P (see Fig. 2) to be used by the knife which is acting on the wood in order that the chips could be separated, will be determined by the relationship:

$$F_P = \frac{1.12 F_{N2} \cdot c(\cos\delta + \mu_3 \sin\delta)\left[\left(\frac{\mu_2}{\mu_1} + 1\right)\cos\gamma + \left(\frac{1}{\mu_1} - \mu_2\right)\sin\gamma\right]}{\frac{\cos\delta}{\mu_1} + \left(\frac{\mu_3}{\mu_1} - 1\right)\sin\delta + \mu_3 \cdot \cos\delta} \tag{7}$$

The force F_P reaches the highest value (during the subdivision of wood) when the log or a cluster (bundle) of wood of the greatest diameter is being subdivided as then the motor that is driving the chipper consumes most energy from the network. The power demand is the highest then. It is a common knowledge that the maximum power is a sum of the power consumed by the motor from the network and the power obtained through the utilization of the kinetic energy of the rotating masses (mainly of the chipper drum). The kinetic energy utilization of the rotating masses depends mainly on (KAWKA et AL. 1980, 1987-1997):

– the moment of inertia of the rotating parts of the chipper assembly – motor reduced on on the chipper shaft, B_{mk},

– time t_r, of cutting by knives the wood raw material of length, l,

– average angular velocity $\omega_{\acute{s}r}$ of the chipper drum,

– coefficient δ_k of non-uniformity in the machine movement (for the drum chipper with V-belt gear $\delta_k \approx 0.2$),

– efficiency η_o of the electric motor and of the mechanical gear, which in the case of drum chippers amounts to $\eta_o \approx 0.75$.

The optimum value of the moment of inertia B_{mk} can be calculated from the formula (1), (2):

$$B_{mk} = \frac{\lfloor P_{\max} - (P_s - P_j) \rfloor \cdot t_r}{\omega_{\acute{s}r}^2 \cdot \delta_k \cdot \eta_o} \tag{8}$$

where: $P_{\max}$ – maximum value of the required power for the subdivision of wood,

P_s – average power of the motor driving the chipper,

P_j – motor power at idle running, during the gaps in feeding the wood.

The time t_r may be expressed using the formula:

$$t_r = \frac{l}{l_{zr}} \cdot t_1$$

where: l – length of the wooden raw material being subdivided,
l_{zr} – length of the chips,
t_1 – time of one passage of the knife of the knife through the subdivided wood, amounting to:

$$t_1 = \frac{s}{v_o} = \frac{\pi \cdot R_1(\alpha - \delta)}{180^\circ \cdot v_o}$$

where: s – length of the knife passage through the wood depending on the thickness of the wood being subdivided,
v_o – rotational speed of the knife cutting edge.

Thus:

$$t_r = \frac{l \cdot \pi \cdot R_1(\alpha - \delta)}{l_{zr} \cdot 180^\circ \cdot v_o} \tag{9}$$

Taking into consideration the above relationship in the equation (8) and performing the suitable transformations one will get:

$$P_{\max} = \frac{B_{mk} \cdot \omega_{\text{śr}}^2 \cdot \delta_k \cdot \eta_o \cdot l_{zr} \cdot 180^\circ \cdot v_o}{l \cdot \pi \cdot R_1 \cdot (\alpha - \delta)} + P_s - P_j \tag{10}$$

The value of the $P_{\max}$ power can be determined from the relationship as follows:

$$P_{\max} = F_P \cdot v_o$$

Hence:

$$F_P = \frac{P_{\max}}{v_o} \tag{11}$$

Taking into consideration the relationships (11) and (10) in the equation (7) and performing the suitable transformations we obtain:

$$F_{N2} = \left[\frac{B_{mk} \cdot \omega_{\text{śr}}^2 \cdot \delta_k \cdot \eta_o \cdot l_{zr} \cdot 180^\circ}{l \cdot \pi \cdot R_1(\alpha - \delta)} + \frac{P_s}{v_o} - \frac{P_j}{v_o}\right] \cdot$$

$$\cdot \frac{\left[\dfrac{\cos\delta}{\mu_1} + \left(\dfrac{\mu_3}{\mu_1} - 1\right)\sin\delta + \mu_3\cos\delta\right]}{1.12 \cdot (\cos\delta + \mu_3 \sin\delta)\left[\left(\dfrac{\mu_2}{\mu_1} + 1\right)\cos\gamma + \left(\dfrac{1}{\mu_1} - \mu_2\right)\sin\gamma\right]} \tag{12}$$

Whether the chip will be cut off from the being subdivided wood depends certainly on the value of the force resisting against shearing F (Fig. 4). This force can be determined from the relationship (6) after the equation (12) were taken into consideration.

$$F_f = \left[\frac{B_{mk} \cdot \omega_{\text{śr}}^2 \cdot \delta_k \cdot \eta_o \cdot l_{zr} \cdot 180^\circ}{l \cdot \pi \cdot R_1(\alpha - \delta)} + \frac{P_s}{v_o} - \frac{P_j}{v_o}\right] \cdot$$

$$\cdot \frac{\left[\frac{\cos\delta}{\mu_1}+\left(\frac{\mu_3}{\mu_1}-1\right)\sin\delta+\mu_3\cos\delta\right][\cos(\gamma-\delta)(1-\mu_4\mu_2)-\sin(\alpha-\gamma)(\mu_4-\mu_2)]}{1.12\cdot(\cos\delta+\mu_3\sin\delta)\left[\left(\frac{\mu_2}{\mu_1}+1\right)\cos\gamma+\left(\frac{1}{\mu_1}-\mu_2\right)\sin\gamma\right]} \tag{13}$$

The condition under which the chips are cut off may be formulated as follows:

$$\tau = \frac{F_f}{b_s \cdot l_{zr}} \geqslant R_{t\parallel} \tag{14}$$

where: $R_{t\parallel}$ – the shear strength of the wood parallel to the grain.

The maximum length of the wood cutting area with the knife $b_{s\,\max}$ depends on the chipper effectiveness and the coefficient φ

$$b_{s\,\max} = \frac{Q\cdot\chi_p}{\psi\cdot\varphi\cdot v_f\cdot H\cdot 3600}\ [\mathrm{m}] \tag{15}$$

where: χ_p – conversion factor of the units m^3/mp (= cubic meters/space meters),
Q – chipper effectiveness [mp/h],
v_f – speed of feeding the wood with the wood feeder [m/s],
H – the diameter or thickness of the wood being subdivided [m],
φ – coefficient of the stoppages in feeding the chipper with the wood,
ψ – coefficient giving consideration to the cutting time with the knives of the wood of length l in relation to the total time of subdividing this raw material.

The coefficient ψ can be expressed with the formula:

$$\psi = \frac{t - t_r}{t} \tag{16}$$

where: t – total time of the subdividing of the wood of the length l,
t_r – time of cutting the wood with the knives determined with the relationship (9),

$$t = t_p + t_r$$

where: $t_p = l/v_p$ – time of feeding the wood of length l.
Hence:

$$\psi = \frac{t_p}{t_p+t_r} = \frac{1}{1+\frac{t_r}{t_p}} = \frac{l_{zr}\cdot 180^\circ\cdot v_o}{l_{zr}\cdot 180^\circ\cdot v_o + \pi\cdot R_1(\alpha-\delta)v_f} \tag{16 a}$$

Taking into consideration the relationships (15) and (16 a) in the equation (14) we obtain, after transformations, the relationship determining the value of the shearing strains in the wood being subdivided.

$$\tau = \frac{F\cdot\varphi\cdot v_f\cdot H\cdot v_o\cdot 6.48\cdot 10^5}{Q\cdot\chi_p\,[1.8\cdot 10^2\cdot l_{zr}\cdot v_o + \pi R_1(\alpha-\delta)\cdot v_f]} \tag{17}$$

The symbols used in the above formula mean accordingly: Q – effectiveness of the chipper in mp/h, v_f – the speed of feeding the wood by a feeder in m/s,

v_o the peripheral speed of the drum in m/s, H – the diameter of thickness of the wood raw material in m, l_{zr} – length of the chips in m, R_1 – the drum radius (Fig. 1) in m, χ_p conversion factor for m^3 of wood into mp (space meter) of wood, F – force of the wood shearing resistance (Fig. 4) in kN, γ, δ – the angles shown in the Figure 4. The value of force F is determined in the formula (13). Using the formula (17) one can calculate the value of the shear strength in the wood during the separation of the chips (in the plane of their separation), and define the parameters of the chipper operation (e.g. its operating efficiency) when the chips are properly separated – the inequity is satisfied $\tau \geqslant R_{t\|}$.

CONCLUSIONS

Basing on the theoretical analysis it is possible to draw the conclusion that the proper conditions for separation of chips are closely connected with the chipper efficiency. At too high efficiencies of the wood subdivision (having determined the length and moisture content) the shearing stresses in the planes of chips separation are too low to create the possibility for a phenomenon of the wood shearing (cutting of the chips).The separation of the chips does not take place in the way of their cutting off (wood shearing), but as a result of the accidentally appearing phenomena of crushing and breaking and this leads up to a considerable deterioration of the chip quality. The potential efficiency of the chips separation depends mainly on the wood moisture content. Decisive are also such factors as the wood shear strength parallel to the grain (depending on the kind and moisture content of wood) as well as the kinetic energy of the masses rotating in the chipper. The use of this energy depends among others on the length of wood.

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OPORY ROZDRABNIANIA DREWNA W RĘBARCE BĘBNOWEJ

Streszczenie

Przeprowadzono analizę sił działających na drewno w procesie jego rozdrabniania w rębarce bębnowej oraz naprężeń występujących w tym czasie w drewnie. Na podstawie analizy teoretycznej stwierdzono, że prawidłowe warunki oddzielania zrębków od reszty drewna są uzależnione od wielu czynników, m.in. od wydajności rębarki. Określono wydajność, w jakiej zrębki są „czysto" odcinane, a nie oddzielane w wyniku przypadkowo występujących zjawisk miażdżenia i łamania drewna. Wyprowadzono wzór umożliwiający obliczenie optymalnej, z tego punktu widzenia, wydajności rębarki. Określono też wpływ parametrów konstrukcyjno-eksploatacyjnych rębarki na proces oddzielania i jakość wytwarzanych zrębków.

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