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THE SYSTEM WOOD CHIPPING IN DISC CHIPPER - PROBLEMS OF UNIFORMITY OF CHIPS LENGTH

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ABSTRACT

The system wood chipping in disc chipper Carthage-Norman in industrial plant in Poland was investigation, because there were problems with obtaining homogeneous length of chips. The knife height, wedge angle of knife, clearance angle (pull-in angle), spout angle, average log diameter and construction parameters of chipper have been measured.

These parameters were used to determine analytical of average length of chips in the studied disc chipper - Carthage-Norman. Model in Matlab/Simulink for the computation of the chip theoretical length was used.

Also carried out the calculation and simulation to determine the maximum and minimum length of chips that can theoretically occur while cutting wood in the studied chipper.

Finally, the theoretical lengths of wood chips and the actual lengths produced during cutting were compared.

KEYWORDS: Wood chipping, chip formation, length chips, disc chipper.

INTRODUCTION

The chip size and chip quality has important implications for pulp properties, pulp production, and pulp quality, particularly in kraft pulping. Therefore the industrial plants that wood chipping strive to produce chips homogeneous size and shape. One of the chipper parameter critical to the production of quality chips is chip length setting.

The chip length is an important parameter determining the chip thickness (Hartler 1986, Uhmeier 1995, Twaddle 1997) which in its turn, in the case of producing chemical pulp, will determine how well a chip is impregnated with the chemicals used.

The chip thickness to chip length ratio typically varies from 1:4 to 1:10. (Hartler 1986) Within a given wood species, the combined effects of chip length setting, spout angle (ε), wedge angle of knife (β), clearance angle (pull-in angle) (α), knife velocity are primary parameters that can be modified to optimize the relationship between chip length and thickness.

Thus uniformity of chips thickness depends largely on the exact settings length of chips on each knife in disc chipper.

Studies systems wood chipping carried out in industrial plant in Poland (Reczulski 2015). The study showed many operational problems related to obtaining chips of different length in the process of wood chipping. It caused difficulties in further technological processes.

The effect of different operational parameters for a wood chipping process (e.g. the wood species, log diameter and rotational speed) on the size distribution of the wood chips was studied by Hellström et al. (2008), Abdallah et al. (2011), Smith and Javid (1999), Twaddle (1997) and Uhmeier (1995).

Some general studies of the production of wood chips for the pulp and paper industry were carried out by Hartler (Hartler 1986, 1996).

However, laboratory studies don't show the actual operating conditions as occur during wood chipping in the industrial plant.

MATERIAL AND METHODS

This study, were carried out on disc chipper's Carthage-Norman. Chipper had 15 knives. The average diameter of the log was 140 mm.

The differentiated height of each knives protruding from a disk surface was measured by using a depth gauge. It was measured with an accuracy of ± 0.1 mm.

The clearance angle (α) measurement was made using a sensor mounted on a tripod with adapter electromagnetic and calipers. The sensor measures the angled of the outer surface of the knife to vertical axis (a) at a given distance (b = 20 mm).

The ratio of these distances "a" and "b" is sin α.

Then

$$\alpha = arcsin\frac{a}{b} \tag{1}$$

The measurement of the sharpness angle (β) of knives, were made using a universal protractor. The measurement accuracy is ±10'.

The Matlab/Simulink for the computation of the chip theoretical length was used.

RESULTS AND DISCUSSION

Many different studies and analytical considerations (Hartler 1986, 1996; Hellström et al. 2008, 2009; Uhmeier and Persson, 1997; Abdallah et al. 2011; Reczulski 2013; Twaddle 1997, Uhmeier 1995) have been conducted to obtain model that defines the length of the chip during cutting wood in disc chipper. However, the models (or equations) are designed for ideal working conditions that occur while cutting wood in laboratory disc chipper (Fig. 1). Such laboratory conditions do not reflect conditions in the industry. In many, industrial research (Reczulski 2015) can be seen that the improper operation of the chipper causes a deterioration of working conditions and increase of chips of different lengths and thickness. This is due inter alia changes in design parameters of chipper. In this paper, the results of industrial research will be used to develop a numerical model defining the actual length of chips obtained in disc chipper.

References (Hartler 1986, 1996; Hellström et al., 2008, 2009; Uhmeier and Persson 1997; Abdallah et al. 2011; Reczulski 2013, 2015; Twaddle 1997, Uhmeier 1995) was used as a basis for the model proposed in this study. This is the theoretical basis for ideal working conditions for chipper. In the proposed model, input parameters are the cutting radius (Rc), knife height (H), clearance angle (α), spout angle (ε), average log diameter (d) and the number of knives on the disk.

These parameters were determined from studies of system wood chipping in disc chipper.

Differentiated knife height "H"

During the study it was found that this parameter for all of the chipper knives ranged from 11.5 to 14.0 mm for a constant width of the knives. Thus, the difference in distance knives from disc "cut" occurs to 2.5 mm. Accordingly, the gap between the blade knives and the place of the anvil ranged to 2.5 mm.

Theoretical of chips length "L"

The chip length setting is calculated as the knife edge projection distance above the face plate divided by the sin ε of the spout angle (Abdallah et al. 2011; Reczulski 2013) (Fig. 1).

$$L = \frac{H}{sin\varepsilon} \tag{2}$$

where: *H*– heights of each knives protruding from a disc surface,
ε – spout angle.

This Eq. 2 is only applicable when the in-feeding wood touches the disc face. The chips length can be adjusted by changing the knife height. In the case of a dropfeed it happens that the chips length is different. Especially in disc chippers with several knives.

Most of the wood chippers have an external feeding system, which allows to control the feeding speed. This keeps the in-feeding wood from touching the disc, and gives the ability to eliminate the energy consumed due to friction.

The parameter - *H*, have a decisive influence on the conditions of chipping wood in the wood chipper and the quality of produced chips. The use of differentiated heights H of each knives protruding from a disk surface leads to cutting wood chips of different lengths L.

Clearance angle (pull – in angle) "α"

The clearance angle (pull-in angle) has major influence on the length of the chips produced in wood chipper, especially the uniformity of this dimension in the following wood chips.

Fig. 1 show the geometrical relationships in the cutting zone of chipper.

There is a close geometrical relationship between the clearance angle (α) and the length of chips (L) (Hartler 1986, 1996).

With Δ ABB1 and ΔB1BC appears that:

$$tg\alpha = \frac{B_1B}{AB_1} = \frac{L \cdot sin\varepsilon}{L_n - L \cdot cos\varepsilon} \tag{3}$$

where:

$$L_n = 2 \cdot R_c \cdot sin\frac{\pi}{i} \tag{4}$$

where: *Ln* - the distance between the knives measured on a chord on the arc cutting of wood log,
Rc - cutting radius, ie. the distance between the axis of the disc and the considered the

point of contact of the cutting edge of the knife with wood log,
i – number of knives in the disc chipper.

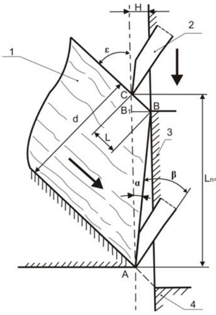

Fig. 1: The cutting wood in disc chipper 1 – log, 2 – knife, 3 – chipper disc, 4 – anvil (α – clearance angles (pull-in angle), L – chip length, H – knife height, ε - spout angle, β – edge angle)

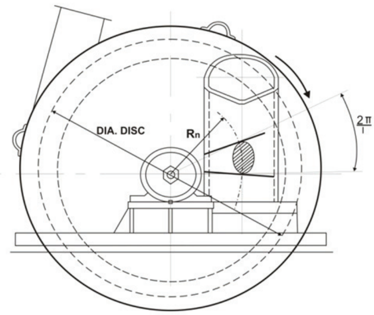

Fig. 2: System wood chipping in disc chipper Carthage-Norman

This formula determines the optimal value of the clearance angle, at which the chips are cut to the required length L (wood is in contact with the disc at the point B), (Fig. 1).

If the actual pull-in angle in disc chipper is smaller than the calculated value -α, cutting wood occurs before contact of log with the disc, and the length of the chip is smaller than a predetermined value L (fines).

When the actual pull-in angle is greater than the calculated value, wood comes into contact too early with the face plate (point B) and cut chips will be deformed or will be longer than a predetermined value L (depending from the design of the disc) (Abdallah et al. 2011; Reczulski 2015).

The analysis of Eq. 3 shows that the optimum value of the angle α depends on the predetermined length of chips L and cutting radius Rc. Cutting radius is a value variable in time, and is depends on the diameter of log and its position in the spout.

It is often assumed for the calculation ($Rc = Rn$) of the average value of the distance from the axis of the disc to the center of the cutting edges of the knives (Rn) (Fig. 2).

For such a chosen pull-in angle, chips are cut in the proper length L only on the radius Rn ie. through the central zone of the cutting edges of the knives.

For radius of less than Rn (closer to the center of the disc) chips are cut in lengths of less than L, while for radius of greater than Rn (closer to the circumference of the disc) chips are longer than a predetermined value L.

The essence of the of cut-off chips of the same length is the variability of the pull-in angle α along the cutting edge of the knife. This value should decrease in the direction from the center of the disc to its circumference. Most often in the disc chipper the pull-in angle is constant along the cutting edge of the knife and produced chips of uneven lengths.

The results showed that the clearance angles (pull-in angles) α for all the knives in the chipper varies slightly from 3° 02' to 3° 07' and to further analysis can be assumed that their value is equal 3°.

Thus, assuming that the clearance angles is a constant value, the parameters that determine the variable length of chips during the cutting wood is primarily the distance between the knives measured on a chord on the arc cutting of wood log (Ln), and knife height (H).

The various height of knives in the disc chipper causes that length *Ln* between the knives considered at a radius of Rc are not the same and therefore could not be fully described by Eq. 4.

If the knives height is too large than the limit value (*H*), (Fig. 3), *Ln*' is:

$$L'_n = L_n - OC \tag{5}$$

With Δ OCC' is:

$$tg\ \varphi = \frac{OC}{OC'}\ then\ OC = OC' \cdot tg\varphi \tag{6}$$

$$OC' = H_1 - H \tag{7}$$

$$L'_n = 2 \cdot R_c \cdot sin\frac{\pi}{z} - (H_1 - H) \cdot tg\varphi \tag{8}$$

If the knives height is too small than the limit value (*H*), (Fig. 4), *Ln*' is:

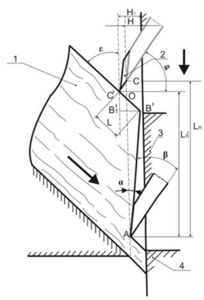

Fig. 3: Chipping configuration for knife height H_1

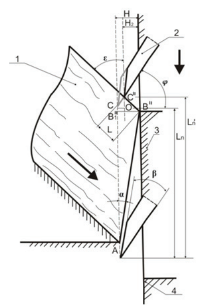

Fig. 4: Chipping configuration for knife height H_2.

$$L'_n = L_n + OC" \tag{9}$$

With Δ OCC" is:

$$tg\ \varphi = \frac{OC"}{OC}\ then\ OC" = OC \cdot tg\varphi \tag{10}$$

$$OC = H - H_2 \tag{11}$$

$$L'_n = 2 \cdot R_c \cdot sin\frac{\pi}{z} + (H - H_2) \cdot tg\varphi \tag{12}$$

An important parameter which affects the length of the chips, and which is present in the above Eqs. 8 and 12 is the parameter *Rc*.

Analyzing height of each knife in the studied disc chipper for any cutting radius *Rc* (Fig. 5, 6) can save that:

Option 1

$$L'_{nmax} = L_n + OC'' + OC \tag{14}$$

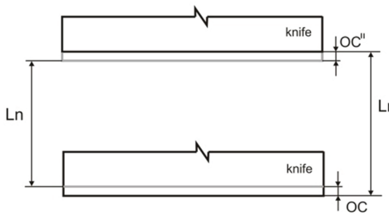

Fig. 5: Chipping configuration for length L_{nmax}^' between the knives.

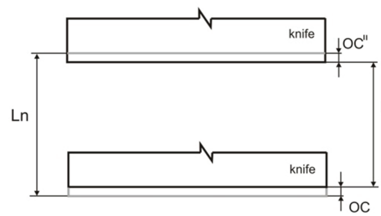

Fig. 6: Chipping configuration for length L_{nmin}^' between the knives.

Option 2

$$L'_{nmin} = L_n - OC'' - OC \tag{15}$$

To determine the radius *Rc*, which is variable parameter during cutting, is necessary to know the diameter of log and its position in the spout and the design parameters of the study chipper.

The Fig. 7 shows the possibility of positioning the log with an average diameter - 140 mm in the spout of disc chipper's Carthage-Norman. In this way was calculated analytically value Rc_{min} and Rc_{max}. The values of these parameters are respectively: 330 ,920 mm.

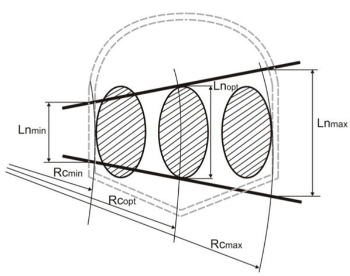

Fig. 7: Possibilities of positioning the log in the spout of disc chipper's Carthage-Norman

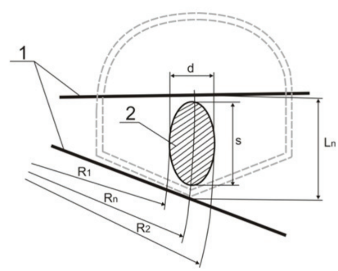

Fig. 8: Setting the log in the middle of the spout of disc chipper

It was assumed that for $Ln \geq Ln_{opt}$ (Fig. 7), length of chips is calculated with Eq. 2, because then each subsequent knife begins cutting of wood when finished cut by knife the previous one.

The parameter Ln_{opt}, occurs in the distance Rc_{opt} and depends on the position of knives in the disc and the actual diameter of the wood. Log cutting for parameter Ln_{opt} shown in Fig. 1.

In this present case, the value Ln_{opt} is not constant for Rc_{opt} = const. due to the different height of each knives protruding from a disk surface.

The maximum value Ln_{opt} which makes chips longest is described as Option 1 (Fig. 5).

The most unfavorable set knives that cause cut chips with the shortest length is Option 2 with the smallest radius *Rc* (Fig. 6).

Model in Matlab/Simulink for the computation of the chip length (for optimal cutting radius $R_1 < R_c < R_2$ and the average log diameter - 140 mm located in the middle of the spout – Fig. 8) was used. Also carried out the calculation and simulation to determine the maximum and minimum length of chips that can theoretically occur while cutting wood in the studied chipper.

The cutting radius (*Rc*), knife height (H, H_1, H_2), clearance angle (α), spout angle (ε), average log diameter (*d*) and the number of knives on the disk are used as input parameters (Tab. 1) in Matlab/Simulink models (Fig. 9).

Tab. 1: Characteristic input parameters.

Parameters	Range
Cutting radius *Rc* (mm)	330-920
Knife height *H* (mm)	13
Knife height max H_1 (mm)	14
Knife height min H_2 (mm)	11.5
clearance angle α (°)	3
spout angle ε (°)	38
average log diameter (*d*) mm	140
number of knives (*i*)	15

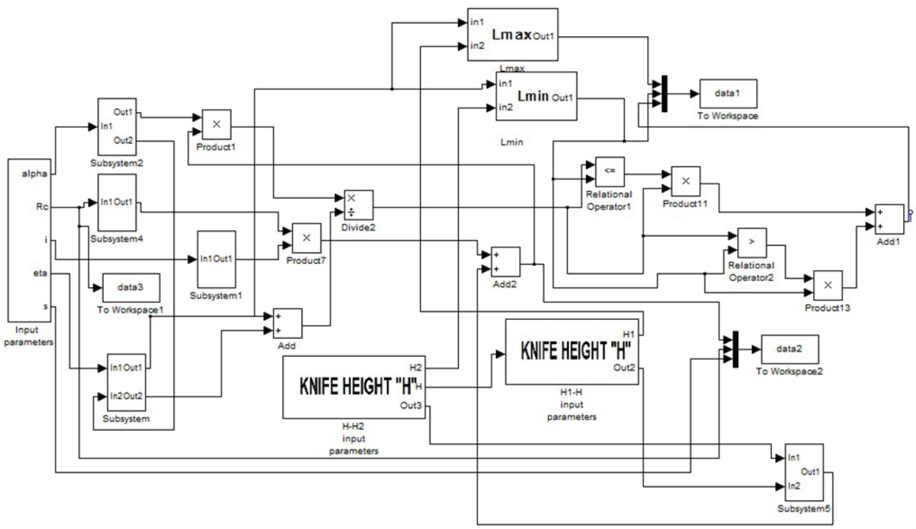

Fig. 9: Panel subsystem block diagram.

The parameters in Tab. 1 were measured in the real industrial conditions and are used as input parameters in Matlab/Simulink models. Numerically calculate the maximum and minimum chips length (L_{min}, L_{max}), that can theoretically arise while cutting wood in the studied chipper were obtained from model. For calculation chips length, the average log diameter (*d*=140 mm) and shape spout of disc chipper have been taken into account, (Fig. 7).

The model output is shown in Figs. 10 and 11.

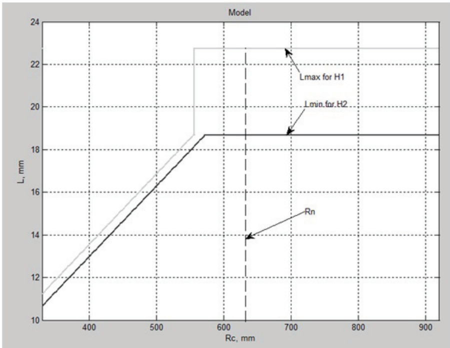

Fig. 10: The simulation results of chips length.

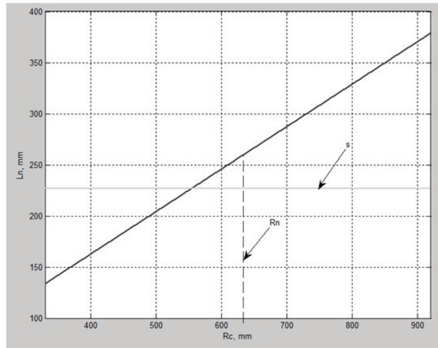

Fig. 11: Comparison of the distance of knives and the length of the contact surface of the wood with disc of the chipper.

It has been calculated numerical that length chips for $Rc_{min} < Rc < Rc_{max}$ oscillate in the range 10.7 – 22.7 mm

for $Rc_{min} - L_{min}$ = 10.7 mm; L_{max} = 11.2 mm

for $Rc_{max} - L_{min}$ = 18.7 mm; L_{max} = 22.7 mm

Fig. 10 shows a large scatter simulation of results for L_{min} and L_{max} for a given range of $Rc_{min}<Rc<Rc_{max}$. It is caused by differentiated height of each knives protruding from a disk surface, too small diameter of the cut wood and distance of knives (*Ln*). This scatter of results will be small when at least two knives will cut wood at a same time. Such a situation is when, Rc < 571.7 mm, assuming d = 140 mm.

When the cutting radius (*Rc*) will be reduced, the distance between the knives also is reduced (*Ln*), (Fig. 11). This causes a reduction actual pull-in angle in disc chipper relative to the optimum value α=3°. In this case, the cutting wood occurs before contact of log with the disc, and the length of the chip is smaller than a predetermined value L.

The decrease in length chips can see in the range of the cutting radius $Rc_{min} < Rc <$ 571.7 mm, (Fig. 10). In the case where Rc > 571.7 mm, each subsequent knife begins cutting of wood when finished cut by knife the previous one. Thus, for Rc > 571.7 mm, the theoretical of length chips, depends mainly on the height of each knives protruding from a disk surface. In this case, the theoretical length of wood chips is calculated using Eq. 2.

Fig. 11 shows a comparison of the distance of knives (*Ln*) and the length of the contact surface of the wood with disc of the chipper (*s*) for d=140 mm in the range of $Rc_{min} < Rc < Rc_{max}$. It can be observed that the lines do not intersect over a range $Rc = Rn$ = 625 mm for a given average log diameter (*d*). The point of intersection in this case is Rc = 571.7 mm. This confirms that each subsequent knife begins cutting of wood when finished cut by knife the previous one.

The theoretical length of the chips, calculated by the model is from 18.7 to 22.7 mm.

The actual average of chips length produced by the chipper was 16-19 mm.

The dropfeed used in the disc chipper is often of cause of various lengths chips - not only in disc chippers with several knives. The above analysis shows that it can happen also in chipper with 15 knives, if the average diameter of the log is too small. In this case each subsequent knife begins cutting of wood when finished cut by knife the previous one. This causes a possible "jumping" wood in the spout and difficulties in obtaining uniformity of chips (Reczulski 2013; Abdallah et al. 2011).

CONCLUSIONS

The uniformity of chips length produced by a disc chipper is keys to increase pulping performance. A chipper which produced fewer overthick chips and pin chips, while achieving a more consistent length -to- thickness ratio, would significantly improve pulping uniformity and pulp consistency.

Obtaining chips of equal length during wood chopping in disc chipper is difficult and impossible from the viewpoint of chipper geometry. Incorrect operation of the chipper causes deterioration of its work and increased chips of different lengths and thus of different thicknesses. Therefore important is continuous monitoring of significant geometrical parameters affecting the chips length (e.g knife height (H), clearance angle (α) or knife edge angle (β).

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