THEORETICAL ASPECTS OF WOOD CROSS MILLING KINEMATICS AND DYNAMICS

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Abstract
A key-factor in the milling process is the chip thickness. Its configuration and values determines the quality of milling and thus the cutting process dynamics.

INTRODUCTION

In order to analyze the kinematics and dynamics of solid wood cross milling it is necessary to analyze the milling process phenomenon for two consecutive rotations of the milling cutter while the cutter forward horizontally on distance $\mathbf{u_z}$ and the calculation of chip (cutting) thickness depending on maximum milling depth $\mathbf{a_{max}}$.

MATERIAL AND METHOD

To determine the chip thickness at a certain time, two positions of the milling cutter are considered. The equation of the two circles centred M_1 and M_2 will be as follows:

- For the circle with the centre in M_1:

$$(x + u_z)^2 + y^2 = R^2$$

- For the circle with the centre in M_2:

$$x^2 + y^2 = R^2$$

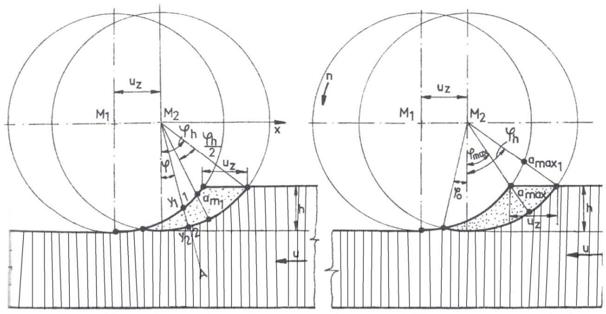

Figure 1 - Chip formation.

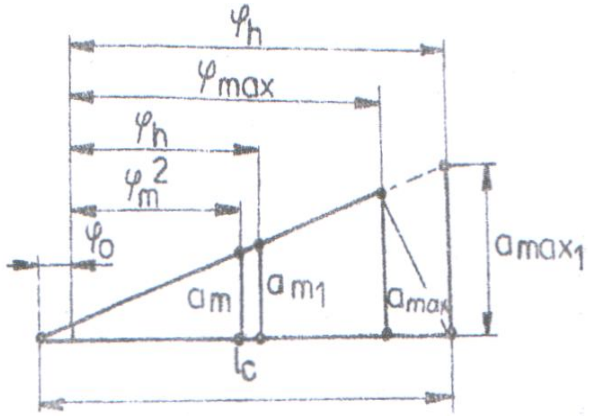

Figure 2. Chip thickness depending on the milling depth

These circles cut cross a beam of straight lines passing through M_2 $x = -ytg\varphi$ and one obtains the ordinate lines of two points that limit the chip thickness M_2A by right side. Thus by crossing the straight line with the circle centred in M_1 one obtains the ordinate line of the 1st point and the following equation:

$$y^2 tg^2\varphi - 2yu_z tg\varphi + {u_z}^2 + y^2 = R^2$$

or

$$y^2(tg^2\varphi + 1) - 2yu_z tg\varphi + {u_z}^2 - R^2 = 0$$

By replacing $1 + tg^2\varphi = 1{:}cos^2\varphi$ one obtains:

$$y^2 - u_z \sin 2\varphi y + ({u_z}^2 - R^2)cos^2\varphi = 0.$$

It results the following equation:

$$y_{1,2} = \frac{1}{2}u_z sin2\varphi \pm \sqrt{\frac{1}{4}sin^2 2\varphi + (R^2 - {u_z}^2)cos^2\varphi}$$

By crossing the straight line M_2A with the M_2 centre circle one obtains:

$$y^2(1 + tg^2\varphi) = R^2$$

or

$y^2 = R^2 cos^{2\varphi}$ sau $y_{1,2} = \pm Rcos\varphi$ of which

$$y_2 = Rcos\varphi$$

Chip thickness corresponding to angle φ resulted is:

$$a_\varphi = \frac{y_1 - y_2}{cos\varphi}$$

$$a_\varphi = u_z sin\varphi + R - \sqrt{R^2 - u_z^2 cos^2\varphi} \qquad [mm]\ (1)$$

As shown in Figure 1 and 2, the chip thickness varies from zero to the maximum value a_{max}. Thus the maximum chip thickness corresponding to a_{max} angle is as follows:

$$a_{max} = a_{\varphi max} = u_z sin\varphi_{max} + R - \sqrt{R^2 - u_z^2 cos^2\varphi_{max}} \qquad [mm] \qquad (2)$$

where $\cos\varphi_{max} = (R-h):(R-a_{max})$

By replacing the angle expression φ_{max} one obtains:

$$a_{max} = R - \sqrt{R^2 + u_z^2 - 2u_z\sqrt{2Rh - h^2}} \qquad [mm]\ (3)$$

Maximum chip thickness can be set approximately by the report resulted from the Figure 1 and 2, as follows:

$$a_{max1} = u_z sin\varphi_h = 2u_z\sqrt{\frac{h}{D} - \frac{h^2}{D^2}} \qquad |mm|\ (4)$$

One can also establish as twice the average chip thickness, the later being considered for angle $\varphi_h : 2$, namely:

$$a_{max1} - 2a_{m1} - 2u_z sin\frac{\varphi_h}{2} = 2u_z\sqrt{\frac{h}{D}} \qquad [mm]\ (5)$$

The average chip thickness can be determined approximately from the surface equality: $a_m \cdot l_c = u_z \cdot h;$

$$a_m = \frac{u_z \cdot h}{l_c} \qquad [mm]\ (6)$$

where l_c is the length of arc circle representing the chip length

$l_c - \sqrt{h \cdot D}.$

To determine the average thickness of the chip the following may be also used:

$$a_m = u_z \cdot sin\frac{\varphi_h}{2} = u_z\sqrt{\frac{h}{D}} \qquad \text{[mm] (7)}$$

As a result of calculations made to determine the chip thickness of wood milling one results:

- The value of chip thickness at a certain time is sett by the 2nd equation;
- The maximum chip thickness can be determined accurately by the 3rd equation but also accepting a normal approximation with the 4th and 5th equations;
- The average chip thickness may be determined by 6th equation 6, but usually one uses the 7th equation.

Chip thickness is a key element in the study of milling dynamics for cross milling, since in this milling method the main parameter is the cutting forces and power.

The study of chip thickness size variation can be done by means of PC software.

In the milling process, throughout the length of contact l_c between the cutter tooth and wood a cutting force is generated on the tooth, which at a certain moment reaches the following value:

$$F_d = K_i \cdot A_i \qquad \text{[N] (8)},$$

where K_i is the specific cutting strength during milling at a particular chip thickness and A_i is the chip cross section at that time.

For the milling machines and tools design calculations and checking purposes the international standards recommend a maximum cutting force of 1 mm per blade according to the formula: $F_{calcul} = 50N/mm$/blade. Thus for a milling cutter, for example, with a blade width of 20 mm, the working force calculated for the cutting machine and tool is: $F_{calcul} = 50 \times 20 = 1000N = 100daN$. In the point of view of the author of the present paper takes into consideration a safety factor (overloading) therefore that the recommended value is:

$F_{calcul} = 1{,}5 \times 100 = 150\ daN$.

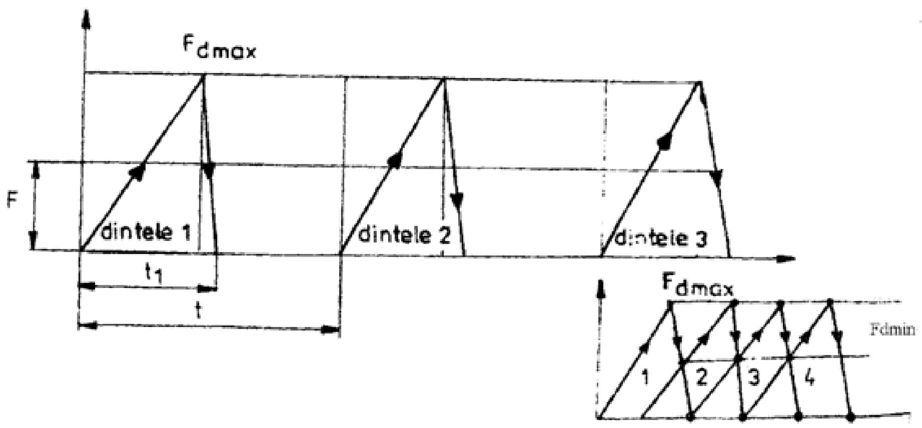

Figure 3. Graphical representation of cutting dynamics.
Legend: "dintele" 1, 2, 3 is the tooth 1, 2, 3.

Based on the average cutting force F one determines the cutting power when milling as follows:

$$P = \frac{F \cdot v}{1000} \, |KW| \qquad [N] \; (9)$$

where v is the cutting speed expressed in m / s

The calculation of the milling cutting speed is determined by the relation:

$$P = \frac{KV}{1000} [KW] \qquad [N] \; (10)$$

where K is the specific cutting work expressed in Nm/cm^3, and V is the volume of material milled per time unit expressed in cm^3/s, which is $V = \frac{A_T u}{60}$ cm^3/s, where A_T is the crossing surface of the milled wood, perpendicular to the feeding direction and u is the feed rate, expressed in m/min.
If the milled section has a height h and width b_1, then V = bhu/60 cm^3/s.

RESULTS AND DISCUSIONS

Given the complexity of wood cross milling and the lack of data on correct values for the dynamic parameters, in this paper we chose the following method for setting them:

- experimental setting of cutting power P according to various factors of milling regime by means of using a precision power meter recorder;
- identifying specific cutting strength specific to cutting forces K, of average equivalent forces F and F_R, and the maximum cutting forces per tooth by using the equations 8, 9 and 10;
- generalization of experimental data on dynamic parameters values by preparing tables, graphs and setting reports calculation.

CONCLUSIONS

Chips formation at cross milling differs significantly from those which occurs in other longitudinal or tangential milling. Thus, for the cross milling with the positive rake angle, the chip formation occurs as follows:

- first phase - the wood fibbers slicing by blade under $\psi = 90°$ angle;
- second two - wood particles shearing according to a longitudinal plan (in fibers plan) normally according to the plan between the early and late wood; this shearing is generated by the teeth raking force;
- third phase – the tangential shearing which is generated by the side blades of raking face; this occurs only in closed cross milling, namely to the manufacturing of joining articles.

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