THE EFFECT OF THE CUTTING EDGE INCLINATION ANGLE ON THE CHIPS EXIT FROM THE CUTTING ZONE DURING PLANE MILLING OF WOOD MATERIALS

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Abstract

The purpose of the study, the results of which are presented in this paper, is the investigation of the regularities of chips and dust particles movement leaving the milling zone. Mathematical equations are established and the following regularities are analyzed for the plane milling process of wood materials: the effect of the cutting edge inclination angle on the chip exit angle; the influence of the cutting edge inclination angle on the speed of the chips moving along the blade and the speed of the chips exiting the cutting zone; the dependencies of the chip exit angle on the friction coefficient of the chips on the surface of the processed material and on the friction coefficient of the chips along the blade surface; the influence of the mill rotation frequency on the chip exit angle.

Key words: *milling, wood material, chipboard, chips, chip exit angle, cutting edge inclination angle*

INTRODUCTION

Woodworking CNC machines are most often used for milling of wood materials. These machines allow the workpiece to be processed from different sides during its single installation on the machine. This technology provides a high quality of processing performance and efficiency. At the same time, most enterprises deal with the problem of the efficient removal of chips and dust from the cutting zone (ROGOZIŃSKI et al. 2015; RUDAK & KUIS 2011).

Woodworking mills operate at frequencies 10000–24000 min^{-1} and feed rates of 3–40 m/min. Referring to this, wood chips and dust have a high initial speed which makes it difficult for the machine aspiration system to capture them (PAŁUBICKI & ROGOZIŃSKI 2016). The chips, not being caught by the aspiration system, can fly away for 3–5 m from the processing zone. Such chips and dust mess up the machine, workpieces, and surrounding space. When chips get into the area of infrared sensors of the CNC machine, they can cause emergency stops and product defects. Insufficient efficiency of chip removal from the cutting zone can cause an increased wear of tools.

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One way to increase the efficiency of collecting waste from the cutting zone of milling woodworking machines is to use the kinetic energy of chips and dust and direct their movement towards the chip receiver (SU et al. 2002; RUDAK & KUIS 2011).

The organization of chip motion in the required direction can be carried out by the inclination of the tool blade. The inclined blade, especially the helical edges, provides

a better chip flow compared to the conventional edge of mill (DARMAWAN et al. 2011).1

To improve the efficiency of their collection by the aspiration system by the use of kinetic energy of chips and dust (KVIETKOVA et al. 2015), it is necessary to understand the processes of the chip and dust exit from the cutting zone.

The purpose of the study is the investigation of the regularities of chips and dust particles movement when leaving the milling zone.

MATERIALS AND METHODS

A chip element with a mass *m*, located in the chip flute of the mill, was considered for the mathematical modelling of the chip exit from the cutting zone. The tool has a radius *R* and rotates with a cyclic frequency ω. The board wood material is milled at the depth of milling *e* (Fig. 1).

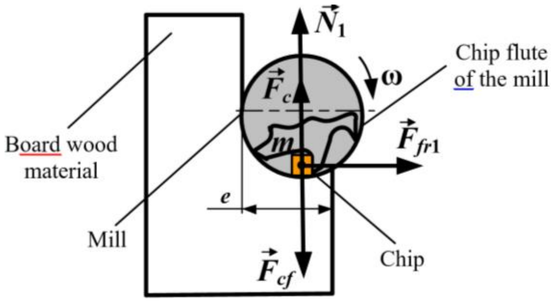

Fig. 1 A chip element, located in the chip flute of the mill

The blade has a cutting edge inclination angle λ. The chip element moves along the blade rectilinearly at the speed V_x (Figure 2, *a*.). When the mill rotates at an angle, providing the release of the chips via flute, the chips leave it at the speed V_{exit}, moving at a chip exit angle ν. The velocity V_{exit} is the vector sum of the velocities of the circular motion V_ω and the velocity V_x.

The motion of a chip particle is considered in the *XYZ* coordinate system, rotating together with the mill at frequency ω. In this case, the *X*-axis is oriented parallelly to the direction of movement of the chips along the blade, and the *Y*-axis is perpendicular to the indicated direction (Fig. 2, *b*.).

Moving along the blade, the chip particle undergoes the action of the centrifugal force F_{cf}, the Coriolis force F_c, and also the reaction of the surface of the processed material N_1 (Fig. 1). The friction force F_{fr1} between the surface of the particle and the surface of the processed material, the gravitational force F_g, and the reaction force N_2 of the blade surface also affect the chip particle movement (Fig. 2, *b*.).

The equation of the equilibrium of forces acting on a chip particle was written neglecting aerodynamic, electrostatic forces and forces acting on a chip particle from other particles:

$$m\vec{a} = \vec{F}_g + \vec{F}_c + \vec{F}_{cf} + \vec{F}_{fr1} + \vec{F}_{fr2} + \vec{N}_1 + \vec{N}_2. \quad (1)$$

The auxiliary angle $\chi = 90° – \lambda$ was introduced. Projection of the forces acting on the chip particle was performed on the axes coordinate.

In the projections on the *X*-axis:

$$ma_x = -F_{fr2} + F_{fr1}\cos(\nu + \chi) - mg\sin\chi. \quad (2)$$

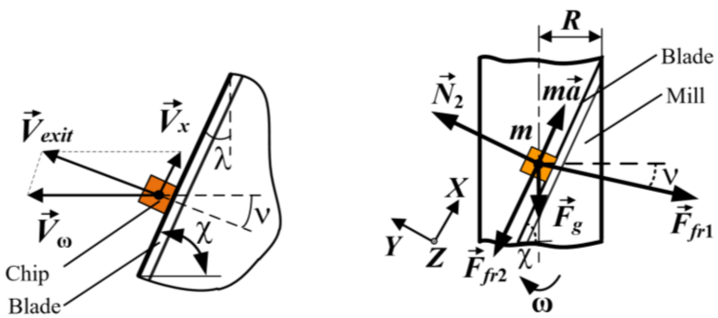

Fig. 2 The scheme of movement velocities at which the chip elements operate (a) and the scheme of forces, acting on the chips in the chip flute of the mill (b).

In the projections on the *Y*-axis:

$$0 = N_2 - mg\cos\chi - F_{fr1}\sin(\nu + \chi). \quad (3)$$

In the projections on the *Z*-axis:

$$0 = F_{cf} - F_c - N_1. \quad (4)$$

The friction force between the particle of chips and the surface of the processed material is determined by the formula:

$$F_{fr1} = \mu_1 N_1, \quad (5)$$

where μ_1 is the friction coefficient between the chip particle and the surface of the material being processed, [-]

The friction force between the chip particle and the surface of the blade is determined by the formula:

$$F_{fr2} = \mu_2 N_2, \quad (6)$$

where μ_2 is the friction coefficient between the chip particle and the blade surface, [-].

Taking equation (4) into account, the equation to determine the friction force between the chip particle and the surface of the material being processed was written down:

$$F_{fr1} = \mu_1 m\left(\omega^2 R - 2\omega V_x \cos\chi\right). \quad (7)$$

From the equation (3):

$$N_2 = \mu_1 m\left(\omega^2 R - 2\omega V_x \cos\chi\right)\sin\left(\nu+\chi\right) + mg\cos\chi. \quad (8)$$

Taking into account equations (2) and (7), and also, knowing that the acceleration $a = \dot{V}_x$ the differential equation was obtained:

$$\dot{V}_x = \mu_1\left(\omega^2 R - 2\omega V_x \cos\chi\right)\cos\left(\nu+\chi\right) - \mu_2\frac{N_2}{m} - g\sin\chi. \quad (9)$$

From the vector sum of the velocities (Fig. 2, *a.)*:

$$\cos(\nu+\chi) = \frac{\omega R\cos\chi - V_x}{\sqrt{V_x^2 + (\omega R)^2 - 2V_x\omega R\cos\chi}}. \quad (10)$$

Equations (8)–(10) allow the process of chip exit from the cutting zone to be analyzed. To solve the equations and designing graphical dependencies, the computer program Math CAD 15 (PTC Inc., USA) was applied. The chip mass was assumed to be m=1g.

RESULTS AND DISCUSSION

The solution of equations (8)–(10) brought the following results. Figure 3 shows the dependence of the chip exit angle ν on the cutting edge inclination angle λ.

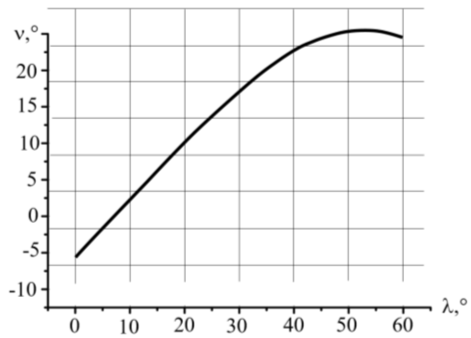

Fig. 3 Dependence of the chip exit angle ν on the cutting edge inclination angle λ (the diameter of the mill 20 mm, the frequency of rotation of the mill 24000 min^{-1}).

For values of the cutting edge inclination angle λ from 0° to 11.3°, the chips are directed downward when they exit. At λ = 11.3° the chip exit angle ν = 0 and chips leave the cutting zone, moving in a plane perpendicular to the axis of rotation of the mill. With a further increase in the angle λ, the chips leave the cutting zone being directed upwards. At an angle λ = 25°, the chip exit angle is ν = 10.4°. With an increase in the angle λ greater than 55°, the angle ν begins to decrease.

Figure 4 shows the dependences of the movement speed V_x of the chips along the blade and the exit speed of the chips from the cutting zone V_{exit} on the cutting edge inclination angle λ.

In Figure 4, it is seen that increasing the angle λ causes an increase in the speed V_x of the movement of the chips along the blade.

The velocity vector V_x is directed along the blade downwards in the interval of values of the angle λ from 0 to 11.3º, which leads to an insignificant increase in the speed V_{exit}. A further increase in the angle λ and the speed V_x results in a decrease in the velocity V_{exit}.

Thus speed V_{exit} increases in the range of angle values from λ from 0º to 55º. This is completely consistent with the results of experiments for milling natural wood. The exit speed of the chips decreased when the cutting edge inclination angle increased (DARMAWAN *et al.* 2011).

Figure 5 shows the dependences of the chip exit angle ν on the friction coefficients.

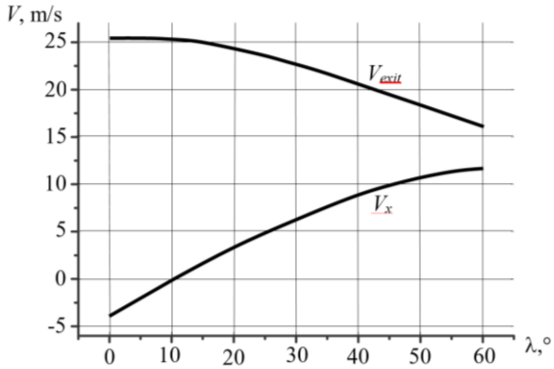

Fig. 4 Dependences of the speed Vx of the movement of the chips along the blade and the exit speed Vexit of the chips from the cutting zone from the cutting edge inclination angle λ (the diameter of the mill 20mm, the frequency of rotation of the mill 24000 min^{-1}).

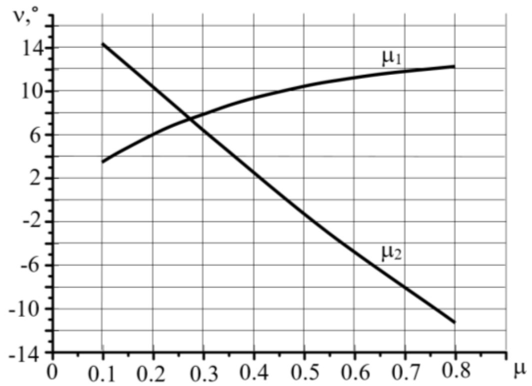

Fig. 5 Dependences of the chip exit angle ν on the friction coefficient μ1 of the chips on the surface of the processed material (at μ2 = 0.2) and on the friction coefficient μ2 of the chips along the surface of the blade (at μ1 = 0.5) (the mill diameter 20 mm, the cutting edge inclination angle λ = 25º).

It can be seen from the graphs in Figure 6 that the values of friction coefficients μ_1 and μ_2 have a significant effect on the value of the chip exit angle. This is consistent with the results of studies that showed a significant effect of the tribological characteristics of the blade on the process of wood materials cutting (VOSKRESENSKIY 1955).

Figure 6 shows the dependence of the chip exit angle ν on the frequency of rotation of the mill *n*.

At the frequency of rotation of the mill n = 1000 min^{-1}, the chip exit angle ν = 2.6º, at the frequency of rotation of the mill n = 3000 min^{-1}, the chip exit angle ν = 9.4º, and with a further increase of the frequency of rotation of the mill, the chip exit angle changes only slightly and remains at the level ν ≈ 10º.

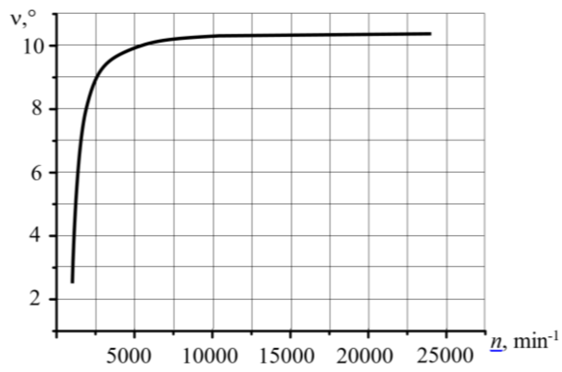

Fig. 6 Dependence of the chip exit angle ν on the frequency of rotation of the mill n (the diameter of the mill 20 mm, the cutting edge inclination angle λ = 25º).

CONCLUSION

Mathematical dependencies allow us to determine the chip exit angle, the speed of the movement of the chips along the blade and the exit speed of the chips from the cutting zone take into account the values of the cutting edge inclination angle, the frequency of rotation and radius of the mill, the chip mass, the friction coefficient of the chips on the surface of the processed material and the chips along the blade surface.

The greatest influence on the value of the chip exit angle is provided by the cutting edge inclination angle. A friction coefficient of the chips along the blade surface has a great influence on the chip exit angle and, the friction coefficient of the chips on the surface of the processed material provides the same effect to a somewhat lesser extent.

The frequency of rotation of the mill when it is more than 5000 min^{-1} does not affect the chip exit angle significantly, but together with the radius of the mill, it determines the chip exit speed from the cutting zone and so the initial kinetic energy of chips and dust.

These mathematical dependencies can be used in the process of constructing wood-cutting mills and in the development of aspiration systems for wood-cutting machines.

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