Design of a Stationary Disc Chipper Project for Dendromass Chipping with Stress Analysis FEM Methods

Jozef Krilek, Branislav Tichý, Ján Kováč, Ján Melicherčík, and Tomáš Kuvik

The design of a stationary disc wood chipping machine was considered, as well as the stress-strain analysis of a cutting knife with a flat and shaped cutting edge, which will produce a dimensional chip. The design consisted of the conceptual design of a cutting knife, a cutting mechanism, and an entire disc chipping machine, which includes cutting tools. The design solution is based on mathematical calculations of the individual parts of the cutting device. Calculations of the cutting mechanism and the cutting tool were performed using the finite element method. The results of the stress analysis found that the maximum stress acting on the edge of the knife during cutting corresponded to the permissible stresses of the knife material and subsequent use in practice. Based on the design and physical parameters of the wood cutting process, the design of the entire chipping machine was simulated and then was modeled using the PTC Creo parametric 5.0 program. Additional finite element analysis was performed using the Creo Simulate 5.0 software.

Keywords: Cutting force; Cutting edge; Chipping device; Stress analysis; Dendromass

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INTRODUCTION

Dendromass is one of the most available energy sources. Unlike oil, natural gas, and coal, it is plentiful throughout the world, and it is renewable. It can be obtained from logging in the form of wood waste, as a residual product in wood processing, or from planned cultivation in order to utilize its energy potential. The primary source of dendromass in Slovakia is from the forestry industry (Kováč *et al*. 2011). For energy purposes, in addition to the part of the harvested wood that is not suitable for use in the wood processing industry, it is also possible to use the so-called residues remaining after harvesting, *e.g.*, the top parts of trees and branches, the ends of trees, calamitous wood (uprooted stumps and the roots of trees), tree thinning, *etc* (Nurek *et al*. 2019). Processed dendromass is increasingly being used as a heat source. Pieces of wood can be burned directly, in the form of wood chips, briquettes, or pellets. The more the forest dendromass is modified, the higher the degree of technology that can be used, which results in lower moisture content and higher calorific values (Malaťák *et al* 2020; Mudryk *et al* 2021). Crushing and chipping of wood waste is the most economically advantageous as well as the most ecological way to process it. Waste material converted into wood chips can be further used as a substitute for wood fuel or for composting and fertilization. When processing biological waste into wood chips, this process is assisted by chopping (chipping) machines, which allow the efficient processing of raw wood materials generated after wood handling. In addition, these machines are also used in the wood industry for the production of agglomerated (fiber and chipboard) and chemical wood processing. Chipping machines are devices that are used for the chipless cutting of wood, which utilizes the cutting effect of chopping knives across the fibers while simultaneously cutting to the required thickness along the fibers. Chopping wood is now gaining the attention of people who realize that chopping wood into wood chips is a reasonable method for utilizing wood and the most possible way to ensure order and a clean forest without finding waste wood. (Owoc and Podlewski 2013). Chopping wood is an essential part of wood processing, which contributes to streamlining the use of wood in the logging industry, as well as processing the wood into new products. In order to make the production process as efficient, high-quality, and economical as possible, the most suitable machines and production technologies must be selected. Currently, chopping wood using chipping machines is one of the most common ways of disintegrating residual wood worldwide. This is one of the reasons why the demand for chipping machines is high nowadays and their development is advancing rapidly.

Fig. 1. Wood waste processing using a chipping device (http://m.sk.biopelletline.com/)

The process of splitting wood into chips using chipping machines of this type is primarily dependent on the system of forces acting on the wood through the chopping knife. A good chip is created when the "clean cutting" of wood occurs. This is expected when the unevenness (τ) is greater than the R_t, where τ is the shear stress in the wood and the R_t is the shear strength of the wood parallel to the fibers. The quality of the chips can undergo considerable deterioration (Kawka 2003; Beňo *et al*. 2018). The cutting tools, *i.e.*, the knives and counter knives, in chipping machines work intermittently and are highly stressed. A cutting knife is characterized by the material and the angle of the cutting edge (β), and when mounted on the cutting disc, by the value of the overlap from the plane of the disc, and when working, by gradually changing the radius of the cutting edge blade. In particular, the steel used for the production of cutting tools must have a high hardness, the cutting edge must be resistant to abrasion and dulling, and the blade material must have a sufficient toughness rating to meet certain types of tool steels, *e.g.*, 19 132, 19 559, and 19 732 (Barontini *et al* 2014; Ťavodová and Kalincová 2018). By reducing the angle of the blade, the proportion of needle-shaped and undersized chips decreases. In addition, as the blunt radius increases, the proportion of dust increases and the sharpness of the cut decreases. The overlap of the knives from the plane of the disc represents the set length of the chips, which also directly proportionally affects the thickness of the chips formed (Štempel 1964).

According to Lisičan (1996), the normal values of the angular elements of a knife (α, β, and δ) are determined from the following criteria: kinematic (α) and technological (β).

From the kinematic point of view, the possibility of feeding the log to the disc is ensured during the operation of the knife, *i.e.*, not only in the position of the log between two knives; for this purpose, the back angle (α) should be at least equal to Eq. 1,

$$\alpha_{min} = arctg\,\frac{z \cdot h_1}{2 \cdot \pi \cdot R_{str}} \quad (1)$$

where α_{min} is the minimum back angle, z is the number of knives, h_1 is the protrusion of the knife edge from the plane of the blade (mm), and R_{str} is the distance from the axis of rotation of the blade to half the length of the knife edge (mm).

The technological aspect (crushing the chopped wood into “chips”) is related to the temperature and type of wood. The optimal temperature for wood is approximately 37 °C during the summer and 39 to 40 °C during the winter.

If the adjustment of the knife and counter knife, *i.e.*, the distance between the knife and the counter-knife, is large (3 to 5 mm) smooth cuts will not occur, and at the point of cutting, bending and stretching between the knife and the counter-knife will occur, which leads to the formation of oversized chips. If the distance between the knife and the counter-knife is set correctly (0.2 to 0.6 mm), then the knife and the counter-knife work as scissors and a clean cut is created (Lisičan 1996).

In order to cut off the wood layer, the knife must apply a total force (F_c) to the wood. This force acts in the direction of the movement of the knife and is equal to the sum of the forces F_O' and F_R'. The component F_O' exerts a force (F_o), which acts in the direction of the wood fibers. This force is needed to separate the chips from the cut layer of wood. The component F_R' exerts a force (F_R) which acts perpendicular to the fibers and cuts the wood fibers. The decomposition of the force (F_R) is shown in Fig 4. The effect of F_R is to rub the cut-out against the gutter. The component F_R'' pulls the chopped cutout to the knife in the opposite direction of friction. This causes a self-feeding effect, meaning that the strain is itself drawn to the disc.

EXPERIMENTAL

Design of the Chipping Device

The chipping machine design model (as shown in Fig. 2) was implemented using the PTC Creo Parametric 5.0 program and consisted of several units. The primary part of the chipping machine is the chipping mechanism, which is securely covered by the machine cover (1) to which the exhaust pipe (2) is attached. The cutting mechanism is driven *via* V-belts (3) and an electric engine (4). All of these parts of the chipping machine are mounted on the frame of the machine (5), which is strong enough to keep the machine in the correct position during operation. The wood is inserted into the chipping machine *via* an inlet chute (6), which includes a feed mechanism (7) driven by a hydraulic unit (8) for a better raw material feeding. The current state of the art does not deal with the construction of cutting equipment, but rather with the size and quality of wood chips (Hellström 2011). The innovative design model ensures higher efficiency of the device by eliminating wear on the cutting edge of the knife.

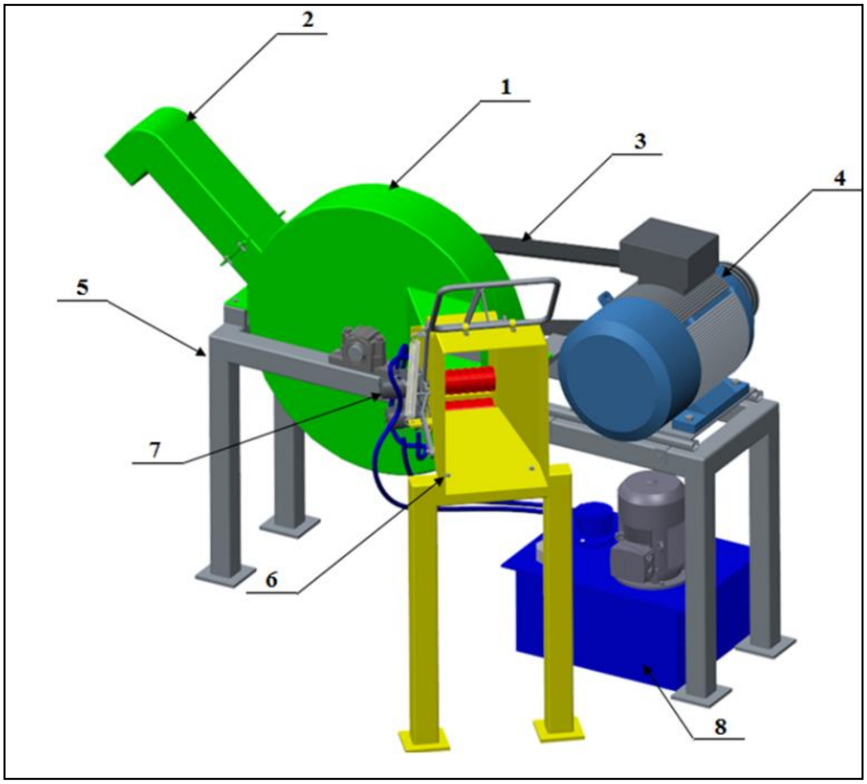

Fig. 2. Design of a disc chipping machine

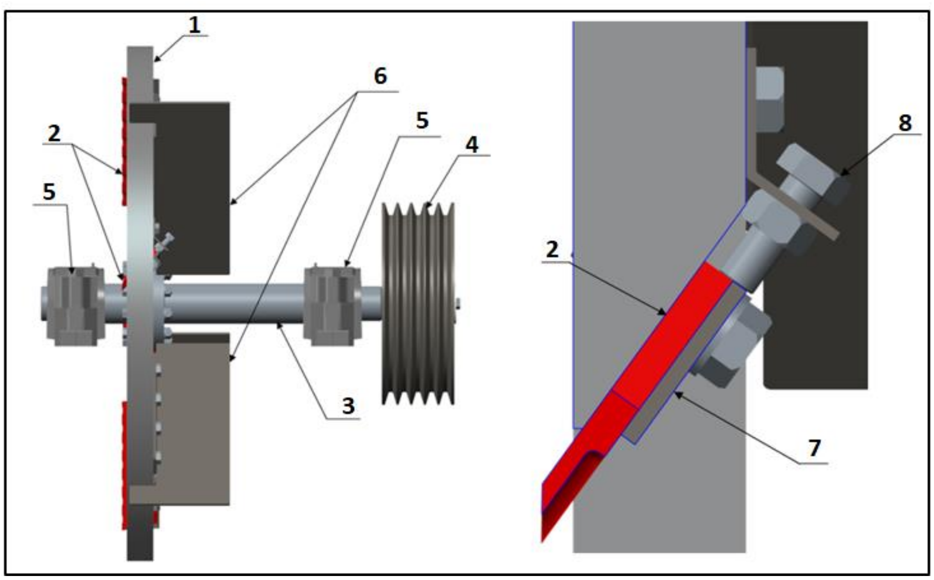

Fig. 3. Constructional design of the cutting mechanism with a detailed view of the mounting part of the knife

(1 - steel cutting disc, 2 - cutting knives, 3 - shaft, 4 - driven pulley, 5 - bearing housing, 6 - ejection blades)

Cutting Mechanism

The chipping mechanism is one of the primary active units of the chipping machine, so its construction is particularly important. Its primary part of the chipping mechanism is a steel cutting disc (1), on the front of which the cutting knives (2) are mounted with screws. The cutting disc is fastened by matching screws to a shaft (3), which rotates *via* bearings housed in bearing housings (5). The drive of the entire cutting mechanism is propelled by the driven pulley (4), which transmits the torque from the electric engine *via* the tongue. The ejection blades (6) screw into the back of the disc and are made of 3 mm thick sheet metal, which prevents the blowing of the chips from the machine. The technical parameters of the construction equipment were designed from commercially available machines, as our contribution is not a solution of the entire equipment. The present study focused on the quality and wear of cutting knives.

Calculation of the Cutting Mechanism

The basic schematics of chopping wood with a disc chipping machine is shown in Fig. 4. A knife with a cutting edge angle (β) is firmly attached to the rotating blade and cuts a layer of wood with a thickness (h_1) from the chopped cut-out. The cut-out rests on the counter knife during the cut. The chopped layer of wood disintegrates into chips with the required dimensions (length *l* and thickness *h*) (Kováč *et al*. 2011).

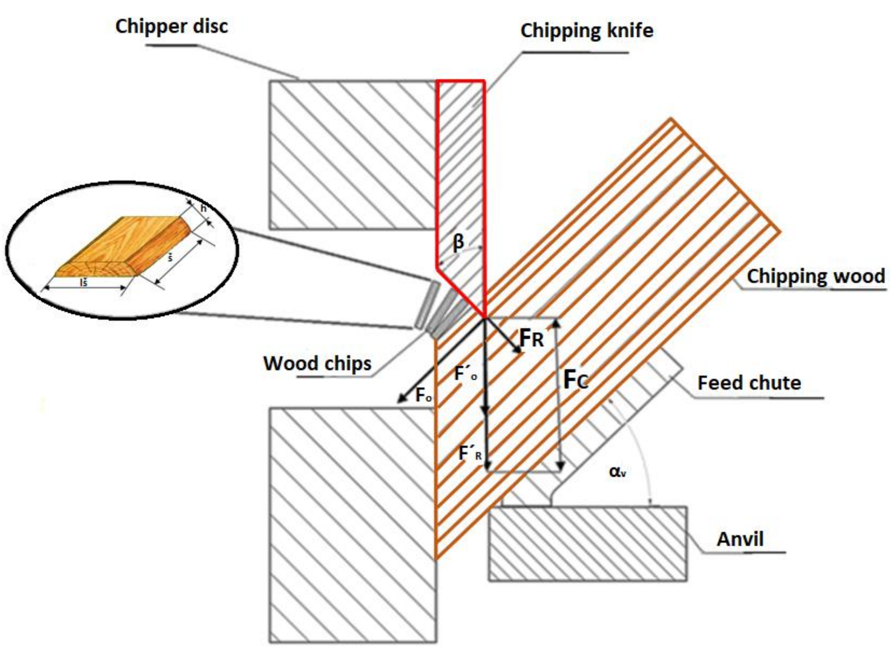

Fig. 4. Wood splitting scheme and force analysis of the splitting process

In order to cut off the wood layer, the knife must apply a total force (F_c) to the wood. Chip separation occurs when α is greater than β, *i.e.*, the force FT is positive. However, if α is less than β, the chip will be pressed against the severed layer of the stem. The angle α is the resulting angle of the inlet gutter given by the angles α_1 and α_2 (Mikleš *et al.* 2004). This force acts in the direction of the movement of the knife and it is given by the sum of the forces F_O' and F_R'; the component F_O' produces a force (F_o) acting in the direction of the wood fibers. This force is needed to separate the chips from the cut layer of wood. The component F_R' causes a force (F_R), which acts perpendicular to the fibers and has the effect of cutting the wood fibers. Figure 4 shows the decomposition of the force F_R. The effect of F_R is to rub the cut-out against the gutter. The component F_R'' pulls the chopped cut-out towards the knife in the direction opposite to friction. It causes a feeding effect on its own, *i.e.*, the wood is drawn to the disc. The cutting results are affected by many factors, *e.g.*, the shape and placement of the gutter, the shape and setting of the knives and the counter knife, the number of knives on the blade and the shape of the blade, the type, moisture content, and temperature of wood, *etc*. Therefore, the optimal ratios for correct chipping are determined experimentally and the machines were built according to empirical data (Krilek and Kováč 2013; Melicherčík *et al*. 2020).

Calculation of Knife Placement in the Drum

When chopping, the pressed part of the wood moves along the back surface of the knife. If the knife were mounted on the blade parallel to its face (Fig. 3) there would be a jump between the knife and the blade and its large shocks would occur after the knife cuts off the layer of wood and the log hits the front surface of the blade with its forehead. Therefore, a smooth transition between the knife and the blade must be ensured in such a way that the knife is inclined at an angle in the blade.

Calculation of the angle of inclination of the knife in the blade = back angle:

$$\alpha = arctg \cdot \frac{z \cdot h_1}{2 \cdot \pi \cdot R} = arctg \cdot \frac{4 \cdot 9{,}2}{2 \cdot \pi \cdot 300} = 1°07' \quad (1)$$

In Eq. 1, z is the number knife (-), h_1 is the overlap of the knife from the knife (mm), and R is the mean cutting radius (mm).

Calculating the knife overhang from the blade surface:

$$l_š = h_1 \cdot \sqrt{1 + tg^2\alpha_1 + tg^2\alpha_2} \Longrightarrow h_1 = \frac{l_š}{\sqrt{1 + tg^2\alpha_1 + tg^2\alpha_2}} \quad (2)$$

$$h_1 = \frac{12}{\sqrt{1 + tg^2 0° + tg^2 40°}} = 9.2\ mm \quad (3)$$

where $l_š$ is the chip length (mm).

Calculation of the Cutting Force

Technical parameters in the implementation of mathematical calculations

The angle of inclination of the inlet gutter in the side view (α_1) equals 0°, the angle of inclination of the inlet gutter in the floor plan ($cos(\alpha_2)$) equals 40°, the knife cutting edge angle (β) equals 35°, the chip length (l) equals 10 mm, and the chip thickness (h) equals 2 mm.

The total cutting force (as shown in Fig. 4) was calculated according to Eq. 4,

$$Fc = F_R' + F_O' = 3449.6 + 153.72 = 3603.32 \ \ [\text{N}] \quad (4)$$

where F_C is the total cutting force (N), F_O' is the force necessary for separating the chips (N), and F_R' is the force necessary for cutting fibers (N).

The relation holds for the force $\mathrm{F_R'F_R'}$, as shown in Eq. 5,

$$F_R' = \frac{F_R}{\cos\alpha_1} = \frac{3449.6}{\cos 0°} = 3449.6 \quad [\text{N}] \quad (5)$$

where F_R is the cutting resistance force (N).

The cutting resistance force (F_R) was calculated according to Eq. 6,

$$F_R = k_c \cdot h \cdot d = 8.624 \cdot 2 \cdot 200 = 3449.6 \quad [\text{N}] \tag{6}$$

where k_c is the total specific cutting force per unit area of cut (*N·mm*$^{-2}$), *h* is the chip thickness (mm), and *d* is the maximum diameter of the chopped wood (mm).

The total specific cutting force per unit area (k_c) was calculated according to Eq. 7,

$$k_c = k_\varphi \cdot K_w \cdot K_d \cdot K_\rho \cdot K_m = 4 \cdot 1 \cdot 1.4 \cdot 1.4 \cdot 1.1 = 8.624 \ \text{N} \cdot \text{mm}^{-2} \tag{7}$$

where k_φ is the specific cutting force per unit area of cut with respect to the cutting direction (1.96 ÷ 4.9) ·(*N·mm*$^{-2}$), K_w is the moisture correction factor (dry wood equals 1 and wet wood equals 0.89), K_d is the corrective factor for the influence of wood species (beech equals 1.4), K_ρ is the correction factor for the effect of wear, *i.e.*, the condition of the cutting edge, of the cutting blades (sharp equals 1.0, medium worn equals 1.4, and worn equals 1.6), and K_m is the correction factor for the effect of wood freezing (K_m is approximately 1.1K_m, which is approximately 1.1) (Svoreň 2009).

Calculation of chip separation force (F_O')

The force $F_O' F_O'$ is distributed into the forces F_1 and F_2, which are perpendicular to the surfaces of the knife edge. Force F_1 causes friction between the wood and the cutting surface of the knife, while force F_2 is distributed on the F_O, in the direction of the wood fibers, and F_T, perpendicular to the wood fibers.

The force F_1 was calculated according to Eq. 8,

$$F_1 = \sqrt{F_2^2 - {F_O'}^2} = \sqrt{268^2 - 153{,}72^2} = 220 \quad [\text{N}] \tag{8}$$

where F_1 is expressed in N.

For the force F_O' F_O', the following relations apply, as shown in Eqs. 9 and 10,

$$F_O' = F_2 \cdot \sin\beta = 268 \cdot \sin 35° = 153.72 \quad [\text{N}] \tag{9}$$

$$F_2 = \frac{F_O}{\cos(\alpha_v - \beta)} = \frac{267}{\cos(40° - 35°)} = 268 \qquad [\text{N}] \tag{10}$$

where F_O' and F_2 are expressed in N.

The resulting angle of placement of the inlet gutter $\alpha_v \alpha_v$ was calculated according to Eq. 11,

$$\alpha_v = \arccos \cdot \frac{1}{\sqrt{1 + tg^2\alpha_1 + tg^2\alpha_2}} = \frac{1}{\sqrt{1 + tg^2 0° + tg^2 40°}} = 40° \tag{11}$$

where α_1 is the angle of inclination of the bottom of the chute from the axis of the chipping machine (°), and α_2 is the angle of inclination of the chute from the axis of the chipping machine in the floor plan (°).

The force F_T stresses the wood *via* tension and the force F_o *via* shear; therefore, there is a need for reduced stress according to the hypothesis of the largest shaping work, as calculated according to Eq. 12,

$$\sigma_{\text{RED}} = \sqrt{3 \cdot (\alpha_0 \cdot \tau)^2 \pm \alpha_{t\parallel}^2} = \sqrt{3 \cdot (0.45 \cdot 26.7)^2 + 2.336^2} = 21\text{MPa} \tag{12}$$

where α_{RED} is the reduced normal strength (MPa), α_0 is the factor between the shear and pressure, $\alpha_{\mathrm{t}\|}$ is the normal tensile stress per unit chip width (MPa), and $\alpha_{\mathrm{tl}\|}$ is the normal compressive stress per unit chip width (MPa).

If the chips are to be separated from the chopped piece of log, the reduced stress σ_{RED} must be equal to or greater than the tensile strength of the wood in the direction perpendicular to the fibers ($\alpha_{\mathrm{tl}\perp}$).

Calculation of the chip separating force (F_O)

The force F_o is created by the action of the edge surface of the knife on the chip face. Its value per unit of chip width ($\check{s}$) is proportional to the chip thickness h ($\check{s}$ is approximately equal to h) and the compressive (tensile) strength of the wood in the direction of the fibers ($\alpha_{\mathrm{t}\|}$). The force F_o was calculated according to Eq. 13,

$$F_{\mathrm{o}} = h \cdot \alpha_{\mathrm{t}\|} = 2 \cdot 133.5 = 267 \quad \text{[N]} \tag{13}$$

where h is the chip thickness (mm), $\alpha_{\mathrm{t}\|}$ is the tensile strength of wood in the direction of the fibers (MPa), and F_o is expressed in $\mathrm{N \cdot mm^{-1}}$ (Krilek and Kováč 2013).

RESULTS AND DISCUSION

The aim of this paper was to gain some knowledge about the course of stress on the cutting edge of the knife. The material EN 41 9802 was used in the construction design of the cutting knife, which is a high-speed tool steel with good toughness. This steel contains the following chemical elements: chromium (Cr), tungsten (W), molybdenum (Mo), and vanadium (V). These chemical elements guarantee the steel abrasion resistance, resistance to high temperatures, and resistance to cyclic stress (Kostúr and Kováč 2014). For applications requiring machining of materials up to a tensile strength of 900 $\mathrm{N/mm^2}$, it is suitable for surface treatment, *e.g.*, nitriding or coating. Depending on the available options, a working hardness of 62 HRC and more is achievable (Ťavodová and Kalincová 2018). The analysis determined whether the cutting knife could withstand the action of the cutting force (F_c = 3.6 kN), as shown in Fig. 5. The force F_c acts continuously on the entire length of the edge of the cutting knife. The grooves made on the cutting edge can affect its strength, so changes in the results compared to a flat cutting edge were investigated. The cutting knives were designed using the PTC Creo Parametric 5.0 program with the definition of the physical parameters of the material EN 41 9802 as follows: a density of 7850 $\mathrm{kg \cdot m^3}$, a modulus of elasticity (E) of $2.05\mathrm{e}10^5$ MPa, and a Poisson's number (μ) of 0.29. The purpose of stress analysis is to determine whether the cutting mechanism is designed in a structurally correct manner (Matej 2013). Only after this was the modeled knife input to the analysis. The cutting force required to load the stressed areas of the cutting knife were determined according to Eq. 4 (Beňo *et al*. 2014; Bodnár *et al*. 2016; Kotšmíd *et al*. 2016). As the next step, the knife model was not allowed to move in directions that corresponded to its actual placement (as shown in Fig. 3). Using the AutoGEM function, a network of elementary elements for final calculations was created (as shown in Fig. 6a and Fig. 8a). As shown in Fig. 6b and Fig. 8b, the cutting knife was plotted as elementary; this function allowed the division of the loaded body into several geometric elements, allowing for more accurate values at the output of the program under loading by individual forces or loads to be obtained. The more elements and nodes used, the more accurate the output and calculation.

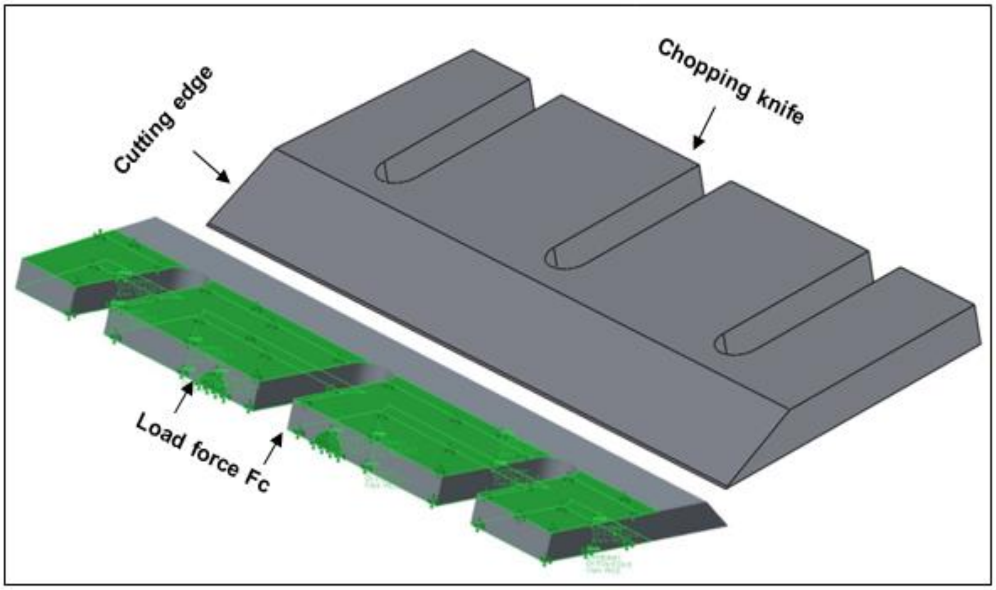

Fig. 5. Chipping knife load and mounting model

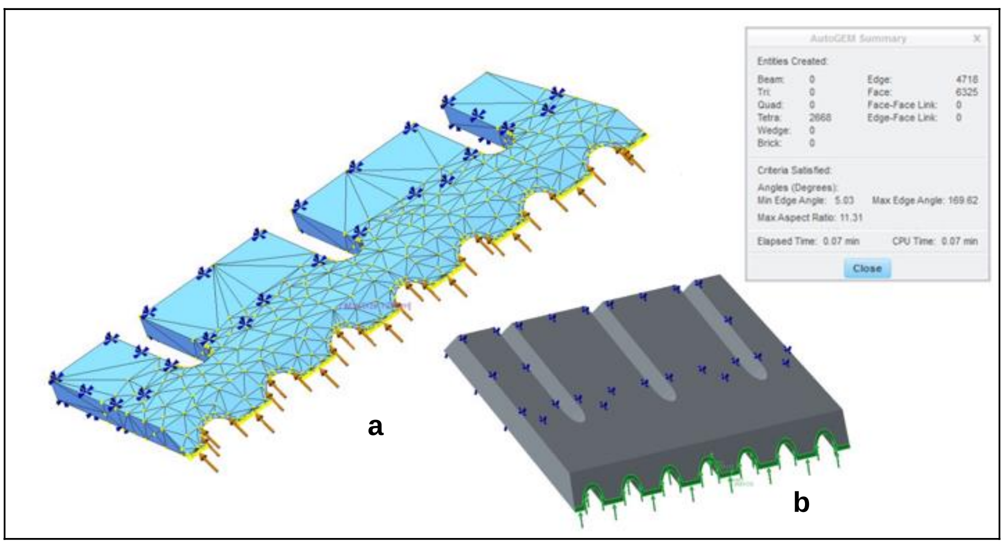

Fig. 6. Finite element net and force loading of the cutting knife with a shaped cutting edge

The cutting edge was loaded with a cutting force (F_c) equal to 3.6 kN, the value of which was obtained using Eq. 2. The force was applied to the surface of the knife edge and the thickness of the surface was equal to the thickness of the chip (2 mm). The knife model with the applied cutting force is shown in Fig. 6. By crosslinking the finite elements, the locals on the cutting part of the knife were thickened with greater precision and smaller gaps were created between the individual elements formed by the crosslinking for the subsequent mathematical calculation. The networking elements formed linear hexagonal elements consisting of 8 knots and a parabolic tetrahedron, each containing 10 knots. They consisted of a large number of vertices, where the individual points could connect and perform a more accurate stress analysis.

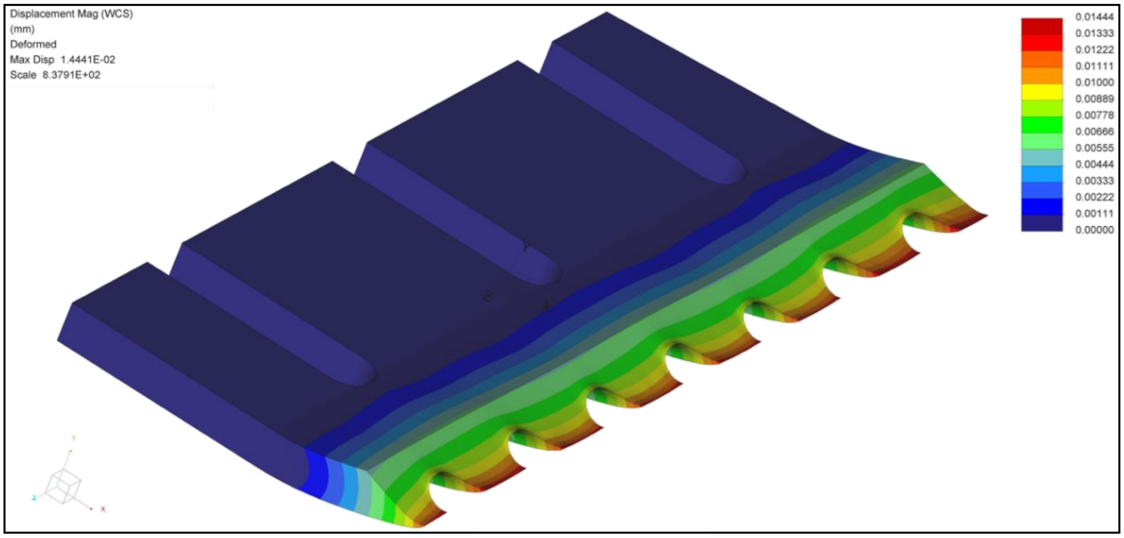

Fig. 7. Deformation of the cutting edge of the cutting knife with a shaped cutting edge

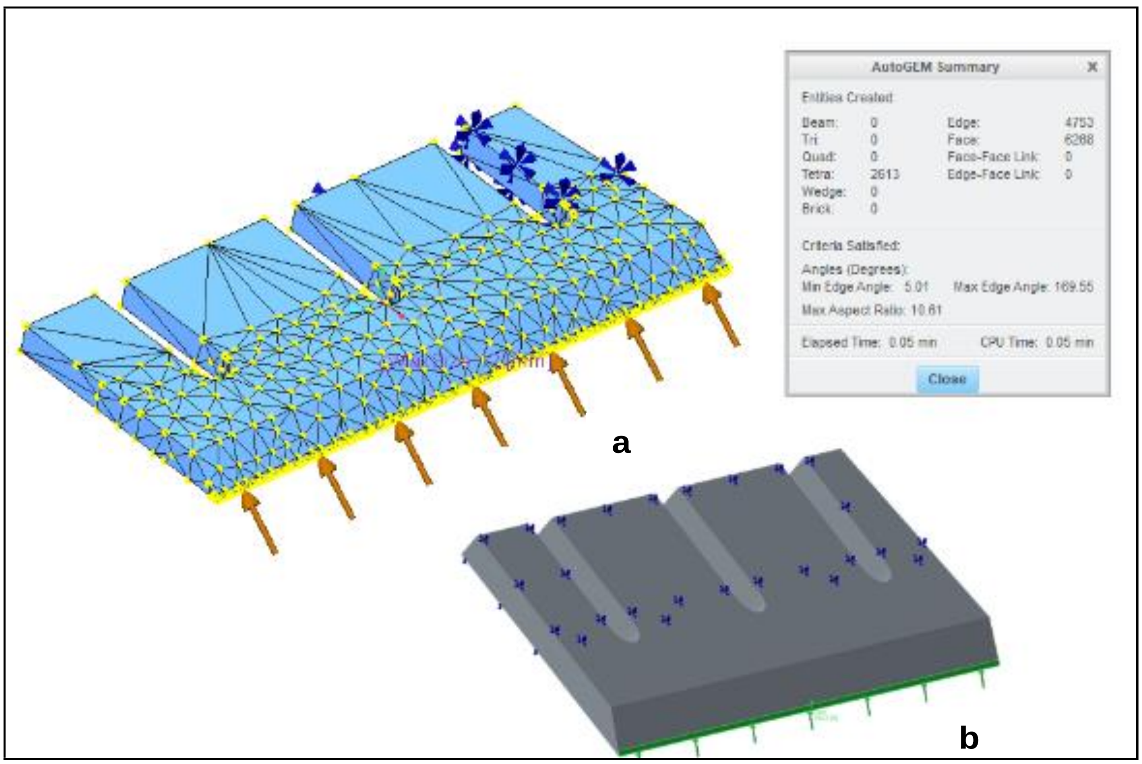

Fig. 8. Finite element net and force loading of the cutting knife with a shaped cutting edge

To compare the stress profiles on the knife with a normal cutting edge, a knife model was created and the parameters for entering the analysis were the same as those set for the knife with grooves. Figure 8 shows a straight-edge knife with an applied cutting force and removed feeds. After starting the analysis and its completion, the results of the total deformation of the knife were obtained. The maximum deflection of the knife in this case is 0.01257 mm, which is a slightly smaller deflection than the knife with grooves (as shown in Fig. 7), where a deflection of 0.01444 mm was recorded. The knife with the resulting deformation is shown in Fig. 9.

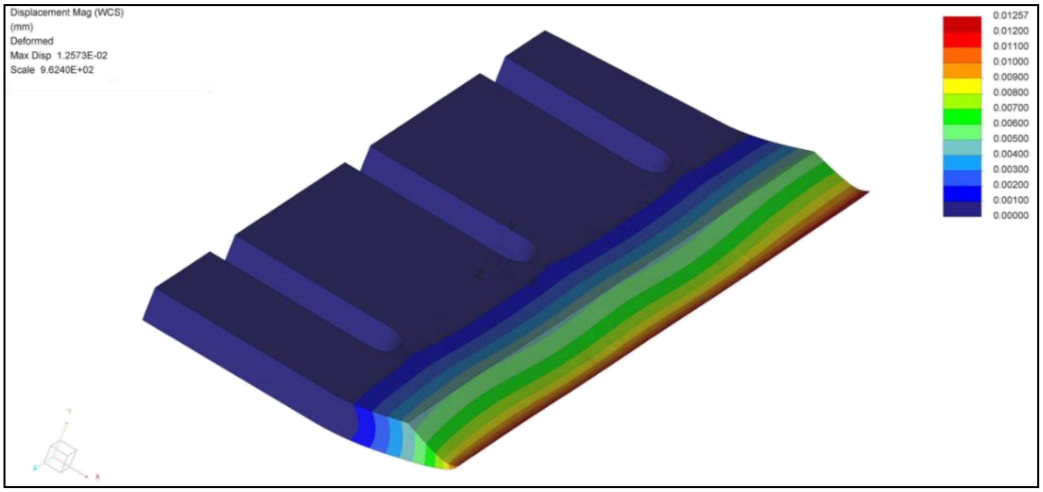

Fig. 9. Deformation of the cutting edge of a cutting surface with a flat surface

As shown in Fig. 10, the stress also ran through the grooves in a uniform course and the maximum stress value recorded was 141 MPa. A closer look shows that the maximum stress value at the clamping grooves for the screws on the edge of the knife was 35 MPa. In fact, the knife is made with a welded blade, where the tool body is made of class 11 structural steel and the blade is made of tool steel class (EN 41 9802). The strength of this tool steel is up to 900 MPa, which implied that the maximum stresses found in the knife did not exceed the allowable value.

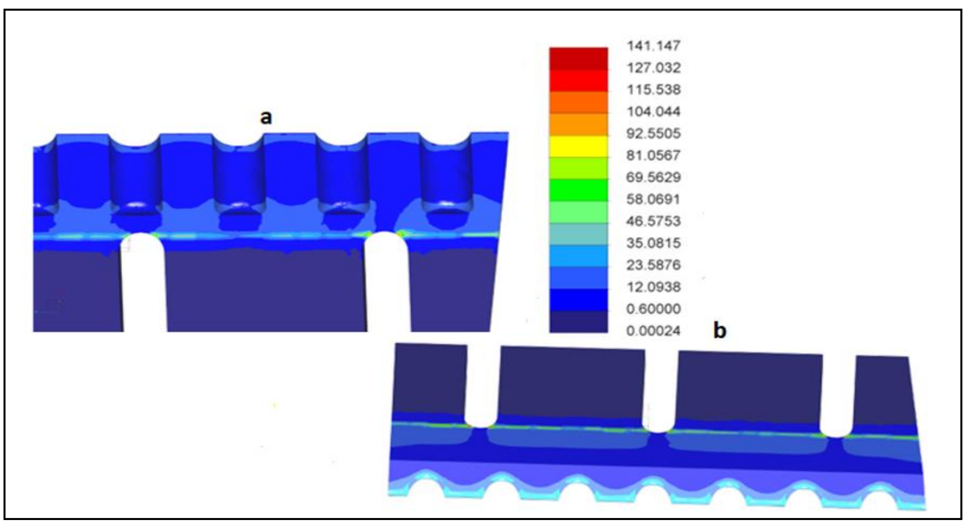

Fig. 10. The course of the stress analysis in the lower and upper part of the cutting knife with a shaped cutting edge

Upon subsequent consideration, it was found that these stresses are greater than the stresses of a slotted knife, due to the smaller area exerted by the force of the knife. The force acting on the knife surface causes greater stresses, which does not agree with realistic assumptions. This fact could be caused by an erroneous estimate of the area on which the cutting force will act on the grooved knife.

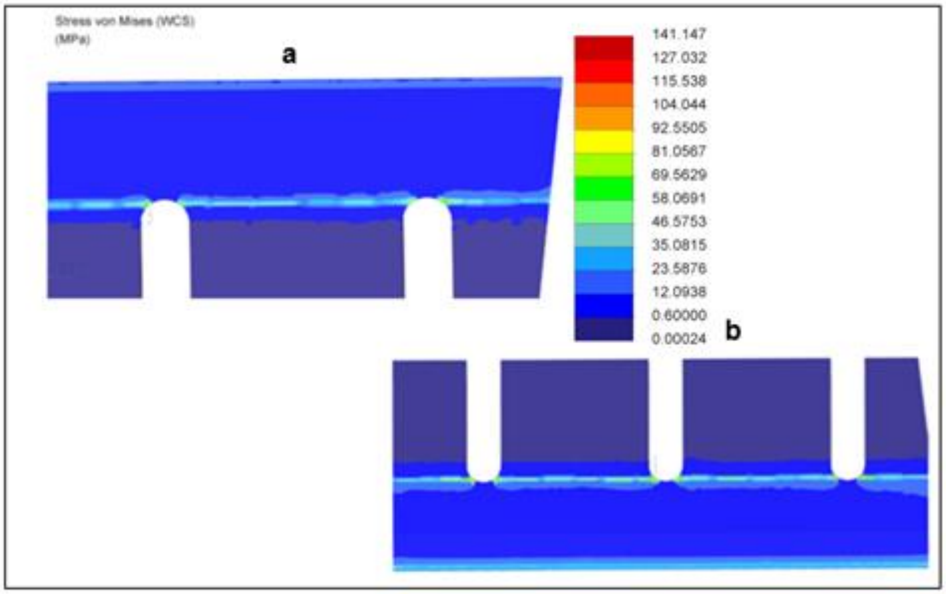

Fig. 11. The course of the stress analysis in the lower and upper part of the cutting knife with a flat cutting edge

CONCLUSION

1. Mathematical calculations accurately determined the shielding force on the basis of the physical and technical parameters during the processing of wood waste or dendromass (F_c equals 3.6 kN).
2. The deformation stress in its basic form is given in Pascals. The value of the final analysis was converted to MPa for the final calculation. The calculated stress-strain analysis evaluated the maximum stress of 141 MPa. There were deformation values at the clamping grooves for the screw connection of the cutting edge of the shielding knife (35 MPa).
3. The value of this analysis would certainly change with respect to the type of connection and surface treatment of the material, *e.g.*, using nitriding, coating, or hardfacing.
4. The maximum deformation of the cutting edge is shown in Figs. 7 and 9. Figure 7 shows the maximum deformation of the cutting edge with a shaped cutting edge of 0.01257 mm, which indicated that it does not limit the function of the cutting knife or its service life. Figure 9 illustrates the output of the stress analysis of a knife with a flat cutting edge, where a deformation stress greater than 0.01444 mm was demonstrated.
5. Stress analysis showed that the material designed by the authors (EN 41 9082) was suitable for the production of chopping knives for the processing of wood waste and dendromass.

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REFERENCES CITED

Barontini, M., Scarfone, A., Spinelli, R., Gallucci, F., Santangelo, E., Acampora, A., Jirjis, R., Civitarese, V., and Pari, L. (2014). “Storage dynamics and fuel quality of poplar chips,” *Biomass and Bioenergy* 62, 17-25. DOI: 0.1016/j.biombioe.2014.01.022

Beňo, P., Kozak, D., and Konjatić, P. (2014). “Optimization of thin-walled constructions in CAE systems,” *Tehnički Vjesnik Technical Gazette* 21(5), 1051-1055.

Beňo, P., Krilek, J., Kováč, J., Kozak, D., and Fragassa, C. (2018). “The analysis of the new conception transportation cableway system based on the tractor equipment,” *FME Transactions* 46(1), 17-22. KEGA 001TU Z-4/2017; VEGA 1/0826/15. WOS, SCOPUS.

Bodnár, F., Beňo, P., Kotšmíd, S., and Luptáková, J. (2016). “Influence of boundary conditions on the solution to a mathematical model for a given wooden plate,” *BioResources* 11(1), 1061-1070. DOI: 10.15376/biores.11.1.1061-1070

Janeček, A., Mikleš, M., and Krilek. J. (2014). “Rationalization on construction and operation of wood chipping production systems,” *Acta Facultatis Technicae* 18(2), 85-95.

Kawka, W. (2003). “The resistances of the wood subdivision in the drum chipper,” *Folia Forestalia Polonica, Series B: Wood Science* 34, 79-89.

Kostúr, J., and Kováč, J. (2014). “Rezné materiály a hodnotenie vhodnosti ich použitia na výrobu nástrojov na delenie dreva[Cutting materials and evaluation of their suitability for use in the production of tools for cutting wood],” in: *XVI. Mezinárodní Vědecká Konference Mladých 2014*, 9-10 September, Prague, Czech Republic, pp. 77-81.

Kotšmíd, S., Kuo, C.-H., and Beňo, P. (2016). “Determination of critical load in a nonuniform circular steel column under the eccentric axial load,” *Mathematical Problems in Engineering* 2016, 1-10. DOI: 10.1155/2016/5987083

Kováč, J., Krilek, J., and Mikleš, M. (2011). “Energy consumption of a chipper coupled to a universal wheel skidder in the process of chipping wood,” *Journal of Forest Science* 57(1), 34-40. DOI: 10.17221/27/2010-JFS

Kováč, J., Krilek, J., and Mikleš, M. (2011). “Energetic consumption a chipper at disintegration wood,” *Journal of Forest Science* 57(1), 34-40.

Krilek, J., and Kováč, J. (2013). *Energetická Náročnosť Sekacích Strojov*[Energy Efficiency disc maschine], Technical University in Zvolen, Zvolen, Slovakia.

Lisičan, J. (1996). *Teória a Technika Spracovania Dreva* [Theory and Technique of Wood Processing], Matcentrum, Zvolen, Slovakia.

Malaťák, J., Gendek, A., Aniszewska, M., and Velebil, J. (2020). “Emissions from combustion of renewable solid biofuels from coniferous tree cones,” *Fuel* 276, article no. 118001. DOI: 10.1016/j.fuel.2020.118001

Matej, J. (2013). "Použitie MSC.ADAMS softvéru na štúdium trenia medzi reťazou a lištou[Use of MSC.ADAMS software to study the friction between the chain and the bar]," in: *Kolokvium ku Grantovej Úlohe č.*[Colloquium on Grant Task no], A. Stacho (ed.), Technical University in Zvolen, Zvolen, Slovakia.
Melicherčík, J., Krilek, J., and Harvánek, P. (2020). "Simulation of stress and strain analysis on a delimbing knife with replaceable cutting edge," *BioResources* 15(2), 3799-3808. DOI: 10.15376/biores.15.2.3799-3808
Mikleš, M., Holík, J., and Mikleš, J. (2004). *Lesné Stroje*[Forest Machinery], Technical University in Zvolen, Zvolen, Slovakia.
Mudryk, K., Jewiarz, M., Wróbel, M., Niemiec, M., and Dyjakon, A. (2021). "Evaluation of urban tree leaf biomass-potential, physico-mechanical and chemical parameters of raw material and solid biofuel," *Energies* 14, 818. DOI: 10.3390/en14040818
Nurek, T., Gendek, A., and Roman, K. (2019). "Forest residues as a renewable source of energy: elemental composition and physical properties," *BioResources* 14(1), 6-20. DOI: 10.15376/biores.14.1.6-20
OwoC, D., and PodlewskI, Ł. (2013). "Analysis of the working time during the production of wood chips used for energy purposes," in: *Mobilné Energetické Prostriedky - Hydraulika - Životné Prostredie - Ergonómia Mobilných Strojov*[Mobile Energy Equipment - Hydraulics - Environment - Ergonomics of Mobile Machines] Technical University in Zvolen, Zvolen, Slovakia.
Štempel, Z. (1964). "Sekanie dreva a sekačky," Bratislava, SVTL 1964, ISBN : 978-80-7414-433-2, 215 s.
Ťavodová, M., and Kalincová, D. (2018). *Možnosti Predĺženia Životnosti Funkčných Plôch Stínacích Nožov* [*Possibility of Lifetime Increasing of Functional Places of Cutting Knives*], Technical University in Zvolen, Zvolen, Slovakia.

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