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BEARINGS LOAD ON A CIRCULAR SAW MILL DURING CUTTING BEECH WOODS

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ABSTRACT

The influence of some technological factors on the magnitude of vibrations of the cutting mechanism in a circular saw mill is presented in the study. The cutting mechanism is driven by four V-belts with a "B" section. During operation, vibro-acceleration was measured using specialized measurement equipment described in the methodology. Measurements are made at four points in the radial direction. Two of them are located near the cutting tool (Ax and Ay) of the machine, and the other two (Bx and By) are near the belt pulley. The results of the experiment are presented graphically. The experiments were carried out at a rotation frequency of 1014 min-1. During the experiments, beech trees were cut down. During the research, attention was paid to some technological factors, including the feed speed of the processed material, ranging from 20 m/min to 60 m/min, and the wood thickness, ranging from 80 mm to 240 mm. The study is aimed at improving the reliability and efficiency of a machine as well as ensuring the accuracy and quality of products.

Keywords: circular saw mill; cutting mechanism; vibrations.

INTRODUCTION

Circular saws are widespread in practice machines. Their universality allows them to be used in diverse woodworking and furniture industry practices. They can be used to process both solid woods from different species, lengthwise and crosswise to the wood fibers, as well as wood-based materials. Circular saws have a relatively simple construction, high productivity, and are easy to maintain. Circular saws should be able to work at different cutting speeds. This is inevitably associated with the machinery required to operate at various rotational speeds. They are a precondition for the emergence of varying cutting forces that create conditions for loads in the mechanisms, and an increased noise and vibration levels lead to errors during operation (Droba *et al*., 2015, Halim *et al*., 2024, Kang *et al*., 2025, Merhar 2021, Orlowski *et al.,* 2020, Schajer *et al*., 2012, Svoren *et al*., 2021, Vesely *et al.,* 2012, Vitchev *et al.,* 2019, Vukov *et al*., 2012, Wei *et al*., 2020, Wu *et al*., 2021). All these loads are borne by the machine bearings, which are constantly subjected to dynamic loads of varying magnitudes and origins. The quality of machining significantly influences every detail. Each part must have an accurate shape, dimensions, and roughness class that meet the tolerances specified in the technical documentation (Kminiak *et al*., 2018; Sydor *et al*., 2021). All these requirements relate to the proper selection of technological cutting modes. The quality of the finished product, the production time, and also the price of the products depend strongly on them. Circular saws in good working order and their operating modes have a significant impact on the entire work process of the enterprise. Constant control and technical serviceability are mandatory parts of the working day in every woodworking and furniture company (Kovatchev *et al.,* 2022). The aim of the present work is to measure and analyse the vibro acceleration (a, m/s2) in the cutting process of beech woods on a circular saw mill. The object of research is the bearing load under varying technological factors. The study is aimed at improving the reliability and efficiency of a circular sawmill machine to ensure the accuracy and quality of products.

MATERIALS AND METHODS

The experiment in the present work was conducted using a circular saw mill *Kara KallionKonepaja Oy* – Finland. The general view of the machine is shown in Figure 1.

Fig. 1 Circular saw mill *Kara KallionKonepaja Oy* – Finland,generalview.

Fig. 2 Circular saw blade D = 1060 mm.

The cutting mechanism of the selected machine has a relatively simple design. This fact helps a lot to conduct the experiments correctly. The mechanism is driven by an asynchronous electric motor with a power of 55 kW, as proposed by the machine manufacturer, and a rotation frequency of 1500 min^{-1}. Torque from the electric motor to the working shaft of the machine is transmitted using a belt drive. Four V-belts with a “B” section are used. The operating frequency of the machine is 1014 min^{-1} which is entirely normal given the diameters of the circular saw blades used. The selected rotational speed is realized by pulleys mounted on the electric motor shaft and the machine shaft. The cutting tool used for the experiments was a circular saw blade with a diameter of 1060 mm shown in Figure 2. The saw is fixed to the circular shaft by an inner and outer circular tool flange, a flange nut, and a pin. The technical data of the cutting tool are shown in Table 1.
The inscriptions in the table are: D - diameter of the circular saw blade, d – blade shaft diameter, B – milling width, α – back angle of cutting, β – angle of sharpening, γ – front angle of cutting, z – number of teeth.

Tab. 1 Technical data of the cutting tool.

Type of instrument	*D* mm	*d* mm	*B* mm	α °	β °	γ °	z бр	Material of the teeth
Circular saw blade	1060	55	5,5	15	50	25	60	HM

The cutting speed was calculated by Formula 1. At a rotation frequency of 1014 min^{-1} the calculated cutting speed was v = 56 m/s.

$$V = \pi.D.n, \text{ m/s}, \tag{1}$$

Where: *D* – diameter of the cutting tool, m;
n –rotation frequency of the cutting tool, s^{-1}.

During the experiment, beech (*Fagus sylvatica*) boards were cut. They have a length of 2500 mm, a width of 400 mm, and thicknesses of 80 mm, 160 mm, and 240 mm. The moisture content of the boards is 40.3% and their density is 823 kg/m^3. Some of the beech boards are shown in Figure 3.

Fig. 3 Beech (*Fagus sylvatica*) boards.

The influence of several critical factors in the cutting process on the vibro-acceleration (*a*, m/s^2) measured in the bearing housings is examined in the paper. The impact of feed speed (*U*, m/min) and wood thickness (*h*, mm) on vibro acceleration (*a*, m/s^2) was determined using a planned two-factor regression analysis. During the research, the feed speed of the processed material is 20, 40, and 60 m/min, and the wood thickness is 80,160, and 240 mm. Table 2 shows the studied factors and their levels in open and coded form.

Tab. 2 Survey factors.

Factors	Factors levels					
	Open	Cod.	Open	Cod.	Open	Cod.
Feed speed *U*, [*m/min*]	20	–1	40	0	60	1
Wood thickness *h*, [*mm*]	80	–1	160	0	240	1

Table 3 shows the experimental matrix. Feed speed is indicated by X_1 and wood thickness by X_2. The results were calculated by the software products *QstatLab5* and *Microsoft Excel*.

Tab. 3 Experimental matrix.

№	*U*, m/min	X_1	*h*, mm	X_2
1	60	+1	240	+1
2	60	+1	80	-1
3	20	-1	240	+1
4	20	-1	80	-1
5	40	0	160	0
6	40	0	240	+1
7	60	+1	160	0
8	40	0	80	-1
9	20	-1	160	0

The intensity of the vibrations was assessed based on the vibro-acceleration (a, m/s^2) measured at different working modes of the machine. The measurements were performed at four measurement points on the bearing housings of the machine's main shaft. Two of them are located near the cutting tool (Ax and Ay) of the machine, and the other two (Bx and By) are near the belt pulley. The circular saw is supported by two double-row self-aligning ball bearings 2312 according to the machine manufacturer. The technical data of the bearing are shown in Table 4. The inscriptions in the table are: *D* - outer diameter, *d* – inner diameter, *B* – width, *C* – basic dynamic load rating, *and C0* – basic static load rating.

Tab. 4 Technical data of the bearings.

Bearing type	*D* mm	*d* mm	*B* mm	C kN	C_0 kN	Maximum allowable rotational speed, min^{-1}
Double-row self-aligning ball bearing 2313	130	60	46	87.1	25.8	5200

The bearings are fixed in a monolithic cast iron body Figure 4. They take on all loads during operation and transmit them to the machine body (www.nskeurope.com, https://www.skf.com). The measurement points on each bearing housing are located mutually perpendicular, radial to the main shaft of the machine Figure 5 (БДС ISO 10816 – 1:2002).

Fig. 4 Cast iron monolithic bearing body.

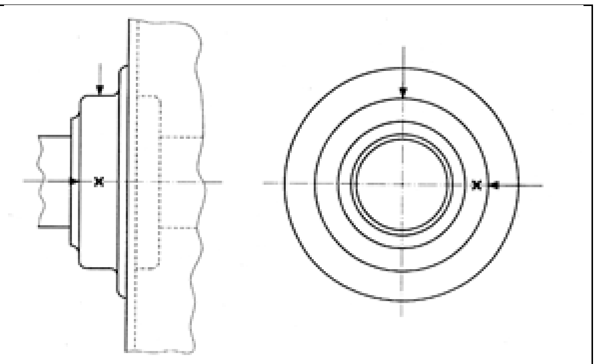

Fig. 5 Measurement points.

The basic scheme of the cutting mechanism is shown in Figure 6. The distance between the circular saw and the front bearing is 240 mm, the distance between the circular saw and the rear bearing is 1040 mm, the distance between bearings is 800 mm and the distance between the rear bearing and belt pulley is 200 mm.

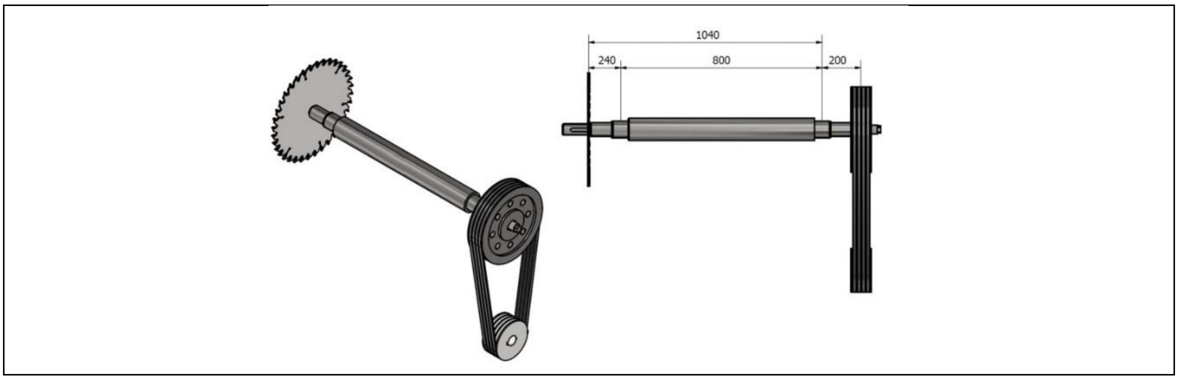

Fig. 6 Cutting mechanism.

Vibro acceleration (a, m/s^2) was measured using a specialized device, the PCE VT-2700, shown in Figure 7. The measurement points are located on the bearing housing of the machine. It responds significantly to the dynamic state in Figure 8.

Fig. 7 PCE VT-2700 Vibration Tester.

Fig. 8 Measuring sensor.

RESULTS AND DISCUSSION

The experimental part includes work trials in cutting beech (*Fagus sylvatica*) boards. The presented results are for the vibro acceleration (a, m/s^2) measured at points A for the bearing near the cutting tool and B for the bearing near the pulley. The measurement directions are respectively: A_x and B_x - in direction parallel to the feed direction. A_y and B_y - in direction perpendicular to the feed direction. Figure 9 shows the vibro acceleration measured at idle in the four directions.

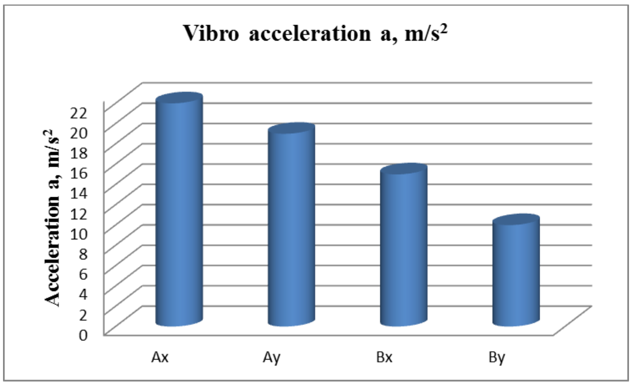

Fig. 9 Vibro acceleration measured at idle.

The regression equations 2 and 3 show the influence of factors at the cutting beech (*Fagus sylvatica*) boards at point A.

$$A_x = 137.666 + 35.666x_1 + 16.833x_2 - 3x_1x_1 - 2.5x_2x_2 - 7.25x_1x_2 \quad (2)$$

$$A_y = 104.111 + 34.666x_1 + 20.833x_2 + 10.333x_1x_1 - 6.166x_2x_2 + 3.25x_1x_2 \quad (3)$$

As it can be seen from the regression equations obtained, the most decisive influence on the vibro acceleration (a, m/s^2) at the cutting of beech (*Fagus sylvatica*) boards is the factor of feed speed (U, m/min). The regression coefficients before X_1 are respectively 35.666 for the A_x direction and 34.666 for the A_y direction. The thickness of the processed material (h, mm) is the second most important factor. The regression coefficients before X_1 are respectively 16.833 for the A_x direction and 20.833 for the A_y direction. The influence of the studied factors in the A_x direction can be seen in Figure 10. Figure 11 shows the vibration acceleration change in the A_y direction.

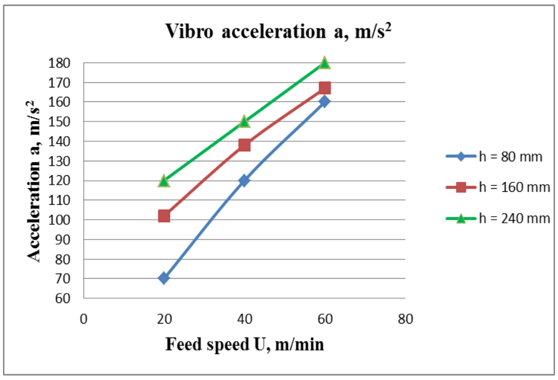

Fig. 10 Vibro acceleration measured at A_x direction.

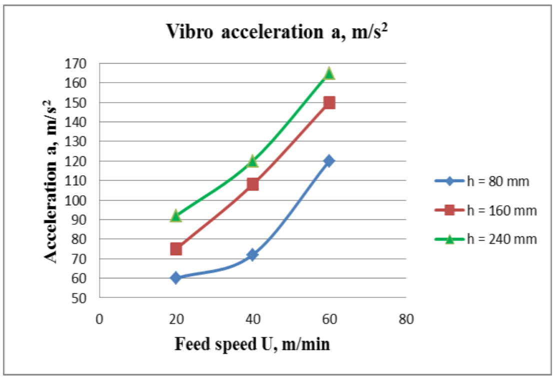

Fig. 11 Vibro acceleration measured at A_y direction.

Figure 10 shows that increasing the feed speed (U, m/min) of the processed material increases the vibro acceleration (a, m/s^2) increases. This tendency was observed in all three thicknesses (h, mm). The lowest measured values are when cutting boards with a thickness of 80 mm are used. The acceleration varies from a = 70 m/s^2 to a = 160 m/s^2. The highest acceleration values were measured at a feed speed of 60 m/min and a board thickness of 240 mm. The acceleration varies from from a = 120 m/s^2 to a = 180 m/s^2.

The same trend is observed in the Ay direction Figure 11. As feed speed increases (U, m/min), the vibro acceleration (a, m/s^2) increases. This tendency was observed in all three thicknesses (h, mm). Slightly lower acceleration values were measured in the Ay direction. For the most significant board thickness of 240 mm and a feed speed of 60 m/min, the value of a varies from a = 92 m/s^2 to a = 165 m/s^2. The processed material is recommended to be fed at a lower speed. For this particular case, 20 m/min and 40 m/min. This will reduce the machine's productivity but will improve machining quality and accuracy (KANG *et al.* 2024, KOVATCHEV et *al.* 2022, KOVATCHEV et *al.* 2023, NASIR *et al.* 2020). Decreases in vibro-acceleration are a prerequisite for maintaining the bearing's technical characteristics for an extended period.

The regression Equations 4 and 5 show the influence of factors on the cutting beech (*Fagus sylvatica*) boards at point B

$$B_x = 69.222 + 11x_1 + 11.333x_2 + 2.666x_1x_1 – 1.333x_2x_2 - 0.75x_1x_2 \quad (4)$$

$$B_y = 62 + 13.5x_1 + 11.333x_2 – 5.5x_1x_1 - 3x_2x_2 + 3x_1x_2 \quad (5)$$

From Equation 4, we can see that in the Bx direction, the two studied factors, feed speed (*U*, m/min) and thickness of the processed material (*h*, mm), have the same influence on the measured vibro acceleration (*a*, m/s^2). The regression coefficients before X1 and X2 are approximately equal (11). In the By direction, the most decisive influence on the vibro acceleration (*a*, m/s^2) at the cutting of beech (*Fagus sylvatica*) boards is the factor of feed speed (*U*, m/min). The regression coefficient before X1 is 13.5. The thickness of the processed material (*h*, mm) is the second important factor – X2 = 11.333. Figure 12 and Figure 13 show the variation in the vibro-acceleration measured in the Bx and By directions..

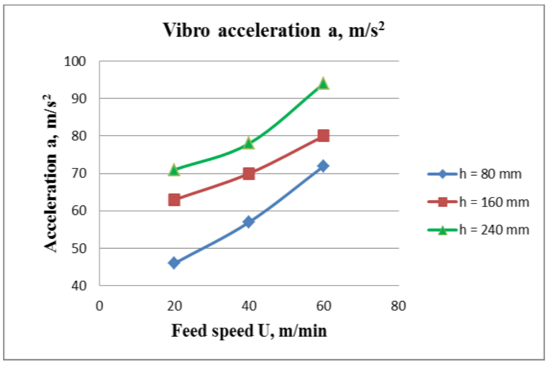

Fig. 12 Vibro acceleration measured at B_x direction.

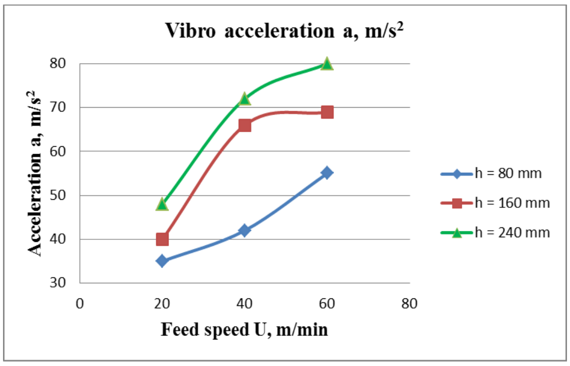

Fig. 13 Vibro acceleration measured at B_y direction.

Figure 12 shows that, in the Bx direction, as the feed speed (*U*, m/min) increases, the vibro acceleration (*a*, m/s^2) increases. This tendency was observed in all three thicknesses (*h*, mm). The lowest measured values are when cutting boards with a thickness of 80 mm are used. The acceleration varies from *a* = 46 m/s^2 to *a* = 72 m/s^2. The highest acceleration values were measured at a feed speed of 60 m/min and a board thickness of 240 mm. The acceleration varies from *a* = 71 m/s^2 to *a* = 94 m/s^2.

The same trend is observed in the By direction. This is shown in Figure 13. When the feed speed grows (*U*, m/min), the vibro acceleration (*a*, m/s^2) increases. This tendency was observed in all three thicknesses (*h*, mm). The highest measured acceleration values are at a feed speed of 60 m/min and a board thickness of 240 mm, from a = 48m/s^2 to a = 80 m/s^2. From the results obtained at point B, it is clearly seen that the vibro acceleration (*a*, m/s^2) levels are lower than at point A. This is entirely normal, as point B is significantly further from the cutting area, and the main load is taken by the bearing at point A.

CONCLUSION

Based on the conducted experimental studies, the following more critical conclusions and recommendations can be drawn:

- The strongest influence on the vibro acceleration (*a*, m/s^2) at the cutting of beech (*Fagus sylvatica*) boards is the factor of feed speed (*U*, m/min). The thickness of the processed material (*h*, mm) is the second most crucial factor. It is evident from the obtained regression equations and the resulting graphs. The presented data show that the selected operating modes of the circular machine do not create a prerequisite for entering dangerous resonance zones. It is recommended to feed the processed material at lower feed speeds (*U*, m/min). It puts less strain on the bearings and protects the machine from costly repairs. On the one hand, a lower feed speed will reduce the machine's productivity. But on the other hand, the lower feed speed reduces vibro acceleration, shocks during working modes, which is a prerequisite for better quality of the processed materials (Xinyu *et al.,* 2023, Kang *et al.,* 2025, Kovatchev et *al.,* 2022, Mohammadpanah *et al.,* 2017, Orlowski *et al.,* 2007, Svoren *et al.,* 2015, Svoren *et al.,* 2022, Ukvalbergiene *et al*., 2007).

- Bearing A, which is located next to the cutting tool, is significantly more loaded during operation. This bearing serves as the central component of the vibrations caused by cutting forces and transmits them to the machine body. Furthermore, this is the bearing exposed to a higher risk of damage.
- Bearing B, which is located near the pulley, is less loaded. It is quite far from the cut area. The vibrations caused by cutting forces do not load it as much as bearing A. Accordingly, the risk of damage is lower.

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