DYNAMICS OF A ROTARY SAW IN TRANSITION PROCESSES

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Abstract

The study presents dynamic calculations of a simple rotary saw equipped in a saw mounted directly on the rotor of an electrical motor in the course of transition processes of: start-up, braking and seizure of the saw in a kerf. During the seizure of the saw in the kerf, usually due to the absence of a cleavage wedge as well as other safety measures, the kinetic energy of the rotary motion of the spindle system (the saw and the rotor of the electrical motor) is transformed into the translational, rotational or, most frequently, plane motion of the processed element and recoil of the material. This results in many very serious accidents and injuries of workers operating the machine tool.

Key words: *dynamics of a machine tool, start-up, braking, seizure, material recoil.*

INTRODUCTION

Machine tools for wood operating at high rotational speeds and employing sharp tools pose serious safety hazards for persons operating them. This refers, in particular, to such machine tools for wood as: the circular saw, bottom spindle milling machine and surfacer, in other words, machine tools where the worker handles the processed elements frequently in direct vicinity of the unprotected tool. In the case of the above-mentioned types of machine tools, it is essential to remember to follow very closely all the safety principles and regulations, especially those referring to the application of appropriate protections, cleavage wedges, tools etc. This study presents a number of remarks connected with the cutting of boards on circular saws together with the dynamic analysis of the movement of the tool (saw) in transitional processes, i.e. during the start-up, braking and seizure of the saw in the kerf.

In order to illustrate the performed analyses, results of calculations for the DMPA-40 transverse-longitudinal saw will be presented [2]. This saw is a simple and cheap tool frequently used in building industry. The table and legs are made of tinned sheet-metal sections. A DNPDa 315 x 2 x 30LB type of saw is mounted directly on the spindle of the one-phase SEg80-2B type electrical motor equipped in a work condenser with the following catalogue data:

- power P = 1.1 kW,
- rotational velocity n= 2870 rpm. (angular velocity ω = 291 rad/s),
- multiplication factor of the starting torque M_r/M_n= 0.65,
- ratio of the maximum to nominal torque M_{max}/M_n= 1,9
- rotor moment of inertia I_w= 0.0014 kgm^2.

DYNAMIC CALCULATIONS OF THE CIRCULAR SAW

In order to carry out dynamic calculations, it is necessary to determine mass moments of inertia of the rotating elements (rotor of the motor which also acts as the spindle and the saw mounted on it).

The moment of inertia I_p of the saw was calculated from the well-known formula [3]:

$$I_p = \frac{m_p D^2}{8}$$

m_p – saw mass,
D – outer diameter of the saw (D= 315 mm).

The mass of the saw was calculated from the following formula:

$$m_p = V \cdot \varsigma_s = \frac{\pi \cdot D^2}{4} \cdot g \cdot \varsigma_s$$

V – volume of the saw,
g – thickness of the saw (g= 2 mm),
ς_s – steel density (ς_s = 7800 kg/m^3)

Following the appropriate substitution and after carrying out calculations, the flowing results were obtained: the mass of saw m_p = 1.21 kg, its mass moment of inertia I_p = 0.0150 kgm^2. The moment of inertia of the spindle system I (the rotor together with the saw) is the sum of the moment of inertia of the rotor I_w and the saw I_p and, in this case, I = 0.0164 kgm^2.

Start-up of the circular saw

The time of the circular saw start-up was calculated using the formula describing Newton's second principle of dynamics for the rotational motion:

$$M_r = I \cdot \varepsilon = I \frac{\Delta\omega}{\Delta t} = I \frac{\omega - \omega_0}{\Delta t}$$

M_r – start-up moment (taken from the catalogue of motors M_r= 0,65 M_n),
M_n – nominal moment (M_n= P/ω),
ε – angular acceleration,
ω_0 – initial velocity (ω_0 = 0),
Δt – time of the start-up.

Hence: $$\Delta t = I \cdot \frac{\omega}{0{,}65 M_n}$$

Following the substitution of numerical values into the above formula, it was calculated that the time of the start-up of the circular saw amounted to about 2 seconds.

The kinetic energy accumulated in the rotating driving system can be calculated from the following formula:

$$E_k = \frac{I \cdot \omega^2}{2} = \frac{0{,}0164 kgm^2 \cdot (291 s^{-1})^2}{2} = 694 J$$

Analysis of the dynamics of the circular saw at the moment of seizure

a/ conditions for the development of seizure and recoil of material.

The seizure and the resulting recoil of material occurs when the points of the saw coming from under the table, due to the lack of cleavage wedge, come into contact with the material before the cutting blade cuts through it completely. This happens when the length of the cut material *l* is greater than chord *s* determined by the intersection of the circumference on which the saw points are situated with the plane of the table (Figs. 2 and 3). The cutting points coming from under the table rub against the slit of the kerf cut it partly (especially, when the cut material is handled improperly, not parallel to the plane of the saw). The absence of the wedge which, among others, prevents the improper feeding of the material creates favourable conditions for the development of this phenomenon. In extreme cases, the cutting points coming from under the table get stuck in the material and the rotational energy of the spindle system is transferred into the processed material which is either rapidly thrown back or lifted and the absence of a protection guard can lead to serious health hazards (Fig. 3).

For the performed calculations, the author assumed that the cut board was a chipboard measuring 1000 x 500 x 18 mm and of the density of ς_p = 700 kg/m^3. Hence, the mass *m* of this board was 6.3 kg.

b/ dynamic calculations

The following two model cases were analysed:

1. The recoil force during seizure has the direction similar to the plane of the processed material. This happens when the points of the saw protrude only slightly above the cut material. The energy of the rotational motion of the spindle and the tool (saw) is then transferred to the processed material in the form of the energy of the translational motion and the processed element begins to travel with a translational motion in the direction which is identical with the direction of the movement of the saw towards the worker operating the machine tool (Fig. 2).

   $$E_k = \frac{I \cdot \omega^2}{2} = \frac{m \cdot v^2}{2}$$

   hence

   $$v = \omega \sqrt{\frac{I}{m}}$$

   After substituting ω = 291 rad/s, I = 0.0164 kgm^2, m= 6.3 kg, we obtain v = 14.8 m/s. The board would achieve this velocity in the case if the energy were transferred in an absolutely elastic manner. In practice, however, part of the energy of the rotational motion of the spindle system is used for deformations and material (board) damage. It is very difficult to estimate the distribution of energy because it can be different in each individual case. If we assume that 50% of the energy is transferred elastically on to the board, while another 50% is used for plastic deformations and machining (damage) of the board, even then the recoil velocity is high and reaches over 7 m/s.
2. The direction of the recoil force during seizure is almost perpendicular to the plane of the processed material. This situation occurs when the cutting points of the saw protrude considerably above the machined material (Fig. 3). The energy of the rotational motion of the spindle together with the tool (saw) is, in such case, transferred to the processed material as the energy of the rotational motion of the processed element and, therefore, it begins to move with a rotational motion and the point of rotation A is situated on the right side of its edge (Fig. 3).

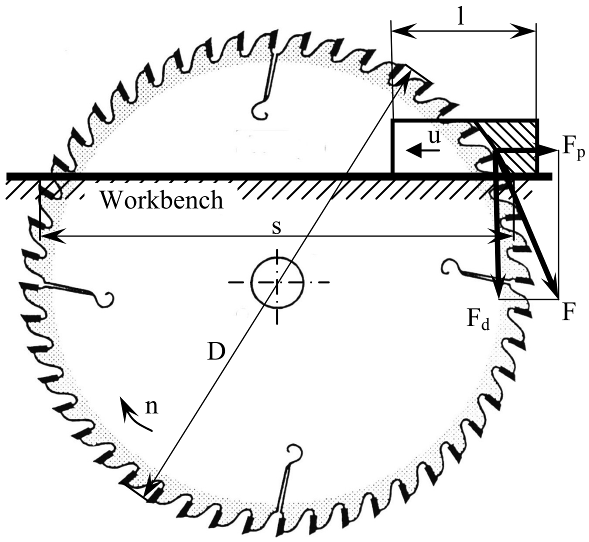

Figure 1. Cutting material on the circular saw – $l < s$ - no conditions for the development of a recoil.

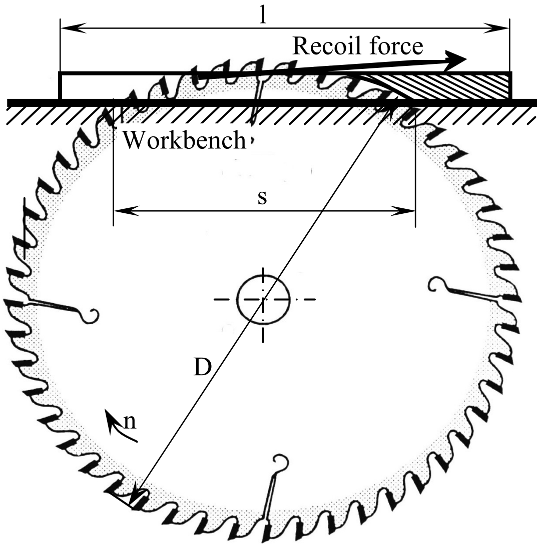

Figure 2. Cutting material on the circular saw with saw points protruding only slightly over the processed material – $l > s$ - possibility of material recoil in the form of the translational motion.

Mass moment of inertia defined with the general formula:

$$I = \int_V l^2 dm$$

for the considered chipboard with the following dimensions: l =1000 mm, b = 500 mm, g = 18 mm against side b= 500 mm is calculated from the formula:

$$I_{pl} = \frac{ml^2}{3}$$

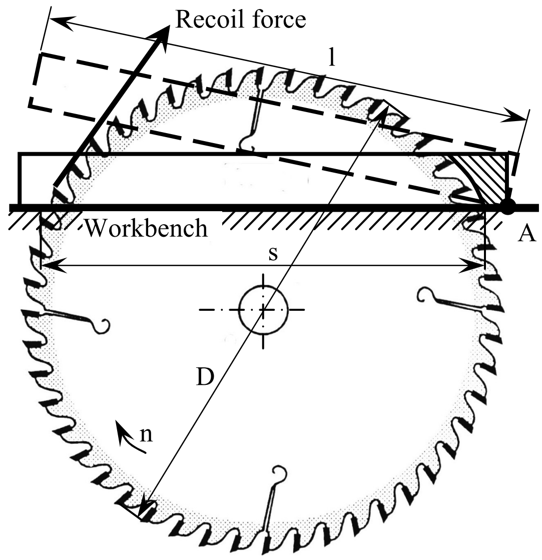

Figure 3. Cutting material on the circular saw with saw points protruding significantly over the processed material – $l > s$ - possibility of material recoil in the form of the rotational motion.

Following the substitution of numerical values, the author obtained the value I_{pl}= 2.1 kgm^2.

The angular velocity of the board can be calculated from the comparison of the kinetic energy of the rotational motion of the spindle system and the board:

$$E_k = \frac{I \cdot \omega^2}{2} = \frac{I_{pl} \cdot \omega_{pl}{}^2}{2}$$

hence

$$\omega_{pl} = \omega \sqrt{\frac{I}{I_{pl}}}$$

After the substitution of numerical values, the angular velocity of the board was calculated ω_{pl}= 25 rad/s (about 245 rpm). The linear velocity with which the end of the board about 1 m away from the axis of rotation moves amounts to: $v = \omega_{pl}$ x l = 25 m/s.

Adopting the same assumptions as above, i.e. that 50% of the energy is transferred elastically on to the board, while another 50% is used for plastic deformations and machining (damage) of the board, the angular velocity is approximately 12 rad/s, whereas the linear velocity of the end of boards – 12 m/s.

Braking of the circular saw

The formula describing the braking of the circular saw is similar to the formula describing its start-up. The start-up torque is substituted by the braking torque M_h [3].

$$M_h = I \cdot \varepsilon = I \frac{\Delta\omega}{\Delta t} = I \frac{\omega - \omega_0}{\Delta t}$$

The objective is to stop the motion of the circular saw, therefore, it is necessary to substitute ω_0=0. Applying the above formula, it is possible to calculate the braking time, on the assumption that we know the braking torque of the brake employed in the given circular saw, or assuming the braking time of Δt – to calculate the required braking torque and select the appropriate brake from the catalogue offered by companies specialised in the manufacture of brakes.

So, for example, in order to obtain the time of stopping the machine tool of Δt = 2s, it is necessary to apply a brake with the following braking torque:

$$M_h = I\frac{\omega}{\Delta t} = 0{,}0164kgm^2\frac{291s^{-1}}{2s} = 2{,}4Nm$$

Despite well-defined requirements, the analysed machine tool was not equipped in a brake.

CONCLUSIONS

The spindle system discussed in this study reaches its rated speed within 2 seconds and the energy of the rotational motion accumulated during this time amounts to nearly 700 J.

If the rotating saw gets jammed in the processed material as a result of mishandling, particularly frequently - following a loose or falling knot and absence of the cleavage wedge, a significant part of the above-mentioned energy is passed to the processed material causing its recoil. If the mass of the processed element (board, log) is considerable, the recoil velocity is small and, frequently, even if there are no appropriate protection and safety facilities, it does not result in the injury of the operator. On the other hand, when the machined element is light, the velocity the saw transfers to the processed material at the moment of recoil is considerable and may be very dangerous if no protections and guards are employed.

In order to stop the machine tool rapidly, it should be equipped in a brake of the braking torque of about 2.5 Nm.

Unfortunately, the described circular saw was not equipped in a brake and, what is more, during the replacement of the saw, both the cleavage wedge and the top and bottom guards were removed. This led to a serious accident in one of the construction enterprises in Poland during which the operator lost three fingers of his left hand.

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