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DETERMINING THE MAXIMUM CUTTING FORCE IN BAND SAW MACHINES WITH REGARD TO THE INFLUENCE OF THE RUN–OUT OF THE BAND SAW BLADE

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Abstract: Maximum cutting forces in band saw machines have been determined, taking into account the total axial run–out in their cutting mechanism according to known normative documents. The run–out in this mechanism is seen as a periodic approach and offset of the band saw blade to the workpiece under a harmonious law. As a result, the velocity of this shift is summed with the feed rate. It has been found that its velocity in certain sections of the band saw blade is comparable to the feed rate and can reach 44% of its magnitude. The cutting forces are equally larger than the traditionally calculated and, within one complete rotation of the band saw blade, change asymmetrically. This extra load on the traditionally calculated cutting forces corresponds to the real operating conditions of the band saw blade.
Keywords: Band saw machines, band saw blades, cutting forces, run–out

INTRODUCTION

The cutting forces in band saw and other woodworking machines are the basis for the strength dimensioning of the elements of their cutting mechanisms, as well as of other mechanisms and elements. These forces also need to be known in view of the proper operation of the machines.

The cutting forces in band saw machines are tangential and radial [4], [5], [9]. According to the famous theory of A. Bershadskiy [4], the tangential force of cutting is determined by the formula

$$P=\frac{KbhU}{V}, N, \qquad (1)$$

where: P – the tangential cutting force, N; b – width of the slot, m; h – height of the slot, m; U – feed rate, $m.s^{-1}$; V – cutting speed, $m.s^{-1}$.

As it can be seen in formula (1), the tangential cutting force is directly proportional to the feed rate, which according to the known literature sources [4], [5], [9] is assumed to be uniform within one complete rotation of the band saw blade.

In these machines, as well as in many others, the geometric accuracy of some of the cutting mechanism elements is essential to their operation. One of the geometrical inaccuracies of this mechanism is the frontal run–out of the guide wheels' crown, which is regulated by standards for universal band saws [2] and band resaws [3]. A second geometric inaccuracy in this mechanism is the linearity deviation of the band saw blade, which during operation is expressed with its run–out on the back side. These two geometrical inaccuracies – the frontal run–out of the guide wheels' crown, as well as the run–out on the back side of the band saw blade, can cause a total axial run–out of the band saw blade. Here it is necessary to introduce some clarification regarding the terms used in the current work. It has been accepted that the frontal run–out of the guide wheels' crown shifts the band saw blade along with its linearity deviations, which are perceived as "its own axial run–out of the band saw blade". The latter, combined with the axial run–out of the guide wheels, is perceived as a "total axial run–out of the band saw blade".

In order to provide clarification of the second geometrical inaccuracy, the reasons why it is obtained can be indicated. They are various – the non–linearity of the back of the band saw blade, inaccurately joining both ends (soldering or welding), rolling, as well as cracking of the blade. The inaccuracies caused because of the first three reasons can be determined during a control check before placing the band saw blade on the machine, the latter, on the other hand, may appear during operation of the machine and thus not be detected. There are recommendations [10], [11] regarding the non–linearity of the back of the band saw blade, however, for the three following reasons mentioned above no such recommendations exist or at least are not known to the author.

There are known methods for straightening band saw blades, as well as ways to measure their offset from linearity [11], but there are no prescriptions regarding their size. In practice, axial run–out of the band saw blades is often seen in a rather wide range. The author has measured values above 1 mm for band resaws and log band saws where there is no back support roller in the guide wheel. This is the first reason for this article, and the second one being that the measured axial run–out of the band saw blades within 6 consecutive complete rotations is very rarely repeatable, both with respect to the first measurement as well as to any previous or next. This gives reason to assume that the total axial run–out of the band saw blade is the sum of its own axial run–out and the frontal run–out of the guide wheels'croun. As a result of this cumulative axial run–out, a part of the teeth of the band saw blade is periodically approaching the workpiece, and another part periodically withdraws from it, thus, the velocity of this approach is summed with the feed rate, and the velocity of offset is subtracted from it. The latter means that the feed rate by which the cutting force of formula (1) is to be calculated needs to be increased or decreased by the velocity of the periodic approach or offset of the tooth line of the band saw blade to the workpiece.

In view of this, the cutting forces of the band saw machines would be different in magnitude compared to the one in formula (1), taking into account the axial run–out. Research in this regard has not been found in any literature known to the author. Therefore, the purpose of the present work is to calculate the maximum velocity of offset of sections of the band saw blade to the workpiece as a result of the axial run–out in the cutting mechanism within the recommendations of the known standards and literature and to compare it with the feed rate. As a consequence, to determine how this affects the cutting forces.

THEORETICAL FORMULATION

In order to achieve the stated objective, it is necessary to calculate two velocities – the velocity of offset of the band saw blade to the workpiece and the feed rate of the workpiece. To calculate the first velocity, it is necessary to: 1 – analyze the geometrical inaccuracies in the cutting mechanism and to determine what impact on the total axial run–out of the band saw blade they would have; 2 – to determine the maximum values of these inaccuracies; 3 – From these maximum values, determine the velocity of offset of the band saw blade to the workpiece.

The feed rate of the workpiece is calculated by means of a known methodology [4].

As mentioned above, the cumulative velocity of offset of the band saw blade to the workpiece can be due to two geometrical inaccuracies – the frontal run–out of the guide wheels'croun and the axial run–out of the band saw blade itself. These two inaccuracies would in a different way cause the band saw blade to move towards the workpiece.

The first geometrical inaccuracy – the frontal run–out of the guide wheels' croun can cause a periodic shift of a part of the saw blade to the workpiece and its return back. This would be the case for each guide wheel, each of which would displace part of the band saw blade independently. At this run–out, a maximum value would be obtained when both guide wheels move the band saw blade in one direction. This is the case when their most protruding parts are at the same angle, e.g., vertically. Such a coincidence is likely to occur when placing the band saw blade on the guide wheels, as well as while the machine is in operation, since it is possible the blade to slip on them. The extent of the offset of the band saw blade to the workpiece due to the frontal run–out of the guide wheels' crown, according to the accepted formulation, is equal to the magnitude of their frontal run–out and its frequency is equal to their rotation speed.

The second geometrical inaccuracy – the axial run–out of the band saw blade, as mentioned above, can be obtained because of four reasons. Therefore analytical determination of its magnitude is practically impossible. Therefore, in order to determine its magnitude, it is necessary to hypothetically accept a case that is possible to happen in practice. This is the case when there is an accumulation of error on the back of the saw due to its deviation from linearity which has not been eliminated. This deviation, according to the German companies producing such saws, is 0,13 / 1000 mm, with only this protuberance being allowed on this part of the saw [10]. This means that the accumulation of error and deviation from linearity can occur on the back of the band saw blade. The latter would be copied onto the tooth line, as in sharpening machines the back is used to base the band saw blade. Its magnitude can be obtained, for example, when the accumulation of error is about half the length of the saw, since the latter is a closed contour. For the above mentioned deviation from linearity and band saw blade length of 7,4 m, which is the length of the band saw blade SB 111, the deviation from linearity is 0,48 mm, which would correspond to the maximum axial run–out of the band saw blade without any other geometrical inaccuracies included in this value. In case of cracking of the band saw blade during operation and in the case of incorrect joining of both ends, this deviation from linearity may be even greater.

In order to calculate the velocities of offset, it is necessary to know the laws under which these movements are accomplished. Since geometrical inaccuracies are of a random nature, [8] such laws are difficult to determine theoretically. In this case, it is expedient to use the results of the above measurements of the inaccuracies, to identify the predominant forms of curves that they describe and to establish the laws according to which the velocities of offset are to be calculated. From these measurements, it has been found that the frontal run–out of the guide wheels' croun, as well as the axial run–out of the band saw blades, describe predominantly sinusoidal shapes in an unfolded form / the solid curve between points A and B in Figure 1). The observed sinusoids are not entirely correct, and the most common inaccuracy is that the two half periods differ. Other shapes have also been established, e.g., linear sections / the dashed line in Figure 1 /, a circle arc, and others with an undefined shape, however, their relation to the sinusoid is approximately two times less. This justifies both calculations in the current work being carried out by a harmonious law [7], [12]. The reasons for the calculations to be carried out by this law are cyclicality and that in this form an intermediate velocity occurs – between a linear and an arcuate with a steep section of the curve.

The influence of the geometrical inaccuracies of the machine regarding the precision of processing is depicted analytically [8]. From the accepted thesis, of the two velocities of offset to be determined by a sinusoidal law, it is necessary to calculate them according to the maximum permissible geometrical inaccuracies and to calculate their maximum values by the formula

$$u_{max} = y_{max} + \vartheta_{max}, \ m.s^{-1}, \qquad (2)$$

where: u_{max} – the maximum total velocity of offset of the band saw blade to the workpiece, $m.s^{-1}$; y_{max} – the maximum velocity of offset of the band saw blade caused by the axial run–out of the guide wheels, $m.s^{-1}$; ϑ_{max} – the maximum velocity of offset of a section of the band saw blade caused by its own axial run–out, $m.s^{-1}$.

The offset velocity of the band saw blade caused by the axial run–out of the guide wheels for a sinusoidal law is determined by the formula [12]

$$y = A_1\omega_1\cos(\omega_1 t_1+\varphi_1), m.s^{-1}, \quad (3)$$

where: y is the velocity of offset of the band saw blade caused by the frontal run–out of the guide wheels'croun, $m.s^{-1}$; A_1 – the amplitude of oscillation of the axial run–out of the guide wheels, m; ω_1 – angular velocity of the guide wheels, $rad.s^{-1}$; t_1 – time, s; φ_1 – the initial phase of the movement, $rad.s^{-1}$.

As it can be seen from the formula above, the velocity of offset of the band saw blade caused by the frontal run–out of the guide wheels' croun is variable and is determined by the angle of rotation. For force calculations, it is necessary to know the maximum velocity that is defined by the formula [1], [12]

$$y_{max} = A_1\ \omega_1, m.s^{-1} \quad (4)$$

In order to calculate this velocity, it is necessary to know the magnitude of the amplitude and angular velocity of the guide wheels. The magnitude of the amplitude is determined by the magnitude of their frontal run–out and is equal to half of it, and the angular velocity is determined by the formula

$$\omega_1 = 2\pi n, rad.s^{-1} \quad (5)$$

where: n is the frequency of rotation of the guide wheels, s^{-1}.

The frequency of rotation of the guide wheels is determined by the formula

$$n = \frac{V}{\pi D}, s^{-1} \quad (6)$$

By replacing formulas (5) and (6) in (4) and expressing the magnitude of the amplitude with the permissible frontal run–out of the guide wheels' croun, for this velocity it is obtained

$$y_{max} = \delta\frac{V}{D}, m.s^{-1} \quad (7)$$

where: δ is the permissible frontal run–out of the guide wheels' croun, m.

The way of determining the velocity of offset of a section of the band saw blade to the workpiece caused by its own axial run–out is illustrated in Figure 1, the indications being as follows: in position 1, the tooth line of the band saw blade is unfolded; position 2 – the workpiece; The cutting speed is indicated by V; The feed rate of the workpiece with U. The offset of a section of the band saw blade to the workpiece is indicated by ϑ, in which case is in opposite direction to the feed rate. The tooth line of the band saw blade is restricted by lines c–c and a–a, with the distance between them being Δ, which is the maximum axial run–out of the band saw blade, calculated above (Δ = 0.48 mm). Between points A and B is shown a half period of one sinusoid corresponding to the unfolded curvature of the band saw blade. When moving half the length of the band saw blade L / 2 in the direction of the cutting speed V, point B moves to point B', thus moving the tooth line to the workpiece at distance AB' = Δ. It can be seen from the figure that moving along the vertical line, the tooth line approaches and withdraws from the workpiece by a sinusoidal law as well.

The calculations that need to be made regarding the velocity of offset of the band saw blade to the workpiece caused by its own axial run–out are analogous to the previous ones. The difference is that the calculations are related to the cyclicality of motion of the band saw blade and not to the guide wheels.

The velocity of offset of a section of the band saw blade from its own axial run–out is calculated by formula (3) and its maximum value ϑ_{max} by the formula

$$\vartheta_{max} = A_2\ \omega_2, m.s^{-1} \quad (8)$$

where: A_2 is the amplitude of oscillation of the sinusoid, as described by its own axial run–out of the band saw blade, m; ω_2 – a circular frequency of the sinusoid described by its own axial run–out of the saw blade / matches the rotation speed of the band saw blade /, $rad.s^{-1}$.

The amplitude of oscillation of the axial run–out of the band saw blade is determined by the formula

$$A_2 = \frac{\Delta}{2}, m. \quad (9)$$

The circular frequency of the sinusoid described by the axial run–out of the band saw blade is determined by the formula

$$\omega_2 = 2\pi f, rad.s^{-1}, \quad (10)$$

where: f the frequency of oscillation of the sinusoidal line, s^{-1}.

The frequency of oscillation of the sinusoidal line is determined by the formula

$$f = \frac{V}{L}, s^{-1}. \quad (11)$$

By replacing formula (11) in (10), (9) and (10) in (8), the maximum velocity of offset of a section of the band saw blade caused by its own axial run–out is obtained

$$\vartheta_{max} = \pi\Delta\frac{V}{L}, m.s^{-1} \quad (12)$$

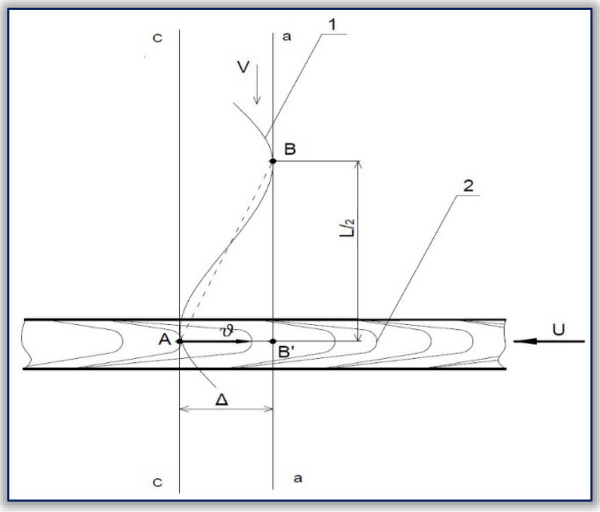

Figure 1: Scheme for determining the velocity of offset of a section of the band saw blade caused by its own axial run–out against the feed rate

RESULTS AND DISCUSSION

In order to determine whether the total velocity of offset of the band saw blade u_{max} is comparable to the feed rate U, it is necessary to make specific calculations for both velocities. The calculations to be made are for the case where the band saw blade is most loaded at a low feed rate (to be comparable to the velocity of offset of the tooth line) and a large slot height. This is one of the possibilities which can be encountered in practice and for which a maximum load on the saw is obtained.

The cutting mode selected to determine the feed rate is with the following parameters for a band resaw: BDK 111: diameter of the guide wheels –D = 1120 mm; Engine cutting power – 22000 W; Blade length – L = 7.4 m; Blade width – 100 mm; Blade thickness – 1 mm; Tooth pitch – 40 mm; Tooth height – 12 mm; Tooth type – flattened; Slot height – 0.7 m; Wood species – beech; Cutting speed – V = 40 m.s–1. The calculations are made according to the methodology exhibited in [4], [5], [9]. As the feed rate is also dependent on the dulling of the cutting tool it has been found that feed rates of less than 0.05 m.s–1 are obtained when the teeth are dulled over 30 μm.

The maximum total velocity of offset of the band saw blade to the workpiece according to formula (2) is calculated for the parameters of the above said machine under the following conditions; Frontal run–out of the guide wheels'croun – δ = 0.0002 and 0.0004 m; / A1 = 0.0001 and 0.0002 m /; The maximum axial run–out of the band saw blade, calculated above, is Δ = 0.00048 m / A2 = 0.00024 m /. It has been found that at these values, the maximum total velocity of offset of the band saw blade to the workpiece according to formula (2) is 0.0152 and 0.0221 m.s–1 for the different prescriptions of the standard.

From the calculations made, it can be seen that the maximum velocity of offset of the band saw blade to the workpiece is a quantity that may be comparable to the feed rate. It can have values of 30.4 and 44.2% of it for a complete rotation of the band saw blade. Considering the above and formula (1) it follows that the cutting force changes in the same way. Considering formula (3), it follows that this force is not a constant quantity and changes with an amplitude ± 0.3P and ± 0.44P, i. by an asymmetric cycle [6]. The analysis made shows that a band saw machine which is within its geometric precision can be loaded with cutting forces over the traditionally calculated and at that by an asymmetric cycle.

Similarly, calculations can be made with other laws regarding the movement of the axial run–out in the cutting mechanism, and higher loads on the band saw be calculated as well.

CONCLUSIONS

- The cutting force in band saw machines, taking into account the axial run–out in the cutting mechanism by a harmonious law, in certain areas of the saw blade may be 44% greater in comparison to the traditional calculation method where it is considered to be a permanent quantity within a complete rotation of the band saw blade;
- For the dimensioning of band saw blades operating at high loads, the asymmetric dynamic load cycle must be considered.
- The obtained results make it possible to make new, different calculations for the load of the shaft and axis of the guide wheels considering the calculated cutting force and its asymmetric load cycle.
- The analysis made shows that the axial run–out of the geometrical inaccuracy of the band saw blade is the greatest. To reduce these maximum cutting forces it is necessary to join the ends of the band saw blade with high precision, which means that the welding machines must be highly accurate as well.

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ACTA TECHNICA CORVINIENSIS BULLETIN OF ENGINEERING
ISSN: 2067-3809