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Some approaches to the determination of saw blade stiffness

Neki pristupi određivanju napetosti lista pile

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ABSTRACT • *In modern sawmill industry a tendency has been observed towards a reduction of the saw blade kerf because of its aiming to increase the utilization of raw material. However, thinner saw blades are much more sensitive to lateral forces and less stable than the thicker ones. Hence, the knowledge about saw blade stiffness is an important factor and may help the user in forecasting the dimensional sawing accuracy. In this paper the basic methodology is shown for the determination of lateral operating tooth tip saw blade stiffness for both frame saw blades and bandsaws. Recommendations are given for choosing an appropriate calculation method versus the saw blade width. Two effective analytical calculation methods for the determination of saw blade stiffness are presented and discussed in details. By these methods stiffness is computed as a function of bending and torsional properties of the saw blade.*

Key words: *saw blade, calculation method, static stiffness*

SAŽETAK • *U modernoj je pilanskoj proizvodnji zamjetna težnja ka smanjenju širine propiljka radi što boljega iskorištenja materijala. Međutim, tanji listovi pila mnogo su osjetljiviji na djelovanje bočnih sila i nestabilniji su od debljih listova. Poznavanje napetosti (krutosti) lista pile važan je čimbenik procesa piljenja na temelju kojega se može predvidjeti točnost piljenja. U ovome su radu prikazane osnove poznatih metoda za određivanje napetosti listova pila jarmača i tračnih pila. Također se daju i preporuke za izbor odgovarajuće metode u ovisnosti o širini lista. Detaljno su razjašnjene dvije analitičke računske metode za određivanje napetosti lista pile, koje napetost računaju kao funkciju savojnih i torzijskih svojstava lista.*

Ključne riječi: *list pile, računska metoda, statička krutost*

1 INTRODUCTION
1 UVOD

The price of logs is by far the most important factor influencing the competitiveness of sawmill industry. In the cost distribution of the regular sawmill costs, the costs of raw material amount to 70 % (***, 1999) or even to 80 % in the USA and Canada (Szymani, 2003). The efforts taken to minimize the saw plate thickness and ultimately saw kerf are of absolute importance to increase the utilization of raw material. However, it is imperative that the saw mill does not loose the material gained by an increased size variation caused by

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unstable sawing. A large number of factors influence the cutting process in the case of narrow - kerf sawing and due consideration has to be taken to varying parameters as compared to sawing with conventional saw blades (Orlowski, 2003a, Prokofiev, 1990, ***, 1999). The decrease in the saw blade static stiffness should be particularly taken into account because this parameter is closely connected with the saw blade ability to resist lateral interactions of lateral forces. The purpose of this work is to submit the basic methodology for the determination of the lateral operating tooth tip saw blade stiffness for both frame saw blades and bandsaws, and give some recommendations for choosing an appropriate calculation method versus the saw blade width. Eventually, two simple analytical calculation methods for the determination of saw blade stiffness are going to be presented and discussed.

2 THEORETICAL BACKGROUND
2 TEORIJSKE OSNOVE

Forces affecting frame saw blade during cutting are shown in Figure 1a. If they are applied in the middle of a free saw blade length there is the state of loads equivalent to the situation in bandsaw operations (Ivankin, 2000, Lehmann and Hutton, 1996, 1997, Prokofiev, 1990, Taylor and Hutton, 1991). For both, frame sawing and bandsaw machining, the static lateral initial stiffness of a saw blade k_0 is defined as a ratio of the strict force F_p (lateral force) situated in the middle of a free saw blade length (Figure 1b) at the line joined bottoms of gullets to the saw blade displacement q (Figure 2):

$$k_0 = \frac{F_\mathrm{p}}{q} \tag{1}$$

For each type of saw (gang saw, band saw and circular saw) the following types of lateral stiffness apply: the inherent stiffness for a non-strained saw blade k, the initial stiffness for a strained saw blade k_0, and the operating stiffness $k_{0\mathrm{r}}$ for a saw blade during cutting (Lehmann and Hutton, 1996, 1997, Orlowski, 2003a, Prokofiev, 1990, Taylor and Hutton, 1991). In the latter the effect of the feed force F_f, which has great effect upon saw blade stability, is taken into account. From the user point of view, the knowledge of the lateral operating tooth-tip saw blade stiffness k_{Tr} is very important because it helps forecasting the dimensional sawing accuracy (Lehmann and Hutton, 1996, 1997, Taylor and Hutton, 1991). However, according to the author, to know the saw blade stiffness coefficient seems to be a good tool for comparing static properties of different saw blades because this parameter does not take into account cutting mechanics, cutting edge sharpness, wood properties, etc. (Orlowski, 2003a).

The cross section of the saw blade with a lateral force F_p acting on the tooth tip situated in the middle of a free saw blade length, and components of the tooth tip deflection q_T are shown in Figure 2.

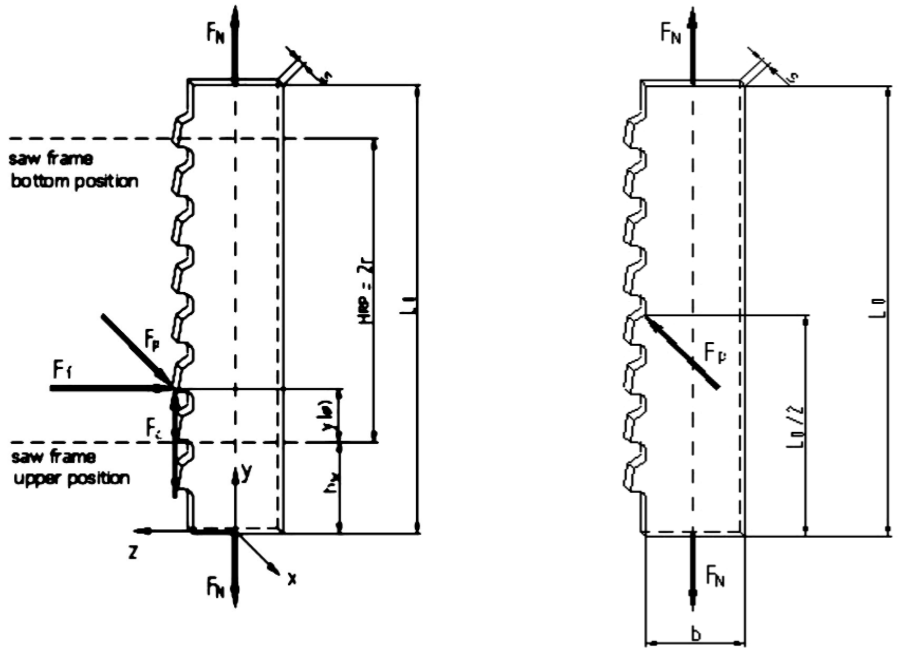


Figure 1
External forces acting on a frame saw blade: a) during sawing, b) position of the lateral force F_p for the determination of the saw blade static stiffness of frame saw blade and bandsaw
Slika 1.
Vanjske sile koje djeluju na list pile jarmače: a) tijekom piljenja, b) položaj bočne sile F_p za određivanje statičke napetosti lista pile

Meaning of the symbols (*značenje oznaka*):
F_c - cutting force (*sila rezanja*), F_f - feed force (*odrivna sila*), F_p - lateral force (*bočna sila*), F_N - straining force (*zatezna sila*), L_0 - saw blade free length (*slobodna duljina lista pile*), h_w - workpiece bottom surface position (*položaj donje površine obratka*), b - saw blade width (*širina lista pile*), s - saw blade thickness (*debljina lista pile*), y - force position (*pozicija sile*)

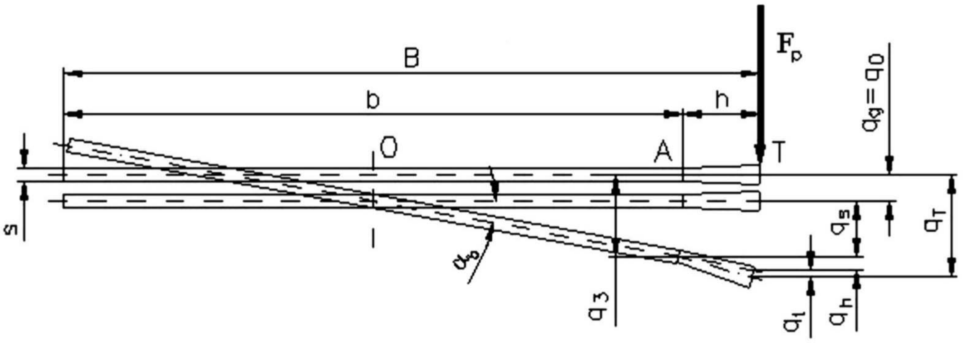


Figure 2
Components of the tooth tip deflection q_T
Slika 2.
Sastavnice otklona vrha zuba q_T

Meaning of the symbols (*značenje oznaka*):
q_g - bending blade deflection (*otklon zbog savijanja lista*), $q_0 = f(kg)$- blade deflection caused by a force F_p placed at the point 0 (*otklon lista prouzročen bočnom silom u točki 0*), $q_s = f(k_s)$ - transverse deflection due to the torsional blade deflection (*poprečni otklon zbog torzijskog otklona lista*), $q_t = f(k_t)$- bending tooth tip deflection (*otklon zbog savijanja zuba*), q_3 - blade deflection caused by a force F_p placed at the point A (*otklon lista prouzročen bočnom silom u točki A*), q_h - tooth tip deflection due to blade torsional deflection (*otklon vrha zuba zbog torzijskog otklona lista*), h - tooth depth (*visina zuba*), α_b - blade torsional angle (*torzijski kut lista*)

The initial tooth tip saw blade stiffness k_T is defined as:

$$k_T = \frac{F_p}{q_T} \qquad (2)$$

and tooth tip deflection q_T is:

$$q_T = q_3 + q_h + q_t \qquad (3)$$

Analytical assessment has been carried out of the significance of the tooth tip deflection q_T components for a wide gang saw blade q_{TT} (Orłowski and Kaliński, 2001) and for mini gang saw blades q_{TM} (Orłowski, 2001). These results have shown that the effect of tooth bending stiffness component upon tooth tip saw blade stiffness is very small because of the large value of tooth bending stiffness in comparison with other parameters (Figure 3). Moreover, these results from the point of view of significance assessment are similar to those obtained for extra wide bandsaws (i.e. tooth bending stiffness k_t = 875 N/mm, tooth tip bandsaw stiffness k_t = 34 N/mm (Lehmann and Hutton, 1996, 1997)). Hence, in forecasting the tooth tip saw blade stiffness this component may be safely disregarded.

For every kind of saw blade, it can be seen that transverse deflection q_s has the largest value due to the torsional blade deflection. Furthermore, this deflection cannot be reduced by extra tensioning because tensioning stresses only affect the static flexural stiffness, whilst they have practically no affect on saw blade torsional stiffness (Orlowski and Kalinski, 1999, Orlowski, 1999, 2000, 2003). It seems that the lack of the effect of the increased straining force of the band saw blade on improvement of the sawn board surface quality (roughness) reported in (Goglia and Beljo, 1999) could also be caused by insensitiveness of the band saw blade torsional stiffness to straining forces.

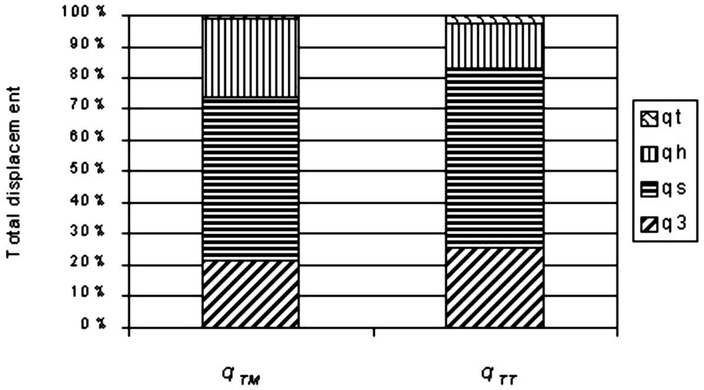


Figure 3
Percentage share of component displacement in the total lateral displacement
Slika 3.
Postotni udjel sastavnica otklona u ukupnom bočnom otklonu

Meaning of the symbols (*značenje oznaka*):
q_{TM} - total tooth tip deflection for mini gang saw blade (narrow) (*ukupni otklon vrha zuba uskih listova pila minijarmača*), q_{TT} - total tooth tip deflection for traditional issue of the gang saw blade (*ukupni otklon vrha zuba uobičajenih listova pila jarmača*)

In forecasting the theoretical sawing accuracy the lateral operating tooth tip saw blade stiffness should be taken into account. For this purpose, the following formulae, proposed in (Prokofiev, 1990) can be used:

$$k_{\mathrm{To}} = k_0\left(1-\frac{F_{\mathrm{f}}^2}{F_{\mathrm{fcr}}^2}\right) \quad (4)$$

or relationship given by Stakhiev (Stakhiev, 2000):

$$k_{\mathrm{To}} = k_0\sqrt{1-\frac{F_{\mathrm{f}}}{F_{\mathrm{fcr}}}} \quad (5)$$

where:

F_{fcr} - the critical feed force for which a saw blade can loose its stability (Feokistov, 1960, Prokofiev, 1990, Veselkova, 1982, Veselkov and Veselkova, 1989). It means that for feed force F_{f} equal to the critical feed force F_{fcr} the tooth operating saw blade stiffness is equal to 0 (Prokofiev, 1990). This force may be calculated by methods given in the following papers (Feokistov, 1960, Prokofiev, 1990, Veselkova, 1982, Veselkov and Veselkova, 1989).

The use of both Prokofiev's formula and Stakhiev's formula gives similar computation results (Orlowski, 2001).

3 SUCCINCT REPORT ON METHODS FOR THE CALCULATION OF STATIC STIFFNESS

3 KRATKI PREGLED RAČUNSKIH METODA ZA ODREĐIVANJE STATIČKE KRUTOSTI

Several analytical and numerical methods for the determination of saw blade stiffness can be found in the up-to-date reference literature. They may be classified versus saw blade width as follows (Orlowski, 2003b):

1. for narrow mini gang saw blades (width b < 40 mm):
- strict calculation method with the use of a beam model SCM/BM (Orlowski, 1999, 2000), which is a simple and simultaneously useful tool for static calculations (verified experimentally);
- finite element method with Timoshenko's beam model included FEM/TB (Orlowski and Kalinski, 1999), that can be applied in static and dynamic computations (verified experimentally); rigid finite element method with the plate model included RFEM/PM (Orlowski and Kalinski, 2001, 2002), which may be used in static and dynamic calculations. In dynamic computation, continuous distribution of lateral force at the workpiece height has been taken into account (verified experimentally in static (Orlowski and Kalinski, 2001) and dynamic conditions (Orlowski and Kalinski, 2002)).

2. for wide gang saw blades and bandsaws, in European conditions (width b < 160 mm):
- Rayleigh - Ritz energy method R-RM (Prokofiev Et al., 1985, Prokofiev, 1990) for saw blades in the width range of 100 - 160 mm. This method does not give a final empirical formula and is categorized as a complicated one (Ivankin, 2000). The method is appropriate for static and dynamic calculations;
- Ivankin's method IVM (Ivankin, 2000) - the static task has been solved with the use of energy method for determination of flexural and torsional deflections, in which displacements were described as trigonometric series. This method can be applied in static calculations for the saw blades in the width range of 80 - 160 mm. Additionally, the paper (Ivankin 2000) also presents an empirical formula that takes into account the effect of continuous distribution of lateral forces at the workpiece height;
- rigid finite element method with the plate model included RFEM/PM (Orłowski and Kaliński, 2002), which may be used in static and dynamic calculations for the saw blades in the width range of 40 - 160 mm (verified for wide saw blades (Orlowski, 2003a) by comparison to the results given in (Prokofiev, 1990));

3. for extra wide bandsaws (width 180 < b < 390 mm):
- exact solution owing to the use of the Galerkin method GM (Lehmann and Hutton, 1996, 1997), which may be applied for the saw blades in the width range of 180 - 300 mm;
- finite element method with 8 node rectangular shell elements included FEM/SE (Taylor and Hutton, 1991), which is suitable for the saw blades in the width range of 220 - 390 mm.

Figure 4 shows the application ranges of the methods used for the calculation of static stiffness of saw blades and bandsaws as a function of saw blade width with calculation errors of the above specified methods in relation to experimental results. It can be clearly seen that there is a lack of a common calculation method whose field of application could cover the whole range of saw blade widths used in sawmill practice. Based on the analysis shown in Figure 4, it

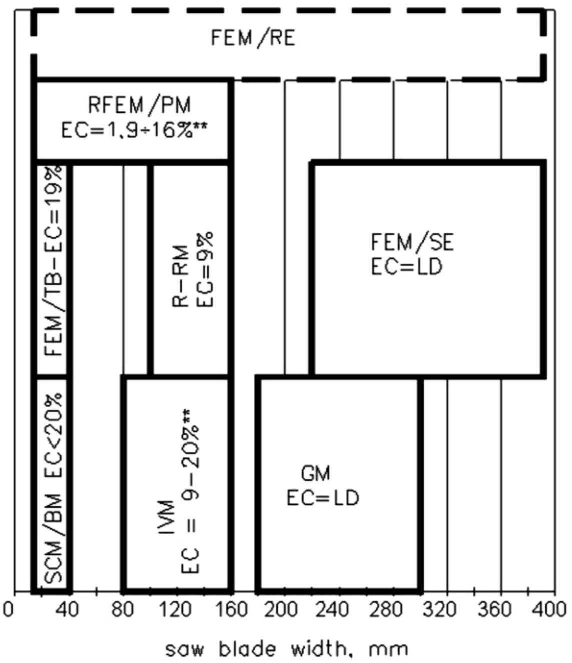


Figure 4
Application ranges of the methods for the calculation of static stiffness of saw blades and bandsaws as a function of saw blade width
Slika 4.
Područje primjene metoda za izračunavanje statičke napetosti listova pila jarmača i tračnih pila s obzirom na širinu lista

Meaning of the symbols (*značenje oznaka*):
SCM - strict calculation method (*stroga računska metoda*), FEM - finite element method (*metoda konačnih elemenata*), RFEM - rigid finite element method (*kruta metoda konačnih elemenata*), R-RM - Rayleigh-Ritz energy method (*Rayleigh-Ritzova energetska metoda*), IVM - Ivankin's method (*Ivankinova metoda*), GM - Galerkin method (*Galerkinova metoda*), BM - beam model (*model grede*), TB - Timoshenko's beam (*Timoshenkova greda*), PM - plate model (*model ploče*), SE - shell rectangular element (*ljuska pravokutni element*) , RE - rectangular element (*pravokutni element*), EC - error of calculation (*greška računanja*), LD - lack of data (*nedostatak podataka*), ** higher values of calculation errors refer to narrower saw blades (*veće vrijednosti pogrešaka računanja odnose se na uže listove pila*), dashed line refers to a nonexistent method (*crtkana linija odnosi se na nepostojeću metodu*)

is possible to choose an appropriate method as a function of saw blade width in compliance with the current calculation requirements.

4 SAW BLADE STIFFNESS AS A FUNCTION OF SAW BLADE FLEXURAL AND TORSIONAL RIGIDITIES
4 NAPETOST LISTA KAO FUNKCIJA SAVOJNE I TORZIJSKE KRUTOSTI

Two effective analytical calculation methods for the determination of saw blade stiffness are presented here. By these methods stiffness is computed as a function of bending and torsional properties of the saw blade (Orlowski, 1999, 2000, Ivankin, 2000). Lateral force F_p applied to the saw (Figure 2) may be substituted with both lateral force applied to point O and torsional moment

$$M = F_p\left(B - \frac{b}{2}\right)$$

In that case, under assumption that the bending tooth deflection is $q_t \ll q_T$, static transverse deflection q_T described by Equation (2), may be calculated as follows (Orlowski, 1999, Ivankin, 2000):

$$q_T = q_g(k_g) + q_s(k_s) + q_h = q_g(k_g) + q_s(k_s) + h \cdot \alpha_b \qquad (6)$$

4.1 Beam model of the saw blade
4.1 Greda kao model lista pile

According to the beam model which has been proposed by the author (Orlowski, 1999, 2000), for narrow saw blades (width b < 40 mm), the initial tooth tip saw blade stiffness can be calculated from the relationship:

$$k_T = \frac{1}{\frac{1}{k_g} + \left(B - \frac{b}{2}\right) \cdot \tan \frac{\left(B - \frac{b}{2}\right)}{k_s}} \qquad (7)$$

Based on the assumption that both lateral force F_p and torsional moment M are unit loads ($F_p = 1$, M = 1) flexural stiffness of the saw blade can defined as:

$$k_g \equiv \frac{1}{q_g} \qquad (8)$$

and torsional stiffness of the saw blade may be expressed as:

$$k_s \equiv \frac{1}{\alpha_b} \qquad (9)$$

In the beam model, bending blade deflection (with the determination of flexural stiffness F_p = 1 N) is as follows:

$$q_g = \frac{F_p}{2 \cdot E \cdot J \cdot p^3} \left[\frac{p \cdot L_0}{2} - \tanh\left(\frac{p \cdot L_0}{2} \right) \right] \qquad (10)$$

where:
p - parameter $\quad p = \sqrt{\frac{F_N}{E \cdot J}}$,

E - Young modulus of the saw blade material,
J - second moment of the cross section area of the saw blade $\left(J = \frac{b \cdot s^3}{12} \right)$.

The blade torsional angle (for the unit torsional moment M = 1 Nmm) is described as:

$$\alpha_b = \frac{1 \cdot L_0}{2 \cdot \eta_2 \cdot b \cdot s^3 \cdot G} \qquad (11)$$

where:
G - modulus of volume elasticity of the saw blade material,
η_2 - coefficient *f(b/s)* (for narrow saws η_2 = 0,333).

4.2 The Ivankin's method - the plate model
4.2 Ivankinova metoda - model ploče

The Ivankin's method allows us to solve the static task of bandsaw stiffness determination with the use of energy method for calculations of flexural and torsional deflections of the plate, in which displacements are described as trigonometric series (Ivankin, 2000). This method is suitable for saw blades and bandsaws whose width range is 80 - 160 mm (Orlowski, 2003b). In Ivankin's method saw blade stiffness is also calculated versus bending and torsional properties of the saw blade. Thus, the Equation (7) may be applied for the determination of tooth tip saw blade stiffness.

For the load as shown in Figure 1b, the Ivankin's method bending blade deflection q_g is expressed as:

$$q_g = \frac{2 \cdot F_p \cdot L_0^3}{E \cdot J \cdot \pi^4} \cdot \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2 \cdot \left(n^2 + D\right)}$$

for the unit force $F_f = 1$ (12)

$$q_g = \frac{2 \cdot L_0^3}{E \cdot J \cdot \pi^4} \cdot \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2 \cdot \left(n^2 + D\right)}$$

where:
$D = \frac{F_N \cdot L_0^2}{E \cdot J \cdot \pi^2}$ - dimensionless constant.

The saw blade torsional angle is described as:

$$\alpha_b = \frac{2 \cdot F_p \cdot \frac{b}{2} \cdot L_0}{\pi^2 \cdot \left(C + \frac{F_N \cdot b^2}{12} \right)} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2}$$

for the unit torsional moment $M = F_p \cdot \frac{b}{2} = 1$

$$\alpha_b = \frac{2 \cdot L_0}{\pi^2 \cdot \left(C + \frac{F_N \cdot b^2}{12} \right)} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2} \qquad (13)$$

The flexural stiffness of the bandsaw (saw blade) and its torsional stiffness can respectively be calculated from Equation (8) and (9).

4.3 Analysis of the presented methods
4.3 Analiza iznesenih metoda

Although, the Ivankin's method gives quite good results, burdened with small calculation errors in comparison to computational results of gang saw blades of similar dimensions and the same value of tensioning stresses as reported in (Prokofiev, 1990, Ivankin, 2000, Orlowski, 2003a), the author does not entirely share the approach of taking it into account for the determination of blade torsional angle of the straining force FN because in the experimental and theoretical investigation of saw blade static properties of both narrow and wide saw blades no effects were observed of this force upon the saw blade torsional stiffness (Orłowski and Kaliński, 1999, 2001, 2002, Orlowski, 1999, 2003a).

When applying the Ivankin's method (IVM) and the Ivankin's modified method (IVMM) adjusted by the author, which do not take into account the denominator expression $\frac{F_N \cdot b^2}{12}$ in determining torsional saw blade stiffness in Equation (13), the saw blade stiffness has been estimated analytically. It means that in the adjusted method (IVMM) tensioning stresses do not affect torsional stiffness, and so in that case the saw blade torsional angle (for the unit torsional moment M = 1) is:

$$\alpha_{\mathrm{b}} = \frac{2 \cdot L_0}{\pi^2 \cdot C} \sum_{n=1,3,5...}^{\infty} \frac{1}{n^2} \qquad (14)$$

The following technical data of the saw blade have been calculated: width b= 110 mm, thickness s=0,9 mm, saw blade free length L_0=358 mm, E=2,15·105 MPa, G=8,1·104 MPa, tensioning stresses σ_N= 300 MPa. Additionally, saw blade stiffness of narrower saw blades of 30 mm in width was computed with the use of the beam model (other parameters were not changed). The results of this evaluation of saw blades stiffness coefficients are shown in Figure 5, Figure 6 and Figure 7.

The most interesting results are presented in Figure 6 and 7. As it could be expected for the saw blade width of 110 mm in the Ivankin's method, torsional stiff-

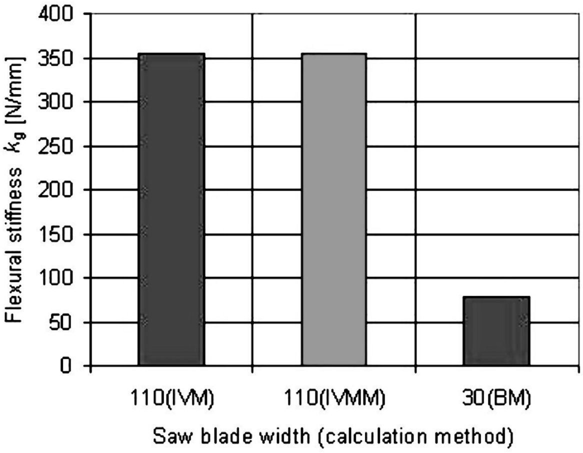


Figure 5
Flexural stiffness k_g of saw blade versus saw blade width and calculation method
Slika 5.
Savojna krutost lista pile k_g u ovisnosti o širini lista odnosno metodi računanja

IVM - Ivankin's method (*Ivankinova metoda*), IVMM - Ivankin's modified method (k_s *for* $F_N = 0$ *N*) (*Ivankinova modificirana metoda*), BM - beam model (*model grede*) (s = 0,9 mm, L_0 = 358 mm, E = 2,15·10^5 MPa, G = 8,1·10^4 MPa, σ_N = 300 MPa)

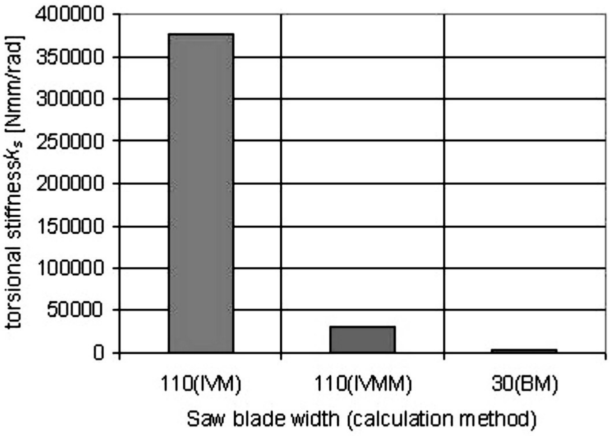


Figure 6
Torsional stiffness k_s of saw blade versus saw blade width and calculation method
Slika 6.
Torzijska krutost lista pile u ovisnosti o širini lista odnosno metodi računanja

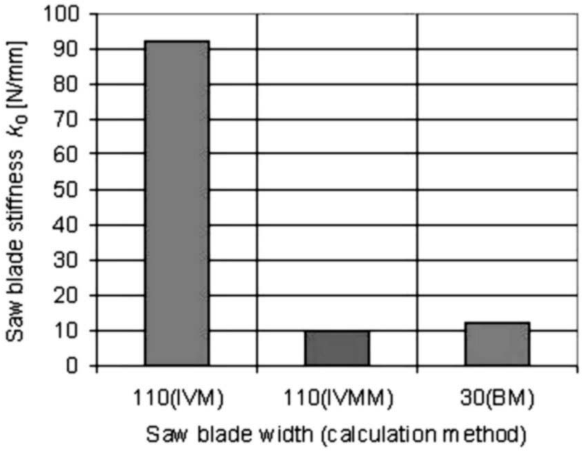
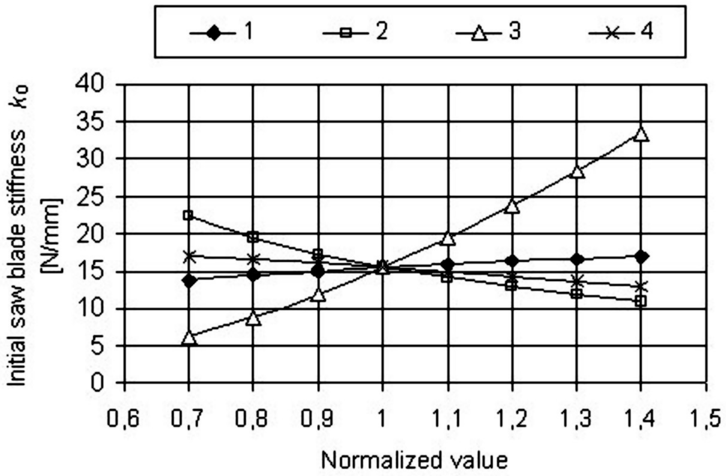


Figure 7
Initial stiffness of saw blade k_0 versus saw blade width and calculation method
Slika 7.
Početna krutost lista pile u ovisnosti o širini lista odnosno metodi računanja

ness has the largest value. However, if the initial saw blade stiffness is computed based on these values, some results are obtained which could lead to false conclusions. It is well known that for the saw blade of the same thickness and free length, under the same value of tensioning stresses, torsional stiffness increases with the increase of the width (Figure 6) but at the same time the initial saw blade stiffness decreases dramatically (Figure 7). This effect is somewhat non-intuitive (Orlowski 2001, 2003a, Lehmann and Hutton, 1997). Hence, from this point of view there is a kind of proof that in the determination of torsional saw blade stiffness the effect of the tensioning force should not be taken into account.

For better understanding of this phenomenon, Figure 8 shows the sensitivity analysis of saw blade stiffness, which enables the analysis of effects relative to individual changes of saw blade parameters.

Figure 8
Sensitivity analysis of the initial saw blade stiffness (the saw blade geometry for the base point - normalized value: b=20 mm, s=0,9 mm, L_0*=358 mm,* σ_N*=250 MPa)*
Slika 8.
Analiza osjetljivosti početne krutosti lista pile (geometrija lista pila za baznu točku - normalizirana vrijednost: b=20 mm, s=0,9 mm, L_0*=358 mm,* σ_N*=250 MPa)*



1 - tensioning stresses (*naprezanja zbog napinjanja*), 2 - saw blade free length (*slobodna duljina lista pile*), 3 - blade thickness (*debljina lista*), 4 - blade width (*širina lista*)

5 CONCLUSIONS
5 ZAKLJUČCI

1. Based on the results of this study, the following conclusive remarks can be drawn Although, at first glance, saw blade stiffness seems to be a simple calculation task, there is not a general method which could be applied for its determination and simultaneously cover the whole range of saw blade width used in industrial practice. Thus, developing a new universal method of calculation for saw blade lateral displacements in both static and dynamic conditions is a great challenge for researches in the area of mechanics. In that case, it is imperative to derive a geometric stiffness matrix for establishing whether the finite element method could be used (Figure 4 - dashed line), because the use of geometric stiffness matrixes found in the reference literature (Gallagher, 1975), for that state of loads, does not give results of calculations that match the experiment or another calculation method. The finite element method is recommended because it can be simultaneously used in static and dynamic computations.
2. When applying methods of saw blade stiffness calculation as a function of both flexural and torsional stiffness, the effect of tensioning stresses upon torsional blade stiffness should not be taken into account because of the phenomenon of the decrease of the initial saw blade stiffness with the increase of saw blade width (with other parameters of constant value), e.g. the presented results of analysis of both Ivankin's method (IVM) and modification of the said method proposed in this paper (named IVMM).

6 REFERENCES
6 LITERATURA

1. Feokistov, A.E. 1960: Ustojčivost' pil'noj lenty pod vozdejstviem na nee usilija podači. Lesnoj Žurnal. Izvestija Vysšych Učebnych Zavedenij (3): 95 - 104.
2. Gallagher, R. H. 1975: Finite element analysis - Fundamentals. Prentice Hall, London.
3. Goglia, V.; Beljo, R. 1997: Band Saw Blade Strain Guides Effectiveness. In: Zbornik. Medzinárodná Konferencia Les-Drevo-Zivotne prostredie'97. International Conference Forest - Wood - Enviroment'97.

Technical University in Zvolen, Slovakia, Zvolen, Working group No 10: Machines-Tools Worpieces and Equipment: 137 - 141.

4. Ivankin, I.I. 2000: Teoretičeskije issledovanija načalnoj žetskosti lentočnych pil. Lesnoj Žurnal. Izvestija Vysšych Učebnych Zavedenij (3): 115 - 122.
5. Lehmann, B.F.; Hutton, S.G. 1996: The Mechanics of Bandsaw Cutting. Part I: Modelling the Interactions Between a Bandsaw Blade and the Workpiece. Holz als Roh- und Werkstoff (54): 423 - 428.
6. Lehmann, B.F.; Hutton, S.G. 1997: The Mechanics of Bandsaw Cutting. Part II: A Simulation of the Cutting Behaviour of Bandsaws. Holz als Roh- und Werkstoff (55): 35 - 43.
7. Orłowski, K., Kaliński, K. 1999: Static Properties of the Frame Saw Blade as a Function of its Flexural and Torsional Rigidities. In: Proceedings of 14th International Wood Machining Seminar, Sept. 12-19, Paris, Epinal, Cluny-France, Vol. II: 725 - 734.
8. Orłowski, K. 1999: The Frame Saw Static Rigidity. In: Javorek L. (ed.) Zbornik prednášok. 2 Medzinárodna Vedecka Konferencia STROJ-NASTROJ-OBROBOK. 8-9 Oct., Nitra. Zvolen: Tech. Univ. Fac. Environm. Vyrobnej Tech.: 95 - 100.
9. Orłowski, K. 2000: Statická tuhost´ pílových listov rámových píl. Drevo, (55)4: 76 - 78.
10. Orłowski, K.; Kaliński, K. 2001: Operating Saw Blade Tooth Stiffness. In: Szymani R. (ed.) Proceedings of 15th International Wood Machining Seminar. Los Angeles, California, USA. July 30 - August 1, 2001. Wood Machining Institute 20, pp. 249 - 259.
11. Orłowski K. 2001. Przemieszczenia poprzeczne ostrzy pił. (Flexural deflections of saw blade teeth, in Polish). In: Oczos K. (ed.) Zbiór prac VI Konferencji Naukowo-Technicznej KSZTAŁTOWANIE MATERIAŁÓW NIEMETALOWYCH. Zakopane 27 - 29 września, Politechnika Rzeszowska, Rzeszów, Oficyna Wyd. Pol. Rzeszowskiej: 219 - 228.
12. Orłowski, K.; Kaliński, K. 2002: Symulacje odkształceń brzeszczotu piły trakowej w procesie przecinania. (Simulations of frame saw blade deflections during cutting, in Polish). In: Rybicki J. and Tylikowski A. (eds.) Zbiór referatów VIII Warsztatów Naukowych PTSK " Symulacja w Badaniach i Rozwoju". Gdańsk-Sobieszewo, 30 sierpnia - 1 września, Gdańsk: TASK Publish., GTN: 293 - 298.
13. Orłowski, K. 2003a: Materiałooszczędne i dokładne przecinanie drewna piłami. (Narrow - Kerf and Accurate Sawing of Wood, Monograph in Polish). Seria Monografie, nr 40, Wydawnictwo Politechniki Gdańskiej, Gdańsk : pp. 146.
14. Orlowski, K. 2003b: Usability of Calculation Methods for Saw Blade Stiffness Determination. In: Proceedings of the 2nd International Scientific Conference Fortechenvi Forest and Wood Processing Technology and the Environment. Brno, Czech Republic, 26 - 30 May. Brno: Mendel Univ. a. Forestry, Fac. Forestry a. Wood Technol., vol. 2: 301 - 310.
15. Prokofiev, G.F.; Choderjan, B.A.; Eršov, S.V. 1985: Načalnaja žestkost' polosovych pil. CNIIMOD - Archangel'sk, Dep. vo VNIPIEI lesprome 17.06.85, No 1589 l.b. 23p.
16. Prokofiev, G.F. 1990: Intensifikacija pilenija drevesiny ramnymi i lentočnymi pilami. Moskva, Lesnaja Promyslennost': 240 pp.
17. Stakhiev, Y. M. 2000: Today and Tommorow Circular Sawblades: Russian Version. Holz als Roh- und Werkstoff, (58): 229 - 240.
18. Szymani, R. 2003: Wood Machining Institute, CA, USA (Personal contact).
19. Taylor, J.; Hutton, S.G. 1991: A Numerical Examination of Bandsaw Blade Tooth Stiffness. Forintek Canada Corp. Report, Vancouver.
20. Veselkova, B.A. 1982: Rešenie zadači ob ustojčivosti ploskoj formy izgiba lentočnych pil. Lesn. Žurnal,(3): 79 - 83.
21. Veselkov, V.I.; Veselkova, B.A.: Orientacija škivov i rabotosposobnost' lentočnych pil. Derevoobrabatyvajuščaja promyšlennost', (2): 9 - 11.
22. ***, 1999: The Handbook. Production, use and maintenance of wood bandsaw steels. AB SANDVIK Steel.

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