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# CALCULATION OF OPERATIONAL STRESSES IN BLADES OF HORIZONTAL MOBILE BANDSAWS

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## ABSTRACT

As a continuation of two accompanying papers of ours, in this paper calculation is done relating to operational stresses in blades of horizontal mobile bandsaws as a part of their operational characteristics. In the case of tensioning the blade by a spring mechanism, when the problem of the tensile forces and stresses is statically indeterminate, our solution (from the first accompanying paper) applies. This requires iterations which are programmed in an excel-file. In it, a number of formulas for stress calculation are programmed which are derived in our second accompanying paper. Several types of stress-components, and stress conditions, are involved. A series of additional computational results are obtained automatically with varying the input data in the excel-file. Stress oscillograms have been drawn, as well. They show that, under equal other conditions, the horizontal bandsaw blade is more threatened by fatigue than a vertical bandsaw blade.

**Key words:** bandsaw blades, horizontal mobile bandsaws, operational tensile forces and stresses in saw bands, automation of stress calculations

## INTRODUCTION

The present paper is devoted to the calculation of operational stresses in mobile bandsaws as a part of their operational characteristics. Bandsaws with a spring mechanism for tensioning the blade are meant. Then the problem of the tensile forces and stresses is statically indeterminate. We give a solution to this problem in (Stefanov & Atanasov 2014/1). An equation for the statically indeterminate tensile force $X$ in the non-cutting span of the blade is presented there. It is valid for both a horizontal and a vertical bandsaw. This equation leads, in (Stefanov & Atanasov 2014/2), to the expressions of stresses from tensile forces in all sections of the blade. In these expressions, stress-components show up with magnitudes depending substantially on spring's stiffness (spring's constant $c$). Such dependency is missing in the studied references. It was important to clarify the correct combination of stress-components.

The stresses from bending of the blade around the periphery of wheels, as well as other stresses, are also presented in (Stefanov & Atanasov 2014/2). In general, a view of all possible nominal stresses and their correct combination into equations for strength calculation has been clearer presented, as the Strength of Materials science requires. Significant differences in the stresses compared to the statically determinate case of blade tensioning by lever-weight or hydraulic mechanism have been highlighted.

The equation for the force $X$ is not directly solvable. The value of $X$ can be computed by iteration. After that, the stresses from (Stefanov & Atanasov 2014/2) can be calculated. That is, in order to practically apply the equations from the two mentioned papers, programming of the calculations is necessary in a way any user would easily understand and use. For this purpose, we offer for free an excel-file named „Stefanov-Atanasov-INNO-2013.xls". It can be downloaded from Internet via the following link: http://dox.bg/files/dw?a=39b1348d00. The user is advised to keep a copy of the original file before entering own input data.

The programming of the excel-file has also been further systematizing the theoretical knowledge and formulae from the two mentioned papers, and taking them to practical application. This is the main content of the present paper. In the excel-file, series of automated computational results are given after varying the input data. The results relate to operational stresses in horizontal mobile bandsaws which are a subject of first author's PhD thesis.

## 1. THE EQUATION FOR *X*

The equation (without any analog in the studied references) is:

$$X = \frac{1}{2d + \pi R + \dfrac{4Ebs}{c}} \left[ -P\left(d_E + \frac{h_p}{2}\right) - \frac{PR}{\mu} - \frac{\pi R \Phi}{2} + 2Ebs\lambda_s - Ebs\Delta l_\theta - Ebsl\alpha_t \Delta t + \frac{2Ebs\Phi}{c} \right] \quad (1)$$

where

$$\mu = \frac{1}{\pi} \ln\left(1 + \frac{P}{X - \Phi/2}\right) \quad (2)$$

$$\Phi = 2\rho bsv^2 \quad (3)$$

$$l = 2d + 2\pi R \quad (4)$$

The symbols in these equations have the following nomenclature:

$E$ – Young's modulus of the blade material. If higher accuracy of the third significant figure is not required, $E$ = 2,06.10$^{11}$ [Pa] (Kisyov 1985) can be accepted for alloy steels;

$\lambda_s$ – pull-out (as a distance) of the left spring's end for pre-tensioning the blade [m];

$c$ – spring's stiffness (spring constant) [N/m];

$R$ – radius of the wheels [m];

$d$ – distance between the axes of the wheels [m];

$d_E$ – distance from the axis of the driving wheel to the detail cut (to vertical basing elements in horizontal mobile bandsaws) [m];

$h_p$ – height of cutting; for a horizontal bandsaw, $h_p$ is the length of the blade's section which is in contact with the detail cut [m];

$l$ – length of the blade [m];

$b$ – width of the blade (distance from the rear edge of the band to the teeth's gullet area, excluding the tooth height) [m];

$s$ – thickness of the blade [m];

$\Delta l_\theta$ – lengthening of $l$ along the central blade fibre as a result from driven wheel tilt, or from both this tilt and driving wheel tilt if any; if the tilt causes shortening of $l$, then $\Delta l_\theta$ is taken with negative algebraic value [m];

$\Delta t$ – heating of the blade [$^o$C];

$\alpha_t$ – coefficient of free thermal expansion per 1$^o$C; if higher accuracy of the second significant figure is not required, then $\alpha_t$ = 12.10$^{-6}$ [1/$^o$C] (Kisyov 1985) can be accepted for alloy steels;

$\mu$ – working coefficient of friction (coherence) of the blade with the driving wheel;

$P$ – cutting force, longitudinal to the blade [N];

$\Phi$ – force of mass inertia of each of the two blade half-circumferential parts [N];

$v$ – cutting speed [m/s];

$\rho$ – mass density of the blade; if higher accuracy of the second or third significant figure is not required, the well-known value of the mass density of iron $\rho$ = 7850 [kg/m$^3$] can be accepted for alloy steels.

In (Stefanov & Atanasov 2014/2), based on Eqs. (1) and (2) the assembly (mounting) tension (pre-tension) of the blade is derived as $X_\text{M} = 2Ebs\lambda_s/(l + 4Ebs/c)$. Hence, the necessary value of $\lambda_s$ for enabling desired pre-tension $X_\text{M}$ is

$$\lambda_s = \frac{X_\text{M}(l + 4Ebs/c)}{2Ebs} \qquad (5)$$

Or, if desired tensile stress $\sigma_\text{M} = X_\text{M}/(bs)$ of mounting tension is introduced, then

$$\lambda_s = \frac{\sigma_\text{M}(l + 4Ebs/c)}{2E} \qquad (6)$$

Anyway, in Eqs. (5) and (6) the spring's stiffness $c$ remains as an independent input data item (which does not result from other data). In another version, $\lambda_s$ can be preferred as an independent input data item. Then the last two equations will provide $c$:

$$c = \frac{X_\text{M} 4Ebs}{2Ebs\lambda_s - X_\text{M} l} \qquad (7)$$

$$c = \frac{\sigma_\text{M} 4Ebs}{2E\lambda_s - \sigma_\text{M} l} \qquad (8)$$

The symbols in the above equations can be seen in Fig. 1, as well. Furthermore, it is to remark that, for the character of this paper, some of the symbols have been preferred as more typical in terms of the Strength of Materials than Woodworking Machines.

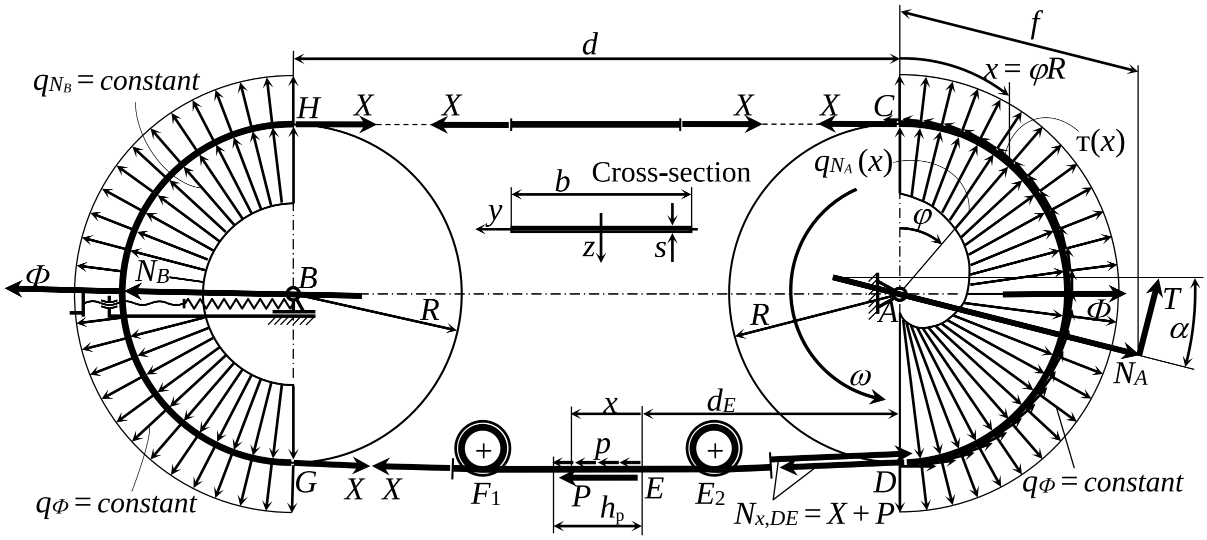


**Figure 1: The blade together with its internal tensile forces**

## 2. PROGRAMMING THE CALCULATION OF *X* AND ITS COMPONENTS IN THE EXCEL-FILE

Due to the uniqueness of Eq. (1) and the following equations, there are no established traditions of reporting $c$ and/or $\lambda_s$ in the studied references. Such traditions will be established from now on. The user may have a preference for any one of the equations (5) – (8). Correspondingly, one of the following Sheets will be opened.

Sheet1 – $X_\text{M}$, $E$, $R$, $d$, $b$, $s$, $c$ are entered. Excel calculates (in the corresponding cells) $l$ by Eq. (4) and $\lambda_s$ by Eq. (5). The value of $\sigma_\text{M} = X_\text{M}/b/s$ is calculated, as well.

Sheet2 – $\sigma_\text{M}$, $E$, $R$, $d$, $b$, $s$, $c$ are entered. Excel calculates the same $l$ and $\lambda_s$, but for $\lambda_s$

Eq. (6) applies now. The value of $X_M = \sigma_M bs$ is calculated, as well.

Sheet3 – $X_M$, $E$, $R$, $d$, $b$, $s$, $\lambda_s$ are entered. Excel calculates $c$ by Eq. (7). The value of $\sigma_M = X_M/b/s$ is calculated, as well.

Sheet4 – Like Sheet2 but now $\lambda_s$ is entered and c is calculated by Eq. (8). The value of $X_M = \sigma_M bs$ is calculated, as well.

Further, the reader can see for example only Sheet1. The equation in each of the functional cells can be checked by double clicking on it. The cells with the input data are highlighted in blue. All numerical data are entered in the above principal units.

The following illustration (Table 1) shows (partly) how the excel-file looks.

**Table 1: Input data and calculation results in the excel-file**

MKG "Wirex"

| $X_M$ | $E$ | $R$ | $d$ | $l$ |
|---|---|---|---|---|
| 227,15 | 2,06E+11 | 0,3 | 1,43 | 4,744956 |
| | $b$ | $s$ | $c$ | $\lambda_s$ |
| | 0,0295 | 0,0011 | 50000 | 9,17E-03 |
| $\sigma_M$ | | | | |
| 7,00E+08 | | | | |
| $\Delta t$ | $P$ | $v$ | $d_g$ | $h_g$ |
| 32 | 10 | 24 | 0,38 | 0,24 |

| $E$ | $\lambda_s$ | $c$ | $R$ | $d$ | $d_g$ | $h_g$ | $l$ | $b$ | $s$ | $\Delta l_\theta$ | $\Delta t$ | $\alpha_t$ | $\mu$ | $P$ | $\Phi$ | $v$ | $\rho$ | $X$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2,06E+11 | 9,17E-03 | 50000 | 0,3 | 1,43 | 0,38 | 0,24 | 4,744956 | 0,0295 | 0,0011 | 0,0015 | 32 | 1,20E-05 | 0,0088851 | 10 | 293,4518 | 24 | 7850 | 500 |
| | | | | | | | | | | | | | | | | | | 331,112 |
| 2,06E+11 | 9,17E-03 | 50000 | 0,3 | 1,43 | 0,38 | 0,24 | 4,744956 | 0,0295 | 0,0011 | 0,0015 | 32 | 1,20E-05 | 0,0168114 | 10 | 293,4518 | 24 | 7850 | 331,112 |
| | | | | | | | | | | | | | | | | | | 331,408 |
| 2,06E+11 | 9,17E-03 | 50000 | 0,3 | 1,43 | 0,38 | 0,24 | 4,744956 | 0,0295 | 0,0011 | 0,0015 | 32 | 1,20E-05 | 0,0167852 | 10 | 293,4518 | 24 | 7850 | 331,408 |
| | | | | | | | | | | | | | | | | | | 331,407 |
| 2,06E+11 | 9,17E-03 | 50000 | 0,3 | 1,43 | 0,38 | 0,24 | 4,744956 | 0,0295 | 0,0011 | 0,0015 | 32 | 1,20E-05 | 0,0167852 | 10 | 293,4518 | 24 | 7850 | 331,407 |
| | | | | | | | | | | | | | | | | | | 331,407 |
| 2,06E+11 | 9,17E-03 | 50000 | 0,3 | 1,43 | 0,38 | 0,24 | 4,744956 | 0,0295 | 0,0011 | 0,0015 | 32 | 1,20E-05 | 0,0167852 | 10 | 293,4518 | 24 | 7850 | 331,407 |
| | | | | | | | | | | | | | | | | | | 331,407 |
| 2,06E+11 | 9,17E-03 | 50000 | 0,3 | 1,43 | 0,38 | 0,24 | 4,744956 | 0,0295 | 0,0011 | 0,0015 | 32 | 1,20E-05 | 0,0167852 | 10 | 293,4518 | 24 | 7850 | 331,407 |
| | | | | | | | | | | | | | | | | | | 331,407 |

| $\alpha$ | $X_1$ | $X$ | $X_\theta$ | $X_t$ | $X_\Phi$ | $X_1$ | $X_F$ | | max $N$ |
|---|---|---|---|---|---|---|---|---|---|
| 0,96145 | 331,4249 | 331,407 | -18,5851 | -22,57548 | 145,4355 | 331,425 | -0,017923 | | 341,407 |
| | $\sigma_1$ | $\sigma_X$ | $\sigma_\theta$ | $\sigma_t$ | $\sigma_\Phi$ | $\sigma_1$ | $\sigma_F$ | | max $\sigma$ |
| | 1,02E+07 | 1,02E+07 | -5,70E+05 | -6,86E+05 | 4,48E+06 | 1,02E+07 | -5,52E+02 | | 1,05E+07 |
| | | 1,02E+07 | | | | 1,02E+07 | | | $\sigma_{bu}$ |
| | | | | | | | | | 3,79E+08 |

| $N_B$ | $N_A$ | $T$ | $f$ |
|---|---|---|---|
| 369,3622 | 379,3087 | 6,366776 | 0,471196 |

For successive approximations to determine $X$, the method of fixed-point iteration has been envisaged (Stefanov 2013). For an initial value of $X$ in Eq. (2), a number in the order of $P$ can be entered, for example $X$ = 500 N. Then Eq. (2) gives $\mu$. By Eq. (1), Excel calculates the first approximation for $X$.

The next approximations are in the next rows of the file. Each row has been formed by Copy and Paste, and uses the input data from the previous row. This provides automatic calculation with any other ("blue") input data, as well. Even the second approximation for $X$ (after the initial one) repeats the first four significant figures, i.e. the iteration proves to be rapidly convergent. The first four significant figures of $\mu$ are repeated in the third approximation. Just in case, five approximations have been set in the file.

By the way, it should be noted that, among its other innovations, the proposed file allows an assessment of the risk of slipping of the saw band on the driving wheel. Indeed, if the selection of the operational input data is not proper, $\mu$ can surpass the ultimate friction value. Excel also calculates $\alpha$ = arctg$\mu$ in degrees.

As well, $N_B = 2X - \Phi$, $N_A = (P + N_B)\cos\alpha$, $T = (P + N_B)\sin\alpha$ and $f = PR/T$ are calculated.

A test can be done with a very little $P$, for example $P$ = 1 N (theoretically at $P \to 0$), and with $v = \Delta t = \Delta l_\theta = 0$. Then, $X = X_M$ is correctly computed. By Eq. (4) from (Stefanov & Atanasov 2014/2), Excel also calculates separately $X_0$ with $P = 0$ (idle running), when $PR/\mu$ in Eq. (1) has denominator $\mu = 0$ (respectively, $\alpha = 0$). By setting $v = \Delta t = \Delta l_\theta = 0$, as well, $X_0 = X_M$ is correctly computed. And, by setting the previous non-zero $v$, $\Delta t$ and $\Delta l_\theta$ with $P = 0$, $X = X_0$ is correctly obtained.

The values of $X_\theta = -Ebs\Delta l_\theta/(l + 4Ebs/c)$, $X_t = -Ebsl\alpha_t\Delta t/(l + 4Ebs/c)$, $X_\Phi = 2Ebs\Phi/(cl$

+ $4Ebs$) are also calculated. As well, for verification, $X_0 = X_M + X_\theta + X_t + X_\Phi$ (= $X_0$ from the previous paragraph) is calculated. If introducing $X = X_0 + X_P$, then $X_P = X - X_0$ is the $X$ component from the cutting force $P$ in Eq. (1); $X_P$ is also calculated in the file.

More tests can be done to confirm the theoretical considerations in (Stefanov & Atanasov 2014/2): with a very high $c$ value (theoretically at $c \to \infty$), with a very low $c$ value (theoretically at $c \to 0$), etc. It is essential that when setting a very low imaginary (conditional) $c$ value in Sheet1 or Sheet3, for example $1.10^{-10}$ N/m, the file becomes valid for the statically indeterminate case with lever-weight or hydraulic mechanism for tensioning the blade, as well. Then $X_\theta$, $X_t$ and $X_P$ become zeros, $X_\Phi$ takes the highest value, $X$ and $X_0$ are equal, and $N_B = 2X_M$. The same effect is achieved in Sheet2 or Sheet4 by setting a very high imaginary (conditional) $\lambda_s$ value. In case $\Delta l_\theta = 0$, the solution is valid for cutting mechanism without tilting the driven wheel.

Along $d_E$, the largest tensile force $\max N_x = X + P$ acts. It is also calculated in the file.

## 3. PROGRAMMING THE CALCULATIONS IN THE EXCEL-FILE FOR OPERATIONAL STRESSES IN HORIZONTAL MOBILE BANDSAWS

Due to limitation in the size of this paper, a horizontal mobile bandsaw “Wirex 1/ZM” (Poland) is only involved for practical calculation of $X$ and stresses in the cutting mechanism. The tensioning of the cutting tool is done by a spring mechanism.

The technical data of the machine involved in the above equations are: wheel diameter $D$ = 0,6 m; cutting speed $v$ = 24 m/s; distance between the wheel axes $d$ = 1,43 m; distance from the axis of the driving wheel to the processed material (to the vertical basing elements) $d_E \approx$ 0,38 m. The technical data of the cutting tool „Carl Röntgen“ (Germany) involved in the computation performance are: thickness $s$ = 0,0011 m; width $B$ = 0,0345 m; height of teeth $h'$ = 0,005 m; length of the cutting tool $l$ = 4,744 m.

Properties associated with the cutting process of black pine (Pinus nigra Arn.) round logs with density $\rho = 750 \div 870$ kg/m$^3$ and humidity $W = 30 \div 40$ % are: accepted cutting height $h_p$ = 0,24 m; average value of the tangential cutting force (longitudinal to the blade) calculated at a feed speed $u$ = 0,083 m/s, $P \approx 10$ N. The mounting force is $X_M$ = 227,15 N. The average value for $\Delta t$ is accepted ≈ 32˚C as obtained in experimental research of a horizontal mobile band cutting tool’s surface temperature (Klepárník & Holopírek 2008).

The highest tensile stress $\sigma_{Nx} = \max N_x/(bs)$ is calculated. The values of $\sigma_X = X/(bs)$, $\sigma_\theta = X_\theta/(bs)$, $\sigma_t = X_t/(bs)$, $\sigma_\Phi = X_\Phi/(bs)$, $\sigma_0 = X_0/(bs)$ and $\sigma_{Xp} = X_P/(bs)$ are calculated, as well. With that, $\sigma_0 = \sigma_M + \sigma_\theta + \sigma_t + \sigma_\Phi$, $\sigma_X = \sigma_0 + \sigma_{Xp}$.

Next, the calculation of the bending stress $\sigma_{be} = Es/(2R)$ is done. Based on the above data of the mobile horizontal bandsaw “Wirex 1/ZM”, $\sigma_{be}$ proves 378 MPa. It is higher than 200 MPa: the stress which results from the practical rule $s \le 2R/1000$. It does not apply to horizontal mobile bandsaws as already discussed in (Stefanov & Atanasov 2014/2).

The highest normal resultant stress up to this point is $\max\sigma_{My,Nx} = \max\sigma_{Nx} + \sigma_{be}$.

When solving the equation for $X$ under specific data, it is clearly seen that the pretension force $X_M$ has the greatest influence on $X$. Finding the optimal value of this force has a great importance for the operation of bandsaw machines. As a result of its increasing, the stability of the saw band will be improved, as well as the accuracy of the shape, dimensions and quality of machined surfaces. The maximum allowable feed speed will increase together with the productivity of the machine. On the other hand, there are restrictions concerning the welding of the saw band ends. Besides, the additional loading of the bearings and the wheels in the cutting mechanism due to higher $X_M$ should not be omitted (Popov 1984).

Another factor in the cutting process with less importance to $X$ is the cutting force $P$. This especially applies to mobile bandsaws where it is difficult to achieve a high feed speed and hence high values of $P$. It is to note that if $P$ increases, the values of $X$ decrease insignificantly. For example, the difference in the force $X$ under $P$ = 10 N and $P$ = 50 N is only 0,07 N which practically has no influence on the stresses in the blade. The cutting height $h_p$ does not affect the values of $X$, either: $h_p$ only influences the third figure in the decimal part of $X$.

The other stresses described in Section 4 in (Stefanov & Atanasov 2014/2) have not been programmed yet in the excel-file due to using up the volume of this paper. They will be subject to next papers of ours with more sophisticated, finite-element analysis instead of application of the classical knowledge of Strength of Materials.

The input data of the considered machine, set in Sheet1, and the obtained values of the forces and stresses, are shown in Table 1. The results show that the normal stresses in the blade are totally dominated by $\sigma_{be}$ from the bending around the wheels. This trend is particularly clear when comparing this type of stresses between a vertical stationary bandsaw and the mobile bandsaw considered. Fig. 2 shows the stress oscillograms of "Wirex 1/ZM" and a log bandsaw with trolley feeding mechanism “DURA”; the second machine has a lever-weight mechanism for tensioning the blade.

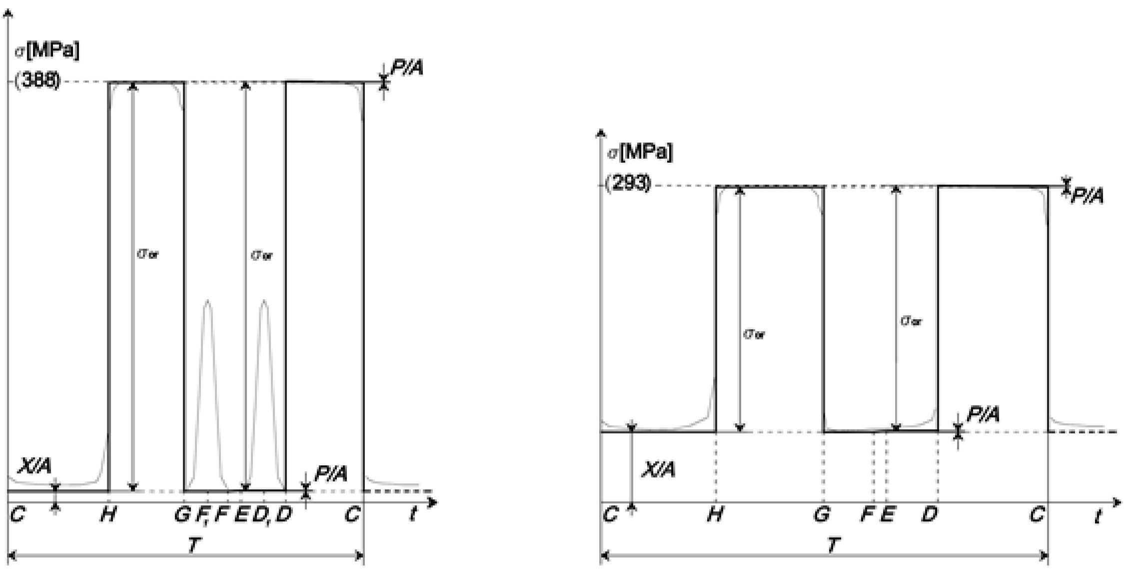


**Figure 2: Oscillograms of $\sigma(t) \equiv \sigma_{My,Nx}$ at horizontal bandsaw “Wirex 1/ZM” (on the left) and vertical bandsaw with trolley feeding mechanism “DURA” (on the right)**

For composing the two oscillograms, concrete computed values have been used based on input data for the vertical machine taken from (Gochev et al. 2008). The separate sections of the oscillogram for the horizontal bandsaw come from the separate blade's sections shown in Fig. 1. The sections of the vertical bandsaw blade are the same and can be seen in (Stefanov 2013). The values of the stress $\sigma_{be}$ from the bending of the blade around the wheels are 378 MPa for the mobile horizontal bandsaw and 227 MPa for the vertical bandsaw with trolley feeding mechanism. The significant difference in these two numbers appears due to the significantly greater diameter of the wheels of the vertical bandsaw (1 m) while the thickness of the blade is the same (0,0011 m) at both machines.

In Fig. 2 on the left, the oscillogram's intermediate local extrema generated by the roller guides of the mobile bandsaw are also illustrated. Their approximate size is taken from (Kondratyuk & Shilko 2004). All sudden changes in this oscillogram confirm that the stressing in the horizontal mobile bandsaw cutting tool is essentially more dynamic, and it is a fact that this tool is more threatened by fatigue than a vertical bandsaw blade.

The considered mobile horizontal bandsaw blade stress values generated as stress components by the cutting force, the centrifugal force of mass inertia, the heating of the blade and the mounting force, are very low in comparison with $\sigma_{be}$. They practically do not affect $\sigma$ (moreover, they have different directions of action).

## CONCLUSION

The proposed excel-file allows quick calculation of the nominal stresses in the blades of both a horizontal mobile bandsaw and a vertical stationary bandsaw. Moreover, the file can be used for bandsaws where keeping the blade tension is enabled by lever-weight or hydraulic mechanism.

Based on the obtained results from calculation of the forces and stresses in the bandsaw blades of horizontal mobile bandsaws, the following conclusions, recommendations and objectives for future research can be identified.

1. By comparing the calculated $X$ values with the experimental results regarding the accuracy of the shape and dimensions of the processed material, it is clearly seen that the increase in the blade tension increases also the operating accuracy of the machine. Optimization of the $X$ value should be achieved according to the emphases in Section 3.
2. In next stage, the authors will reveal the full picture of the stresses by the finite-element method, using contemporary software "Autodesk Inventor" or "SolidWorks".
3. Most of the modern bandsaw machines have an indicator that displays the current stress in the cutting tool. In all cases, it is not clear if the cross section of the cutting tool and our equation for $X$ are taken into consideration. Clarification of this issue is pending.

Very often in the practice with machines having spring mechanism for keeping the tension of the cutting tool, the worker has to re-tension the blade additionally after a certain period of time, and in some cases even after a cut. All this causes a loss of time and decreases the productivity. Therefore, in addition to the quality of bandsaw blades preparation, to improve the working accuracy and performance of the machines, the authors recommend using the lever-weight and hydraulic mechanisms for keeping the tension.

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