



COMPUTATION OF THE TEMPERATURE DISTRIBUTION IN SPRUCE DETAILS DURING THEIR ONE SIDED HEATING IN THE PRODUCTION OF STRINGED MUSIC INSTRUMENTS

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Abstract

A 1D linear mathematical model for the computation of the non-stationary temperature distribution along the thickness of subjected to one sided heating wood details before their bending has been suggested.

For the computation of the temperature distribution along the details' thickness at given temperatures of the heating body and of the surrounding air a software program has been prepared in FORTRAN, which has been input in the calculation environment of Visual Fortran Professional. With the help of the program, computations have been carried out for the determination of the 1D temperature distribution along the thickness of spruce details with an initial temperature of 20 °C, moisture content of 0.15 kg.kg⁻¹, and thicknesses of 6 mm, 8 mm, and 10 mm during their 10 min one sided heating at temperatures of the heating body 100 °C and of the surrounding air 20 °C. The obtained results are graphically presented and analyzed.

Key words: *spruce details, one sided heating, plasticizing, bending*

INTRODUCTION

A mandatory component of the technology for production of curved wood details is their plasticizing up to the stage that allows their bending without any waste. The duration of the heating of the wood details aimed at their plasticizing before bending depends on many factors: wood specie, thickness and moisture content of the details, temperature of the heating medium, radius of the bending, etc. (Angelski 2010, Deliiski and Dzurenda 2010, Gaff and Prokein 2011).

One sided heating is applied to the outside parts of the corpse of the string music instruments (violins, violas, cellos, contrabass, mandolins and guitars) so that it is plasticized before bending. In the practice, most often those details are with width in-between 5 mm to 10 mm and about 15% moisture content. The classical technology for plasticizing of such details has been using a metal tube heated up to the temperature in the range of 100 °C ÷ 150 °C (Figure 1). The bending of the details is done gradually around the cylindrical surface of the heated tube. Most frequently the tube is heated by electric heaters located in it, equipped with an automatic control of the desired temperature.

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A well-known fact is that the degree of plasticizing and deformability of the wood depends considerably on the temperature distribution in the details volume at the moment of their bending (Trebula and Klement 2002, Vidlov 2003, Deliiski 2003, Angelski 2010, Deliiski and Dzurenda 2010). In the specialized literature there are very limited reports about the temperature distribution in subjected to all sided heating wood details before their bending (Angelski 2010) and there is no information at all about the temperature distribution in details during their one sided heating.



Figure 1. General view of equipment for bending of wood details used in the production of outside parts of the corpse of string music instruments

The current work presents a 1D linear model for the calculation of the temperature distribution along the thickness of wood details subjected to one sided heating in order to be plasticized before bending. Analysis of the model solutions has been provided for the case of one sided heating of spruce details with different thickness, which are bent in order to be used in the string music instruments.

MECHANISM OF THE 1D HEAT DISTRIBUTION IN THE WOOD DETAILS DURING THEIR HEATING

During the heating of wood details aimed at their plasticizing along with the purely thermal processes, a moisture-exchange occurs between the processing medium and the details. The values of the moisture diffusion in the details are usually hundreds of times smaller than the values of their temperature conductivity (Chudinov 1966). These facts determine a not so big change in defunding moisture in the details, which lags significantly from the distribution of heat in them during the heating.

This allows disregarding the exchange of moisture between the details and the heating medium and the change in temperature in them to be viewed as a result of a pure thermo-exchange process, where the heat in them is distributed only through thermo-conductivity. Because of this the mechanism of heat distribution in wood details can be described by the equation of heat conduction.

When the width of the details exceeds their thickness by at least 3 ÷ 4 times, then the calculation of the change in the temperature only along the thickness of the details during their one sided heating (i.e. along the coordinate x , which coincides with the thickness) can be carried out with the help of the following 1D mathematical model (Deliiski 2003):

$$\frac{\partial T(x, \tau)}{\partial \tau} = a(T, u) \frac{\partial^2 T(x, \tau)}{\partial x^2} \quad (1)$$

with an initial condition

$$T(x, 0) = T_0 \quad (2)$$

and following boundary conditions:

- from the side of the heating – at a prescribed surface temperature, which is equal to the temperature of the metal heating body T_m :

$$T(0, \tau) = T_m(\tau), \quad (3)$$

- from the opposite side – at convective heat exchange between the details' surface and the surrounding air environment:

$$\frac{\partial T(X, \tau)}{\partial x} = -\frac{\alpha(\tau)}{\lambda_s(\tau)} [T_a(\tau) - T_s(\tau)], \quad (4)$$

where a is the temperature conductivity of the details' wood, $m^2.s^{-1}$;

T – temperature, K;

T_0 – initial temperature of the subjected to heating details, K;

T_m – temperature of the heating metal body, K;

T_s – temperature on the detail's surface at its opposite side during the heating, K;

T_a – temperature of the air environment near the opposite side during the heating,

K;

u – moisture content of the details' wood, $kg.kg^{-1}$;

x – coordinate along the thickness of the details: $0 \leq x \leq X = h$, m;

h – thickness of the details, m;

α – heat transfer coefficient between the details' surface at their opposite side and the surrounding air, $W.m^{-2}.K^{-1}$;

λ_s – thermal conductivity of the details' wood on the surface at the opposite side, $W.m^{-1}.K^{-1}$;

τ – time, s.

Because of the very tight contact between the subjected to heating detail and the heating metal body the temperature of the heated surface of the details is equal to the temperature of the body. This fact is mathematically described by eq. (3).

The opposite side of the detail is subjected to cooling in atmospheric conditions of free convection during the heating. For the calculation of the heat transfer coefficient in such conditions of heating of horizontally situated plates Chudinov (1968) suggests the following equation:

$$\alpha = 3.256 [T_s(\tau) - T_a(\tau)]^{0.25}. \quad (5)$$

The meaning of the variables in equation (5) has been explained above.

RESULTS AND DISCUSSION

The mathematical model, which is presented in common form by the eqs. (1) ÷ (5), has been solved with the help of explicit schemes of the finite difference method. This has been done in a way, analogous to the one used and described in (Deliiski 2003, Deliiski and Dzurenda 2010) for the solution of a model of the heating process of prismatic wood materials. For the solution of the model a software program has been prepared in the calculation environment of Visual Fortran Professional.

With the help of the program as an example computations have been made for the determination of the 1D change of the temperature in subjected to one sided heating non-frozen spruce (*Picea Abies Karst*) details with thicknesses of $h = 0.006$ m, $h = 0.008$ m, $h = 0.010$ m, initial wood temperature of $t_0 = 20$ °C, and wood moisture content of $u = 0.15$ kg.kg⁻¹ during their 10 min heating at $t_m = 100$ °C.

The calculations have been done with average values of the wood temperature conductivity $a_c = 2.736 \cdot 10^{-7}$ m².s⁻¹ and of the wood thermal conductivity cross-sectional to the fibers of the details $\lambda_c = \lambda_s = 0.2668$ W.m⁻¹.K⁻¹ for spruce wood with $u = 0.15$ kg.kg⁻¹ and fiber saturation point $u_{fp} = 0.32$ kg.kg⁻¹ in the temperature range from 20 °C to 100 °C. These average values if a_c and λ_c have been obtained using the mathematical description of a_c and λ_c depending on the temperature, wood moisture content and fiber saturation point of the wood species (Deliiski 2003, 2013, Deliiski and Dzurenda 2010). The calculated values of a_c and λ_c for spruce wood with $u = 0.15$ kg.kg⁻¹ in the temperature range from 20 °C to 100 °C are shown in Table 1.

Table 1. Change in a_c and λ_s of spruce wood with $u = 0.15$ kg.kg⁻¹, depending on t

Parameter of the wood	Temperature t , °C					Average value for $t = 20 \div 100$ °C
	20	40	60	80	100	
$\lambda_c, \text{W.m}^{-1}.\text{K}^{-1}$	0.2341	0.2502	0.2664	0.2826	0.2987	0.2668
$a_c \cdot 10^7, \text{m}^2.\text{s}^{-1}$	2.5799	2.6634	2.7412	2.8139	2.8818	2.7360

Figures 2, 3 and 4 present the temperature change calculated by the 1D model in 4 equidistant from one another characteristic points along the thickness of the details with widths $h = 6$ mm, $h = 6$ mm and $h = 10$ mm, respectively, during their one sided heating at $t_m = 100$ °C. The coordinates of those points are shown in the legends of the figures.

According to equation (3), the temperature at the details surface being in contact with the heating body (i.e. the characteristic point with x -coordinate = 0 mm) is equal to its temperature t_m due to the extremely high coefficient of heat transfer between the body and the wood during their very close contact.

The above results show that through one sided heating of details the non-stationary change of the temperature in the characteristic points of their thickness goes on according to complex curves. By increasing the heating time those curves gradually approach asymptotically to their biggest values, decreasingly dependant on the remoteness of the points from the heated surface of the details. Those biggest temperature values are achieved when a stationary temperature distribution occurs along the details thickness.

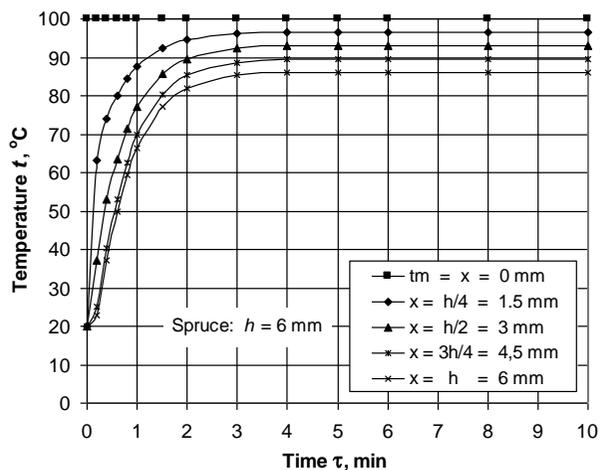


Figure 2. Change in t along the thickness of spruce detail with $t_0 = 20\text{ }^{\circ}\text{C}$, $u = 0.15\text{ kg.kg}^{-1}$ and $h = 6\text{ mm}$ during its one sided heating at $t_m = 100\text{ }^{\circ}\text{C}$ and $t_a = 20\text{ }^{\circ}\text{C}$

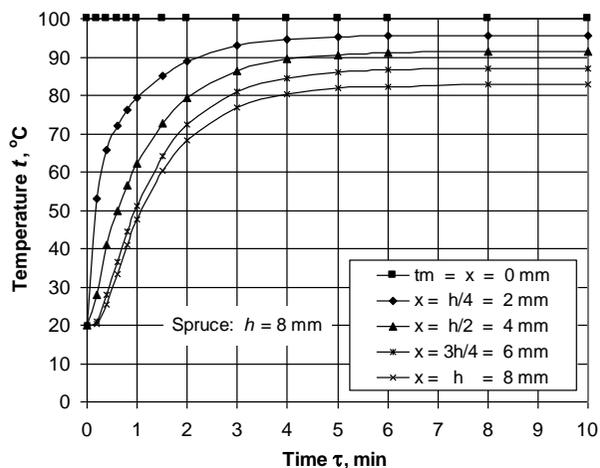


Figure 3. Change in t along the thickness of spruce detail with $t_0 = 20\text{ }^{\circ}\text{C}$, $u = 0.15\text{ kg.kg}^{-1}$ and $h = 8\text{ mm}$ during its one sided heating at $t_m = 100\text{ }^{\circ}\text{C}$ and $t_a = 20\text{ }^{\circ}\text{C}$

At temperature of the heating body of $t_m = 100\text{ }^{\circ}\text{C}$ the stationary temperature distribution along the thickness of the studied spruce details (with precision of up to $-0.2\text{ }^{\circ}\text{C}$) occurs upon reaching the following temperatures at their non-heated side:

- $86.0\text{ }^{\circ}\text{C}$ for details with $h = 6\text{ mm}$ after heating duration of 3.5 min ;

- 82.7 °C for details with $h = 8$ mm after heating duration of 6.4 min;
- 79.7 °C for details with $h = 10$ mm after heating duration of 9.7 min.

At $t_m = 100$ °C the most slowly changing temperature of the details surface, t_s , that is in contact with the outside air environment, reaches temperatures of 50 °C, 60 °C, 70 °C and 80 °C, which are necessary for the start of bending of details with different radii after a duration of one sided heating, equal respectively to:

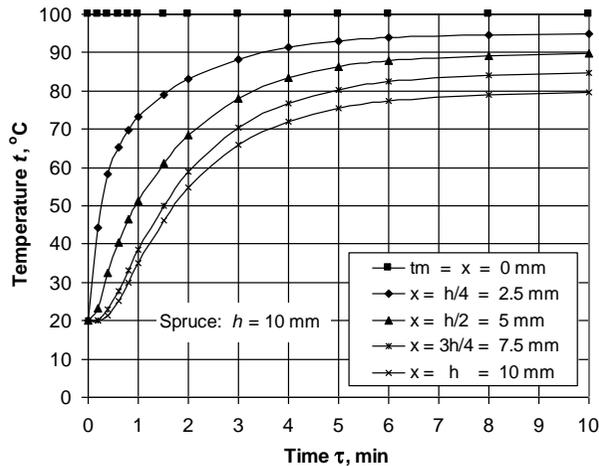


Figure 4. Change in t along the thickness of spruce detail with $t_0 = 20$ °C, $u = 0.15$ kg.kg⁻¹ and $h = 10$ mm during its one sided heating at $t_m = 100$ °C and $t_a = 20$ °C

- 0.6 min, 0.8 min, 1.0 min and 1.8 min at $h = 6$ mm;
- 1.1 min, 1.5 min, 2.1 min and 3.9 min heating $h = 8$ mm;
- 1.7 min, 2.4 min, 3.6 min and ≈ 10.0 min at $h = 10$ mm.

It should be mentioned that the minimum required temperature, at which the details are sufficiently plasticized and their faultless bending at a given radius could be started, depends on their thickness, on the temperature of the heating body and the surrounding air, as well as on the wood specie and the moisture content of the wood. The presented and solved mathematical model allows us to calculate the necessary duration of the one sided heating of wood details according to the above mentioned factors.

CONCLUSIONS

The article shows and analyzes diagrams of 1D non-stationary and stationary distributions of the temperature along the thickness of flat spruce details subjected to one-sided heating in order to be plasticized before their bending upon the production of outside parts for the corpses of stringed music instruments.

The diagrams are visualised according to the results, calculated by a linear mathematical model, which has been presented in the current article.

The results from the computer solutions of the model could be used for the following purposes:

- visualization and technological analysis of the temperature change along the thickness of details from different wood species, with different thickness and moisture

content, during their one sided heating before bending, accomplished by a heating body with different temperatures;

- to determine the duration of details' heating, which is necessary for achieving the minimum required plasticity of the details before their bending with a specified radius;
- scientific model based automatic control of the heating process of details before their bending.

As an example for the use of the model a 1D distribution of the temperature along the thickness of flat spruce details with thickness of 6 mm, 8 mm and 10 mm, initial wood temperature 20 °C and moisture content of 0.15 kg.kg⁻¹ during their one sided heating in order to be plasticized for a period of 10 min at temperature of the heating body $t_m = 100$ °C and temperature of the air environment near the opposite side of the detail during the heating $t_a = 20$ °C before being bent is calculated, visualised and analysed.

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REFERENCES

1. ANGELSKI, D., 2010: Researches over the processes of plastisization and bending of furniture wood details. PhD Thesis, University of Forestry, Sofia (in Bulgarian).
2. CHUDINOV, B. S., 1966: Theoretical research of thermo physical properties and thermal treatment of wood. Dissertation for DSc., SibLTI, Krasnoyarsk, USSR (In Russian).
3. DELIISKI, N., 2003: Modelling and technologies for steaming wood materials in autoclaves. Dissertation for DSc., University of Forestry, Sofia (in Bulgarian).
4. DELIISKI, N., 2013: Computation of the Wood Thermal Conductivity during Defrosting of the Wood. *Wood research*, 58 (4): 637-650.
5. DELIISKI, N., DZURENDA, L., 2010: Modelling of the thermal processes in the technologies for wood thermal treatment. TU Zvolen, Slovakia (in Russian).
6. GAFF, M., PROKEIN, L., 2011: The influence of selected factors on coefficient of bendability. *Annals of Warsaw University of Life Sciences, Forestry and Wood Technology*. No. 74: 78-81.
7. TREBULA, P., KLEMENT, I., 2002: Drying and hydrothermal treatment of wood, TU Zvolen, Slovakia (in Slovak).
8. VIDELOV, H., 2003: Drying and thermal treatment of wood, University of Forestry in Sofia, Bulgaria (in Bulgarian).