Nencho Deliiski[1]

Microprocessor system for automatic control of logs' steaming process

Mikroprocesorski sustav za automatsku kontrolu procesa parenja trupaca

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ABSTRACT • *This paper presents an electrical scheme and working algorithm of the system for automatic control of the steaming medium temperature tm and level of condensed water with inbuilt specialized microprocessor programmable controllers. The system calculates the set values, takes automatic measurements, displays, and regulates the temperature of the steaming medium, and measures and regulates the level of condensed water in the steaming pit, as well. Besides this, the system signals and records in its own controller memory the values and times of the occurrence of unallowably high deviations of tm from its set values with a possibility for a resulting reading and analysis of these records on the controller displays. Some of these systems are already integrated, as a result of which the quality of the steaming process has improved and the specific heat consumption has been reduced significantly.*

Key words: *logs, steaming pits, condensed water, automatic control, programmable controller*

SAŽETAK • *U radu je prikazana električna shema i radni algoritam sustava za automatsku kontrolu srednje temperature i razine kondenzirane vode pri parenju trupaca uz pomoć ugrađenoga specijaliziranog mikroprocesorski programabilnog kontrolera. Sustav izračunava određene odabrane vrijednosti, automatski obavlja mjerenje, prikazuje i regulira temperaturu medija za parenje te mjeri i regulira razinu kondenzirane vode u jami za parenje. Usto signalizira i u memoriju bilježi vrijednosti i vrijeme pojave nedopustivo velikih odstupanja srednje temperature medija od odabrane vrijednosti, uz mogućnost čitanja i analize zabilježenih vrijednosti na displeju uređaja. Neki od navedenih uređaja već su u uporabi, što je rezultiralo povećanjem kvalitete procesa parenja trupaca i znatnim smanjenjem jedinične potrošnje topline.*

Ključne riječi: *trupci, jame za parenje, kondenzirana voda, automatska kontrola, programabilni kontroler*

[1]The author is asociate professor at the Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria
[1]Autor je izvanredni profesor na Fakultetu za drvnu industriju, Šumarsko sveučilište, Sofia, Bugarska

1 INTRODUCTION
1 UVOD

An overwhelming majority of logs, used in the production of veneer, is subjected to steaming with the aim of plasticization of wood.

The duration and consumption of steaming process energy depend on dimensions and initial temperature of logs, on texture and micro-structural features of wood species, on anisotropy of wood and on the content and aggregate condition of the containing water, on the law of change and temperature values of the steaming medium t_m, etc. (Chudinov, 1968; Shubin, 1990; Trebula and Klement 2002; Videlov, 2003). A correct and effective control of this process is possible only with good knowledge of its physics and the extent of influence of each of numerous factors, which are included in a mathematical model (Deliiski, 2003).

An important problem during the steaming in pits, where direct steam is introduced for steaming of logs, is not to allow sinking of lower layers of logs into the formed condensed water.

This paper describes the creation of a microprocessor system for automatic control of the temperature t_m and of the level of condensed water in pits, used for steaming wood materials. An example is given for the use of such a system, in which the algorithm of computation of the automatic realization of logs steaming regimes in pits is based on the solution of a multi-parameter model, developed by the author. This model takes into account the physics of wood plasticization process before rotary cutting or slicing of veneer.

2 MATHERIAL AND METHODS
2 MATERIJAL I METODE

2.1 Mathematical modelling of logs' heating process
2.1 Matematičko modeliranje procesa zagrijavanja trupaca

The length of a majority of logs subjected to steaming exceeds, as a rule, their thickness by a minimum of 3 times. Consequently the heat transfer from the frontal sides of logs can be ignored, because it has no impact on heating in their cross section, which is equidistant from the frontal sides (Chudinov, 1968; Shubin, 1990). In these cases the process of heating is simplified and from a 2-dimensional heating along the length and the radius of the logs, it is reduced to a 1-dimensional heating only along the radius. The mechanism for spreading the temperature only along the radius of cylindrical wood materials can be described by the following equation (Deliiski, 1979):

$$\rho_{\mathrm{w}} \cdot c_{\mathrm{we}} \cdot \frac{\partial T(r,\tau)}{\partial \tau} = \lambda_{\mathrm{wr}} \cdot \left[\frac{\partial^2 T(r,\tau)}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T(r,\tau)}{\partial r} \right] + \frac{\partial \lambda_{\mathrm{wr}}}{\partial T} \cdot \left[\frac{\partial T(r,\tau)}{\partial r} \right]^2 \tag{1}$$

with an initial condition

$$T_{\mathrm{w}}(r,0) = T_{\mathrm{w0}} \tag{2}$$

and a boundary condition

$$T_{\mathrm{w}}(0,\tau) = T_{\mathrm{m}}(\tau) \tag{3}$$

where are

T - temperature (*temperatura*), K;
T_w - wood temperature (*temperatura drva*), K;
T_{w0} - wood temperature at the beginning of steaming (*temperatura drva na početku parenja*), K;
T_m - steaming medium temperature (*temperatura medija parenja*), K;
c_{we} - effective specific heat capacity of wood (*specifični toplinski kapacitet drva*), $J \cdot kg^{-1} \cdot K^{-1}$
λ_{wr} - thermal conductivity of wood in radial direction (*toplinska provodljivost drva u radijalnom smjeru*), $W \cdot m^{-1} \cdot K^{-1}$;
ρ_w - wood density (*gustoća drva*), $kg \cdot m^{-3}$;
r - radial coordinate (*radijalna koordinata*), m: $0 \leq r \leq R$;
R - log radius (*polumjer trupca*), m;
τ - time (*vrijeme*), s.

In (Deliiski, 2002; Deliiski, 2003) a mathematical description has been made for the effective specific heat capacity c_{we} as a sum of specific heat capacity of wood itself c_w and of ice formed in it by freezing of free water c_{fw} and of hygroscopic bounded water c_{bw}, respectively, as well as a mathematical description of wood density ρ_w and thermal conductivity, in which the following equation has been derived for λ_{wr}:

$$\lambda_{\mathrm{wr}} = \lambda_{\mathrm{w0r}} \cdot b \cdot [1 + \beta \cdot (T - 273{,}15)] \tag{4}$$

where λ_{w0r} is the radial thermal conductivity of wood at 0 ^oC, i.e. at T = 273,15 K; b and β coefficients, which like λ_{w0r}, depend on wood moisture content u, on presence or absence of ice in the wood, and on basic wood density (based on dry mass divided by green volume).

The following system of equations has been derived by passing to final increases in equation (1) with the use of the explicit form of finite-difference method (Deliiski, 2003) and taking into account the equation (4):
where are

of a mathematical model), resource-saving regimes are offered for steaming of logs in pits, whose general form is shown in Fig. 1. The results of the model obtained by personal computer based on different combinations of initial and boundary conditions of heat transfer during the steaming process, encountered in the practice, have been processed in an appropriate way. As a result, the following equation has been

$$\rho_{\mathrm{w}} \cdot c_{\mathrm{we}} \cdot \frac{T_i^{n+1} - T_i^n}{\Delta \tau} = \lambda_{\mathrm{w0r}} \cdot b \cdot \left\{ \left[1 + \beta \cdot \left(T_i^n - 273{,}15\right)\right] \cdot \left[\frac{T_{i-1}^n + T_{i+1}^n - 2 \cdot T_i^n}{\Delta r^2} + \frac{1}{r} \cdot \frac{T_{i-1}^n - T_i^n}{\Delta r} \right] + \beta \cdot \frac{\left(T_{i-1}^n - T_i^n\right)^2}{\Delta r^2} \right\} \quad (5)$$

Δr - the finite space increment, i.e. the step of calculation network, built on the radius of the log subjected to heating, with which the model is solved by the finite-difference method, m;

Δτ - finite time increment, i.e. the step of calculation network on time coordinate, s;

i - consecutive number of nodes in the network on the linear coordinate r: $1 \leq i \leq M$;

n - consecutive number of nodes in the network on the time coordinate: $0 \leq n \leq N$.

With the use of Windows based software packet VISUAL FORTRAN PROFESSIONAL created by Microsoft for the solution of the model, the coordinate *r* can be calculated by the equation

Then, the value of *T* in any node of

$$r = (i-1) \cdot \Delta r \quad (6)$$

the calculation network constructed on the radius, at the moment $n + 1$, is determined in accordance with already calculated values of *T* in the previous moment *n* by the following system of equations:

derived for the calculation of the duration of plasticization of logs τ_{P} with the help of a microprocessor programmable logic controller (PLC), inbuilt in the system for automatic control:

$$\tau_{\mathrm{p}} = F \cdot D + H \cdot D^2 - L \cdot D^2 \cdot \frac{t_{\mathrm{b}}}{100} \quad (8)$$

where are

D - diameter of logs (*promjer trupaca*), cm;

t_{b} - initial temperature of wood subjected to steaming, assumed to be approximately equal to the initial temperature of the steaming medium in the pit (*početna temperatura drva koje će se pariti, uz pretpostavku da je približno jednaka temperaturi medija parenja u jami*), ^{o}C;

F, H, L - coefficients, which depend on wood species, wood moisture content, presence or absence of ice in the logs, as well as values t_{b}, t_{m0}, t_{m1} and t_{m9} in Fig.1 (*koeficijenti, koji ovise o vrsti drva, sadržaju vode u drvu, o tome jesu li trupci smrznuti ili ne, te o vrijednostima* t_{b}, t_{m0}, t_{m1} *i* t_{m9} *na sl.1*).

$$T_i^{n+1} = T_i^n + \frac{\Delta \tau \cdot b.\lambda_{\mathrm{w0r}}}{\rho_{\mathrm{w}} \cdot c_{\mathrm{we}} \cdot \Delta r^2} \cdot \left\{ \left[1 + \beta \cdot \left(T_i^n - 273{,}15\right)\right] \cdot \left[T_{i-1}^n + T_{i+1}^n - 2 \cdot T_i^n + \frac{1}{i-1} \cdot \left(T_{i-1}^n - T_i^n\right) \right] + \beta \cdot \left(T_{i-1}^n - T_i^n\right)^2 \right\} \quad (7)$$

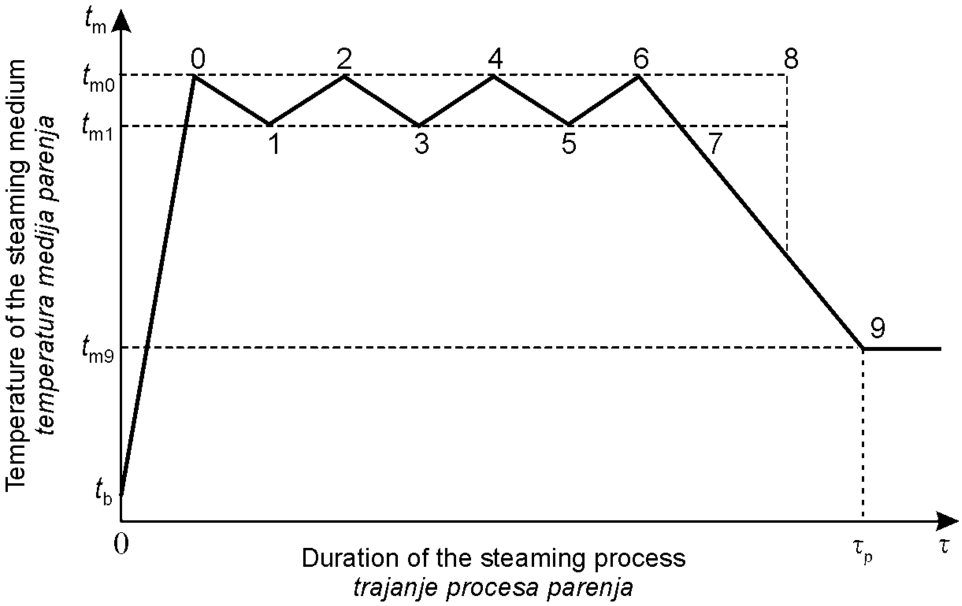
2.2 Algorithm for the calculation of regimes for automated logs' steaming

2.2 Algoritam za proračun re□ima automatiziranog parenja trupaca

Based on the results obtained through wide experimental and simulation studies of logs' plasticization process (with the help

Fig. 2 shows the dependences between coefficients *F, H,* and *L* in equation (8), obtained as solutions of the mathematical model, at the temperature of the steaming medium t_{m} in the equipment for the plasticization of logs, working under atmospheric pressure.

Figure 1
General form of resource-saving regimes for steaming logs in pits, which are realized by a microprocessor PLC
Slika 1.
Opći oblik režima parenja trupaca u jamama, koji je ostvaren mikroprocesorom PLC

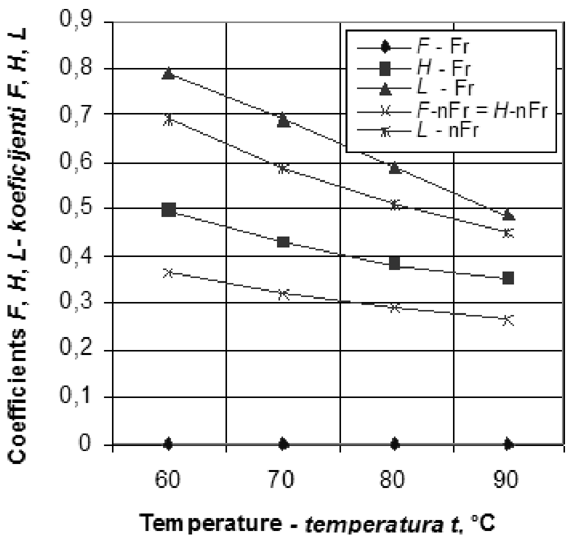


These dependencies are related to heating of poplar logs with $d \geq 0.2$ m, where the notations Fr and nFr in the legend of Figure 2 refer to frozen and non-frozen logs, respectively.

The studies show that each steaming regime with duration τ_p at the time of its automatic realization is purposefully divided into 10 periods of the same magnitude. During the first period, the temperature of the steaming medium t_m increases gradually from its initial value t_b to the maximum value for the concrete regime t_{m0} (Fig.1). During the next 6 regime periods a cyclical change occurs of t_m to t_{m0} from t_{m1} and from t_{m0} to t_{m1}. Throughout the last 3 periods a gradual decrease of t_m from t_{m0} to t_{m9} occurs with the aim of equalizing the temperature along the entire volume of logs before the next rotary cutting or slicing of veneer. Thermal energy accumulated in the wood and in the pit is used maximally during the process and the danger of cracking the logs after their taking out of the pit is minimized.

In the production of veneer, at the beginning of every work shift, steamed logs must be brought to a heated and very elastic state. A shorter time τ_p is required for reaching one and the same stage of plasticization of logs, when the regime temperatures are relatively high, and a longer time τ_p, when the temperatures t_{m0} and t_{m1} are lower. Because of this, depending on the available technological time from the beginning of steaming until the beginning of veneer slicing, steaming should occur according to such a regime (i.e. at such values of t_{m0}, t_{m1} and τ_p), which would ensure the completion of the plasticization process at the desired moment. This means that relating to the

Figure 2
Change in the coefficients F, H, and L in equation (8) for frozen (Fr) and non-frozen (nFr) poplar logs, depending on t_m
Slika 2.
Promjene koeficijenata F, H i L iz jednadžbe (8) za smrznute (Fr) i nesmrznute (nFr) trupce topole u ovisnosti o temperaturi medija parenja t_m



same logs, the system for automatic control must have the opportunity to carry on regimes with a different degree of intensity, and consequently with a different duration τ_p and a different specific energy consumption (required for 1 m^3 wood).

The equations for the coefficients *F*, *H* and *L* at different temperatures t_{m0}, t_{m01} and t_{m9} (Fig. 1), together with equation (8), make part of an algorithm for the calculation of regimes for steaming logs of different diameters and different wood species with the help of a microprocessor PLC. 8 degrees of intensity numbered 0 through 7 are entered and they are fully sufficient to cover all cases occurring in steaming logs practice. For different wood species and different degrees of intensity, the regime temperatures change up to 95 °C. The algorithm for the calculation by use of the PLC at any concrete regime input of tm includes a linear interpolation of t_m between t_m two neighbouring points in Fig.1, i.e. from t_b to point 0, from point 0 to point1 and so on through point 9.

Fig. 3 and Fig. 4 show, as examples, the change in the duration of regimes τ_p for steaming of poplar logs containing ice at t_b =-10 °C and for logs not containing ice at t_b =0 °C, respectively, depending on their *D* and on the degree of regime intensity, as calculated by the PLC according to equation (8). The duration and intensity of each calculated regime ensure that any given wood species will reach an optimum temperature (Mörath, 1949), required for the steamed logs during rotary cutting or slicing of veneer.

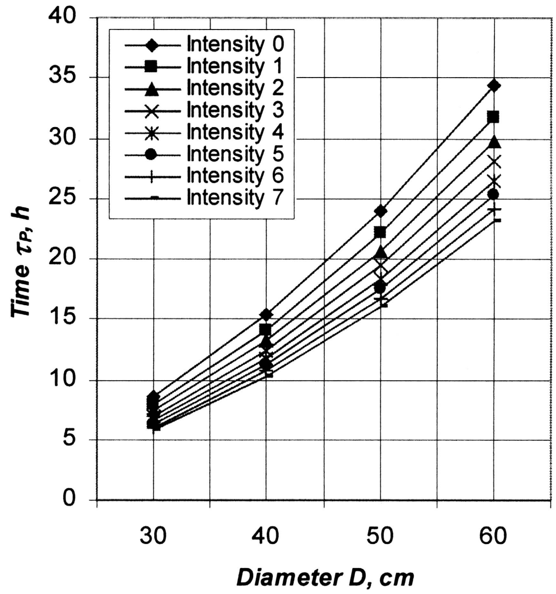


Figure 3
Change in the duration of regimes τ_p for steaming poplar logs containing ice at t_b= -10 °C depending on their D and on the degree of regime intensity
Slika 3.
Promjene trajanja procesa parenja τ_p smrznutih topolovih trupaca početne temperature t_b= -10 °C u ovisnosti o promjeru D i intenzitetu procesa parenja

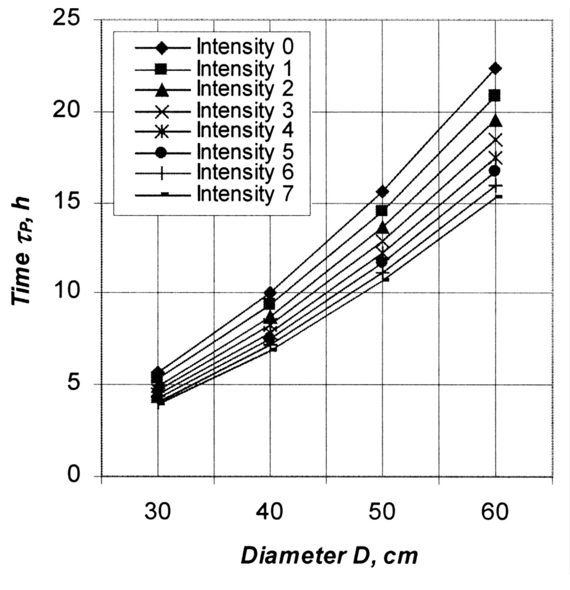


Figure 4
Change in the duration of regimes τ_p for steaming poplar logs containing ice at t_b=0 °C depending on their D and on the degree of regime intensity
Slika 4.
Promjene trajanja procesa parenja τ_p smrznutih topolovih trupaca početne temperature t_b=0 °C u ovisnosti o promjeru D i intenzitetu procesa parenja

3 RESULTS AND DISCUSSION
3 REZULTATI I RASPRAVA

As a result of research, microprocessor system for automatic control of t_m and of the level of condensed water in the steaming pit has been developed.

Fig. 5 shows an electrical scheme of the system for automatic control of temperature of the steaming medium t_m and of the level of condensed water in pits, used for steaming wood materials, which we developed and implemented in the production. Two microprocessor programmable controllers *CT* and *CL* are used in this system. They are produced by Delta Instruments - Sofia, a firm certified according to ISO 9001.

The controller *CT*, in which development we have taken part, is used for calculating the parameters of regimes for steaming wood, according to the above-described algorithm, as well as for their automatic realisation. The thermo-resistant sensor for measuring t_m in the pit is labelled as *RT* in the scheme. With the help of the controller buttons, the operator enters the value for the diameter *D* of logs, their wood species, he specifies whether they contain ice or not, and enters the desired intensity of the steaming regime and initiates it.

When the current value of t_m turns out to be lower than the one calculated by the controller set value, with the help of its relay KT, the controller makes a signal for opening the valve YAT, which feeds steam to the pit. When the temperature t_m increases and reaches its current calculated value, the relay KT switches off and feeding of steam to the pit stops.

In the system for automatic control, there are two methods for the termination of the regime of logs' steaming - automatic and manual. In the first case the controller *CT* stops the steaming process at the moment of expiring of the calculated duration τ_p and at the same time activates the sound signal *HA* (Fig. 5). In the second case, after reaching the time τ_p this controller only activates the signal *HA* for a certain time and continues to support automatically a constant temperature t_{m9} (Fig. 1). This support of $t_{m9}=const$ continues until the moment, at which the operator stops the steaming process with the controller buttons and well-plasticized logs in heated condition are subjected to the rotary cutting or slicing machine.

The controller *CL* is used for measuring with the help of a 4-electrode sensor *SL* and for automatic regulation of the level of condensed water, which forms a water layer at the bottom of the pit, through which the steam is introduced for heating the logs. The electrode COM is common for all measurement circuits in this controller. The location of the lower ends of the electrodes LL and HL gives the input values for regulating the correspondingly minimum and maximum level of condensed water, while the lower end of the electrode AHL corresponds to the alarmingly high level of condensed water.

When the condensed water reaches the level HL during its rise, the controller CL with the help of its relay KP creates a signal for switching on the contactor KL, which controls the electrical engine of the pump, which is not shown on Fig. 5. When

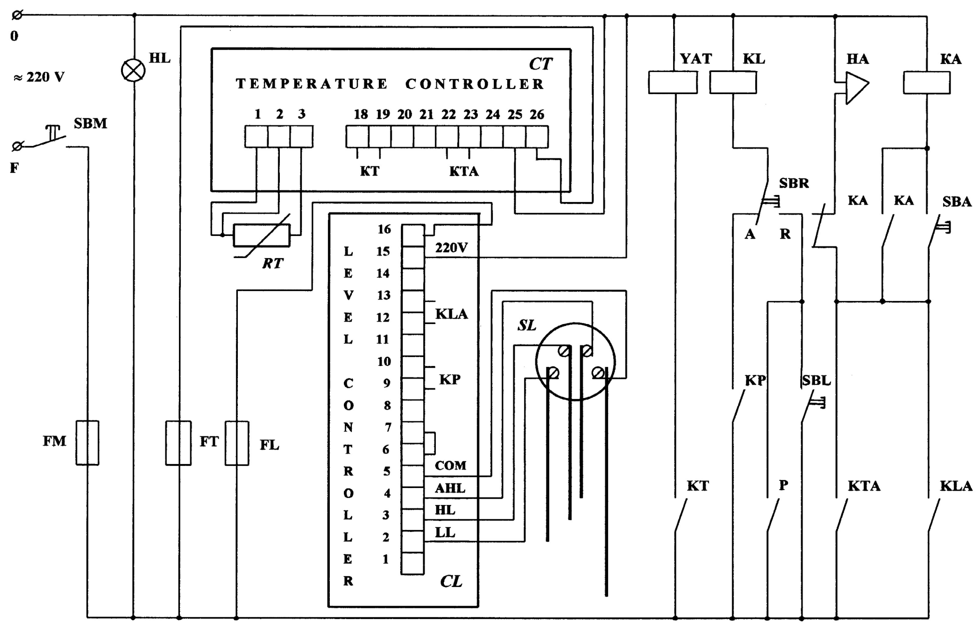


Figure 5
Electrical scheme for the system of automatic control of t_m and of the level of condensed water in the pit
Slika 5.
Električna shema za sustav automatske kontrole temperature medija i razine kondenzirane vode u jamama za parenje trupaca

reaching the level of LL by decreasing condensed water, the relay KP switches off, which causes turning off of the contactor KL the controlled by it pump.
When the condensed water has to be completely removed from the pit and wood refuse cleaned, the switch SBR must be set to position R and by pressing the button SBL, the pump switches on automatically. When the condensed water is completely removed from the pit, the contact P of the pressostat opens and the contactor KL switches off. This way the engine of the pump is protected from operating in the unallowable "dry" regime.

The frontal panels of the controllers *CT* and *CL* are shown in Fig. 6.

With the controller *CT*, the functions for recording and reading the values of t_m are entered in cases where t_m breaches the limit values set by the operator in relation to the set values of t_m calculated under the controller current regime. It is possible to record and read the astronomical time and date when t_m has breached the set values, as well as the time when it has re-entered within the set values after consecutive breach. With the help of the controller buttons, the records can be read of inadmissibly high deviations of t_m from its regime values.

At every deviation of t_m from the limit values, a LED lightens up on the front panel of the controller CT and the relay KTA switches on, which initiates a sound alarm HA (Fig. 5). The alarm switches on at the end of the steaming regime too, and here also a corresponding controller LED lightens up.

The alarm HA is also activated when the alarming level AHL of condensed water is reached in the pit; then the relay KLA of the controller CL switches on.

The operator can switch off the activated alarm HA when necessary by pressing the button SBA (Fig. 5).

The duration and level of deviation of t_m from the set values is integrated and automatically compensated by the controller *CT* in accordance with the entered algorithm. The duration of the steaming regime is proportionately corrected, which provides the attainment of optimum plasticization of logs when rotary cutting or slicing of veneer.

In case of failure of power supply to the system for automatic control during the time of steaming, the controller *CT* memorises the last calculated set value of t_m before the failure. Once power has been restored, the controller enters this value of t_m as regime value and aims at reaching it and sustaining it constant during the interval equal to the time when there was no power. After this time has gone by, the controller continues calculating the set values of t_m according to the entered algorithm until the end of the steaming process.

If during the time of catching up with the pause a new power failure occurs, then its duration is added to the time needed to catch up with the lack of power from the previous failure.

The following parameters can be seen on the displays of the controller CT:

Figure 6
Front panel of the controller CT (left) and of the controller CL (right)
Slika 6.
Prednja strana kontrolera CT (lijevo) i kontrolera CL (desno)

- current set value of t_m calculated by the controller;
- current measured value of t_m in the pit;
- current astronomical time, date, and month;
- total duration τ_p of the regime calculated by the controller;
- time τ_c passed from the start of the regime until the current moment;
- the remaining time until the end of regime, equal to the difference $\tau_p - \tau_c$;
- thickness of logs subjected to steaming, which is entered by the operator and according to which the controller has calculated τ_p;
- duration of the pause during regime time, when there was no power supply to the system for automatic control;
- duration of the interval during which the steaming regime has been corrected due to extremely large deviations that occurred at t_m;
- initial temperature in the pit, at which the regime was started;
- wood species of the logs in the pit, entered by the operator;
- presence or lack of ice in the logs declared by the operator;
- sequence of regime period carried on at the moment.

4 CONCLUSION
4 ZAKLJUČAK

The developed system for automatic control has been implemented in the "Obnova" factory in Cherni Osam, Bulgaria for steaming in 3 pits of beech, poplar and pine logs, intended for the use in the production of plywood. The individualization of the regimes for thermal treatment for each share of logs with the help of the controller *CT* ensures carrying out practically flawless steaming, obtaining good production quality, improvement of veneer quality and quantity, and significant (up to 35%) decrease in the specific consumption of steam.

The automatic regulation of the level of condensed water in the pits, with the help of the controller *CL*, eliminates the submerging of lower layers of logs into water, which leads to the decrease in the specific consumption of thermal energy during veneer drying. Also, unwanted change is avoided of the natural colour of wood that can be caused by impure condensed water.

A part of the developed system, which only includes the use of the controller *CT*, has been implemented with analogical positive results in a few factories in Bulgaria for resource- and energy-saving steaming of lumber from different wood species in chambers and in pits.

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Corresponding address:

Assoc. Prof. NENCHO DELIISKI, PhD
Faculty of Forest Industry
University of Forestry
Kliment Ohridski Bd. 10
1756 SOFIA
BULGARIA
E-mail: Deliiski@netbg.com