Programmable Control for Lumber Drying in Chambers

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Abstract: - A programmable control system for the convective drying of lumber in chambers is developed, based on specially designed drying algorithm, which allows computing the set-point values for the temperature and the relative humidity of the heating and drying air as a function of the wood type, wood thickness and the current average value for the wood moisture content and wood temperature. The special three channel measuring instrument ensures reliable and correct on line wood moisture measurement results for the correct set points calculation of the main controller in different working regimes. This individualization of the drying regimes according to the parameters of each consignment of different materials ensures optimization of the quality and minimization of the energy costs of the whole process. Besides, the implementation of the developed control system proves its high reliability. It is not only cheaper but also easier to tune service and apply in small woodworking companies.

Key words: - Programmable controller, wood drying process, wood moisture content, automatic control

1 Introduction

The control systems of lumber convective drying in chambers are complicated and expensive for the small woodworking companies [1]. On the base of our long time experience in the area of technology, equipment and control of hydrothermal processing of wood material, on one hand, and in the development of microprocessor controllers, on the other hand, we designed and put into practice a series of algorithms and small programmable logic controllers (PLC) for automatic convective drying of lumber, applicable also in very small chambers [2-7].

The aim of this paper is to present the results from the development and implementation of a control system for the convective drying of lumber in chambers, based on new drying algorithm and control functions, which are embedded in PLCs, characterized by high functionality, easy servicing and low cost. The system also improves the quality of drying.

2 Control System Design

The control system is based on developed drying algorithms, on moisture and temperature measurements of the drying air, on real moisture and temperature of the wood and set-points computation and programmable control. These algorithms along with some logic functions are embedded in specially designed PLCs, which can be used independently or together in an integrated system for the control of the lumber drying process.

2.1. Three-Channel Measuring Instrument for Wood Moisture and Temperature

The most informative parameters of the drying process are the actual moisture U and the temperature T_m in the material. A special instrument DWH-03, shown in Fig.1, is developed to measure the moisture content in the lumber in three different chamber zones and the temperature in one point [2].

The measuring method is based on DC conductivity measurement between fixed in the material electrodes and then on calculations, taking into account the wood samples, wood type and current wood temperature. The very large dynamic range of the resistance 100Ω - 100GΩ and very noisy environment are the main problems, solved by DWH-03 instrument. The actual temperature is measured by a Pt100 sensor, hammered into one of the samples. Using three pair electrodes the

Fig.1. Measuring Instrument DWH-03 for wood moisture content and wood temperature

instrument can easily check the errors and calculate more reliable value for the wood average moisture content.

DWH-03 can be used as independent instrument or in a system with a main drying controller. The connection between them is galvanic isolated RS485 serial interface, Modbus protocol. Measured values in the three samples and calculated average values are input data for deriving of the working set points.

2.2. Controller for Inside Chamber Air Temperature and Relative Humidity

The controller, shown in Fig.2, is designed to measure the temperature T and the relative humidity RH of the air in the chamber, to compute the set-point values of T and RH, and to control the whole wood drying process.

The temperature T and the relative humidity RH are measured by a probe, made by the company Rothronic, Switzerland. Two miniature sensors are mounted on its tip – one a high-temperature capacitive sensor for RH, and another – a resistance thermometer Pt-100.

The principle of operation of the sensor for RH is based on the absorption of the water molecules in the air by a high-molecular polymer, coated over a ceramic plate, which results in change of the capacitance of the measurement circuit. The information from the sensors is converted by the help of a specially developed electronic transmitter into unified current signals in the range 4÷20 mA, which are proportional to the instantaneous values of the measured variables T and RH. These signals are transmitted to the analog inputs of the controller.

The programmable controller at operator's option can operate in the following three modes:

- Stabilizing control – the operator periodically enters the set-point values for the temperature SP-T and for the relative humidity SP-RH of the processing

Fig.2. Programmable controller for computation, measurement and control of T and RH

medium and the controller keeps the measured variables close to their set-points. This type of control is used in drying of rare wood species, absent from the controller menu, or when testing the operation of the actuators of the control system of the drying process;

- Programmable control – after the operator enters data for the wood species, the thickness of the lumber, the initial wood moisture content U_b and the desired final moisture content U_f, the controller computes SP-T, SP-RH and the duration L of the separate stages of the drying process according to the drying algorithm and carries out the automatic control;
- Monitoring control – the controller computes the parameters of the drying process and carries out the entire control of the drying process as a function of the current value for the wood moisture content U_{av} of the lumber. The values for U_{av} are received as current signals of 4 ÷ 20 mA from the analog output of the measuring controller DWH-03 from Fig.1.

The controller computes the values for SP-T and SP-RH and continuously controls the drying process till U_f is reached, accounting for the current values for U_{av} and the data entered by the operator that specifies the wood species and the lumber thickness.

The controller in Fig.2 performs the following functions:

- measurement and visualization of T and RH of the drying agent – the air in the chamber;
- visualization of U_{av} of the wood;
- calculation of the values of SP-T and SP-RH during the initial (InHTT), intermediate (ImHTT) and final (FHTT) hydro-thermal treatment of wood materials;
- automatic warming up of the drying chamber and the wood materials in it at the beginning of the process without letting inside moistening fluid. The warming up

of the chamber continues till a specified temperature in it is reached that avoids the undesired condensation of the moistening fluid on the cold materials and on the chamber walls;

- automatic ON-OFF or PID control of T and RH by continuously comparing the computed by the controller set-points for the controlled variables and their current values. The control of T and RH is accomplished by changing of the inflow into the chamber of heating agent, moistening fluid and cool air and the outflow from it of the humid air;
- automatic switching on and reversing of the rotation of the fans in the chamber;
- automatic switching off of the drying at reaching a specified final value for U_f of the wood and sound signalization of the end of the drying process.

There are additional embedded in the programmable controller functions for automatic recording and reading of the measured values for T and RH in the chamber, that are out of the ranges ΔT and ΔRH, entered by the operator, defined with respect to the currently computed values for SP-T and SP-RH.

The controller also keeps a record on the day time and the date when T and/or RH go out of the ranges and when they enter back into these ranges. Each time T or RH leave the range on the front panel of the controller the corresponding LED is lighted and a sound alarm is activated.

The records that register the impermissible great deviations of T and RH from their computed set-point values can be retrieved and read by pressing keys on the controller's displays, thus enabling analysis of the reasons, provoking these deviations.

3 Algorithm for Computation of Set-Points SP-T and SP-RH

The algorithm for the computation of SP-T and SP-RH is developed and explained in [7] after a profound analysis of:

- the available literature and Internet data about the recommended and used in practice modes for drying of lumber of various wood species [1, 3-5];
- the functional facilities of the existing computer-integrated systems for automatic control of the process of convective drying of lumber;
- the long-years research and engineering experience of the authors in this area.

A database in the form of a table for the basic mode of drying in the controller software is filled in after entering of corresponding password for each wood species. The mode parameters include the basic values for SP-T, SP-RH and L of the various stages of the process of drying as function of the current value for the wood moisture content U of the lumber (Table 1).

The initial (InHTT), the intermediate (ImHTT) and the final (FHTT) hydro-thermal treatment of the wood materials comprise separate stages of the process of drying in the algorithm, that correspond to change of U in the ranges, shown in the first line of Table 1.

The basic table contains no values for SP-T, SP-RH and L за InHTT, ImHTT, and FHTT nor for the duration L_{2B} of the stage corresponding to U_b>45%. The controller computes the duration of the stage for U_b>45% from the equation:

$$L_{2B} = C_{L2}(U_b - 45) \quad (1)$$

and fills in the corresponding cell of Table 1 with the computed value L_{2B}. The coefficient C_{L2} is related to the wood species.

The controller uses the data from Table 1 as well as the operator's input for the thickness d (in mm) of the drying materials, U_b and U_f to compute SP-T, SP-RH and L for the different stages of the drying process and records them in the so called operational table – Table 2. The operational table contains the values for SP-T and SP-RH, which should be reached by the end of each of the stages as well as values for SP-L for each stage in case of programmable control.

The controller computes the values for SP-T_{iW}, SP-RH_{iW} and SP-L_{iW} to fill in operational Table 2, considering their corresponding values SP-T_{iB}, SP-RH_{iB} and SP-L_{iB} in the basic Table 1 according to the following equations:

Table 1. Basic values for: set-point for temperature SP-T_{iB} and for relative humidity SP-RH_{iB} in the chamber; duration of the separate stages ST-L_{iB} for each wood species (i = 2÷9) from the controller's database

Drying stage / Parameter	1 Initial HTT (InHTT)	2 U>45%	3 45≥U >35%	4 35≥U >25%	5 25≥U >20%	6 Intermediate HTT (ImHTT)	7 20≥U >19%	8 19≥U >11%	9 11≥U ≥6%	10 Final HTT (FHTT)
Air Temperature T, °C		T_{2B}	T_{3B}	T_{4B}	T_{5B}		T_{7B}	T_{8B}	T_{9B}	
Relative Humidity of the Air RH, %		RH_{2B}	RH_{3B}	RH_{4B}	RH_{5B}		RH_{7B}	RH_{8B}	RH_{9B}	
Duration of the Drying Stage L, min		L_{2B}= f(Ub)	L_{3B}	L_{4B}	L_{5B}		L_{7B}	L_{8B}	L_{9B}	

Table 2. Operational values for SP-T_{iW}, SP-RH_{iW}, and SP-L_{iW}, computed and used by the controller during the control of drying of lumber of given wood species, d, U_b, and U_f, $i = 1 \div 10$

Drying stage / **Parameter**	**1** Initial HTT	**2** U > 45%	**3** 45≥U >35%	**4** 35≥U >25%	**5** 25≥U >20%	**6** Interme-diate HTT	**7** 20≥U >19%	**8** 19≥U >11%	**9** 11≥U ≥6%	**10** Final HTT
Air Temperature T, °C	T_{1w}= =f(Ub)	T_{2w}	T_{3w}	T_{4w}	T_{5w}	T_{6w}= =f(T_{5w})	T_{7w}	T_{8w}	T_{9w}	T_{10w}= =f(Uf)
Relative Humidity of the Air RH, %	RH_{1w}= f(RH_{2w})	RH_{2w}	RH_{3w}	RH_{4w}	RH_{5w}	RH_{6w}= =f(RH_{5w})	RH_{7w}	RH_{8w}	RH_{9w}	RH_{10w}= =f(RH_{9w})
Duration of the Drying Stage L, min	L_{1w}= =f(d,Tb)	L_{2w}= =f(Ub)	L_{3w}	L_{4w}	L_{5w}	L_{6w}= =f(d)	L_{7w}	L_{8w}	L_{9w}	L_{10w}=f(d)

$$T_{1W} = f(U_b) + dT \quad (2)$$

$$T_{iW} = T_{iB} - C_T(d-60)T_{iB}, \quad i = 2 \div 9 \quad (3)$$

$$T_{6W} = T_{5W} + 1 \quad (4)$$

$$T_{10W} = f(U_f) \quad (5)$$

$$RH_{iW} = RH_{iB} + C_{RH}(d-60)RH_{iB}, \; i = 2 \div 9 \quad (6)$$

$$RH_{1W} = RH_{2W} + dRH$$

with the restriction $RH_{1W} = 92$ if $RH_{1W} > 92\%$ (7)

$$RH_{6W} = RH_{5W} + dRH \quad (8)$$

$$RH_{10W} = RH_{9W} + 3dRH \quad (9)$$

$$L_{1W} = C_{L1}d - C_{L1}d(T_b - 20) \quad (10)$$

$$L_{iW} = L_{iB} + C_L(d-60)L_{iB}, i = 2 \div 9 \quad (11)$$

$$L_{6W} = C_{L6}d \quad (12)$$

$$L_{10W} = C_{L10}d \quad (13)$$

where the subscript i denotes the number of the column in Table 2 with the values for SP-T, SP-RH and SP-L, $i = 1 \div 10$, T_b is the temperature of the drying medium, which corresponds to a specified value for U_b and from which the drying starts.

The meaning of the variables dT, dRH, C_T, C_{RH}, C_L, C_{L1}, C_{L6} and C_{L10} is explained in [7].

During the individualization of each drying regime the controller carries out linear interpolation of the values for SP-T, SP-RH and SP-L in each two adjacent columns of Table 2. The controller software imposes restrictions on the values for d, U_f, U_b (for programmable control), entered by the operator, and offers an option whether to be switched on or not the InHTT in the drying regime. Depending on U_b and U_f (, the number of the columns in Table 2 can vary from 1 to 10.

4 Simulations of Drying Regimes

Equations (1) ÷ (13) as well as a number of logic conditions, developed on C++ and embedded in the controller software, comprise an algorithm for optimized model based [8] automatic control of the convective drying process of lumber in chambers.

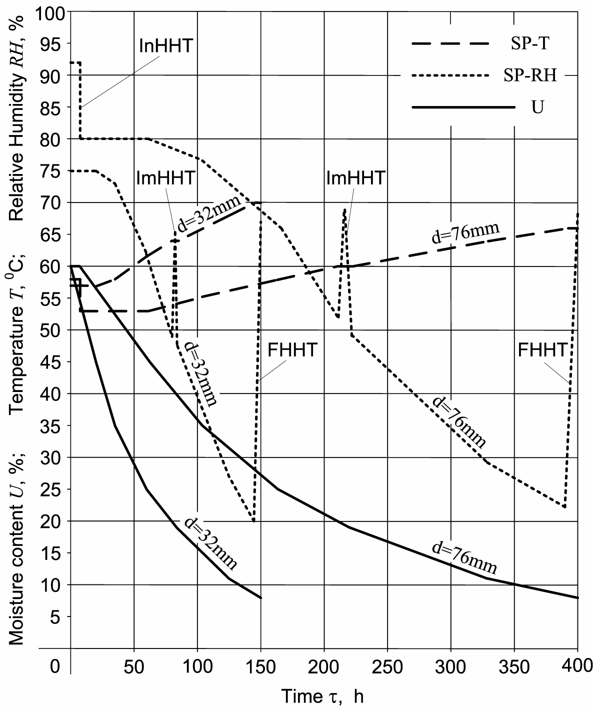

Fig. 3. SP-T and SP-RH profiles as functions of U and τ during the drying of pine lumber with d=32 mm and d=76 mm

The operation of the algorithm is illustrated by means of example, shown in Fig.3, where are given the computed by the controller values for SP-T and SP-RH during the drying на pine lumber with thicknesses d=32mm and d=76 mm. There a low-temperature drying is considered when the heating medium (agent) in the chamber is hot water instead of steam.

In the process of wood drying the controller displays continuously the current values for T, RH, U, SP-T and SP-RH. Optional indication can be requested via the controller's keys for:

- the wood species of the lumber in the chamber;
- the lumber thickness d;
- the initial wood moisture content U_b;
- the final wood moisture content U_f;
- the whole duration of the drying process;

- the direction of the rotation of the fans in the chamber;
- the time left till the end of the fans' rotation or before the end of the pause between the turning of the direction of the rotation;
- the time from the start of the process;
- the time left to the end of the process;
- the values for all parameters from Table. 2;
- the current type of control;
- the current day time and date.

5 Conclusions

The developed control system is implemented in several plants in Bulgaria, Serbia and Macedonia. The controllers prove the effectiveness of the embedded control functions for carrying out of the algorithm for the convective drying of lumber of various wood species and thickness. They also demonstrate high exploitation reliability and easy tuning and allow various operation modes – the cheaper for the end user programmable control with only one controller from Fig.2, or the monitoring control with the two instruments. The controller from Fig.2 carries out automatic convective drying along with thermal treatment of wood materials according to the requirements of Standard ISPM 15 [6] and with envisaged RS connection to a upper level supervisory controller.

In the developed control system for the first time a new way for the calculation of the set-points for the temperature SP-T and for the relative humidity SP-RH is applied:

- the values for SP-T and SP-RH are calculated for a thickness in mm, which is specified by the operator as an input to the controller, and not for a given group of thicknesses of the materials;
- the values for SP-T and SP-RH are not constants for a specified time interval, i.e. 5% or 10% from the change in U, but are treated as continuously changing with the current value for U, as shown in Fig.3.

This individualization of the drying regimes according to the parameters of each consignment materials ensures optimization of the quality and minimization of the energy costs of the whole process.

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