Development of automated control system for wood drying

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Abstract. The article considers the parameters of convective wood drying which allows changing the characteristics of the air that performs drying at different stages: humidity, temperature, speed and direction of air movement. Despite the prevalence of this type of drying equipment, the main drawbacks of it are: the high temperature and humidity, negatively affecting the working conditions of maintenance personnel when they enter the drying chambers. It makes the automation of wood drying process necessary. The synthesis of a finite state of a machine control of wood drying process is implemented on a programmable logic device Omron.

1. Introduction
Drying of wood is a complex physicochemical process in which mutually related physical, mechanical, chemical and biological processes occur [1,2]. Initially the moisture content of freshly cut trees is 50-60%: after 1.5 or 2 years of natural drying the moisture content of wood can reach 20–30% - which is equilibrium moisture (so-called air-dry wood). To reduce the humidity of the wood to the state of room-dry (8–15%), it must be dried forcibly in special drying chambers or it should be placed in conditions of an artificial microclimate with the specified parameters (concerning temperature, speed and humidity of the air) [3]. An important characteristic is equilibrium humidity (Emc), which is established during the process of moisture exchange between the wood and the ambient air. A model of material and energy balance of the wood drying has been widely discussed. The urgent task is to create a management system with a set of regulated parameters designed to control the process of wood drying.

2. Equipment and devices used in the studies
The theoretical part of the article was developed using the General systems theory and the theory of Finite-state machine. In practical implementation, the authors use the microcontroller OMRON. They study monitoring and control of wood drying with the OMRON CX-Programmer version 7.1 and CX-Designer software version 2.1.

3. The results of the study and their discussion

3.1. The main factors that describe the dynamics of wood drying
Let us analyze the parameters of wood drying process as a system that implements the mapping of the family of sets \( X_2(t) \) onto the set of elements \( X_1 \), i.e.

\[ X_1 \subset RX \{ t \}. \]
Let us divide the subset of all elements of $X_2(t)$ into an index greater, or smaller, or equal to $j$:

$$X_j^g(t) = \left[ x_1(t_1), x_2(t_2), \ldots, x_j(t_j) \right], \quad X_j^s(t) = \left[ x_{j+1}(t_{j+1}), \ldots, x_p(t_p) \right]$$

Then,

$$X_j R_1 \left[ X_j^g(t), X_j^s(t) \right]$$

Let us decompose $R$ into binary relations $R^j$ and $R^s$:

$$X_j R^j \left[ X_j^g(t), C \right], \quad C^j R^s X_j^s(t)$$

The set $X_j$ depends on the intermediate term $C$ and does not depend on the elements $X_2(t)$ for which the index is less than or equal to $j$. Elements $C$ describe the state of the wood drying system. Depending on its own factors (tree age, wood species and others); the state of the object is characterized by a steady $R^j$ or unsteady $R^s$ mode, depending on which the requirements for managing the object change. As available operated parameters to monitor the process of wood drying, it is offered to use: a purge air, humidifying and heating. The ratio of control actions and monitoring parameters is shown in Table 1.

### Table 1. Controlling actions and monitoring of drying parameters.

| №  | Operating influences | Notation | Monitoring | Notation |
|----|----------------------|----------|------------|----------|
| 1  | Fan                  | $y_F$    | Air velocity (m/s) | $V$      |
| 2  | Spray                | $y_S$    | Equilibrium moisture (%) | $E (Emc)$ |
| 3  | Heater               | $y_H$    | Temperature ($^0C$) | $T$      |

When monitoring the parameters of wood drying, an important characteristic is the equilibrium moisture (Emc) of wood, which is established during the process of moisture exchange between the wood and the surrounding air. The humidity of the air will lead to either humidification of the wood (if the humidity of the air exceeds the moisture content of the wood) or its drying [4]. When humidity and temperature of the ambient air stabilize, the humidity of wood will also stabilize, which will correspond to the humidity of the surrounding air [5]. With the termination of moisture exchange, the moisture content of the wood attain equilibrium; such moisture is reached, as a rule, under the conditions of an artificial microclimate, presented below in the form of a structural diagram of the control system model (Figure 1).

![Figure 1. A block diagram of the system of wood drying management.](image)

The kinetic curve of wood drying is divided into three periods: material heating, period of constant drying speed and a period of uniformly falling drying rate.

3.2. Research on the relationship between multidimensional control tasks

The relationship between the monitoring parameters is defined by the binary relations $R$ which can be understood as functional relations, preferences, sequences and others reflecting the essence of the relationship (Figure 2) [6].
In the synthesis of multidimensional control systems, significant difficulties are associated with the presence of static and dynamic cross links between different inputs and outputs of the system [7]. Researches of mutual influence of a purge by hot air, humidifying and moisture of wood (Figure 2) have shown that the temperature of environment is the most dominating factor, which influences equilibrium moisture (Figure 3).

From the point of view of operational control of deviation, it is possible to propose the construction of a combinational automatic control of the drying process on binary logic [8].

3.3. Analysis of the combinational diagram
In order to develop a combination scheme of operational control, a truth table was constructed, taking into account the influence of the dominant parameters, deviation of the specified values from the norm and control actions (Table 2).

| Sensors for monitoring of parameters | Equipment management | Emergency Signal |
|-------------------------------------|----------------------|-----------------|
| Moisture  | Temperature | Steam | Fan | Air heater | Spray |  |
| 0         | 0          | 0     | 0   | 0          | 0     | 0   |
| 0         | 0          | 1     | 1   | 0          | 0     | 0   |
| 0         | 1          | 0     | 1   | 1          | 0     | 0   |
| 0         | 1          | 1     | 1   | 1          | 0     | 0   |
| 1         | 0          | 0     | 1   | 0          | 1     | 0   |
| 1         | 0          | 1     | 1   | 0          | 1     | 0   |
| 1         | 1          | 0     | 1   | 1          | 1     | 0   |
3.4. Synthesis of combinational logic circuits

To obtain logical equations of the equipment operation, the authors have received a minimal disjunctive normal form using Karnaugh map (Table 3–6) [9].

| Table 3. Karnaugh map (Fan). | Table 4. Karnaugh map (Air heater). |
|-------------------------------|-------------------------------------|
| TV  | Emc  | 00 | 01 | 11 | 10 | 00 | 01 | 11 | 10 |
| 0   | 0    | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 1  |
| 1   | 1    | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 1  |

\[ y_f = \overline{ET} \lor TV \lor ET \lor EV \lor TV \lor \overline{EV} \]
\[ y_H = \overline{ET} \lor TV \]

| Table 5. Karnaugh map (Spray). | Table 6. Karnaugh map (Emergency Signal). |
|-------------------------------|-------------------------------------|
| TV  | Emc  | 00 | 01 | 11 | 10 | 00 | 01 | 11 | 10 |
| 0   | 0    | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 1   | 1    | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 1  |

\[ y_S = \overline{ET} \lor \overline{EV} \]
\[ y_{ES} = ET \lor V \]

On the basis of the obtained logical equations Ladder Diagram has been developed using the Omron software and hardware complex (Figure 4) [10].

Figure 4. A fragment Ladder Diagram.

The operational panel of drying process developed by means of program CX-Designer is shown on Figure 5. The system can operate in both automatic and manual modes.
4. Conclusions
In the work, the actual problem to develop the automated control system for wood drying is solved, and the following main results are obtained:

1. Relationship of the internal factors affecting the wood drying are identified; now it is possible to develop a matrix of States, taking into account the cross coupling of control loops.

2. Synthesis of the finite automaton performed on the hardware-software complex Omron is carried out.

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Figure 5. An operator panel for drying process.