MODELLING OF THE COGNITIVE MAP FOR THE MULTIDIMENSIONAL OBJECT'S CONTROL SYSTEM

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***Abstract**: The instruments of synthesis in modelling of cognitive maps based on interpretation of functions characterizing the concepts and their interrelation by set of well-defined terms expressed by arguments of bivalent logic are suggested.*

1. Introduction

The problem of technological processes' control in complex multiply connected, inertial, non-stationary and nonlinear objects with the distributed parameters is in that the regulation of the parameters characterizing technological process is usually made by one-dimensional proportional integral derivative (PID) controllers that are by linear control facilities [6,7,10].

Therefore, poor quality of control and as a result an increase in a share of finished goods' spoilage and unjustified energy consumption is caused. The analysis of the works devoted to automation of complex processes in a number of industries shows that potential opportunity of multidimensional PID controllers and the fuzzy logic controllers for decrease of an error regulation and mutual influence's compensation of regulation contours in the mentioned control systems and, on this basis, improvement of finished goods' quality and reduction of energy losses are almost exhausted [6,7]. Thus there is a need for development of the concept, models, methods and algorithms of the specified processes' logical control allowing to improve the quality of technological operations' control due to the experience and knowledge of subject domain experts into the correct operating algorithms and programs.

2. Theoretical basis

Cognitive modeling based on cognitive maps [1-3] allows to use incomplete, indistinct and even contradictory information of the expert in subject domain on a research's complex object for its control. Cognitive maps are used for determination of the most essential and significant interrelations, determination of the factors' value influencing the studied problem and also indications of the operating influence of necessary size, form and the sign application for the purpose of receiving the desirable results [4].

The Cognitive Computer Modelling (CCM) is the way of the analysis providing determination of force and the direction of factors influence on the transfer of a controlling object to a target state taking into account similarity and distinction of various factors influence on controlling object [5,8]. The basis of such cognitive models is usually represented by the classical cognitive map.

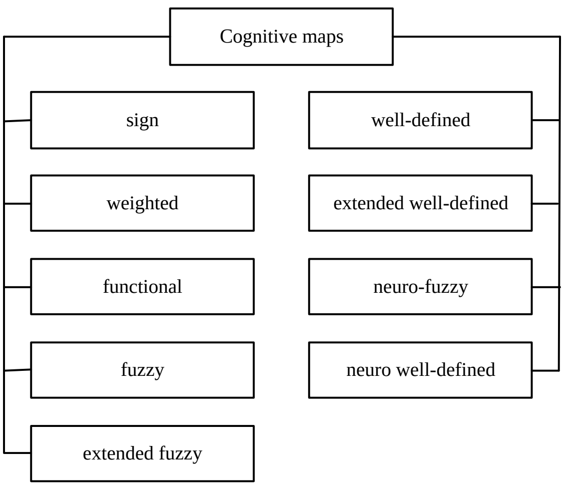

***Fig.1** – Classification of cognitive maps*

The analysis of literature shows that at present time the greatest distribution was gained by the following types of cognitive maps [1-3,8]: sign, weighed, functional, fuzzy, extended fuzzy and neuro-fuzzy cognitive maps.

The lack of sign, weighted and functional cognitive maps is the low accuracy of modeling which in most cases has qualitative feature. For this reason decrease in finished goods' consumer properties and also an excessive consumption of raw materials and energy in industrial technological installations which control systems are constructed on the basis of cognitive maps is observed. The advantage of fuzzy, extended fuzzy and neuro-fuzzy cognitive maps is the possibility of verbally presented algorithms modeling of the complex systems functioning comprised of various physical nature subsystems and, thus, to make use of unique professional experience of subject domain experts for creation of intellectual control systems. However fuzzy, extended fuzzy and neuro-fuzzy cognitive maps haven't found broad application in the control systems significant for modern society processes, demanding high precision (deep oil refining, nano - and chemical technologies, etc.) because of a big error of the defuzzification procedure.

The basic notion of the cognitive maps theory is the concept. A concept is the basic (indivisible) element of the considered system [1-3,5]. Let K is a set of concepts (elements) of the considered system, and a set of relations, each of which describes influence force of one concept (concept reason) on other concept (concept investigation). The orientation of this relation means that the concept source influences a concept receiver, i.e. change of values (states) of a concept source leads to change of values (states) of a concept receiver.

The activity of experts and analysts directed to a research of a situation and decision-making by means of cognitive maps represents methodology that is logic-time structure of various methods and receptions application: creation of the cognitive map, its parameterization, obtaining of situations' development forecasts, verifications, cognitive map's updating and decision-making [3,5].

The situation of the cognitive map is designed on the basis of experts' poll carried out in several phases. The first stage allows to define basic factors and to determine the value of relations. Then local cognitive maps are designed. After on the basis of expert estimates local cards brought together in one cognitive map of a situation. Accumulation of knowledge in the studied situations allows to reveal bonds character [4,5,9].

In the situation's analysis two types of tasks are solved: statistical and dynamic. The statistical analysis considers the current situation with influence of factors at each other, situational stability in general and search of structural changes for obtaining system's stability.

The dynamic analysis serves for generation and the analysis of possible changes in situation's development over time. In the dynamic analysis tasks indistinct sizes are attributed not only to relations, but also to factors. At the same time, if values of relations in the course of the analysis are considered as constants, then the size attributed to a factor changes over time. The size of a factor allows to estimate influence force on a factor and to express result of total influences as a factor's concrete value. The concept of a situation's condition gives the chance to speak about situation's development over time under the influence of various external influences which are expressed in change of factors' values i.e. to

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set a forecast task (a direct task) and also to investigate possibilities of situation controlling, i.e. to look for the influences leading to the necessary (target) state (the return task).

2.2. Principles of control

Let’s consider the principles of multidimensional (complex) objects’ control on the basis of cognitive maps, with interpretation of concepts and relations between them by a set of arguments of two-valued logic on the example of a prepreg manufacturing with use polymeric binding and woven filler [4,5,8,9].

The device of models is necessary for designing of complex technological objects’ controlling system. It enables to describe model of control in the form of rules and algorithms of the operating influences formation, and to represent this model in the course of the operation for the operating influences formation. At the heart of such device of models it is rational to use the principle of control according to situational model in which management process is considered as serial change of situations, certain controlling effects are connected with each of which. At the same time the operating system on the basis of situations’ model has to monitor the current situation and form operating influences appropriate to this situation. The model can be presented in the form of the cognitive map which describes situations, transitions and corresponding control instructions, and is aprioristic information for the organization of controlling process [5,9,11].

Such cognitive map will represent hierarchy of states with the set rules of interpretation. It combines multiple levels realized by the addition to model’s conditions of any level of other model considered as internal for an initial state and also the multidimensionality realized by introduction of several internal models for initial states.

Values of the parameters of the cognitive map specifying representation of model for direct control it is set in the form of the automatic machine of the special type which is carrying out model processing on the basis of its recursive bypass on active arches and also interaction of elementary models on the basis of current states checking.

Multidimensional hierarchy is more powerful modulating system in comparison with one-dimensional.

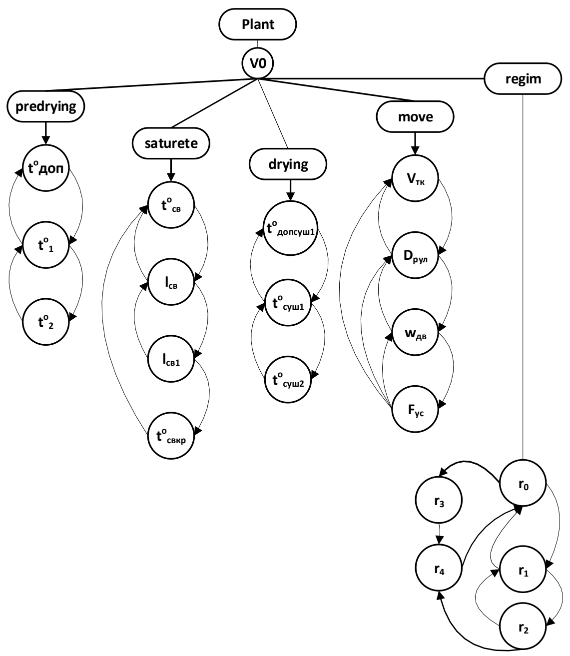

***Fig. 2** – Cognitive map of multidimensional hierarchical model of a prepreg’s production*

The multidimensional model of a prepreg manufacturing (fig. 2) reflects four interconnected processes, each of which is substantially independent:

- subdrying of fabric for an oil agent elimination;
- the fabric saturation which is characterized by indicators of binding;
- the fabric drying which is characterized by indicators of flying agents removal out of fabric;
- fabric moving necessary for maintenance of fabric’s movement speed and taking-up of a ready prepreg to a roll.

The Dryer model reflects a condition of fabric’s subdrying. Conditions of this model consider: admissible temperature (tº admis.); the precritical temperature which is characterized by emergence of temperature increase (decrease) above admissible (tº1); the critical temperature leading to accident in technological process (tº2).

The Saturate model reflects fabric’s saturation process by binding. The condition of this model considers: temperature of binding (tº bind.), level binding in an impregnating bathtub (l bind.); level of the binding, its characterizing reduction in an impregnating bathtub and replenishment from a tank (lbind.1); decrease in temperature binding below admissible that can cause violation of technological process (tº bind. crit.).

The Dryer model reflects a condition of fabric’s drying. Conditions of this model consider admissible temperature on zones of drying (tº admis. drying); the precritical temperature which is characterized by emergence of temperature increase (decrease) above admissible (tº drying1); the critical temperature leading to accident in technological process (tº drying2).

The Move model reflects the speed of the fabric’s movement taking into account change of a roll’s diameter at taking-up: admissible speed of the fabric’s movement (V fabric); the change of a roll’s diameter (D roll) leading to change of the moment on the device of taking-up of a ready prepreg that leads to change of engine’s angular speed (w eng.); the critical tension of a prepreg leading to break of a prepreg (F ang. speed) and emergency.

The Regime model reflects the generalized condition of installation in relation to critical parameters of subdrying and drying processes and emergency operation. Its state consider: normal mode (r0); the precritical mode – increase (decrease) in temperature is higher than admissible (r1); the critical mode – the mode of an emergency (r2); break of a prepreg (r3); the postcritical mode – elimination of malfunction in work of installation (r4).

The Regime model arches providing transitions of a state have the activity predicates determined by a condition of other models.

All processes are connected among themselves for object controlling and are characterized by independently measured parameters and can be controlled independently of each other [4].

The arch predicate (r0, r1) is true if the Dryer model is in a state (tºdrying1) and the Saturate model of being able (tº bind. critical).

P01 = Path (1, Dryer, tºdrying1) ^ Path (1, Saturate, tº bind. critical).

The arch predicate (r1, r2) is true at change of temperature above (below) of critical:

P12 = Path (1, Dryer, tºdrying2) ^ Path (1, Dryer, tº2) ^ Path (1, Saturate, tº binding critical) ^ Path (1, Move, F ang. speed).

Arch predicates (r0, r3) it is true at a prepreg’s break:

P03 = Path (1, Move, Fang. speed).

Arch predicates (r3, r4) and (r2, r4) are true in the absence of a prepreg’s break and change of temperature above (below critical):

P34 = P03 = P12.

The arch predicate (r4, r0) is true if processes of Dryer, Saturate, Move is normal:

P40 =^ Path (1, Regime, r0).

The analysis of the cognitive map begins with definition of factors’ total influence at each other, considering, both direct influence, and mediated when one factor influences another through a chain of intermediate factors. For this purpose at first the cognitive map is presented in the form of a connectivity matrix (table 1) in which the values of direct connections between factors are placed. Then for it the matrix of transitive short circuit on a formula is defined:

$$R= V_{i=1}^{\infty} \cdot R^{i} \qquad (1)$$

where R is a connectivity matrix.

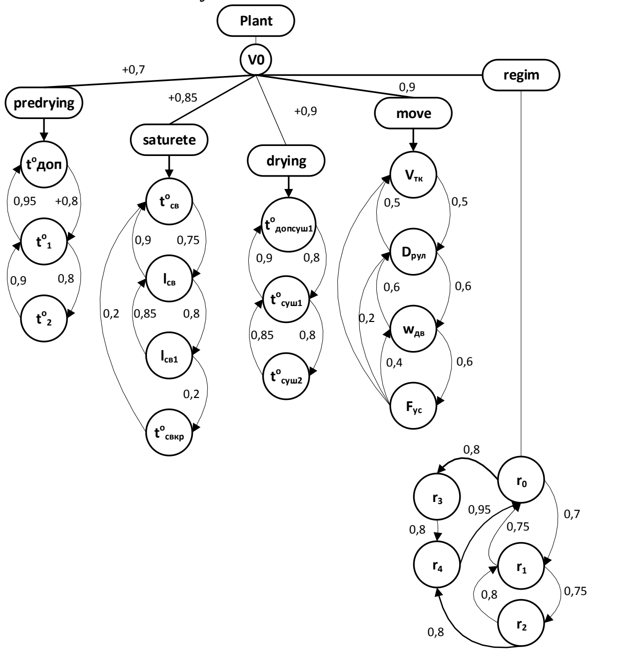

***Fig. 3** - Fuzzy cognitive map of multidimensional hierarchical model of a prepreg's production*

***Table 1** – Matrix of processes' connectivity*

subdrying	$t_{admis.}$	t_1	t_2
$t_{admis.}$	0	0,8	0
t_1	0,95	0	0,8
t_2	0	0,9	0

saturation	$t_{св}$	$l_{св}$	$l_{св1}$	$t_{свкр}$
$t_{binding}$	0	0,75	0	0
$l_{binding}$	0,9	0	0,8	0
$l_{binding1}$	0	0,85	0	0,2
$t_{binding\ critical}$	0,2	0	0,2	0

drying	$t_{addit.\ drying1}$	$t_{drying1}$	$t_{drying2}$
$t_{addit.\ drying1}$	0	0,8	0
$t_{drying1}$	0,9	0	0,8
$t_{drying2}$	0	0,85	0

movement	V_{fabric}	D_{roll}	W_{engine}	$F_{ang.\ speed}$
V_{fabric}	0	0,5	0	0
D_{roll}	0,5	0	0,6	0
W_{engine}	0	0,6	0	0,6
$F_{angular\ speed}$	0,2	0,2	0,4	0

***Table 2** – Full matrix of interference*

subdrying	$t_{admis.}$	t_1	t_2
$t_{admis.}$	0	0,8; 0,95	0
t_1	0,95; 1	0	0,8; 0,85
t_2	0	0,9; 0,95	0

saturation	$t_{binding}$	$l_{binding}$	$l_{binding1}$
$t_{binding}$	0	0,75; 0,85	0
$l_{binding}$	0,9; 1	0	0,8;0,9
$l_{binding1}$	0	0,85; 0,95	0
$t_{bind.critical}$	0,2; 0,4	0	0,2; 0,4

drying	$t_{admis.\ drying1}$	$t_{drying1}$	t_{dryng2}
$t_{admis.\ drying1}$	0	0,8; 0,95	0
$t_{drying1}$	0,9; 1	0	0,8; 0,95
$t_{drying2}$	0	0,85; 0,95	0

movement	V_{fabric}	D_{roll}	W_{engine}	$F_{ang.\ speed}$
V_{fabric}	0	0,5; 0,75	0	0
D_{roll}	0,5; 0,6	0	0,6; 0,8	0
W_{engine}	0	0,6; 0,9	0	0,6; 0,8
$F_{ang.\ speed}$	0,2; 0,4	0,2; 0,3	0,4; 0,5	0

According to the analysis of processes' physical model influence of some parameters on a prepreg manufacturing process is revealed. Factors which influence are significant for output parameters are fabric subdrying temperature; fabric drying temperature; speed of the fabric's movement.

The influence of such factors as a speed of the fabric's movement, binding's density and temperature, fabric's humidity, ambient temperature is statistically insignificant. It is connected with the fact that the range of these factors variation is very limited.

For an illustration of well-defined terms use in cognitive maps in fig. 4 the universal numerical axis of parameter p which represents with located on its n of accurate terms T1 – Tn with l width is depicted. For example, the Wij function of influence of a concept of i on j concept can be such parameter.

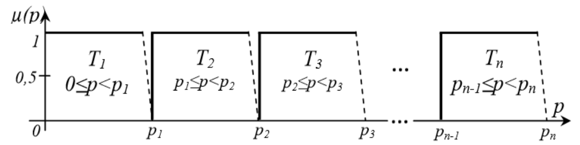

***Fig. 4** – Well-defined terms of parameter p on a universal numerical axis*

As T1 terms – Tn represent accurate sets, their functions accessories have a rectangular shape. And the value of these functions is equal to unit for all accurate values of physical quantity in each of the mentioned sets.

Influence are presented in well-defined cognitive maps of the Wij function by set of accurate terms (fig. 4). Here i and j – any couple of concepts entering the considered cognitive model.

Analytical expression a term set of influence function of a concept of i on a concept of j is the following:

$$T(W_{ij}) = \sum_{s}^{n} W_{ijs}\ ((i-1)l \le p < il) \qquad (2)$$

where n is quantity of well-defined terms with width of l used for Wij function interpretation by set of well-defined terms.

According to expression (2) influence extent of a concept of i on a concept of j will be defined by a term of Wijs which in present moment is equal to logical unit. And such property in total of accurate terms only one term has. The parameters characterizing concepts well-defined cognitive maps are usually represented in the form of constants or the determined analytical expressions [10-12].

3. Conclusion

As well-defined terms by the logical nature are arguments of binary logic, it is offered to make concepts' relations and their parameters by the corresponding set of functions of Boole's algebra which arguments can be well-defined terms, output signals of timers and counters and also discrete variables from other external devices. Thereof there is an opportunity in developing cognitive maps to use such highly effective instruments of synthesis as the sequential equations and Quine-McCluskey minimization method. In addition the use of well-defined terms significantly simplifies such basic procedures relating to cognitive maps as the description of concepts' state and interference, accumulation of several concepts influence on one concept and modeling of system dynamics.

Cognitive maps with interpretation of the parameters characterizing concepts state and their influence functions, set of well-defined terms (they have a rectangular shape of accessory function and by the logical nature are arguments of bivalent logic) allow to increase the accuracy and speed of cognitive models. They simplify the description of concepts' states and interference, accumulation of several input concepts influence on one output and also dynamics modeling and the stability analysis.

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