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Fuzzy Logic in Automatic Control of Concrete Thermal Treatment Using Shuttering with Heating Elements

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ABSTRACT

The paper presents the issues considering fuzzy logic application in the procedure of concrete thermal treatment using shuttering with heating elements, the schemes and methods of control. The fuzzy associations matrix made up of 25 rules was developed for this controlling system on the basis of general engineering judgments. The paper demonstrates the results of testing two types of regulators - with the proportional plus integral control law and with the fuzzy logic. The shields and the panels of shuttering with heating elements were determined to be carefully torn after the thermal treatment with the help of hand screws or cranes and specialized detachable device. After removing the termo shuttering the concrete is held under the coat, tarpaulin or inventory inclosure. Herewith it is necessary to avoid severe cooling, which may cause large thermal stress within the concrete and its alligatoring. It is simplicity and technological reliability that points out the method of concrete treatment in shuttering with heating elements. The shuttering can be used almost at any frosts. Moreover, it saves the metal when producing electrodes, the modes of shuttering are easily regulated and the concrete temperature may be automatically controlled through special settings. To conclude, it is necessary to point that the fuzzy control principle ensures the management sustainability at sudden changes in the dynamic parameters of the controlled object. The concrete thermal treatment by means of heating shields does not impose any specific requirements to the concrete structure and materials during its production. The concrete electro termo shuttering shall be applied both in winter and in summer in order to accelerate its hardening and acquiring necessary strength, which is of a great importance in cast-in-place construction, when the intensification of the hardening process imposes significantly the total construction time limit. Each covering is equipped with a cable entry with plug-in connector, designed for the maximum calculation value of the electric heaters current. The specific direct-current resistance of the applied carbon electric materials determines the ways of connecting electric heaters into one- or three-phase circuit and also the coatings linear dimensions.

KEYWORDS
Fuzzy logic; concrete thermal treatment; automatic control; strategic management; formation dynamics; structure formation; enterprise informatization.

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Introduction

The automatic control system of the concrete thermal treatment in the shuttering with heating elements requires providing the concrete mix with the necessary temperature speed raising and the concrete cooling in variable external factors (the external air temperature and the wind speed), ensuring the high quality of the building construction and the desired strength during the shortest period of time with the

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minimum energy consumption (Zavyalov, 2000; Zavyalov & Rulnyov, 2001; Zavyalov et al., 1992; Murtazaev et al., 2015a; 2015b; Kuladzhi et al., 2015; Ilyukhin et al., 2015).

Nowadays while designing the management systems of complex, nonlinear objects, the mathematical models with the fuzzy logic system are applied (Hooper et al., 2012; Nonaka et al., 2007; Hooreweder et al., 2012; Guimaraes & Jonas, 1981). The control model is not defined clearly by the system of differential equations, but is implemented through fuzzy situational network, which is a balanced transition through the reference situations depending on the source information and the target aim (Mintsaev, 2009; Mintsaev & Libenko, 2005; Mintsaev & Burdacheva, 2009).

This formulation of the problem significantly differs from the classical, which is usually solved in the automatic control theory, where the error signal between the specified and the current control parameter is used as the controlling one (Jin et al., 2012; Thomas et al., 2008; Muller et al., 2002; Dawicke et al., 1990; Okayasu & Sato, 2012; Nonaka et al., 2007; Savas, 2000; Bush, 1985). The far-reaching possibilities of using such systems while implementing technological processes in the construction are shown on the examples of the mathematical modeling of the concrete shuttering control system in the interactive mathematical system MATLAB 6.0, using the special facilities: SIMULINK and FAZZYLOGICTOOLBOX (Yun et al., 2012; Pach et al., 2012; Munoz et al., 2012; Huda & Edi, 2013).

Materials and Methods

The following discrete proportional integral control algorithm was used for the normal temperature control system of a poured concrete with a feedback [5]:

$$\Delta u(t) = k_c\left[e(t) - e(t-1)\right] + \frac{T}{2T_i}\left[e(t) - e(t-1)\right], \tag{1}$$

where Δu(t) — the increment of the input control action, e(t) — an error, kc — the coefficient of the regulator transfer.

The control scheme of the concrete thermal heating using shuttering with heating elements on the basis of a fuzzy logic was projected in accordance with linguistic variables related with the field of the artificial intelligence (Figure 1).

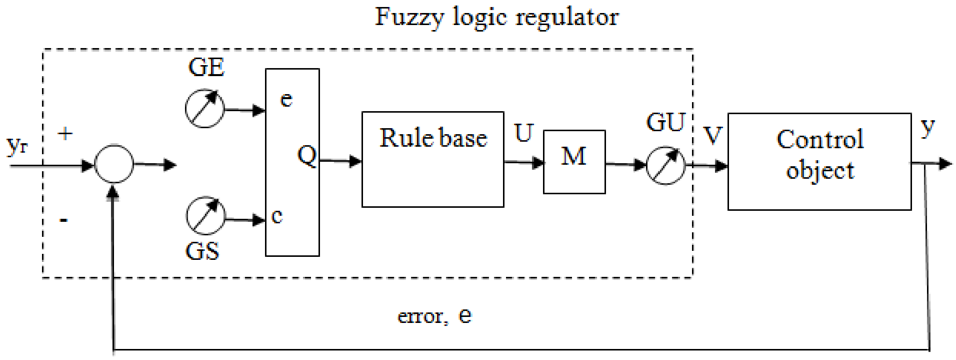

Figure 1. The structural scheme of the fuzzy control system

This system represents a set of conventional linguistic operators which define the specific control situations. It would be enough to establish a link between an error and the change in the process error in order to make such a control input change that will provide the satisfactory system control. These simple linguistic rules could be formulated on the basis of observations or simple process investigations.

It is needed to indicate the following input variables: an error e(t) representing a mismatch between the desired and the actual temperature of the concrete mix and the rate of error change c(t), for the control system of the concrete thermal treatment. The signal (voltage u(t)) is the output or the fuzzy variable control, which is sent by the thyristor power switch with the analogue control to the built-in electric heater.

The fuzzy variables are represented in the matrix format in the form of seven fuzzy subsets: from the negative to the positive high values (fig.2). The fuzzy associations matrix made up of 25 rules was developed for the thermal treatment control system on the basis of general engineering judgments.

	NL	NM	NS	ZE	PS	PM	PL
PL				4 PL	3 PL	2 PL	1 PL
PM				10 PM	9 PM	8 PM	5 PL
PS			17 PS	14 PS	13 PS	11 PM	6 PL
ZE	23 NL	21 NM	18 NS	16 ZE	15 PS	12 PM	7 PL
NS			25 NS	20 NS	19 NS		
NM				22 NM			
NL				24 NL			

Figure 2. The matrix set of fuzzy rules for the control system

Each group of elements in the matrix defines one fuzzy association, or a rule, that specifies how to change the control variable for the observed values of the input fuzzy variables ei and ci. As an example, the interpretation of Rule 7 will be shown (PL, ZE, PL) in natural language: if an error (a mismatch) of the temperature of the cured concrete is positive and large, and the rate of error change is close to zero, the heater should be set to a positive high temperature.

It should be mentioned also that it is not required for all matrix elements to be filled. Some rules may be omitted or, on the contrary, be added, depending on the complexity of the management tasks.

The triangular and trapezoidal membership functions were selected for the fuzzy variables subsets (fig.3).

It is clearly seen that the subset of three fuzzy variables ZE (the values close to zero) is narrower than the others; this allows increasing the control accuracy near the specified value. On the ground of heuristic ideas it is accepted that the continuous fuzzy subsets are intersectioned by about 25%.

The distinctions between values which correspond to different subsets got lost within the excessive intersection. And within the too small intersection there appears the tendency towards "double-valued" control. In the real world the intersections allow to smooth the transition of control actions at each other during the regulator operation. The membership function values were established on the basis of technological requirements to the thermal treatment process.

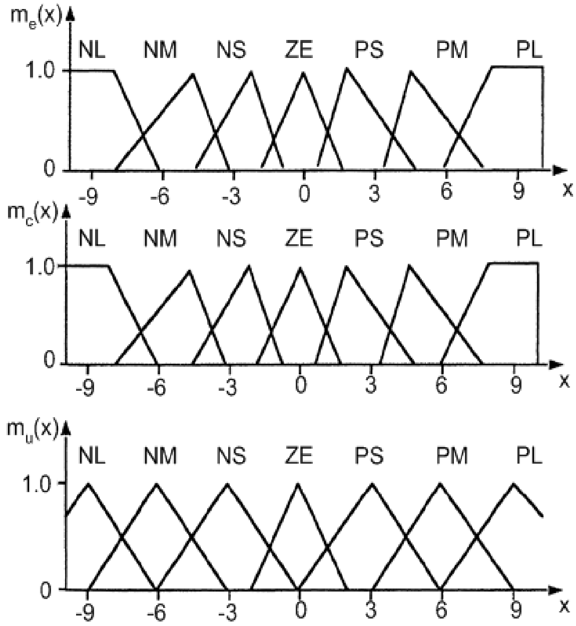

Figure 3. The functions of fuzzy subset

The hypothesis of rule is combined by the operation И, which corresponds to the activation of the fuzzy set-conclusions ui with the quotient wi, calculated in accordance with the definition of fuzzy intersection operation:

$$w_i = m_{ei}(e) \wedge m_{Ci}(c), \quad (2)$$

where mei and mC_i — the correspondent degrees of membership for the error and the rate of error change.

The output fuzzy sets form depends on the used coding circuit of the amplitude frequency modulation. In this case, the coding circuit with a minimum correlation was used, in which the fuzzy set-conclusions ui is cut to the wi level within the set of output fuzzy values and takes the minimum value at other points:

$$m_{0i}(y) = v_i \wedge m_{ui}(y), \quad (3)$$

where 0i(y) — the degree of membership of the activated output fuzzy set on the interval of the output values of its universal set.

In practice the value w0i(y) is not a univalent; thus, the system combines all these functions into a real output membership function based on definition of the fuzzy combining operation:

$$m_0(y) = w_{0i}(y) \vee m_{0i}(y) \vee ... \vee m_{0i}(y), \quad (4)$$

In order to convert the fuzzy output controlling signal into the clear form a discrete procedure of fuzzy centroid transformation is applied:

$$u = \frac{\sum_{j=1}^{p} y_i m_O(y_i)}{\sum_{j=1}^{p} m_O(y_i)}, \quad (5)$$

where the output universal set converts into the discrete values p in increments of Δy:

$$y_p = y_{p-1} + \Delta y .$$

Results and Discussions

Proceeding form the theory to the practice of using fuzzy regulators it should be mentioned that the tendency of unpredictable changing of the control system parameters appeared to be one of the characteristics of the automatic control system of concrete termo heating. Two types of regulators were tested (proportional integral and fuzzy) on the stability with the imitation of sudden changes in the process parameters. In the real object it equals to a sudden speed change and wind direction, which blows the shuttering of the concreting section, and, accordingly to the coefficient of its heat transfer. The mathematical experiments on comparing the stability and the adaptive properties of the compared control algorithms are shown in Fig. 4.

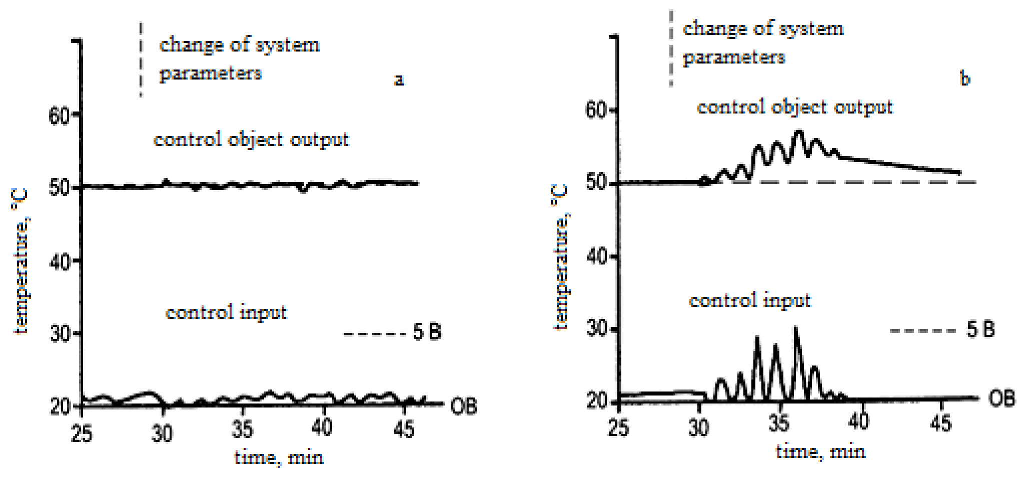

Figure 4. The regulators characteristics: a) the regulator with fuzzy logic b) the proportional integral regulator

While studying the regulators, the worst quality characteristics were revealed in the proportional integral regulator. Despite the integrating effect of proportional integral, the deviations were observed at the object output arising from the control resistant saturation. At the same time, the integrating effect of proportional integral helped to remove these deviations. Better control characteristics were observed in the fuzzy logic regulator. Unlike the load demand, the object dynamics changes were not so significant. The fuzzy logic regulator can convert the process error information and the speed of error changing into corresponding control actions, providing small fluctuations in the output.

Conclusion

The experimental investigations have shown that the regulators with the fuzzy logic could be effectively implemented in the concrete thermal treatment processes using shuttering with heating elements, also including the real time management systems. This way of fuzzy management provides the sustainability of the management process within the sudden changes in the dynamic parameters of the controlled object (in this case-the process of automatic concrete thermal treatment using shuttering with heating elements).

Disclosure statement

No potential conflict of interest was reported by the authors.

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