TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2010, 10B, 275-288

CONCEPTION OF THE SMALL-PIECES BUILDING PRODUCTION' AUTOMATION

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Summary. In a paper, the conception of the small-pieces building production' automation is shown on the classical control automatic and fuzzy sets theories basis.

Key words: production structure, decomposition, control system, mathematical model, synthesis, regulator, fuzzy control model, CIM.

0. INTRODUCTION

The lime-sand, ceramic, facing bricks and wall stones are widely used in building. Urban street' beautification is based on the sidewalk tile sine qua non. Product' quality depends on the input materials' characteristics and production technology. The humidity, granulometric composition and density of components, the mix preparation technology and the control methods have dominant influence on product' quality. The mix input materials' characteristics depend on the preparation technology, humidity, density and other stochastic disturbances. Hence the production' automation is required for these disturbances compensation. Moreover, the real production analysis shows the manual (non-automatic) mode dominating – separate operations are automated only. Hence the necessary product quality is not reached [1-6].

1. SMALL-PIECES BUILDING PRODUCTION' INVESTIGATION

Main investigation aim is a development of conception of the small-pieces building (SPB) production' automation through effectiveness improvement on the up-to-date automated control methods. Next tasks are decided thereto:

1. SPB production' decomposition as a complex control object (CO). SPB production' investigation.
2. General automated control system structure development of SPB production.

3. Development and investigation of the batching and mix preparing mathematical models as control objects.

4. SPB' mix preparing automatic control algorithm synthesis.

1.1. CO' decomposition

The 9 typical largest SPB plants analysis shows that 63 operations are used in SPB' production (7 operations – remote control, 7 operations – half-automatic control, 49 – manual control) [1]. This production is a complex automated CO, which includes 6 autonomous workshops with common material threads. As a most complex case, the general CO structure of lime-sand bricks production is shown in a figure 1.

Every subsystem has two levels:

1. Technological equipment for concrete operation.
2. Technological equipment' complex.

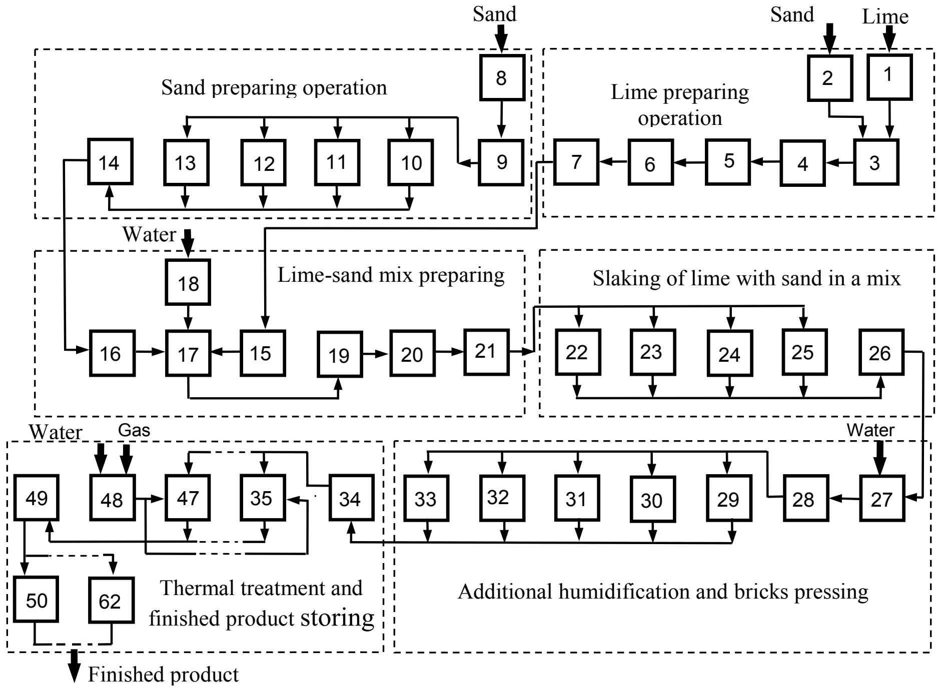

Fig. 1. General CO structure of lime-sand bricks production (a most complex case): 1 – feeder of lime bunker; 2, 8 – feeders of sand bunker; 3, 4, 9, 14, 19, 21, 26 – conveyors; 5 – screw feeder; 6 – ball mill; 7 – crushed lime pneumatic transport; 10, 11, 12, 13 – sand accumulating bunkers with feeders; 15 – prepared lime batch bin; 16 – prepared sand batch bin; 17 – water-lime mixer; 18 – water batch bin; 20 – elevator; 22-25 – reactors' feeders for lime mix; 27 – critical mixer; 28 – conveyor-distributor; 29-33 – pressing apparatus; 34 – electrotruck; 35-47 – autoclaves; 48 – steam generators; 49 – moving winch; 50-62 – finished product area

Hence SPB' production has three levels – subsystems' hierarchy (first level) and concrete subsystem (second and third levels). According to CO structure the hierarchical computer integrated manufacturing (CIM) was offered (see figure 2; denotations correspond to figure 1) [7-9].

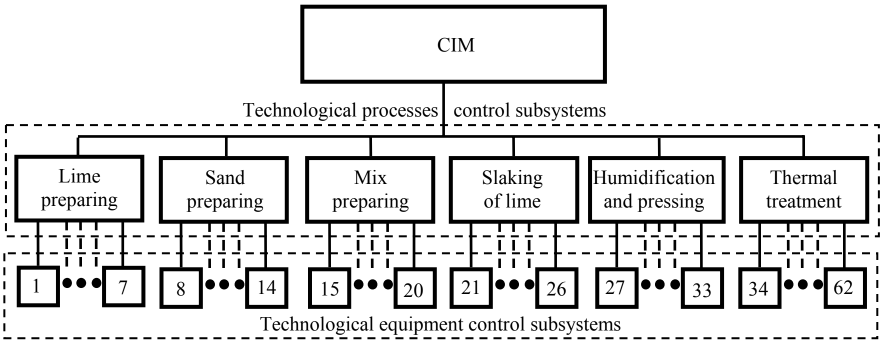

Fig. 2. Hierarchical computer integrated manufacturing of the lime-sand bricks production

CIM' lower level includes the equipment local control subsystems with programmable microcontrollers. Middle level includes the concrete technological process' automatic controls subsystems. Upper level coordinates the whole technological processes complex functioning on the internal and external information.

Lime and sand preparing, slaking of lime, additional humidification do not require automatic control and, therefore, use traditional methods. The component mix preparing (has dominant role) and thermal treatment are most important technological processes in SPB production. Most complicated case is a first, which includes the preset humidity and components quantity. Hence CMI' synthesis we will see only for this first case but it can be prolongated to thermal treatment.

1.2. Mix preparing process mathematical model

At first, we will investigate the CO properties.

At mix preparing, all SPB production technologies use analogical operations such as batching and mixing. General scheme of the mix preparing CIM with preset humidity is in a figure 3.

Mixer' output humidity is controlled by humidity sensor D_{VL}. Humidity regulation is realised through the mixer 7 input' water discharge changing. Operator sets the dry components' common productivity. Batch bin sets is calculated in a setters' control block: $Q_i^* = Q^* \cdot k_i^*$, where Q^* – batch bin dry components' common productivity, Q_i^* – batch bin i preset productivity. Let use coefficient $k_i^* = Q_i^* / Q^*$, $\sum_{i=1}^{N} k_i^* = 1$ and $Q = Q^* = \sum_{i=1}^{N} k_i^* \cdot Q_i^*$.

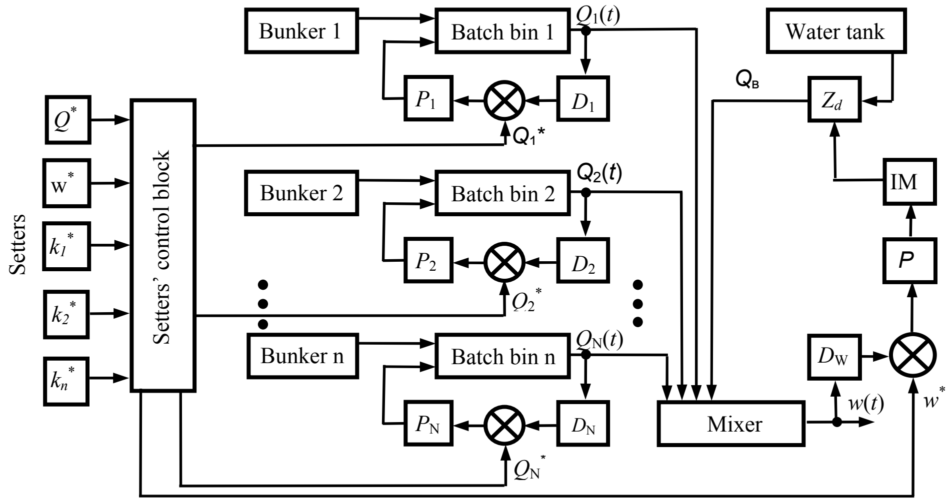

Fig. 3. General scheme of the mix preparing CIM with preset humidity:
D_1-D_N – batch bin productivity sensors; P_1-P_N – batch bin productivity regulators; P – mix humidity regulator; IM – water batch bin actuator (into mixer); w – humidity sensor; Z_d – water discharge regulation valve, Q_1-Q_N – batch bin productivities

As CO the batching model is:

$$Q_i(t) = L\{U_i(t), F_i(t), X_i(t),\}, \quad i = 1,2,...,n,$$

where: $Q_i(t)$ – batch bin i productivity ($i = 1,2,..,N$); L – conversion function; $U_i(t)$ – batch bin i control actions' vector; $F_i(t)$ – batch bin i disturbances' vector; $X_i(t)$ – batch bin i state space variables' vector; N – quantity of batch bins.

Disturbances' vector is shown as:

$$F_i(t) = \{w_{um}(t), d_{um}(t), \rho_{um}(t)\}, \; m = 1,2,...,l,$$

where: $w_{um}(t)$ – humidity of the m initial component; l – quantity of mix components; $d_{um}(t)$ – granulometric composition of component with index m; $\rho_{um}(t)$ – fractional composition of component with index m.

Sliding valve with conveyor feeder is used for batching often. Actuator includes the DC or AC motor with screw pair. This pair moves sliding valve for the output window size' changing. Motor electromechanical time constant is considerably bigger to electromagnetic time constant and, therefore, last constant is ignored. Hence actuator' transfer function includes the first order aperiodic link and integrator consecutively.

$$W_{им}(s) = \frac{L\{\varphi(t)\}}{L\{u_p(t)\}} = \frac{k_{им}}{s(T_{им}s + 1)}, \tag{1}$$

where: L – Laplacian; $\{\varphi(t)\}$ – output signal – screw' rotation angle (screw is operated by electric motor); $u_p(t)$ – control (input) signal (regulator' output) – electric voltage; $k_{им}$ – multiplication coefficient; $T_{им}$ – actuator' time constant.

Sliding valve' transfer function can be approximated by non-inertial link:

$$W_{ш}(s) = \frac{L\{h(t)\}}{L\{\varphi(t)\}} = k_{ш}, \tag{2}$$

where: $h(t)$ – sliding valve' moving; $k_{ш}$ – multiplication coefficient.

Conveyor feeder' transfer function can be approximated by next link:

$$W_{лп}(s) = \frac{L\{Q(t-\tau)\}}{L\{h(t)\}} = k_{лп} \cdot e^{-\tau s}, \tag{3}$$

where: $\tau = \frac{l_{лп}}{v_л}$ – transport time delay (from load point to weighting point' moving time); $l_{лп}$ – conveyor transportation distance; $v_л$ – conveyor speed.

Tensometric sensor is used for weight measurement and has the non-inertial link' model:

$$W(s) = \frac{L\{u_\partial(t)\}}{L\{Q(t)\}} = k_\partial, \tag{4}$$

where: $u_\partial(t)$ – weight sensor output electric voltage; k_∂ – multiplication coefficient.

Hence, batching mathematical model has next differential equation after transformations:

$$\frac{d^2 u_\partial(t-\tau)}{dt^2} + a_1 \frac{du_\partial(t-\tau)}{dt} = bu_p(t), \tag{5}$$

where: $a_1 = \frac{1}{T}$, $b = \frac{k_O}{T}$.

Component mixing model can be presented in next view generally:

$$w(t) = L\{U_c(t), F_c(t), X(t)\}, \tag{6}$$

where: $w(t)$ – the mix components humidity; $U_c(t) = Q_в(t)$ – control vector – water discharge (it is used for preset w^* regulation, is entered the mixer); $F_c(t)$ –

disturbances vector – component batch bins productivity changing $\Delta\, Q_i(t)\ (i=1,2,...,l)$, component humidity $w_i(t)\ (i=1,2,...,l)$ changing also.

Disturbances vector can be presented in next view:

$$F_c(t)=\{Q_i(t),\, w_i(t),\, (i=1,2,...,l)\}.$$

Mixer is a most complicated CO. It is adequately (with the ideal displacement model usage) approximated by the first order aperiodic link with delay.

$$W_c(s)=\frac{L\{w(t)\}}{L\{Q_в(t)\}}=\frac{k_c\exp(-\tau_c s)}{T_c s+1}, \qquad (7)$$

where: k_c – transfer constant; $\tau_c=\dfrac{l_c}{v_c}$ – mix humidity' signal time delay; l_c – mixer length; v_c – material' average speed in a mixer; $T_c=\dfrac{V_c}{Q_c}$ – mixer' time constant; V_c – mixer' chamber volume; Q_c – dry components' sum productivity at the mixer input.

Humidity sensor has complicated structure with the data average' preprocessing. Hence this link' transfer function is presented by the first order aperiodic link with multiplication coefficient $k_{дв}$ and time constant $T_{дв}$:

$$W_{дв}(s)=\frac{k_{дв}}{T_{дв}s+1}. \qquad (8)$$

Component mixing process' mathematical model is presented by differential equation:

$$\frac{d^4u_{вл}(t-\tau_c)}{dt^4}+a_{3c}\frac{d^3u_{вл}(t-\tau_c)}{dt^3}+a_{2c}\frac{d^2u_{вл}(t-\tau_c)}{dt^2}+a_{1c}\frac{du_{вл}(t-\tau_c)}{dt}=b_cu_p(t), \quad (9)$$

where:

$$a_{1c}=\frac{1}{T_{имс}T_cT_{дв}},\quad a_{2c}=\frac{T_{имс}+T_c+T_{дв}}{T_{имс}T_cT_{дв}},\quad a_{3c}=\frac{T_{имс}T_c+T_{имс}T_{дв}+T_cT_{дв}}{T_{имс}T_cT_{дв}},\ b_c=\frac{k_{ос}}{T_{имс}T_cT_{дв}}.$$

1.3. Model linearization

Batching and mix preparing processes' differential equations were linearized with Pade series. At two expansion terms the equations (5) and (9) has next view:

$$\frac{d^3u_д(t)}{dt^3}+a_2^{'}\frac{d^2u_д(t)}{dt^2}+a_1^{'}\frac{du_д(t)}{dt}=b_0u_p(t)+b_1\frac{du_p(t)}{dt}, \qquad (10)$$

$$\frac{d^5 u_{вл}(t)}{dt^5} + c_4 \frac{d^4 u_{вл}(t)}{dt^4} + c_3 \frac{d^3 u_{вл}(t)}{dt^3} + c_2 \frac{d^2 u_{вл}(t)}{dt^2} + c_1 \frac{du_{вл}(t)}{dt} = b_{0c} u_{pc} + b_{1c} \frac{du_{pc}}{dt}, \quad (11)$$

where: $a_1^{'} = \frac{1}{0{,}5\tau T}$, $a_2^{'} = \frac{T + 0{,}5\tau}{0{,}5\tau T}$,

$$c_1 = \frac{1}{0{,}5\tau_c T_{имс} T_c T_{дв}}, \quad c_2 = \frac{T_{имс} + T_c + T_{дв} + 0{,}5\tau_c}{0{,}5\tau_c T_{имс} T_c T_{дв}},$$

$$c_3 = \frac{0{,}5\tau_c (T \; + T_c + T \;) + T_{имс} T_c + T_c T_{дв} + T_{имс} T_{дв}}{0б5\tau_c T_{имс} T_c T_{дв}},$$

$$c_4 = \frac{0{,}5\tau_c (T_{имс} T_c + T_c T_{дв} + T_{имс} T_{дв}) + T_{имс} T_c T_{дв}}{0{,}5\tau_c T_{имс} T_c T_{дв}},$$

$$b_0 = \frac{k_o}{0{,}5\tau T}, \quad b_1 = -\frac{k_0}{T}, \quad b_{0c} = \frac{k_{oc}}{0{,}5\tau_c T_{имс} T_c T_{дв}}, \quad b_{1c} = -\frac{k_{oc}}{T_{имс} T_c T_{дв}}.$$

Hence batching process’ mathematical model is adequately presented by the third order differential equation (10), mixing process’ mathematical model – by the fifth order differential equation (11).

2. SPB PRODUCTION AUTOMATIC CONTROL SYSTEM’ SYNTHESIS

2.1. Batching process automatic control system’ synthesis

Batching control quality’ requirements are not strict. The main requirement is the components’ preset constant ratio (every batch bin discharge’ stabilization). In this case the transient process has not limitations and, therefore, batching process automatic control system’ synthesis can be presented as terminal task. It is recommended to use the batch bin productivity’ minimal dispersion (in normal regime without overshoots) as a control criterion.

Weight sensor’ delay is considerably less than CO time constant. Hence, we can apply usual P-regulator to the mix components batching automatic control. Also it is confirmed by the close-loop system characteristic equation’ roots. Close-loop system’ differential equation has next view (CO (10)):

$$\begin{aligned} &\frac{d^3 u_д(t)}{dt^3} + a_2 \frac{d^2 u_д(t)}{dt^2} + (a_1 + b_1 K_p) \frac{du_д(t)}{dt} + b_0 K_p u_д(t) = \\ &= K_p \left[\; b_0 u_p(t) + b_1 \frac{du_p(t)}{dt} \; \right], \end{aligned} \quad (12)$$

where: K_p – P-regulator’ multiplication coefficient.

We know that b_1<0 and, therefore, close-loop automatic productivity control system' stability is possible at true inequality $a_1 + b_1 K_p$>0 only. Hence, together with (10) we can obtain the stability' insufficient precondition:

$$K_p < \frac{1}{0{,}5\tau k_0}.$$

As we can see, at $\tau = 0$ the control system will be stable with any value of the regulator' multiplication coefficient. For asymptotic stability it is necessary and sufficient that all roots of characteristic equation must have negative real values:

$$\det[sE - A] = 0\,, \tag{13}$$

where: $E -$ unity matrix; A – coefficients matrix of linear stationary system (10):

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -b_0 K_p & -(a_1 + b_1 K_p) & -a_2 \end{bmatrix}.$$

System stability requires the next condition performing:

$$(a_1 + b_1 K_p) a_2 > b_0 K_p\,. \tag{14}$$

From (14) with (10) we can obtain stability' condition:

$$K_p < \frac{(0{,}5T + \tau)\tau T^2}{0{,}5\tau^2 T^2 (4T + \tau) k_0}. \tag{15}$$

As we can see in (15), the stability conditions are deteriorated at the delay and time constant increasing (numerator is decreased, but term is increased). At delay non-limited increasing the coefficient K_p is decreased to zero.

Short example. At $T = 0{,}4\ s$, $k_0 = 2\ s^{-1}$ and $\tau = 0{,}1 \div 0{,}5\ s$ the coefficient K_p is changing from 11,8 to 0,67. Hence, for the batching automatic control we can use traditional P-regulator.

2.2. Mixing process automatic control system' synthesis

Mixing process automatic control system' synthesis has difficulties – the time constant and humidity information delay are non-stationary and inversely depend on productivity. More, the delay (near 50 s) and time constant (near 100 s) ratio' analysis shows P-, PI-, PID-regulators usage impossibility $(\tau_c / T_c \geq 0{,}5)$. Also the mix humidity sensors are errorprone. If humidity sensors are idle then CIM is non-stable.

The mix preparing process' main requirement is humidity stabilization in preset technological limits. Control criterion is a humidity dispersion minimization without the state space variables' limits. The main control conception is a terminal task.

In this case, it is reasonable to use the specialists' experience in an automatic fuzzy control system [17-19]. This principle permits the working and new projecting plants' automation. For this algorithms realisation the fuzzy control language (FCL) is used.

Functional scheme of the mix preparing' fuzzy control algorithm with preset humidity is shown in a figure 4.

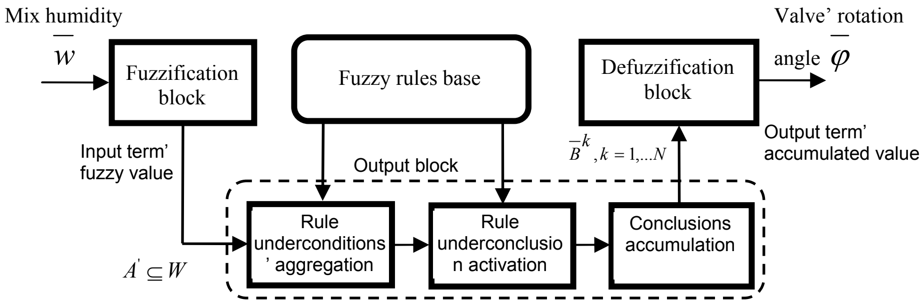

Fig. 4. Functional scheme of the mix preparing' fuzzy control algorithm with specified humidity

2.3. Mix preparing process' fuzzy control algorithm

Water and dry components mixing' fuzzy control process is based on well-known Mamdani algorithm [20-22].

Fuzzy regulator' input information is a mix factual humidity $\overline{w}(t)$, output information is a control signal (valve' rotation angle $\overline{\varphi}$ – water discharge' mix input – preset humidity maintenance).

Specialists' experience permits to formulate next heuristic rules, which are used for the mix humidity' manual regulation.

1. If mix is dry then open valve with big angle.
2. If mix is insufficiently humid then open valve with not big angle.
3. If mix is sufficiently humid then do not move the valve.
4. If mix is too humid then close valve with not big angle.
5. If mix is wet then close valve with big angle.

Specialists' heuristic experience shows that mix humidity is controlled from 12 % to 30 % (optimal value is 21 %). Valve moving angle 180^0 (from "close" to "open" positions). Optimal humidity value corresponds to the valve position angle 90^0.

Water discharge' regulation is controlled according to this angle position (left side - discharge' increasing, right – decreasing).

CO' fuzzy control software is MATLAB Fuzzy Logic Tooldox [20] (see figure 4).

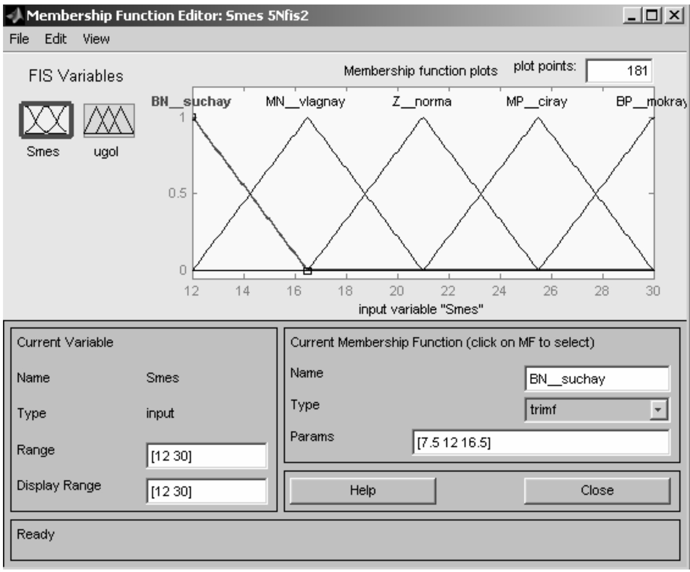

Fig. 5. Input variable space' partition and membership function' selection

Input variable W (mix humidity) range divides into ($2N+1$) subranges. At $N=2$ every subrange has triangle membership function with a vertex in a subrange' centre (membership function' value is 1). Lets define the fuzzy set' width of the input fuzzy variable W in diapason [12, 30]. Membership functions intersect each other in level 0,5 (see figure 5).

The fuzzy set' width of the output fuzzy variable "φ – rotation angle" is in diapason [0, 180]. According standard abbreviations for linguistic variables we will define next values: NB (negative big); NM (negative middle); Z (zero, near zero); PM (positive middle); PB (positive big).

According to the input and output variables space' partition we obtained SISO control structure: the mix humidity w (regulator' input) and the valve' rotation angle φ (regulator' output). In this case, we have five fuzzy rules:

RULE 1: IF «mix is dry» THEN «open valve with PB angle»
RULE 2: IF «mix is insufficiently humid» THEN «open valve with PB angle»
RULE 3: IF «sufficiently humid» THEN «valve rotation angle is Z»
RULE 4: IF «mix is too humid» THEN «close valve with NB angle»
RULE 5: IF «mix is wet» THEN «close valve with PB angle»

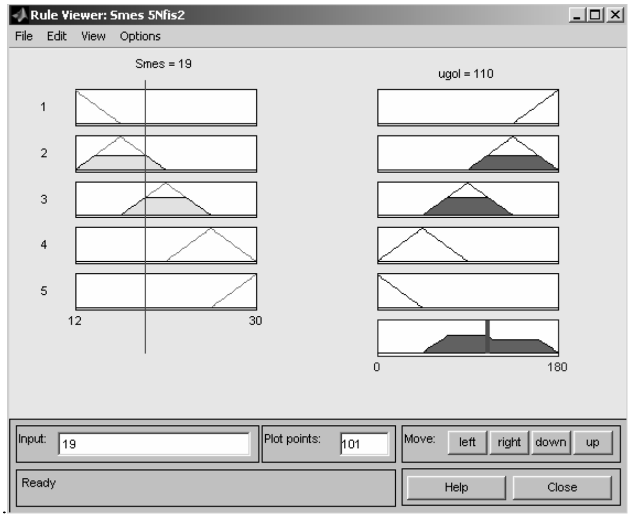

Fig. 6. Example of the fuzzy control calculation
at the valve rotation angle 110^0 and humidity 19 %

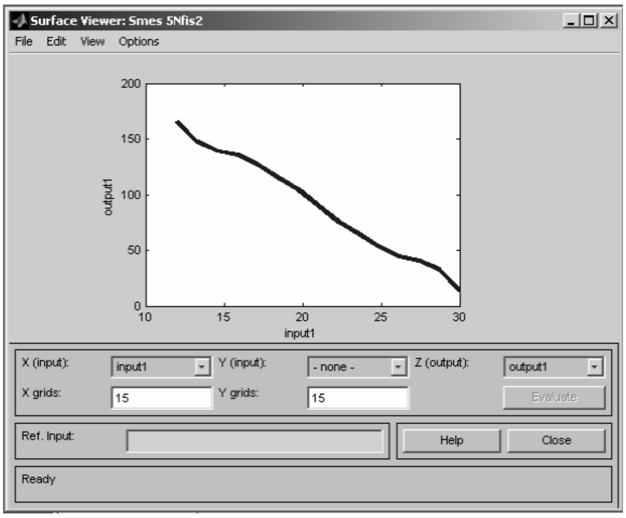

Fig. 7. Input and output variables relation' example

Rule base is preset. It is described by the fuzzy rule sets $P=\{R_1, R_2, R_3, R_4, R_5\}$, by sets of the input linguistic variable $W=\{w_1, w_2, w_3, w_4, w_5\}$ and by sets of the output linguistic variable $\varphi=\{\varphi_1, \varphi_2, \varphi_3, \varphi_4, \varphi_5\}$.

Figure 6 shows example of the fuzzy control calculation at the valve rotation angle 110^0 and humidity 19 % with above proposed fuzzy rules.

Visual analysis (see figure 7) of the input and output variables relation shows the fuzzy regulator' adequate normal functioning.

Figure 8 shows functional scheme of the humid mix preparation' fuzzy control system with Mamdani fuzzy conclusion. Above described fuzzy method and [16] comparison analysis shows that first case has minor blocks and relation quantity. It provides decreasing of calculations, simplification of soft and hard ware, increasing of control system' effectiveness.

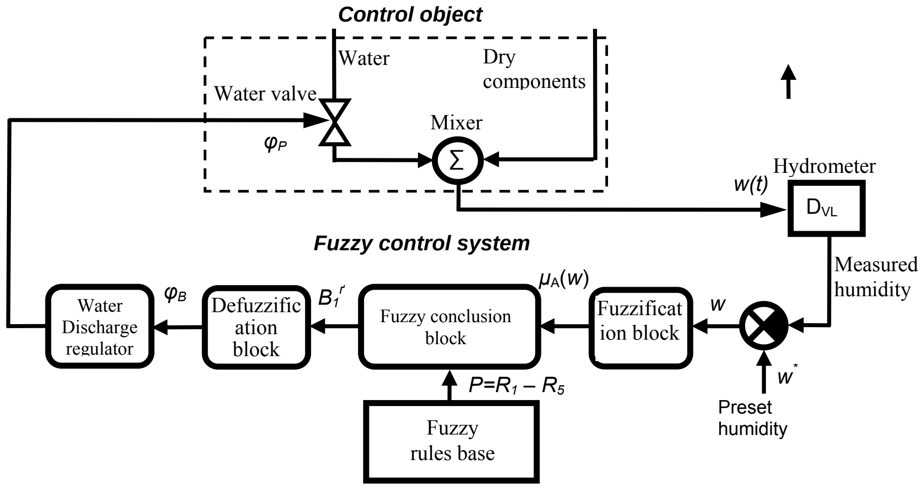

Fig. 8. Functional scheme of the humid mix preparation' fuzzy control system with Mamdani fuzzy conclusion

3. CONCLUSION

This paper SPB production investigations permit to do next conclusions:

1. SPB production has hierarchical structure with three levels – the separate technological equipment control (first), the technological equipment complex control (second), SPB production control as a whole close-loop system (third).

2. SPB production' CIM was developed with three levels – automatic control by the separate technological equipment (first), the technological equipment complex (second), SPB production CIM (third).

3. Two level mix preparing process' automatic control system was developed (batching' P-regulators (first), mix process' fuzzy regulators with Mamdani method usage (second)).

This investigation main perspective is offered as the Diophantine equations usage for the technological equipment complex control.

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КОНЦЕПЦИЯ АВТОМАТИЗАЦИИ ПРОИЗВОДСТВА МЕЛКОШТУЧНЫХ СТРОИТЕЛЬНЫХ ИЗДЕЛИЙ

Ульшин В.А., Зубов Д.А., Горбунов А.И.

Аннотация. В статье приведены результаты разработки концепции автоматизации производства мелкоштучных строительных изделий с использованием классической теории автоматического управления и методов нечеткого управления.

Ключевые слова: структура производства, декомпозиция, система управления, математическая модель, синтез, регулятор, нечеткая модель управления.