Nuro-fuzzy activation sub-system of effective control channels in adaptive control system of agglomerative process

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Abstract
Comprehensive and formal problem statement of synthesis of adaptive systems of automatic control of multilevel technical processes is given in the article. Complex synthesis strategy of similar systems in case of agglomerative production is suggested. The results of theoretical and experimental researches show that the developed methodology of passive and active adaptation of automatic control system of technical process (ACSTP) of agglomeration is necessary design concept of low-sensitivity control systems to uncontrolled process disturbances of charge preparation and agglomerating.
Key words: ADAPTIVE CONTROL SYSTEM, NEURAL NETWORKS, NEURO-FUZZY SYSTEM, AGGLOMERTAION

In research and technology and corresponding industrial ACSTP realizations by Ukrainian and foreign agglomerative complexes there achieved certain positive results, but such tasks were solved not complex and are mainly separate local control systems. Problems of operating management of related plants and also automatization of correlation of various levels of the system almost were not investigated and were not realized in manufacturing industry.

Analytical review of works connected with the problems of automatic control of agglomerative process [1-3] showed that in conditions when characteristics of agglomerative stock and state of production equipment change, final operating factors of agglomerative shop significantly depend on the effectiveness of automatic control over the sub-systems of lower level, which is primarily determined by adoptive and robust properties of local ACSTP. In such a way ACSTP of agglomeration should include: chemical identification system or raw materials fed into charge; automatic control system of loading and unloading modes of stock from the hopper of charge preparation plant; charge preparation automatic control system; automatic control system of charge loading onto the sintering belt; automatic control system of sintering process on sintering belt. Also the system of complex automatization of technological sintering process should solve the tasks of metering of burden stock components, moisture control and adjustment, control of the course and end of sintering process. Herein the information about the course of the process should be available for all local subsystems, thus it is necessary to create single information field connected with data measurement system of separate processing lines.

In order to prove the relevancy of the task, let us consider the existing problems of automatization of agglomerative production at “YUGOK” JSCo, Kryvyi Rih, as the most typical agglomerative complex of the district. So for conditions of “YUGOK” JSCo, in 1985 according to the Ministry of Iron and Steel Industry of the Ukrainian SSR order there was developed ACSTP project by agglomerative complex. In 1990 there was implemented only subsystem of automatic monitoring of technological situations in conditions of charge preparing section, which was subjected to significant reduction of functional power towards planned one.

In 1998 the state of agglomerative shop automatization of “YUGOK” was defined as unsatisfactory and the one, which does not meet modern working conditions. According to the Position of innovative priorities of the state, Plan of scientific and technical development of Ukraine for 1999-2000, item 129, chapter 2.4 (mining production) on the base of the Order of the Cabinet of Ministers of Ukraine from 14.12.98 No 1971, item 10, affirmed by the Ministry of Ukraine in affairs of science and technology, Gosinnofondom of Ukraine dated 29.12.98 No 13/ 2-1-4494 there decided upon the necessity of development and implementation of complex program of automatization of agglomerative production with the assistance of scientific resource of Kryvyi Rih technical university.

As of 2010 in conditions of “YUGOK” there implemented four local ACSTP. They are the systems of ACSTP of 14th section ROF-2, ACSTP of crusher in conditions of crushing plant, ACS of central heating plant and ACSTP of charge preparation. Implemented systems are built on the modularity principles, architecture openness, standardization of all system components, which simplifies essentially servicing of this informative complex. Defined systems are built on modern controllers and designed according to three-level scheme. On the low level there occurs signal transmission from the primary detectors and their front-end processing. Middle level is realized on the base of Mitsubishi controllers, Melsec series with standard Ethernet-interface. Algorythmic management of the object is fulfilled on the middle level. Higher level is the level of general control and determination of corresponding setpoints.

Taking into account automatic control functions and functions of process operation with the ability to correct setpoints and change of control criteria, the authors suggest ACSTP, which is built according to hierarchic three-level principle. In functional relation developed ACSTP of agglomeration has the structure, which provides functionality in conditions of processing of complex of interrelated tasks, each of which is the element of control system. ACSTP functionally provides processing of analogue (measuring, operating control and regulation) and discrete (processing, operational accounting, management, signalization) signals.

Taking into account developed generalized functional scheme of sintering bay (fig.1), the authors developed subsystems of lower level of ACSTP sintering, which include the following systems of automatic regulation (SAR): SAR of charge loading onto the sintering belt, which is oriented toward control of set level of materials in charging hopper with account for productivity of sintering belt and corresponding correction of productivity of dished feeder; CAR of charge bed depth at sintering belt, functions of which are control and management of sintering temperature, sintering belt velocity taking into account gas permeability (evacuation) of the layer of sinter charge; SAR of “charge materials-water” ratio, which according to real value of charge weight, fed into nodulising drum, keeps the set level of industrial water flow rate automatically for pelletizing with correction according to moisture content in the intermediate hopper HSC considering delayed action of this production equipment;

SAR of charge temperature at the output of nodulising drum, keeps preheat temperature of charge above dew point at set level (60-65 C °), in order to increase initial charge bed porosity on the sintering belt due to exclusion of overmoisturizing; SAR of “charge materials-water” ratio in nodulising drum provides complete burning of gas under the condition of technological air-gas ratio; SAR of charge surface temperature under ignition furnace, which keeps optimum regime of ignition of solid fuel (coke) of charge due to fed of set quantity of mixed gas, and in such a way necessary thermal regime for ignition of upper layers of charge is provided; SAR of “gas-air” ratio in hearth is meant to provide full gas combustion by means of rate control of ventilating air; SAR of charge sintering on the sintering belt provides necessary vertical velocity of sintering taking into account conditioning with conveying speed of sintering belt.

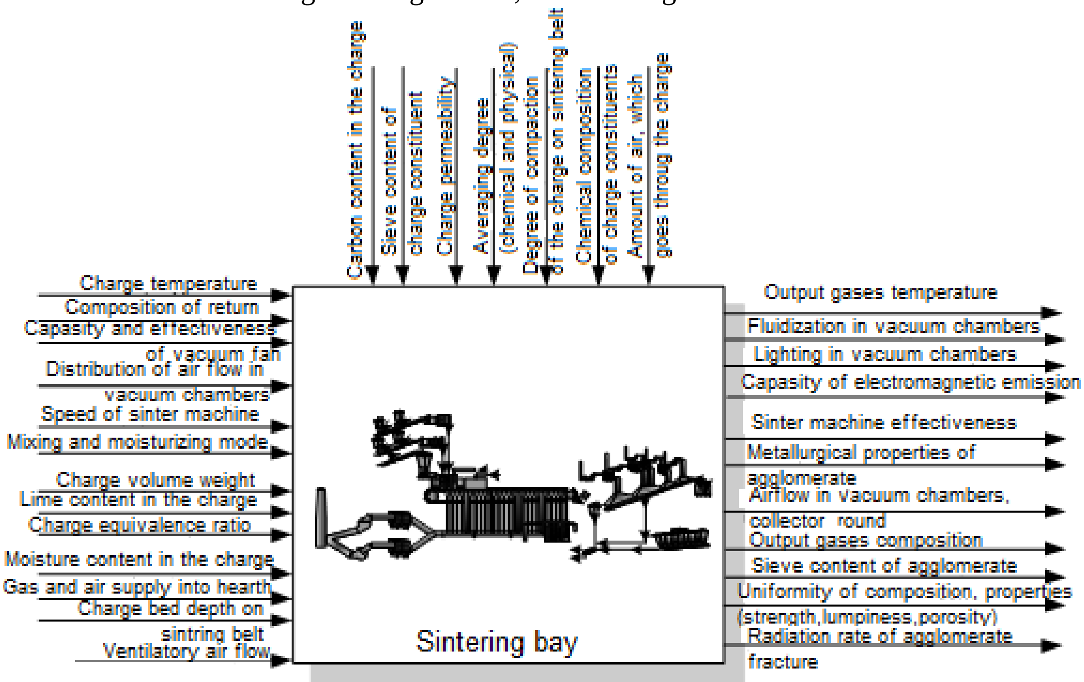

Figure 1. Generalized functional scheme of sintering bay

As most of the initial indexes of TP are not subjected to direct inspection, we used complex estimation of proxy indicators of dynamic behavior of sintering process as basic proxy indicator of completeness of sintering [4]. In case of full assessment qualification to requirements of technology, it is suggested to define algorithmically effective control channels of sintering TP taking into account dynamic behavior of charge preparing TP: correction of “charge-water” ratio; change of ignition temperature of charge upper layers, which is on the sintering belt; correction of sintering belt velocity.

Developed adaptive ACSTP provides the following functions: information reception from the system of lower and middle level; control of sufficiency of incoming information; formation of video sequences, graphs and other information in the form accessible for overseeing technical process course; making it possible to change the parameters of subsystem of lower level of ACSTP; transfer of control data (process conditions setpoints) in the system of lower level.

As for reliability, ACSTP information functions of agglomeration correspond to the indexes of improved reliability and maintainability. Subsystems provide the following: frequency of sensors' scanning not more than 100 ms; frequency of control loop processing not more than 100 ms; formation and issuance of accident-prevention action not more than 100 ms; formation and issuance of emergency message not more than 1s, ACSTP run frequency is not more than 1 min.

Objectives and control criteria of adoptive ACSTP of agglomeration

Securing of specified productivity of each agglomerative machine with specified chemistry and physical properties at reduced material and power consumption for manufacturing is control criterion of agglomerative complex.

Agglomerate quality is subjected to the current specification TC U 322-228-7-2001, which include the following indexes: mass fraction of iron in agglomerate and permitted deviations; basicity (CaO / SiO_2 ratio) and permitted deviations; mass fraction of iron, manganese and other elements oxides with permitted deviation; fraction composition 0-5 mm in agglomerate after screen sizing under hoppers DTs -1; agglomerate hardness indexes (tests in the drum according to DSTU-3200-95) - impact strength (%fraction composition> 5.0 mm), friction resistance (%fraction composition < 0.5 mm). Agglomerate quality estimation is made according to TC indexes and the following data: fraction (%) of tests, which are within the limits ±0.5% and ±1.0% according to deviation from basic iron content; fraction (%) of tests, which are within the limits ±0.05 and ±0.08 units according to deviation from basicity.

Objective function is formed as control task, under which the profit is of maximum value [5]. The profit includes trade price of agglomerate (Pa), prime cost of raw materials (Pra), mass of produced agglomerate per unit time (Ma).

$$P = (Pa - Pra)Ma \qquad (1)$$

According to objective function of adoptive ACSTP there suggested [5] to define:

$$\begin{cases} Ma = f_p(\overline{V}_p, \overline{z}) \to \max \\ Pra = f_c(\overline{V}_c, \overline{z}) \to \min \end{cases} \qquad (2)$$

where $\overline{V}_p, \overline{V}_c$ - objective vector; $\overline{z}$ - vector of quality factors of agglomerate.

Adoptive ACSTP, generalized scheme of which is given in the figure 2, is developed taking into account optimum relationship cost/effectiveness of the system. In particular, applied hardware facilities correspond to the requirements; high reliability of performance and guaranteed reliability of hardware facilities; correspondence of used hardware and license software utilities to the international quality standard ISO 9001; popularity of suggested decisions based on the usage of equipment and basic software of leading producing companies, which guarantee service backup of their systems, flexibility and availability of different modules and subsystems; stiffness to environmental conditions of performance is provided by usage of protected industrial boxes (IP-65 protection), built software and hardware protection from unauthorized actions, operators and maintenance team errors; low cost of service system management, which is conditioned by long term of trouble-free operation, high reliability of hardware and software means, possibility of modernization and modification of the system including operation staff; possibility of integration into control system of higher level without additional charges, due to built-in software support of remote access and exchange default protocols.

Closed ACSTP is realized in the form of tree-level hierarchic structure. Choice of multilayer structure of control system is conditioned by invariability and fail-operational capability principals and for each hierarchical level, except the highest, there foreseen local measure of control.

Lower level – informative- measuring equipment and mechanisms of local SAR. The level has autonomy property, which allows to continue object control by hand when breakdown of middle and upper levels. The main task of the level is to provide appropriate data concerning the dynamics of TP and well-timed response to control signals.

Middle level is made by functionally and geographically-distributed local subsystems of control, combined by single network with upper level. There foreseen batch operation of control subsystems both in the mode of stabilization of output parameters and in the mode of software control in case when breakdown of upper level of control.

Upper level includes multimachine general use computer complex on the base of industrial PC with significant assortment of peripheral and auxiliary equipment for fusion, processing, storage and provision of technical information. Control is fulfilled both in automatic and supervisory state. Control criteria may be changed depending on the current economic strategy of the company.

Functional peculiarities of the developed by agglomerative production adoptive ACSTP includes the algorithm of automatic change of control factors of local ACS (fig.3) depending on the technical-and-economic conditions of production. The figure 3 shows two possible variants of ACS operation of burden surface temperature under ignition furnace, which has technologic limits (400-1500 °C) and is measured by the following devices: TERA-50, DISK-250, gr.-250 with accuracy class 0.5; 1.) in the absence of limits for gas consumption, as control parameter there taken fed of mixture of natural and blast-furnace gases with thermal property Q = 2800÷3000 Kcal/nm^3 into the hearth, which is measured by DM, BPL-1K BIK, DISK-250 equipment (0-2000 nm^3 /hour, accuracy class –

2.0) and has the following limits: excess air factor 1.2 – 1.4; gas mixture pressure not lower than 1.0 кPa (100 kgs / sm^2), at reduction of pressure upper level of ACSTP generates actuating signal, which goes to slowdown of sintering machine 2.) under the condition of reaching of gas limit up, control goes to SAR of charge sintering on the sintering belt, which uses running speed of pallets (sintering achine) with the limit < 5.0 m/min as control parameter.

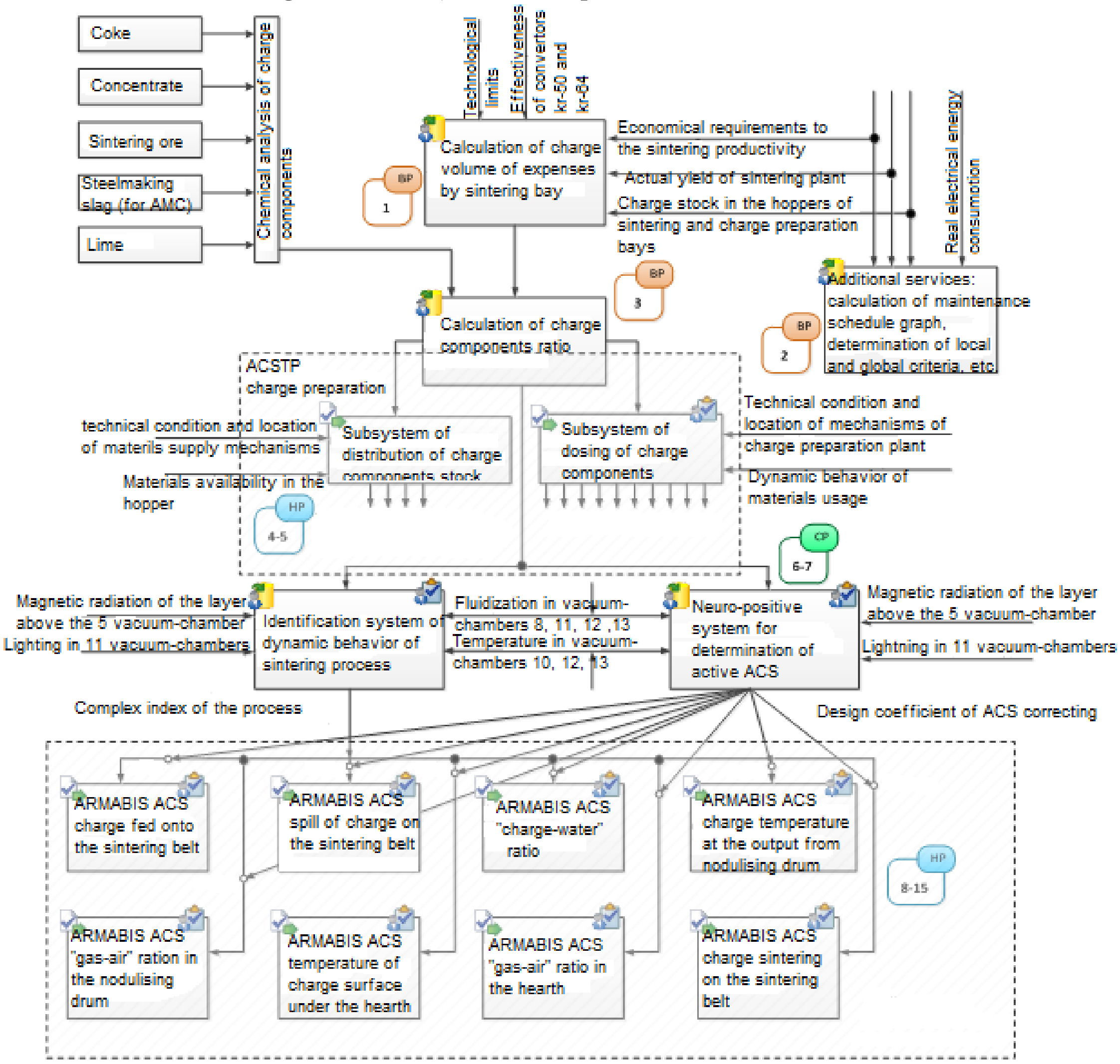

Figure 2. Functional scheme of adoptive ACSTP by agglomerative complex

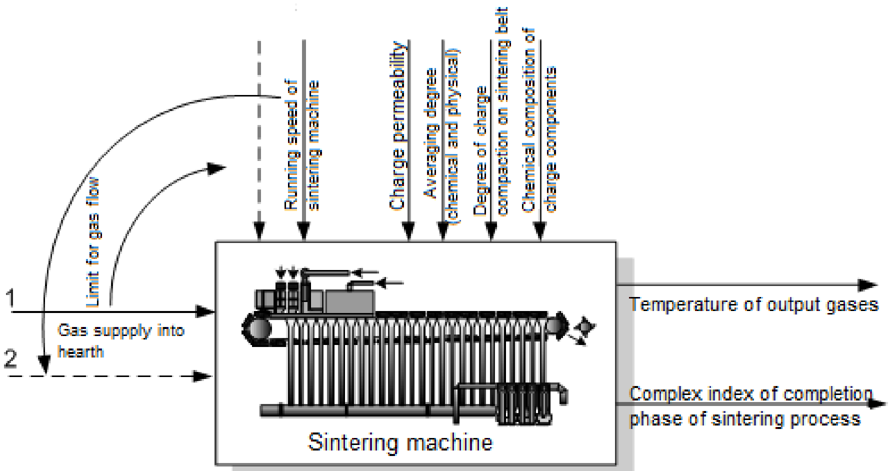

Figure 3. Working version of simplified functional scheme of agglomerative machine

Typical functional scheme of local adaptive ARMABIS-SAR. Fulfilled statistical investigations of control object according to the channel "temperature of charge ignition – temperature in 24 vacuum-chamber" allowed to develop functional scheme of adoptive ARMABIS-SAR of the charge surface temperature under ignition furnace (fig. 4) according to the developed methodology [6].

As the flow of natural and blast-furnace gas with caloric power Q = 2800÷3000 Kcal/nm3 at the excess air factor 1.2÷1.4 Qr=700 m3/hour provides the temperature of charge ignition 1100oC, which due to compliance with conditions of productive process to the Process Instruction PI 228-AP–56-2003 allows to complete the process of sintering above the 24 vacuum-chamber (proxy indicator is maximum temperature 220 oC in 24 vacuum-chamber) as the signal there taken the value 220 oC. m3/hour.

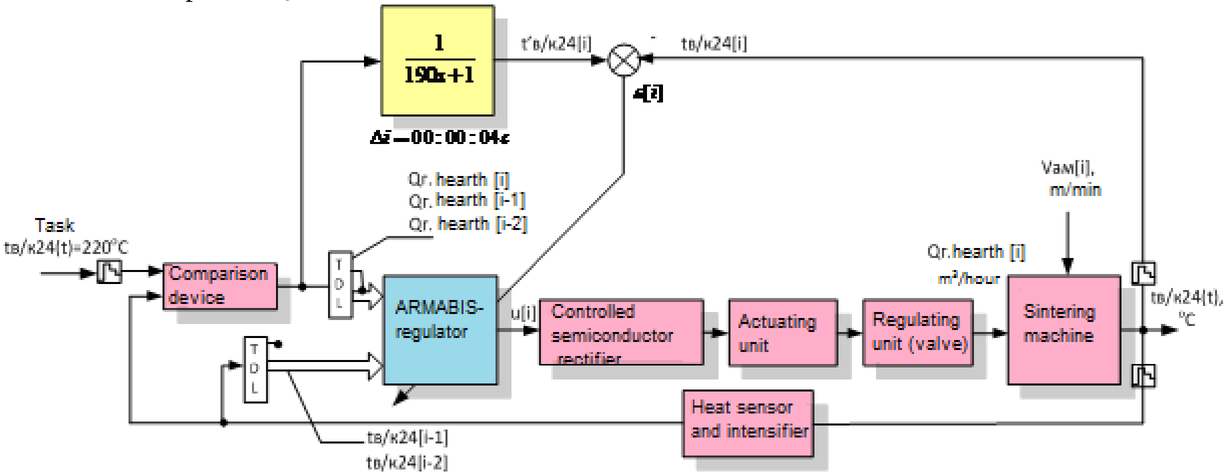

Figure 4. Structural scheme of adaptive ARMABIS-SAR of the temperature of charge surface under ignition furnace

Fulfilled researches of specific nature of sintering process management witness that in the present technology it is impossible to stabilize proxy indicator of the process in conditions of uncoordinated control of complex of independent SAR. In such a way while management according to the channel "gas flow into hearth – complex indicator" nonuniformity of air speed, which goes through the charge layer, and sintering speed respectively, leads to reduction of gas flow into the hearth, while in this process conditions, effective control parameter from the point of view of technical-and-economic criteria, will be sintering belt speed.

Besides, nonuniformity of physicochemical properties of the charge and its influence on the sintering process additionally speaks for the necessity to develop subsystem of coordination of work of local SAR complex.

Synthesis method of Neuro-fuzzy system of determination of active SAR

Relevancy of application of neuro-fuzzy systems of determination of active SAR in the structures of adoptive ACSTP is substantiated by the presence of uncertainties connected with the choice of effective channels of control of complex multilevel objects. So, the developed adaptive ACSTP of agglomerating counts eight local ARMABiS-SAR (fig. 2), control influences of which are different, however controlled parameter is the one – complex index. In order to coordinate control channel in adaptive ACSTP of agglomerating there applied neuro-fuzzy system of determination of active SAR, in the base of which there is the developed method and structure of self organizing neuro-fuzzy emulator of reserve dynamics [6].

Performance principle of the developed structure of adoptive ARMABiS-SAR with neuro-fuzzy system (fig. 5) is based on the combination of two subsystems with various control parameters into single complex, in such a way we are able to realize Krasovskiy separation theorem [7], where the possibility of separate synthesis of informational and managing part of ACS is theoretically based. Developed system (fig.5) consists of fast internal circuit, synthesized according to separation theorem [7] in deterministic formulation with ARMABIS-regulator. It gives robust properties to the system and is oriented towards stabilization of complex index of dynamic behavior of TP and more inertial outer circuit, which provides calculation of setpoint correction taking into account the dynamics of change of proxy initial indexes (in the fig. 5 as proxy indicator there used the temperature in 24 vacuum-chamber).

ACSTP (fig.5) includes the following functional units: FNK- fuzzy-neural controller, which functions on the base of production rules copy and logical deduction of neuro-fuzzy emulator of reserve dynamics of control object; FNN1 - neuro-fuzzy emulator of reserve dynamics of an object; FNN2 –emulator of Jacobian system, which functions on the base of adaptive algorithm of self-organization of fuzzy neural network of Vang- Mendel; BA-adaptation unit of parameters of production rules on the base of terms of security of adoptive properties of the system, set law of control and minimization of integral performance criterion of control.

Operation algorithm of the developed adoptive ARMABiS-SAR with neuro-fuzzy correction system of setpoints:

0°.With system start there set the following values: limit Euclidean distance r between the elements of input vector $\bar{x}$ and center of cluster $c_{lk}(k)$ of corresponding tuple according to the attributes (c, w, L) the correlation of parameters of membership functions, where the input data will belong to corresponding therm; limiting error of approximation ε;

1°. The following steps (1-2) refer to adjustment of emulator of reverse dynamics and identifier of Jacobian system, correlation of which is $cluster = < c, w, L >$ and $cluster\_2 = < c', w', L' >$ respectively.

As the system is in the parameter adjustment mode, at the output controller there formed the signal according to optimizing algorithm of emulator membership function.

1.1 On the base of the first pair of data $< x_1, y_1 >$ there created the first tuple according to attributes (c, w, L) correlation $cluster\_2 = < c, w, L >$ of cluster parameters with center $c_1 = x_1$. It is accepted that $w_1 = y_1$ and cardinal number $L_1 = 1$.

1.2 There created the first tuple with attributes (c, w, L) according to input data $< y_1, x_1 >$ correlation $cluster = < c, w, L >$ of cluster parameters with center $c_1 = y_1$. It is excepted that $w_1 = x_1$ and cardinal number $L_1 = 1$

2°. After reading of k-th test pair $< x_k, y_k >$ and $< y_k, x_k >$ (for emulator of reverse dynamics) there calculated the distances between input vector and all the existing centers for $l = 1,2,..., M$.

2.1 If $\|x_k - c_{l_k}\| > r$, than there created new tuple according (c, w, L). In this case $c_{M+1}(k) = x_k$, $w_{M+1}(k) = y_k$, $L_{M+1}(k) = 1$. Parameters of before created clusters do not change, i.e. $w_l(k) = w_l(k-1)$ $L_l(k) = L_l(k-1)$ for $l = 1,2,..., M$. Clusters amount M increases per unit ($M \leftarrow M + 1$), cardinal number of correlation on this stage is not restricted.

If $\|x_k - c_{l_k}\| \le r$ than the data is included into l_k-th cluster, parameters of which are specified according to classical adoptive algorithm of self-organization of neuro-fuzzy network of Vang-Mendel.

2.2 If $\|y_k - c_{l_k}\| > r$ than there created new tuple according to attributes (c, w, L) of correlation. In this case $c_{M+1}(k) = y_k$, $w_{M+1}(k) = x_k$, $L_{M+1}(k) = 1$. Parameters of created before clusters did not change, i.e. $w_l(k) = w_l(k-1)$ $L_l(k) = L_l(k-1)$ for $l = 1,2,..., M$. Clusters amount M increases per unit ($M \leftarrow M + 1$),cardinal number of correlation on this stage is not restricted.

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3°. The system is transferred into on-line mode of parameters adjustment of production rules according to algorithm of neuro-fuzzy controller adaptation in order to minimize objective function.

4°. Alongside with the initialization of step 3, there takes place removal of non-informative parameters relation of clusters of emulator of reverse dynamics.

5°. Formed control response at system stability is checked [6].

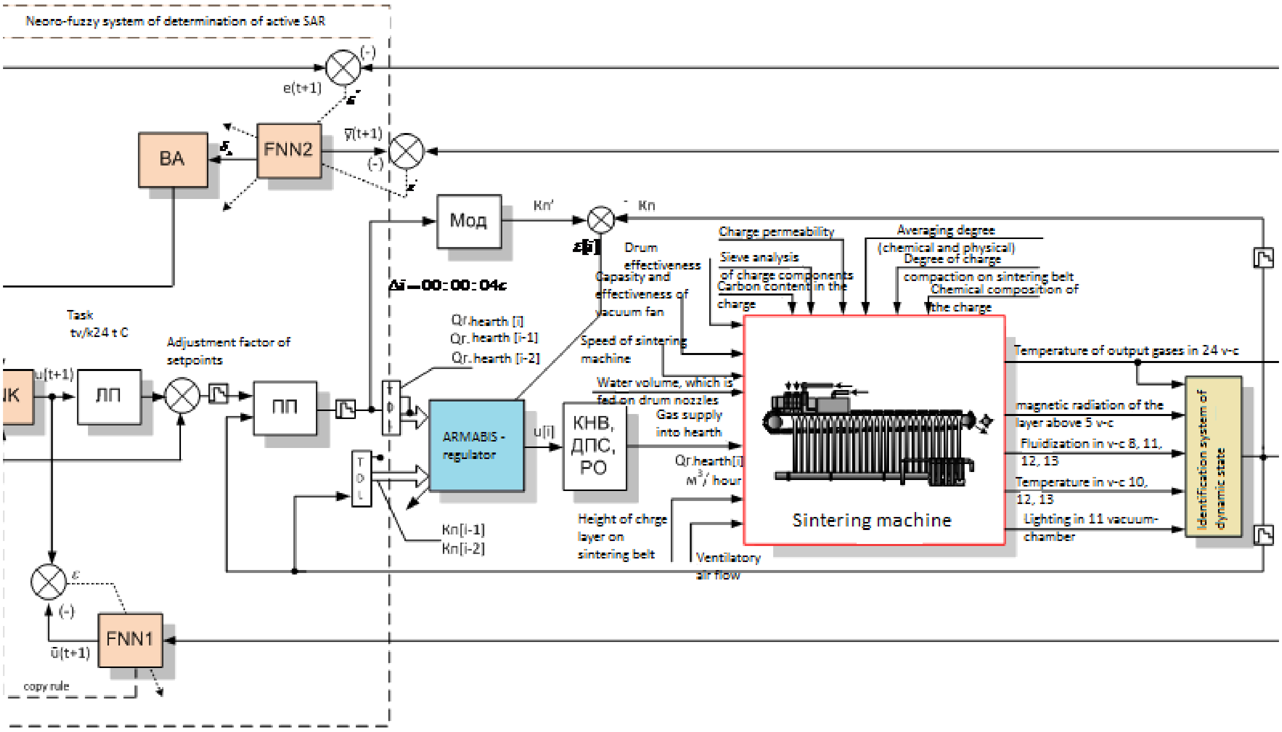

Figure 5. Structural scheme of adoptive ARMABIS-SAR of charge surface under ignition furnace with neuro-fuzzy system of determination of active SAR

6°. The condition of reaching of limiting error is checked and working mode with On-line parameters adjusting of production rules is continued, otherwise the system is transferred to the regime of parameters adjusting of production rules (step 2.2).

Conclusions

In such a way suggested ACSTP of agglomeration is based on the application of the developed methods of synthesis of adoptive neuro-fuzzy subsystem, which fulfills current estimate of state vector in random medium of system operation and robust adaptive ARMABIS-regulator, which uses current estimate of state vector and current estimate of parameters of control object models. Synthesis concept of neuro-fuzzy systems of control is developed; its advantages and disadvantages allow to conclude that effectiveness of application of fuzzy-set theory and fuzzy subsystems in adoptive ACSTP is proved only in the case when fuzzy elements are used at higher hierarchical levels of multilevel SAR and their action cannot imply the output of control system beyond stability limits.

According to developed adoptive ARMABiS-SAR, neuro-fuzzy subsystems are used as superstructure to the local ones and fulfill the functions of adjusting of setpoints on the base of analysis of change dynamics of Jacobian system according to initial parameters of concrete ARMABiS-SAR. The last allows to restrict working range of control response variation taking into account observance of stability terms of the system and allows to fulfill current estimate of state vector in random medium of system functioning and quickly determine effective control channel taking into account technical-and-economic criteria.

Refernces

1. Application 63-33527, Japan MKI4 C22 B1/20. The way of control of ignition surface while crude ore agglomeration. Mikki Kacuyuki, Hakobidzaki Hideaki. Published 13.02.88.
2. Hamada Katsushige, Murai Tatsunori, J Jyoko Tadatsugu, Makamura Yuji, Morioki Keiji. (1992). Progressive ACS TP of agglomerative process. *Sumitomo Metals.* 44, No 1, p.p.151–160.
3. Korotich V. I. , Frolov Ju. A., Bezdezhskiy G. N.. *Aglomeracija rudnyh materialov* [Aglomeration of crude ore]. Ekaterinburg, GOU VPO UGTU UPI, 2003, 400 p.
4. Shchokin V. Experimental proof of electromagnetical radiancy theory of sinter charge. Development of ore field. Kryvyi Rih, 1999, No 67, p.p. 93-97.

5. N. V. Fedorovski, V. V. Danshin, V. I. Gubanov, R. I. Sigua. Avtomatizacija fabrik okuskovanija zheleznyh rud i koncentratov [Automatization of sintering of iron ore and concentrates plants]. Moscow, Metallurgiya, 1986, 339 p.
6. Shchokin V., Tkachuk V. (2014). Automatization of agglomerative production on the base of application of Neuro - Fuzzy controlling systems of the bottom level. *Metallurgical and Mining Industry*. No 6, p.p. 32–39.
7. Krasovskiy A. A., Bukov V. N., Shendrik V. S. *Universalnye algoritmy optimalnogo upravlenija nepreryvnymi processami* [Universal algorithms of optimal control of continuous processes]. Moscow, Nauka, 1977, 272 p.