System of process control for associated concentrate nanostructures production

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Abstract. The article presents developed automated process control system of the associated concentrate nanostructure production and the technical and system software, which includes a local process control system and software and hardware that are shared by the technological purpose. The main technological parameters controlled and managed by the APCS are reflected. The article presents the composition of lower-level control system of the plant for production line nanomaterial products, software and hardware complex heat-exchanger and coagulator. The requirements to the functioning modes of the APCS ACNP are presented. It is shown that the developed automated control system of technological process of associated concentrates nanostructures provides the opportunity for the system structure development, including the increase in the number of measurement points using a margin of 10% on signals of input / output. While software and information support of automated control systems CNAA involves changing the configuration of the system and possibility of its expansion through modernization and the introduction of new tasks (complexes of tasks and algorithms).

1. Introduction
The existing methods of production of nanostructures in the form of spherical silicon dioxide and fullerene-like carbon require special power, increased consumption of raw materials and energy [1-6]. Microsilicon is an integral by-product of silicon and ferrosilicon production [7-12]. It is obtained by the purification of gaseous emissions of the metallurgical industry, which improves the environmental situation at the plants, but creates a significant problem of utilization [13-21]. In Norway, after the official adoption of technological decisions in the form of standards and relevant specifications, microsilica was used as a modifying agent in concrete since 1980 [18]. At present, nanosilica presents the greatest interest to researchers as a modifier of the concretes strength and building mixtures [19-20]. For the mass use of nanomaterials, it is important to develop technological solutions for the creation of high-tech production. At the same time, the technology should be based on the selection of nanostructures in the form of fullerene-like carbon particles and spherical silicon dioxide, not microparticles.

The analysis shows that it is appropriate to use the associated technology of obtaining concentrates of nanostructures in the form of fullerenelike carbon by trapping nanosized dust from electric arc ore-thermal furnaces in the production of silicon as well as enrichment and conditioning of concentrates from stale stamicarbon gas cleaning systems sludge [22-23].
In this paper, an automated process control system of the associated concentrate nanostructure production (APCS ACNP) is considered.

2. Purposes of the development of APCS ACNP

In the development of APCS ACNP as the main objectives were taken:

- operational control and decision-making management based on analysis of the incoming information about the state of the process;
- prevention of erroneous actions of personnel;
- automatic prevention of emergency situations;
- selection of technological modes based on rapid adjustment modes according to laboratory tests and on the indications of process analyzers that are installed on the flows;
- adaptability to possible changes in the process and control algorithms, reducing the time spent on the orientation of personnel in the regime and operational environment, timely detection of problems and deviations;
- analysis of technological parameters and forecasting of optimal equipment operation modes.

In addition APCS ACNP must be operated in the following modes:

a) The automatic mode is the main operation mode at serviceable technical means and a normal condition of technological object of management. This mode includes all the functions of the upper and lower levels of the system, control functions, automatic regulation, blocking. In this case, the possibility of operative operator’s intervention in the operation of the system is provided.

b) Remote mode - auxiliary control mode of the system. This mode allows the operator-technologist remotely (from the operator's workplace) controlling individual elements of electrical equipment in accordance with the priority and level of access. In this mode all functions of control, management and blocking of the devices which are not brought to the mode of remote control are automatically carried out.

c) Local "manual" mode – auxiliary mode of the system. It is included by technological personnel at the time of preventive or repair work on the object of. This mode provides a level of control parameters (due to indicating instruments, set in place, the operator panel with control parameters fixing on the server), alarm and local control of basic drives and mechanisms.

The operator's workstation shall provide the following modes of operation:

a) automatic;

b) automated.

In automatic mode, the operator's workstation must perform the following tasks:

a) collection, processing and presentation of information for process and equipment control and management;

b) identification and signaling of equipment malfunctions;

c) processing and archiving of operational information on the state of technological equipment and technological process controlled parameters values;

d) diagnosis of the work of APCS TP;

e) synchronization of a single astronomical time with the APCS TP for obtaining silicon in electric arc furnaces.

Automated workstation operation should provide the operator with the following tasks:

a) process equipment management;

b) selection of regulators operating modes (manual, automatic);

c) selection of required information;

d) work with archival data and background information;

e) changes of settings of regulators.
3. Automation object
The automation objects presented in Figure 1 to be considered in general case:

a) installation of process gases from ore-thermal furnaces thermal energy extraction;
b) nanosized dust pre-coagulation installation;
c) nanodispersed dust capture module;
d) nano-containing products production line shop.

![Technological scheme of dust capture from ore-thermal furnaces gases](image)

Figure 1. Technological scheme of dust capture from ore-thermal furnaces gases:
1 - gases from the OTF; 2 - heat exchanger; 3 - coalescer; 4 - unloading in special vehicles; 5 - bag filter; 6 - transportation system; 7 - exhaust fans; 8 - release of purged gases into the atmosphere; 9 - the nanomaterial products shop.

| №  | Equipment                      | Purpose                                                                                     |
|----|--------------------------------|--------------------------------------------------------------------------------------------|
| 1  | Receiving hopper               | Initial dust auger feed in repulper                                                         |
| 2  | Water container                | Storage and supply of water in repulper                                                     |
| 3  | Regulator                      | Mixing the initial dust from the receiving hopper with water                                |
| 4  | Flotation machine              | Fullerene-like flotation of carbon particles and deposition of spherical silica              |
| 5  | Capacity for flotation agents  | Storage and supply of flotation agents (kerosene, pine oil) to the flotation machine        |
| 6  | Drum vacuum filter             | The flotation machine chamber product primary drying                                         |
| 7  | Calcination rotating oven      | Calcination of the machine product chamber                                                   |
| 8  | Reactor                        | The hydrofluoric acid washing of the foam product from the flotation machine                |
| 9  | Acid capacity                  | Storage and supply of hydrofluoric acid to the reactor                                       |
| 10 | Water capacity                 | Storage and supply of water to the washing foam product tank                                |
| 11 | Revolver vacuum filter         | Acid and foam product separation after reactor                                              |
| 12 | Foam product washing tank      | Water washing of the dried foam product from the flotation machine to remove the reaction residues with hydrofluoric acid |
| 13 | Coagulator                     | Condensation of solid particles under the influence of coagulant                            |
| 14 | Coagulant tank                 | The coagulant flow into the coagulator                                                      |
| 15 | Revolver vacuum filter         | Primary drying of the carbon-containing product from the coagulator                         |
| 16 | Oven                           | Carbon-containing product calcination                                                       |
| 17 | Packing line                   | Products packaging                                                                          |
### Table 2. Shop equipment for the nanocarbon line products manufacturing.

| Object of control                      | Controlled parameter                              | Value unit | Parameter value |
|----------------------------------------|--------------------------------------------------|------------|-----------------|
| **Vibrations**                         |                                                  |            |                 |
| Main exhausts bearings                 | The running gear bearings vibration              | mm/sek     | 0-7,1           |
| **Temperature**                        |                                                  |            |                 |
| Flue gas at the heat exchanger inlet   | Gas temperature                                 | 'C         | 150-200         |
| Flue gas at the outlet of the heat exchanger | Gas temperature                           | 'C         | 90-140          |
| Piping at the inlet of the heat exchanger | The temperature of the accumulative fluid       | 'C         | 20-30           |
| Pipeline at the outlet to the heat exchanger | The temperature of the accumulative fluid       | 'C         | 80-100          |
| Flue gas at the entrance to the coagulator | Gas temperature                              | 'C         | 0-350           |
| Flue gas at bag filter inlet           | Gas temperature                                 | 'C         | 0-300           |
| The flue gas duct before the exhaust   | Gas temperature                                 | 'C         | 0-300           |
| The ducting after the exhaust          | Gas temperature                                 | 'C         | 0-250           |
| Main exhaust bearings                  | bearing lubricant temperature                   | 'C         | 0-90            |
| Chamber product temperature            | Temperature in rotary kiln                      | 'C         | 600-650         |
| The carbonaceous product temperature   | The temperature in the furnace                  | 'C         | 350-400         |
| **Pressure**                           |                                                  |            |                 |
| Flue gas at the heat exchanger inlet   | Gas pressure                                    | kPa        | 1,5-2,0         |
| Flue gas at the outlet of the heat exchanger | Gas pressure                                   | kPa        | 1,5-2,0         |
| Coagulator                             | Differential pressure                           | kPa        | 3,4-4,3         |
| The flue gas duct before the exhaust   | Gas pressure (vacuum)                           | kPa        | 4,9-6,3         |
| The ducting after the exhaust          | Gas pressure (vacuum)                           | kPa        | 2,6-1,2         |
| Flotation machine                      | Air supply line pressure                        | MPa        | 0,2-0,4         |
| **Expense**                            |                                                  |            |                 |
| Piping at the inlet of the heat exchanger | Consumption accumulation of fluid             | m³/h       | 140-150         |
| Flotation machine                      | Flow rate of air supplied to the flotation machine | m³/h | 1,4-1,5 |
| Water container                        | The consumption of water from network           | m³/h       | 0,2-1,3         |
| **Level**                              |                                                  |            |                 |
| Bag filter                             | The level of collected dust                     | min-max    | 10-90           |
| Coagulator                             | The level of collected dust                     | min-max    | 10-90           |
| Receiving hopper                       | Raw material level                              | %          | 20-80           |
| Water container                        | Water level                                     | %          | 70-85           |
| Regulator                              | The pulp level                                  | %          | 60-85           |
| Capacity for flotation agents          | The level of flotation reagents                  | %          | 25-95           |
| **Concentration**                      |                                                  |            |                 |
| The clean flue gas after bag filter    | Dust concentration in purified gases            | mg/ m³     | 0-50            |
| Shop for the production of nano-       | Concentration of SiO2 dust in the working area air | mg/ m³ | 0,4-0,5 |
| containing products                    |                                                  |            |                 |
| **Density**                            |                                                  |            |                 |
| Repulper                               | The pulp density of repulper                    | kg/ m³     | 1060-1120       |
| **Humidity**                           |                                                  |            |                 |
| Packing line                           | Humidity SiO₂                                    | %          | 2-3             |
More detailed description of the process gases thermal energy recovery unit is presented in [24], a description of the pre-coagulation unit and the nanodispersed dust capture module is presented in [15].

Shop for the nano-containing products line production includes a number of equipment presented in table 1. Table 1 also presents the purpose of the shop equipment for the nanocarbon line products manufacturing.

Table 2 presents the main technological parameters characterizing the technological process of associated production of nanostructures concentrates.

Due to the fact that automation objects are separate processing facilities, in this regard, APCS ACNP includes a local process control system and program-technical complexes (PTC), partial for technological purposes:

a) heat exchanger PTC;
b) PTC coagulator nanosized dust;
c) an automated trap control system module of nanodispersed dust;
d) automated production control system of nano-containing products.

Omitting the details of obtaining nanostructures concentrates physical and chemical processes, we consider the technical and software aspects and controlled automation objects parameters.

4. Technical aspect of the system
The lower (field) level of the software and hardware complex of the heat exchanger consists of the following purchased devices and automation equipment:

- accumulating liquid temperature sensor at the inlet of the heat exchanger;
- accumulating liquid temperature sensor at the outlet of the heat exchanger;
- gas temperature sensor at heat exchanger inlet;
- gas temperature sensor at the outlet of the heat exchanger;
- gas pressure sensor at heat exchanger inlet;
- gas pressure sensor at the outlet of the heat exchanger;
- pressure sensor (discharge) of electrolysis gases in the flue at the inlet to the FCM;
- accumulating fluid flow sensor in the heat exchanger;
- control accessories in complete with electric actuators.

Field-level program-technical complex of coalescent nanodispersed dust consists of following purchase devices and automation sources:

- gas temperature sensors at the inlet of the coagulator;
- differential pressure sensors in the coagulator;
- collected dust level sensors in the hopper coagulator;
- control accessories complete with electric actuators.

Collection and processing of signals at the lower level is carried out with the help of Siemens Simatic ET-200 purchased distributed input/output station. The control station consists of the following purchased elements:

- Siemens SM 331, Siemens SM 332 modules analog signal processing input/output 4-20 mA (+2 - +10 In) DC signal processing transducers;
- Siemens SM 321, SM 322 Siemens - modules of discrete signal processing input/output 24 V DC;
- Siemens Simatic IM 153-1-interface modules for communication between Siemens Simatic ET-200 distributed input/output station and Simatic S7-1200 base controller unit via PROFIBUS DP network.

The control at the lower level should be carried out by Siemens Simatic S7-1200 PLC. The PLC is comprised of purchased items:
• central processor module CPU 1200C various performance modifications to supply a constant or varying current;
• communication module CM1242-5 to connect the controller to the PROFIBUS DP;
• 4-channel switch CSM 1277 for building Ethernet/Profinet network structures;
• PS 1207 stabilized power supply with input voltage ~ 120/230 V and output voltage =24V;
• operator panel TP 900 Comfort series Simatic HMI Comfort Panel, designed to visualize the modes of operation of the heat exchanger, documenting and storing information about the operation of the equipment, emergency situations and actions of operational personnel;
• additional components in the form of SIMATIC Memory cards, input signal simulators for debugging controller programs and buffer battery module.

The structure of the lower (field) level of the APCS of the nano-containing product line shop for the manufacturing includes the following purchased devices and automation:

a) thermoelectric temperature transducers for temperature control in furnaces;
b) electromagnetic flowmeters designed to measure and control the flow of water, acid, coagulant, pulp;
c) hydrostatic level gauges designed to measure the level of liquid reagents and water in containers;
d) radar level transmitters intended for level measurement and control in technological devices;
e) level switch designed for level monitoring in filters;
f) pH meters designed to measure the pH of hydrofluoric acid;
g) density meters designed to control the density of foam and pulp;
h) gas analyzers designed to monitor and alarm the FCM of hydrofluoric acid and SiO2 dust in the air of the working area;
i) hygrometers designed to measure and control the humidity of SiO2;
j) shut-off and control accessories complete with electric actuators designed to regulate the parameters of the process;
k) programmable logic controller (PLC) SIMATIC S7-300, designed to control the lower level;
l) stations of the distributed input-output ET-200M intended for information interaction with object of management and regulation of parameters of technological process;
m) the control station (CS) intended for PLC placement;
n) the control and management station (CMS), designed to accommodate the distributed input/ output station ET-200M;
o) stations of pumps control intended for control of pumps in the "manual" mode and the alarm of its functioning modes;
p) variable frequency equipment drive control station (VFEDCS) Danfoss designed to accommodate, ensure normal operation and visually monitor the operation of the PSU;
q) the compressor control station designed to control the compressor in "manual" mode and to signal its operating modes.
r) u) control stations for automatic lines including dispensers and packaging equipment.

The upper (Supervisory) level CNATP APCS consists of the following purchased items:
a) the workstation (WS) the operator-technologist intended for providing access to the measured and calculated parameters of technological process, control actions input implementation and control of their performance;
b) the technological server intended for storage of operational information and formation of archives;
c) arm shift supervisor intended to implement the functions of APCS ACNP control and management in general, accounting and documentation formation;
d) engineering station, designed to perform work, to configure and maintain operation of the APCS ACNP in general;
e) network equipment.

The top-level equipment management and control lower-level control system station of the plant for nanomaterial line products production are located in the operator's room.
5. Conclusion
The developed automated process control system for the nanostructure production of associated concentrates provides the possibility of developing the system structure, including an increase in the number of measurement of points, using a margin of 10% for input-output signals. At the same time, the software and information support of APCS involves changing the configuration of the system and the possibility of its expansion through modernization and the introduction of new tasks (complexes of tasks and algorithms).

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