MODERN CONCEPTION OF THE HYDROTRANSPORT SYSTEMS PROGRESS IN THE SEA MINING

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The actuality to develop the Experimental Automatic Control System (EACS) of sea mining enterprise (SME), together with sea equipment and technology for deep-water mineral deposits development, is shown. The necessity to take into consideration influence of modern EACS SME on parameters of equipment and technology for deep-water deposits development is grounded, although the back influence is evident. The strategy and basic principals to project the EACS SME, having as a part developed functional scheme of submarine equipment control subsystem, that complexly reflects the processes of mineral extraction from sea-bottom and their transportation to carrying vessel, are offered. This scheme is based on usage of functional model of technological equipment for bottom block and hydraulic lifting with high speed, that allows to enhance efficiency of submarine equipment work by optimization, regulation and stabilization of parameters, and also by concordance of elements working modes of the complex. The patented method to start up and stop the submerged equipment of SME, having increased reliability and efficiency in conditions of high depth, inscribes naturally in the scheme ideology. The set of scientific research programs is developed, which can be used as the basis to create the program calculation complex to control the main technological processes of SME. The presented elaborations are the basement to develop the technical task for projecting of Experimental ACS of sea mining enterprises.

Each year the reserves of many non-ferrous metals, being extracted from continental deposits by traditional method, are steady decreasing. The modern stage of development of oceans mineral potential is connected with experimental output of Ferrimanganese concretions (FMC). So, the projects to create the efficient methods and media to develop deep-water deposits are going to be of the most importance.

The article deals with actual problem of sea mining enterprises (SME) creating, which operation is mainly connected with multipurpose work of technologists, engineers and specialists in the field of control systems. The functioning of such complexes implies usage of unique high technology equipment in conditions of great depths. The efficiency of such equipment is basically determined by control technology. Today definite progress can be noticed only in the field of technical media development (hydraulic lifting systems and, partly, seabed harvesters). But low research activity is focused on forming requirements from the side of technologists and engineers to the control system, being developed.

However, questions of EACS SME development are actual even today, because their realization influences sufficiently the level of sea equipment and technology, also it requires more intellectual efforts and time. Based on experience in this field of many years, the authors suppose, that EACS’s SME are needed to be projected in the same time with development of technology and equipment, because its functionality and architecture will stress considerably on compatibility of units and aggregates being planned for application. In the other words, even if structure of ACS does not determine design of aggregates and functional units, but it influences at least their type, dynamic characteristics and, also, methods and parameters of adjusting.

The authors are convinced of, that technology, equipment and control system should correspond to the level of certain stage of deep-water mineral deposits development. They also should be taken into consideration only within system approach, when the parameters of every indicated direction set strict limitations on characteristics of the other ones. This statement points to the necessity of
coordination (taking into consideration the formulated requirements and limitations) on the international level of efforts by developers of different countries and national agencies, specializing in the certain direction, that will allow to increase the efficiency of fulfilled research through minimization of waste time and work.

ACS equipment should include above-water part, set on a vessel, and submersible part, set on elements of SME submerged structure. Besides, media providing testing of units, aggregates and devices of ACS on the stages of installation and operation should also be included in the control system. Today it is difficult to designate the terms of ACS putting to practical application. At the same time, new, qualitative and suitable in expansion solutions, which usage in ACS will entice developers to refuse previously selected equipment to the benefit of modern samples, arise every year in the automation media market. This situation may sufficiently limit development of ACS, because exchange of one technological element will lead to change or readjusting of elements getting in contact with it. So, it is necessary to follow module criterion, apart from supporting criteria of development being set de facto (in order to provide full needed functionality and reliability). The sense of such approach is to present ACS as a quite big number of interacting subsystems with high level of autonomy, in order to minimize influence of changes, being made in structure of any subsystem, on adjacent subsystems.

It is stressed in the article on development of experimental ACS (EACS) of sea mining enterprise, which will allow, in addition to experimental extraction of FMC, to work through problem aspects, to verify working ideas and hypotheses, also to compare the efficiency of contesting solutions.

EACS SME is intended for control of equipment to give a workout to mining technology, for reaching and supporting of FMC extraction technological parameters, for creating conditions of SME safe operation in all working modes and carrying out pull-down and restorative works. EACS SME is unique and non-linear system with great inertia of controlled processes [1]. EACS structure is highly complicated by realization in it a big quantity of adaptive models and algorithms of processes prognostication at speeded time scale. Besides, stabilization schemes of controlled processes and concordance of functional elements control parameters must be engaged in EACS [2].

In general view EACS SME may consist of a central coordinating subsystem (while realizing a centralized control approach) and following basic subsystems, interacting with it [3]:
- subsystem of Seabed harvester (SH) movement control;
- SH navigation subsystem;
- mining-preparation-lifting of FMC control subsystem;
- local systems of technological equipment control;
- subsystems of measuring information processing;
- subsystem of technical media diagnostics;
- subsystem of mineral dressing;
- subsystem of wastes collecting;
- subsystem of raw loading on ore transportation vessels.

The authors of article believe, that despite of the final architecture, EACS SME must obligatory include two connected subsystems: "central coordination subsystem" (CCSS) and FMC "mining-preparation-lifting control subsystem" (MPL SCC).

CCS in intended for the overall coordination and concordance of all technological links work. Physically this subsystem is based on computational net, disposed on a vessel, including Database control subsystem(s) (DBCS) for collecting and processing of information, going from other subsystems; operator terminals; programmed CAE-complex, realizing the speeded time models of interacting subsystems. The authors group is engaged in designing of that CCSS part, which is connected directly to MPL SCC. In particular, the computational net is presented by several computers of x86 and ARM architecture, connected by Fast Ethernet protocol. MySQL is used as DBCS. The data exchange with MPL SCC is fulfilled by ModBus protocol. The data is formed in XML-lines, in which the calls of server procedures by SOAP technology are built-in. The basis model "Dynamics of multiphase mixes movement", created and verified by authors in SolidWorks medium, forms the base of developed program complex, realizing the speeded time models. Today we have a basis model and also several models of speeded time for MPL SCC realized as add-in modules to SolidWorks system, and besides as independent databases, working separately from SolidWorks.

MPL SCC is responsible for processes control of mining, preparation for lifting and hydraulic lifting of FMC on a base vessel. The preparation to lifting includes washing off silt, crushing to optimal sizes and pumping over FMC through a flexible pipeline into a bunker-dozer, disposed on a technological platform. The common influence of FMC mining, preparation and lifting parameters has caused exactly the expediency to single out the minimal configuration of submarine equipment in SME structure, the control of which should be made by MPL SCC. It consists of the following:
- self-propelled seabed harvesters with based on them equipment for washing off sea-bottom sediments and FMC crushing to optimal sizes [3];
- pipe for pumping over FMC through a flexible pipeline (FP) into a bunker-dozer (BD);
BD with screw feeder and its auxiliary equipment, placed on technological platform;
- airlift or pipe hydraulic transportation system.
MPL SCC is intended for coordination of FMC mining, preparation for lifting and hydraulic lifting processes of FMC, technological equipment diagnostics, technological processes parameters control, technological equipment start-up and stop control, interaction with central coordination subsystem, technological process protocolling, operative analysis of production situations and giving recommendations on repair-restoration arrangements.

The structural scheme of suggested MPL SCC, having maximum favourable conditions for ACS (being the most problematic link) efficient work as a principle while providing coordination and concordance of all technological links, is shown on figures 1 and 2 [4]. Idea of the structure is distribution of functions and elements of MPL SCC to three hierarchical levels, where the results of upper level work are transmitted to the lower ones as mode parameters and limitations.

The problems of probable production situations analysis, diagnostics of efficiency and control of technological equipment reliability, regulation of production processes parameters are being solved within the developed structure, in order to minimize energy consumption and stabilize equipment rational working modes.

![Diagram showing the structure of MPL SCC](image)

**The 1st level. Response on outside commands of Central coordination subsystem (CCSS)**

- MPL SCC parameters adaptation to change of the whole working time of submarine equipment.
- Reconfiguration and adjusting of MPL SCC parameters while obtaining the corresponding command from CCSS.

**The 2nd level. Control of reliability and efficiency**

- **Control of technological equipment**
  - Prognostication of accidents development
  - Technological equipment diagnostics
  - Prognostication of controlled processes stability
  - Equipment maintenance and restoration
  - Support of equipment installation and dismantling
  - Protocolling of equipment work and refusals
  - Emergency stop of equipment

- **Control of the EACS media reliability**
  - Testing of EACS equipment
  - Testing and restoration of computational process
  - Control of command-measuring information reliability
  - Protocolling of EACS equipment refusals/errors and exceptions generating
  - Reserve data convine
  - Blocking of error CCSS commands or request for their execution confirmation

To the 3rd level

**Figure 1. Consolidated structural-functional scheme of MPL SCC of experimental ACS of sea mining enterprise. The first and the second levels**

The most of the second and the third blocks of presented scheme are developed by creating of main module net of command-measuring controllers (CMC), being based on microprocessors of ARM architecture. CMC provide control of computational circuits and sensors, also they make measuring transformations and two-direction transmitting of measuring information by connection lines [5]. Originally, CMC development fulfilled based on 16-digit RISK-microcontrollers made by Amtel and Microchip. But they were replaced by modern ARM-compatible chips made by Texas Instruments, Motorola and XScale companies, because the last ones have wider means for energy consumption and productivity regulation, adjusting, program code adaptation etc.
Figure 2. Consolidated structural-functional scheme of MPL SCC of experimental ACS of sea mining enterprise. The third level.
Besides, progressive programming technologies as JIT-compilation are fully being supported by Java and Net-compilers for ARM processors. Development of software for CMC based on the managed-code has allowed to save time by possibility of efficient and freely adopting of JIT-code on x86-compatible personal computers. CMC programming was carried out using C++ language, as the most flexible for this range of problems. The written programs have high level of universality, because of being compiled, whether to machine code for processors of x86 and ARM architecture or to JIT-code of Microsoft .Net Framework database, almost without changing of initial code. The data exchange between CMC is fulfilled by ModBus и ProfiBus protocols. ModBus is the most suitable due to its work over TCP transport protocol, that simplifies adjusting of distributed CMC in laboratory conditions.

Let’s proceed to description of each level. The first block is formed by "MPL SCC parameters adaptation to change of the whole working time of submarine equipment" block and "Reconfiguration and adjusting of MPL SCC parameters while obtaining the corresponding command from CCSS" block. The first block is intended for readjusting of technological process in accordance with new time duration of SME work, which may be changed in connection with emergency situation of global nature, for example, storm-warning. Tactic goals of EACS may be changed depended on mining complex working hours, that will influence first of all operation of MPL SCC. The second block serves for transmission and low-level execution of CCSS definite commands spectrum. For instance, refer to switching between the complex productivity mode, having minimal energy consumption, and maximum productivity mode.

The second “Control of reliability and efficiency” level solves the problems of control and prognostication of efficiency of technological equipment and EACS functional elements [6]. Information on condition and working modes of units and aggregates is transmitted here from all command-measuring controllers MPL SCC. At the second level the blocks are divided into two groups: "Control of technological equipment" and "Control of EACS media reliability”. Here condition and functionality of equipment are determined by special tests, also equipment efficiency and reliability indexes are forecasted.

The results of reliability and efficiency control problems solution are returned to CCSS for their visualization on operator terminals as recommended instructions on equipment maintenance and reservation. Also the results are transmitted to the third level as working modes limitations. The work of "Prognostication of accidents development" block is periodical request for information on technological equipment reliability, which is presented as input data for algorithms and models of SME equipment efficiency and reliability forecasting. Diagnostics of technological equipment (see corresponding block) is fulfilled by measuring circuits of EACS SME. Diagnostic information is transmitted to CCSS and is represented on operator terminals. It is also written to special databases and used in automatic circuits of response on equipment refusal. The “Prognostication of controlled processes stability" block is grounded on models work in speeded time. The "Equipment maintenance and restoration" block may be used both in automatic and automatized modes. Maintenance is mainly carried out by equipment lifting up to the ocean surface, using widely automatized means of installation and dismantling, included in the described subsystem. Restoration of equipment is generally fulfilled by aggregate method.

There is a necessity to control EACS own means, apart from SME units and aggregates efficiency control. Blocks of the second group are used for this purpose. The process of EACS equipment testing is periodic transmitting of test-letters to remote command-measuring controllers and following analysis of their execution. The “Testing and restoration of computational process” block refers mainly to software. Purposes of the block are computational resources control, quality of links between components, and also taking measures to restore EACS functionality after system falling out of steps. The “Control of command-measuring information reliability” block is densely connected with two above described blocks. Reliability of command-measuring information may be broken by interferences of different nature, erasing during information transmitting in long connection lines. Usage of coding stable to interference is provided in this block to prevent distortion of information. Reserve copying of experimental, intermediate and primary data is carried out automatically with set periodicity, that allows to restore efficiently the computational process in the case of calculation system damage.

The third level is divided on three layers of problems according to frequency and priority of their solution [7]. The first layer includes problems of control strategy identification, FMC stock control and throughput parameters optimization on minimal energy consumption criterion. The problem of strategy identification includes determination of whole working hours of SME submerged part (Tω), taking into consideration economic profitability and different time limitations. The productivity on solid part is determined based on just mentioned (m3). The control of solid material stock in technological lines is intended to provide stable, uninterrupted FMC supply to lifting from interrupted, irregular FMC feeding by SH. It is solved with help of a bunker-
dozer, local regulation systems and, also, usage of prognostication models of solid inflow from SH and FMC dozing into transport pipeline (TP).

It is necessary to note, that “bunker-free” technology may be more efficient in some cases during mining of poor mineral deposits, due to less technological operations number, apart from impossibility of lifting throughput parameters optimization [8].

The “Hydraulic lifting block” includes the “Stabilization of lifting parameters” and “Regulation of pulp consumption in TP” sub-blocks, which are based on “Stationary and transitive lifting processes” models. The models of speeded time are realized integrated in CCSS program CAE-complex, as mentioned above.

“Model of hydraulic lifting transitive processes” is used to determine the parameters of non-stationary modes within the patented automatized method of SME submarine equipment start-up and stop [2]. Start-up and stop of Deepwater airlift hydraulic hoist (DAHH) are fulfilled on mixer of optimal submerging depth, when reaching coordination of transitive modes parameters of hydraulic lifting elements with bottom block working characteristics, in accordance with the developed method.

The method has the following benefits:

- realization of DAHH start-up immediate on the mixer, which submerging depth corresponds to the maximum efficiency factor in the working mode;
- control of DAHH start-up process is carried out in automatized mode in complex with transitive modes in mining equipment elements of bottom block;
- reliability of start-up procedures and stability to different disturbances are guaranteed;
- DAHH start-up duration is provided taking into consideration daily task of mineral raw materials lifting.

The method is realized according to algorithms given on figures 3 and 4, being bound to position of lock-regulation fitting (figure 5).

The following is taken as the initial condition before the start-up: SH is ready on the initial position, the compressor is switched off, the screw and HS pump drives are switched off, slide-valve V3 is shut off.

The principle of developed start-up procedure includes preliminary pressure decreasing in the mixer through the following operations execution.

1. The compressor is forced to max. productivity
2. Lifting of the last solid portion to TP outlet
3. Compressor Off
4. Compressor is forced to max. productivity
5. Lifting of the last solid portion to TP outlet
6. Compressor Off

The end

The following is taken as the initial condition before the start-up: SH is ready on the initial position, the compressor is switched off, the screw and HS pump drives are switched off, slide-valve V3 is shut off.

The principle of developed start-up procedure includes preliminary pressure decreasing in the mixer through the following operations execution.

1. The beginning
2. SH On, HS pump On
3. Synchronization of processes (t2 delay)
4. \( p_{\text{in}} > p_{\text{max}} \)?
5. No
6. Open \( V_1, V_2 \), K. On
7. Water pushing out pipelines
8. Close \( V_3, V_7 \), Open \( V_5 \)
9. Air bulbs lifting till going off TP
10. Open \( V_5 \), Water acc. in TP
11. The screw is On
12. First portion of SM lifting to LP outlet
13. The end

The end

The following is taken as the initial condition before the start-up: SH is ready on the initial position, the compressor is switched off, the screw and HS pump drives are switched off, slide-valve V3 is shut off.

The principle of developed start-up procedure includes preliminary pressure decreasing in the mixer through the following operations execution.

1. The beginning
2. SH Off
3. HS release from solid material
4. HS pump Off
5. Bunker release from solid material
6. Screw Off
7. NSLP?
8. No
9. Compressor is forced to max. productivity
10. Lifting of the last solid portion to TP outlet
11. Compressor Off
12. The end
Parallel execution of operations on raw material preparation and transportation is provided in order to decrease the start-up duration. Process of the bottom-block preparation for transportation includes accumulating in BD of some FMC amount \( M_0 \) to the moment when the airlift is ready to transport the pulp. Duration of the airlift preparation process may be, according to preliminary estimation, whether less or equal to the bottom block preparation process. So, the “delay duration” \( t_d \), on which one need to shift the beginning of the airlift start-up relative to the beginning of the bottom block start-up, is calculated in the algorithm.

\[
t_p = \frac{m_{\text{BPR}} - m_b}{m_{\text{BPR}}} - t_e - t_g - t_v,
\]

where \( m_{\text{BPR}} \) — medium mass throughput of the bunker filling with solid material; \( m_b \) — mass of solid material in the bunker; \( t_e \) — duration of water pushing out from pipelines through the lower TP section; \( t_g \) — duration of water acceleration in feeding pipe; \( t_v \) — total duration of slide-valves switching.

Not less important benefit of the developed method is a possibility to use “The next start light procedure” (NSLP). The sense of NSLP is to stop submarine equipment in such a way, that pressure in the mixer is less than the maximum pressure created by compressor. It will allow to fulfill the next start-up through light procedure (direct feeding of compressed air to the mixer without preliminary procedure of water pushing out TP). It is made by shutting down \( V_2 \) slide-valve before compressor switching off during stop procedure, that leads consequently to reducing the water column height in TP, and, so, pressure decreasing in the mixer.

The problem of decreasing of transitive processes duration in sea mining equipment elements has been solved within the developed method, due to simultaneous carrying out of hydraulic lifting and bottom block start-up operations and also realization of the next start light procedure.

Now return to MPL SCC scheme. The question of the given blocks on all levels requires taking into detailed consideration. On the first level, the duration of work within twenty-four hours of SME submerged part \( t_1 \) is determined, being limited by solution results of “MPL SCC parameters adaptation to change of the whole working time of submarine equipment” and “Reconfiguration and adjusting of MPL SCC parameters while obtaining the corresponding command from CCSS” problems. On the second level, \( t_2 \) time within current twenty four hours is determined, being limited by the problems of reliability control and efficiency. Obtained \( t_1 \) and \( t_2 \) values are directed to a comparison block, where one takes the lesser of values. After that the hour’s productivity on solid material \( m_s \) is calculated based on daily economic profitability.

So determined value \( m_s \) is transmitted to SH productivity regulation block, having this parameter as basic one. Inside this block, \( m_s \) is conformed to the observation vector \( X_V \), coming from the Deepwater navigation subsystem (DNSS), defining landscape features and density of concretions bedding. DNSS is a separate subsystem, interacting with MPL SCC, and it is going to be developed within separate research work in the nearest future. Real productivity \( m_R \), generally being different from the given productivity, is calculated based on shift of concordance of \( m_s \) and \( X_V \). The problem of SH root forming is solved in the same time with SH productivity control, providing maximum full extraction from current zone. Information vector \( X_{SH} \), including SH movement characteristics (speed, direction etc) is provided as back connection in order to increase the precision of navigation model functioning. The value of current real productivity \( m_R \) is measured and transmitted then to the pulp regulation block in FP and to the model of solid material inflow from SH, because, as mentioned above, SH productivity regulation block can not provide guaranteed given productivity \( m_s \). The pulp regulation block in FP, in cooperation with static and dynamic FP and pump unit models, provides necessary throughput of FP for FMC pumping over bunker. The model of solid inflow from SH prognostication is formed from combination of \( m_s \), \( m_p \), \( X_P \) parameters and the current pulp throughput in flexible pipeline \( Q_{FP} \). Information vector \( X_{FP} \) (prognosis of solid material stock in bunker-dozer) is transmitted to FMC dozing model, where, based on \( X_{FP} \) and information of solid material stock in
bunker-dozer, setting values of test stock within limitations of medium productivity, such values of stock and productivity are calculated, that provide uninterrupted operation of hydraulic lifting, if solid material inflow from SH is varied. The outlet of FMC dozing model, within which the optimization problem of pulp transportation parameters is solved on criterion of minimal energy consumption, is \( U_{OZ} \) vector, defining limitations on current productivity of hydraulic lifting.

Control vector \( U_{OZ} \) is transmitted to the block of hydraulic lifting parameters stabilization and, in the same time, during solving of the optimization problem, is transformed to corrective vector \( U_{OP} \), which is also transmitted to the stabilization block. The information on energy consumption of hydraulic lifting and its working mode current parameters is transmitted from local regulation system to the block of throughput parameters optimization. Optimizer, setting test values of throughput parameters (throughput and density of hydraulic mix), determines such their values, when the energy consumption of lifting process is minimal. The correction of these parameters, taking into consideration \( U_{OZ} \) and \( U_{OP} \) vectors with following transmitting to blocks of pulp throughput and density regulation as control signals, is fulfilled. \( U_{OP} \) vector is also transmitted to SH productivity regulation block for the following changing of SH productivity, in case if hydraulic lifting, working in optimal mode, does not provide transportation of required pump amount.

DIRECTION OF FURTHER RESEARCH ACTIVITY AND CONCLUSIONS

The subject of further research work is revision of missing modules of program-calculation CAE-complex and its beta-testing in different hardware configurations of central coordination subsystem of experimental ACS and submarine equipment control subsystem of sea mining enterprise.

Presented materials give just part of information on wide range of problems, connected with projecting and operation of sea mining enterprises. The group of authors, working in this direction for more than 30 years, is aware of complexity and many aspects of set problems, and also of many stages of their solution. But the authors think, that publishing of intermediate results is made at the proper time, because, by analogy with space equipment development, theory of this question should take the lead over practice. Besides, theoretic works have been powerful stimulus for practical realization of some design ideas, taking into consideration thorough study of complex physical phenomena. The authors group has in total more than 150 inventions in the field of sea mining industry, confirmed but patents of Ukraine and other countries. In particular, hybrid sets of principally new type, combining advantages of pump and airlift versions, feature enhanced technical-economic results, use efficiently energy accumulated by ocean and low-temperature potential of deep water. There are inventions, apart from hydraulic transport questions, in the fields of mineral dressing, using alternative sources of energy and reducing of technogeneous influence of industrial plants on submarine flora and fauna with purpose to minimize ecological damage [8].

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