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Automation of the production process of the cluster pumping station: justification for controller selection

Automatización del proceso de producción de una estación de bombeo de clúster: justificación para la selección del controlador

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ABSTRACT:
The paper discusses the methodology for selecting technical means of automation of a cluster pumping station, in processes that have to do with the oil industry, including a description of its technological process, the purpose and structure of automation systems. Justification of the choice of the controller and its modules is carried out, as well as the the calculation of energy consumption
Keywords: Automation, production process, cluster pumping station, controller

RESUMEN:
El documento discute la metodología para seleccionar los medios técnicos de automatización de una estación de bombeo de clúster, en procesos que tienen que ver con la industria petrolera, incluida una descripción de su proceso tecnológico, el propósito y la estructura de los sistemas de automatización. Se justifica la elección del controlador y sus módulos; Se realiza el cálculo del consumo de energía.
Palabras clave: Automatización, proceso de producción, estación de bombeo de clúster, controlador

1. Introduction

The enterprises of the oil production branch carry out a complex set of production processes for oil and gas extraction, transport, primary treatment, storage, and external pumping.

In the process of oil production, the formation pressure drops, so there is a need to increase it. For this purpose, cluster pumping stations (CPS) are used as the key unit of the formation pressure maintenance system (FPM) of the oil field.

CPS's production process has two stages: water treatment and injection into the formation; control functions on CPS's production equipment are carried out at each stage. Such functions include production parameter monitoring and regulation, as well as timely notification of the personnel on deviation of the parameters from the rated values and prevention of emergencies, which is possible with the use of the hierarchical structure of the automated control system.

Instrumentation should comply with the production process requirements and provide reliable information about its progress. Processing of the received information and calculation of control actions at the average level are performed by the programmable logic controller in accordance with the developed algorithm and program.

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2. Methodology

2.1. Production of the block cluster pumping station

The largest percentage of oil recovery is provided at the fields with the use of water drive modes. But during the operation, the pressure in oil formations decreases and the oil production volume drops. Therefore, the method of formation pressure maintenance is widely used in the West Siberian fields to enhance oil recovery. For this purpose, special process equipment has been developed to ensure that water is supplied to forcing wells at a pressure exceeding the formation pressure.

Formation pressure maintenance system is formed by water conduits for oil-field water and block cluster pumping stations (BCPS). BCPS equipment includes: a block of pumping units, a block of auxiliary pumps, a power substation, and a manifold block. The water supply from the BCPS to the block of water distribution manifolds (WDM) located on well pads is carried out by high-pressure water conduits, while high-velocity water conduits, through which the water is supplied to pumping wells each having control head and underground equipment are used from WDM to wells [1].

2.2. Purpose of the automation system

Creation of any automation system should ensure optimal management of the production process, which is only possible if the process regulation modes are observed with the specified accuracy and failure-free operation of the equipment [2].

The cluster pumping station process equipment does not feature close location, so it requires a centralized control of all devices from the operator's room, automatic control and regulation of the main process parameters of units and tanks, alarming on deviations from the rated modes, support of emergency protection, archiving of the current information, formation of the process parameter change trends.

2.3. Structure of AS

The automation system structure should be selected taking into account the possibility of performing all the necessary functions which ensure optimal and safe production process. In accordance with the above automation volumes, a three-level structure of AS consisting of the lower, middle, and upper levels was selected.

The lower level which is formed by instrumentation, process parameter signaling devices, and actuators directly interacts with the production process. These automation means provide collection of information about the production process state, equipment performance and exert certain influence on individual units of the process chain, which allows optimizing treatment and pumping of water into the formation.

At the middle level of BCPS, software and hardware modules (blocks) for controlling the units and nodes of programmable logic controller (PLC), as well as the secondary process parameters control system devices are used.

The main task of the controller in the automation systems is collection and analysis of information about the current state of the unit; this information should be processed in order to form the control signals for the actuators, execution of a certain algorithm, and prepared before transferring it directly to the upper level. In addition to the above mentioned functions, the controller provides the possibility to perform control operations upon the operator's command.

The functions to be performed by the microprocessor controller in the BCPS automation system include:

• measurement and regulation of the process parameters in order to ensure and optimize the specified operating modes of the unit;

• control of serviceability, process equipment operating modes, remote control of the process equipment;

• execution of emergency protection and alarm system functions in order to ensure safe workflow;

• display and registration of information, drawing up of reports and records, archiving;

• support of communication with other levels of the system and communication with the other systems.

The system's upper level is usually formed by a workstation which is equipped with the appropriate software and allows the operator to remotely control the station's units.

The automation system's upper level ensures the following functions:

• receiving information from the controller about process parameters and equipment state with signal database formation;

• drawing up process parameters trends both in real time and in historical mode;

• operating control of the production process;

• archiving of lower level events, as well as the operator's actions [3].

2.4. Selection of the automation equipment

At the lower level, the automation system should ensure measurement of the parameters including pressure, temperature, vibration, gas content, and current. For this purpose, it is necessary to select sensors according to the measurement accuracy requirements, instrumentation measuring limits, ease of installation and maintenance, price, possible operation environment [4].

Besides, sensors, converters, and actuators used in the system have only electrical version and the required types of explosion protection, climatic design, and intrinsic safety.

Water supplied to the pumps should not contain any mechanical impurities; its purity degree determines the process conditions, its intensity, and pump’s service life. Therefore, the water should be treated in the filter block. Its contamination degree is determined by pressure difference on the pump filter, so this parameter should be controlled with the necessary accuracy. The pressure difference change on the pump filters is allowed within 0-0.1 MPa; the instrumentation should have the basic error of max. 0.15. A number of sensors, the characteristics of which are given in Table 1 comply with such requirements to process parameter and measurements accuracy.

Table 1

Characteristics of pressure difference sensors

	Metran-150 CD	**ZOND-10-DD-1162**
Measurement range, MPA	0,00004-100	0,00025-1,6

Temperature range	-10 ÷ 50°C	-10 ÷ 50°C
Output signal, mA	4-20 /HART	4-20 /HART
Accuracy class	0.15	0.25
Protection	IP66	IP50
Power supply, V	24-36	14-38

The performance characteristics of these devices are approximately the same, but Metran 150-CD pressure difference sensor has a higher accuracy class, so it was decided to use it.

Reliable operation of pumps depends on conformity of the pressure at its inlet to the nameplate characteristics. The limits of pressure variation at the pump inlet should range from 0 to 1.5 MPa and the absolute measurement error should not exceed 0.15.

A number of sensors can be used for this purpose. Their characteristics are given in Table 2.

Table 2
Characteristics of pressure sensors

	Metran 150 TG	**Rosemount 3051S**
Measurement range, MPA	0…100	0…68,9
Ambient temperature range,° C	-50…+70	-51...+85
Output signal, mA	4-20	4-20
Basic conventional error, %	±0,15	±0,055
Protection	Explosion-proof shell	Explosion-proof shell

The technical capabilities of these sensors are roughly the same; the Rosemount 3051S sensor has even a higher measurement accuracy, but considering advisability of using devices of the same brand for controlling the pressure at the pump inlet, Metran 150 TG sensor of explosion-proof version was selected.

The interface level in the GS-1 separator varies between 0.5-3 m. According to production standards, the level indicator should have the absolute error of not more than 5%.

The level indicators with the technical characteristics corresponding to the above requirements are given in Table 3.

Table 3
Characteristics of
the level indicators

	UZS-600	**Rosemount 2120**	**Sapfir 22-DU**
Measurement range, m	0,08-6	0,1-3	Up to 10m

Ambient temperature range,° C	From -40 to + 80	From -40 to + 80	From -50 to 120
Output signal, V	Relay, 24	Relay, 24	Relay, 24
Basic absolute error	±2	±1	±1
Protection	Explosion-proof shell; IP65 dust and moisture protection	Explosion-proof shell; intrinsically safe; IP66 dust and moisture protection	Explosion-proof shell; intrinsically safe; IP66 dust and moisture protection
Power supply, V	9	20-264	24-36

Technical capabilities of these sensors are roughly the same; the measurements range of UZS-600 is more convenient but it has a higher measurement error, so the Sapfir 22-DU indicator was selected.

To a large extent, centrifugal pump unit performance depends on condition of the bearings the temperature of which should not exceed 90C, so this parameter is measured continuously with the required degree of accuracy; the basic conventional error of the temperature sensors should not exceed 0.5 %.

Table 4 shows a number of sensors characteristics of which comply with the requirements to accuracy and conditions of bearing temperature measurement on pump units.

Table 4
Characteristics of the pump bearing temperature sensors

	TSM 320	**TSP JUMO**	**TSMU Metran-274**
Measurement range, °C	From 0 to 120	From -50 to +600	0-100
Ambient temperature range, °C	From -60 to +60	From -45 to +100	From -45 to +70
Output signal, mA	4-20	4-20	4-20
Limit of admissible basic conventional error, %	°0,5	°0,1	°0,25

Technical capabilities of these sensors are roughly the same; taking into account advisability of using devices of the same brand TSMU Metran-274 resistance thermal converter could have been used, but it was decided to apply TSM 320.

Since degassing is an important step in the water treatment process chain, safe workflow requires gas content control function in the system.

To measure the gas content level, possible options of devices were considered. They are given in Table 5.

Table 5
Measure of gas content level

Sensor name	**SKZ Kristall**	**STM-30**	**STG 1**

Measurement range	CH4 — 10- 20% of LFL CO — 20-100 mg/m3	0... 100% of LFL CH4 — 0- 5%	CH4 — 10- 20% of LFL CO — 0-200 mg/m3
Operating temperature	1…45°C	-40…50°C	-10…50°C
Alarm actuation time	CH4 — 15 s CO — 180 s	7 s	CH4 — 15 s CO — 45 s
Output signal	pulse	pulse	relay contacts

The system uses the STM-30 sensor which is widely applied in the production processes of extraction, processing, transport of gas, oil, and petroleum products in the fuel and energy complex, in the power generation at heat stations and state district power stations.

Exceeding the permissible vibration limits may lead to the pump unit failure; therefore, this parameter is subject to mandatory monitoring and indication. Emergency protection should be designed on the basis of its data. To measure this parameter, the system uses the IDV 2002-2 sensor which is a smart vibration sensor. It ensures control of vibration frequency, vibration acceleration, vibration rate, vibration displacement of the unit, which are the main vibration characteristics. The selected sensor has the following parameter ranges:

- frequency variation from 10 to 100 Hz;
- vibration acceleration variation from 0 to ± 10 G ± 5;
- vibration velocity variation from 0 to ± 800mm/s ± 5;
- vibration displacement variation from 0 to ± 2mm ± 5%.

The sensor converts the measured values in real time and transmits them to the control or monitoring systems of the user via standard interfaces. With this type of sensor, vibration control is performed in two mutually perpendicular axes.

The sensor is powered by a stabilized power supply with voltage of +5V ± 10% and power consumption of up to 1W. The ambient temperature variation ranges from -40 to 180 °C; IP67 case design allows using the sensor in corrosive media.

Consumption of water pumped into injection wells is an important process parameter for the system of formation pressure maintenance in the fields and it should correspond to the volume of this oil-bearing area development project, so BCPS controls it. For this purpose, a vortex ultrasonic water meter (SVU-200) with the measurement range from the lowest operating consumption value of 80 m3 to the highest operating consumption value of 200 m3 is used. The device has the accuracy class of 2.5 %, which is quite sufficient in terms of technology.

Oil pressure in the pumps should ensure accident-free conditions for their operation. To control this parameter, a number of options given in Table 6 were considered.

Table 6
Comparative characteristics of indicators

Parameter	**DM-2005**	**HS-210**	**SDU-M**
Country of manufacture	Russia	Taiwan	Russia
Accuracy class	1.5	1.5	1.5
Measurement range, MPA	0 – 2,5	0,05-1,55	0,02-0,6

Permissible error limit, %	±1,5	±1,5	±1
Measured medium	Liquid and gaseous media	Liquid	Liquid and gaseous media
Service life, not less than	10 years	10 years	10 years

For the use in the designed system, the DM 2005 sensor which is explosion-proof and measures the overpressure and vacuum pressure of liquids, steam, and gas was selected. The measurement results allow using them to control the external electrical circuits providing signaling and blocking. Depending on the field of application, the sensors can provide pressure measurement in the range from 0 to 160 MPa. Its accuracy class 1.5% meets the technology requirements.

Electric motor current is an important parameter for determining its performance, so this parameter is controlled by IPT-1 sensor. It converts the alternating current of the industrial frequency into direct current with the variation range of (4 - 20) mA and transmits it to a remote registration system via a two-wire line.

The sensor can be applied in a wide range of ambient temperature ranging from minus 45 to plus 60 °C, with relative humidity of up to 95% at temperature of plus 35 °C, atmospheric pressure of 460-800 mm Hg.

Electric actuators characteristics of which are given in table 7 are used for direct control of the degree of opening of the process valves and gate valves.

Table 7
Specifications of actuators

Name	**MEO**	**MEP**	**AUMA**
Torque range	6.3-10000 N · m	6.3-4000 N · m	10-32000 N · m
Output speed	-	-	4-180 rpm
Full stroke time	10-160s	10-160s	-

The system uses the MEP actuator which ensures changing the position of control valves and gate valves.

The actuator operation is controlled by electric drive control unit (EDCU 1) which uses variable resistance transducers or inductive displacement pickups and position switches. They monitor the degree of opening in percentage and display it on a seven-segment LED display. In addition, the actuator state is displayed on the discrete LEDs "Closed", "Open", "Alarm", and "Motor current".

Operating switching of power circuits is formed by semiconductor three-phase reverse relay. To open the power circuits in case of emergency situations, as well as to deenergize the control circuit, there is an electromagnetic relay, which is switched before the operating semiconductor relay.

The actuator can be monitored in automatic mode with regulator control with 05 mA or 020 mA output current signal or in manual, local, or remote control mode.

Electric drive control unit includes BP4 power supply unit, MKK control and switching module, MK switching module, and MS adapter module.

The total number of signals is 108. Including:

- 30 discrete;
- 68 analog;

• 10 discrete outputs.

3. Results

3.1. Justification for controller selection

The main purpose of the controller is to perform the function of interaction between the field equipment and the operator's workstation, so the medium level is an essential part of any supervisory and control system.

Information of sensors and indicators in the form of standard signals is sent to the controller, where they are processed for further calculation of control influences on the actuators. The processed information from the controller is sent to the upper level to the operator's workstation, which allows the operator to monitor the entire process and, if necessary, correct it with certain actions [5].

The controller specifications should meet the production process requirements in terms of the speed of response to changes; should be sufficient to process the necessary information volume, provide a convenient programming option for organization of the control process; should have efficient channels for communication with elements of the field equipment and with the operator's workstation [6].

Controllers of the same application class have roughly the same specifications, so the choice is often subjective. Table 8 shows specifications of some PLCs.

Table 8
Comparative characteristics of PLCs

Brand	**Allen-Bradley**	**SIEMENS**	**VersaMax**
Processor	SLC-5/05	CPU 221/224	IC200CPU001
Power supply, V	4 types: 2¸10A/5 0,46¸2,88/24	0,46¸2,88/24	12/24, 120/240
Memory capacity of data and programs, Kb	16	10	12
Bit operation execution time, µs	0.37	0.37	1.8
Scan time, ms/K	0.9	-	-
PID control	Yes	Yes	yes
Floating-point operations	Yes	Yes	yes
Capacity I/O (discrete)	960	1024	2048
Real time clock	Yes	Yes	yes
Programming language	LadderLogic	Structured control language	Relay logic and instructions language
Built-in ports	RS-232, Ethernet	RS-232	RS-232, RS-485

Installation type	Chassis 3/30	DIN	DIN rail
Operating temperature range, 0C	0…+60	-20 ... +60	40…+60

The controllers given in Table 8, according to their technical data, can be used in the production process control system at BCPS, but the programmable logic controller of Allen-Bradley SLC — 500 ROCKWEL AUTOMATION company was chosen for automation system designing, since it is better studied and its properties better meet the system requirements.

3.2. Controller modules selection

The microprocessor controller in the formation pressure maintenance system should perform the following functions:

collection of readings from discrete and analog sensors;

calculation of regulatory parameter;

regulation of control valves;

communication with the system's upper level.

Based on the list of functions and information, the SLC 5/03 processor was selected. Availability of the built-in port of DH-485 network, as well as RS - 232 channel in this processor provides asynchronous serial communication data interface with terminal devices. The selected processor has sufficient memory capacity of 8 KB.

Eleven modules in thirteen slot chassis are required for the automation process. The modules were selected according to the number of digital input signals, digital output signals, analog input signals.

Zero slot of the first chassis contains processor of the SLC 5/03 controller.

The first and the second slots contain 1746-IB32 digital input modules, each with 32 channels. The discrete signal has voltage of 24 V.

The third slot contains 1746-OB16 module which has sixteen channels with voltage of 24 V.

Resistance temperature detector TSM 320 and TSM 50M are connected to 1746 - NR8 and 1746 - NR4 modules having eight and four channels accordingly. They are installed in fourth to eighth slots. The word of initialization for the resistance modules is given in Table 3.2.

Ninth to eleventh slots contain 1746 - NI8 modules designed to convert signals from the analog sensors into binary code. 1746-NI8 modules are used to process analog signals ±10 V, 1¸5 V, 0¸5 V, 0¸10 V, 0¸5 mA, 0¸20 mA and 4¸20 mA. They allow the sensor readings to be converted directly into engineering units. This module requires pre-initialization.

3.3. Power consumption calculation Discussion of the results

The selected modules are installed in two thirteen-slot and one four-slot chassis. Each module has a specific current consumption which serves as a basis for calculating the total power consumption for each chassis, taking into account the power margin, and selecting the necessary power supply. The power consumption is summarized in Table 9.

Table 9
Power consumption of the first chassis

		Current consumption, A

No.	Module	5 V	24 V
0	SLC-5/03 1747-L532C	0.5	0.175
1	1746-IB32	0.106	0
2	1746-IB32	0.106	0
3	1746-OB16	0.280	0
4	1746-NR8	0.100	0.055
5	1746-NR8	0.100	0.055
6	1746-NR8	0.100	0.055
7	1746-NR8	0.100	0.055
8	1746-NR4	0.050	0.050
9	1746-NI8	0.2	0.1
10	1746-NI8	0.2	0.1
11	1746-NI8	0.2	0.1
Total current, A		2.494	0.745

From the current calculations for thirteen module chassis, it can be concluded that 1746 - P3 power supply is the optimal option, as it has a permissible load of 3.6 A on 5 V bus and 0.87 A on 24 V bus.

3.4. External electrical connection diagram

The controller's external electrical connection diagram includes the following elements that are part of the CPS automation system:

microprocessor controller for controlling and regulating the unit's operation,

instrumentation for informing the controller about the unit's state and tools for regulating the unit's production process.

Instrumentation structure includes:

level sensor of Sapfir-22-DU type;

pressure sensor of Metran 150-TG type;

pressure difference sensor Metran 150-CD;

Temperature sensor Metran-286;

signal device of emergency upper and lower pressure values DM-2010.

To regulate the level, there is a control valve in the buffer-degasser actuated by electric actuator of 44MEP-B type which is controlled through the starter of PBR-3A type and BRU-42 manual control unit [7].

The controller consists of a chassis with CPU and I/O modules installed in it. The chassis has a power supply unit which is supplied with 220V AC voltage. The power supply unit provides 24VDC voltage.

Signals from the electronic transducers of Sapfir-22-DU, Metran 150-TG, Metran 150-CD sensors are connected to Metran-602-Ex power supply unit by two-wire circuit, providing power to sensors with a constant voltage of 36 V and spark protection of the sensor's signal circuits. Metran-602-Ex is supplied with 220 V AC power supply.

Current signals of 4-20 mA standard from the sensors pass through the power supply units and are transferred to the corresponding terminals of the analog signal input module channels by wires.

MEP-6300 actuator is controlled both with the help of the controller via PBR-3A and with the help of BRU-42 manual control unit. The manual switch on BRU-42 is used to select the control mode. When working in automatic mode, two discrete 24V DC signals ("Less" and "More") are used to control the actuator. Signals are sent to the BRU-42 inputs from the discrete signal output module channels. The module is supplied with 24V DC voltage from the chassis power supply unit.

The MEP actuator is powered by 220 V AC voltage supplied through the PBR-3A starter which changes the actuator's motor rotation direction by changing the phases and switching off power in the event of the control signal loss and shutdown of the actuator in the end positions by signals from S1 and S2 limit switches installed in MEP.

To indicate the regulator's position, a position indication unit of BSPT-10 type which is built into the MEP is used. The unit generates a standard current signal of 4-20 mA which is connected to the analogue input module via a two-wire circuit.

220 V AC power is connected to MEP for power supply of the indication unit.

4. Conclusions

Automation systems used in any production process are created taking into account its peculiarities, which makes it possible to determine the equipment, provide remote control (if necessary), ensure controlled production parameters, select emergency protection and alarm system versions, and design the control loops. Execution of functions required for optimal control of the process of water treatment and pumping it into reservoirs by the automation system can be provided by its hierarchical structure.

To measure production parameters, like temperature, pressure, current, vibration and level, modern devices ensuring the required measurement accuracy, operation reliability, and parameter variation range were selected.

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