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APPROACHES TO BUILDING OF SENSOR NETWORKS FOR GEOMECHANICAL MONITORING SYSTEMS

There have been formulated essential issues describing specifics of geomechanical monitoring of mines. Supported approaches to selection of technical parameters and design of instrumentation for geomechanical monitoring have been presented. Examples of actual implementation of geomechanical monitoring networks, operation algorithms and ways for further development have been described.

Keywords: geomechanical monitoring, mine, strain gauge, hybrid network, strain gauge, coordinator, repeater, potentiometric sensor.

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Considering the features of mine workings as an object of strain gaging, to form the organizational concept of monitoring of mine's geomechanical state is not a simple task [1–3]. Selection of measuring instruments, measuring points, methods of collecting and transmitting the taken-off data is significantly influenced by the considerable length and configuration of the workings, as well as by wide range of changes in the recorded parameters [4–6]. In this connection, when building the concept, a number of fundamental issues should be addressed.

1. Determination of features and design of strain gauges.
2. Ensuring the sufficient self-contained operation time of gauges from accumulator battery pack.
3. Ensuring the accuracy of the information received.
4. Reducing the probability of information loss.
5. Transmitting of information from gauges to the point of data collection and display on the automated workstation (AWS) of the system operator.
6. Organizing the operation of the measuring complex, etc.

Experience in application of gauges manufactured by OJSC «Avangard» in the systems of geomechanical and structural monitoring of the gypsum mine OJSC «Knauf Gips Novomoskovsk», mine «Gluboky» of OJSC «PGKhO» (Krasnokamensk), the hangar for storage of potassium salt in OJSC «Uralkali» (Berezniki city, Perm Krai), the interchange of the Alabian-Baltic tunnel made it possible to formulate a number of approaches to the choice of technical parameters and design of measuring equipment for geomechanical monitoring.

1. measuring range and high sensitivity of gauges in mine conditions may not be appropriate for the set measurement task. This method demonstrates high efficiency in the systems of structural monitoring of the mine, where anchors are used as the gauges' clamping elements. After installation, the anchors have a sufficiently large stroke, which can lead to the failure of gauge sensor elements (open thermistor), so they should be used in cases where the gauge can be placed directly on the structural member.

2. In a number of cases, it is expedient to replace the strain gage sensor element of the gauge with a displacement sensor that has a sufficient measurement range, high mechanical strength and stability of the parameters over time. In this case, it is necessary to use articulated transitions on the sensor that will ensure the operability of the structure if the direction of the vector of influence and the working axis of the sensor are under misalignment. Thus, the use of potentiometric displacement sensors as the sensing elements, which most satisfy the requirements for both the range and accuracy of the measured values and for mechanical strength and resistance to external influences, is a suitable solution.

3. Duration of self-contained operation depends on how timely the data are collected from sensors. It is important to take into account that if the sensors do not communicate with the coordinator at the set time, the sensors will be in the active energy-consuming mode for at least 30 minutes, which will lead to the rapid discharge of the batteries.

4. The accuracy of the information received is determined by the correctness in the adjustment of the parameters of the sensor itself and the accuracy of location on the unit.

5. The manufacturer keeps in possession a certified metrology bureau, at the stand of which all sensors are

calibrated. As a rule, during verification, the sensors are removed. To reduce the costs of sensors' removing and installing, it is recommended to have a buffer stock of sensors. This is a small number of sensors that are tested immediately before installation. They are installed in-place of a group of sensors, which are removed for verification. Accordingly, after verification, the removed sensors are installed in-place of the next group, and so until all sensors are verified.

6. The cause of information loss is the discharge of batteries of one of network elements. In this regard, it is necessary to periodically monitor the voltage of the batteries of all non-volatile components of the network for the purpose of their prompt replacement. It is advisable to read the voltage of the batteries simultaneously with the reading of the sensors.

The network method of organizing the complex and the wireless method of information transmission is the most optimal for the convenience of data collection, as it allows remote acquisition of data from a set of sensors by one operator from one point in a very short time-period.

The solution to this problem is to build a branched network that connects various control points inside the mine with the personal computer (notebook PC) of the operator situated in the building of the office-and-utility complex.

An example of the mine's geomechanical monitoring network architecture, that actually implements the formulated principles is shown on Fig. 1, and the network structure – on Fig. 2.

The network composition (Fig. 2) includes the following components:

- automated operator workstation, consisting of a PC (notebook PC) with preinstalled software;
- sensor network coordinator;
- repeaters;
- strain gauges.

All elements (except for the sensor network coordinator) are designed for operation with battery autonomous power supply and have two modes of operation: low power mode and active mode. The active mode corresponds to the moments of data transmission over the network and maximum power consumption. At other times, the network devices are in the reduced mode of power consumption.

The physical protocols connecting the Sensor Network Coordinator with the automated workstations are the USB port protocol (for local connection) or GSM (3G/GPRS) connection (for remote connection).

In each underground observation station there is a coordinator of the sensor network and a set of sensors (up to 50 pieces). The sensor coordinator detects the information from sensors with the operator-preset interval (for example, 7 days), and in the automatic mode transmits the information to the automated workstation or to the central server of the system via repeaters and network coordinator. In case of communication failure (mechanical damage of network element, loss of GSM-network signal or battery discharge in one of the network elements), the sensor coordinator saves the received data (up to 100 measurements) in the built-in flash memory and transmits them to the automated workstation or to the central server of the system after the connection has been established.

The technological basis for the automated system of geomechanical and structural monitoring is a hybrid sensor network of strain gauges. The hybrid sensor network is distributed to separate subnetworks (segments), which can be either wireless (or conforming with 2.4 GHz ZigBee standard or conforming with LoRaWAN868 MHz standard, depending on configuration of the object), or wired according to RS485 [7, 8] standard. All sensors, included in the system composition, are designed for round-the-clock operation in automatic mode.

Algorithm of the system functioning:

1. Recovery of sensors and sensor coordinator from the low power consumption mode.

Measurements are conducted periodically with T-interval set by the operator. Initially, the sensors and the sensor coordinator are in the low power consumption mode. At the end of the set T-interval, the sensor coordinator and its sensors simultaneously switch to the active mode. The simultaneity is ensured by fine-tuning of the real-time clock (RTC), which are pertaining to sensor coordinators.

2. Measurements and transmission of results from sensors to the sensor coordinator.

After step 1, the sensors measure the strain values and voltage values of the batteries. The measured values are transmitted to the sensor coordinator over the wireless network. Having received a response from sensors, information on the voltage of the involved battery is added via the sensor coordinator and recorded in the internal memory of the coordinator. Upon request from AWS, a parcel is generated and transmitted over the network via repeaters to the network coordinator.

3. Sending the parcel over the network.

Sending the parcel switches to active mode all repeaters of network branch, which connect the sensor coordinator and the network coordinator. Each device adds information on battery voltage to the transmitted parcel.

4. Reception of parcel by network coordinator and data exchange with the operator's AWS.

The sending of data, that have been delivered via one of the branches to the network coordinator, is transferred to the operator's AWS.

5. Data transmission from network coordinator to sensors.

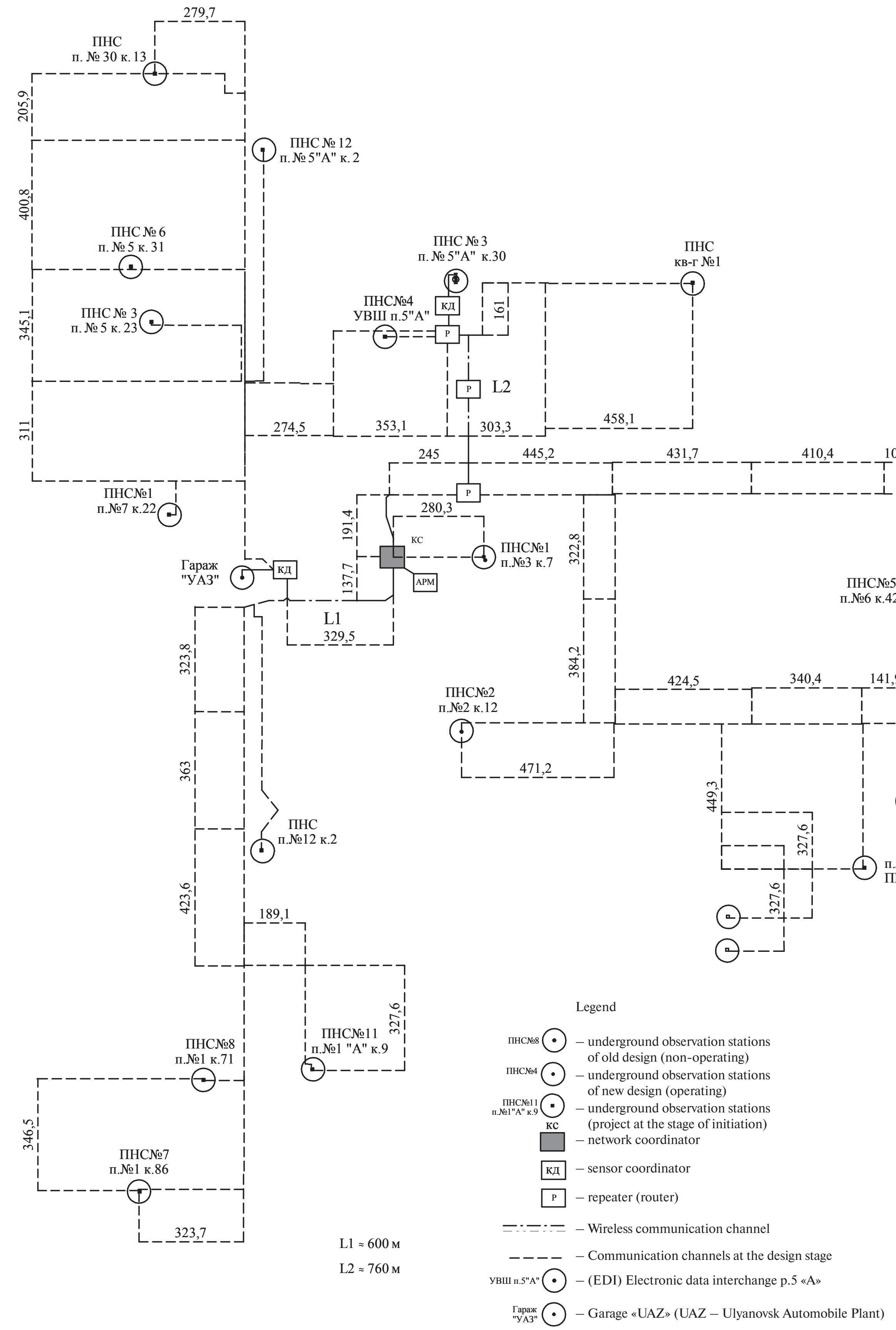

Figure 1. The architecture of wireless data transmission network from the underground observation station to the operator's computer.

The data from the operator's AWS via the network coordinator are transmitted via the active branch that caused the data exchange to the sensor coordinator. The sensor coordinator transmits the received data to the sensors, setting a new operating mode in them, if it has been changed, and switches the sensors to the reduced power consumption mode.

6. Switch to the lower power mode.

After step 5, the «Sleep» command is sent to the network through the network coordinator and the switch to the reduced power consumption mode takes place. The repeaters receiving this command through the network subsequently switch to the low power consumption mode, if at the same time the other branch is not active and if the «Sleep» command has been received on all active channels.

7. The actions specified in steps/clauses 1–6 are periodically repeated for the sensors of all underground observation stations of the system.

8. Processing and presentation of data to the operator.

The received data are processed in the operator's AWC and displayed as strain/ deformation values and battery voltage values.

The developed algorithm of system functioning and its individual elements were probed during the actual implementation of the monitoring system for the geomechanical state of the mine (or quarry) in three projects implemented by OJSC «Avangard».

The first of them is the system for monitoring the state of underground workings and the roof condition of the gypsum quarry of OJSC «Knauf Gips Novomoskovsk» (Fig. 3). This work was conducted under the patronage of the Tula Academy of Mining Sciences. The observation stations located there were equipped with string measuring elements. Periodically, while surveying the observation stations, the patrol personnel recorded changes in the position of the string plummet. Though, the stations equipped with sensors manufactured by OJSC «Avangard», when combined into a single network, would allow to take off measurements during run-time.

The second project included the works on equipping the «Gluboky» quarry of OJSC «PGKHO» (Krasnokamensk city) (Fig. 4). In this case, all pavilions, in which the workings' condition was monitored, were combined into a single network and the data from them were sent to the aboveground dispatcher station via the network coordinator and the data transmission unit. The coordinator's connection with the dispatcher station was performed via the RS-485 cable, laid in the well on the surface.

The third successfully implemented project was the work on outfitting of hangar for storage of potassium salt in OJSC «Uralkaly» in Berezniki city, Perm Krai (Fig. 5).

The first two projects involved a very laborious and expensive process of construction and outfitting the deformation pavilions – that is the necessity of niche mining, drilling the three pairs of orthogonal boreholes and installing the deep benchmarks.

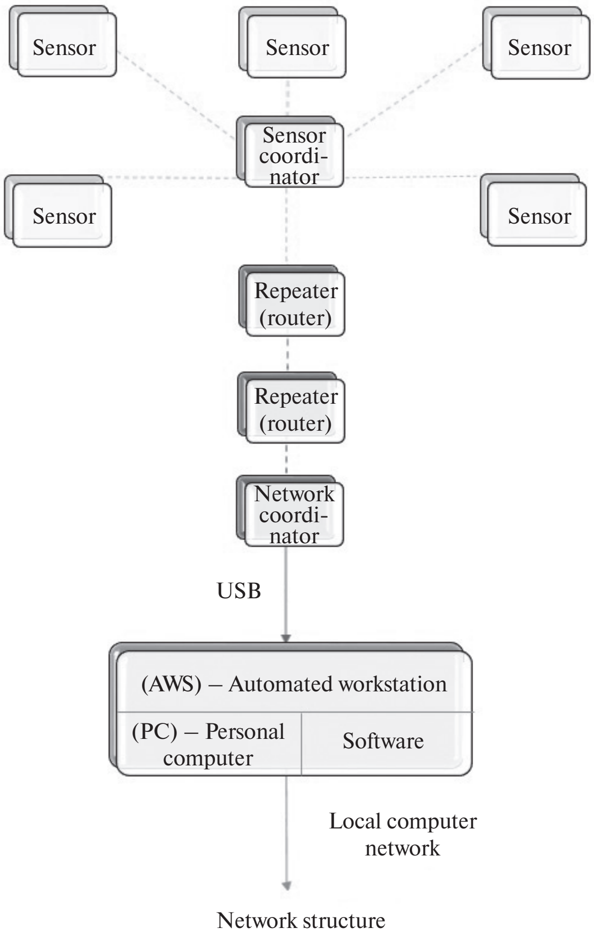

Figure 2. The architecture of the wireless data transmission network from the underground observation station to the operator's computer

All that determined the mandatory development of a new strain gauge design, allowing to:

- refuse from niche construction;
- measure the three deformation components at one point (borehole) instead of drilling three pairs of boreholes;
- combine the benchmark and the sensor, which made it possible to refuse from installation of long (1520 m) benchmarks in each borehole;
- simplify the installation of a large number of measuring points for the strain tensor in underground workings.

In which case, the creation of the system for monitoring the geomechanical condition of the mine (or quarry), the principles of construction of which have been described above, is possible only on the basis of sensor network of strain gauges.

The system of monitoring the geomechanical state of the mine is designed to monitor the current stress-strain state of its bearing structures and the movement

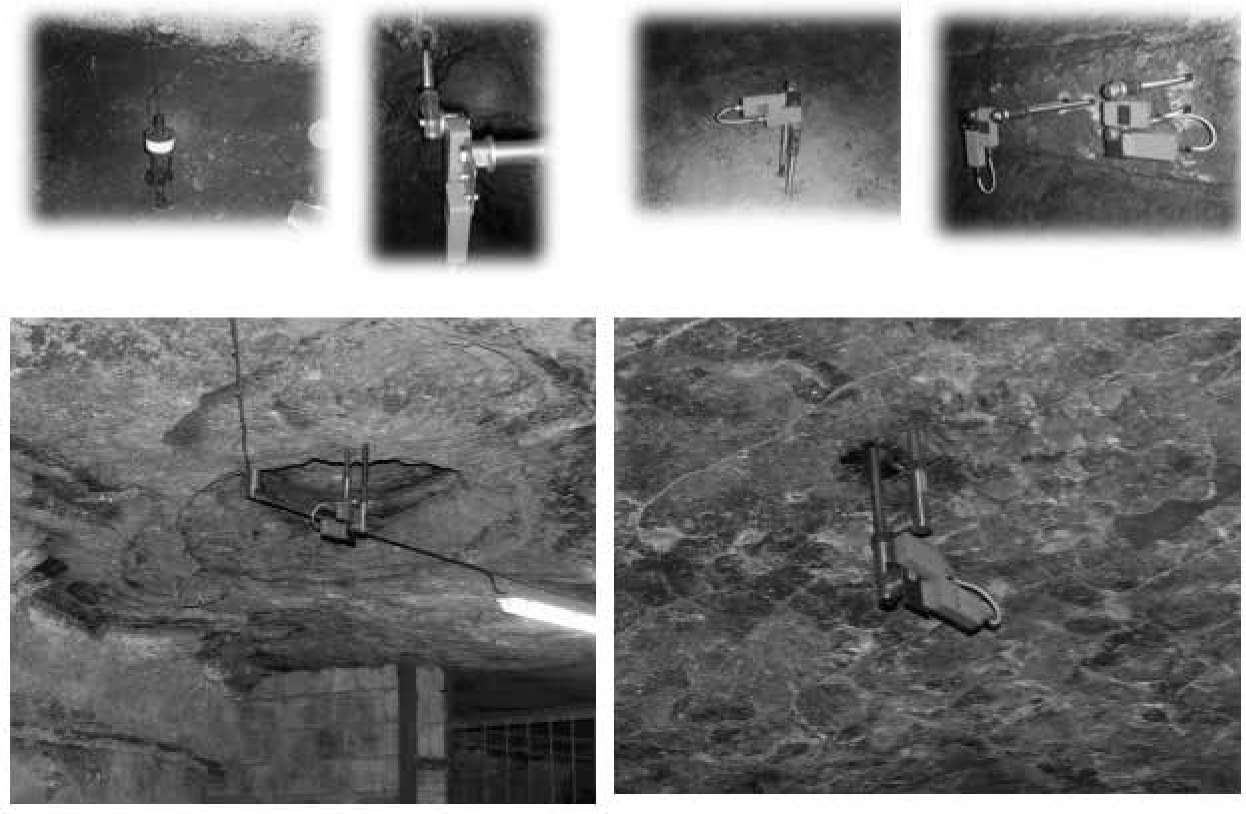

Figure 3. Monitoring the condition of underground workings and monitoring the roof condition of OJSC «Knauf Gips Novomoskovsk» quarry

Figure 4. The system of deformation monitoring at «Gluboky» quarry of OJSC «PGKHO» (Krasnokamensk city)

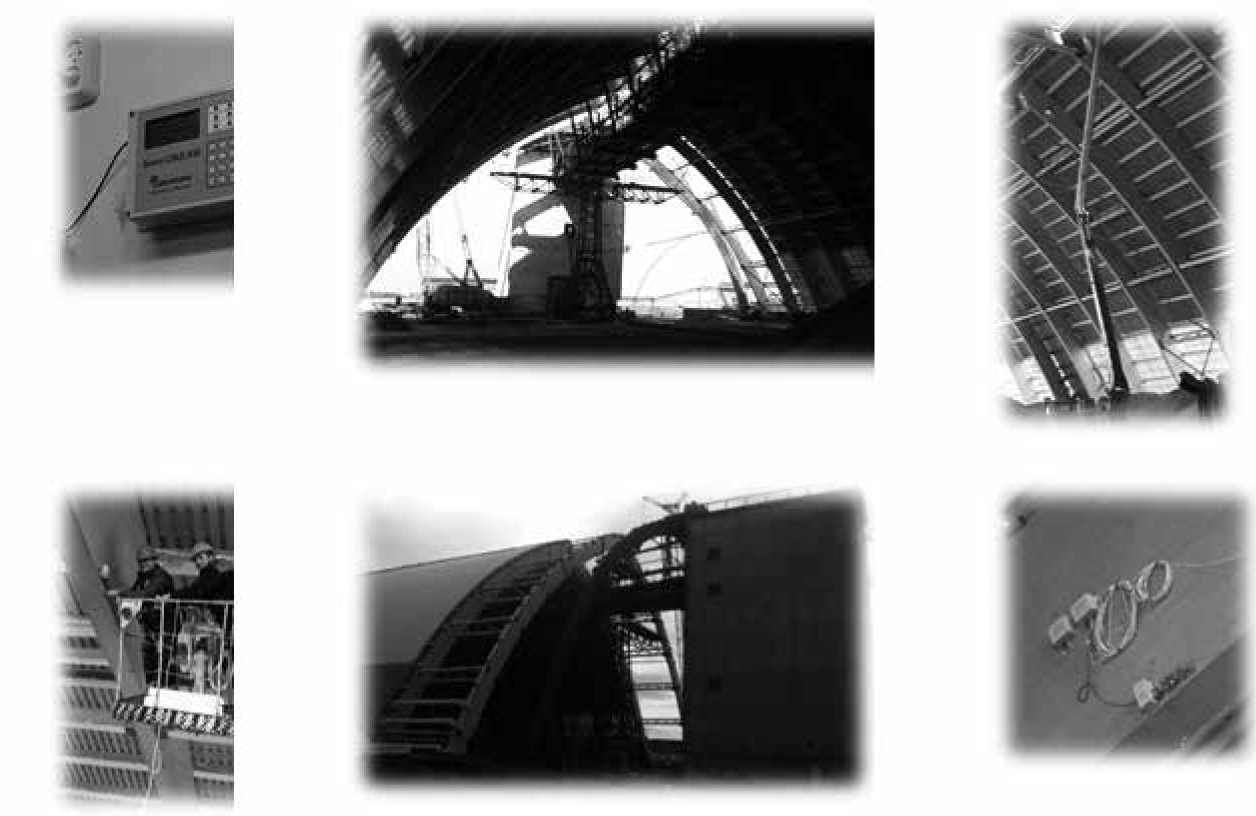

Fig. 5. The system of monitoring the roof deformation in OJSC «Uralkaly» (Berezniki city, Perm Krai)

of rock formations in the process of mine development and thus provides:

- periodical control of the stress-strain state of the bearing structures of the mine and the state of the seams with the delivery of information on the place where the measured values approach the critical values;
- flexibility of configuration when installing sensors and sensor nodes;
- when the measured values of critical stresses and strains/deformations are exceeded, the formation of alarm signals, the delivery of information on the location exceeding the design values of strength and strain;
- automatic registration of events in the AWS software, issue of event reports as requested by operator;
- Possibility of browsing the state of the object through a web browser;
- automatic notification by sms-messages of the persons-in-charge in case of inadmissible values of stresses and strains/deformations in the elements of mine structure and critical movement of rock massifs.

The advantages of the data collection subsystem are as follows:

- Reduction of labor costs for installation, commissioning and maintenance;
- Simplicity of system build-up;
- High fault tolerance in the event of a possible sensor failure.

Since the process of mine structure deformation and movement of rock formations is very slow and a continuous flow of information is required only in the emergency situations, the algorithm of system operation allows to set intervals of polling the sensors from 5 seconds to 1 month. In most cases, 1–2 measurements per 24-hr day are sufficient for object monitoring. Such polling interval of the system (when using the standard battery packs) provides receipt of information on the state of the object within one year, and in case of continuous sensor polling – from 7 to 15 days.

Experience in implementing the proposed concept of constructing the system of geomechanical monitoring of mines and quarries based on sensor network of wired and wireless strain gauges with such experience obtained by OJSC «Avangard» in its implementation of projects for the systems of geomechanical monitoring of the gypsum mine of the LLC «KNAUF-GIPS» Novomoskovsk, the «Gluboky» mine of OJSC «PPGHO» (Krasnokamensk city), a hangar for storage of potassium salt in OJSC «Uralkaly» (Berezniki, Perm Krai), the interchange of the Alabian-Baltic tunnel confirmed the long-term benefits of practical application of the proposed concept of constructing the system of geomechanical monitoring based on the sensor network of strain gauges.

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