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NEW METHODS AND INSTRUMENTS IN MINING

Equipment for Microseismic Monitoring of Geodynamic Processes in Underground Hard Mineral Mining

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Abstract—The article describes engineering decisions on equipment for acquisition of microseismicity data, that improve information content of microseismic monitoring of geodynamic processes in underground hard mineral mining.

Keywords: Microseismic monitoring, geodynamic processes, data acquisition system, rock mass, downhole seismic equipment.

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The scarce information on a rock mass state and processes running in it permanently contributes to the risk of catastrophic manifestations of rock pressure, hydro- and gas-dynamic phenomena. The early detection of problematic areas increases the time to analyze a situation and to take measures directed to improve the safety of underground mineral mining operations.

The efficient process for remote monitoring of geodynamic processes is the passive microseismic monitoring (MSM) involving the seismic signal acquisition and identification of hypocenters, power and mechanism of observed events based on seismic data.

In the mining industry the microseismic monitoring is practiced by low-channel underground systems with linear receiving antennas and/or few (one ore three) surface seism stations. The known hardware-software solutions are distinguished for low spatial resolution and sensitivity to receive seismic signals, and low capacity to detect weak power events within a rock mass. Eventually, MSM functions are limited to identification of rock burst parameters, statistical survey of seismicity with plotting correlation relationships of rather low forecasting value.

To improve informativity of microseismic monitoring, the researchers from the Institute of Mining and the Institute of Petroleum Geology and Geophysics, Siberian Branch RAS, jointly developed the MSM hardware–software complex (MSM HSC) adapted to receive and to process weak seismic events at underground hard mineral mining. The new-designed complex provides identification of spatial location and estimation of geometric parameters of geodynamic evolution zones based on prompt solution of direct seismic problems in an anisotropic media, evaluation of energy and kinematic parameters (spatial displacements vs. time) of geodynamic processes, selective identification of microseismic events, induced by deformation and filtration processes.

The present paper concerns the hardware solutions of the complex developed on the basis of general-purpose commercial telemetric seismic systems. The hardware of MSM complex provides microseismic monitoring of geodynamic processes in a rock mass by means of a complex observation system, comprising underground (mine) and surface receiving antennas, integrated into a single complex, including:

a) few underground linear receiving antennas at mine workings from 6–12 three-component receiving stations with 10–50 m interval between them;

b) surface areal antenna capable to receive seismic signals from 48–1024 seismic signal sources; receive stations, mounted at the daylight surface with 30–50 m interval between them;

c) data collection and processing system.

MSM HSC provides non-stop acquisition of microseismic data in SEG-Y or SEG-D format at 10–150 Hz frequency range with time reference precision of 1 μs and sensitivity of microseismic oscillation receive at least 85 V/(m·s).

The hardware of the complex is presented in Fig. 1 (general view), Fig. 2 (structural scheme) and in Fig. 3 (functional scheme).

The new-proposed architecture of MSM HSC is distinguished for integration of surface and underground receiving antennas into a single complex. The data from the underground receiving antennas are cabled through underground router, main cable, barrier block of underground mine information network SBGPS (GRANCh company, Novosibirsk) [1], then through a router and Ethernet surface corporative network of the mine to computer (Figs. 1, 2). It is important to note, that up to now SBGPS system is mounted at five mines of SUEK with perspective introduction of this system at all coal mines owned by this company. The technical issues of MSM HSC–SBGPS compatibility were solved in cooperation with GRANCh.

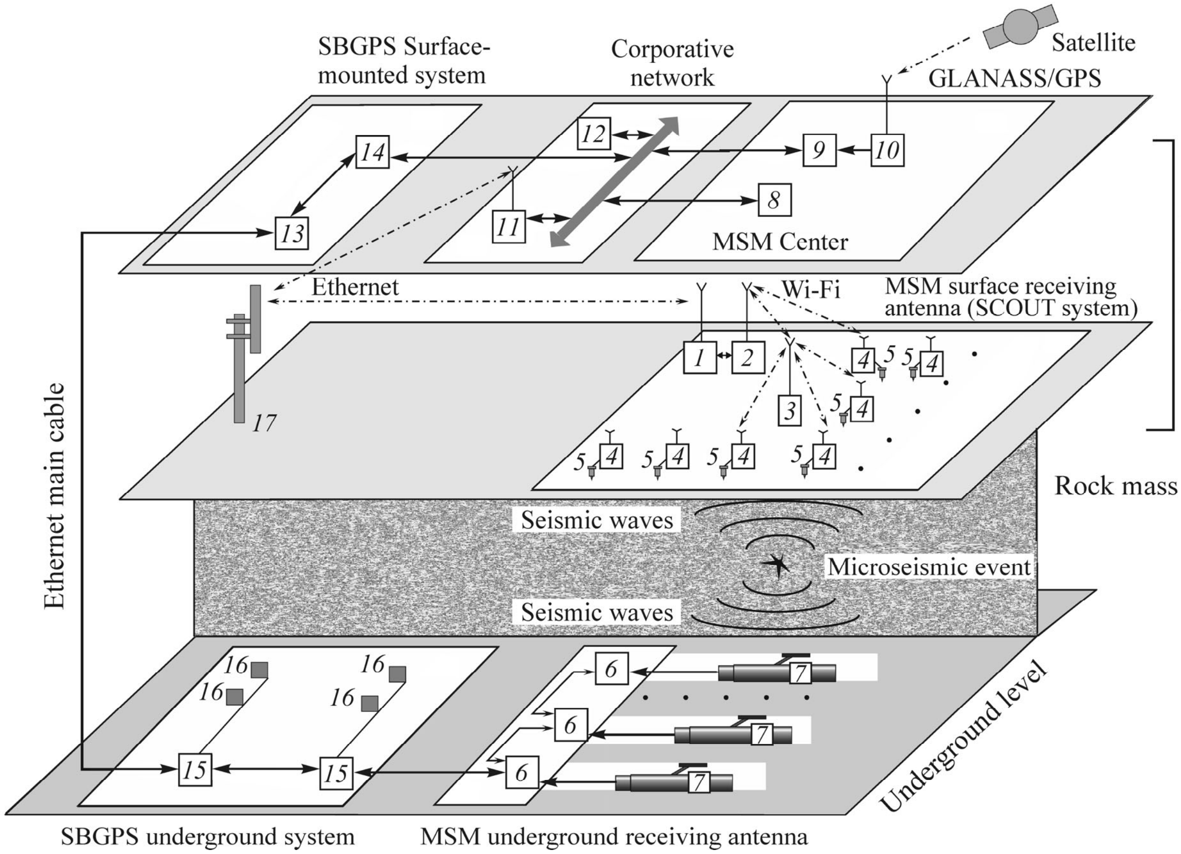

Fig. 1. General view of hardware of MSM HSC to monitor geodynamic processes in a rock mass: *1, 11*—users' station of Ethernet software network; *2*—DCP SCOUT station; *3*—Wi-Fi access point ; *4*—surface receiving station (SRS)–SCOUT field module; *5*—GS-One seismic receivers; *6*—underground receiving station (URS)–SCOUT up-dated field module for a mine; *7*—downhole seismic sensor; *8*—data collection and processing computer, MSM HSC; *9*—synchronization module for protocol IEEE 1588; *10*—receiver GLONASS/GPS; *12*—Ethernet corporative network mine server; *13*—barrier block for surface section of SBGPS information mine system; *14*—router of Ethernet corporative network at the mine; *15*—underground router of SBGPS information mine system; *16*—base station (BS) of SBGPS information mine system; *17*—access of Ethernet wireless network.

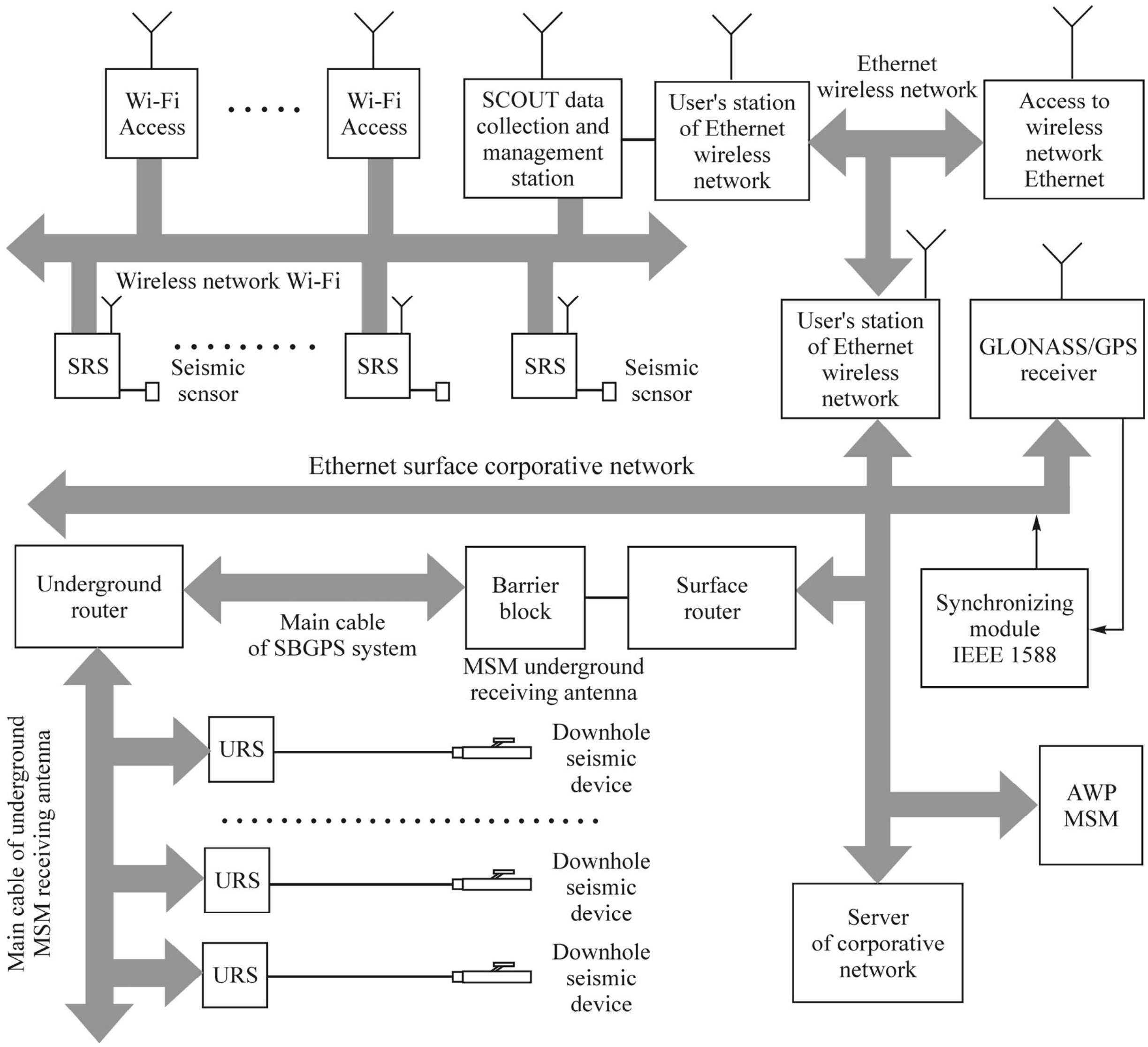

Fig. 2. Structural hardware scheme of MSM HSC to monitor geodynamic processes in a rock mass (AWP-automated working place, viz., computer).

The data from the surface receiving antenna are sent to SCOUT surface station (SKB SP", Saratov) [2] and then through Ethernet software communication network and customers' station to Ethernet corporative network of the mine and to MSM HSC computer.

The application of the homotypic field modules assures the single format (SEG-Y, SEG-D) of recorded data and formation of homogeneous database in MSM HSC for further editing and processing of the data.

The synchronization of surface field modules is performed by GPS built-in receivers. The timing of underground field modules is also carried out by GPS signal, transmitted from GPS-receiver through Ethernet corporative mine network and SBGPS underground information network according to PTP protocol (IEEE 1588) by means of synchronization modules IEEE 1588 (Fig. 2).

The digital signal processor ADSP BF 518 (Analog Devices Co.) used in SCOUT field module was equipped with built-in access controller EMAC (Ethernet media access controller) as shown in Fig. 3 [3]. Functional capacity of EMAC controller are expanded in this processor to meet IEEE 1588, namely, TSYNC module and other functions were added to provide the operation under standard IEEE 1588 in Ethernet [3].

The output timing PPS signal formed by using programmed values of start time (PPS_ST) and period (PPS_P) in ADSP BF518 processor provides flexible capabilities. Finally, the output signal is generated by impulses at time moments (PPS_ST + *n** PPS_P), where *n* = 1, 2, 3… *N*. PPS_P value is preset equal to 1 s and PPS_ST equals any not-yet-due time moment, being second multiple in the basic version of using PPS signal. Output PPS signal is used as the basis to form a periodical signal with the completely programmed frequency and start time.

The above capabilities of ADSP BF 518 processor provide simple adaptation of SCOUT field module to operation in combination with underground receiving antennas. The up-dated module version has spark-explosion-safe body and elimination of GPS receiver from its design alternatively to a production module version, as well as minimized volume of a built-in flash card and internal accumulator capacitance. The technical issues of SCOUT field module adaptation to operation in combination with underground receiving antennas MSM HSC were solved with the producer of this device.

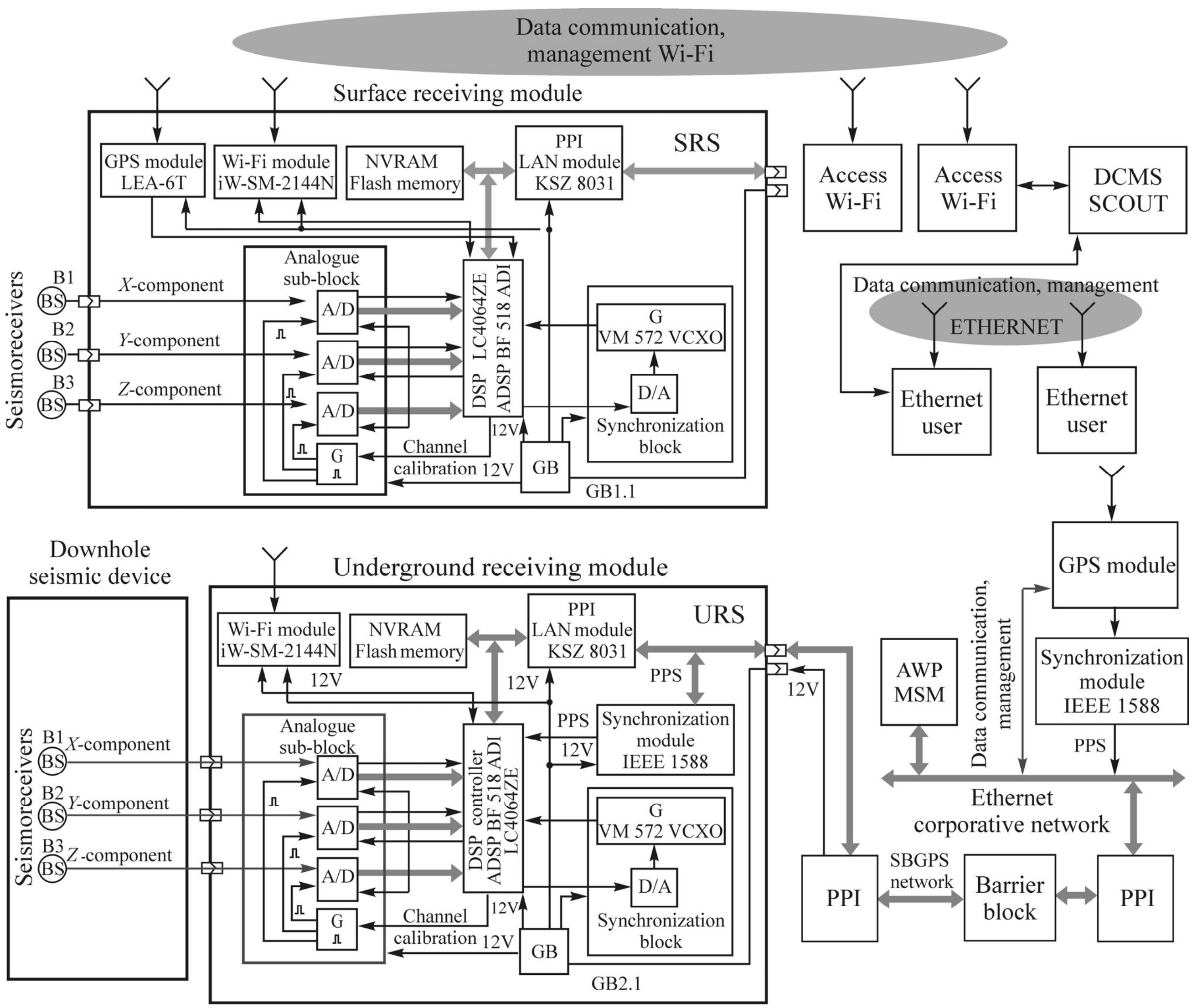

Fig. 3. Functional hardware scheme of MSM HSC to monitor geodynamic processes in a rock mass (PPI—interface converter (a router); DCMC SCOUT—data collection and management computer of surface receiving antenna).

The transmission of signals of underground field module URS is mainly performed through cable interface Ethernet (Fig. 3), alternatively to a standard surface field module SRS using Wi-Fi wireless data transmission to data-management station SCOUT [2]. This solution is justified with the following arguments:

a) cable data transmission permits high chronometrical precision of MSM data logging;

b) the cable connection of the underground field seismic module to an underground router or a basic station of the information mine system SBGPS allows a simple power supply arrangement from an external spark-explosion-safe battery (power source) being a component of an underground router or a SBGPS basic station.

This technical solution on an underground receiving antenna eliminates necessity in periodical replacement of electrochemical batteries of field seismic modules URS under mine conditions with no assignment for operating personnel concerned to go down to the mine and appreciably lowers the MSM operation cost.

An integrated component of an underground receiving station is a new-proposed downhole seismic sensor, convenient for prompt mounting and fixation of three-component seismic receivers based on geophones GS-One [4] in boreholes of 48–76 mm in diameter and up to 7–10 m in depth.

The downhole seismic sensor has a pneumatic pressing drive and the pressing module is manufactured based on a transverse hydrofracturing initiator by using chemically active compositions, developed by scientists of IM SB RAS within project no. RFMEFI60414X0096. Unification of downhole instruments lowered the cost of a new-developed MSM HSC prototype.

General view of a downhole seismic sensor of MSM HSC is demonstrated in Fig. 4. The downhole seismic sensor consists of a downhole instrument A1 and two optional devices for its mounting within a borehole: low-volume nitrogen balloon with pressure regulator, manometer, and incline-angle tester.

The downhole instrument body of 40 mm in diameter and 400 mm in length is made of steel and contains input clamps to connect to power lines *1* and a high-pressure pneumatic hose *2*.

The complete complex scheme of the downhole seismic sensor MSM HSC is shown in Fig. 5. The instrument is installed in a borehole by means of a rammer (not shown in the figure). The rammer is helpful in manual placement of the instrument into a borehole with its axial rotation. After the instrument is properly placed at a preset depth, the electric cable K1 is connected to the incline–angle tester and the instrument is set up in the operation position by using the readings of voltmeter graded in terms of incline angle from – 90° to + 90°. The receiver of Z-component of MSM oscillations is directed vertically in the operation position.

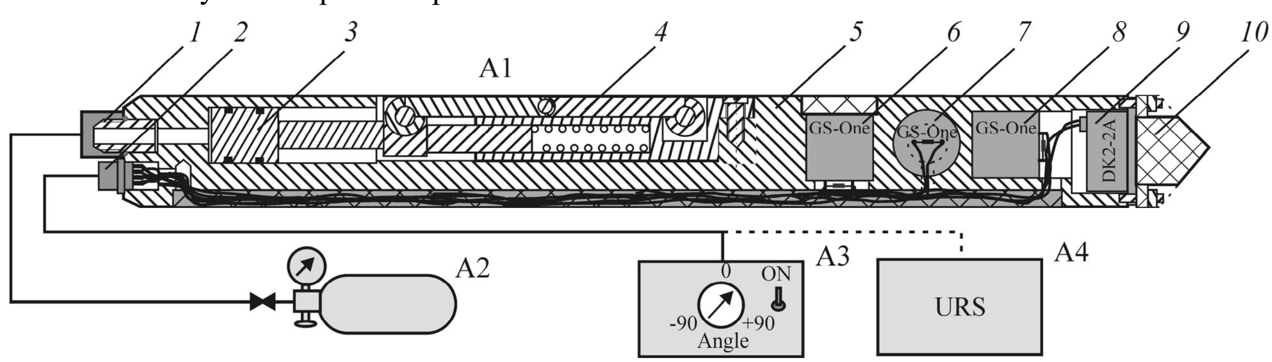

Fig. 4. General view of downhole seismic sensor MSM HSC: A1—downhole device: *1*—socket; *2*—inlet connection of pneumatic system; *3*—pneumatic drive of a pressing module; *4*—pressing module; *5*—body; *6*—seismic receiver of Z-component of MSM oscillations; *7*—seismic receiver of *X*-component of MSM oscillations; *8*—seismic receiver of *Y*-component of MSM oscillations; *9*—incline angle meter; *10*—protection cap; A2—low-volume nitrogen balloon with pressure regulator and manometer; A3—incline-angle tester; A4—SCOUT field seismic module of underground receiving station (URS).

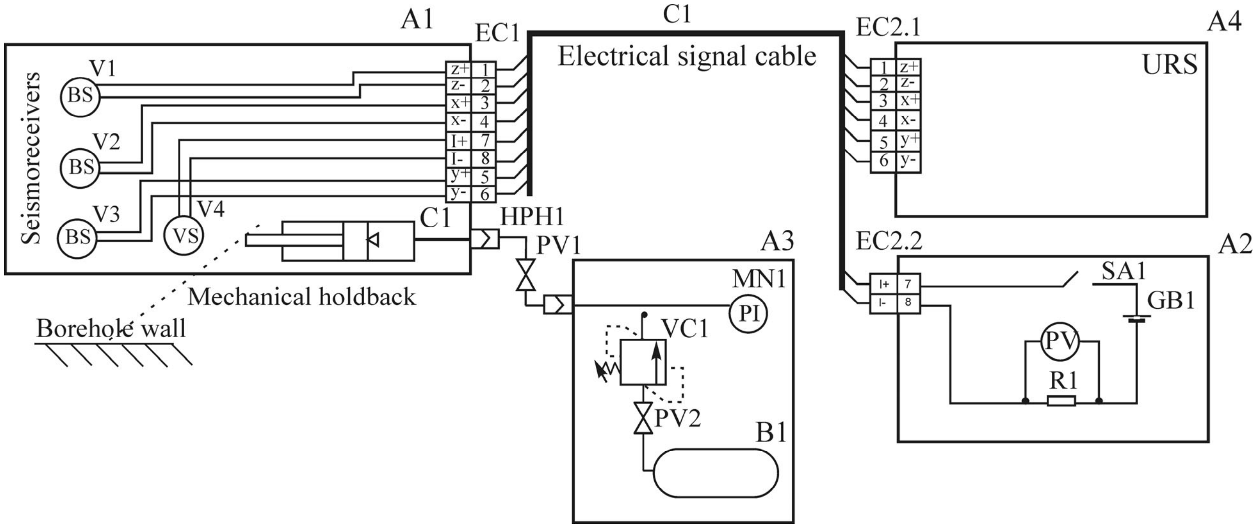

Fig. 5. Electrical and pneumatic functional scheme of connections and sub-connections of the downhole seismic sensor MSM HSC: A1—downhole instrument: V1–V3—seismic receivers; V4—incline angle gauge; C1—pneumatic drive of the pressing device; A2—incline angle tester: SA1—tumbler; PV—voltmeter; R1—measuring resistance of current loop; GB1—galvanic battery; A3—pneumatic source: PV1, PV2—pneumatic valves; VC1—gas valve-controller of output-pressure; B1—balloon 3 dm^3 with nitrogen compressed up to 20 MPa; A4—field seismic module SCOUT; C1—electric signal cable (4 pairs on screen); HPH1—high-pressure рукав of 6 mm in cross-section diameter; EC1, EC2—electrical connectors.

After the instrument is turned to the operation position, the pneumatic line of the instrument (HPH1) is connected to a nitrogen balloon with gas regulator and the output pressure set by the readings of manometer (MN1) within 1–3 MPa, thus pressing the instrument to a borehole wall with force of 200–600 N. The pressing force can be adjusted upwards, if required.

After the instrument has been pressed to the borehole wall, a rammer is removed from the hole, the incline-angle tester and pneumatic source are switched off, and the instrument is connected through cable C1 with URS mine version of SCOUT field seismic module.

The underground station coordinates, determined by the mine surveying service, are communicated to the operation memory of SCOUT field module through Wi-Fi of a secured portable tablet computer, equipped with SCOUT-service software. The tablet computer also diagnoses the field seismic modules, and connected-to-them geophones or seismogroups by testing the following parameters: coefficient of URS amplification, noise of receiving URS track, displacement of zero of receiving URS track, mutual interference of URS channels, co-phase interference elimination by URS receiving track, URS internal memory state, state of URS batteries, geophone resistance, isolation of geophone cables, incline or zapping of geophone coil, deviation of zero, microseismic noise level.

Following these tests, the communication of underground receiving station (URS) with MSM HSC computer is checked and tested, and the system for synchronization after protocol IEEE 1588 is tuned.

The successful test results give the grounds to grant admission for operation of the underground MSM-receiving station.

The application of the new-proposed downhole seismic instrument is optimal in labor costs, materials and production effectiveness: appreciably smaller diameter of reference boreholes and respective lower costs of their drilling, no need in a casing pipe and a large-size sensor, as compared to GITS system proposed by researchers working for VNIMI [5, 6].

The new-designed downhole seismic instrument exhibits threefold higher receiving sensitivity to microseismic oscillations, the mounting depth is increased from 0.5 m to 7–10 m., it allows lower technogenic noise interference and substantially improves the efficiency in extraction and localization of weak seismic events, as compared to field seismic modules of Mikon-Geo system, designed by researchers of IPSM (TU 4314-001-44645436-2011) [7].

The network system for seismic monitoring SSSM, proposed by ELGEO, Kazakhstan, can be considered the closest analogue to the new-designed MSM HSC instrument [8]. Its features are:

a) the downhole sensor is not equipped with a hold-down device with no allowance for its mounting in long-distance horizontal boreholes.

b) receiving antenna consists of separately located surface and underground receiving stations rather than alternative antenna groups in MSM HSC system. This leads to higher costs of the surface MSM data-collection system because of the use of greater number of users' stations in Ethernet wireless network for moderate- and long-distance data transmission. The less expensive two-level architecture of the surface data collection system from antenna groups, connected through Wi-Fi, is used in MSM HSC system. The communication of the antenna groups with the MSM-data collection centre is practiced through the users' Ethernet wireless network stations;

c) SSSM system has got non-adjustable interval of discretization of analogue-digital converter in 2 μs. Alternatively, SCOUT field modules enables to set quantization period from 0.25 to 4 μs, thus expanding functionality of the facilities.

It is important that the similarity in parameters of industrial seismic telemetric recorders of different producers is preconditioned by one-type modern circuit designs and the element base, as well as the application of digital signal processors.

The new-proposed hardware and software complex for microseismic monitoring is designed for the integrated (surface and underground) application of high-sensitive observation systems, feasible monitoring of geodynamic phenomena based on location and evaluation of the seismic event energies along with variations in speedy anisotropy of rocks evaluated from the analytical data on wave fields generated by sources of microseismic events.

CONCLUSIONS

Engineering solutions for collection of microseismic data are developed to improve the information content of microseismic monitoring of geodynamic processes at underground hard-mineral mining, including the number of receiving channels, rock mass scope under monitoring by receiving stations, optimization of conditions for receiving of signal to noise ratio.

The new-designed hardware solutions for microseismic monitoring of geodynamic processes provide integration of surface and underground receiving antennas into a single complex with a single format of data recording for subsequent editing and processing.

The downhole seismic instrument for prompt mounting of three-component seismic receivers in bore-/blastholes 48–76 mm in diameter at depth up to 10 m from the face wall with the hold-down force to hole wall up to 600 N.

ACKNOWLEDGMENTS

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