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RECENT SOLUTION OF THE DISTRIBUTED CONTROL AND MEASUREMENT SYSTEM IN THE JERONÝM MINE – MODULAR SYSTEM

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ABSTRACT
Distributed control and measurement system for evaluation of hydrologic, geomechanical and other parameters has been built up in the medieval ore mine Jeroným. The instrumentation is generally based on commercial measurement and control kit and sensors. Technique of implementation of special sensors, e.g. laser distance meter and/or CCBM probe for measurement of rock massif stress changes, is also described.
The distributed system is integrated into the existing seismic recording station equipped by data transmission via GSM network. Comprehensive monitoring system is modular in order to have possibility to change the system configuration.

KEYWORDS: Jeroným Mine, geomechanical monitoring, seismological monitoring, measurement of joint aperture

INTRODUCTION

Detailed investigation of mine workings stability in the Jeroným mine is being conducted in under the terms of grant GAČR 105/06/0068 "Investigation of factors influencing stability of medieval Jeroným mine in Čistá". Basic information on Jeroným mine and the present status of geological, geomechanical, hydrogeological and seismic monitoring have been described in the article of Kaláb et al. (2006, 2007). It has been mentioned there that it is necessary to build up a monitoring system with continuous data recording (data sampling for a number of hours) in the underground in order to obtain reliable experimental information for realisation of the grant project. The nomenclature of mine workings and monitoring parameters as mentioned have been taken up from the mentioned article.

General requirements for building a monitoring system can be enumerated as follows:

- Automatic registration of selected, so far manually recorded values measured quarterly:
  - change in the level of mine water
  - opening of joints in rock mass (joint aperture)
  - cross-section convergence
- Possibility of inclusion of further methods of measurement:
  - change of tensor stress state of rock mass by CCBM (Compact Conical ended Borehole Monitoring)
  - deformation of roof of the chamber K2 by means of laser distance meter
- Modular architecture enabling gradual extension of the system
- Sensor of measured parameters at distance of hundreds of meters from the central registration units. Installation of sensors and cable network should not visually damage historical mine working
- Equipment must be functional for a long time in mine atmosphere with 100% (approx.) relative humidity
- Automatic function without attendant. Telemetric approach to registered data
- Low cost of realization

The Distributed Control and Measurement System (DCMS) optimally fulfils the requirements on spatial distribution and modular architecture mentioned above.

PRINCIPLES OF THE DISTRIBUTED CONTROL AND MEASUREMENT SYSTEM FUNCTIONING

At present, most of the systems for measurement, control and automation are realised as DCMS (for example, control of technological processes, security systems but also electrical equipments of motorcars).

DCMS is based on computer communication - see block diagram in Figure 1. DCMS consists of a control unit (Master Unit, MU), communication busbar BUS and remote addressed functional units ARU (Addressed Remote Unit). BUS enables bi-directional communication. Communication between MU and ARU proceeds with defined protocol.

ARU have analogue signal (AIN) inputs, analogue outputs (AO) and inputs as well as outputs of status signals (DI, DO). The individual sensors S are connected with the AIN. Similarly, the sensors of

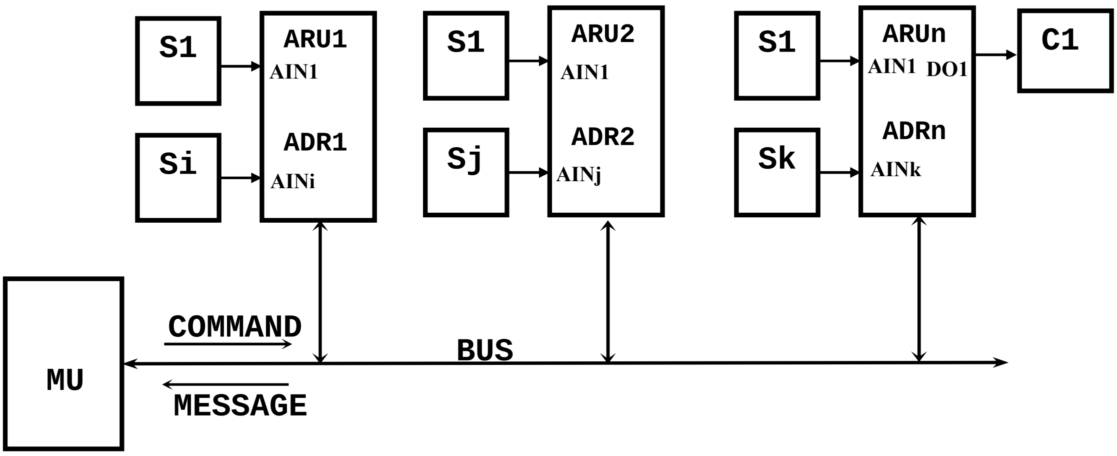

Fig. 1 Simplified block diagram of distributed control and measurement system.

status parameters can connect with inputs DI and with outputs AO and DO of the equipments for controlling external processes. For simplification, Figure 1 shows only the equipment C1 connected with DO1 ARU with the ADRn address.

MU sends control command along BUS to particular ARU. Control command contains address of units (for example, ADRn) and instruction for implementation of a specific function (for example, measurement of signal from sensor S1). Command is implemented only by the addressed ARUn and then it sends a message, which contains the measured data or the confirmation of the implemented command, through BUS back to MU. BUS can be realised as any bi-directional communication channel (metallic line, radio channel etc.), but it may have a complicated topology than that presented in Figure 1 (for example, it can be branched). It is possible to switch over communication channels using converters (for example RS-485/Ethernet).

Many modular systems with ARU equipped with inputs and outputs of unified signals are commercially available for industrial automation, as well as master units in form of an industrial PC. All types of standard communication channels (for example, standard RS-485, CANBUS, Ethernet) can be used as a communication bus.

Concerning reliability of operation of the equipment installed in an extensive area, it is important that ARUs galvanically separate the input and output circuits from busbar and MU. Danger of foreign disturbing potential energy intrusion (dispersion current, stroke of thunder) is thus eliminated.

DISTRIBUTED CONTROL AND MEASUREMENT SYSTEM IN THE JERONÝM MINE

The modular system MicroUnit developed by the company Tedia a.s. (www.tedia.cz) has been selected for realization of DCMS. Measuring units MU611 (6xAIN, 12-bit, DIO) and MU1211 (12xAIN, 16-bit, DIO), which communicate along metallic busbar of standard RS-485 by CRC secured AIBus2 protocol, are used for measurement of analogue unified signals. Selected speed of data transmission along DCMS BUS was 9600 bps (bit per second). At this low speed along with quality of used cable it is possible to achieve reliable communication up to the distance of approximately 500 m, which is completely satisfactory for the area of Jeroným mine. In case of necessity it is possible to strengthen the bus RS-485 and extend the bus transceiver.

The code word of AIBus2 protocol is 10 bits long. It contains bit address of unit on busbar (Bus_Adr), bit defining function (Fn), bit address of periphery in the given unit (Per_Adr), bit state of information, 4 bits for data transfer and 2 bits of check sum. Detailed description of the protocol is available at server www.tedia.cz. Protocol AIBus2 enables addressing up to 255 ARU with up to 255 peripheries (AIN, AO, DIO).

The seismic equipment in Jeroným mine has been monitored from June 2004. The installed seismic station is equipped with seismometers SM3 and recording apparatus PCM3-EPC with telemetric transmission of data through the GSM net. The apparatus works in trigger mode (Knejzlík and Kaláb, 2002). It consists of data acquisition system PCM3 and a single board PC (Advantech Biscuit PC PCM-3864). During the period when recording of seismic data is not triggered, the PC decodes only the time information of DCF. In case of more efficient PC, free machine time is available in this mode. This can be advantageously utilized for MU functioning in the built DMS. The free serial port COM1 is available for communication with DCMS BUS. The converter RS-232/RS-485 with automatic communication direction switching is installed between serial port COM1 and busbar DMS BUS. The charging of ARU (12V DC) is conducted parallely with DMS BUS.

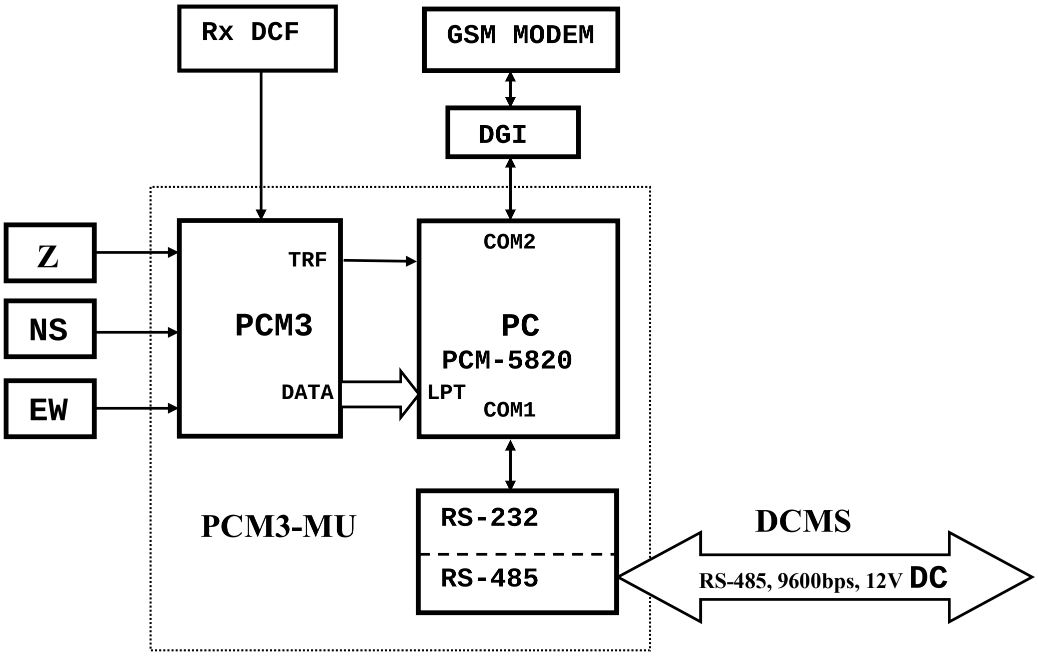

Fig. 2 Simplified block diagram of registration apparatus PCM3-MU.

Seismic data recording has the highest priority. If recording starts, activity of the MU control unit is interrupted until recording is finished. Simplified block diagram of modified registration apparatus is in Figure 2. Seismometers Z, NS and EW are connected with inputs of data acquisition system PCM3. The code of time information is transferred from receiver of time signal R_x DCF to PCM3. PCM3 carries out all functions related with digitalisation of seismic signal and control of triggered data recording. PCM3 contains also delay lane data, which enables recording of signal history section before triggering of registration. The delayed data along with the synchronically delayed time signal DCF are transferred from PCM3 to PC through parallel (LPT) part.

Active signal trigger flag (TRF) initialises the recording of seismic data. More efficient single desk PC Advantech PCM-5820 is used. Recording apparatus PCM3-EPC modified in this way is branded as PCM3-MU.

Control program for recording of seismic data was further supplemented by a module for controlling DCMS and data recording. At present it is possible to use units MU611, MU111, MU1211 and CCBM (maximum 10 addresses). The controlling routine for laser distance meter is being prepared. The data for each address are recorded into individual file dms_ADRn data.

Recording apparatus PCM3-MU is installed in chamber K1 inside the housing with the IP65 cover (Fig. 3). Receiver of time signal R_x DCF, isolation block DGI and GSM modem are installed in the main shaft and close to the surface. Yagi antenna of GSM modem is installed on the tower close to the shaft.

Use of the apparatus PCM3-MU as the master unit has markedly eased and made cheapened the realization of DCMS, as it is possible to use field verification of installed hardware and telemetric connection.

Monitoring points, established during the first half of 2007, are in chamber K1 and its vicinity (KV2, KD1, KD2) and in the proximity of chamber K2 (KV3, KK1) – see Figure 1 in the article by Kaláb et al. (2008). The following sensors have been installed in chamber K1 and in its vicinity since November 2007 and are presently used:

- KD3 and KD4 for measurement of joints openings (aperture of joints).
- KT1 for measurement of mine atmosphere temperature.
- CCBM1 and CCBM2 for measurement of rock mass tensor stress state changes.

There is a plan to install a laser distance meter in chamber K2 for measurement of roof deformation. That is why DCMS BUS has been installed only between chambers K1 and K2 so far. It is realized as 7 venous screened cables (1 pair for RS-485, 1 pair for charging, 3 veins kept as reserve).

Analogue signals from the sensors mentioned above are transmitted by unified current signals 4-20 mA to inputs of ARU and the sensors are also charged by them. Theoretically it would have been possible to use ARU with individual address for each sensor. This would have been an ideal solution in the matter of safety of DCMS in case of a thunder stroke, as each sensor would be isolated from the rest of the equipment. Installation of large number of ARU (installed in places with difficult access) is, however,

Fig. 3 Installation of PCM3-MU apparatus and water-tight box containing ARU1 and interfaces for CCBM1 and CCBM2 in the chamber K1.

not advantageous in the matter of installation and maintenance. Another disadvantage would have been the requirement of higher charging current (less time of operation from reserve accumulator) and lastly the high cost. As a second extreme, it would have been possible to connect all presently installed sensors to one ARU. It is, however, dangerous in case of a thunder stroke on surface above mine workings when dangerous differential potentials may be intruded in the system from the distance sensors by a spark-over unless their grounding is single-point (analogue inputs of ARU have common signal ground). As a compromise solution, all the analogue signals from sensors in K1 and its surrounding have been connected to ARU1 MU1211 (KV2, KD1, KD2, KD3, KD4) and others (KV3 and KK1) on ARU4 MU611 installed near the entrance to K2.

The sensing probes CCBM are used as intelligent ARU (ARU2, ARU3) with implementation of AIBus2 protocol (see Knejzlik et al., 2008). Block diagram of an interface for connecting CCBM to DCMS is represented in Figure 4. The interface consists of a communication converter RS-232/RS-485 with automatic switching of communication direction and from DC/DC converter, which changes feeding voltage 12 V from DCMS Bus to 5 V. The interface isolates circuits of CCBM probe from DCMS BUS. Signal ground CCBM is connected with locally earthed LGND in the place of the sensing probes installation.

Figure 3 shows the photograph of water-tight box, where ARU1 and 2 pieces of interface for sensing probes CCBM (ARU2, ARU3) are installed together with DC/DC converters for measuring sensors feeding.

SENSOR FOR MEASUREMENT OF CHANGES IN MINE WATER LEVEL

Differential pressure sensors (type LMP 33li) developed by the company JSP Nová Paka have been selected for the measurement of changes in mine water level. These have a range of 3m and 10m with standard output of 4-20 mA. Special casing, which ensures isolation of measuring membranes from aggressive mine water by rubber back filled with

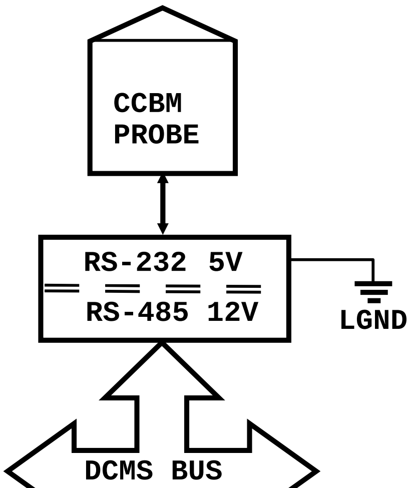

Fig. 4 Block diagram of interface for connecting sensor heads CCBM to DCMS.

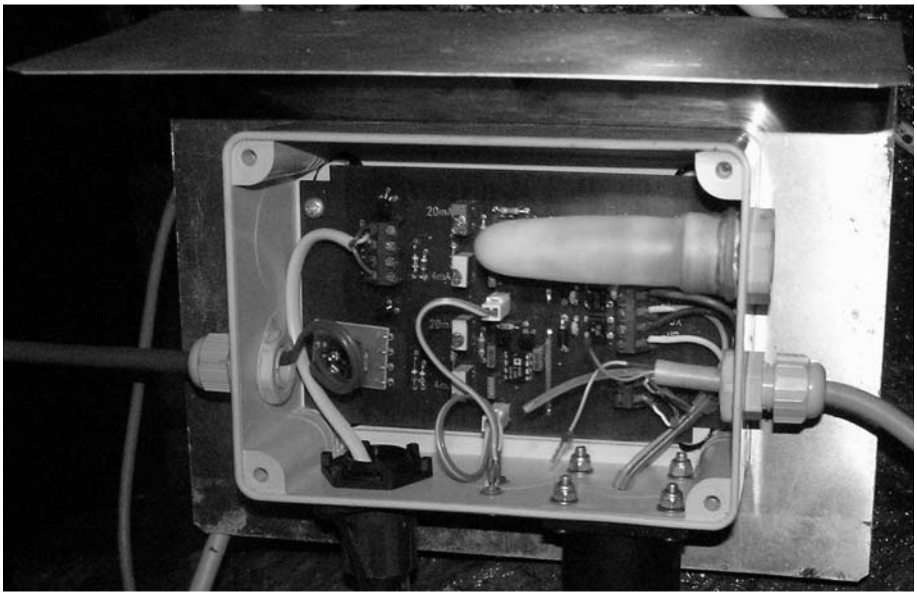

Fig. 5 Termination of compensatory tube of LMP 33li sensor in a waterproof box separated from the surrounding atmosphere by a rubber bag.

silicon oil, has been developed. This casing prevents contamination of measuring membranes by sludge and its sticking. As the sensor LMP 33li is differential, the space above the measuring membrane is connected through a compensatory tube inside the cable to the surrounding atmosphere. This tube is introduced to the water tight box containing signal conditioners for other sensors (KD2 and KT1) separated from the surrounding atmosphere by rubber bag - see Figure 5.

It is possible to use level measuring probes LMP307 or LMP308 from the same producer for measurement of mine water level. As per the producer, the accuracy of measurement is 0.1% in the range of measurement.

MEASUREMENT OF JOINT APERTURE AND CONVERGENCE

Two types of commercially available sensors are used for measurement of joint aperture and convergence:

- Micro-Measurement Linear Displacement Sensors series HS10 (range 10mm) and HS25 (range 25 mm), Measurements Group, Inc. (www.measurementsgroup.com)
- Inductive sensor LD630 (range 25 mm), OMEGA (www.omegaeng.cz).

HS series sensors use a fully active 350 Ohm strain-gauge bridge to sense spindle displacement, giving infinite resolution and excellent linearity. The gadgetry of HS sensors is apparent from Figure 6. The spindle is pushed forward by extension spring.

Signal conditioner was developed for analogue signal transmission (Im, current loop 4-20 mA) from strain gauge (HS series) and temperature (Pt100) sensors to inputs of ARU. The signal conditioner can be also utilised for measurement of temperature by means of resistance thermometer Pt100. The wiring schema of the signal conditioner, coupling of strain gauge sensor HS25 and of Pt100 temperature sensor is in Figure 7.

Accuracy of measurement of joint aperture and convergence is dependant on long-time stability of sensor displacement and drift of signal conditioner. The manufacture of HS10 and HS25 sensors does not specially mention the long term stability and includes it into total errors of measurement, which as per catalogue data should not exceed 0.1% of the range (0.01 mm for HS10 and 0.025 mm for HS25). Error in measurement is affected also by temperature distribution of the strain-gauge bridge. Here, the manufacturer determines the coefficient of 0.01%/°C for the whole range of measurement. Typical temperature drift on input stress asymmetry of the utilised operational amplifier is 1μV/°C, which matches to an error of 0.012%/°C during exciting voltage of bridge at 1.25 V and sensitivity of

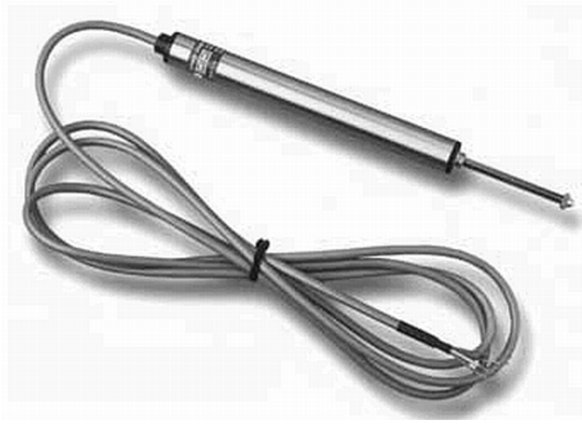

Fig. 6 Displacement Sensor HS25.

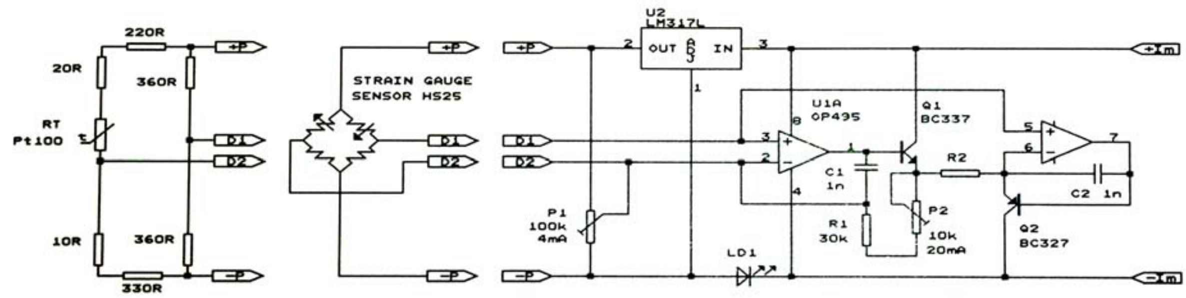

Fig. 7 Wiring schema of signal conditioner with both strain gauge and temperature sensor.

Fig. 8 Sensor for joint aperture-cased sensor HS25 installed in vertical joint (enclosure IP68). Station KD2.

6.4 mV/V. As per Figure 7 temperature error of HS 25 sensor with signal conditioner should not exceed 0.006 mm/°C (without the influence of thermal extensibility of metallic parts). This is a negligible value, as the Jeroným mine keeps a temperature of about 8 ^{0}C during the whole year.

To obtain better temperature stability it was decided to use inductive displacement sensors LD630 of Omega Company for stations KD3 and KD4. This type has an inbuilt signal conditioner with unified current output 4-20mA. Mechanical construction and dimensions are similar to case of HS25 in Figure 6. Two types of casings for protection of sensors against the mine atmosphere have been developed for installation of sensors, which has enabled their assembly in the underground. Figure 8 shows the first type of cased sensor HS25 installed in vertical joint. The spindle of HS25 sensor has been sealed using a rubber bag. The main body of the sensor is moulded. Such construction offers the highest protection but requires modification of the sensor.

Different type of casing design and fixing of sensor for joint aperture measurement installed at station KD1 is shown Figure 9.

The case of the sensor is constructed of chromium-plated parts for plumbing installation. A rubber bag is used for sealing the moving spindle, which touches the adjustable supporting spine. Sensor cases, as well as the supporting spine, are screwed on the bolts that are pasted to the rock mass by fast-setting cement. Special material is used for drilling of holes and holding of bolts during cement setting. A special sensor (HS 25 or LD 630) is isolated from the case and tips touching the spine are electrically isolated. Thus the resulting electrical force of isolation between measuring points and rock mass is improved.

Displacement sensor HS10 was also used as a sensor element of the convergence meter. Convergence meter has been conceived as a telescopic rod, which is supported by a gas spring between the measuring points. It consists of sensoring part closed inside the covering and extension rod. The sensor part with its cover removed is shown in Figure 10. Displacement sensor HS10 is mounted in parallel with the telescopic gas spring. The support plate opposite the sense spindle of HS10 sensor is mounted on the spindle spring. Signal conditioner is installed on the sensing part of the convergence meter.

Length of the extending rod is modified at the place of installation according to its specific conditions. Metallic dishes are pasted on the rock mass and tips of convergence meter are supported on to them. The top is on the spindle of gas spring - see Figure 10. Length of the lower tip at the end of the extension rod is adjustable. The gas spring is prestressed by the length of the lower tip, so that the convergence meter fixes into the tips. Finally, the supporting plate is set into suitable position with respect to displacement sensor and is secured.

External protection cover made from clad tubes of 110 mm in diameter protects the convergence meter in the mine. This protection covering is dismounted as

Fig. 9 Sensor for joint aperture measurement at station KD1. On the left of the sensor, a check glass slide is pasted across the joint.

shown in Figure 11. This figure shows only the upper and lower flange and socket with cable outlet.

CONVERSION OF MEASURED ANALOGUE SIGNALS TO PHYSICAL QUANTITIES

Measured signals x[adr, ch] are converted to the physical quantities by the software running in MU using formula:

Pq[adr, ch] = R[adr, ch].(x[adr, ch] –
– C0[adr, ch])/(C1[adr,ch]-C0[adr, ch]),

where: adr – BUS address of ARU, ch – ordinal number of measuring input,
R[adr,ch] – constant, range of physical quantity,
C0[adr, ch] – constant, calibration of zero,
C1[adr, ch] – constant, calibration of maximum.

The constants mentioned above, stored in configuration file, are fixed in the course of laboratory calibration of individual sensors. Resulting numerical values of physical quantities are stored in data files dms[adr], individual for each ARU. Sampling interval is 1 hour.

Fig. 10 Sensoring part of convergence meter KK1.

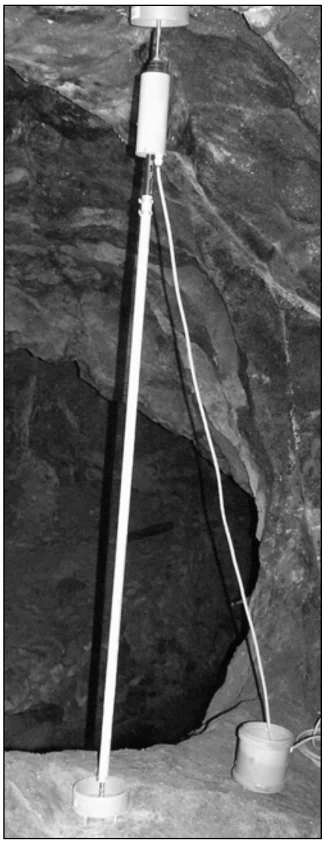

Fig. 11 Convergence meter KK1 with dismounted covering.

REPARATION OF ROOF DEFORMATION MEASUREMENT IN CHAMBER K2 WITH USE OF A LASER DISTANCE METER

Roof of chamber K2 is at the height of 7 m above the floor. Installation of mechanical extensometer would require high scaffolding, which would be very difficult and costly in the conditions of Jeroným mine. It is also possible to measure changes in the roof height with steadily installed laser distance meter LDM. In such case it is not necessary to install any equipment on the roof as LDMs are able to measure reflection from rough surface. In comparison with mechanical measuring instruments, laser measurement has lower accuracy and resolution ability. Laser measurements of distance are performed regularly by LDM type Leica DISTO in Jeroným mine. It was verified by this instrument that measurements of changes in height of roof of chamber K2 by reflection from roof are also reliable.

LDM as sensor for industrial automation is available in market. As an example, we here mention the parameters of AccuRange 4000 laser rangefinder developed by Acuity Company (www.acquitylaser.com):

- Range of measurement up to 16.5 m
- Accuracy 2.55 mm (during reflection from diffused surface)
- Resolution ability 0.32 mm
- Cover type IP67
- Output: digital RS-232, optional analogue 4-20 mA

This type of LDM would be advantageous for application in DCMS. Its main disadvantage is its high price. However, other commercially available equipments have similar parameters.

Based on good experience with LDM Leica DISTO, we have decided to integrate this type of LDM in the DCMS. Leica DISTO™ A6 is now available in market and is equipped with communication interface Bluetooth. The manufacturer states these parameters:

- Range of measurement 0.05-200 m (up to 100 m without reflecting target)
- Accuracy +/- 1.5 mm
- Resolution ability 1 mm

LDM Leica DISTO™ A6 uses simple text protocol for control instruction and measured data transfer. For the purpose of its use as ARU in DCMS it is necessary to resolve the following:

- Interface with compiler of protocols Aibus2-Leica DISTO™ and communication Bluetooth.
- Installation of LDM Leica DISTO™ in suitable cover on firm stand.
- Module of control program MU for communication of ARU with LDM.

We will assume that LDM will be installed in the beginning of 2008.

CONCLUSION

Distributed monitoring system is gradually being built in the historical mine working Jeroným in Čistá near Mariánské Lázně. The system enables monitoring of seismic loading, changes of mine water level, movement on joints in rock massif, convergence, changes of tensor stress state in rock massif and changes of geometry of mine working. The system has open architecture and is easy to extend it modularly by other sensors as well as methods of measurement. Single desk computer installed in the seismic recording apparatus is used as a control unit. Telemetric transmission of measured data to the evaluation centre located in the Institute Geonics, Academy of Science of the Czech Republic, Ostrava, is realised by switched connections through GSM network.

Presently, two sensors are installed for measurement of changes of mine water level, 4 sensors for measurement of joint aperture, 1 convergence meter, 2 temperature measurements and 2 probes CCBM for measurement of changes in stress state of rock massif. The laser distance meter Leica DISTO™ A6 is used in investigation for the measurement of roof deformation in chamber K2.

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