FMGM 95

FIELD MEASUREMENTS IN GEOMECHANICS

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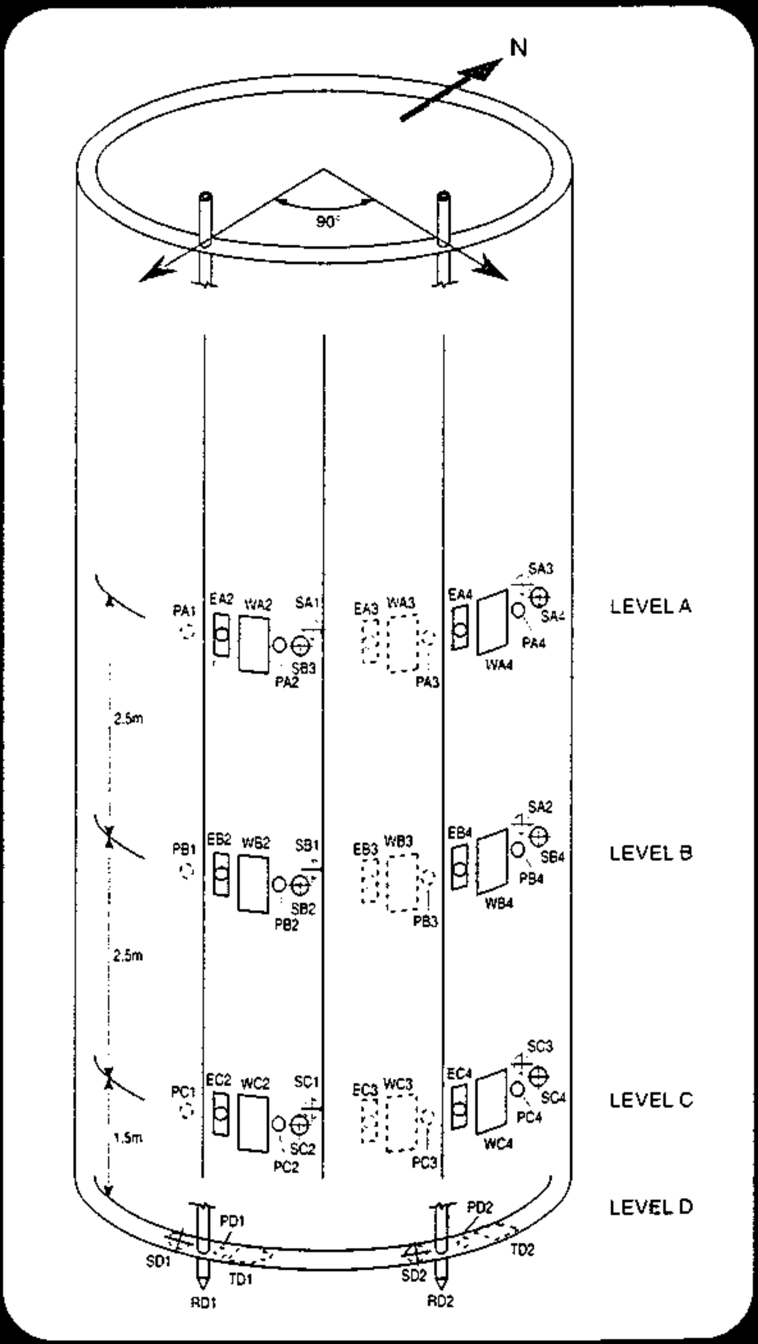

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COVER PHOTOGRAPH

Diagram of the instrumentation installed on a large scale skirt pile model for penetration and load testing. Model dimensions: 10 m in length, 5 m in diameter and 0,2 m wall thickness. Max applied load = 5000 kN; 180 channels of instrumentation data acquired automatically.

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PROBLEMS RELATED TO THE INSTALLATION OF A DATA ACQUISITION AND CONTROL SYSTEM FOR GEOMECHANICAL MEASUREMENTS IN UNDERGROUND WORKINGS

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ABSTRACT

Safety precautions in the Greek underground bauxite mines exploited by the room and pillar method, necessitated the installation of a system for the contiguous automatic monitoring of geomechanical data, such as loads on the rock bolts and displacements of the roof of the mining excavations. The devices installed are based on electronic components that translate the measured values into electric signals which are transmitted through the necessary wirings at the data acquisition unit where analog signals are converted into digital. The reliability of the system is investigated against environmental factors such as humidity, temperature, dust concentration and corrosiveness of the local atmosphere, adequacy of the cover protection of the sensory devices, disturbance due to electronic noise, damage due to blasting operations, as well as against adverse effects due to inexperience of the personnel and rearrangement of instruments according to the production schedule.

1. INTRODUCTION

Production of bauxite ore in Greece comes mainly from underground mines exploited predominantly by the room and pillar mining method. Competitiveness in the international market necessitates the decrease in the production cost, which in turn obliges to a continuous improvement of mining operations through the introduction of large scale mechanization, increased room spans, enhanced productivity and improved ore recovery.

The ore deposit in which the test takes place is located 750m above sea level in a depth of 450m with an average dip of 20^{o} , a W-SW/N-NE strike and an average thickness of 5.6m, varying between 2 and 14m. The hangingwall of the deposit consists of stratified and thinly bedded limestones. Expansion shell rock bolts are used for roof reinforcement. Till now, ground control is based on empirical observations of roof failure modes, conventional low cost measurements of the roof-floor convergence and the rock deformation, on pillar surveillance, pillar joint survey and on rock bolts pull out strength tests etc. (Economopoulos et.al. 1991).

However a number of controlled roof failures occurred mainly during the gradual increase of the room spans at the depillaring stage, i.e. of the gradual reduction of the pillar dimensions. The modes of roof failure observed are grouped into nine types, i.e. critical joints, midspan or abutment tensile cracking, ineffective rock bolts, proximity to junction drifts, improper rock bolt spacing, low strength of the immediate roof, peripheral spalling, karstic erosion and bent roof strata (Economopoulos et al, 1993a).The greatest roof falls occurred as violent incidents of relatively short duration (up to 48 hours) with precursor indications such as noise from the roof rock mass and the pillars, fall of small sized rock fragments, formation of tensile cracks on the roof (voussoir beam mechanisms) and bolt failure, while pillars in the affected area showed signs of heavy loading and spalling (Economopoulos et.al., 1994). Furthermore the existence of karstic voids in the roof in conjunction with faults affect the stability of the limestone roof and of the bauxite pillars (Economopoulos et.al., 1993b).

For keeping the safety standards high, monitoring of the mine is considered necessary, and low cost data acquisition and control system(DACS) is developed and tested in situ.

2. STRUCTURE OF THE DATA ACQUISITION & CONTROL SYSTEM

The data acquisition and control system (DACS) was especially developed for achieving real time geomechanical measurements in the underground bauxite mines. The main part of the system is based on a previous research work, focused on the development of an air -monitoring system for diesel-powered underground mines (Kontothanassis, 1994). The devices of the system are based on the structure of "electronic type" systems, in order to achieve optimal results during monitoring and control of the rock mass behavior.

Such components "translate" the measuring value of the desirable parameter (i.e. displacement, load etc.) into an electric signal of appropriate scale, which is then transmitted, through the necessary wiring to the data acquisition unit.

The basic structural element of the system consists of a PC compatible computer, in which all information from the sensors and the other devices are registered. This PC unit involves microprocessor, memory, power supply, without any keyboard and output devices, such as monitors or printers and plotters, which are considered optional. The structure of the system is shown in Figure 1. Resistance signals stream to the system from strain gage sensors, which are measured as part of a Wheatstone bridge circuit. This is symmetrical with four elements that enhance the system capability to detect small changes in the sensor. A continuous signal flow from the sensor streams to the interface and via an amplifier and a transformer reaches the computer, where interpretation of data and output of results is performed. The system is rugged and reliable, easily installable and relatively inexpensive. Isolation is used to protect people and equipment from contact with high voltage.

Data are transferred through cables in the form of analog electric signals. Before their entry into the computer, they are subjected to specific processing in order to be transformed into digital form. Thus , the necessary compatibility is achieved through a developed signal conditioning interface, which is then connected to a special electronic circuit which forms an analog to digital converter. In addition to the A/D, other components are required to obtain optimum performance , such as an amplifier, a sample/hold (S/H) circuit, a multiplexer and signal conditioning elements. The amplifier provides the A/D converter with the required high-level signal to perform efficiently. The multiplexer allows many input channels to be serviced by one amplifier and A/D converter. Software can control these switches to select the channel for processing at a given time.

The signal conditioning circuit pre-processes the input signal. Signal conditioning is divided into active, for amplification and isolation, and passive, for voltage division, surge protection and filtering. In this particular application an analog output signal is required for the activation of the external warning devices and a reverse process is followed. The computer is supplied with developed software, on which the undisturbed operation of the system, the storage of the measurements and the application of the appropriate criteria, for the control of the hangingwall and the support of the necessary decisions, are based. Polling is the simplest method for detecting a unique condition and then taking appropriate action. It involves a software tool which contains all the required measurements, analysis, decision making algorithms and planned actions.

Certain specifications regarding the operation method, the necessary power supply, the frequency of measurements, the environmental parameters and the required maintenance process of the sensors and the other electronic components, are established during the design and development stage of the system.

Strain gage transducers are modeled by a current source (4-20 mA) for being less sensitive to any magnetically induced noise than the voltage-driven devices. The maximum allowable cable length depends on several factors, such as the signal noise type, the signal level, the cable type, the noise source type, the distance between the cable and the noise sources, the noise frequency and the required accuracy. A shielded wire cable, 4-20 mA signal, accuracy 0.5%, a bandwidth limited to 10 Hz and cables 400 m long are proven to be sufficiently reliable for this typical underground mine environment. Signal entering in the system may include unwanted noise, which has to be minimized for achieving high accuracy. The major noise transfer mechanism includes conductive, inductive and capacitive coupling. The switching of high-current loads (i.e. booster ventilation fans) in nearby wiring may induce noise signals by magnetic coupling. Signal wires running close to AC cables may pick up 50/60 Hz noise by capacitive coupling. Allowing more than one power or signal path, ground loops may be produced that induce errors by conduction. The system is capable of monitoring and controlling up to 8 transducers at a maximum distance of 150 m from the central processor. It is used for continuous monitoring of roof response in a typical mining room from the beginning of the extraction until the end of the retreating stage.

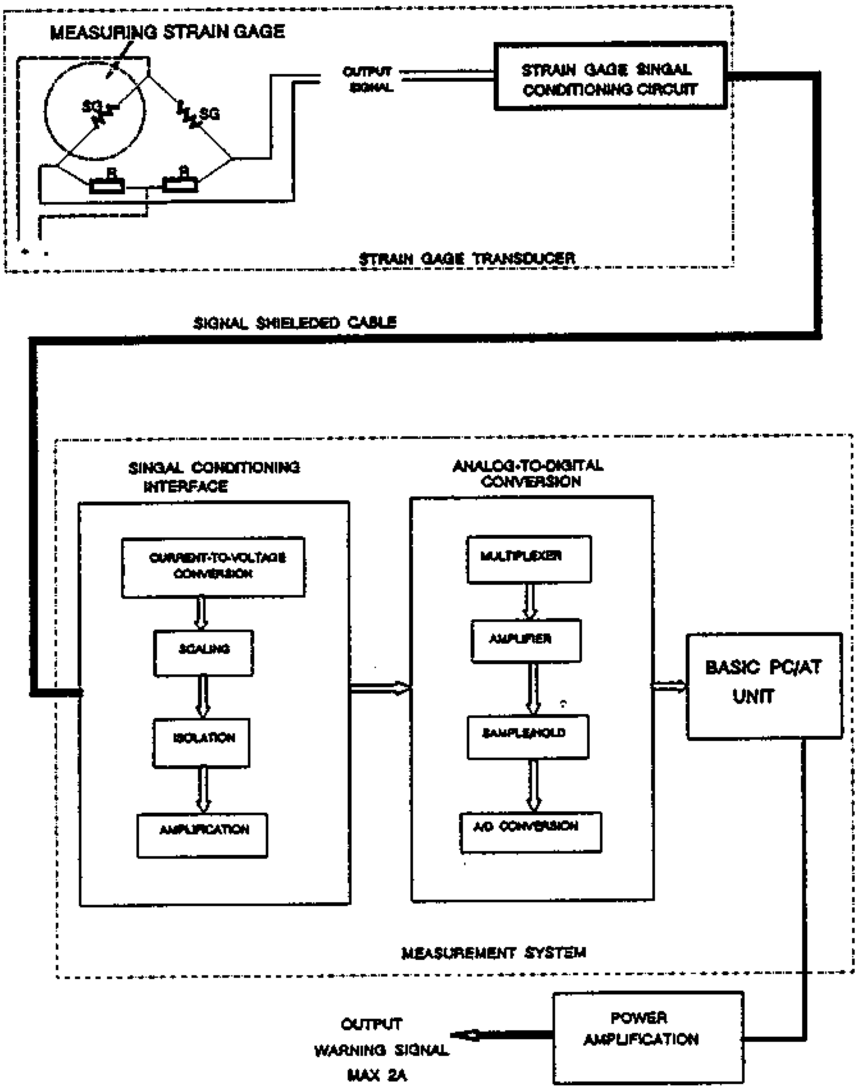


Fig.1 - Structure of the system

Roof deformation and stress changes are measured through load cells, rock compression displacement transducers and strain gages. Load cells and displacement transducers were acquired from the market. Strain gaged rock bolts were developed by bonding of strain gages on expansion shell rock bolt bars, 2.1m long and 16 mm in diameter, installed in 38 mm diameter boreholes. The instrumented bolts were calibrated in a laboratory uniaxial tension machine for the determination of the voltage change directly against with the known applied axial load. The rock compression displacement transducer measures the contraction of limestone layers by detecting the relative displacement that occurs between the roof surface and a fixed anchor, installed at the bottom of a 3m deep borehole. It has a rated output of 1 mV/V , a maximum excitation voltage of 10V, a bridge resistance of 350 Ω and a rated capacity of 50 mm, is calibrated in situ. The load cell is used to measure the loads acting on the rock bolt. It is characterized by the same specifications with the rock compression displacement transducer and a rated capacity of 20 tons.

The system is installed in the underground bauxite mine for evaluation and verification of its performance under real in situ conditions. Two instrumented bolts, an electrical load cell and a rock compression displacement transducer are installed and connected to a strain gage signal conditioning circuit. The data are collected and stored on a floppy disk of a PC, located approximately 60m away from the face . The system operates 24h/day and readings are performed executed at regular intervals, providing a continuous real time monitoring and control of the tested limestone roof.

3. RELIABILITY ANALYSIS OF THE SYSTEM

Reliability of a system is the probability of its function without failure under given conditions for an intended operating time period. It depends on the time of operation and on the environment. For continuous operation of the system for a time interval t, it is given by :

$$R(t) = 1 - F(t) \text{ or } R(t) = 1 - \int_0^t f(t)dt \text{ since } F(t) = \int_0^t f(t)dt \qquad (3.1)$$

where, R(t) is the reliability function evaluated at time t,
F(t) is the cumulative failure distribution and
f(t) is the failure density function.

The hazard rate z(t) of a part or a system, is the conditional measure of the rate at which failures occur. It's value, which is defined as the number of failures per unit time x number of components exposed to failure, is given by :

$$z(t) = \frac{f(t)}{1 - F(t)} \qquad (3.2)$$

Reliability distinguishes three characteristic types of failure rates which may be inherent in the system. These are exhibited by the "bathtub" and hazard rate curve (Fig.2) . This curve shows the decreasing hazard rate during the early life of the system, constant hazard rate during the normal operating life of the system and the increasing hazard rate during the wearout life of the system. For exponential distribution, which is the most widely used and well established statistical distribution for explaining the general failure distribution of electronic type systems during their normal operating life period, when the failure occurs at random, the reliability function is :

$$f(t) = \lambda \cdot e^{-\lambda \cdot t}, \; z(t) = \lambda, \; R(t) = e^{-\lambda \cdot t}, \; t \geq 0 \qquad (3.3)$$

where, t=period of operation and
λ=constant failure rate of a part or of a system, i.e. total number of failures per total operating time.

The most important factor for the application of this model is that the hazard rate must be constant and the age should have no effect on the hazard rate of the system. The mean time to failure (MTTF) is defined as the mean of the failure distribution of the component or the system :

$$MTTF = \int_0^\infty R(t)dt \qquad (3.4)$$

For constant hazard or failure rate MTTF is defined as the total operating time per total number of failures. The availability A of the system is :

$$A = \frac{MTTF}{(MTTF + MTTR)} \qquad (3.5)$$

where, MTTF corresponds to an 1/λ exponential failure distribution and
MTTR is the mean time to repair.

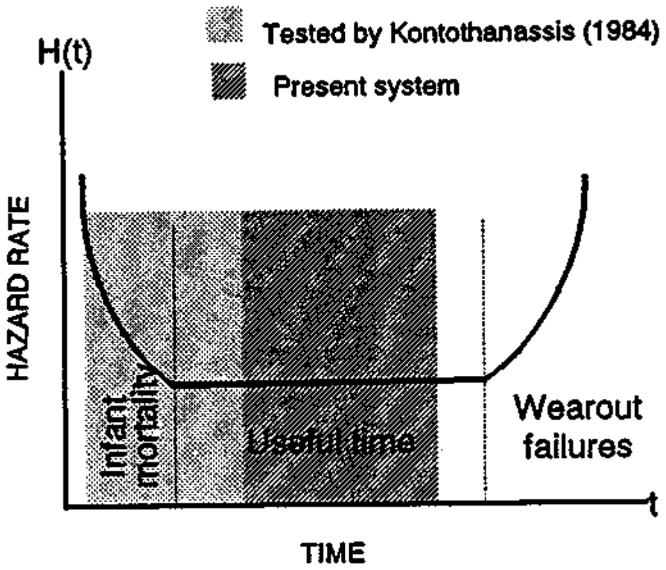


Fig.2 - Hazard rate curve of the "electronic type" system

The analysis of the structural-reliability model of the system is based on the "series configuration", being analyzed in four subsystems i.e. the Measurement Processing Subsystem (MPS), the Warning and Control Sub-system (W&CS), the Signals Modulation and Transformation Sub-system (SMTS) and finally, the Sensory Devices Subsystem (SDS) (Fig. 3). The MTTF of the system with sub-systems connected in series and having constant failure rates and the λ values are:

$$MTTF = \frac{1}{\lambda_{MPS} + \lambda_{W\&CS} + \lambda_{SMTS} + \lambda_{SDS}} \qquad (3.6)$$

$$\lambda_{system} = \frac{1}{MTTF_{system}} \qquad (3.7)$$

The sensory devices are connected in parallel so that any probable failure of a device does not provoke the failure of the subsystem. A system or a subsystem is considered to be in parallel from the reliability point of view, if only one component needs to work for the system success. The reliability of a parallel system is :

$$R_{system} = 1 - (1 - R_1) \cdot (1 - R_2) \cdot (1 - R_3) \ldots (1 - R_n) \qquad (3.8)$$

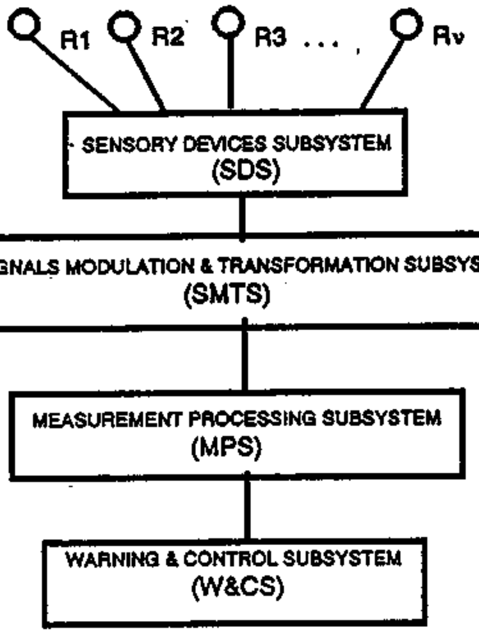
For the subsystem of sensory devices of the two strain gaged bolts, the load cell and the rock compression displacement transducer, the reliability is given by :

$$R_{SDS}(t) = 1 - (1 - e^{-\lambda_{SG1} \cdot t}) \cdot (1 - e^{-\lambda_{SG2} \cdot t}) \cdot (1 - e^{-\lambda_{LC} \cdot t}) \cdot (1 - e^{-\lambda_{RCDT} \cdot t}) \qquad (3.9)$$

where, λ_i is the constant failure rate of each sensor device, such as the load cell etc.
In Table 1 the failures which occurred during the operation of the system are shown.

Table 1. Observed failures

Hours of continuous operation	failure (subsystem)	problem
500 h	SDS	cut of LC output signal cable
1250 h	MPS	failure of floppy disk drive
Total hours =1700		



$$R(SDS) = 1 - (1-R1)(1-R2)(1-R3)...(1-Rv)$$

$$R(SYSTEM) = R(SDS)\ R(SMTS)\ R(MPS)\ R(W\&CS)$$

Fig.3 - Analysis of the structural-reliability model of the system

According to O'Connor (1991), the estimation for MTTF is approximately 2500h. From Table 1, $MTTF_{W\&CS}$ for each subsystem is:

Table 2. Reliability parameters of the subsystems

Subsystem	MTTF [h]	λ [10^{-4}/h]
MPS	1250	12
W&CS	2500	4
SMTS	1700	6

For the estimation of λ_{SDS} the following frequency parameters are evaluated :

$$\lambda_{LC} = \frac{2}{1700} = 1.2 \cdot 10^{-3},\ \lambda_{SG1} = \lambda_{SG2} = \lambda_{RCDT} = \frac{1}{1700} = 5.8 \cdot 10^{-4}$$

Under the assumption of constant failure rate for 100 h of operation,

$$\lambda_{SDS} = \frac{-\left[\ln(1-(1-e^{-\lambda_{SG1}\cdot 100})\cdot(1-e^{-\lambda_{SG2}\cdot 100})\cdot(1-e^{-\lambda_{LC}\cdot 100})\cdot(1-e^{-\lambda_{RCDT}\cdot 100}))\right]}{100} = 2.0 \cdot 10^{-7}$$

Thus, from (3.6)the mean time failure of the system (MTTF) is 454,5 h, and from (3.7) the constant failure rate of the system λ is 2,2 .10^{-3}. The reliability of the system is evaluated by (3.3) :

$$R(t) = e^{-0.0022 \cdot t}$$

The availability (A) of the system if we consider that MTTR is 4h, is 99,1%.

A similar DACS system with sensory devices for air quality monitoring in underground mines was tested under similar conditions (Kontothanassis, 1994). It is assumed that the system is in the normal operating life and the failure rate is constant. The system for air quality monitoring was tested underground for 112 days and for 265.5 hours of operation. It's reliability analysis results were :

$$\lambda_{MPS} = 7.5 \cdot 10^{-3},\ \lambda_{W\&CS} = 7.5 \cdot 10^{-3},\ \lambda_{SMTS} = 1.1 \cdot 10^{-2},\ \lambda_{SDS} = 2.1 \cdot 10^{-4}$$

The mean time to failure of the system (MTTF) was 38.2 h, the constant failure rate (λ) was 26.2×10^{-3}, the reliability R(t) of the system was $e^{-0.0262 \cdot t}$ and the availability A was 98.7%.

4. PROBLEMS ENCOUNTERED

The system has been under operation in the underground mine for more three months. During that period, the problems which are faced are originated from, the installation of the devices, the construction of the instrumented bolts, the breaking of the cables, the rearrangement of the cabling, the drop of voltage and the impact of the environment.

Great care must be given to the correct installation procedures, to the calibration of the devices and their protection from damage caused by detonations in nearby stopes. It takes about two shifts, three workers and a platform for the installation of a complete DACS system in an underground mine (installation of devices, positioning of cables, drilling of drillholes, installation of sensory devices and calibration). The installation of the rock compression displacement transducer needs two days. The whole system can be transferred to another site very easily. All the sensory devices except the low cost strain gaged bolts are reusable for measurements in different mine sites.

For obtaining precise strain measurements both the correct adhesive and the proper mounting procedures must be employed. When mounting a strain gage, it is important to prepare carefully the surface of the bolt where the strain gage is to be located. Surface preparation includes solvent degreasing, abrading, application of gage layout lines, conditioning and neutralizing. The reliable performance of resistance strain gages is seriously affected by the underground mine environment (moisture, humidity, temperature etc.). Thus, the strain gages must be well protected with special rubberized coatings against humid environment and any mechanical damage. It takes about three days to construct and test ten strain gaged bolts.

Detonations caused two breaks up to now to the cables which connect the sensors with the signal conditioning circuit. All the cables are installed just below the roof to minimize hazards of damage from mining equipment or human error. The position of the cables has to be changed sometimes according to the evolution of mining operations for ensuring their protection from damage. The output signal cables must be protected against cutting and corrosion.

Voltage drops, during the initial stage, caused incorrect readings and necessitated the installation of a voltage regulator. Hard environmental conditions, such as humidity and dusty air, damaged a disk drive of the PC and necessitated its replacement. Nevertheless, the rest of the hardware , which is installed into steel boxes for better protection, operates till now satisfactorily. The power supply devices must be designed according to special specifications for the underground mine environment.

The percentage of the relative humidity constitutes the most significant parameter of the underground atmosphere and affects decisively the operation of the electronic circuits of the system. The protection of the central unit and the sensory devices improves the actual life duration and the availability of the system.

The corrosiveness of the underground atmosphere was relatively low and no particular indications of corrosion were observed on the metallic parts of the system.

The sensory devices were well protected against humidity and dust. Additional covers were made for RCDT and strain gage signal conditioning circuit device for their protection from nearby blasting.

The air temperature in the mine was considered to be ideal for the operation of the system's electronic and electric components and contributes to their protection against failure due to overheating.

The investigated sources of electronic noise showed no indication of significant influence to the sensors' output electric signal. The proposed techniques, based on the development of the appropriate software and on the installation of low-pass filters, are proved efficient. They are recommended for any similar application.

The vibrations generated by nearby production blasting do not affect the performance of the sensory devices.

The employment of qualified personnel or the suitable training ensure the correct operation of the system and will decrease the early failure rate during the installation stage. During this ordinary operation, the system operates automatically and requires very little maintenance.

The production schedule is not actually interrupted when the rearrangement of the sensory devices is needed.

5. CONCLUSIONS

A low cost and reliable monitoring system for real-time geomechanical measurements is developed and reference is made to the anticipated problems. The ways to solve different problems are analyzed. Up to now the operation of the system fulfills its main requirements. The installation of the system is done easily and quickly, even under adverse underground mining conditions. It gives real time reliable measurements. The system may be operated by the foremen and the data may be easily read from the monitor or from the floppy disc. The construction and operation cost of the system is low and competitive with similar products produced in the international market. It is quite advantageous since it may be connected with sensory devices by different companies which fulfill some minimum technical specifications (output voltage etc.). The capabilities of the system are very high. The number of sensors and the length of cables can be optionally increased. It is characterized by large storing capacity and it is tested under real adverse mining conditions. It can be used for different kinds of measurements such as geomechanical measurements, air monitoring etc. It can be used both in underground mines and in tunnelling. Its further application and extension will strengthen the confidence on its reliability.

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