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IMPROVEMENTS IN METHODS FOR MONITORING ANCHOR CASINGS IN MINING EXCAVATIONS OF KGHM POLSKA MIEDŹ S.A. MINES

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Abstract: This article presents the results of works carried out by KGHM CUPRUM Sp z o.o. CBR (Research and Development Centre), on behalf of KGHM Polska Miedź S.A. It is aimed at improving previously used monitoring methods of mine excavation anchor casings used in underground copper ore mines of KGHM Polska Miedź S.A. It presents a method allowing for continuous measurement and recording of load changes in instrumented anchors. This method was developed by request of KGHM Polska Miedź S.A. Particular attention was paid to issues related to the impact of dynamic changes of rock formation pressure on the excavation in anchor casing.

Keywords: anchor casing, monitoring, dynamic manifestations of rock formation pressure

INTRODUCTION

The use of anchor casings creates an effective method of protecting underground mine excavations in KGHM Polska Miedź S.A. mines. This is due both to favourable geological and mining conditions (enabling their usage) and the undeniable advantages of this type of casing – using the rock formation`s natural ability to support itself and enabling full mechanization of its implementation as well as economic factors. Conditions and principles for the use of anchor casings in underground copper ore mines are defined in "Appendix no. 3" of the Regulations of the Ministry of Economy from 28th of June 2002 on occupational health and safety, conduct of traffic and specialist fire protection in underground mines (Official Journal no. 139, item. 1169 from

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2006, no. 124, item. 863 and from 2010 no. 126, item. 855) titled “The design, execution and control of anchor casings in coal mines and in copper, zinc and lead ores mines”, point 2″, “The design, execution and control of anchor casings in copper, zinc and lead ores mines”.

An accurate assessment of the interactions between the natural rock and installed anchor casings, in real mine (underground) conditions is beset with many difficulties (Cała et al., 2001). In the case of support casings, basic information about their correct functioning and physical condition is already provided by a visual assessment of damage (deformations, cracks) allowing for prompt implementation of remedial measures necessary to preserve the stability of the excavation. Anchor casings, except for the portion located at ceiling level, are built into the opening and practically inaccessible for direct evaluation of their condition and thus effectiveness.

The control of an anchors' effectiveness is basically executed using torque wrenches and load capacity tests using hydraulic dynamometers. These tests are conducted randomly and allow only a judgement of the adequacy of anchor installation and its actual load capacity on site. The stability of an excavation is assessed by ceiling strata separation indicators (SRS), periscopic sight glasses (to observe strata separation in boreholes) and convergence meters (to measure the compressive forces), which do not provide information about the load exerted on built-in anchors. Both excessive loading of anchors – which may result in breaking of the bolt or destroy its fixing into the rock formation – and a significant decrease or complete loss of tension are phenomena that threaten the stability of underground mining excavations and consequently the safety of the staff. Knowledge of actual loads exerted on excavation casings, their physical condition and simultaneously the deformations occurring at ceiling level are an irreplaceable tool to identify and evaluate the effectiveness of excavation protection. Monitoring of interactions between anchor casing and rock formation is only possible using specially designed control and measurement instruments. Accurate measurement of pre-tension and then control of anchor load variations over time is enabled by special dynamometers (installed in built-in anchors) or by instrumented anchors placed for testing purposes. Application of these methods to monitor the state of anchor effort has been limited so far only to research into interactions between the anchor and the rock formation. Tests concerning interaction between anchor and rock formation required by law, as well as additional tests are limited to inspection only, they do not allow for continuous monitoring of anchor load changes.

The basis for continuous monitoring of anchor load changes requires construction of adequately rugged devices, allowing continuous monitoring and measurement (and recording of results), over a relatively long time period, in difficult mining conditions. The basic method of anchor casing load testing is currently achieved using instrumented anchors. The operation of instrumented anchors is based on known and successfully used (for a long time) methods of resistance strain measurement, utilizing the principle that the resistance of metal wire changes with a change in its length. It is a precise method of measurement, which, with knowledge of the dimensions of the test subject, allows for accurate measurement of forces acting on it (based on so-called tensometric rosettes, various types of force sensors manufactured to very high standards of accuracy and used in many test fields and measurements). Instrumented anchors allow measurement of the load carried by the casing but also the stress distribution along the length of the bolt. In the case of tie anchors, due to the character of their interaction with the rock formation, it turns out to be a basic issue. Measurements using instrumented anchors can be divided into two basic groups:

- measurements carried out by (periodic) inspection
- measurements of a continuous nature.

Inspection tests are simple to prepare – with the help of a suitable device, combined with an instrumented anchor; the anchor load is periodically measured. Periodically performed measurements, however, have a major drawback – they do not allow for continuous tracking of occurring variations that may have a sudden character e.g. sudden changes or fluctuations of rock formation pressure. Information concerning the impact of seismic shocks on interactions between the anchor casing and the rock formation, especially in relation to resulting load changes seems to be essential in assessing the suitability of different types and designs of anchors to be used in mining conditions as characterized by the presence of such phenomena.

Continuous measurements are, however, difficult to implement due to the requirement to use apparatus capable of continuous measuring and recording over a relatively long period of time (many months). In 2005–2011, KGHM CUPRUM Sp. z o.o. CBR, on behalf of KGHM Polska Miedź S.A. performed tests of load variations in tie and expansion anchors resulting from the impact of seismic activity. These tests were conducted using instrumented anchors in combination with a specially developed (for this purpose) prototype apparatus – enabling continuous measurement and recording of anchor load variations, particularly the impacts caused by seismic phenomena.

METHOD FOR CONTINUOUS MEASUREMENT OF ANCHOR LOAD CHANGES

In contrast to inspection measurements, the continuous measurement of anchor loads proves to be a technically difficult and complicated issue. A specialist measurement system was developed in KGHM CUPRUM Sp. z o.o. CBR in cooperation with the Institute of Mining, Wrocław University of Technology, on behalf of KGHM Polska Miedź S.A. The system utilised advanced technology and specialised (dedicated) software to continuously monitor variations in anchor loadings in real underground conditions, to assess the influence of dynamic impact of rock formation pressure on the performance of basic casing anchors in underground mining excavations in KGHM Polska Miedź S.A. mines. The impulse to undertake these works was some reservations concerning the effectiveness of ceiling protection using expansion anchors during occurrences of dynamic fluctuations of rock formation pressure (Dębkowski et al., 2003).

The developed measuring method allows for measurement and recording of rapidly varying loads on casings caused by seismic vibration of the overhead rock ceiling. Each seismic shock is a source of elastic vibrations, propagating through the rock formation in the form of seismic waves. Existing knowledge clearly indicates that not the direct energy of the shock itself but the parameters of the wave have a significant impact on the loads placed on a ceiling protected by anchor casings (John & Zahrah, 1987). The main task of developed equipment is continuous measurement and recording of instrumented anchor load changes during many months and capturing the impact of rock formation vibrations on anchors, especially at the moment the shock wave reaches the installed sensor positions.

The basic measuring arrangement is composed of instrumented anchors, measurment amplifier enabling tensometric measurements (supporting instrumented anchors), a portable computer and UPS power supply (Madziarz & Sawicki, 2005). The use of a "Spider 8" amplifier (Hottinger Baldwin Messtechnik) enables integration with different types of sensors, including strain gauges, inductive bridges and others. High measurement accuracy and reliability of the results are guaranteed by the manufacturer through the use of proprietary solutions implemented in the device, effectively eliminating the impact of thermo-electric or galvanic interferences or the impact of electromagnetic fields on the performed measurement. In contrast to measurements conducted by inspection (periodically), the measuring system continuously monitors all connected instrumented anchors. A computer (using the appropriate application) continuously monitors the progress of measurements, analysing the recorded changes of axial forces in the bolts of connected anchors and decides to record or remove them (overwrite). This allows for efficient use of memory. To capture the quickly varying (dynamic) load changes of an anchor it is necessary to use a high frequency sampling rate (several hundreds Hz). No less important is ensuring a stable and uninterrupted power supply to the measuring equipment. For this purpose a high-capacity UPS power supply is used, which provides emergency back-up power to measurement devices even in the case of a power outage lasting many hours. In addition to a measuring amplifier and a computer supervising the course of measurements, the basic components in the measurement suite are the instrumented anchors. Instrumented anchors designated for measurements are conventional anchors fitted out for planned tests. By scaling instrumented anchors on a strength testing rig, on which strain gauge readouts can be accurately calibrated to known forces applied to the anchor, is possible to gain very accurate measurements of forces bearing on the anchor once it is installed in position in the mine – the anchor acts as a dynamometer (the method of attaching the strain gauges to the anchor bolts eliminates the impact of rod bending on the measurement of axial forces in the bolt).

CONTINUOUS MEASUREMENTS OF ANCHOR LOAD VARIATIONS IN UNDERGROUND COPPER MINES OF KGHM POLSKA MIEDŹ S.A.

After laboratory tests the above described measuring system was installed in mining conditions in D field, section G-22 of the "Polkowice-Sieroszowice" mine, characterized by relatively high seismic activity with the presence of high-energy shocks (Butra et al., 2006, Dębkowski et al., 2007). Simultaneous measurements were carried out on anchor load variations and associated seismic shocks arriving at installed triaxial accelerometer and strata separation sensors (both in the ceiling in close proximity to the instrumented anchors) The measurements were experimental, but the results showed without a doubt that by using well developed measuring methods it is possible to carry out continuous (not just periodic inspection) measurements of static and dynamic anchor load variations in real mining conditions. This represented significant progress in the field of monitoring interactions between anchors and rock formations during an occurrence of seismic phenomena and considerably increased the prospect of recognising issues related to the resistance of anchor casings to dynamic loads. Analysis of test results did not confirm reservations concerning the use of expansion anchors for the geological and mining conditions in which the tests were conducted (frequent seismic activity), field D, OG "Polkowice I" in "Polkowice-Sieroszowice" mine (Madziarz et al., 2010).

The consequence of a series of pilot tests dedicated to expansion anchors was a commencement of works aimed at assessing tie anchor bolt load variations during occurrences of dynamic phenomena (using the developed measuring system). The test relating to the impact of seismic shocks on the performance of anchor casings was carried out in the G-3/4 field in the "Rudna" mine (Madziarz et al., 2011). Choice of test location in this field resulted from its characteristic high seismic activity. Instrumented anchors used for measurement of seismic impact on anchor performance were typical anchors used in this field (RM tie anchor and KS expansion anchor). The purpose of the experiment was, among others, to compare the work of both types of anchors in identical geological and mining conditions, under the influence of seismic waves with the same characteristics. Measurements of tie anchor load variations and distortions in overhead ceiling rock formations were conducted concurrently with those for expansion anchors. Measurements and datalogging were constant, with only short breaks due to technical reasons (readout of results, inspection and maintenance of equipment).

The main technical problem in obtaining measurements of tie anchor load variations proves to be the uneven distribution of stresses along the bolt in this type of anchor, depending on the arrangement of the boundaries of ceiling rock strata separation and stress distribution in a pole-glue-rock arrangement. Analogous expansion anchor testing requires only one measurement point on the bolt of the instrumented anchor (one pair of strain gauges), due to the nature of the anchor`s loading – as a tendon attached at its two ends. For this reason, the instrumented tie anchors intended for continuous measurements were installed at carefully chosen locations. This demanded placement of a limited number (for technical reasons) of strain gauges on the anchor bolt at selected points (the necessity to pull out many sensor cables from the end of the bolt). Strain gauges arranged on instrumented anchors were placed based on preliminary measurements carried out using an instrumented anchor produced by Arnall-Poland, a preliminary assessment of the construction of ceiling rock in the intended installation location and an endoscopic examination to enable monitoring of the rock strata characteristics for the place of installation. Due to the increased number of measuring points on the anchor bolt it was also necessary to increase the number of measurement channels monitored by the measurement apparatus, in relation to the arrangement used for the monitoring of expansion anchors (Madziarz & Sawicki, 2009).

MEASUREMENT SYSTEM USED FOR MONITORING OF INSTRUMENTED TIE ANCHORS

The following is a components' description of the test rig used to monitor the performance of anchors under effects from seismic shocks and the impact of a receding mine face, performing continuous measurements of strata separation and monitoring vibrations in overhead ceiling rock formations:

- two independent measuring systems, each composed of a "Spider 8" measuring amplifier and a laptop computer (supervising the course of measurements)
- 4 instrumented anchors (2 tie anchors and 2 expansion anchors)
- prototype vibration sensor measuring high frequencies
- ply separation sensor operating continuously
- sensing and logging system to record vibrations in overhead rock formations (ACS apparatus composed of triaxial accelerometer sensor and a digital recorder with a permanent memory and an autonomous power supply).
- UPS power supply to stabilise line voltage and provide backup in the event of a power outage (up to 7 hours).

The measuring apparatus is placed in a lockable, metal cabinet to protect delicate equipment against mechanical damage or interference from unauthorized personnel (Fig. 1). The substantial modification of measurement method compared with the original solution was the introduction of a prototype ceiling rock vibration sensor utilising "quick" measurement (i.e. operating at a high sampling frequency) of instrumented anchor load variations. This solution enabled a precise correlation between the moment the seismic wave front reaches the instrumented anchors and the start of dynamic measurement. This enables a better use of computer memory and significantly simplifies the laborious analysis of recorded anchor load variations, eliminating any records not directly related to the impact of ceiling rock vibrations. The vibration sensor is mounted on the ceiling of the excavation and is connected to a “Spider 8” measuring amplifier. The measurement application (program) continuously controls the signal from the vibration sensor. The application is initiated with basic settings thus:

- 400 samples in a single recorded data packet (Count 400), sampling frequency of 800 Hz
- vibrational amplitude at which full recording is triggered (with high sampling frequency) is 1 m /s^2.

Fig. 1. The interior of the equipment cabinet at an underground test position
(„Spider 8”measuring amplifiers, portable computers and UPS power supplies shown in the picture)

If, after start of application and commencement of measurement, the vibration sensor detects the set threshold (or larger) amplitude of ceiling rock vibrations the apparatus begins dense recording of measurements, which consists of writing into text file measured values of all sampled channels at the high sampling frequency of 800 Hz. If no signal appears triggering a “quick” measurement the recording comprises only a single measurement value of each monitored channel, each representing an arithmetic average from a 10-minute period of measurement. Figure 2 shows the user's graphic interface of the measurement application.

In addition to continuous measurements of anchor load variations and the characteristics of rock formation vibrations reaching instrumented anchors, the procedure also comprises tests of ceiling rock strata separation (necessary to evaluate the performance of casings) using endoscopic examination of ceiling holes (endoscopic method) and measurements using an electronic strata separation sensor. This enables both the accurate evaluation of the geological structure of the ceiling rock in the tested area and a determination of the extent of strata separation and its size. Measurements using strata separation sensors were carried out either continuously or by inspection (to verify the accuracy of measurement results).

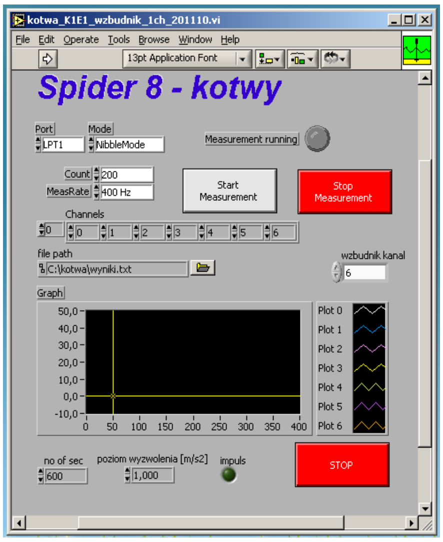

Fig. 2. User's graphic interface of measurement application

RESULTS OF MEASUREMENTS

Tests in the G-3/4 field of the "Rudna" mine were carried out in many stages, over a period of several years (Madziarz et al., 2011). Presentation of their full results significantly exceeds the capacity of this publication. In a recent series of measurements over several months, 31 seismic shock events were measured and recorded (energy levels from $1.2 \cdot 10^3$ to $1.7 \cdot 10^7$ J with epicentres located at distances from 89 m to 475 m from the measuring position). These recordings were made independently and simultaneously by the seismic vibration sensors and by the instrumented load anchors, which were controlled by a prototype vibration sensor. The recorded seismic phenomena were characterized by a wide amplitude range of both acceleration and the velocity of vibrations. The largest measured vibration velocity was 296 mm/s (at a frequency of 6.6 Hz), exceeding the level of 0.2 m/s, i.e. the value considered as being an upper limit for events not causing destructive impact to excavations. This event was measured to have an energy level of $5.4 \cdot 10^6$ J, with the epicentre at a distance of 188 m from the measuring position. Continuous load variations on monitored anchors recorded over a period of several months are shown in Figure 3.

Taking into account the primary purpose of these tests, their most important result is an understanding of the dynamic nature of instrumented anchor load variations, precisely at the moment a seismic wave arrives at the anchor. Examples of recorded parameters of seismic waves reaching the test position are shown in Figure 4, and anchor load variations related to them are shown in Figure 5.

It should be noted, that not all shocks registered during the test period were captured by the recording apparatus. In order to analyse their impact on the instrumented anchors it was necessary to simultaneously record the vibrations using ACS seismic equipment and the prototype vibration sensor. The reason for a failure to record all events during the test period was probably an insufficient amplitude of signals reaching the test position to activate the prototype vibration sensor (below its setpoint).

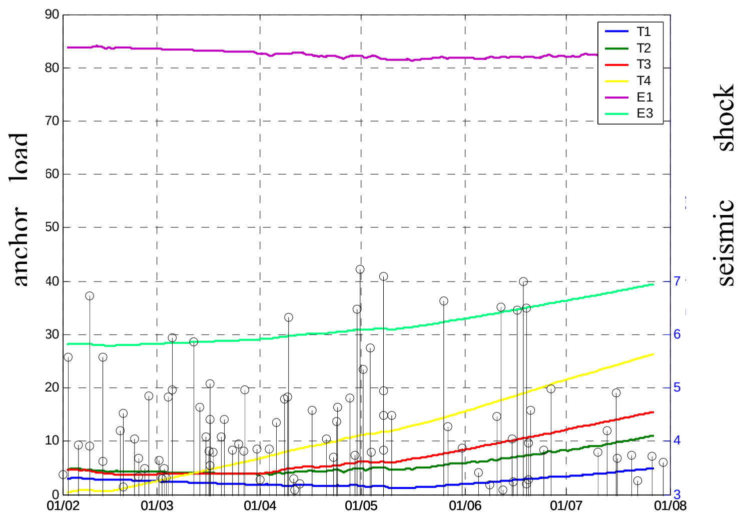

Fig. 3. Variations of forces in tie anchors in monitored positions (T1, T2, T3, T4) and expansion anchors E1 and E3 shown against background seismic activity

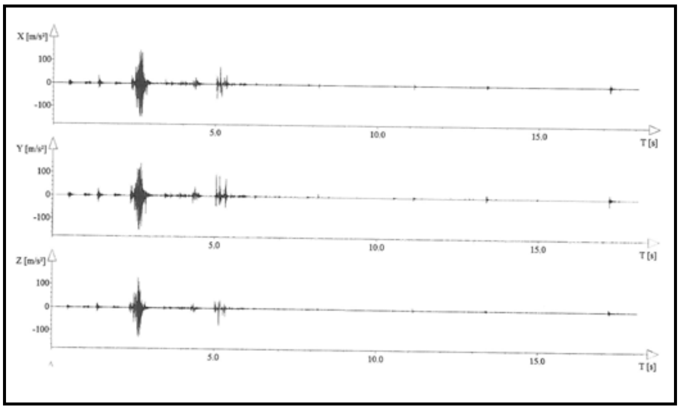

Fig. 4. Diagram of vibration acceleration resulting from a shockwave with an energy level of $5.4 \cdot 10^6$ J (epicentre at a distance of 188 m from the test position)

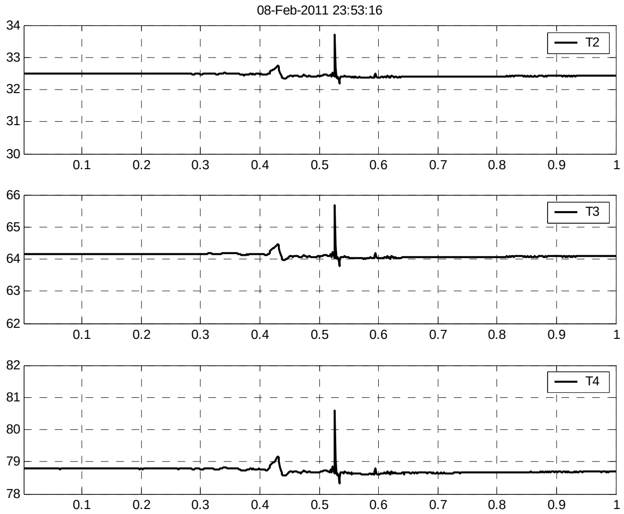

Fig. 5. The recorded dynamic impact on instrumented anchor load variations from a shock with energy level of $5.4 \cdot 10^6$ J, at a distance of 188 m from the test position

SUMMARY

Despite the technical difficulties related to the implementation of continuous monitoring of anchors, especially in detecting the impact of rock formation shocks on variations of their loading, the task appeared to be successful in long-term works carried out by KGHM CUPRUM Sp. z o.o. CBR, on behalf of KGHM Polska Miedź S.A., to the extent possible to achieve with underground testing in real world geological and mining conditions. Previously implemented measurement solutions with the use of instrumented anchors hardly enabled the evaluation of static impacts due to the cyclical nature of measurement. Assessments of the effects of dynamic phenomena associated with shocks were made indirectly, by analyzing the results of measurements made before and after the event in question (inspection measurements). The innovative attempts to carry out continuous monitoring of load variations in instrumented anchors presented in this publication were performed using a specially developed (for this purpose), technically advanced measuring system, using dedicated software for continuous control of tests – which allowed an effective use of computer memory (to save measurements carried out at high sampling frequency in order to capture dynamic interactions). These underground measurements represented significant progress compared with existing methods for monitoring mine excavation anchor casings, demonstrating the prospect of implementing continuous anchor casing monitoring in difficult mining conditions.

On the basis of these developed technical solutions to the task of monitoring and recording load variations on anchor casings in a real world mine environment and on practical experience gained (from present tests), KGHM CUPRUM Sp. z o.o CBR (on behalf of KGHM Polska Miedź S.A.) is currently conducting highly advanced tests on an innovative, compact, autonomous device designed for continuous monitoring of the performance of "MM-1" basic casing anchors. Testing of prototype devices has already been carried out in laboratory and underground conditions.

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