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FIRST RESULTS FROM LONG-TERM MONITORING OF DISTANCE USING A LASER DISTANCE METER IN SHALLOW MEDIEVAL MINE

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ABSTRACT
The oldest mine cavities of the Jeroným Mine were already mined out more than 400 years ago. That is why it is necessary to determine the stability of individual parts of underground spaces. The assessment of stability of mine cavities is based on the long-term monitoring of chosen parameters. A distributed measurement network has been operated here using several different types of sensors. A laser distance meter that is used for measuring the height of a large chamber is one of these sensors. The results obtained from this monitoring are presented. Even if no apparent correlation seems to be visible between Earth's tides and LDM variations, some features of recorded data, like dynamical frequency crossover in the power spectrum, could be due to the tidal cycles of the Earth.

KEYWORDS: Laser distance meter, Earth tides, Jeroným mine

1. INTRODUCTION

The Jeroným Mine is a National Cultural Heritage Site of the Czech Republic located at Čistá in the Sokolov Region. At present, the whole system of mine workings (cavities) is divided into two separate parts, one called the Old Mine Workings (denoted OMW below) and the other the Abandoned Mine Workings (denoted AMW below). The Jeroným Mine site forms part of the European Mining Heritage Network. The OMW are specifically related to the extraction and processing of tin during the second half of the 16th century. The AMW however, were created during the period of more than 400 years of exploration and extraction that took place afterwards (e.g. Iványi, 2000; Tomíček, 2007; Žůrek and Kořínek, 2004; Žůrek et al., 2008).

Quarterly geotechnical observations of the stability of selected parts of the AMW have been carried out since the year 2002. The convergence of mine workings along standard profiles, the fluctuations in the level of water standing in the mine and the growth of natural geological discontinuities in the rock mass have all been monitored. However, these measurements do not provide a record of the sudden fluctuations in these parameters.

Since the year 2004, the seismic loads on the mine workings have been monitored, especially when blasting was being undertaken during the restoration of the drainage adit. To obtain more objective and specific information about the state of stress-strain and the stability of this shallow mine (about 30 – 50 m below surface), a program of experimental work was designed and, in 2005, a distributed measurement network (DMN) was built (Kaláb et al., 2006, 2008a; Knejzlík and Rambouský, 2008). The DMN was designed as an addition to the existing system for periodic seismological monitoring in the mine working so that there would be a "continuous" record of the measured values. This network system is integrated with the existing seismic recording station equipped for transmission of data to the recording station in Ostrava via the GSM network. The monitoring system has a completely modular design so that the configuration of the system can be changed as required. At present, the distributed network operates using several different types of sensors (about 25 sensors are used now); however, it is possible to append up to a total of 250 sensors. Current monitoring points include:

- measurement of the seismic load on the mine working (three component digital recording),
- continuous measurements of fluctuations in the level of the mine water table (3 measuring points),
- continuous measurements of resistivity and pH of mining water (1+1 point),
- continuous measurements of the opening (closing) of natural fractures in the rock mass - (8 points, inductive sensors, vibrating wire crackmeter),
- continuous measurement of the vertical direction of convergence (1 point), continuous

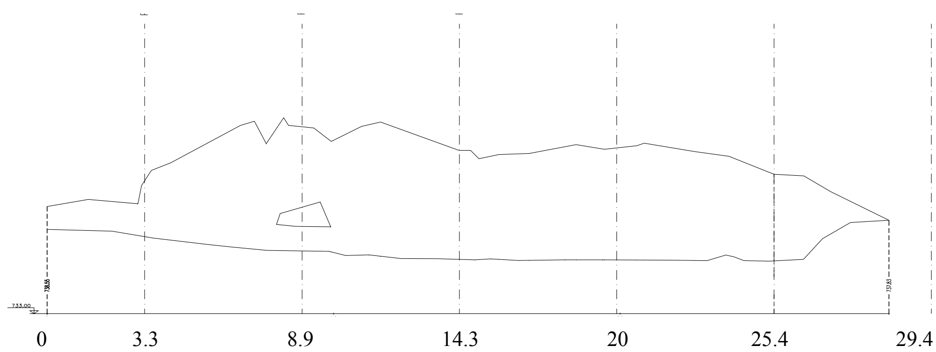

Fig. 1 Longitudinal section of the K2 chamber marking transverse sections; distance is in meters (Hrubešová et al., 2007)

measurement of the floor to ceiling height of the chamber using a laser distance meter (1 point),

- continuous measurements of the temperature of the mine atmosphere (2 points),
- continuous measurements of changes in the tensor of the stress state in the rock mass (2 points).

Results of both types of quarterly and continuous observations document only insignificant changes. However, it was selected the most critical structures and places. Some results (e.g. water level fluctuation) are significant for determination of safety in mine spaces (e.g. Kaláb et al., 2008a, 2008b, 2010; Knejzlík et al., 2010). Important changes are expected during reconstruction in mine spaces (e.g. driving of connection adit).

A laser distance meter (denoted LDM below) is used for the measurement of the height of an inaccessible ceiling of mining chamber in the DMN. Results from this monitoring are presented in this paper.

2. LASER DISTANCE METER

The chamber named K2 (about 50 m below surface) is a large space (Fig. 1). Its ceiling is at the height of about 7 m above the floor. The floor and ceiling have a very rough surface and the floor can be flooded. The installation of an anchor of mechanical extensometer requires high scaffolding. However, it is possible to measure convergences of the ceiling height with a permanently installed laser distance meter. In this case, it is not necessary to install any equipment on the ceiling, as LDM is able to measure reflection from a rough surface. On the other hand, laser measurement has a lower accuracy and resolution ability in comparison with mechanical measuring instruments.

In the Jeroným mine, laser measurements of chamber ceiling heights are performed by LDM type Leica DISTO - regular quarterly manual measurements. Based on this experience we have decided to integrate Leica DISTO^{TM} A4 to the DMN (for details see Knejzlík et al., 2010). 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 +/- 1mm (0.1 mm in remote control mode).

LDM Leica DISTO^{TM} A4, together with the interface, is installed in a waterproof case, which is equipped with anvisor and body tube on the foreside. The case is mounted on a modified parabolic satellite antenna tripod. The body tube is used as protection against drip water from the ceiling; vertical measurement is not possible in the mine due to drops of water. The foot-wall of the K2 chamber consists of blocks of rock, deposits of mud and flowing or stagnant mine water (Fig. 2).

The tripod of the LDM was mounted on a roughly horizontal outcrop of granite. The laser was directed at an approximately uniplanar plane on the ceiling, which was perpendicular to its beam direction (12º from vertical). The diameter of the laser beam at the reflecting surface was about 8 mm. Measurement was started on 14th May 2008. The sampling interval was set to 1 hour. A chart of instantaneous values of data recorded by LDM since 14th May 2008 until 1st July, 2010 is presented in Figure 3.

The medium measured value is h = 5912 mm and all the data lies within the interval of declared accuracy of LDM Leica DISTO^{TM} A4 (+/- 1.5mm) with the exception of 3 values recorded on 19th October 2008. We suppose that those extreme values could be impressed by vibrations of the tripod caused by seismic activity (West Bohemia seismic swarm 2008; Horálek et al., 2009; Kaláb and Lednická, 2010). Figure 4 shows the time variation of the LDM since 20th October 2008 until 25th March 2010 – an

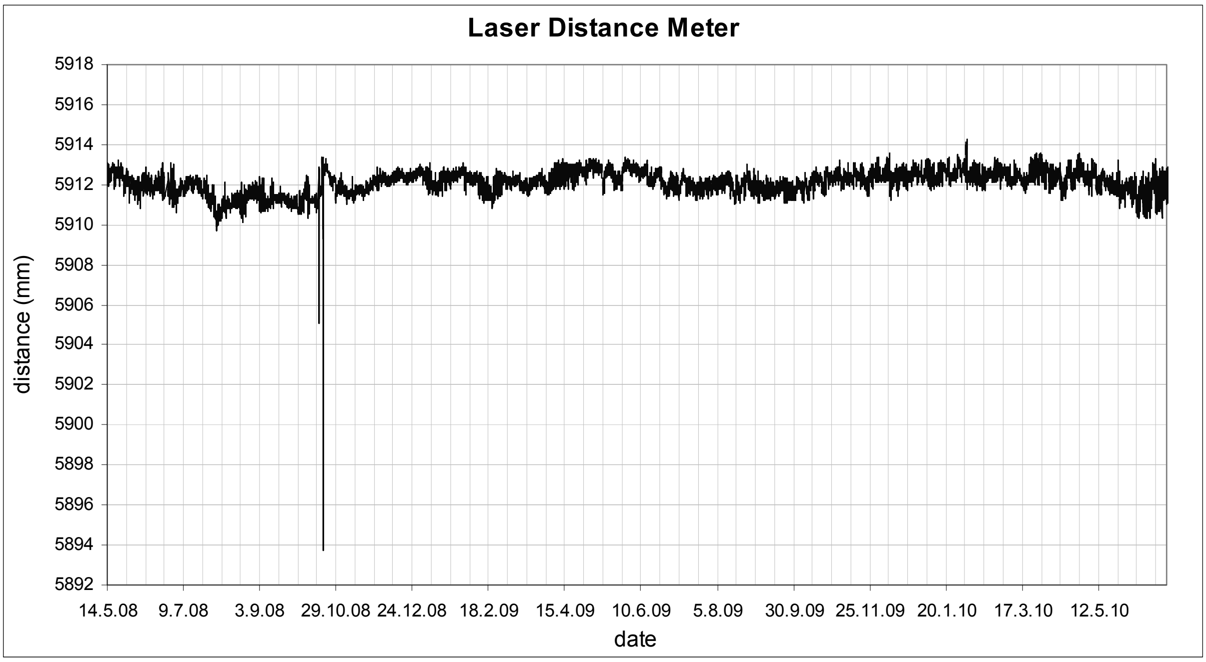

Fig. 3 Plot of laser distance meter data since 14th May 2008 until 1st July 2010.

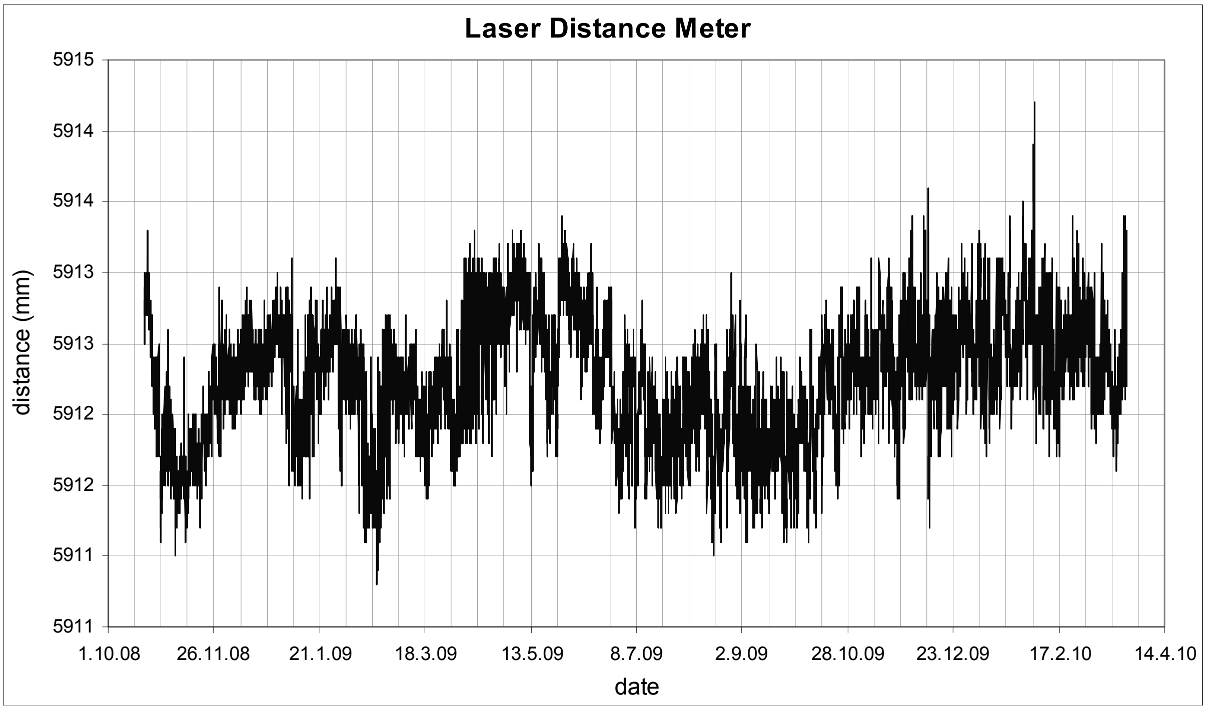

Fig. 4 Plot of laser distance meter data since 20th October 2008 until 25th March 2010.

interval for subsequent analysis. As is mentioned above, the sampling time is 1 hour. The existence of two types of temporal fluctuation is apparent, these are:

- long-range variation, which is quite smooth and slowly oscillating,
- short-range variation, seemingly noisy.

They are probably caused by a combination of real variations of distance evoked naturally, by measurement errors of Leica DISTO™ A4 and by the temperature instability of the primitive tripod. The rough reflecting surface of the ceiling and its roughly perpendicular direction notably lowers the accuracy of measurements.

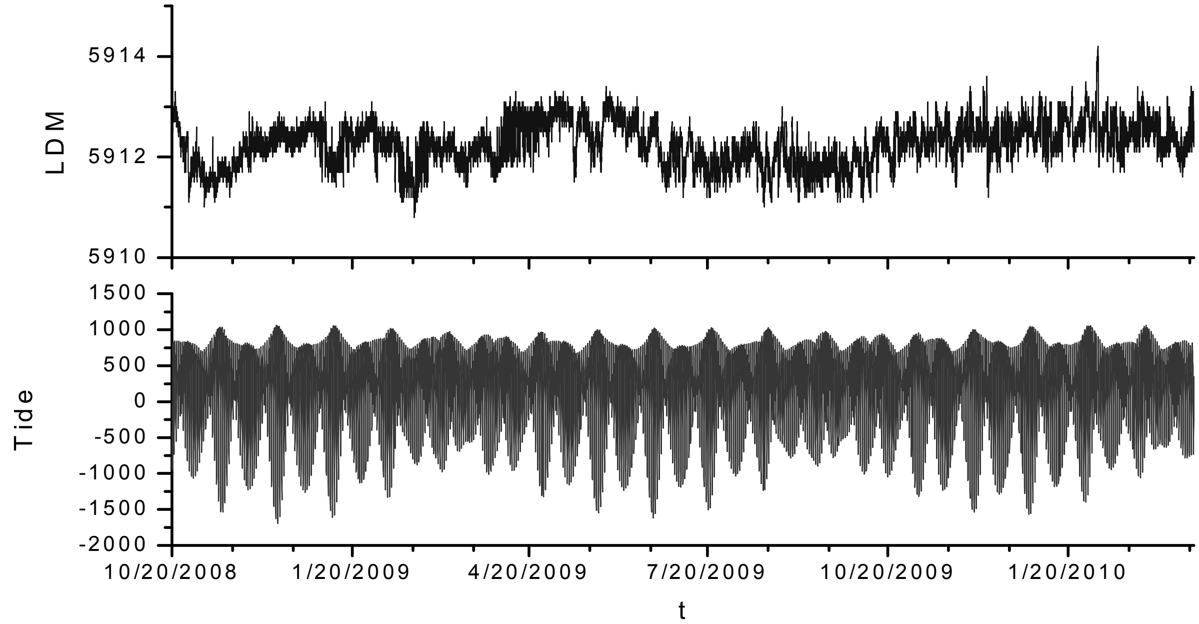

Fig. 5 Time variation of both the LDM and the synthetic Earth tide.

3. LDM VARIATION AND EARTH'S TIDES

The Earths tides are related to the deformation of the solid body of the Earth on many different timescales as it rotates in the gravity fields of the moon and the sun (Stacey, 1992). Earth's tidal deformations are represented by the combination of harmonic waves with different periods and amplitudes. The largest tidal component is the lunar principal wave M2 with a period of 12.42 hours. The second largest amplitude is the wave K1 with a period of 23.93 hours, which results from a combined influence of the Moon and the Sun. Other important components are the solar principal wave (or S2 wave) with a period of 12 hours, and the lunar principal diurnal wave (or O1 wave) with a period of 25.82 hours. Semidiurnal waves with periods of about 12 hours are primarily considered to link with the Earth's rotation. The diurnal waves with a period of about 24 hours are primarily explained by the inclination of the Moons orbit around the Earth and the Earths orbit around the Sun to the Earth Equator. The combined action of the Moon and the Sun and their relative movements produce a complex picture of tidal deformations (Saraev et al., 2010).

In order to see if the LDM variation is linked with Earth tidal deformation of the crust, we calculated the synthetic Earth tide at the location of the mine. The synthetic Earth tide, in the same measurement period, was calculated by means of the software Tsoft (http://seismologie.oma.be) (Fig. 5).

The power spectral density of both the LDM and the synthetic Earth tide is presented in Figure 6. The spectrum of the tide (red line) shows several peaks, the largest is linked with the M2 and K1 components. The power spectrum of LDM (black line) has a typical power-law behaviour, which appears linear if plotted in log-log scales. At low frequency bands, the scaling exponent; estimated as the slope of the line fitting by a least square method to the spectrum in its linear range, is about 1.2. At high frequency bands, the spectrum is approximately flat, indicating white noise behaviour at those frequencies. Furthermore, the LDM spectrum does not show any particular frequency peak, especially at those frequencies where the tide shows peaks. Therefore, it could be argued that Earth tide should not modulate the time variation of the LDM. However, it is quite visible that the crossover from the power-law behaviour to the white noise behaviour is around the frequencies corresponding to the highest tide peaks; so, probably the Earth tide could have a role in producing such a dynamical change point.

4. CONCLUSION

To obtain more precise data about the stress-strain state of underground spaces of selected parts of the medieval Jeroným Mine, a comprehensive study was started. This study includes research of older (and often undocumented) materials, quarterly and continuous monitoring of significant geological, geotechnical and geomechanical parameters and numerical modelling of current and supposed situations. Mathematical modelling is integral part of stability and stress-deformation analysis of the area of interest in the Jeroným mine. Modelling the stress-deformation and stability situation in the bedrock of the mine is somewhat complicated as to specific geological structure and hydrogeological situation in the area of interest, by properties of the rock environment influenced by insufficiently known degree of weathering of the granite massif, irregular geometry of underground mine workings and remnants of earlier mining activities often without any necessary documentation. The results acquired by the mathematical model may contribute not only for verification of the existing stability situation of the given locality, but they are also significant for creating an idea of development of the stable situation in connection with anticipated construction work, the variation of form of mining areas and the fluctuation of underground water level in certain parts of the mine (Hrubešová et al., 2007, 2010; Kaláb et al., 2008c).

The height of an inaccessible ceiling of a mining chamber is one of the parameters observed using a distributed monitoring network. In the case of the laser distance meter, the main task is the verification of the possibility of long term, sufficiently accurate measurement without a reflecting target. It is possible to declare that the presented design of LDM is sufficiently accurate and stable for planned continuous monitoring of the stability of the K2 chamber during the driving of a connecting gallery in the near future. The results obtained show that the power spectrum of recorded data from the laser distance meter does not show any particular frequency peak, but two different dynamical behaviours at low and high frequency bands. Even if no apparent correlation seems to be visible between Earth's tides and LDM variations, some features of recorded data, like dynamical frequency crossover in the power spectrum, could be due to the tidal cycles of the Earth.

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Fig. 2 LDM Leica DISTO™ A4 installed in K2 chamber.

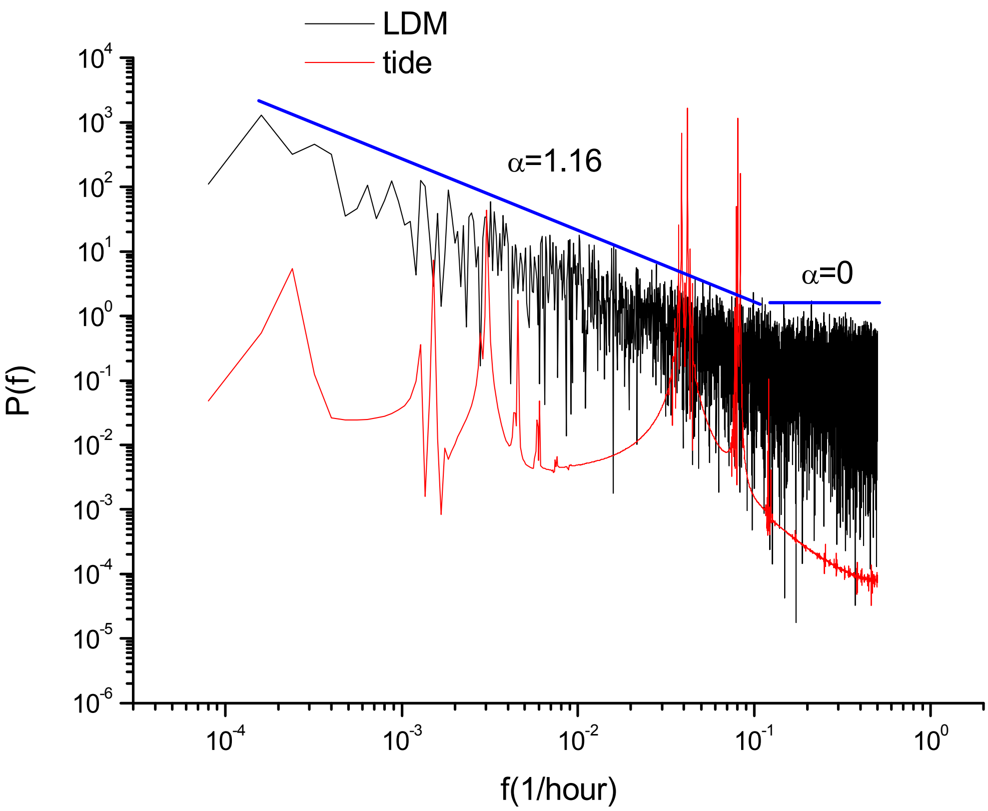

Fig. 6 The power spectral density of both the LDM and the synthetic Earth tide.