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Preliminary study of the possibility to use a mobile measurement rosette for testing horizontal distortions***

1. Introduction

Rapid development of modern measurement technologies allows information so far not achievable to be obtained, yet it results in the necessity to consider a number of parameters related to the influences of external conditions.

Temperature is an important factor affecting the condition of materials and systems. The most widely discussed aspect, in terms of thermal influences, is the linear and volume thermal expansion of objects; it is, however, worth mentioning that temperature affects also elasticity, magnetic properties, electric resistance, thermoelectric force and many other parameters characterising objects and systems [6]. At that point, our attention focuses only on the effect of temperature variations on the rosette length, since changes of its cross-sectional area, which add to the volume expansion, are of no practical importance for the topic being studied.

Analysing values of the linear coefficient of thermal expansion (LCTE) of alloys and aluminium, it can be stated that only in narrow temperature ranges, the linear variations of length are proportional to the temperature variations. This results in two terms being formulated: true and average coefficient of thermal expansion (ASM International). In practice, especially in geodesy, the average linear

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coefficient of thermal expansion is used, which describes properties of the material in a certain temperature range with a single value. Its value can be interpreted as tangent of the inclination angle of a straight adjusted to the plot of length variation in a given temperature range.

2. Description of the Measuring System

2.1. Subject of Study Using Mobile Rosette

Underground mining exploitation causes a series of negative effects on the surface of mining land. The most strenuous effects, from the perspective of building structures, are the compressive and tensile forces. Measurements carried out so far do not allow a complete description of phenomena present on the mining land surface to be given. Within the framework of the research project N520 006 31/1364 by the Department of Protection of Mining Area, Geoinformatics and Mining Geodesy, the project has been developed and a prototype of the device referred to as the "mobile measurement rosette" has been built. The main assumption of the device developed is a quasi-continuous monitoring of surface displacement above the edge of mining exploitation.

2.2. Construction of the Mobile Rosette

The prototype automatically measures variations of distance between the points. The operating principle of a single system component is based on the measurement of variation of distance between two points. An aluminium bar is permanently fixed to one point, and a digital calliper of accuracy ± 0.02 mm in the other. When the distance between the two points changes, the rod moves the position of the calliper slide. Variations of the distance are recorded by a PC connected with the calliper through a signal cable. The measurement results are recorded at desired intervals or each time when the reading of the calliper changes by a value not exceeding 0.01 mm. At the same time, temperature of the rod is recorded by the PC system at preset intervals. Mobile measurement rosette comprises three above-mentioned components placed on a T-shaped rosette during the field tests. Points determining the measurement rosette are stabilised in soil, in a form 0.5 m long of steel bars. Stability of setting is increased by aluminium plates connected with the subgrade. Arms of the rosette stretch to the distance of 3 metres in each direction. The diagram of the rosette is shown in figure 1.

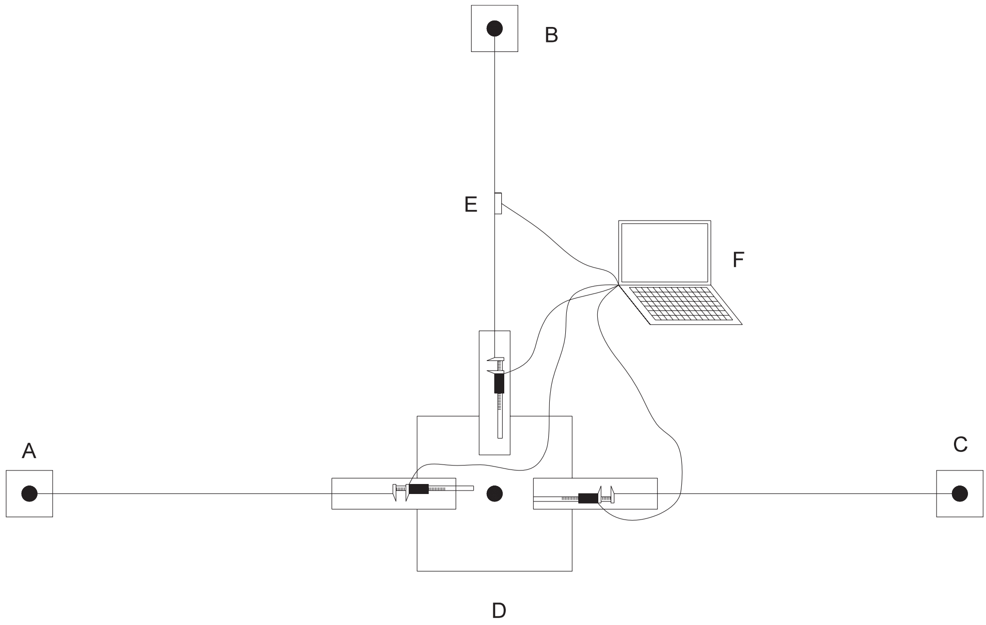

Fig. 1. Design of the mobile rosette:
A, B, C – anchoring points, D – central point with a set of electronic callipers,
E – electronic thermometer, F – PC

3. Laboratory Tests

3.1. Stand for Determining the Coefficient of Linear Thermal Expansion

The first stand for determining the coefficient of linear thermal expansion at the Department of Mining Geodesy and Environmental Engineering AGH University of Krakow, was designed and completed in 1998. Reconstruction of the system lasted from November 2003, and was possible thanks to the funds obtained from the research grant KBN 18.25.150.667. The system utilises the method of optical imaging, consisting in observation of variations of the structure length with a pair of spiral microscopes mounted on a fixed base of known length. With the three thermocouple sensors of T type with measuring joint (Cu-CuNi), it is possible to determine temperature of the material located in the chamber. The system is suitable for determining the LCTE of invar band of precise battens; however, after slight adjustments, it can be used also for testing the LCTE of other materials.

The first stand for determining the coefficient of linear thermal expansion was described in detail in the monograph *Laboratory testing of levels and precise battens* [2], and presented in figure 2.

Fig. 2. Stand for determining the coefficient of linear thermal expansion

Material temperature is recorded with the use of SOFTORL T8 application made by Introl. The data is then imported into authors' software, in which readings from both microscopes are recorded, based on which length variations of the material tested are calculated, and graphic presentations determining the LCTE value are generated.

3.2. Determining the LCTE of an Aluminium Rosette in the Geodetic Metrological Laboratory AGH Krakow (Fig. 3)

Chamber tests can be performed in temperature range –10°C to +50°C. However, due to high value of LCTE of aluminium and limited operating range of spiral microscopes, the temperature range was limited to +5°C to +35°C.

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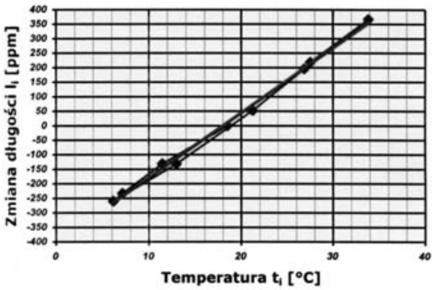
Współczynnik liniowej rozszerzalności termicznej (WLRT)

Zakres pom.: **2,864 [m]** Data: **03.04.2009**

Nr	t_i [°C]	l_i [ppm]	$\hat{l}_i$ [ppm]	ε_i [ppm]
1	18,49	0,00	10,81	-10,81
2	11,46	-130,81	-146,37	15,56
3	7,15	-233,49	-242,80	9,30
4	6,16	-259,57	-264,83	5,25
5	12,97	-131,31	-112,68	-18,63
6	21,26	53,29	72,83	-19,54
7	26,88	196,38	198,40	-2,03
8	33,87	367,12	354,76	12,35
9	27,54	218,89	213,20	5,69
10	20,76	64,48	61,65	2,84



WLRT α_T = **22,36 ± 0,48** [ppm/1°C]

Opracował:
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Fig. 3. Certificate of determination of LCTE for the bar being examined

Since the design and material utilised were identical, one component of the system was subjected to measurements (single, 3-metre long bar). As a result of measurements and initial calculations, for each thermal threshold, relative variations of the l_i length and average temperature of the aluminium bar t_i are obtained. The data is substituted into the model of linear regression, which will then be solved with the smallest square method, together with evaluation of the model.

This finally results in issuing a certificate of determination of the linear coefficient of heat expansion for the bar being tested, which contains the following information: length of measurement base, values of the temperature and length variation, equalisation results, graphical presentation and the value of the coefficient together with its uncertainty of determination.

The LCTE of the bar being examined was 22.36 μ/m/°C, and its uncertainty of determination 0.48 μ/m/°C. The determination coefficient for each model was 1.00. Certificate of determination of LCTE for the bar being examined is presented in figure 3.

4. Field Tests

4.1. Experimental Test Field

In order to verify the laboratory tests in practice, field tests of the mobile measurement rosette were carried out. The tests were carried out in area subjected neither to the impacts of mining exploitation, nor to the influence of communication routes (roads, railway etc.), high buildings and technical infrastructure. It was assumed that the rosette points would not be subjected to displacement. Figure 4 shows the mobile rosette in the test field. With the above assumption, the distance variations recorded theoretically, between the points, will only be the result of variation of bar length due to the temperature variations.

The test measurement was performed in such a manner that the broadest possible range of temperature variations be achieved for the material being examined, assuming the beginning and end of the measurement session at the same thermal threshold. The measuring cycle was started at 8.00 p.m. at the temperature of 12°C and finished at 6.00 p.m. the following day. The amplitude of temperature variations was 25°C (in the range from 6.5°C and 31.5°C). That corresponded to the temperature range in which the LCTE had been determined in the laboratory. During the measurement no rain was recorded, cloudiness was very limited and the system was exposed to direct sunlight.

Fig. 4. Mobile rosette in the test field

4.2. Results of Field Tests

Measurements carried out in almost whole 24-hour period allowed to determine basic values which describe accuracy of the system. In figure 5, a plot of variations of readings from digital callipers, during the entire measurement cycle, is presented. Raw data is marked with blue, and the reduced data in pink, respectively.

During the first part of the measurement carried out in night (between 8.00 p.m. and around 7.00 a.m.), no significant variations between the raw and reduced data, resulting from the effect of temperature, were discovered. Variations in that part of the measurement were of up to 0.4 mm. In the other part of the measurement, the variations were much more significant, reaching up to 1.5 mm. Attention should be drawn to the difference between the minimum and maximum readings of the callipers, which is 1.87 mm. For the reduced data, the difference between the minimum and maximum readings is only 0.5 mm. Taking into consideration the length of rosette arms (3.00 m), this yields in distortion of some 0.17 mm/m. Such value can be regarded as the minimum identifiable distortion as can be obtained from measurements with the aforementioned system. The figures given are the averaged values for 3 arms of the rosette.

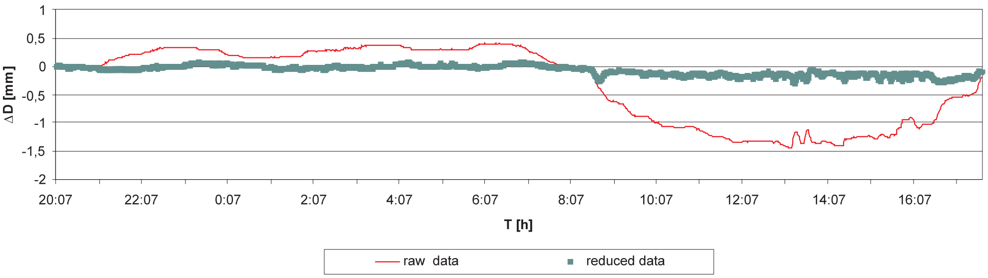

Fig. 5. Plot of variations of readings from digital callipers during the entire measurement cycle

5. Conclusions

The laboratory tests performed resulted in determining the coefficient of linear thermal expansion of 22.36 μm/°C. The field tests support the necessity of adjustments to be made due to temperature variations in relation to the results of the measurements. Bearing in mind high value of the thermal expansion coefficient of aluminium, temperature variations in the measurement systems must be essentially recorded. Only when accurate correlation of the material temperature and readings of the measurement system is achieved, it will be possible to eliminate the effect of thermal expansion of the material of which the mobile measurement rosette is made. Field tests allowed also the minimum distortion values to be estimated, as can be established with the system, at the level of 0.17 mm/m.

In view of the above, it can be concluded that the measurement system referred to as the "mobile measurement rosette" can be effectively used for testing horizontal distortion in areas subjected to effects of mining exploitation.

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