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SOME TEMPERATURE INFLUENCES ON LEVELS AND THEODOLITES

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SUMMARY: This work was instigated by some recent investigations on deformations of instrumental parts caused by temperature influences. The authors have considered the importance of temperature influences on levels and theodolites, as well as possibilities for their elimination. The sources and mechanism of temperature changes and temperature inhomogenity of the instrument's parts are outlined. There are also some examples of the changes of instrument's temperature caused by heat transfer (conduction, convection and radiation). Investigation is illustrated by results of our own examination of the level Ni002 and theodolite T3000. In general, it is recommended for temperature effects to be investigated and determined in the form of the functional dependence. Some additional conclusions which are of interest for the optimization of the measuring procedure are derived.

1. INTRODUCTION

The theory of errors of geodetic measurements is based in general on the assumption of constancy of instrumental errors (collimation error, transit axis dislevellement, vertical circle index error etc.). On the basis of this assumption, the measurement programs and the sequence of measurement operations are prescribed in order to insure that the measurement yield the results with random errors only. In reality very often this assumption is not fulfiled because constructers and manufacturers have not found yet convenient and cheap way to suppress or compensate for instrument errors variations. Therefore, it is necessary to know laws that these variations obey during measurement. If variations are significant, it is necessary to take them into account by modified measurement program or adequate corrections. Seldom there is oversight in construction causing severe consequences like thermally unprotected spirit levels of astronomic theodolites Wild T4 and Kern DKM 3A (Milovanovic, 1967) or magnetically unprotected compensator of precise automatic level Zeiss Ni1 (Rumpf and Meurisch, 1981).

Many investigations of the influence of magnetic field on compensators were initiated by Rumpf and Meurisch. For the most part these works have considered the phenomenological side of the problem. The simplified picture of the physics involved has given the possibility for quantitative estimation of the magnetic effects on Jena precision compensator levels (Marold and Wahnert, 1990). These authors have done experimental investigation of magnetic effect on many Jena levels. Their conclusion is that Ni002A and RENi002A can be used for precise levelling when usual magnetic fields are present. Nevertheless, our opinion is that due to the possibility that pendulum strips might be higly influenced in one way magnetic field, caution and periodic control of magnetic influence on these levels are necessary. On the other hand, Marold and Wahnert pointed out that, irrespective of what levelling instrument is used (bubble level or compensator level), futher investigations of the refraction effect in the vicinity of electric cables are necessary.

Besides investigations of magnetic effect and refraction effect in the vicinity of electric cables, we believe that it is necessary to consider temperature influence on modern levels and theodolites as well. Significant temperature influence on levels and theodolites was demonstrated in the past (Rueger, 1973; Milovanovic, 1967; Hirsch, 1970). In our opinion, it is necessary for the estimation of temperature effects and related corrections to determine functional dependences (structural relationship), as it was shown in literature (Milovanovic, 1965).

2. TEMPERATURE AND TEMPERATURE DIFFERENCES IN LEVELS AND THEODOLITES

The absolute temperature change of instrument and its parts appears during warming and cooling process. Heat influences of surroundings are transmitted transfer to the instrument by conduction, convection and radiation. During the process of reaching the stationarystate, temperature of any point of the instrument obeys the exponential law in the first approximation. This process produces temperature gradient inside instrument due to the different materials instrument parts are made of, and their geometric shape. However, inhomogenity may appear in the stationary conditions too. The reason may be some heat source inside the instrument itself (lighting, step motor), locally dependent heat transfer coefficient, wind and various external heat sources (Sun, observer, sky, soil, surrounding surfaces). The mechanism of the temperature changes of the instrument and its parts, the origin of the temperature differences inside instrument and its parts as well as their variations are explained in the literature by heat transfer theory. We would like to give some examples for the temperature changes, temperature differences and variations of the temperature differences of instruments.

2.1. The temperature change of theodolite T3000 by cooling

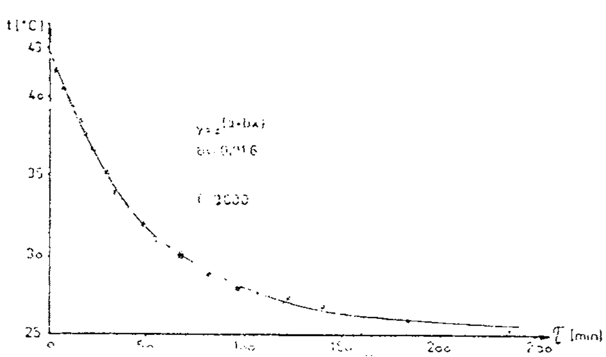

Fig. 1. Time dependent temperature of the T3000 theodolite.

Theodolite T3000 was warmed in climatic chamber up to the temperature of $+40^o$ C, and then put on a pillar in the laboratory with fixed temperature of $+25^o$ C. Temperature of the instrument was measured with the built in thermometer. Figure 1 shows that temperature follows the exponential law.

2.2. The temperature difference between the sides of the telescope tube of Wild T4 caused by night sky radiation

During clear sky night the telescope of the theodolite Wild T4 (set up on a pillar) was pointed on different zenith distances. The temperature difference between the sides of tube in the vertical plane was measured by thermistors. This difference was measured after the stationary state was reached. Figure 2 shows that the temperature difference depends on zenith distance in complete agreement with Lambert law.

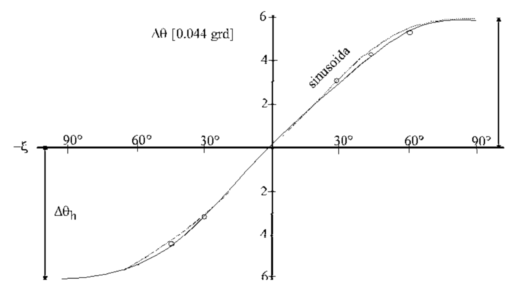

Fig. 2. Dependence of the temperature difference on zenith distance.

2.3. The temperature difference between the ends of the Horrebow Talcott level tube of Wild T4 caused by convection

The theodolite Wild T4 was placed on a pillar during ten clear sky nights. The telescope was positioned in meridian plane. The temperature difference between the ends of Horrebow Talcott level tube was measured by thermistors in stationary state. Figure 3 shows the dependence of the temperature difference on the azimuth of the wind direction (angle of stream).

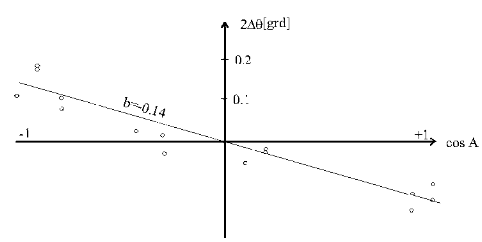

Fig. 3. Dependence of the temperature difference on azimuth of the wind direction.

2.4. The time dependent variation of the temperature difference between the ends of the level tube

Theodolite Wild T4 was placed on pillar during clear sky night. The telescope was positioned in meridian plane. The temperature difference between the ends of the level tube was measured with thermistors. After the theodolite was turned through 180^o the variation of the temperature difference was continiously measured. Figure 4 shows that variation of the temperature difference follows the exponential law.

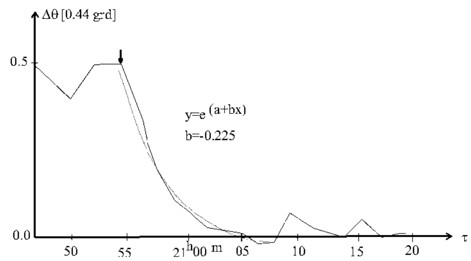

Fig. 4. Time dependent temperature difference between the ends of the level tube.

2.5. Time dependent variation of the temperature difference between the sides of the telescope tube

The theodolite DKM 3A was placed on pillar during the clear sky night. The telescope was positioned in horizontal plane. The temperature difference between the upper and lower side of the telescope was measured with thermistors. The screening of the telescope caused change in temperature difference. Figure 5 shows that the variation of the temperature difference follows the exponential law.

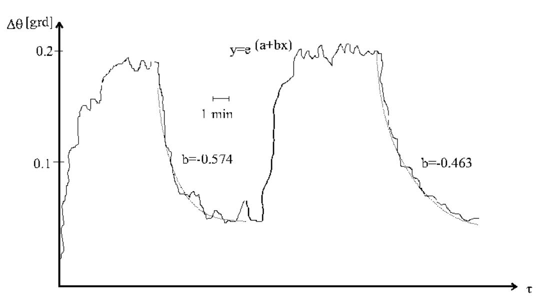

Fig. 5. Time dependent temperature difference between the sides of the telescope tube.

3. TEMPERATURE INFLUENCES ON LEVELS AND THEODOLITES

Temperature influences are related to absolute instrument temperature, as well as to temperature differences inside the instrument itself. The former may be illustrated by temperature dependence of the level graduation angular value, and the latter by influence of the temperature difference between the end of level tube on bubble position (the bubble moves towards the warmer end of level tube). For some temperature effects there are formulae that can be used for their quantitative a priori estimation. For others, only the determination of empirical relationships is possible.

For the angular shift β of the spirit level bubble with ethylether as liquid, the following relation holds (Drodofsky, 1956):

$$\beta'' = 16.8 \times 10^2 \ \tau \qquad (1)$$

where τ is the temperature gradient along the level tube in grd/mm.

For optical wedge a well known relation exists:

$$\delta = (n - 1)\ \theta \qquad (2)$$

where δ denotes the deviation of the incident light ray, n is refractive index of glass, and θ is the wedge angle. On the basis of formula (2), it is possible to estimate variation $\Delta\delta$ of the deviation angle δ caused by variation $\Delta\theta$ of the wedge angle θ caused in turn by thermal deviation of the wedge. Therefore $\Delta\delta$ is the function of refraction index and dilatation coefficient of glass.

In the following, we shall give some examples of experimental determinations of the temperature dependence of instrumental errors of theodolites and levels (c–collimation error, s–vertical index error, i–angle between the line of sight and the horizon). We would like to stress that the attention was paid to determination of the functional dependence (structural relationship).

3.1. The temperature dependence of collimation error

This dependence was determined for theodolites T3000 and Theo010A. Figure 6 shows the straight lines of functional dependence. It is necessary to point out that the straight lines are based on four series of measurements performed in different periods. For joint use od data related to Theo010A, an appropriate reduction was necessary, but not for the data of T3000. There are no significant changes of the collimation error of T3000 between the series of measurement.

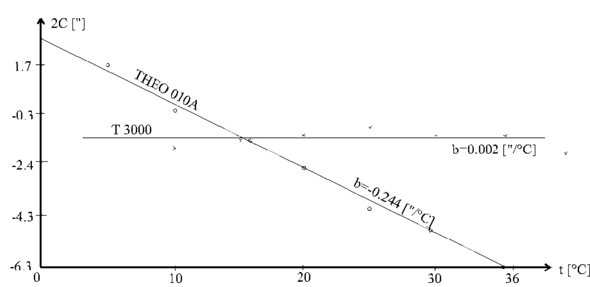

Fig. 6. Temperature dependence of collimation error.

3.2. The temperature dependence of vertical circle index error

This dependence was determined for the group of classical theodolites (T2, Theo010A and DKM3A), as well as for the modern theodolite T3000. Figure 7 shows that there is a significant temperature dependence of index error for classical instruments.

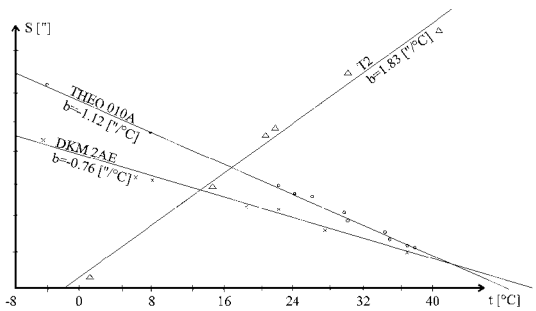

Fig. 7. Temperature dependence of vertical index error for classical instruments.

On the other hand, it can be seen from Figure 8 that the first temperature range involves significant change of index error for T3000 while the second does not. It is evident that there is a certain shift between two sets of data which didn't allow the joint use and estimation.

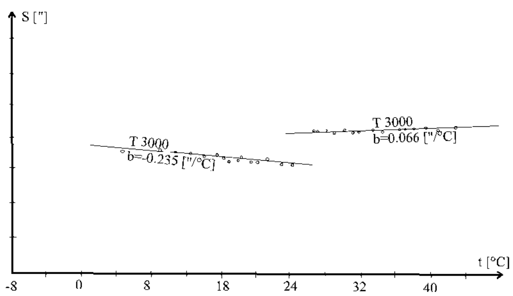

Fig. 8. Temperature dependence of vertical index error for modern theodolite T3000.

3.3. The temperature dependence of angle i

For the determination of this dependence, levels Ni 004 and Ni 002 were used. Figure 9 shows both sets of data. It is obvious that significant temperature dependence of angle i exists in case of classical level Ni 004. Level Ni 002 didn't show any trend that had to be estimated.

It must be mentioned that the data for Ni 002 were obtained as half differences of two instrument positions, after checking the hypothesis of constancy of instrument quasi horizon. However, this level is highly sensitive to sudden temperature changes as it can be seen from Figure 10. It is interesting to note that the angle i resumes its initial value after reaching the stationary state.

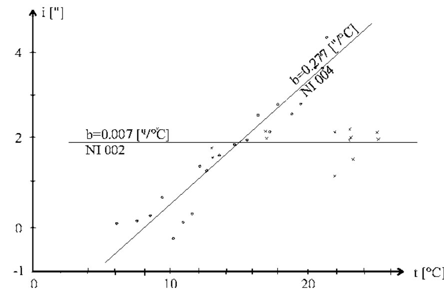

Fig. 9. Temperature dependence of the angle i for Ni 004 and Ni 002.

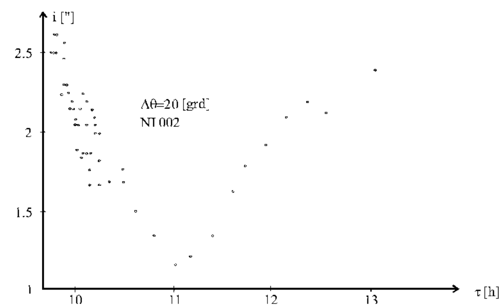

Fig. 10. Sudden temperature changes influence on angle i.

4. CONCLUSION

The above results may be summarized as follows:

1. Diminishing of the temperature influences on modern instruments is evident, but further improvements are necessary.
2. The above investigations suggest further improvement of thermal compensation of T3000 compensator in lower temperature range.
3. Thermal protection seems to be reasonable solution against sudden temperature influences on Ni 002 level's sight line.
4. It is recommended for manufacturer's technical specifications to contain parameters of the temperature dependences of instrumental errors.

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НЕКИ ТЕМПЕРАТУРСКИ УТИЦАЈИ НА ЛИБЕЛЕ И ТЕОДОЛИТЕ

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Оригинални научни рад

Овај рад је подстакнут неким од новијих истраживања деформација делова инструмената узрокованих температурским утицајима. Аутори су разматрали важност температурских утицаја на нивелире и теодолите, као и могућности елиминације тих утицаја. Истакнути су извори и механизми температурских промена и нехомогенитета температуре појединих инструменталних делова. Дати су примери промена температуре инструмената узрокованих преносом топлоте (кондукција, конвекција и зрачење). Истраживање је илустровано резултатима сопствених испитивања нивелира Ni 002 и теодолита T3000. У општем случају препоручује се да температурски утицаји буду истраживани и одређивани у облику функционалне зависности. Изведени су и други закључци који могу бити од интереса у процесу оптимизације мерења.