# Determining Temperature Dependence of Collimation Error of Digital Level Leica DNA 03

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**Key words**: digital level, collimation error, temperature changes, calibration, thermal expansion

## SUMMARY

The appearance of digital levels has enabled geodetic professionals the high automation in the process of levelling, which has significantly shortened the field work. As with conventional levels, it should be examined and its metrological characteristics should be determined. One of the important characteristics is the horizontal line of sight. For this purpose, digital levels use compensators of different construction and accuracy.

Like the classical one, the digital level is used in various temperature conditions. It is therefore of crucial interest to determine how the position of the line of sight in relation to the horizon is changed, i.e. how the collimation error is modified with the change in temperature. This paper describes an experiment which determines the change of collimation error with the change of temperature at high precision digital level Leica DNA 03.

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## 1. INTRODUCTION

Determination of the height difference using levels at horizontal line of sight is called geometric levelling. The result of measuring the height difference must have defined accuracy as a quantitative concept, and repeatability as the proximity of concurrence between the results of subsequent measurements of the same height difference conducted in the same measurement conditions. The results of measuring height difference are reached by using a measurement system that consists of a surveying instrument - level, accessories and auxiliary equipment. The level is subject to testing, i.e. verification of its stability or an ability to maintain its metrological characteristics over time. Metrological testing of the level is carried out within the accredited Metrological Laboratory for Angle and Length Calibration [1], of the Institute of Geodesy and Geoinformatics of the Faculty of Civil Engineering, University of Belgrade, in compliance with the international standard ISO 17123-2:2002. Calibration is performed in the laboratory with controlled temperature ($t^o = 20 - 22^o C$) with the precisely defined equipment [6]. Within calibration, external examination and measurement procedure are performed in order to:

- determine horizontality of the line of sight, collimation error, and
- determine measurement uncertainty.

The horizontality of the line of sight is achieved by a compensator. Accuracy of bringing the line of sight into a horizontal position depends on both technical characteristics of the compensator and the temperature and shock the instrument is exposed to during operation. The result of the experiment in this study is determination of temperature dependence of the line of sight of digital Leica DNA 03 with the compensator.

## 2. BASIC CHARACTERISTICS OF THE INSTRUMENT LEICA DNA 03

In 1990, Leica Geosystems AG was the first to introduce the digital level NA2000. This level was a revolution in the technology of that time, since it used bar-code rods. In 1991, Leica introduced a new level of this type, NA3000. Since these levels proved to be well-accepted in the practice and the market, Leica has produced the second generation of digital levels: DNA-03 and DNA-10 [8]. The hardware and software of this digital level is fully adapted to the new bar-code technology. The principles this instrument is operating on are based on the model NA3003. Besides its circular level, this instrument contains a magnetic compensator which brings the line of sight into a horizontal position. The instrument platform is located closer to the lens and provides protection against temperature changes. The instrument also has a horizontal limb, which is located in the lower part of the instrument. The graduation of the limb is in the interval of 1°.

The rods are equipped with highly sensitive CCD linear sensors sensitive to visible light. The incoming beam is divided into two parts: the visible part and the part for electronic measurement (CCD) [9]. The electronic measurement uses the spectrum part of the beam, which is partly located in the visible part of the spectrum. The halogen light allows measurement in the conditions of reduced visibility.

The technical characteristics of the level DNA-03 are shown in Table 1 [4].

Table 1. The technical characteristics of the level DNA-03 [4]

| **Accuracy** | Standard deviation height measurement per 1km (ISO 17123-2) |
|---|---|
| **Electronic measurements:** | |
| with Invar staffs | 0.3 mm |
| with standard staffs | 1.0 mm |
| Optical measurements | 2.0 mm |
| Distance measurement (standard deviation) | (electr.) 1 cm/20 m (500 ppm) |
| **Range:** | |
| Electronic measurement | 1.8 m – 110 m |
| Optical measurement | from 0.6 m |
| **Electronic measurement:** | |
| Resolution height measurement | 0.01 mm |
| Time for single measurement | Typically 3 seconds |
| **Telescope magnification** | 24x |
| **Compensator:** | |
| Type | Pendulum compensator with magnetic damping |
| Slope range | ±10' |
| Compensator setting accuracy | 0.3" |
| **Environmental conditions:** | |
| Working temperature | –20°C to +50°C |
| Storage temperature | –40°C to +70°C |
| Humidity | 95%, non condensing |

## 3. THEORETICAL POSTULATES

Due to external conditions influences the level, particularly temperature, there is a different expansion or shrinkage of certain parts of the level which causes the change of relation of certain level axis during measurement. Another important change is certainly a deviation of the line of sight from the horizontal plane, known as the collimation error (Fig 1).

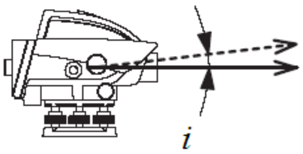


Figure 1. Collimation error *i*

Non-horizontality of the line of sight or the angle the line of sight forms with the horizon, the collimation error "*i*" seems like an error of height difference when the distances between the front and rear rods are not equal. Given the distance difference between the front and rear rod at the stations within levelling traverse, and different temperature of measurement and calibration of the level, non-horizontality of the line of sight at height difference can have a random character. Error in height difference is of random character, since it depends on the distance of rods which is also accidental and is equal to:

$$\sigma_{R\Delta i} = \Delta i(\Delta t)\sigma_{\Delta d}$$

where: $\Delta i$ - is change of the collimation error by 1°C; $\Delta t$ - temperature difference at measuring and determining the collimation error

Generally, this error is removed by setting permissible temperature difference at measuring and determining the collimation error. According to optical levelling procedures it is recommended to make multiple readings to check the variation of the readings and the time-dependent behaviour of the instrument's occasional drifts [3]. The software integrated into the Leica DNA03 level provides an opportunity to determine and rectify the angle of non-horizontality in four ways:

- From the centre,
- Kukkamäki,
- Förstner and
- Näbauer.

The From the centre method is known as the classical method, since it is implemented with other types of levels.

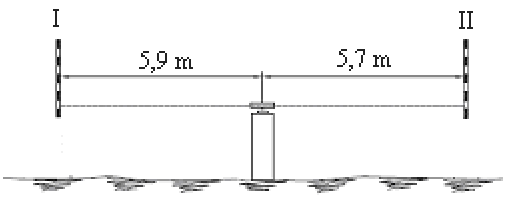


Figure 2. Levelling from position 1

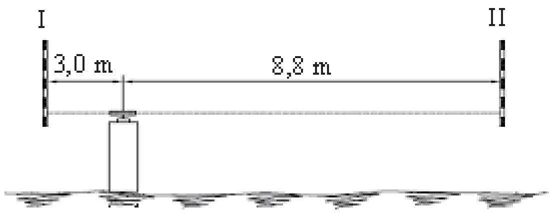


Figure 3. Levelling from position 2

Determining the collimation error with the From the centre method consists of measuring the height difference of the levelling side from the positions 1 and 2, respectively, within the polygon of the Metrological Laboratory (ML160) according to the following procedure.

Levelling from the position 1 (Figure 2): From the central pillar of the laboratory on which the instrument is set up, the reading is executed with fixed rods labelled I and II. The reading is done in four series with the change of height of the level. The change of height of the level is done by acting on the position screws. For each pair of readings the height difference is calculated:

$$\Delta h_j = \left(l_{II} - l_I\right)_j,\ j = 1,\dots 4 \tag{1}$$

where:

$\Delta h_j$ - height difference obtained by levelling from position 1,

$l_I, l_{II}$ - reading on the fixed rods,

$j$ - series number.

Levelling from the position 2 (Figure 3): The level is set up on the pillar number 2 of the laboratory and the reading begins on the fixed rods labelled I and II. The reading is done in four series with the change of height of the level. The change of height of the level is done by acting on the position screws. For each pair of readings the height difference is calculated:

$$\Delta h'_j = \left(l'_{II} - l'_I\right)_j,\ j = 1,\dots 4 \tag{2}$$

with:

$\Delta h'_j$ - height difference obtained by levelling from position 2,

$l'_I, l'_{II}$ - reading on the fixed rods,

$j$ - series number.

Upon the completed observation, we proceed to determine the angle *i*. The angle *i* is determined in four series.

$$i_j = \frac{\Delta h'_j - \Delta h_j}{d_p - d_z}\rho'',\ j = 1,\dots 4 \tag{3}$$

with:

$d_p$ - distance to the closer rod (labelled II) when levelling from the position 1

$d_z$ - distance to the farther rod (labelled I) when levelling from the position 2.

Distances between $d_p$ and $d_z$ represent calibration values of the Metrological Laboratory. Definite value of the collimation error is determined as a simple arithmetic mean from all the series:

$$\bar{i} = \frac{\Sigma i_j}{4}, \; j = 1, \ldots 4 \tag{4}$$

From deviations of certain measurements from the arithmetic mean:

$$v_j = \bar{i} - i_j, \; j = 1, \ldots 4$$

measurement uncertainty of determining the collimation error *i* is calculated, through the expression:

$$\sigma_{\bar{i}} = \sqrt{\frac{\Sigma v_j v_j}{3 \cdot 4}}, \; j = 1, \ldots 4 \tag{5}$$

If the condition is met:

$$\bar{i} \geq t_{0.05,9} \cdot \sigma_{\bar{i}} \tag{6}$$

where $t_{0.05,9} = 2.26$ the quantile of Student distribution for the probability *p*=95% and 9 degrees of freedom, the collimation error *i* has the value $\bar{i} \pm \sigma_{\bar{i}}$, and if the previous condition is not met, the previous collimation error *i* does not exist, i.e. its value is considered to be zero.

If the measuring uncertainty for determining the collimation error *i* is larger than $\Delta i / t_{0.05,9}$, where $\Delta i$ is the maximum recommended value of the collimation error *i* for the appropriate level, rectification of the level must be carried out and the procedure of determining the collimation error *i* is repeated upon the completed rectification. The levels with declared measuring uncertainty better than 1 $\mathrm{mm}/\sqrt{\mathrm{km}}$ should have the collimation error lower than 5", which is the maximum value recommended by national standard for precise measurements of height differences.

The “From-the-centre” method is chosen to be implemented in the laboratory ML160 because it is the method recognized and recommented in the standard ISO 17123-2:2002.

## 4. EXPERIMENT

On the polygon of the Metrological Laboratory (ML160), testing and rectification of the level Leica DNA 03 No. 332103 was carried out, according to the previously described from the centre method. After that, we determined the change of the collimation error *i* under the influence of temperature changes, by cooling and heating the instrument. The instrument was turned on before the procedure of cooling and heating, in order to avoid the temperature changes caused by internal electronic circuits. The measuring equipment was as follows: DNA-03 instrument and the corresponding invar rod No. 23829.

Instrument Leica DNA 03 is cooled in a chamber of the Institute of Materials and Structures of the Faculty of Civil Engineering in Belgrade to the temperature of -10°C. Due to insufficient retention in the chamber, its operating temperature in the laboratory was 3°C. The instrument is placed on the reinforced concrete pillar 4, *d*=5.9 m away from the invar bar-code rod. 10 measurements were carried out for each degree of temperature cooling in the range of 3°C to 25°C.

The results of the measurements are free from gross errors in the case when the measurement standard is unknown according to the following procedure:

$$\begin{aligned} \overline{X} &= \frac{1}{n}\sum_{i=1}^{n} X_i \\ X_n &= \max\left|X_i - \overline{X}\right| \\ \overline{X}'_i &= \frac{1}{n-1}\sum_{i=1}^{n-1} X_i \\ \sigma_i^2 &= \frac{1}{n-2}\sum_{i=1}^{n-1}\left(X_i - \overline{X}'_i\right)^2 \\ \left|X_i - \overline{X}_i\right| &< t_p(f)\sigma_i\sqrt{\frac{n}{n-1}},\ f = n-2 \end{aligned} \tag{7}$$

where:

$n$ - number of measurements,

$\overline{X}$ - arithmetic mean of the measurement,

$X_n$ - measurement that most deviates from the arithmetic mean,

$\overline{X}'_1$ - arithmetic mean calculated without $X_n$,

$\sigma_i$ - assessed measurement standard,

$t_p(f)$ - quantile of student's distribution,

$f$ - degrees of freedom,

$p = 1 - \alpha,\quad \alpha = 0.05$.

Applying (7), 4% measurements most deviating from the arithmetic mean, $X_n$, are identified and excluded from forther data processing.

After that, the calculation of the collimation angle *i* was carried out for each reading, according to the expression:

$$i'' = \frac{\bar{X}_{t=j^\circ} - \bar{X}_{t=h^\circ}}{d} \cdot \rho'' \quad (8)$$

where:

$\bar{X}_{t=h^\circ}$ is the reading with horizontal line of sight,

$\bar{X}_{t=j^\circ}$ is the reading at the temperature $\mathrm{j} = 3^{\circ}\mathrm{C}, ...25^{\circ}\mathrm{C}$,

*d* is horizontal length from the instrument to the rod.

Table 2. Data after cooling

| No. | t[°C] | $n$ | $f$ | $\bar{X}$ [m] | $m$ [μm] | $i$["] |
|---|---|---|---|---|---|---|
| 1 | 3 | 8 | 7 | 1.12169 | 4.63 | 6,8 |
| 2 | 4 | 8 | 7 | 1.12170 | 16.85 | 7,4 |
| 3 | 5 | 10 | 9 | 1.12171 | 20.03 | 7,5 |
| 4 | 6 | 10 | 9 | 1.12168 | 32.34 | 6,7 |
| 5 | 7 | 10 | 9 | 1.12166 | 15.81 | 5,7 |
| 6 | 8 | 9 | 8 | 1.12164 | 4.41 | 5,1 |
| 7 | 9 | 9 | 8 | 1.12162 | 6.01 | 4,5 |
| 8 | 10 | 8 | 7 | 1.12150 | 11.88 | 0,1 |
| 9 | 11 | 10 | 9 | 1.12148 | 6.32 | -0,3 |
| 10 | 12 | 9 | 8 | 1.12147 | 4.41 | -0,8 |
| 11 | 13 | 9 | 8 | 1.12144 | 5.00 | -1,8 |
| 12 | 14 | 9 | 8 | 1.12145 | 7.82 | -1,5 |
| 13 | 15 | 9 | 8 | 1.12145 | 5.00 | -1,6 |
| 14 | 16 | 10 | 9 | 1.12144 | 8.16 | -1,8 |
| 15 | 17 | 10 | 9 | 1.12145 | 7.38 | -1,4 |
| 16 | 18 | 9 | 8 | 1.12145 | 4.41 | -1,4 |
| 17 | 19 | 10 | 9 | 1.12147 | 7.38 | -0,7 |
| 18 | 20 | 10 | 9 | 1.12148 | 5.27 | -0,6 |
| 19 | 21 | 10 | 9 | 1.12149 | 8.43 | -0,2 |
| 20 | 22 | 10 | 9 | 1.12149 | 7.89 | 0,0 |
| 21 | 23 | 9 | 8 | 1.12150 | 5.27 | 0,4 |
| 22 | 24 | 10 | 9 | 1.12151 | 0.00 | 0,6 |
| 23 | 25 | 10 | 9 | 1.12153 | 4.83 | 1,2 |

The reading at the temperature of 22°C is accepted as the reading with horizontal line of sight. The temperature of 22°C is chosen following the recommendation of the manufactor's licenced service in Serbia, where this temperature is declared as nominal for this instrument. The table 2 shows definite values of the arithmetic mean free of the gross errors impact

$\bar{X}$ [m], values of standard deviations $m$ [μm] and values of the angle $i$ at different temperatures of instruments.

In accordance with the maximum recommended value of the collimation error of 5" for the level that has the declared measuring uncertainly larger than 1 $\text{mm}/\sqrt{\text{km}}$, it can be noticed that the important change of the collimation error is recorded in the temperature of 3°C to 10°C. The diagram of the change is shown in Figure 4.

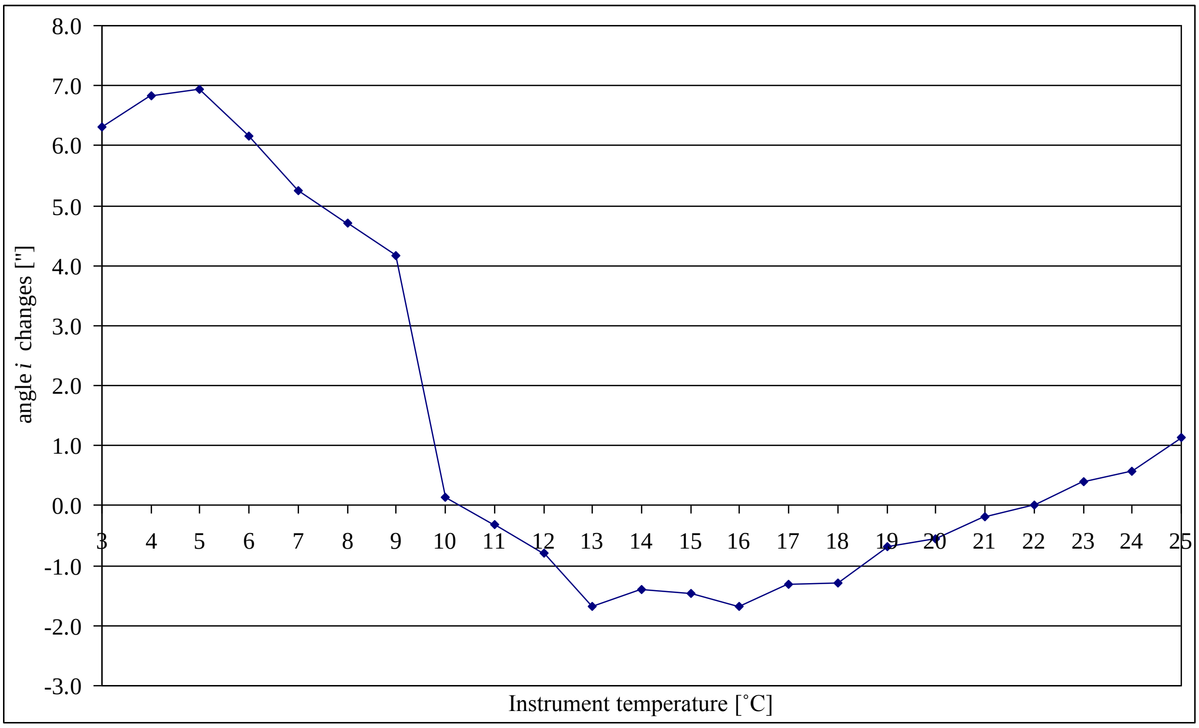


Figure 4. Change of the collimation error *i* for different temperatures of the instrument – cooling

The same procedure was repeated at the process of heating the instrument, for the temperature range from 38°C to 28°C. When heating the instrument, the reading at the temperature of 28°C was accepted as the reading with the horizontal line of sight. The temperature of 28°C was the lowest one that the instrument could reach without additional cooling, since the experiment was performed during the summer. Assuming that the line of sight is horizontal at this temperature (collimation error = 0), Table 3 shows the angle "*i*" at other temperatures, which is graphically illustrated in Figure 5.

Table 3. Data after heating

| No. | t[°C] | $n$ | $f$ | $\bar{X}$ [m] | $m$ [μm] | $i$["] |
|---|---|---|---|---|---|---|
| 1 | 38 | 10 | 9 | 1.12148 | 33.81 | -2,4 |
| 2 | 37 | 10 | 9 | 1.12156 | 20.25 | 0,5 |
| 3 | 36 | 8 | 7 | 1.12158 | 4.63 | 1,2 |
| 4 | 35 | 9 | 8 | 1.12157 | 7.07 | 0,8 |
| 5 | 34 | 9 | 8 | 1.12156 | 9.28 | 0,4 |
| 6 | 33 | 10 | 9 | 1.12156 | 8.76 | 0,5 |
| 7 | 32 | 10 | 9 | 1.12157 | 14.30 | 0,6 |
| 8 | 31 | 9 | 8 | 1.12156 | 5.00 | 0,3 |
| 9 | 30 | 10 | 9 | 1.12155 | 7.89 | 0,1 |
| 10 | 29 | 10 | 9 | 1.12155 | 4.83 | 0,0 |
| 11 | 28 | 10 | 9 | 1.12155 | 20.44 | 0,0 |

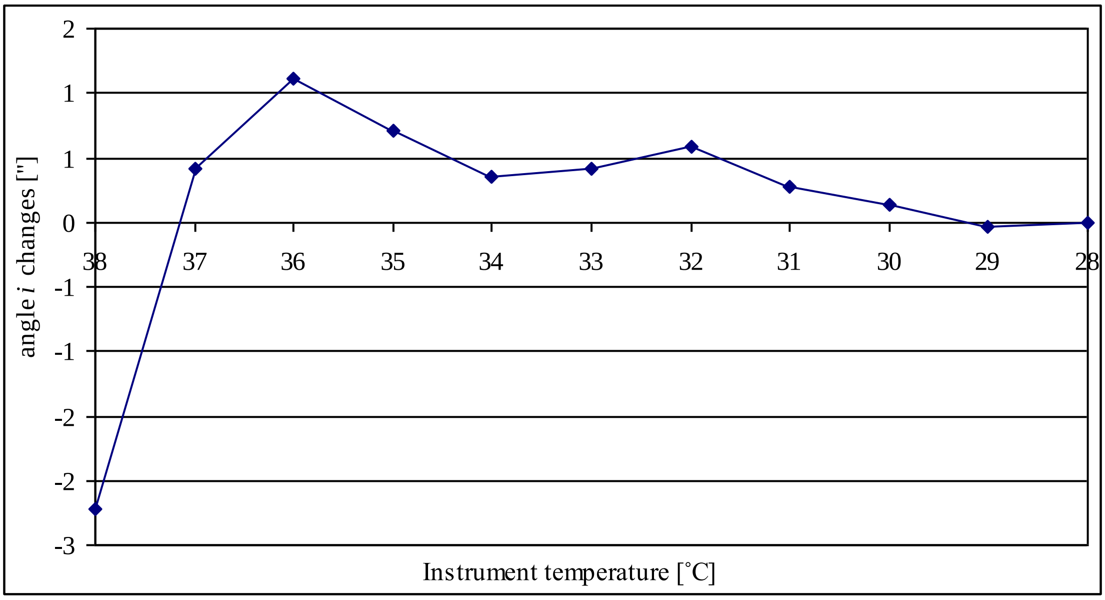


Figure 5. Change of the collimation error $i$ for different temperatures of the instrument – heating

As the maximum recommended value of the collimation error is 5", it can be noticed that in the process of heating the instrument, for the temperature range from 38°C to 28°C there are no significant changes up to temperature of 37°C.

## 5. CONCLUSION

Leica DNA 03 level is the instrument of modern design that largely facilitates the work of geodetic professionals due to its software and possibilities.

The testing of the effects of temperature changes of the instrument on the position of the line of sight at the digital level with the compensator during cooling and heating was carried out in the Metrological Laboratory of the Institute of Geodesy and Geoinformatics of the Faculty of Civil Engineering in Belgrade. The testing has shown that the change of the collimation error ranging from +10°C to +40°C is not significant, i.e. the changes are within the limits determined for precise levels. At the temperatures under +10°C there are significant changes of the collimation error *i* and their values should be considered, i.e. while working at low temperatures (as declared by the manufacturer, the instrument can be used at temperatures up to -20°C), the value of the collimation error should be specially determined so that corrections for the real value of non-horizontality of the line of sight could be entered into the measurement results.

Comparing the results with similar testing of classical levels with the compensator, ZEISS Ni002 [5], [2], and digital levels [7], it can be concluded that with the digital Leica DNA-03 level, the change of the collimation error is significant at lower temperatures (it is not the case with classical levels). Moreover, the classical level shows the linear trend of changing the collimation error with the change of temperature [5], while with the digital one it is not the case, but the changes of the collimation error are of random character.

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## BIOGRAPHICAL NOTES

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