On the Systematic Behaviour of the Digital Levelling System Zeiss DiNi12

Dr. Mikko TAKALO, Paavo ROUHIAINEN, Pekka LEHMUSKOSKI and Veikko SAARANEN, Finland

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ABSTRACT

In this paper we describe the tests of the Zeiss DiNi12 digital levelling system in the Metsähovi test field in 2000-2001 and experiences during the field season 2001 of the Third Levelling of Finland in Lapland. The behaviour of the Zeiss DiNi12 can be characterized by instrument dependent bias between fore and back measurements. The mean of the fore and back levellings seems to be unbiased. We also studied the sights to the lower and to the upper end of the bar code rod. We discovered that when the sighting distance is from 10 to 40 metres the extreme rod readings are only slightly erroneous.

CONTACT

Mikko Takalo, Senior Researcher, Dr.Tech.
Paavo Rouhiainen, Researcher, M. Sci.
Pekka Lehmuskoski, Researcher, M. Sci. and
Veikko Saaranen, Researcher, M. Lic.
Finnish Geodetic Institute
Department of Geodesy and Geodynamics
P.O.Box 15
FIN-02431 Masala
FINLAND
Tel. + 358 9 295 550
Fax + 358 9 295 55 200
E-mail: mikko.takalo@fgi.fi; paavo.rouhiainen@fgi.fi; pekka.lehmuskoski@fgi.fi; veikko.saaranen@fgi.fi

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INTRODUCTION

In 2000-2001 three Zeiss DiNi12 digital levels were purchased by the Finnish Geodetic Institute (FGI). The digital levelling system consists of a levelling instrument with a CCD sensor and a bar code rod. The instrument processes the rod reading by scanning a sector image of the bar code rod and comparing it to the scale stored into the memory of the instrument. The tests to find out characteristics of the Zeiss DiNi12 and to determine the measuring accuracy were started in November 2000 (TAKALO et al. 2001a). The bar code rods were calibrated using the vertical laser rod comparator of FGI (TAKALO 1999). In order to study the accuracy of the Zeiss DiNi12 system, a test field was established in the neighbourhood of the Metsähovi research station (TAKALO et al. 2001b). Until now, three complete test series have been concluded. After half a year test period all our three Zeiss DiNi12 levels were taken to Lapland where we carried on the Third Levelling of Finland (MÄKINEN and SAARANEN 1998). In our first field season with the Zeiss DiNi12 a clear systematic behaviour came out.

SYSTEMATIC EFFECT OF THE ZEISS DINI12

In precise levelling the height difference dH is measured twice, in opposite directions A and B, and their misclosure is denoted here by $\Delta = dH_A + dH_B$. The symmetric method improves the accuracy, enables to reveal gross errors and even to estimate the accuracy of levelling. However, in Denmark, the cumulative sum of misclosures $(\Sigma\Delta)$ of levelling sections was reported to grow or decrease systematically (SCHMIDT 2000). The following reasons were proposed:

1) vertical movement of the rod base and the tripod,
2) way to set up and adjust the level and
3) change of ambient temperature.

In the Third Levelling of Finland the automatic level Zeiss Ni002 and the spirit level Wild N3 were used in 1978-2000 (LEHMUSKOSKI *et al*. 1993). In these measurements $\Sigma\Delta$ per kilometre was mainly small and random. For a digital levelling system $\Sigma\Delta$ has been reported to be remarkable (LITHUANIA 2001). In 2001 the Third Levelling of Finland was continued by three teams in Lapland applying the Zeiss DiNi12 digital system. Each team used its own labelled instrument. The cumulative sum was almost linear and rather large in case of two levelling teams, whereas, in the case of the third team it changed considerably during the season (Fig. 1. and Table 1.).

In order to find out if the cumulative sum is caused by

1) movement of the rod base,
2) observer,
3) level or
4) tripod

a series of test measurements were performed in the Metsähovi test field where the rod bases are permanent. Thus, the first assumption was excluded. The levels, the tripods and the observers were interchanged during the measurements so that each observer levelled approximately one third of his measurements with one level and one tripod. The sighting distances in Metsähovi were approximately same as in Lapland and the weather conditions also were almost similar. It was verified that the observer and the tripod have a minor effect on $\Sigma\Delta$ but the level, on the contrary, has a clear systematic effect (Fig. 2 and Table 1).

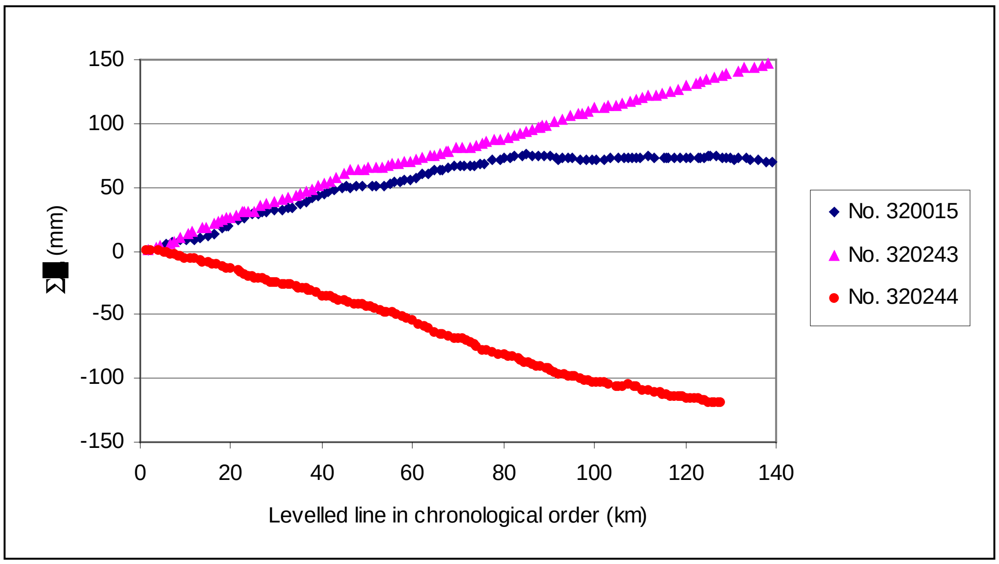

Fig. 1. $\Sigma\Delta$ of double run levelling during the field season 2001 in Lapland with the digital levelling system Zeiss DiNi12.

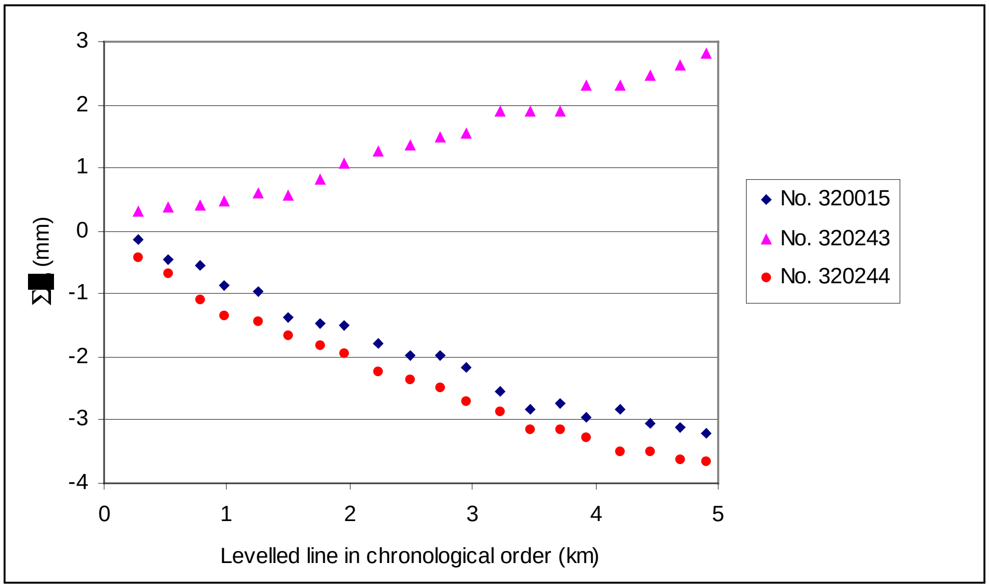

Fig. 2. $\Sigma\Delta$ of double run levelling in the Metsähovi test field in autumn 2001 with digital levelling system Zeiss DiNi12.

Table 1. Mean of the reduced Δ/km obtained in Lapland (Δ_L)/km and in Metsähovi (Δ_M)/km with the standard deviations of the mean. In the last column is given the difference between Lapland and Metsähovi.

	In Lapland (L)			In Metsähovi (M)			
Level	Intervals	Length (km)	(Δ_L)/km (mm)	Intervals	Length (km)	(Δ_M)/km (mm)	L-M (mm)
320015	110	139	$+0.46 \pm 0.07$	20	5	-0.67 ± 0.14	+1.13
320243	102	138	$+1.06 \pm 0.06$	20	5	$+0.59 \pm 0.12$	+0.47
320244	139	128	-0.91 ± 0.05	20	5	-0.74 ± 0.10	-0.17

According to Table 1 the levels 320243 and 320244 have a large systematic effect in the line levelling and a smaller one in the Metsähovi test field. In spite of a remarkable difference between forward and backward levellings, there is no statistical difference between the instruments when we consider the mean of the double run levellings in Metsähovi (Fig. 3).

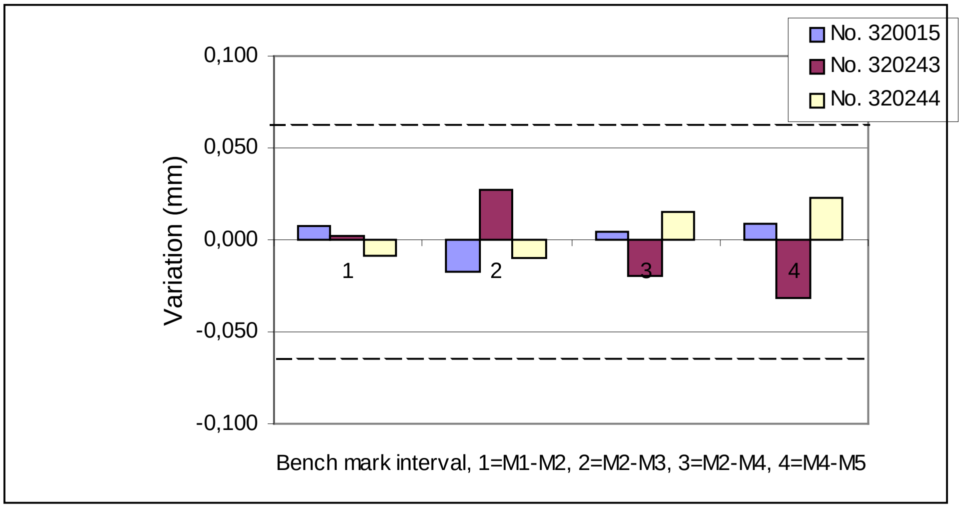

Fig. 3. The variation of the means of double run levellings for each instrument in Metsähovi in autumn 2001. The standard deviation of the mean is here ±0.07 mm.

The large systematic Δ can be explained partly in case of two instruments with the movement of the rod, but not with the movement of tripod neither with the observer's way to handle the instrument? In Lapland and in Metsähovi the effect was independent of air temperature. Thus, the one explaining factor could be the un-reversibility of the instrument compensator after turning the instrument from back rod to fore rod as shown in Appendix 1.

ROD READINGS ABOVE 2.8 M AND BELOW 0.2 M

The digital levelling technique differs from the optical level in two main aspects:

1. The rod reading in digital technique is obtained by electro-optical means, a CCD sensor instead of human eye and
2. Every rod reading represents a group of code lines instead of one.

For instance, the manufacturer of Zeiss has reported (FEIST *et al*. 1995) that this type of instrument uses a 30 cm sector of the coded rod to process the rod reading. Thus, the image processing may meet problems when the measuring sector is reduced. Hence, the precision of the rod reading may decrease due to the lower number of the coded lines. Many authors e.g. SCHAUERTE (1995) and RÜEGER (2000) have reported about this problem.

We studied the reading error of the Zeiss DiNi12 by sighting near the upper and lower end of a bar code rod. The height differences between the reference point (A) and the point (X) were measured (Fig. 4). The point X consists of eight steel bolts set into a concrete base, in which the rise of one step is approximately 2 cm. The measurements were carried out using 3 m bar code invar rods and the sighting distances 10 m, 20 m, 30 m, 40 m, 50 m and 60 m. The observation procedure at each set up was X, A, A, X (See Fig. 4). The rod readings between 2.82 m and 2.97 m were taken from the upper part of the rod and correspondingly, from the lower end between 0.04 m and 0.21 m. The rod readings A were taken from the middle part of the rod. Before and after each study the reference height differences were measured using the 10 m sighting distance and the readings were taken from the middle part of the scale. The weather conditions were favorable for precise observations.

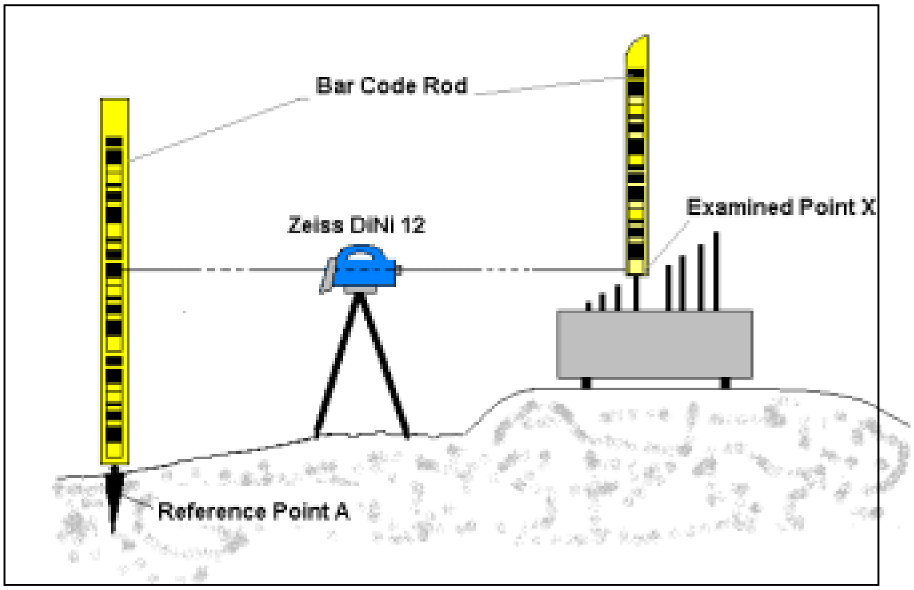

Fig. 4. The principle of the FGI study in the sighting tests of the Zeiss DiNi12. The site of the instrument is shematic in the picture.

By comparing the observed height difference to the reference value, we obtain the bias, i.e., observed minus reference. The graphs of the bias for each sighting distance are given in Figs. 5 and 6. The estimated error of the bias, less than ±0.05 mm, is derived from our separate tests of the Zeiss DiNi12 and it depends on the distance.

According to the Figs. 5 and 6 we can recognize that only a few bias values with the one sigma bars are outside of zero.

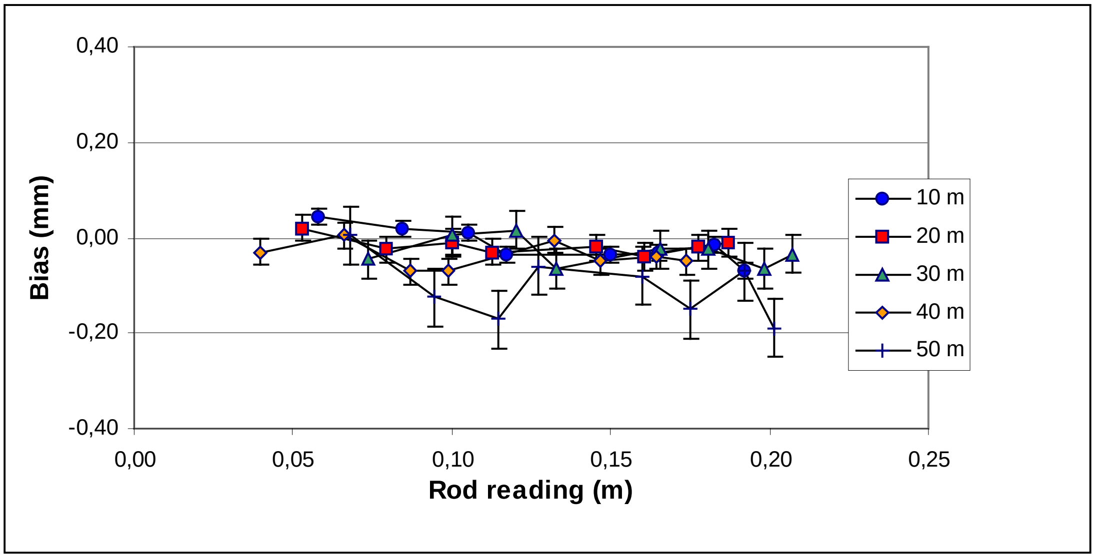

Fig. 5. Error of height difference with one sigma bars when sighting to the lower part of the Zeiss bar code rod No. 14087. The instrument was Zeiss DiNi12 No. 320244.

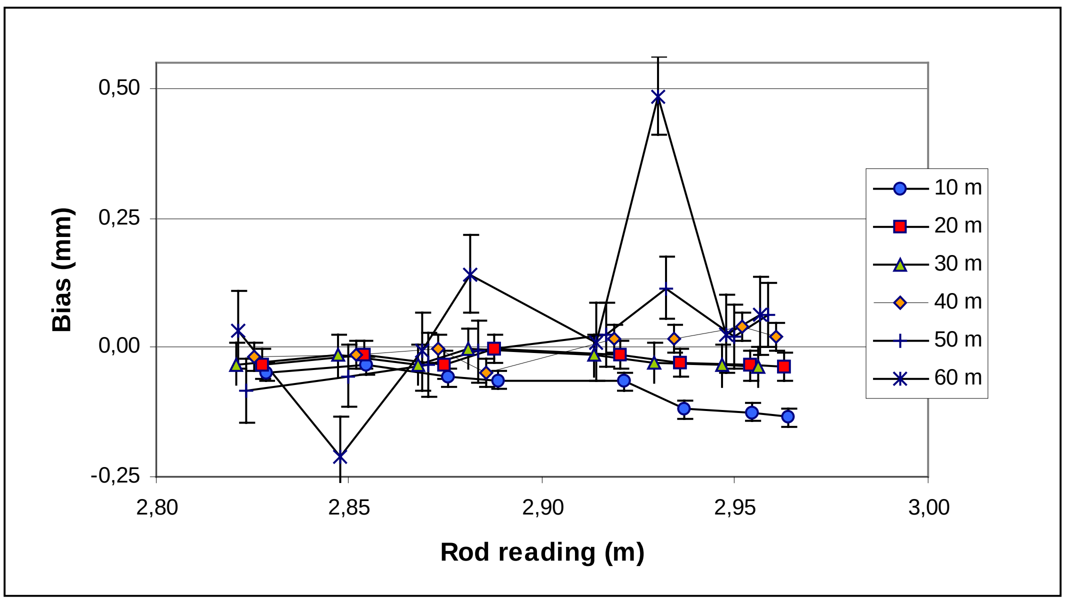

Fig. 6. Error of height difference with one sigma bars when sighting to the upper part of Zeiss bar code rod. The instrument and the rod are the same as in Fig. 5.

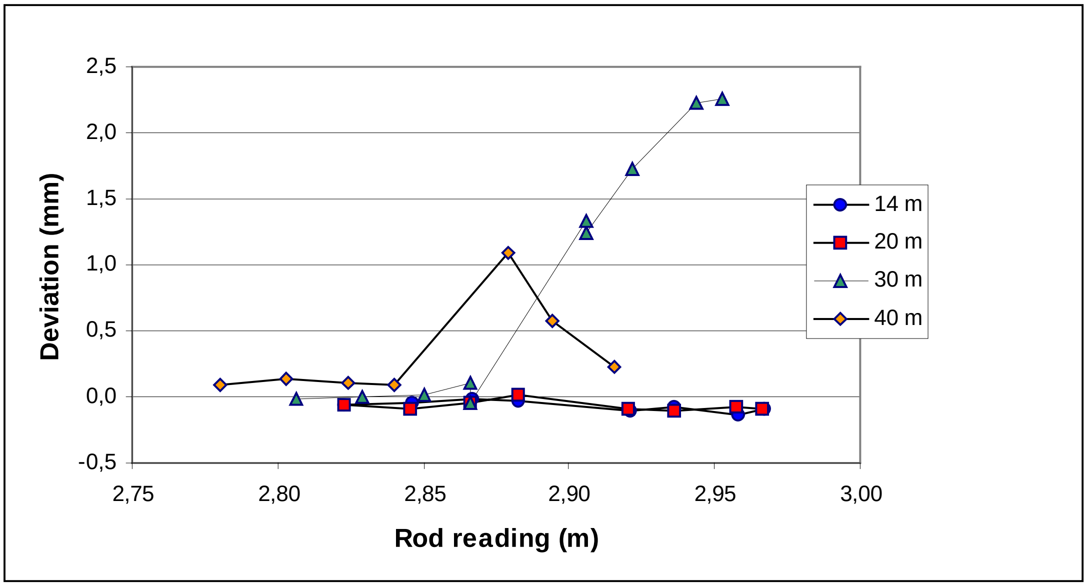

Fig. 7. Error of height difference when sighting to the upper part of Zeiss bar code rod with restriction of measuring sector below. The instrument and the rod are the same as in Fig. 5.

Fig. 7 illustrates a result of an exceptional test, when the sighting to the upper end of the rod was partly disturbed by the top of the car on the FGI parking place. So in this case there was also a restriction of the measuring sector below. Owing to the lack of bar code lines the Zeiss DiNi12 occasionally did not operate at all or gave a misreading of some millimetres.

CONCLUSIONS

According to the FGI study of the Zeiss DiNi12 digital levelling system in Lapland and in Metsähovi we can state that the sum of the double run levellings is strongly dependent on the instrument.

Due to the large misclosure one should always make the double run measurement, and even during as short time interval as possible.

If the user of the Zeiss DiNi12 has no chance to avoid the sights to the bottom or to the top of the bar code rod, we recommend the sighting distances shorter than 50 m. Especially, when the 30 cm measuring sector is blocked by some extra obstructions, observations may contain a fatal error.

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APPENDIX

Effect of fore-back difference in levelling

In the precise levelling the bench mark interval is measured always forward, i.e., in A-direction and backward, in B-direction as illustrated in Fig. 8.

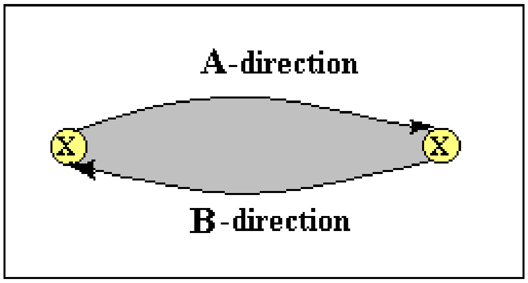

Fig. 8. Double run levelling.

Assuming that the observations are unbiased, the following equations are valid

$$dH_A = -dH_B$$
$$dH_A + dH_B = 0$$
$$dH = (dH_A - dH_B)/2$$

The horizontal level as given by the compensator of the Zeiss DiNi12 can be changed when turning the instrument from the back rod to the fore one. Thus, the observed height difference is biased. While measuring the height difference, $T_0 – E_0 = 0$, in A-direction the back rod reading T_A is assumed to be correct, but the fore reading E_A includes the error v_A (Fig. 9) and the length of sighting distances are supposed to be here equal.

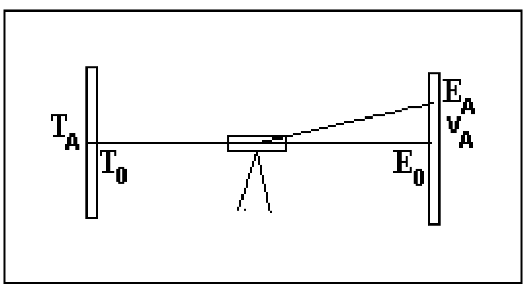

Fig. 9. Levelling in A-direction.

Thus, the observed height difference is

$$dH_A = T_A - E_A = T_0 - (E_0 + v_A) = - v_A.$$

and in B-direction (Fig. 10) the corresponding error is v_A and the height difference is

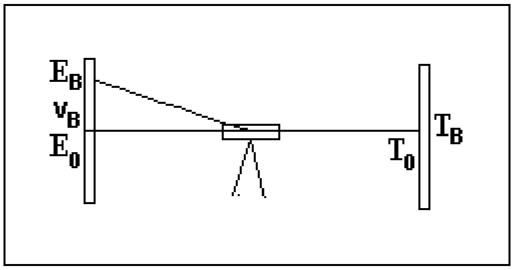

Figure. 10. Levelling in B-direction.

$$dH_B = T_B - E_B = T_0 - (E_0 + v_B) = - v_B.$$

Assuming that the tilt effect in both directions is equal

$$|v_A| = |v_B| = v$$

then the difference between fore and back measurement includes the error

$$dH_A + dH_B = -(v_A + v_B) = -2v,$$

that disappears from the mean of height differences of fore and back measurements

$$\begin{aligned} dH &= (dH_A - dH_B)/2 \\ &= [(-v_A -(- v_B)]/2 \\ &= (-v +v)/2 = 0 \end{aligned}$$