Investigations concerning the use of the leveling system during downtime 2004

Georg Gassner, Alignment Engineering Group
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To achieve the tight requirements on the control and alignment measurements during the downtime 2004 an extensive test procedure of the used equipment must be carried out. In case of the digital leveling instruments, additional special investigations have to take place. The digital levels have the advantage of delivering highly accurate and fast measurements in an automated measuring process. The digital levels have the disadvantage, that they give less accurate measurements in some cases. To investigate these cases, a fully automated vertical comparator has been developed at SLAC.

1.1 Scale Determination

To achieve the highest accuracy with a level in combination with a rod, the determination of the scale factor is necessary. This test needs to be repeated regularly to ensure that the equipment is working correctly. In Figure 1 the results of a scale determination are given. The graph shows the dependency of the height deviations from the position on the staff where the measurements were taken. In Table 1 the scales for our rod's and level's are given.

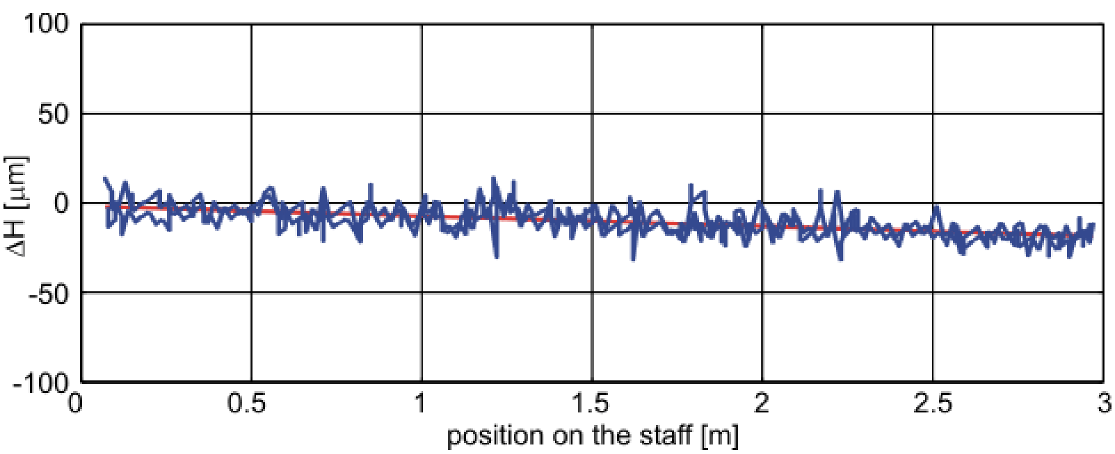

Figure 1: Scale factor of -6 ppm for the Leica DNA03 in combination with a 3 m rod (NEDO 9660); the blue line gives the deviations of single height readings from the interferometer readings; the red line is the regression line

Table 1: Scale determination for the different Level and Rod compbinations

Rod #	Rod length [m]	scale [ppm] LEICA DNA03 SN:331757 SW: 121.4430	scale [ppm] ZEISS BLAU SN: 310002 SW: 3.40	scale [ppm] ZEISS GELB SN: 701116
9660	3 m	-6 ± 1.2		
9946	3 m	2 ± 1.2		
9743	3 m	-4 ± 1.2		
9960	3 m	1 ± 1.2		
9846	2 m	0 ± 2		
9913	2 m	-6 ± 2		
13702	2 m		0 ± 2	3 ± 2
13710	2 m		-1 ± 2	-5 ± 2
10377	1.75 m		-9 ± 2.4	
10378	1.75 m		-8 ± 2.4	
10379	1.75 m		-7 ± 2.4	
10380	1.75 m		-7 ± 2.4	

1.2 Critical Distances

It is well known in the metrology community that digital levels give inaccurate results at certain distances. The Leica NA3000 for example has a critical distance at about 15 m where deviations of up to 0.8 mm could occur, Reithofer et al. (1996). Woschitz (2003) has investigated this effect and found that it occurs when the size of code lines, projected onto the CCD array, have exactly the size of one pixel. If a multiple of code lines is mapped to a whole number of pixels also a deviation occurs, but smaller. Taking these findings, we tested our instruments at their critical distances.

For the DNA03 one code element of the size of 2.025 mm is projected onto the CCD array with the size of one pixel at a distance of 26.7 m. We are only interested in sighting distances of up to 15 m so we carried out experiments around a sighting distance of 13.35 m where one code element is projected onto two pixels and around 8.9 m (1 code element is projected onto 3 pixel). The results for the 8.9 m distance are given as an example in Figure 2. A sinusoidal pattern is recognizable in the results but its magnitude is rather small with a range less than 50 μm.

A similar situation is observable with the DiNi12 where the code elements have a width of 10 mm. For example at a distance of 10.98 m one code element is projected onto the CCD array with the same size as 38 pixels (Woschitz, 2003), results of this experiment are given in Figure 3.

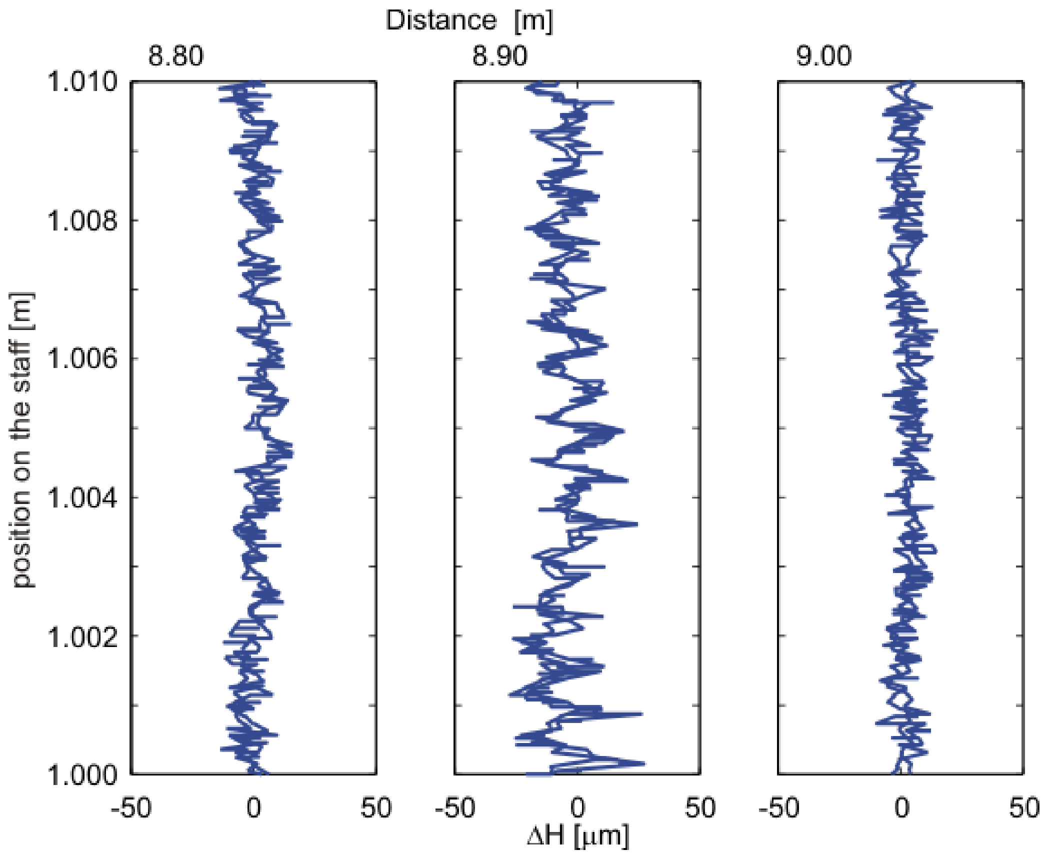

Figure 2: Measurements at and around the critical distance of 8.9 m with the DNA03

1.3 Defocused Measurements

With the new instruments we use (Leica DNA03 and Trimble DiNi12) the critical distances do not cause deviations like they occurred with the old Leica Series. Anyway if there is an additional error source like a slightly unfocused set-up these deviations are becoming no longer negligible (Woschitz, 2003). We have measured the critical distance of 10.98 m with a DiNi12 once focused and once with a slightly defocused (focused 0.25 m behind the scale) set-up. This slight blurring is hardly recognizable but causes, in our experiment, a two times bigger deviation at this critical distance with a range bigger than 0.1 mm, see Figure 3.

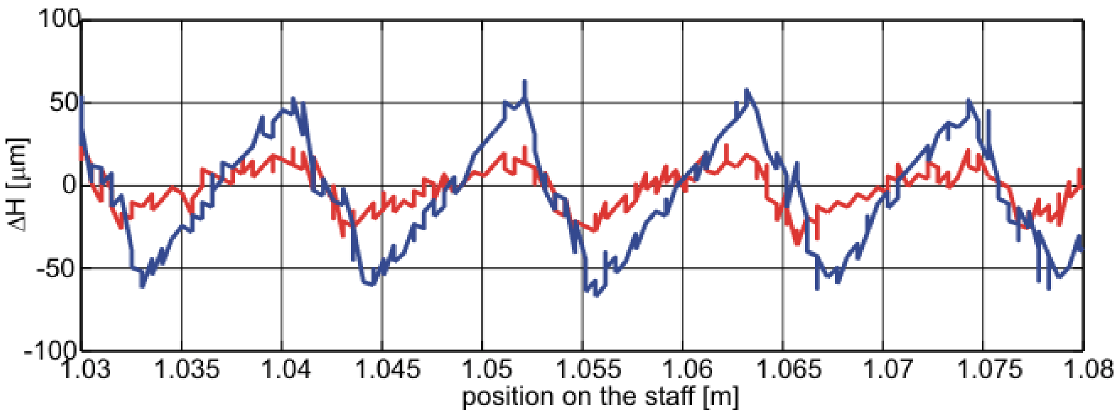

Figure 3: Measurements at a critical distance of 10.98 m with the DiNi12. The red line shows the focused case, the blue line the slightly unfocused case (250 mm behind the scale).

1.4 End Section of the Staff

In practice the lower staff end is avoided due to refraction effects. Additionally with digital levels the upper end section has to be avoided. For the determination of the height reading, a certain area of the code on the leveling rod is used by the level. If only parts of this area are visible, as is the case at the end sections of the staff, inaccurate measurements are the consequence, see Figure 4.

The DiNi12 uses a maximal 300 mm section of the staff (Trimble, 2001) to determine the height reading (at close sighting distances up to 3.5 m a smaller section of the staff is used because the optic has an opening angle of 5°). The 2 m rod has a visible code section from 0.039 m to 1.940 m. Using only measurements when 300 mm of the scale are visible, the usable section on the 2 m rod ranges from 0.189 m to 1.790 m.

The Leica DNA03 does not use a fixed range on the staff for the final height reading but a section visible at an opening angle of 1.1°. When measuring at the staff end then, that window is shifted into the visible code section, Schneider and Dixon (2002). With measurements at the rod ends at several sighting distances up to 15 m, the following formula was determined to avoid rod end sections on the staff where corrupted measurements could occur.

$$H\,[mm] = \text{start of visible code on the staff} + 20 + 6.9 \cdot \text{sighting distance}\,[m]$$

Using a 2 m rod with the DNA03 at a sighting distance of 3 m this results in a usable code section from 0.078 m to 1.899 m.

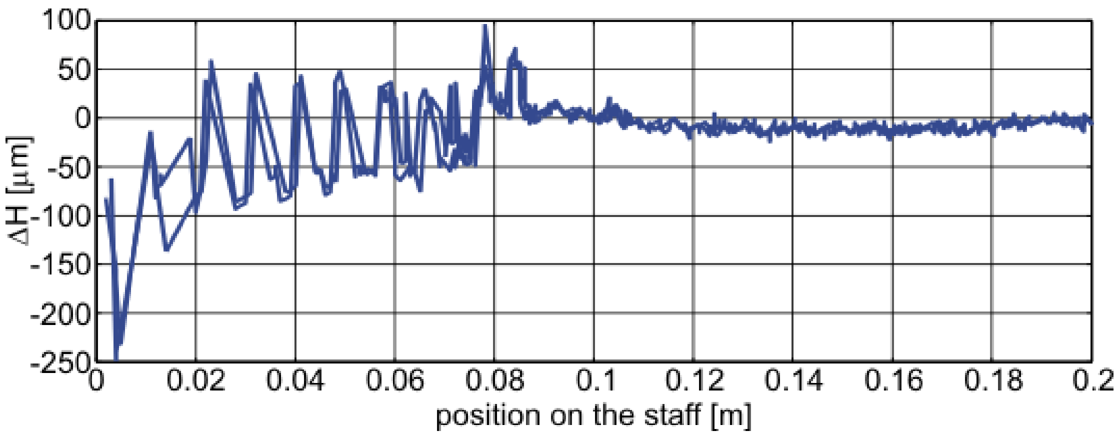

Figure 4: Results of height readings at the end section of the staff with the DNA03 at a sighting distance of 7.5 m.

1.5 Illumination

Leveling instruments are passive measurement systems that use ambient light to read the rods. In tunnels, we use flashlights to illuminate the rods and allow measurements. Therefore tests with our instruments have to be carried out to find out if the inhomogeneous illumination of flashlights has an effect or not.

By taking more then 100 measurements at a sighting distance of 3 m, illuminating the staff with a flashlight (Black & Decker Snake Light) in front of the rod and up to an angle of about 45°, either no measurements were taken or the measurements were correct.

But taking measurements with the illumination at a very steep angle (see Figure 5) deviations of up to 0.1 mm could be invoked. This can be explained by a shadowing effect of the code elements. During the manufacturing process the whole scale is first covered with a black layer and then with a yellow layer. The top yellow layer is removed with a high energy laser to make the black color visible. Due to this process the code elements have a certain thickness of a few micrometers, Fischer and Fischer (1999).

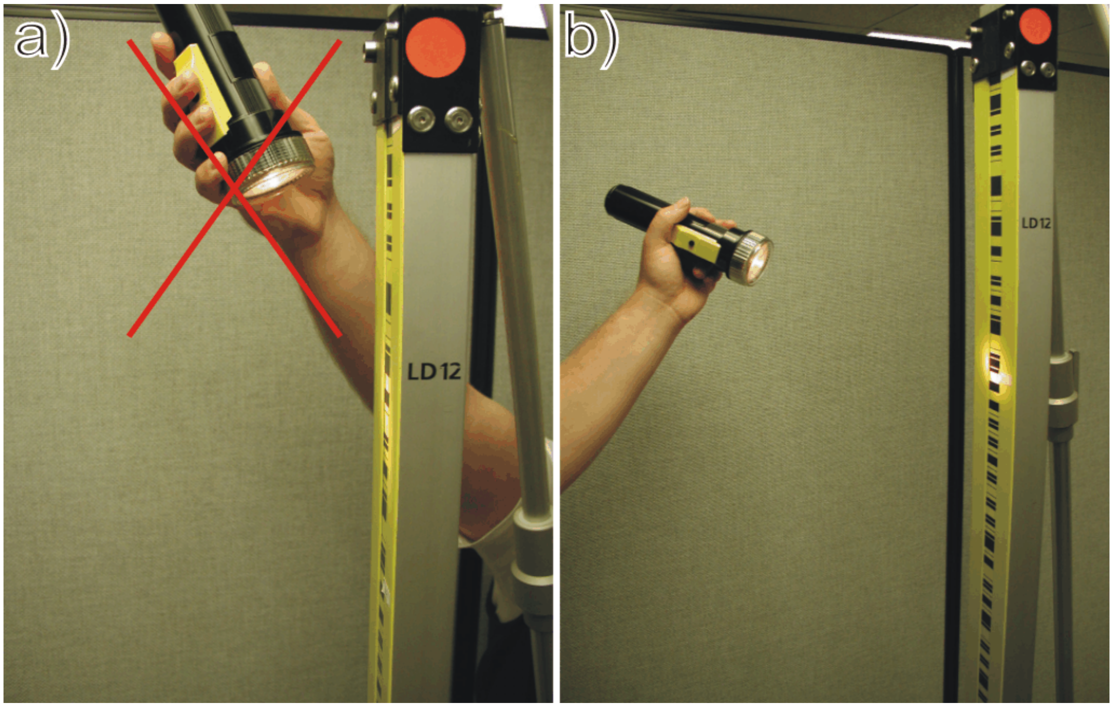

Figure 5: Illumination of the rod. With the angle of the illumination as depicted in picture a) wrong readings would be achieved. With the illumination as in picture b) the illumination did not cause wrong readings.

References

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