

# **Procedure for Analyzing Geometrical Characteristics of an EDM Calibration Bench**

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## **SUMMARY**

One of the methods to determine the accuracy of an EDM total station is by a calibration procedure on a measuring bench, with a laser interferometer to monitor the real distance. For this specific calibration method an alignment of the prism and a solid knowledge of the construction of the bench is indispensable. Aberrations of the bench in lateral or vertical way, or rotations of the carrier may cause instabilities in receiving the reflected laser beam of the interferometer.

This paper describes a measuring and correction procedure, by using a Trimble S6 robotic total station, combined with an LSP-30 laser interferometer on an EDM measuring bench. The study highlights that the lateral and vertical errors on the distance, as well as the rotation movements of the carrier, can be corrected rather accurately. However, the error on the horizontal distance, which increases in relation to the distance, could not completely be removed from the dataset. Additional research is required to solve this issue.

# Procedure for Analyzing Geometrical Characteristics of an EDM Calibration Bench

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## 1. INTRODUCTION

The calibration and accuracy of total stations is one of the most important topics in surveying and science. In 2003, Ghent University constructed an adapted calibration room for calibrating EDM total stations (Figure 1 and Figure 2). On the basis of a measuring bench of 20 m, a Lasertex LSP-30 laser interferometer is mounted and pillars to set up the total station. The rail for the movable prism carrier on the measuring bench is not a perfect straight line but shows evidence of small vertical and horizontal offsets and thus pitch, roll and yaw of the movable prism carrier. Therefore, in 2010 a survey was conducted using a Trimble S6 total station in order to be able to quantify these offsets and pitch, roll and yaw angles.

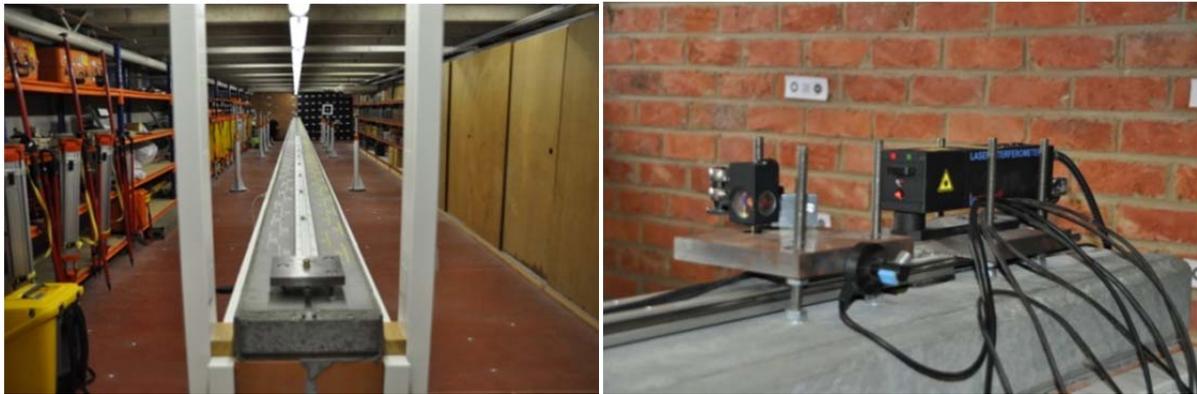


Figure 1: EDM measuring bench (left) and LSP-30 laser interferometer

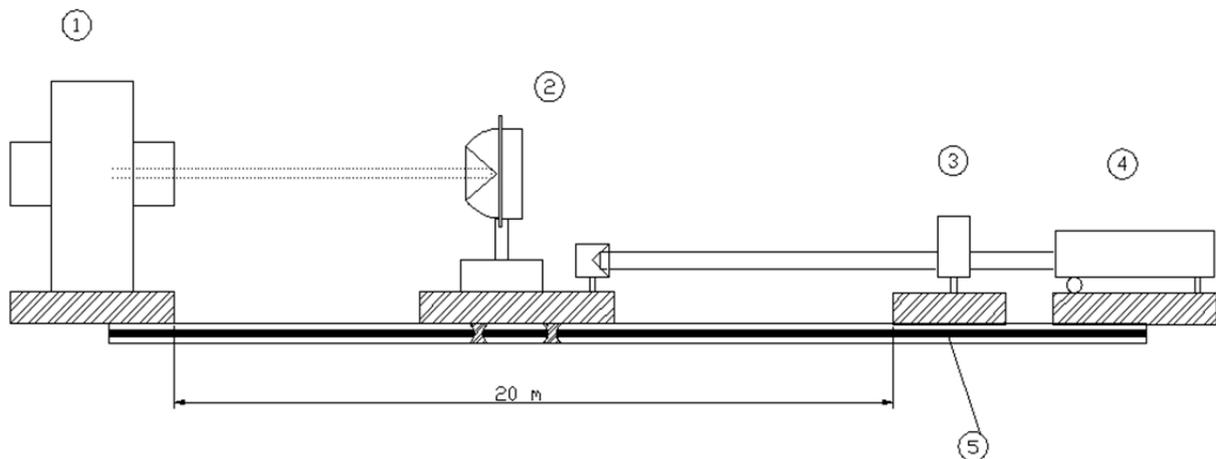
## 2. MEASURING METHOD

The basic principle to test the EDM of a total station is the comparison of, on the one hand, distance differences measured by the total station and, on the other hand, distance differences measured by an interferometer. The interferometer used is a Lasertex LSP-30 HeNe laser with a wave length of 632.991354 nm, a range of 30 m, a resolution of 1 nm and an accuracy of 1.5 ppm. As the accuracy of a total station is typically 2 mm + 2 ppm in comparison to the 0.001 mm + 1.5 ppm of the interferometer, the distance differences of the interferometer can be assumed as the “true values” to define the distance deviations of the tested total station.



**Figure 2:** Movable carrier and EDM total station (left) and construction of the calibration bench (right)

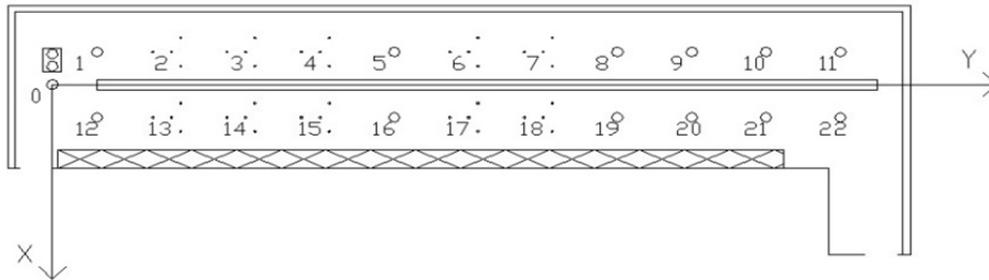
In the set-up of the measuring bench (**Figure 3**) at Ghent University, the total station (1) tested and the interferometer (4) are positioned on fixed points at each side of the moving carrier (2) with 2 prisms. There is one prism for the total station EDM measurements and one small prism for the interferometer measurements. A fixed small prism (3) is also needed for the Michelson type interferometer in order to create an interference pattern.



**Figure 3:** Scheme of the measuring bench

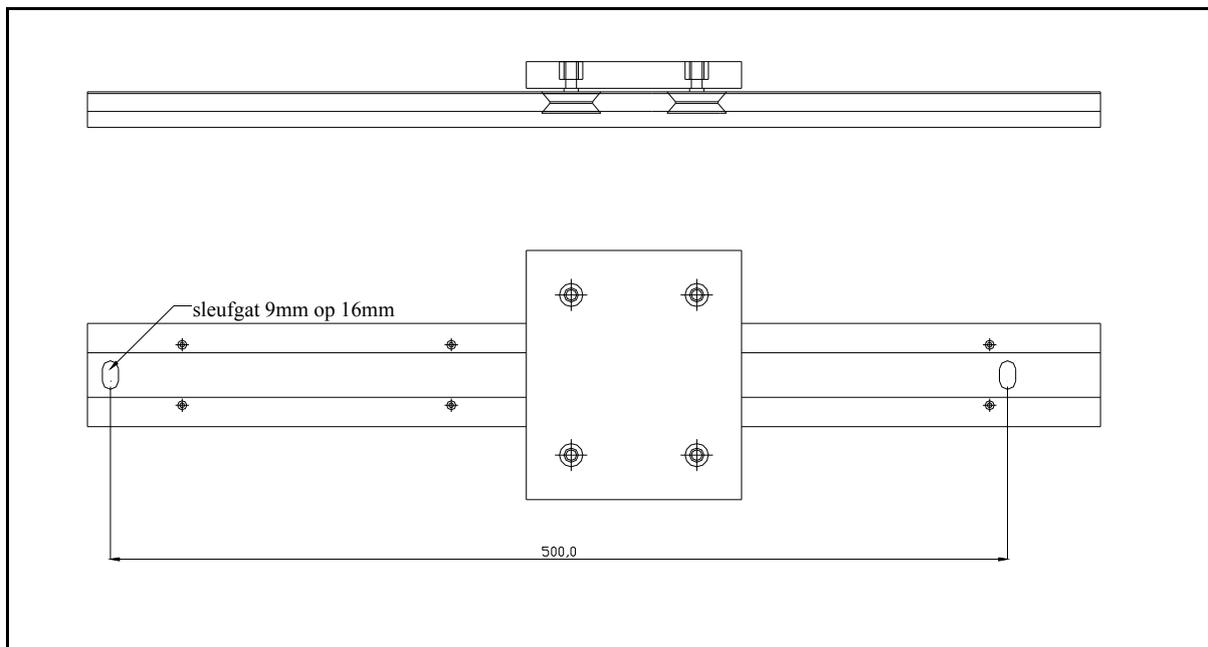
Before starting the measurements, the additional constant of the total station prism (2) was computed according to the procedure of the ISO 17123-4 (2001) norm. To do so, the distances between 7 rectilinear points (yielding in total 21 distance combinations) were measured by the Trimble S6 total station (interval distances between 1 and 3 m using pillars 12, 14, 16, 19, 20, 21 and 22 (Figure 4)).

The measuring bench is a 29 cm large brick wall of approximately 20 m long and 1 m high, filled at the inside with stabilized sand and with at the upper side a reinforced concrete beam of approximately 10 cm high. The total weight of the measuring bench is 105 kN.

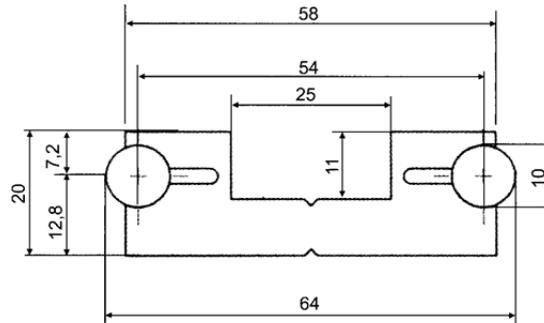


**Figure 4:** Floor plan of the calibration room at the Ghent University (Source: Van Den Bouverie, 2003)

The movable prism carrier is connected to an aluminum rail (CTS type AD208) with moving carrier (M208) (Figure 5). The carrier is made of steel and uses four gliding wheels that make contact with the outside circular steel tubes (10 mm diameter, Figure 6) and is moved manually for the moment (automation options are being considered). Both circular steel tubes consist each of three subsequent tubes with a length of 6 m and one with a length of 2.2 m, totaling 20.2 m. At the cross-over of the wheels from one tube to the next a slight “click” can be heard and more significant pitch, roll and yaw offsets are observed.

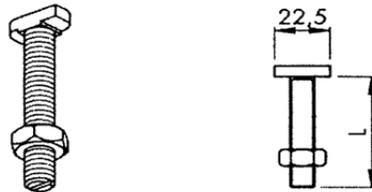


**Figure 5:** Longitudinal section and plan view of the bench rail (AD 208) (Source: Catalogue S.A. Vermeire-Belting N.V. Lineaire Geleidingen)



**Figure 6:** Cross-section of the rail (Source: Catalogue S.A. Vermeire-Belting N.V. Lineaire Geleidingen)

Every 600 mm an adjustable screw connection (Figure 7) is made between the rail and the concrete wall. This allows to modify the altimetric and planimetric profile of the rail within a range of approximately 20 mm. However, for the duration of our tests, no changes to the rail profile were made as we intended to analyze the lateral and height offsets and pitch, roll and yaw angles.



**Figure 7:** Halfen screw HS 28/15 (Source: Catalogue Halfen)

The atmospheric conditions like temperature, air pressure and humidity, which could affect the laser beam of the interferometer. These conditions need to be as constant as possible (Armitage, 1999). They are measured by four evenly distributed temperature sensors, one air pressure sensor, one humidity sensor and they are monitored by the Lasertex software with an accuracy of respectively 0.1 Kelvin, 1 hPa and 10 % relative humidity at regular intervals in order to check any side effects. There is no air-conditioning in the calibration room but as the room is located in the basement of a university building with only very small windows, temperature is typically 20 degrees Celsius and the more important temperature variation is less than 1 degree during a day or less than 5 degrees during a year.



**Figure 8:** Movable carrier with two targets on the base plate under the tribrach

After determining the additional constant and having checked the atmospheric conditions, the measurements of the offsets and angles can start. The principle used is that these offsets and angles are derived from horizontal and vertical angle measurements performed by the total station (angle accuracy of 2") towards two targets solidly attached to the base of the movable carrier (**Figure 8**).

The first step is to place the movable carrier at the opposite end of the bench, just in front of the laser interferometer, and to make sure that the total station prism is levelled correctly by using the tubular level built into the prism carrier placed on the prism tribrach. At this point, the parameters of the total station are set. The total station height is modified so that the vertical angle equals 100 grad. The horizontal angle is set to 0 grad. This procedure using a "reference point" and "reference direction" simplifies a relative comparison between the measured results at all points of the measuring bench.

In the next step, the carrier is positioned again at the beginning of the bench, near the side of the total station, and the first point can be measured. The total station will record the vertical angle VA (grad), the horizontal angle HA (grad) and the slope distance SD (m). The operator will register this data for both the prism and the left and right target (in reflectorless mode).

At the other end of the measuring bench an LSP-30 laser interferometer with a stable Zeeman HeNe-laser is used, connected to a PC. This PC is running software which is visualizing the atmospheric parameters (temperature, air pressure and humidity) and measured distances.

The complete procedure of measuring the distances with the total station and recording the data of the laser interferometer is repeated approximately every 15 cm, until the carrier reaches the end of the measuring bench ( $\pm 20$  m).

### 3. ANALYSING THE GEOMETRICAL MOVEMENTS OF THE BENCH

#### 3.1. Calculating the horizontal distance and the corresponding error

The horizontal distance HD can be deduced from the measured data by Formula 1:

$$HA_{prism,i} = \cos(HH_i) \times \sin(VH_i) \times SA_i \quad (\text{Formula 1})$$

With:

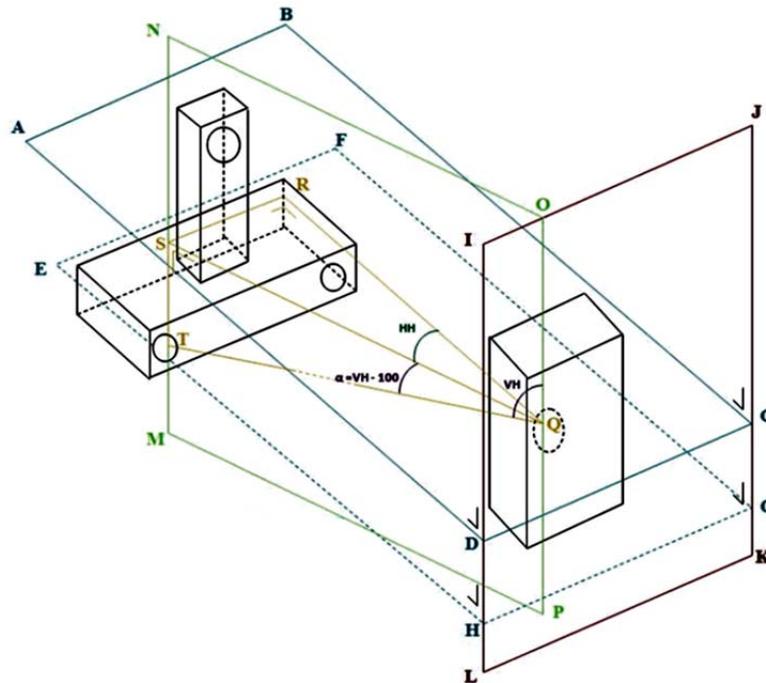
- HA = Horizontal Distance (mm);
- HH = Horizontal Angle (grad);
- VH = Vertical Angle (grad);
- SA = Slope Distance (mm).

This is illustrated by Figure 9, where:

- Plane ABCD is horizontal through reference prism;
- Plane IJKL is vertical through the total station vertical and the horizontal axis;
- Plane EFGH is horizontal through the left target;
- Plane MNOP is vertical through the left target and the total station vertical axis.

And with:

- QT = SA = slope distance;
- SQ = QT projected on ABCD;
- RQ = SQ projected perpendicular on IJKL.



**Figure 9:** Visualization of the measured and reduced data

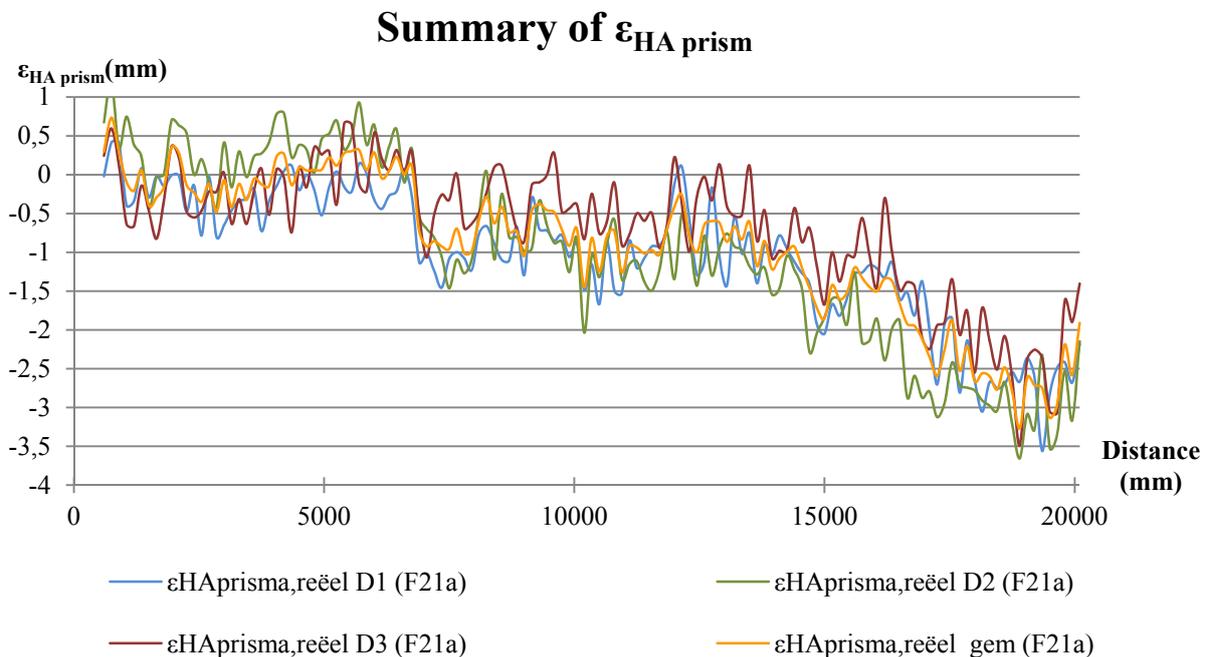
The error on the horizontal distance ( $\epsilon_{HD}$ ) can be calculated by using Formula 2 and is based on a combination of the data, received from the total station and the data of the interferometer.

$$\epsilon_{HA_i} = [HA_{prism,i} - (HA_{prism,l} - DL_l)] - DL_i \quad (\text{Formula 2})$$

With:

- $HA_{prism,i}$  = Horizontal Distance at point  $i$  (mm);
- $HA_{start}$  = Horizontal Distance at the startpoint  $i$  (mm);
- $DL_i$  = Distance measured by the Laser interferometer at point  $i$  (mm).

The error on the horizontal distance seems to increase as the distance between the total station and the carrier increases (Figure 10). The entire procedure has been repeated three times, all producing very similar results. Also Brown's study (2003), investigating the scale error of a total station by using a measuring bench, produced similar results. Neither one of these two surveys could give an acceptable solution or explanation for this phenomenon. The control of possible cycle slips also could explain this aberration, so additional survey will be required.



**Figure 10:** Average error on the horizontal distance

### 3.2 Calculating the vertical and lateral offsets (movements) of the carrier

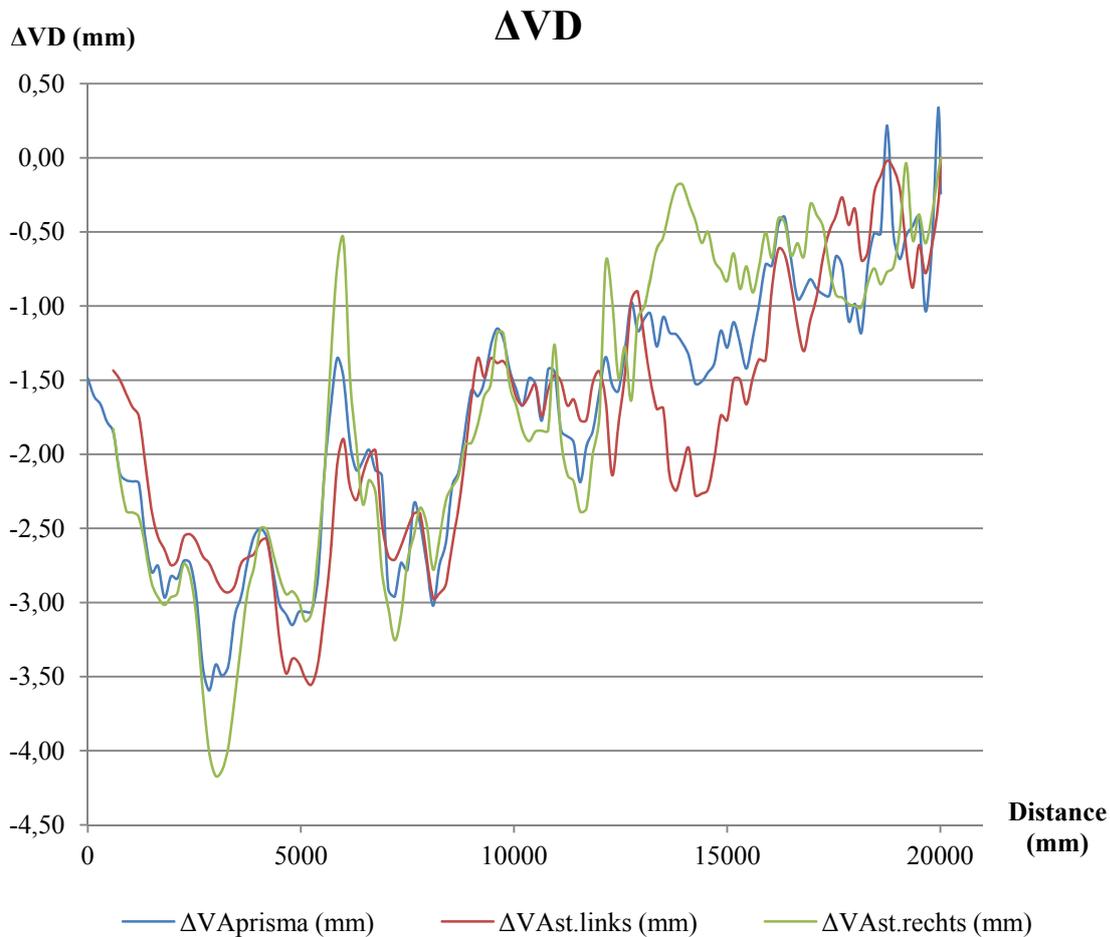
The vertical movement of the carrier needs to be compared with the reference position at the end of the measuring bench, determined at the start of the measurement. The vertical distance ( $VD_i$ ), as well as the lateral distance ( $LD_i$ ), can be determined at all points of the bench during the measurement with Formula 3.

Afterwards, a relative comparison between the vertical distances at all points Formula 4 is carried out.

The offset on the vertical distance will be positive in case the measured height at a specific point on the measuring bench is higher compared to the reference point ( $\Delta VD_i > 0$ ), while the opposite is true for a lower position at the measuring bench ( $\Delta VD_i < 0$ ) (Figure 11).

$$VA_i = \cos(VH_i) \times SA_i \quad (\text{Formula 3})$$

$$\Delta VD_i = VA_i - VA_{reference} \quad (\text{Formula 4})$$



**Figure 11:** Vertical offset

A similar reasoning can be applied in order to determine the lateral offset ( $\Delta LD_i$ )(Figure 12). There are a lot of similarities between these two calculations (Formula 5, 6). An offset to the left, looking from the total station in the direction of the laser interferometer, corresponds to a negative error on the lateral distance ( $\Delta LD_i < 0$ ), while the opposite is true for an offset to the right side ( $\Delta LD_i > 0$ ).

$$LD_i = \sin(HH_i) \times \sin(VH_i) \times SA_i \quad (\text{Formula 5})$$

$$\Delta LD_i = LD_i - LD_{reference} \quad (\text{Formula 6})$$

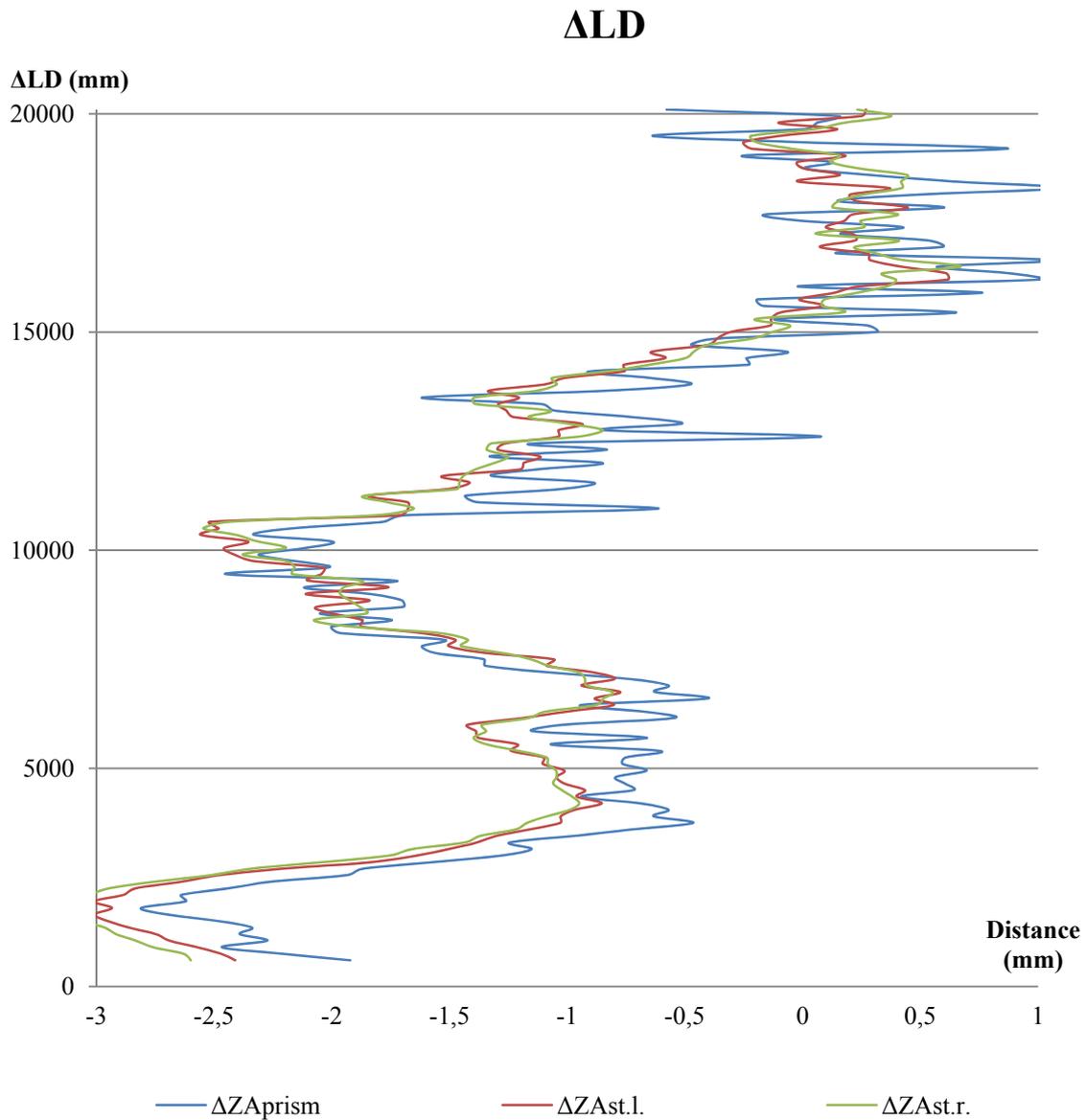


Figure 12: Lateral offset

### 3.3 Calculating the pitch and roll motion of the carrier

The offsets on the vertical and lateral distances are not the only ones having an influence on the geometrical characteristics of the bench. The rotation movements of the carrier are also important. Similar to the movements of an aeroplane, the rotation on the short axis of the carrier (upwards/downwards movement of the carrier) is called the pitch motion (Figure 13, left), while the rotation on the long axis (inclination to the left/right) is called the roll motion (Figure 13, right).

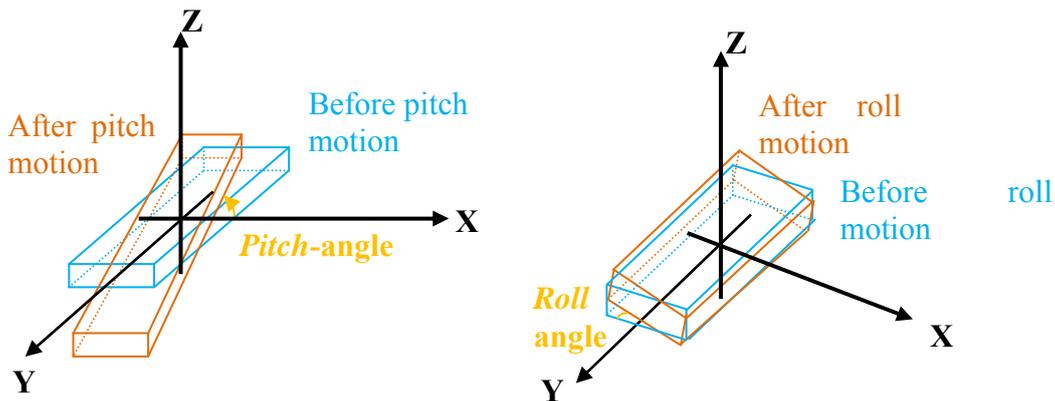


Figure 13: Pitch motion (left) and roll motion (right)

Both motions can be calculated by using the above data, measured by the total station ( $pitch_{measured}$ ,  $roll_{measured}$ ) (Formula 8 - 12), but pitch and roll changes can also be immediately retrieved from the total station, if the total station has an electronic 2-axis compensator and is placed on the carrier ( $pitch_{ts}$ ,  $roll_{ts}$ ). In the latter case using an electronic compensator, absolute pitch and roll orientation remains uncertain as the tribrach between the movable carrier and the compensator built into the total station yields an unknown pitch and roll offset. These two movements have an influence on the final results. The pitch motion results in an error on the EDM total station distance, whereas the roll motion will result only in a distance error of second order.

The following corrections for these two motion types were applied :

$$pitch_{measured,i} = \arctan\left(\frac{VD_{prism,i+1} - VD_{prism,i-1}}{HA_{prism,i+1} - HA_{prism,i-1}}\right) \quad (\text{Formula 8})$$

Averaging the data on the previous and next point will result in more reliable results, than when they are calculated only at point  $i$ . At the beginning and at the end of the bench there is no point  $i - 1$  and point  $i + 1$  available, so these points are replaced by the data of point  $i$ .

$$pitch_{corrected,i} = pitch_{measured,i} - (\overline{pitch_{measured}} - \overline{pitch_{ts}}) \quad (\text{Formula 9})$$

$$\delta_{HD_{pitch,i}} = \sin(pitch_{corrected,i}) \times D_{prism} \quad (\text{Formula 10})$$

$$HD_{pitch,i} = HD_{prism,i} + \delta_{HD,pitch,i} - HD_{reference} \quad (\text{Formula 11})$$

$$roll_{measured,i} = \arcsin\left(\frac{\Delta VD_{stickers,i}}{D_{prism}}\right) \quad (\text{Formula 12})$$

$$roll_{corrected} = roll_{measured,i} - (\overline{roll_{measured}} - \overline{roll_{ts}}) \quad (\text{Formula 13})$$

$$\delta_{LD,roll,i} = \tan(roll_{corrected}) \times D_{prism} \quad (\text{Formula 14})$$

With:

- $\delta_{HD\ pitch,i}$  = correction on the horizontal distance;
- $D_{prism}$  = length of the prism arm;
- $HD_{pitch,i}$  = corrected horizontal distance;
- $\Delta VD_{stickers,i}$  = difference in height between the left and the right sticker;
- $\delta_{LD\ roll,i}$  = correction on the lateral distance

Indications for the existence of roll motion can be found within the analysis of the differences between the offsets on the vertical distances on the left and right target. In the ideal situation there will be no difference between the left and right target vertical offset. When differences between both can be observed in the graphs, the operator has to be aware of the existence of a potential roll motion. The roll motion will manifest itself in a major lateral offset of the prism, but this has only a secondary effect on the distance measured by the total station.

#### 4. COMMENTS

A first comment is about the reference point used. Throughout the whole process it became obvious that a fixed reference point external to would be better and more reliable to compare to, than the relative reference used at the end of the measuring bench.

The second comment is that, when applying this procedure in other surveys, the operators must be aware of the fact that these error corrections are set up for the measuring bench at the Ghent University. For every conducted study, the exact conditions of the actual situation must be taken into account. Any additional automation and the specifications of the used bench must be considered before using the above formulas.

#### 5. CONCLUSION

The executed survey shows that a precise knowledge of the geometrical characteristics of the used measuring bench is indispensable and can provide important improvement factors. This survey has developed a methodology for calculating the vertical and lateral distances, the corresponding errors on these distances and the roll and pitch motions by using a total station. It became obvious that this method yields a good relative comparison of the vertical and lateral offsets and of the pitch, roll and yaw values but that an accurate absolute quantification of these values is not easy.

In the next future we plan interferometric angle measurements (pitch and roll) on the same measurement bench. It will be interesting to compare the results and the accuracies of both methods.

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