

User Information on Calibration of Total Stations

This document intends to give useful information about the calibration of total stations. The first part explains what calibration is and when it has to be done. The second part covers the more theoretical explanation of the instrument errors, and the final part gives instruction how and what has to be calibrated.

What is calibration?

Accurate measurements with total stations assume that all instrument axes are perfectly perpendicular to each other. Also, the RL EDM reference laser beam, the ATR zero point, and the line of sight are coinciding precisely.

Unfortunately these requirements are never perfectly fulfilled. Even with great care when manufacturing the instrument, small deviations from the target position of the different components occur. Also during the normal working life of the instrument, small movements inside the instrument can occur. There are different possible reasons for this:

- Result of temperature changes, as every material expands and contracts with temperature
- Shocks (e.g. during transportation)
- Stress during normal use

Even small deviations can lead to measurement errors which are greater than the specified accuracy of the instrument.

These deviations can happen with every instrument, no matter if it is mechanical or electronic, and independent of the manufacturer.

For most electronic instruments the main deviations can be determined by the user. This procedure is called calibration. Following calibration, all measurements will then automatically be corrected arithmetically by the instrument.

Electronic calibration

The following instrument errors can be determined when executing the onboard calibration routine:

- c Line-of-sight error
- a Tilting axis error (only TPS1100/1000)
- l,t Compensator index error
- i Vertical-index error
- ATR ATR zero-point error

See chapter "Instrument errors – Theory" for explanation of these errors.

Once determined, the instrument software continuously applies the corrections to the measurements.

Mechanical adjustment

The following errors cannot be corrected arithmetically and have therefore to be adjusted mechanically:

- Circular bubble on instrument and tribrach
- Visible red laser beam (RL EDM)

Especially when measuring reflector-less to edges or inclined planes a divergence of the visible red laser beam from the line-of-sight can lead to measurement errors, because the RL EDM will not measure exactly to where you are pointing. Therefore the red laser beam has to be adjusted from time to time.

Please read the manual for explanations regarding the mechanical adjustment.

Other influences to the accuracy

Careful calibration and adjustment is inevitable for accurate measurements but doesn't guarantee them. There are many additional factors which can affect the measurement accuracy:

- One sided instrument and tripod warming (e.g. from sunlight) ⇒ use an umbrella
- Heat shimmer and unpredictable refraction
- Instrument has not acclimatised to surrounding temperature
- ...

In addition when high precision measurements are required it is strongly recommended that two-face measurement techniques are used.

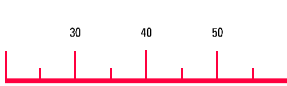
Two-face measurements eliminate most of the instrument errors (also inaccurate determined instrument errors) through averaging the measured angles.

When to calibrate your instrument?

Instrument errors are determined and set to zero during production process. But as mentioned above the values can change and therefore the instrument should be calibrated regularly by the user. Always keep in mind that a total station is a very sensitive high precision instrument that should be handled with great care.

Additional user calibration should be done in the following cases:

- **before first use**; as the instrument might have had a long journey with large temperature differences
- **after long periods of work**
- **after long storage periods**



- **after big temperature difference**; it is strongly advised to recalibrate an instrument if the working temperature differs more than 10°C (18°F) from temperature which existed at the previous instrument calibration. Also calibrate with large difference between storage and working temperature (allow for sufficient acclimatization of the instrument before calibrating!!!)
- **after rough or long transportation** ⇒ mechanical shocks; take measures to protect the instrument from shocks.
- **periodically for high accuracy jobs**

What has to be considered when calibrating

Following instrument calibration, the electronically determined instrument errors are applied to every measurement. If the calibration routine was executed inaccurately, this will adversely affect all following measurements. Great care must therefore be taken during the whole calibration process.

Follow the advices below to determine precise instrument error values:

- **Good atmospheric conditions**, i.e. no strong heat shimmer, are essential ⇒ measure in the morning or with overcast sky.
- **Level-up** the instrument precisely using the electronic bubble
- The instrument, tribrach and tripod should be **secure and firm**
- Make sure that the instrument and the tripod are **not exposed to direct sunshine**, as this may cause one-sided heating of instrument or tripod.
- Before starting the calibration routine, make sure that the instrument had enough time to **adapt to the ambient temperature**. As a guide, the time for acclimatisation should be at least 20 minutes or 2 minutes per 1°C (1 minute per 1°F) of temperature difference (between storage and working temperature)

Instrument errors – Theory

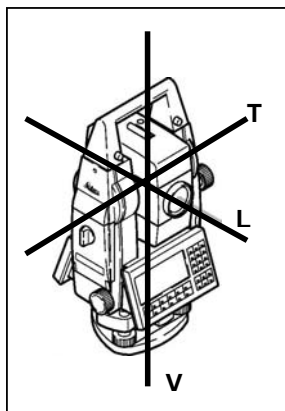
To understand the instrument errors it is important to know the instrument axes.

Instrument axes

The three axes of a total station are the Vertical axis **V** (also called Standing axis), the Tilting axis **T** and the Line of sight **L**.

Instrument errors occur if the instrument differs from the following conditions:

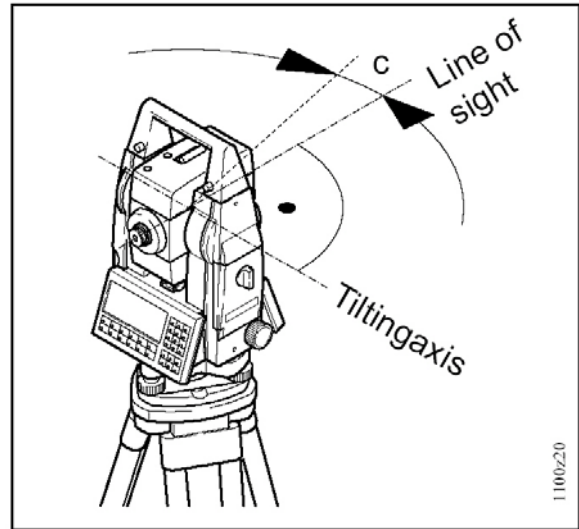
- The Line of sight **L** is perpendicular to the Tilting axis **T**



- The Tilting axis **T** is perpendicular to the Vertical axis **V**
- The Vertical axis **V** is perfectly vertical

Line-of-sight error (c)

The line-of-sight error (also called Hz-collimation error) is caused by the deviation “c” between the optical line-of-sight (the direction the crosshairs in the telescope point) and the line perpendicular to the tilting axis.



This error affects all horizontal circle readings and increases with steep sightings. The affect to the vertical angle is very small and can normally be ignored.

The following table shows the influence of a line-of-sight error of c=10” to the horizontal angle for different vertical angles:

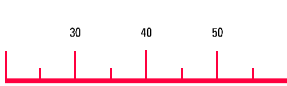
Zenith angle	Error in Hz
90°	10”
60°	12”
30°	20”

This effect can be eliminated by precisely defining the line-of-sight error with the instrument’s on-board calibration function or with two-face measurements.

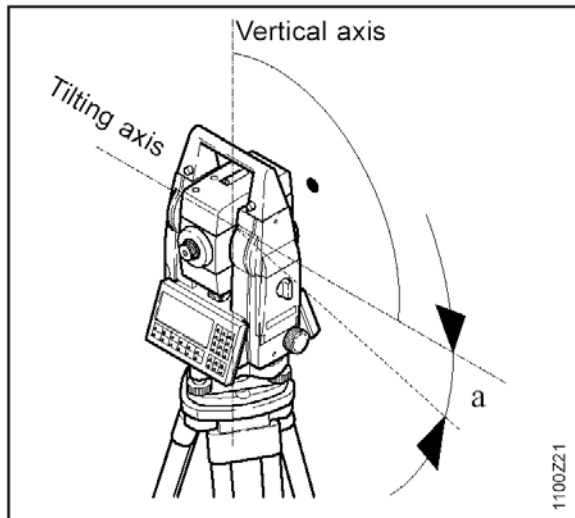
The line-of-sight error must be determined to a horizontally located target to avoid influences of the tilting axis error.

Tilting axis error (a)

The tilting axis error is caused by the deviation “a” of the mechanical tilting axis from the line perpendicular to the vertical axis.



The tilting axis error can be observed when the telescope is moved vertically along a vertical line (e.g. an edge of a house) and the crosshair moves away from the vertical line although the instrument hasn't turned (in Hz).



This error has no effect on exactly horizontal sightings but it increases with steep sightings. It has an impact on horizontal readings. The affect to the vertical angle is very small and can normally be ignored.

The following table shows the influence of a tilting axis error of $a=10''$ to the horizontal angle for different vertical angles:

Zenith angle	Error in Hz
90°	0''
60°	6''
30°	17''

This effect can be eliminated as well by precisely defining the tilting axis error with the instrument's onboard calibration function (only TPS1000/1100), or with two-face measurements.

As the error only has an effect on steep sightings it can only be determined with observations to targets located either significantly below or above the level of the instrument. To avoid influences from the line-of-sight error, this error has to be determined prior to the tilting axis calibration.

Vertical axis error

The vertical axis error (also called standing axis error) is not a instrument error, but a set-up error. It occurs if the vertical axis is not in truly plumb.

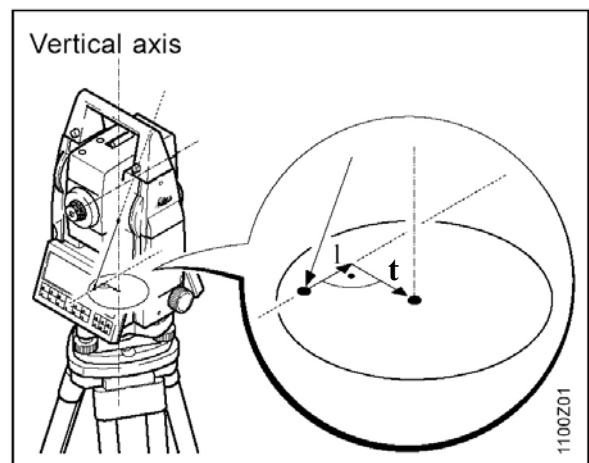
The vertical axis error affects both the horizontal and the vertical angle readings and **can not be eliminated by two face measurements.**

It can be avoided by carefully levelling the instrument. With modern instruments containing in-built two axis compensators, the levelling only has to be made roughly as the fine levelling is arithmetically corrected by the compensator.

Compensator index error (l,t)

The principle of the electronic compensator is quite similar to that of a circular bubble. It consists of a small container filled with a special fluid. Due to gravity the surface of this fluid is always horizontal. Sensors interacting with the surface of this fluid are used to determine the longitudinal and lateral tilt of the instrument. The horizontal and vertical angles are then automatically corrected.

A compensator index error occurs when the zero point of the compensator is not in the plumb-line. With a dual axis compensator the index error of the compensator is divided into two components, one alongside (longitudinal **l**) and the other crosswise (transversal **t**) to the telescope.



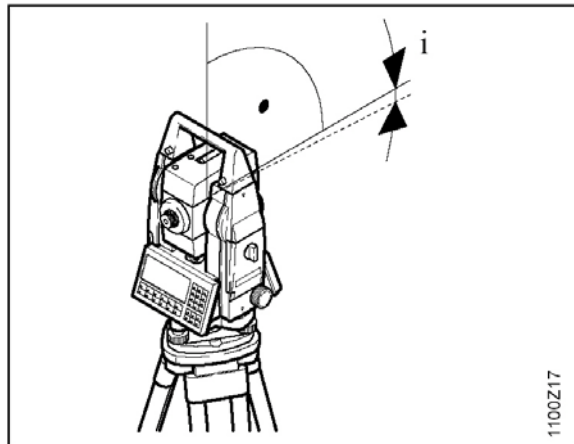
The longitudinal compensator index error "**l**" is similar to the V-index error and affects only vertical angle readings. On the other hand the transversal compensator index error "**t**" is similar to the tilting axis error and mainly impacts the horizontal angle. The impact on the angle increases with steep sightings.

The effect of both errors (**l&t**) can be eliminated by running the compensator calibration or by two-face measurement.

In order to get correct tilt values it is important to adjust the compensator index from time to time with the onboard calibration function.

Vertical index error (i)

A vertical index error “i” exists if the 0° mark of the vertical circle reading doesn’t coincide with the instrument’s mechanical vertical axis.

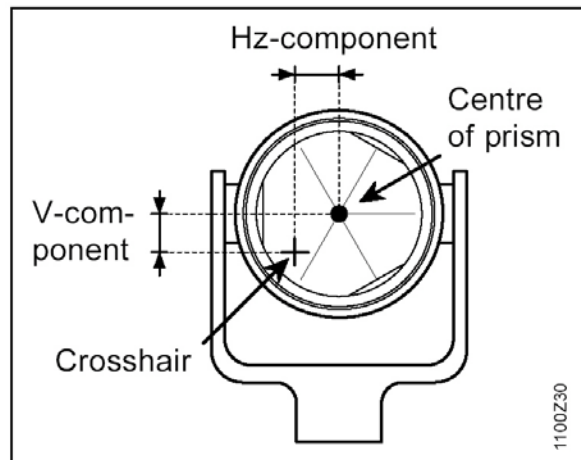


The V-index error is a constant error that affects all vertical angle readings independent from the steepness of the aiming. The V-index error has no impact on to the horizontal angle.

The effect of the V-index error can be avoided by precisely defining this error with the instrument’s onboard calibration function or with two-face measurement.

ATR collimation error

The ATR collimation error is the angular divergence between the line-of-sight and the ATR CCD camera axis.



The Hz-component of the ATR collimation error affects the horizontal angle where the V component affects the vertical angle.

The ATR calibration routine allows to determine the alignment of the centre of the ATR camera with the optical line-of-sight.

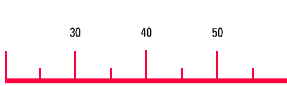


Please note, that when measuring with ATR, the crosshairs may not be exactly on the prism centre, even if the ATR is newly calibrated. This is not an error as the divergence to the centre is measured by the ATR and the angles are automatically corrected. Especially when measuring with EDM mode “FAST”, the instrument positions only roughly (to save time) and corrects the remaining divergence by the ATR.

Summary:

Instrument Error	affected angles		eliminated with 2-face meas.	automatically corrected by instrument
	Hz	V		
c: Line-of-sight error	√		√	√
a: Tilting axis error	√		√	√ ¹⁾
l&t: Compensator index error	√	√	√	√
i: V-index error		√	√	√
ATR collimation error	√	√		√
Standing axis error ²⁾	√	√		√ ³⁾

- 1) only for TPS1000 and TPS1100 instruments
- 2) setup error, not an instrument error
- 3) standing axis error is automatically corrected if compensator is activated



Calibrating TPS1100

Before starting calibration make sure that the conditions are appropriate and you have made all preparations (see earlier chapter “What has to be considered when calibrating”). The calibration functions can be accessed from the instrument main menu. The following functions exist:

- l,t Compensator index error determination
- i V-index error determination
- c/a Line-of-sight error and tilting-axis error determination; the two procedures will be in sequence
- i/c/a Simultaneous determination of the V-index and the line-of-sight error with following tilting-axis error determination
- ATR ATR zero-point error determination; additionally the line-of-sight and V-index error can be measured simultaneously. The procedure can be executed several time to average the instrument errors.

Immediately after the first measurement of each procedure has been completed, motorized instruments automatically change to the second face. It is important that in **all cases, the target is always aimed manually.**

Log-File

To track which instrument errors have been calibrated, a log-file can be created (Press [SHIFT F2] in the Calibration Main Menu). If the log-file is enabled, the measurements and results of the calibration are stored in an ASCII-file.

This file is created in the directory \LOG on the memory card.

Compensator index error determination

No target is needed for this procedure. Make sure that the instrument isn't touched and stands firm during the whole measurement process.

It is very important to thoroughly acclimatize the instrument before starting the procedure!

V-index error determination

To determine the V-index error, aim the telescope at a target at about 100m distance at the same level as the instrument (horizontal line-of-sight). The target does not have to be a prism, but the target should be suitable for precise aiming.

Always take greatest care when manually aiming at the target!

Use the ATR calibration routine to execute the V-index error determination several times to get a precise value.

Line-of-sight error determination

As with the V-index error aim at a target at about 100m distance located at the same level as the instrument.

The target does not have to be a prism, but the target should be suitable for precise aiming.

Always take greatest care when manually aiming at the target!

Use the ATR calibration routine to execute the line-of-sight error determination several times to get a precise value.

Horizontal angles are only corrected by the line-of-sight error when the correction is turned “On” (“Hz-Corr.” ⇒ “On” in the dialog where also the “Compensator” can be switched “On” and “Off”)

Tilting-axis error determination

Prior to the tilting-axis determination, the line-of-sight error should be determined.

As the tilting-axis error only occurs with steep sightings, the target used to determine this error must be located low or high. It might be difficult to get 100m distance but try to measure to a high or low point located as far as possible away from the instrument (e.g. a church tower or another high building)

As with the line-of-sight error, the horizontal angle is only corrected by the tilting-axis error if correction is turned to “On”.

ATR zero-point determination

Use a Leica standard prism which is located at the same height as the instrument at a 100m distance. **Do not use a 360°-prism for the calibration, even if you intend to measure with one afterwards.**

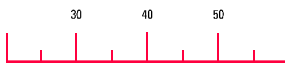
Choose good atmospheric conditions for ATR calibration.

In addition to the ATR zero-point the line-of-sight and V-index error can be determined at the same time.

This procedure can be executed several time to increase the accuracy of the instrument errors. The result is the mean of all the measurements taken. Also the standard deviation of each error calculation is shown. With this you get information about the accuracy of each error calculation and if the accuracy is bad, further measurements can be made or the procedure can be repeated.

When calibrating the ATR the final pointing has to be done manually. Take great care when aiming at the target!

Please read the TPS1100 user manual for a step by step explanation of the different calibration functions.



Calibrating TPS700

Before starting calibration make sure that the conditions are appropriate and you have made all preparations (see earlier chapter “What has to be considered when calibrating”). The calibration functions can be accessed from the system menu. The following functions exist:

- 1 Horiz. Collimation
- 2 Vert. Index; simultaneously the compensator index error is determined
- 3 ATR Calibration

Compensator index error determination

With TPS700 the compensator index error is automatically measured when executing the “Vertical Index” calibration function.

It is very important to thoroughly acclimatize the instrument before starting the procedure!

Horizontal collimation error determination

To determine the line-of-sight error aim at a target at about 100m distance at the same level as the instrument (horizontal line-of-sight).

The target does not have to be a prism, but the target should be suitable for precise aiming.

Always take greatest care when manually aiming at the target!

Horizontal angles are only corrected by the line-of-sight error when the correction is turned to “On” (“Hz collim.” ⇒ “On” in the “Angular & Compensator” setting dialog)

Vertical index error determination

Aim the telescope at a target at about 100m distance at the same level as the instrument. The target does not have to be a prism, but the target should be suitable for precise aiming.

Always take greatest care when manually aiming at the target!

ATR Calibration

Use a Leica standard prism for the ATR zero-point determination which is situated at the same height as the instrument at a 100m distance. **Do not use a 360°-prism for the calibration, even if you will measure with one afterwards.**

Choose good atmospheric conditions for ATR calibration.

This procedure can be executed several times to increase the accuracy of the instrument errors. The result is the mean of all the measurements taken. The standard deviation of the ATR Hz & V collimation error calculation is also shown. With this you get information about the accuracy of the error calcu-

lation and if the accuracy is bad, further measurements can be done or the procedure can be repeated.

When calibrating the ATR, the final pointing has to be done manually. Take great care when aiming at the target!

Please read the TPS700 field manual for a step by step explanation of the different calibration functions.

Summary

Instrument errors occur as a result of inherent mechanical imperfections (e.g. the axes are not exactly perpendicular to each other). By using the on-board calibration routines, these errors can be determined. The instrument will then always apply these corrections to all measurements automatically.

As this inherent imperfections can change with time and temperature, the calibration procedure must to be done regularly.

The procedure for determining the instrument errors has to be done precisely and with great care as wrongly determined instrument error values affect all subsequent measurements.



Leica Geosystems AG
CH-9435 Heerbrugg
(Switzerland)
Phone +41 71 727 31 31
Fax +41 71 727 46 73
www.leica-aeosvstems.com