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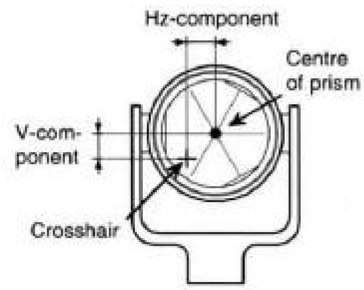



# Compensators, Stability Check, and Automatic Target Recognition

February 2002

## Introduction

The intent of this document is to describe the function of compensators in surveying instruments and the Stability Check and Automatic Target Recognition systems in Leica TCA1800 Total Stations.

## The Compensator

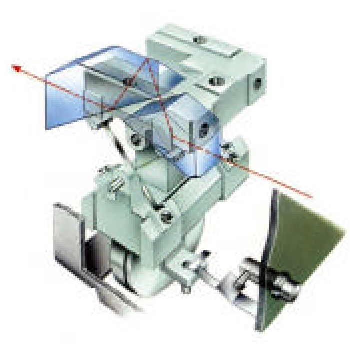
A compensator is a mechanical device to determine the artificial horizon in theodolites and levels. Aircraft use something similar to indicate if the plane is tilting. Aircraft artificial horizon systems rely on gyros to determine the horizon; are only accurate to a few degrees; and work in virtually any attitude (tilt) of the aircraft. However, survey instrument compensators are simply gravity seeking devices, they are extremely accurate, but have an operating range only within a few angular minutes from the true horizon. The survey instrument needs to be leveled to within this operating range, for the compensator to take over and do its job.

### Damping systems

Compensators need to be free to seek gravity, however they need to settle down and remain stationary while the survey measurements are conducted. A completely free, near frictionless, compensator will take a long time to settle down (if ever) and will be impractical to use. The solution was to develop damping systems, which create some friction to speed up the settling and provide some resistance to movement of the compensator caused by very minor jarring of the instrument.

### Levels

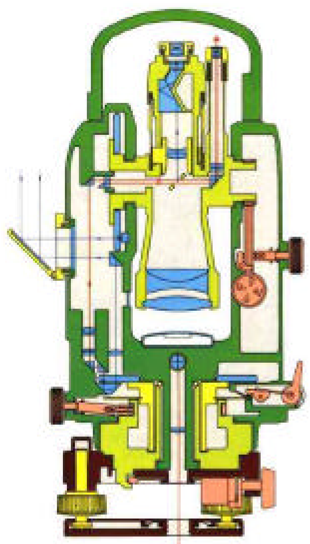
A compensator in a level is essentially a pendulum that seeks gravity along the axis of the telescope. Most automatic levels are equipped with a wire hung magnetically or pneumatically dampened single axis compensator, positioned just forward of the eyepiece. By utilizing prisms, the compensator corrects for error in the level of the line of sight. The diagram to the left shows a compensator from a NA2 auto level, which has a push button mechanism to verify the operation, or to free stuck compensators. The circular device at the bottom of the diagram is a pneumatic damping mechanism. The NA2002 digital level utilizes a magnetically dampened compensator. Old tubular levels, such as a Dumpy level did not utilize compensators and had to be continuously re-leveled on unstable ground.



When using a level it is a good practice to tap the compensator button, or the body of the level, after each setup prior to the first measurement.

**Theodolites**

A compensator in a theodolite is designed to primarily correct the zenith angle for errors due to tilt of the standing axis. The old T16 mechanical theodolite utilized a single axis compensator to correct the vertical angle scale reading.



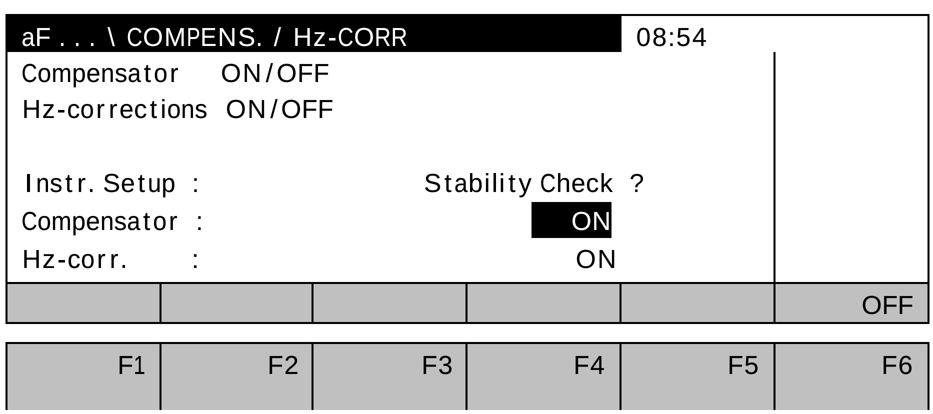
All of our earlier electronic Theodolites (T2000, T1600, and T1610) also utilized a single axis compensator to correct the tilt of the standing axis in the direction of the telescope.

The TCA1800 is equipped with a dual axis, oil dampened compensator positioned on the U-Frame opposite the battery location. The longitudinal and transverse tilt angle of the Standing Axis is determined by the compensator to establish the artificial horizon. The compensator in the TCA1800 can determine the artificial horizon to an angular accuracy of 0.3 seconds. The operating range of the compensator is 3' 47".

Leveling any survey instrument or device with a bubble vial has always required shading the vial from the sun. This is because the effects of heat from one side of the vial effectively moved the bubble towards the heat source. This is especially true when the instrument itself is relatively cool and the effect of the sun is quite contrasting. Since the TCA1800 is leveled electronically (rather than using the bubble) many operators don't concern themselves with shading the instrument. This is wrong! The TCA1800 should be given time to adapt to the ambient temperature and protected against uneven warming from one side. There is a temperature sensor under the compensator within the TCA1800. The TCA1800 adjusts all the calibration values based on temperature changes. In order for the adjustments to the calibration data to be accurate, the temperature sensed by the instrument must be representative of the overall instrument and not just one side of it.

Since the TCA1800 has dual axis compensators, the instrument can be leveled electronically without turning the alidade. Dual axis compensators also correct errors associated with horizontal angles due to tilt in the standing axis.

Each time the TCA1800 is turned on, it wakes up with the compensator on. The compensator can be turned off. In which case it will stay off until the instrument is turned off, or the operator turns it back on manually. <u>You should not work with the compensator off except in extremely rare instances</u> when the instrument is set up on very unstable ground or is being



impacted by strong jarring, and only very approximate data is needed.

When the compensator is off, the vertical angles relate to the standing axis and not the true plumb line. Also, the horizontal angles are not corrected for standing axis tilt when the compensator is off.

## The Stability Check

Since the compensator is mechanical, it is subject to small disturbances whenever the instrument is bumped, moved, or operated in conditions of wind, vibration, etc. Normally the compensator settles down very quickly in recovering from such disturbance.

However, in situations needing the utmost of accuracy, it is important to verify that the compensator is settled before taking the measurement. The TCA1800 provides a means to do just that. The TCA1800 can be configured for a Stability Check to be performed before each measurement. This is a toggle On/Off setting that is retained in memory even after the instrument is shut off. This setting is made from within the Additional Function (aF button) menu.

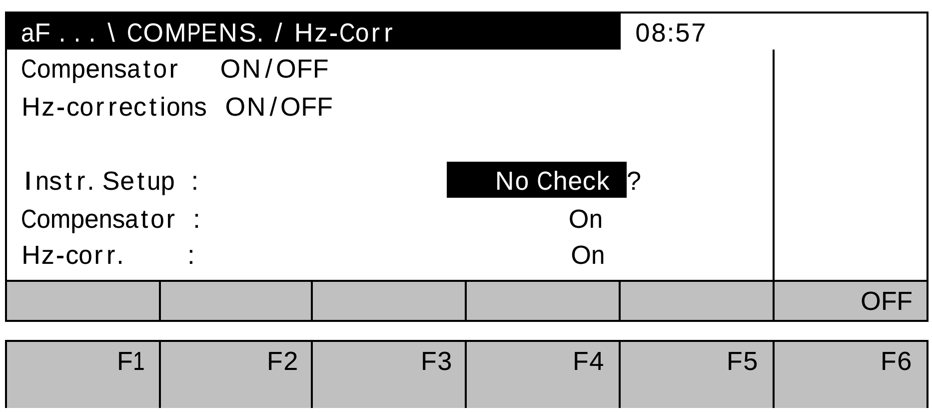
### Stability Check On

If the TCA1800 is configured for "Stability Check On" it performs a stability check on the compensator before each measurement. The stability check ensures that the compensator is settled and that the readings accurately depict the tilt of the compensator.

There may be instances when the user requests a measurement before the compensator is completely settled. In this case, the TCA1800 indicates this condition by issuing an Error 355 - "Stability Check Failed". Nothing will be recorded until the error is cleared and the measurement taken again.

### Stability Check Off

If the TCA1800 is configured for "Stability Check Off", the instrument bypasses the check for small disturbances in the compensator. It uses the compensator reading as is. This reading is always accurate with respect to what the compensator senses. However, since the stability check is not performed, this value might differ slightly from the true horizon. Hence, there could be very small amount of error (tilt) in the compensator reading.



This possible tilt is normally very small, and will always be within the operating range of the compensator.

Note: The TCRA1101 does not have the capability to perform a stability check on the compensator. The error from the compensator being slightly disturbed in the TCRA1101 is within the angular accuracy of that instrument.

**Accuracy**

With the TCA1800 Stability Check turned off, small tilt errors could exist in the compensator readings. Since any error in the compensator reading is undetermined, it is not possible to have a defined statement of accuracy in that condition.

**Resultant Positioning Accuracy**

The Positional Accuracy is a function of distance and EDM measuring mode. These figures combine the performance of the angle systems, ATR, and EDM to provide accuracy of measured positions. To achieve these accuracies, you must have Stability Check turned on.

| EDM Mode | Distance | Accuracy |
|---|---|---|
| Standard | 100m<br>500m<br>1000m | 2mm<br>2 to 3mm<br>10mm |
| Precise | 200m<br>500m<br>1000m | 1mm<br>2 to 3mm<br>10mm |

**When to use it**

For most of the survey work conducted by ODOT surveyors (working close to traffic or on construction sites) the compensator is continually being disturbed by traffic vibrations, wind, etc. In these conditions it is difficult to work with Stability Check on. Instrument operators have reported a high frequency of "Error 355" messages. For most measurements, with the exception of high precision control surveys, the Stability Check option can be safely turned off.

## Automatic Target Recognition

The TCA1800 is a motorized Total Station. The instrument is equipped with a motor that drives the vertical movement (telescope) and one that drives the horizontal movement (Alidade). In order for the instrument to turn to a particular position, both motors have to come into play. The action of repositioning the telescope to a new location involves the following steps:

1. Acceleration - from a stationary position to full speed.
2. Cruise - continuing at full speed to just before target position.
3. Deceleration - Slowing down and stopping at the new position.

Motors alone do provide some benefits, such as staking out pre-determined points. If the instrument knows its location, orientation, and height, and the stakeout point's location and target height, the instrument can calculate the horizontal and vertical plate readings and subsequently utilize the motors to turn the instrument to those settings for stakeout.

However, motors coupled with Automatic Target Recognition (ATR) opens up opportunities never possible before. The primary opportunities presented by this combination are:

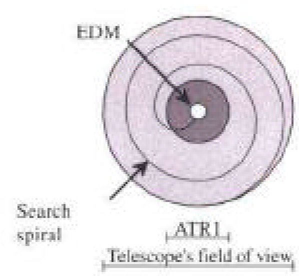
- Automatic telescope rotation. The instrument being able to rotate to any position automatically.
- Aiming to the target. The instrument being able to see and acquire the target within instrument accuracy specifications.
- Dynamic Surveying. The continuous surveying of the trajectory of a moving target or the guidance of a moving construction machine, such as: tunnel-boring machines, earth moving machines, graders, and paving machines.
- Remote Control – enables the operator to control the instrument remotely from anywhere within the range of radio communication.

**How it works**

The ATR system utilizes a fixed focus CCD (charged coupled device) video camera integrated into the telescope. The optics of the telescope is shared by the ATR, EDM, and by the normal operator's view. This is a fully coaxial system enabling measurements to be taken in both Face 1 and Face 2.

If the TCA1800 is configured for ATR, for the instrument to acquire the target, the sequence of events is as follows:

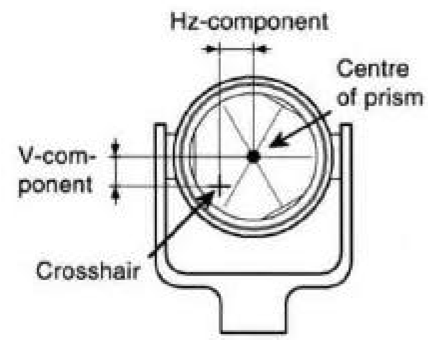
1. The operator points the telescope roughly to the target and initiates a distance measurement. There is no need to focus the telescope to fine-point the target. However, the prism must be within the maximum range for ATR, which is 1000m.
2. The laser diode of the ATR emits an infrared laser beam, which is coaxially transmitted through the telescope out along the line of sight. This beam has a field of view (or spot size) of 0.5 degrees. If the prism is within the ATR field of view, it will acquire it immediately. If the prism is not within the ATR field of view, the TCA1800 will begin a spiral search of the telescope field of view (which is 1.5 degrees). The ATR field of view is 1/3 that of the telescope, and 5 times that of the EDM. The EDM spot size is 0.1 degrees.




3. If the prism is found within this search, the telescope immediately stops moving and the laser beam is reflected back to the instrument. The reflected beam enters the objective lens of the telescope; is passed through a beam splitter, which separates it from the EDM beam and from stray light in the visible wavelength range. The beam is then guided through several lenses to magnify the image and finally to the CCD video sensor.
4. The reflected beam forms a spot on the CCD device. The position of this spot is precisely determined and compared to the position of the exact center of the CCD array. This provides the horizontal and vertical angle corrections (ATR offsets) that need to be made to the angles read by the angle measuring system. If the telescope crosshair (line

of sight) is precisely at the center of the prism, these angle corrections will be zero. After ATR has acquired the target, if you look through the telescope you will see that the crosshair is not positioned precisely at the center of the prism. The difference between the crosshair and the prism center is the ATR offset.

5. At this point the instrument knows the actual angular values to the target. It could display them and simply stop. However, these angle corrections are used to refine the pointing of the telescope to a certain amount. The need to not point the telescope precisely at the target is simply speed. The angular values are known very precisely and there is no need to have the crosshair exactly on the target. Many operators are uncomfortable with this as they were used to seeing the crosshair precisely on the target. Just be aware, future instruments may not have crosshairs and optics as we now know them. The need to point the telescope close to the target is twofold. First, the EDM (with it's small field of view) needs to be on the target for it to work. Second, so that the operator can visually confirm the correct targeting. If the instrument is in calibration, it will move to within 5mm of the target center.




6. The distance measurement is automatically invoked and upon completion, the horizontal and vertical angles, and the ATR derived offsets are locked until the alidade, or the telescope is turned.

**ATR Modes**

Other than the standard mode for ATR (used for static targets) there is a Lock mode in which the instrument will track a moving prism. If the prism being tracked moves behind an obstruction and continues at the same trajectory and velocity, the instrument will pick up the prism when it emerges from the other side. The prism can be obstructed for only a few seconds.

**Measuring Accuracy**

The accuracy of ATR and of the angle measurements are generally the same. Under a certain distance, ATR accuracy predominates. That distance is determined by the angle accuracy of the instrument.

The ATR accuracy is a function of the distance-measuring mode.

| TCA1800 EDM Modes and Accuracies | |
|---|---|
| Standard | 2mm + 2ppm |
| Precise | 2mm + 1ppm |
| Fast | 3mm + 2ppm |
| Tracking | 5mm + 2ppm |
| Rapid Tracking | 10mm + 2ppm |

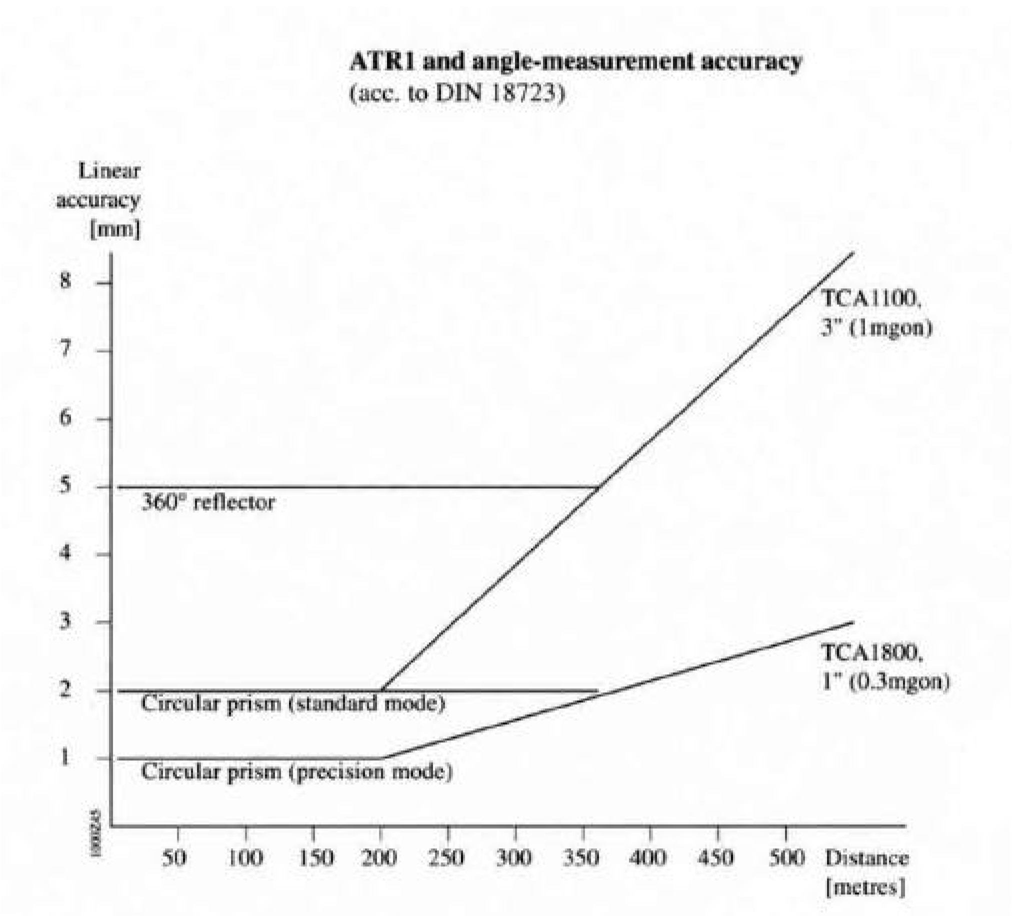
The allowed ATR offsets are larger in EDM Fast-mode than in EDM Standard-mode. As a result the crosshairs will always be very close to the prism center when measuring in Standard-mode whereas in Fast-mode the crosshairs might be off more than 2 angular minutes. When EDM Fast-mode is being used in conjunction with ATR Lock-mode, the instrument is less sensitive to movements of the prism.

Maintaining the following conditions can maximize ATR accuracy:

- Prism exactly positioned. Do not use the 360 degree prism.
- Keep the prism clean and free from fog.
- Use under constant light conditions. Keep the background dark.
- Avoid atmospheric disturbances, including refraction.

Depending on the EDM selected, ATR expects a certain amount of stability for the prism. During the first stage of measurement, ATR investigates the stability of the prism. If it is acceptable, the angle corrections are then determined.

| Mode | Stability |
|---|---|
| Standard | 2mm |
| Precise | 1mm |
| Fast | 3mm |
| Tracking | 3mm |
| Rapid Tracking | 3mm |



## ATR Calibration

Accurate calibration of the ATR is important. The targeting error is a systematic instrument error and can be measured and compensated for. The ATR calibration procedure defines the axis of the CCD camera according to the optical line of sight. The procedure determines the offset between the target as seen by the operator's eye via the telescope reticule, and as it is seen by the CCD of the ATR system. In operation, this offset is applied to each measurement made using ATR.

ATR calibration should be made:

- When you first receive your instrument.
- Prior to any high precision survey operations.
- Following long or rough transport.
- Following prolonged storage.
- When working in harsh conditions.

## Setting the HZ Circle with ATR On

When setting the horizontal circle to a particular value for a backsight (with ATR on), the procedures are as follows:

1. Using the station setup procedure, the quick set function, or directly from the measurement dialog, approximately point to the prism, type in the HZ value, and press Enter.
2. The instrument will automatically position to the prism using ATR.
3. You will notice that the HZ value displayed is not exactly what you entered, and that the telescope is not positioned exactly at the center of the prism. Remember, the difference between the crosshair and the prism center is the ATR-offset. The displayed HZ value corresponds to the actual crosshair direction. The entered value is the direction to the prism center and the orientation value set for the backsight.

## Displayed Values

If ATR is on and you measure a distance to any prism by pressing DIST, the ATR-offsets are applied. The displayed angle values refer to the prism center. By pressing the REC button these values are stored (REC always stores the displayed values). Once the data has been recorded the ATR-offsets are no longer applied and what you see on the display are angle values referring to the telescope axis (the point the crosshairs are pointing at).

The same thing happens if you measure a distance with DIST and then move the telescope or leave the current dialog. As you do so the ATR-offsets are ignored and what you see are the non-corrected values again. When using the ALL button to measure a point the ATR-offsets are applied and the corrected angles are recorded. But since ALL is a sequence of DIST and REC, the ATR corrected angles are only visible on the display for a moment. After the measurement is finished the angles on the display refer to the telescope's axis again.

*References: Various Leica instrument manuals and published articles.*