Leica TS30
White Paper

- when it has to be **right**

Leica Geosystems

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The Art of Achieving Highest Accuracy and Performance

Abstract

This white paper presents the world's most advanced total station – the Leica TS30. The TS30 combines unmatched accuracy and quality. To achieve highest accuracy, quality, and performance, the latest technology is essential – this required extensive developments by Leica Geosystems. The mechanical construction of the TS30 in combination with high speed angle measurement systems, direct drives using piezo technology, and the electro optical distance measurement system delivers the impressive measurement accuracy and performance of the new total station.

Introduction

Highly precise and accurate surveying has always been an important aspect in challenging surveying and engineering projects all over the world. Beside the optimum measurement network configuration and the appropriate operation of the survey equipment by survey engineers, the survey instruments are the most important factor for the success of any challenging projects. Since the beginning of the 19th century, Leica Geosystems has always provided engineers with the latest, revolutionary and most accurate technologies and solutions achieving the highest possible accuracies.

More than 75 years ago, the precision 0.5"-theodolite Wild T3 was introduced. It attracted great interest in the survey community due to its highly precise measurements. In the 1970s, the time arrived where electronics and automation evolved in survey engineering products. At the beginning of the 1980's, Leica Geosystems provided the first total station – the TC2000 – to combine highest precision and highest quality measurements along with automation to survey engineers (cf. Figure 1). The TC2000 was equipped with the first high precision electronic angle measurement system developed by Leica Geosystems and with the fully integrated electro-optical distance measurement system. Continuing to provide the best equipment for survey engineers, Leica Geosystems released the total station TCA2003 in the mid 1990s. The TCA2003 was the next generation of 0.5"-total stations. In addition to the electro-optical distance measurement system, the measurement efficiency was significantly improved by the automation of the measurement process due to automatic target recognition (ATR). The latest generation of highest precision total stations from Leica Geosystems – the TS30 – has reached the pinnacle. Accuracy, performance, along with the unlimited flexibility and scalability through complete compatibility with Leica Geosystems' System 1200 components are key benefits of the new Leica TS30 Total Station.

Figure 1 – Leica Geosystems' 0.5"-total stations.

The demand for more precise, more accurate, more reliable, and more efficient survey instruments will never end. The survey engineering projects become larger and more challenging with respect to time, costs, and quality. These challenges bring stronger requirements for total stations beyond highest precision and accuracy. This also includes reliability, robustness, automation and efficient operation. In addition, long service intervals, short downtime, and the reduced maintenance costs are significant factors to efficient project completion.

The World's Most Precise, Accurate, Reliable, Robust and Quickest Total Station – the Leica TS30

Leica Geosystems' solution to the increasing demand on precision and efficiency is the unique total station Leica TS30 (cf. Figure 1). The TS30 provides an angular accuracy of 0.5" (tested according to ISO 17123-3). The distance measurement accuracy with the PinPoint EDM to Leica prism targets is 0.6mm + 1ppm (tested according to ISO 17123-4). Depending on the atmospheric conditions and the target reflectivity, distances can be measured up to 12'000m. For reflectorless measurements, the TS30 is equipped with Leica Geosystems' System Analyzer technology for distance measurements of more than 1000m on natural targets (cf. Bayoud, 2006).

The TS30 allows very quick, highly accurate and precise measurements. It is specifically designed for the highest measurement quality of manual and automated measurement processes.

The newly developed direct drives using piezo technology enable very quick and efficient automated measurements. The rotation speed of the alidade and telescope is up to 200 gons per second. The TS30 is more than four times faster than total stations with conventional drives. Its direct drives alone result in a significant increase of automated measurements possible per hour. Furthermore, the direct drive performance establishes the optimized automation performance for one-person surveying and dynamic tracking applications. Additionally, the automatic target recognition (ATR, up to a range of 1000 m), the PowerSearch (PS), and the Electronic Guide Light (EGL) support an efficient and automated surveying process.

The TS30 is fully integrated into Leica Geosystems' X-Function. This offers unlimited flexibility through the compatibility with all System 1200 components. The total station, GNSS SmartAntenna, and the onboard software SmartWorx are completely interoperable and modular by design.

This white paper focuses on the new developments and technologies of the TS30. Particular focus is made to the mechanical construction, the angle measurement system, the motorization with the direct drives using piezo technology, and the electro-optical distance measurement.

Mechanical Construction

The design and construction of a total station for highest accuracy and precision in combination with high-speed performance requires new solutions compared to current total stations. The TS30 features an extremely sturdy standard (alidade) to guarantee the robustness and the 0.5"-angular accuracy under changing and tough external conditions (temperature changes, wind, rain, etc.). Beside the physical design of the standard, the homogeneity of the material structure is essential. Therefore, the standards of the TS30 are produced with a low-pressure casting technology. The material is slowly poured into the mold forced only by gravity. As a result, less stress occurs on the material compared to the pressure die-casting procedure, which is used widespread for the production of total stations. The low-pressure casting technology contributes to the stiffness of the standards. Furthermore, to reach the maximum stiffness and stability of the TS30, the standards and the alidade have been enlarged compared to typical 1"-total stations.

Figure 2 shows a cross-sectional drawing of the TS30. The drawing visualizes, in particular, the position and size of the horizontal and vertical coded glass circles. The coded glass circles are part of the horizontal and vertical angle measurement systems. An important influence to angle measurement precision and resolution are the size of these circles. A larger diameter improves the angular precision and resolution. Therefore, the diameter of the TS30 coded glass circles have been enlarged approximately 15% compared to typical 1"-total stations. The design and construction of the standards and the alidade provide for the size of the enlarged coded glass circles.

Adding to the efficient operation of the TS30, an additional third fine drive and a user defined SmartKey have been added. The third fine drive for vertical motion of the telescope allows an ergonomic one handed operation of the total station. The third fine drive is located close to the horizontal fine drive (cf. Figure 2). The one handed operation enables very efficient surveying and keeps the other hand free for holding, for instance, additional electronic devices or plans.

The user defined SmartKey is located on the side of the TS30 standard in line with the tilting axis between the horizontal and third fine drive (cf. Figure 2). There are no tangential forces on the alidade of the TS30 when the SmartKey is pushed allowing movement-free triggering of the measurements. The user can define the functionality of the SmartKey. This allows easy customization for the operation of the TS30 depending on the application.

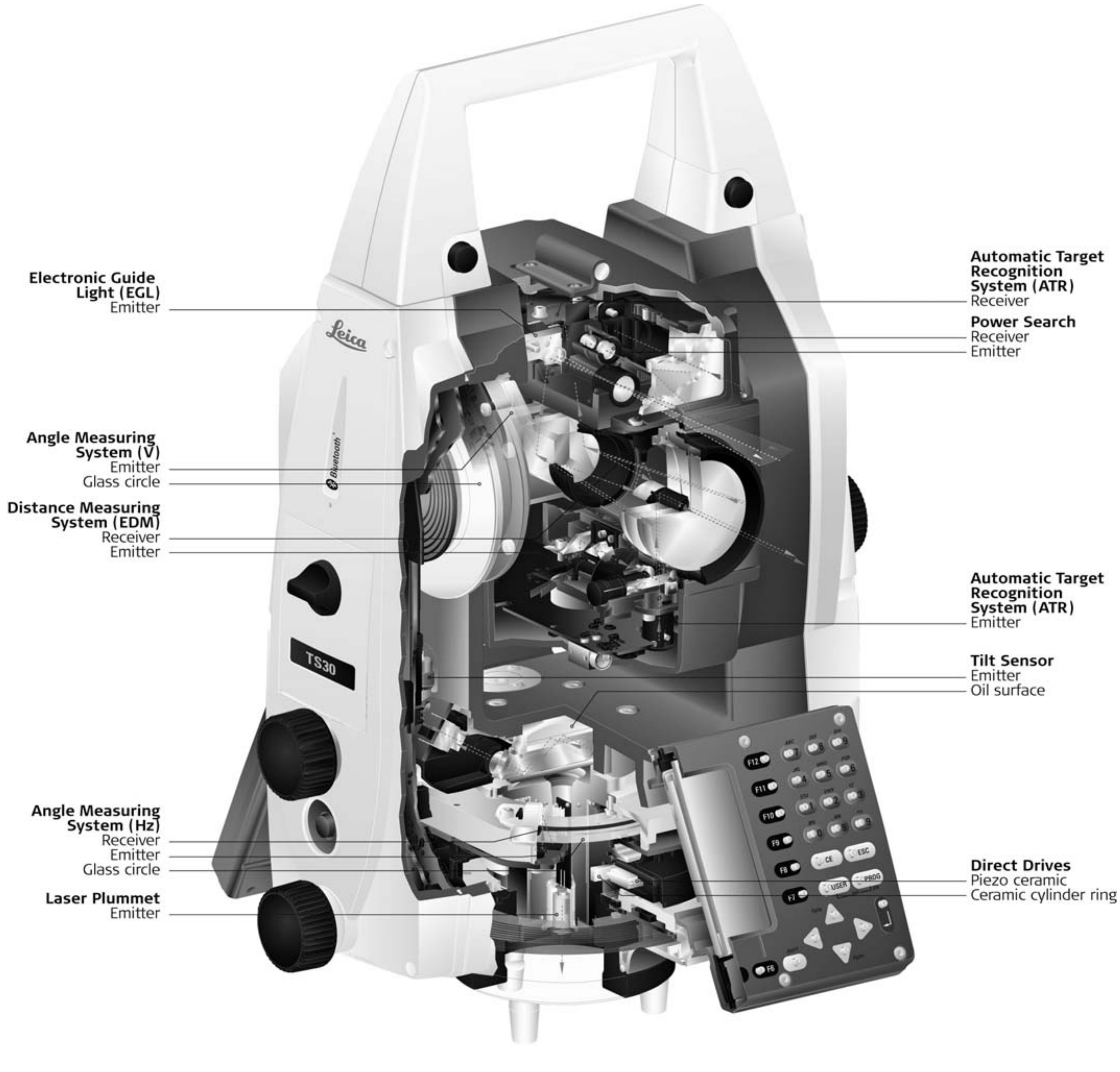

Figure 2 – Cross-sectional drawing of the Leica TS30 Total Station.

Angle Measurement

The angle measurement system - for horizontal and vertical angles - is a very significant component of the TS30. It must guarantee highly precise and accurate angle measurements under the high speed performance of the direct drives. The angle measurement system mainly consists of a coded glass circle and four encoders - quadruple angle reading. An encoder mainly consists of a light source (LED), mirrors for reflecting the emitted light, and a line sensor. The code on the glass circle is based on radially aligned lines and is absolute and continuous. No initialization of the instrument is required prior to the measurements. Figure 3 shows a 3D-illustration of an exemplary single encoder and the coded glass circle of the angle measurement system.

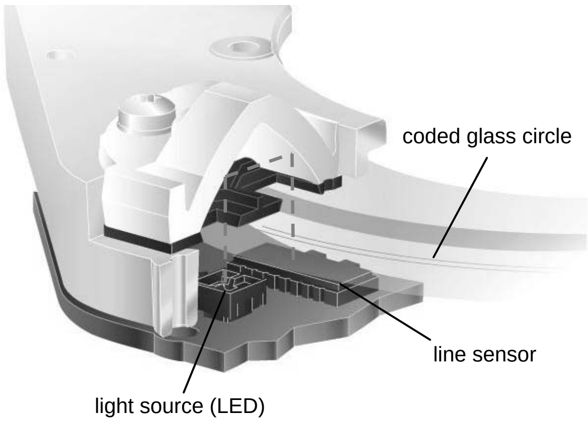

Figure 3 – Single encoder of the angle measurement system with a light source (LED) and a line sensor.

For the angle measurements, a light - emitted by the LED - is projected through the coded glass circle on the line sensor. Finally, the image from the line sensor is encoded and transformed into relative angle information. A first coarse angle is detected with an accuracy of about 0.3gon based on the coded lines. The precise angle measurement is based on the position of the coded lines' centroid. The calculations are performed with algorithms developed by Leica Geosystems. For a position determination, at least 10 code lines have to be captured by the line sensor. To increase the interpolation quality of the actual position, a minimum of 30 code lines are used for the signal processing.

Important characteristics and advantages of the TS30 angle measurement are the high measurement frequency - up to 5000 angle measurements per second - and the quadruple angle detection system. The quadruple angle detection system measures the actual position of the coded glass circle. The high detection frequency allows a direct and precise motor controlling based on the encoders of the angle measurement system. A designated position can be precisely achieved by the direct drives without any iterative corrections of the position. For conventional total stations, the motor controller uses an additional encoder on the motor axis due to the fact that the angle measurement frequency is only a few hertz. The motor encoder itself is fast but inaccurate which requires synchronization with the angle measurement system from time to time. Nevertheless, differences may occur between motor encoder and angle measurement system which results in inaccurate positioning of the alidade. An iterative positioning is the consequence.

For the highly precise and accurate angle measurements of the TS30, the actual position of the coded glass circle is detected by the quadruple angle reading system. The advantages are significant. Systematic and periodical errors can be eliminated thus the measurement accuracy is increased. Furthermore, the reliability of the angle measurement is enhanced.

By using two encoders for the angle measurements, the periodic error of the eccentricity of the coded glass circle compared to the standing axis of the total station is eliminated. Another two encoders remove further minor π-periodic errors which are determined by the system.

In addition, the angle measurement accuracy is improved by a factor of about 0.7 with four encoders compared to two, according to the variance propagation, cf. equation (1). In addition, the reliability of the angle measurement is improved by increasing the number of angle measurements.

$$\sigma_{4encoders} = \frac{1}{\sqrt{2}} \sigma_{2encoders} \qquad (1)$$

The angle measurement accuracy of the TS30 is proven and certified by Leica Geosystems' TPM-2. This Theodolite Test Machine (cf. Lippuner and Scherrer, 2005) is part of Leica Geosystems' calibration laboratory for length and angle. The laboratory is accredited by the Swiss Accreditation Service SAS, which belongs to the Swiss Federal Department of Economic Affairs DEA. The standard deviation (1σ) of the TPM-2 angle measurements are 0.018mgon (0.058") for horizontal angles and 0.028mgon (0.091") for vertical angles. To test the angle measurement accuracy of the TS30, the horizontal and vertical angle measurements are compared with the measurements of the TPM-2. The standard deviation is calculated according to ISO 17123-3. For the TS30, the angle measurement accuracy is 0.15mgon (0.5"). Test samples of the TPM-2 with the TS30 are shown in Figure 4 and Figure 5. The figures present the differences of the horizontal and vertical angle measurements between TPM-2 and TS30 with reference to the horizontal and vertical angles.

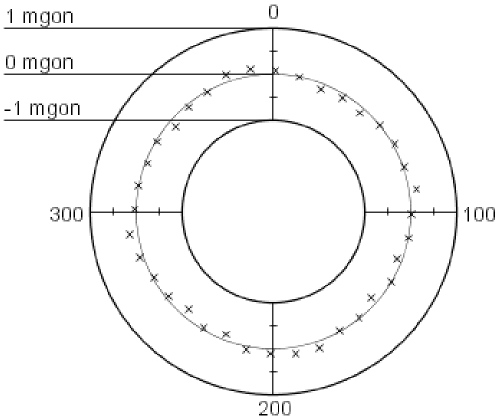

Figure 4 – Results of TPM for HZ-angle: standard deviation ISO 17123-3 (n = 36): 0.14mgon.

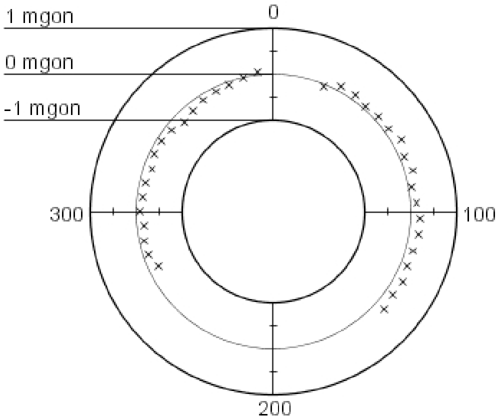

Figure 5 – Results of TPM for V-angle: standard deviation ISO 17123-3 (n = 36): 0.13mgon.

The final step of the angle measurement procedure is the correction of the detected raw angles by the following four parameters (Leica Geosystems' quadruple angle corrections):

- Actual longitudinal and transversal inclination of the total station horizon measured by the inclination sensor (l, t)
- Vertical index (i, related to the standing axis)
- HZ-collimation error (c, line of sight error)
- Tilting-axis errors (a)

Another user efficiency advantage is that the HZ-collimation error, the tilting-axis error, and the vertical index can be periodically determined by the user following a standard field procedure and registered in the total station.

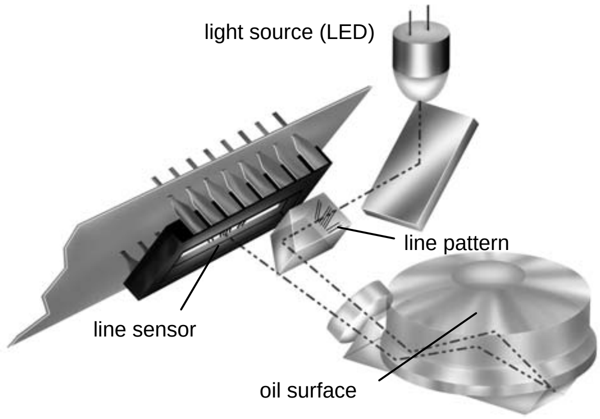

Figure 6 – Principle of the dual axis inclination sensor.

The dual axis inclination sensor monitors the horizon of the total station. In the ideal case, the horizon of the instrument is perpendicular to the plumb-line. The inclination sensor detects the actual deviations of the verticality. Figure 6 shows the principle of the dual axis inclination sensor which is implemented in the TS30.

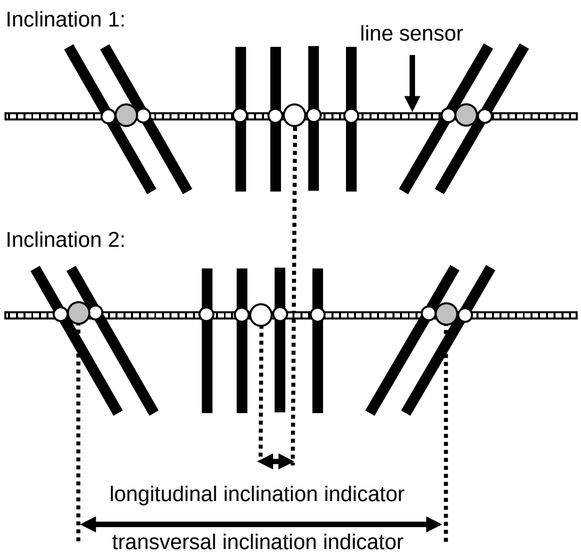

Figure 7 – Line pattern for measuring longitudinal and transversal inclination by a one-dimensional line sensor. The line patterns move along and across the line sensor. The centroids of the line patterns are essential for the detection of longitudinal and transversal inclination.

The inclination sensor mainly consists of an oil layer in a casing together with a prism and mirror, a prism with line patterns, a one-dimensional line sensor, and a light source. The line pattern is projected on the line sensor after passing the oil layer and reflected twice on its surface. The specific triangular line pattern allows the detection of both inclination components by means of a one dimensional receiver (cf. Figure 7). For transversal inclinations, the spacing between the differently oriented lines is altered. For longitudinal inclinations, the centre of the entire line pattern is shifted along the line sensor. The actual concept of the dual axis inclination sensor enables a very small construction size of the compensator. This allows it to be positioned in the centre of the standing axis of the total station. Thus, the liquid surface displacement is minimized from its horizontal position when rotating the alidade. This minimizes the settling time for the oil layer and allows instant measurement after a rotation.

Motorization

The motorization of the TS30 uses direct drives based on the piezo principle, which directly transforms electric power into mechanical movements. The incorporation of maximum speed and acceleration capabilities together with the infinitesimal step sizes are the main characteristics of the TS30 direct drives. Infinitesimal step size is needed for the highest precision measurements. The TS30 is the only total station which uses direct drives based on the piezo principle for horizontal and vertical movements of its alidade and telescope.

The piezo effect was discovered in the year 1880. This effect describes the generation of an electric potential by applying mechanical stress to certain crystalline minerals (e.g. quartz). The inversion of this effect – the inverse piezo effect – shortens or lengthens the crystalline minerals by exposing them to an electric potential. The deformations of the minerals (size and direction) depend on the polarization of the crystalline minerals and the strength of the electric field. An alternating electric field results in cyclic variations of the crystalline minerals. The cyclic variations can be used for operating actuators. Instead of using crystalline minerals, ceramics can be artificially produced as piezo-electric materials. This enables the use of the piezo effect in many applications (cf. Uchino and Giniewicz, 2005).

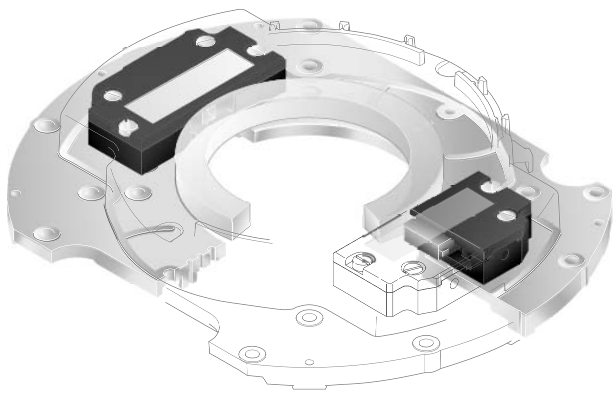

Figure 8 – Direct drive of the TS30 Total Station.

For the TS30 direct drives, a pair of diametrically mounted piezo-electric ceramics is used to accelerate and precisely move a ceramic cylindrical ring – the rotor – which is attached to the rotating parts of horizontal and standing axis (cf. Figure 8). The mounted ceramics are polarized and divided into two excitation electrodes – an active and a passive electrode (cf. Figure 9). The activity of the particular electrode can be changed. Furthermore, a nose of ceramics on top of the electrode between the two electrodes transfers the movements of the mounted ceramics to the ceramic ring. The mounted ceramics and the moving nose in particular perform elliptical movements. To generate these movements, the ceramics are stimulated by a sinusoidal alternating voltage. Additionally, the directions and the speed of the elliptical movements are defined by the particular active segment of the mounted ceramics and the strength of the alternating voltage.

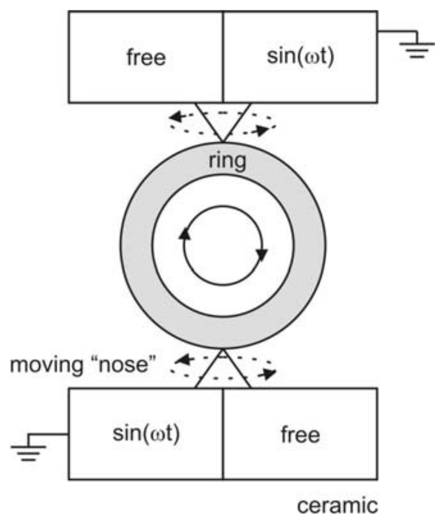

Figure 9 – Functional principle of a direct drive using piezo technology.

The direct drives using piezo technology enable high speed motorization and acceleration capabilities together with infinitesimal step sizes at low power consumption. The step sizes are in the range of nanometers. Unmatched durability and extended maintenance cycles of the direct drives are achieved by a subsequent elimination of the transmission drives' moving parts. No gears are used for the movements. Furthermore, the TS30 direct drives do not produce a magnetic field nor are they affected by them. This guarantees the unrestricted operation of these direct drives in magnetic fields as they can appear for instance in electric power plants.

Compared to conventional drives, the main advantages of the TS30 direct drives are the following properties:

- High speed (up to 200gon/s)
- High acceleration (up to 400gon/s^2)
- Long durability and robustness
- No noise emission
- Compact design
- No power consumption at rest

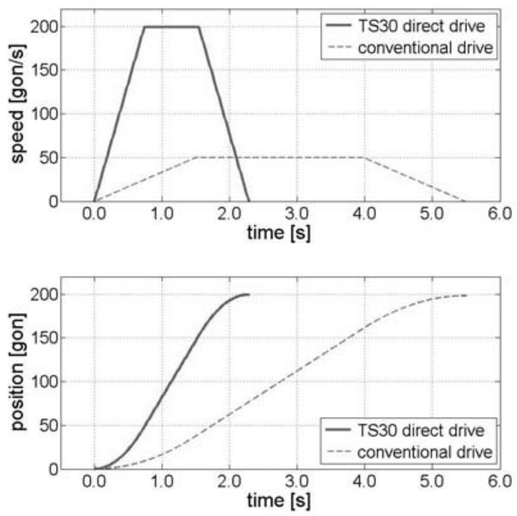

Figure 10 – Comparison of a TS30 direct drive and a conventional drive in terms of speed and positioning time.

The direct drives of the TS30 Total Station significantly reduce the positioning time of the alidade and the telescope. Figure 10 shows a comparison between a direct drive using piezo technology and a conventional drive for changing face while performing a rotation of 200 gons. The actual speed and position is plotted in relation to the time. The maximum speed for the TS30 direct drives is at least four times higher than for conventional drives. As a result, the time for positioning is cut in half.

The power consumption of the drives for total stations is generally a crucial factor for the operating time of the instruments when using battery power. Less power consumption, specifically when at rest, significantly extends the operating time. An advantage of the direct drives is that the TS30 only needs power when in motion. There is no power consumption at rest. The direct drives are able to hold the horizontal and vertical positions of the alidade and telescope without using any power. This saves energy, does not produce any uncontrolled heat and enables measurements for longer time periods compared to other drives. The control of the internal heat is a crucial factor for achieving highest measurement accuracies. Furthermore, the actual horizontal and vertical positions of the TS30 alidade and telescope are clutched very stable. This enables a stable telescope position without any jitter during the aiming and measurement processes. A qualitative comparison between the TS30 direct drive, a conventional drive and a magnetic drive is given in Table 1.

	TS30 direct drive	Conventional drive	Magnetic drive
Drive speed	++	-	+
Acceleration	++	-	+
Resolution	++	+	+
Power consumption at rest	+	+	-
Telescope aiming stability	++	++	-

Table 1 – Comparison of different drives for total stations (++ superior advantage, + advantage, - disadvantage of respective drive technology).

Direct drives using piezo technology feature a significantly longer lifetime compared to conventional drives. Due to the fact that direct drives do not use any gears or bearings there is almost no abrasion detectable which extends the drive lifetime. In addition, the maintenance intervals can be reduced significantly.

Electro-Optical Distance Measurement

For the electro-optical distance measurements (EDM) on prisms, reflector tapes or natural targets, a visible laser beam, which is coaxial to the optical axis, is transmitted by Leica Geosystems' PinPoint EDM-system. The reflected light is detected by a sensitive photo receiver and converted into an electric signal. By digitizing, accumulating, and analyzing the signal, the distance to the object is determined. The modulation frequency of 100MHz is the time base for the high distance measurement accuracy.

Leica Geosystems' reflectorless PinPoint R1000 EDM measures to natural targets at ranges of more than 1000m. To realize these long distance measurements without any prisms or reflector tapes, Leica Geosystems' proven System Analyzer was implemented. This procedure allows the evaluation of the total signal information for the distance determination and combines the advantages of the phase and time-of-flight measurements without having their individual disadvantages (cf. Bayoud, 2006). In addition, the System Analyzer properties are defined for each individual measurement for both the EDM laser beam and the target qualities. Finally, the distances are calculated with modern signal processing methods based on the principle of maximum-likelihood. The new EDM system increases the sensitivity which leads to a major increase of the reflectorless measurement range.

For the total station TS30, the Leica PinPoint EDM was improved to achieve even greater accuracy. The established PinPoint EDM enables distance measurement accuracy, on Leica round prisms (GPH1P), of 0.6mm + 1ppm (tested according to ISO 17123-4). The EDM system cleverly chooses measurement frequencies depending on the environment conditions. The improved EDM uses additional and different frequencies and suspends multiple reflections between instrument and target. Furthermore, the measurement process considers more measurements which increase the accuracy and enhance the reliability of the measured distance.

The PinPoint EDM provides many advantages for the distance measurements of the TS30 Total Station. Besides the very high measurement quality and reliability, the PinPoint EDM allows measurements even under adverse atmospheric conditions, such as dust, smoke, mist, rain or snowfall, etc.

The distance measurement accuracy of the TS30 is verified in Leica Geosystems' accredited measurement laboratories by comparing the measured distances to nominal distances determined by an interferometer. The results of a test sample are shown in Figure 11.

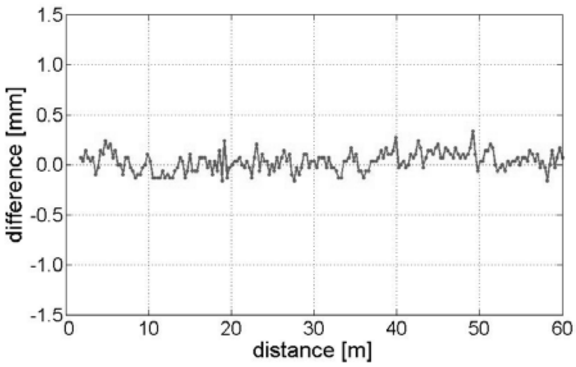

Figure 11 – Distance differences measured by interferometer and TS30 for different distances.

Beside electronic and signal analyzing improvements of the distance measurements, the shape of the laser beam was significantly improved. This results in an optimized laser beam profile and footprint. The inhomogeneous peripheral light of the laser beam is cut off from the laser beam. The peripheral light can disturb the distance measurement by unintentional reflections at the objects. In addition, the laser beam is reshaped by an anamorphic lens (cf. Figure 12). The new reshaped laser beam enables increased distance measurement performance specifically to prisms.

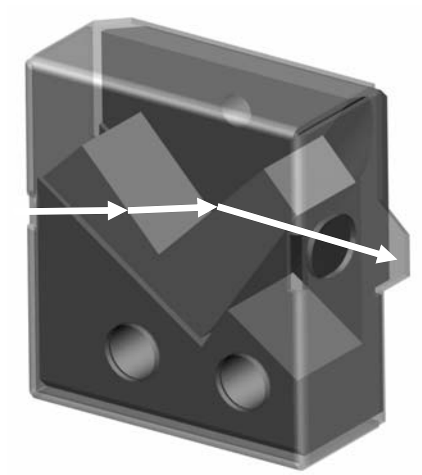

Figure 12 – Anamorphic lens to reshape the laser beam and schematic beam path.

Summary - Benefits of the Leica TS30 Total Station

The TS30 combines accuracy, precision, performance, and efficiency to master complex surveying and engineering projects completing the art of achieving highest accuracy and performance. The benefits of the Leica TS30 Total Station are huge. Employing the latest technology allows an enormous increase of the measurement efficiency in the field. The TS30 covers a measurement range (on prisms and reflectorless) which could never be achieved before with such precision and accuracy. Additionally, the TS30 is fully integrated into Leica Geosystems' X-Function.

High Precision and Accuracy

The specific mechanical construction and the fast quadruple angle measurement system of the TS30 enable angle measurements with a precision of half a second. Highest accuracy and best performance require a unique mechanical design which minimizes the influences of the environmental conditions on the measurements. In addition, a third fine drive allows an ergonomic one handed operation of the TS30. The user defined SmartKey enables the triggering of measurements without any tangential forces to the alidade.

Quick and Reliable Performance

Quality, reliability and efficiency are of paramount importance for the success of any surveying or engineering projects. The TS30 Total Station combines them all. The measurement efficiency and performance of the TS30 is the result of the optimal combination of the different sensors. The fast and precise angle measurement system (up to 5000 angles/s), the PinPoint EDM-system, and the motorization of the TS30 by direct drives using piezo technology all allow highly precise positioning in less time than was possible until now. Long lifetime and extended maintenance intervals complete the reliability of the TS30.

X-Function

The TS30 is completely integrated into Leica Geosystems' X-Function. On top of the hardware compatibility (e.g. GNSS, radio handle, accessories, etc.) and Leica Geosystems' data management, the TS30 is operated by SmartWorx. Thus, all Leica application programs are available with the well-known and established graphic user interface. The integration of the TS30 into the Leica Geosystems' X-Function enables unlimited flexibility and scalability through complete compatibility with System 1200 components.

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