NATIONAL RADIO ASTRONOMY OBSERVATORY
Socorro, New Mexico

VLBA Antenna Memo Series No.21

Leica Geosystems Equipment Demonstration

J. E. Thunborg
August 12, 1999

Attachments: Laser Tracker Spec. Sheet, Axyz Software Description, Motorized Theodolite Spec Sheet.

Kevin Adams and J. W. Isern from Leica Geosystems demonstrated a laser tracker, multiple head theodolite system and a total station theodolite at the very large array on July 13, 1999. These systems could possibly be used as an alternative to the photogrammetry system discussed in VLA Test Memo #220 for VLBA panel setting. This memo will attempt to discuss the pros and cons of each of these systems. The spare VLBA subreflector was targeted and used for this demonstration. The performance on an actual antenna still needs to be evaluated for each of these systems. We will not conduct subsequent evaluations unless it proves impossible to set the panels using holography.

3D Laser Tracking Interferometer

A laser tracking interferometer equipped with a precision absolute distance meter (model LTD500) described in the attached literature was demonstrated. This system can track and record the 3D position of a retroreflector with a velocity up to 4 meters/second. This system is capable of extremely accurate measurements. The 1σ absolute accuracy of a coordinate is 5 μm/m without the absolute distance meter. This accuracy improves with the absolute distance meter that has a 1σ distance measurement accuracy of 25 μm for a 2 to 35 meters range. The distance meter also allows the tracker to reacquire a target when the beam is interrupted without having to return to a home point.

In order for this system to work on a 25-meter antenna, a fast way to move the retroreflector around the primary reflector is needed. Measuring the dish as quickly as possible reduces the error induced by thermal deformation. Traditionally, for antenna measurements, the tracker is mounted at the center of the dish. The retroreflector is then positioned on a long stick and ran over the surface by an operator in a manlift. This process seems a little slow for our requirements. If we were to use a laser tracker for dish measurement, it may be worthwhile to design a small robot that travels over the dish like a toy car. A device of this sort would allow us to accurately map the surface in a very short time.

The primary advantage of a laser tracker would be for subreflector repair. Software is available for the laser tracker that will develop a NURBS surface from a file of coordinates. The tracker will then display the Z-axis deviation of an object from this surface. This would allow a mechanic doing hand repair on a subreflector to apply or remove a thin layer of coating and then verify the resulting surface in real time.

The laser tracker requires more equipment and setup than other systems. It is also quite costly. A complete system with the distance meter, calibrators, targets and other required hardware will cost approximately $200k. This however is not a lot greater than a complete photogrammetry system which with all the bells and whistle is approximately $175k.

Multiple Head Theodolite System

Another way to accurately map the dish is with multiple theodolites and the Axyz Software described in the attachment. This system uses two theodolites focused on a simple target and triangulates to get very accurate XYZ coordinates relative to an arbitrary coordinate system. This system can be nearly as accurate as the laser system above depending on the angle between the theodolites. When the theodolites are in line with the target, this system can not triangulate accurately. In order to map a primary reflector I suspect 3 theodolites would be required to avoid both theodolites becoming aligned with the targets. The software can handle up to 4 theodolites.

The system uses motorized theodolites that spare measuring time by motoring very close to the preprogrammed target points. The theodolites then must be hand aligned with the targets. Michael Brenner of Engineering Metrology Services uses a CCD device to attain the fine adjustment of a motorized total station theodolite allowing him to map large antennas in approximately 4 hours. Similar measurement times could probably be accomplished with a 3-head theodolite system.

This system is also rather expensive. A 2-head system with all the calibrators and accessories would cost approximately $90k. A similar 3-head system would run about $120k.

Total Station Theodolite System

The total station theodolite is a theodolite equipped with a distance meter. Additional information is included in the attachment. The distance meter requires a retroreflector for the distance measurement. Stick on targets similar to those used in photogrammetry could be used. The distance measurement 1σ accuracy is 250 μm. Michael Brenner of Engineering Metrology Services is currently using this system to measure antennas. A Total Station Theodolite is supposedly capable of measuring a 25-meter dish to 250-micron precision using preprogrammed target positions in about 4 hours. This option is not as accurate as the above options, but it is very easy to use and is quite a bit less expensive.

The Leica motorized TDM 5005 total station theodolite with ½ arc second angle accuracy (equates to 50 μm error at farthest parts of dish) and 250 μm distance accuracy list price is about $27k. We are currently using Wild T2 theodolites for antenna alignment and feed positioning. These theodolites are approximately 30 years old and are somewhat out of date. Our accuracy requirement for antenna alignment and feed positioning at both the VLA and VLBA is increasing. Therefore, a theodolite such as this may soon be a required addition to our tool inventory.

There is a chance that this theodolite could be used to provide the real time feedback required for subreflector repair. The theodolite would have to be set up in such a way that the distance measurement inaccuracy's effect on the subreflector measurement along the pathlength would be minimized.

A well equipped total station theodolite runs about $30k.

LT 500/LTD 500
The principle of a three-dimensional laser tracker

LT500 – measuring head

The measuring head of the laser tracking system consists of a single beam interferometer, a tilting mirror driven about two axes, each with a direct drive DC motor and optical angle encoder, as well as a position sensing device (PSD).

LTD 500 – measuring head

In addition to the features of the LT 500 described above, the LTD 500 contains a high precision absolute distance meter which can measure the absolute distance to the reflector via the tilting mirror.

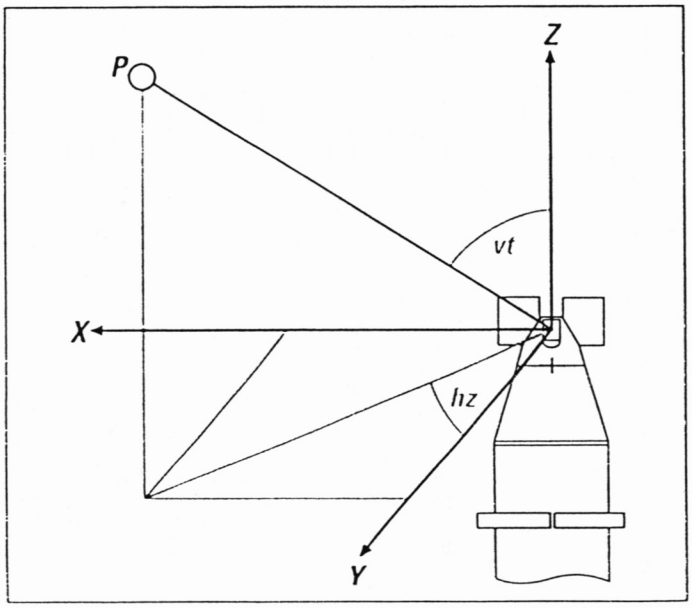
Method of point location

Coordinates are generated based on the method of polar point determination, that is, the direction of the laser beam in space and the distance between the measuring head and the reflector are measured. These measurements are taken at a rate of up to 1000 times per second and converted to the more common cartesian coordinates by a computer.

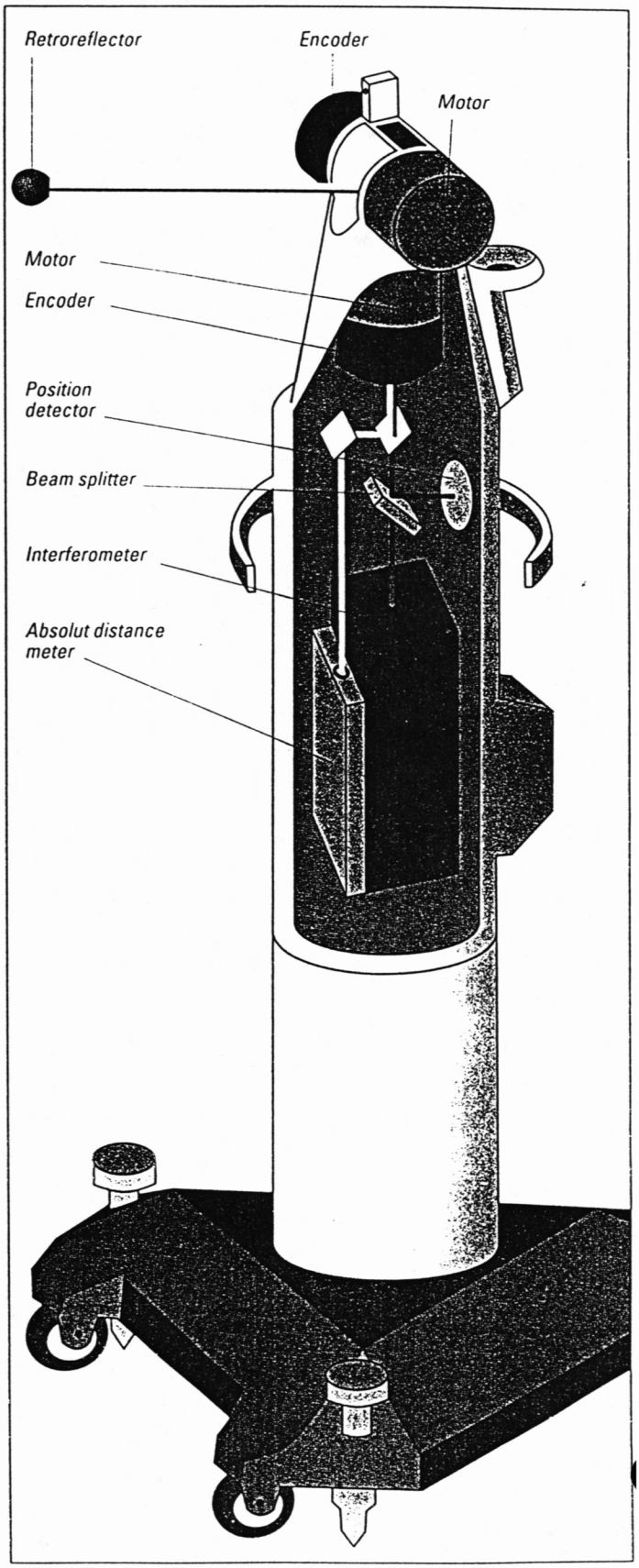
Parallel offset

The laser beam is reflected back to the laser head directly along its transmission path as long as the reflector does not move. When the reflector is moved, the transmitter laser beam no longer hits the optical center of the reflector. Instead, the reflected beam follows a parallel path according to the rate of the shift. This parallel offset is determined at the position detector – a two-dimensional position-sensitive photodiode within the measuring head – by the measurement of voltages and is factored into any distance measurements taken by the interferometer.

The calculated angle corrections for the tilting mirror are converted to analog signals and sent to the motor amplifiers in order to point the laser beam back on the center of the reflector. This calculation is done 3000 times per second, allowing continuous tracking of any path. Because the retroreflector shifts the laser beam parallel to the angle of the movement of the reflector, the maximum track speed is not greatly affected by distance.



Polar point determination



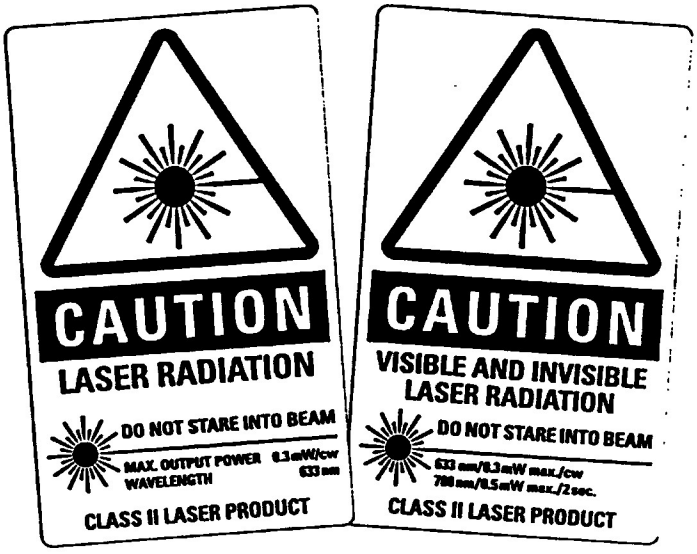
3D-Lasertracker: The principle

LT 500/LTD 500
Technical Data

Tracking		
Max. target speed		
at right angles to the laser beam	> 4.0 m/s	
in the direction of the laser beam	> 6.0 m/s	
Max. acceleration		
in all directions	> 2 g	
Range of measurement		
horizontal	± 235°	
vertical	± 45°	
distance	0–35 m	(0–115')
Retroreflector	corner cube, cateye, corner cube prism	
Accuracy		
Angle resolution	0.14"	
Distance resolution	1.26 µm	
Reproducibility of a coordinate*	± 5 ppm (µm/m)	
Absolute accuracy of a coordinate*		
for non-moving target (static)	± 10 ppm (µm/m)	
for moving target (dynamic)	± 20–40 ppm (µm/m)	
Laser Interferometer		
Principle of operation		
Single-beam interferometer	heterodyne	
Safety class 2	< 0.3 mW/CW	
Wave length	633 nm (visible)	
Beam diameter (1/e²)	ca. 4.5 mm	
Absolut Distance Meter (only LTD 500)		
Principle of operation	light polarization modulation	
Resolution	1 µm	
Accuracy*	± 0,05 mm	(0.002")
Measurement range	2–35 m	(7–115')
Safety class 1	< 0.4 mW/5 sec.	
Wave length	780 nm (infrared)	
Beam diameter	ca. 10 mm	

Ambient Conditions		
Working temperature (three ranges)	+5°–+40° C	41°–104° F
Storage temperature	–10°–+60° C	
Humidity	10–90% (non-condensing)	
Air pressure/elevation		
operation	0–3000 m	0–10 000 ft
storage	0–7000 m	0–23 000 ft
Dimensions and Weight		
Sensor unit		
dimensions LT 500/LTD 500	220 x 280 x 855 mm 8.7" x 11" x 33.7"	
transit axis height	805 mm	31.7"
weight LT 500	30.0 kg	66.1 lb
weight LTD 500	31.5 kg	69.0 lb
Controller		
dimension	455 x 350 x 200 mm 17.9" x 13.8" x 7.9"	
weight	10.5 kg	23.1 lb
System Computer		
Personal Computer	Compaq Pentium™	
Operating system	Windows®95	
Rate of measurement	1000 points/second	
Real time output	via parallel interface	

Note:
The accuracy shown above (*) is stated as a 2 σ (sigma) value
In North America, it is customary to state accuracy as a 1 σ (sigma) value
ex. Accuracy of Absolute Distance Meter 1 σ ± 0.025 mm (0.001")



LT 500 *LTD 500*

Leica Geosystems
1-800-367-9453

T 500 manufactured under US Pat. Nr. 4714 339

Patent pending: LTD500 and corner cube prism

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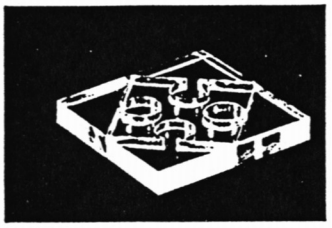
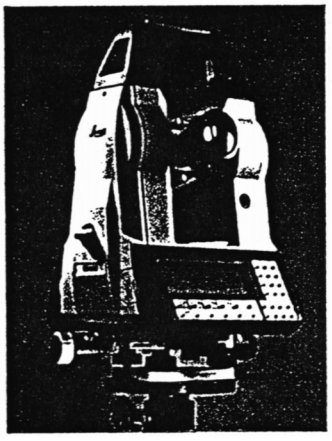
513 McNicoll Ave.
Willowdale, Ont.
Canada M2H 2C9
Tel: (416) 497-2460
Fax: (416) 497-2053

3155 Medlock Bridge Rd.
Norcross, GA
USA 30071
Tel: (770) 447-6361
Fax: (770) 734-1392

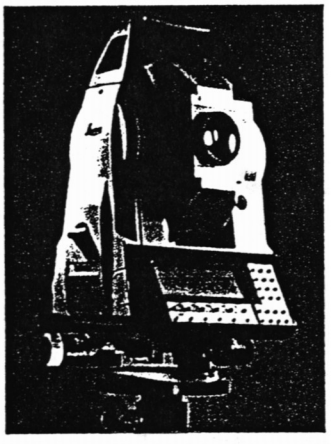
Porfirio Dias Pontiente 35
Colonia Nochebuena
Mexico D.F. 03720
Tel: +52 5 563 5011
Fax: +52 5 611 3243

Axyz STM & MTM – The theodolite modules





TM5005



TDM5005

The concept

Axyz MTM, the multiple-theodolite module, and Axyz STM, the single theodolite module, form the interface between Leica theodolites or total stations and the Axyz core data module CDM. Because of their small size and low weight, theodolites and total stations are highly convenient and easy to adapt to measurement environments and conditions. They can be efficiently set up for use at short notice, even for minor jobs in which there are only a few points to be measured. In addition, theodolite measuring systems allow contactless measurement. In particular, the new, motorized generation offers hitherto unparalleled ease of measurement and significantly improved efficiency.

The two modules are based on different methods:
Axyz STM – the polar method for angle and distance measurements to retro-reflecting targets or prisms.

STM supports the following total stations:
- TC2002
- TPS5000 (TDM/TDA types)
- TPS1000 plus Axyz Comm (TC/TCM/TCA types)

Axyz MTM – The triangulation method for angle measurements to easy visual target with at least two instruments.

MTM supports the following theodolites and total stations:
- T(C)2002
- T3000, T3000A
- T(C)2000
- E2, E2-I, E20, E20-I
- TPS5000
- TPS1000 with Axyz Comm

Intelligent instrument commands

Measurements can be triggered and controlled either from the PC keyboard or via instruments. The obvious place to command and control Leica theodilites and total stations is the instrument itself. This saves time in every way, and the measurement sequence can be controlled with the aid of the comprehensive measurement functions and status display.

Instrument-related features

Each theodolite can be individually addressed, which allows it to work independently. All Leica theodolites and total stations have a highly accurate levelling system which allows you to make measurement in relation to the vertical or to position workpieces precisely horizontal.

There are additional functions for checking the stability of the measurement environment. Axyz offers all these features as a basis for your accurate measurements.

Measurement options

Measurements are performed at the touch of a key, or continuously. The information is transmitted to the database only if requested. If a point on the object cannot be targeted directly, e.g. because it is covered by a tool, or because if can only be determined by indirect means, use a special marker such as the offset rod. Measure to the points which lie upon it, and you will immediately obtain the coordinates of the obscured point.

Where targets of a particular thickness are used, the system uses a correction function to consider this offset volume. This means that the target point is reduced to the point of interest.

Thanks to Windows 95 there are further convenient ways of making your work easier, for example prompted measurement sequences using script programming.

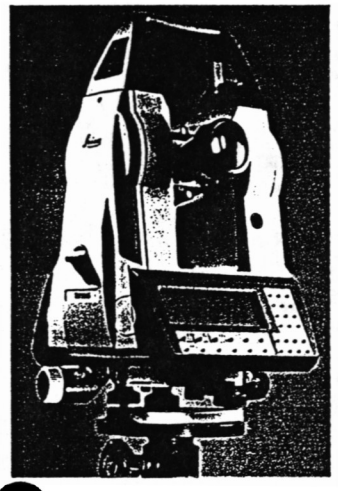
Orientation MTM

How can a coordinate system be fixed? Several methods can be used, depending on the requirements:
- A "machine coordinate system", i.e. a local system with its origin in the first instrument;
- A workpiece coordinate system, i.e. an object-related system defined by control points with design coordinates.

There are specific functions for this, for example:
- Station setup (MTM only) through accurate and approximate collimation of the instruments;
- The use of various scale bar with different reference lengths;
- Targeting of control points to define the workpiece coordinate system;
- Changes of instrument locations to record the entire object, if you have fewer instruments than the measurement task requires

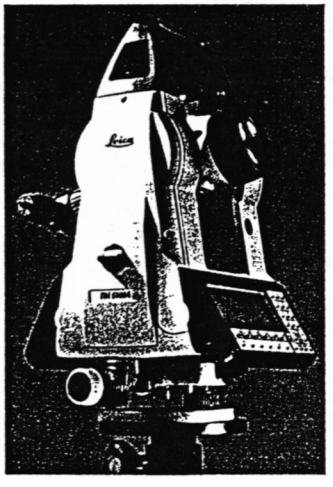
TPS 5000 – modular – motorized – mobile

Precision theodolites from Leica Geosystems provide the basis for numerous measurement applications in industrial metrology.

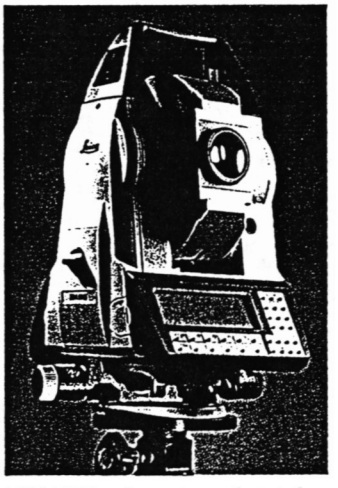


5005 – the standard industrial theodolite
- ***Angle measurement accuracy 1 σ = 0.5"***
- ***Motorized operation***
- ***Improved ergonomics***

TDM 5005 – the industrial total station
- ***Built-in distance meter***
- ***Typical distance measuring accuracy ± 0.5 mm (< 120 m)***
- ***Motorized operation***
- ***Improved ergonomics***



TM 5100/A – the highest precision in the world
- ***Angle measurement accuracy 1 σ = 0.5"***
- ***Motorized operation***
- ***Improved ergonomics***
- ***Precision alignment telescope***
- ***Targeting down to 0.6 m (2 ft)***
- ***TM 5100A with autocollimation device***



TDA 5005 – the automatic total station
- ***Built-in distance meter***
- ***Typical distance measuring accuracy ± 0.5 mm (< 120 m)***
- ***Automatic target recognition***
- ***Target tracking***
- ***Remote control possible from target point***
- ***Improved ergonomics***

Leica theodolite systems have the following features:

Mobility

- The measurement system can be taken to the object; measurements are made directly on site.
- Interruption of the production process is reduced to a minimum.
- The object does not need to be put in a particular position because the measurement system can operate in a coordinate system defined by the object.

Motorization

- Motorized Leica theodolites and total stations can be positioned to design points by means of software commands.
- The instrument is automatically positioned to the next measurement point in predefined inspect sequences using reference data.
- Carrying out the job requires considerably fewer manual settings, i.e. measurements are speeded up, standstill times cut.

Modularity

- You can select the best combination for your measurement job from Leica's array of theodolites, total stations and accessories.
- The Axyz software platform allows you to adapt and add to further measuring equipment at any time.

Ergonomics

- The typical Leica design of the TPS 5000 series is a perfect blend of user-friendliness and functionality.
- The dazzle-free, easy-to-read display field provides the necessary overview.
- Freely positionable fine drives with microswitches made for reliable and convenient operation.

Theodolites and total stations ideally complement today's large and expensive coordinate measuring machines

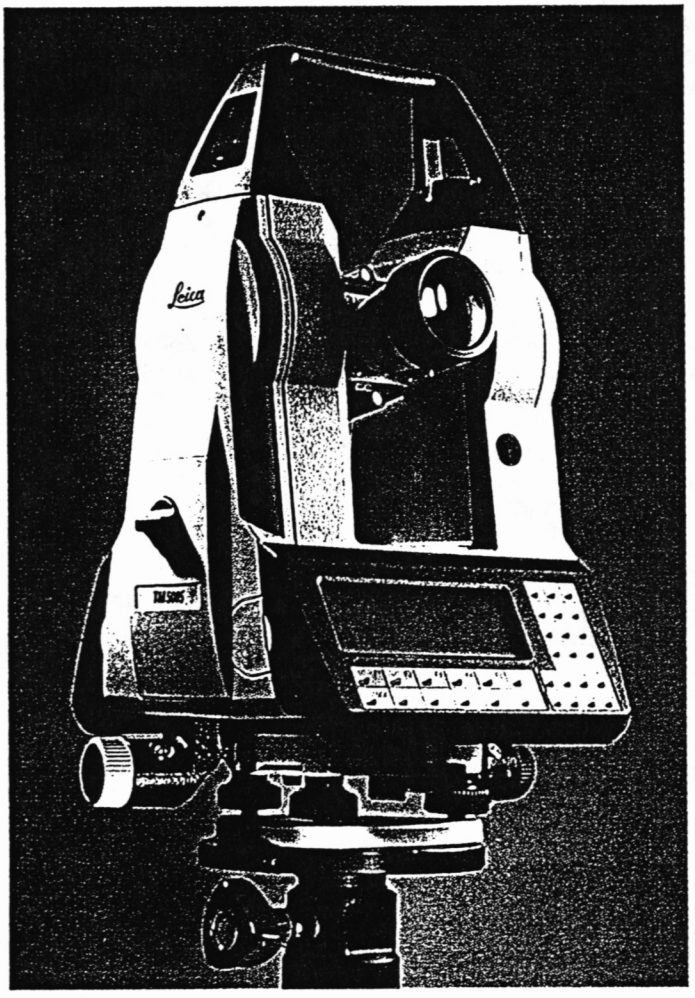
You can rely on Leica's know-how in theodolite development. It has combined mechanical engineering, optics, electronics and software perfectly to provide a level of efficiency never before reached. The intelligent measurement system relieves you of routine jobs so that you can keep your mind free for production and setting work.

Even if you don't spend 100% of your working day measuring – Leica theodolites from the TPS system 5000 will help you measure more quickly, more precisely and with less strain. This improves your productivity and minimizes your costs per production unit.

We can help you solve your measurement problems. Let us know your requirements and experience. This will provide the basis for rational further developments and successful cooperation.

TPS 5000 – new standards for industry

Our users had the ideas – Leica transformed them into reality. The result is a family of instruments tailored specifically to industrial applications that are setting new standards.



TM 5005 – the basic version of the motorized industrial theodolite

TPS 5000 instruments are available in two versions:

- as a pure angle measuring instrument for calculating horizontal and vertical angles, i.e. as a theodolite.
- as a combination of angle and distance measuring instrument in the form of a so-called total station.

The hardware

Maximum precision in directional measurement (horizontal and vertical angle) to an object point is possible with the Leica TPS 5000 family of theodolites and total stations.

The object or measurement point is targeted with a telescope and a special reticule. The position of the object point at the angle of intersection of two or more theodolite sightings can be determined to about 15 microns ($^{15}/_{1000}$ mm) at a range of 5 m. This is equivalent to the average thickness of a hair.

This precision is conditional upon:

The setting accuracy

The instrument can be set to an accuracy of 0.5" (0.15 mgon) by means of the motorized fine drives. In order to guarantee this high degree of accuracy extremely high quality is required of the telescope optics and the angle encoding system. The TPS 5000 series meets this quality requirement.

The instrument also features self-checking which guarantees a high degree of error-free measurements. Residual adjustment errors can be determined and allowed for simply with the aid of the software.

The automatic compensator

The compensator defines the exact reference to the horizontal. Residual inclination or changes to the instrument set-up are detected and compensated. Objects can thus be levelled exactly and the deviation from the horizontal can be measured. This makes the instrument a quasi 3D leveller.

The behaviour of the instrument is also monitored internally and the operator is given warning if the instrument is no longer operational for measurements.

User-friendly operation

Leica instruments have always been designed to ensure that users can maintain a natural posture when making measurements so that they can concentrate on their work without fatigue.

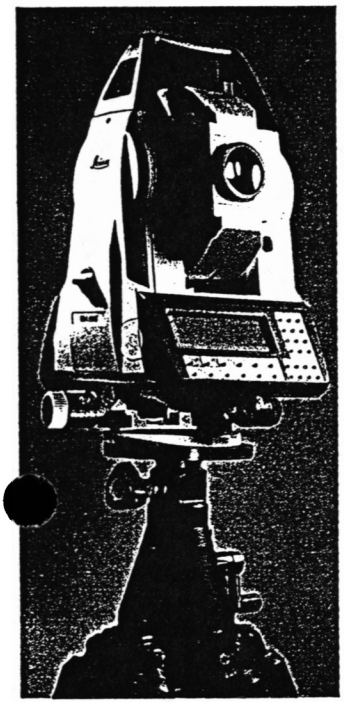
Industrial theodolites have the following additional advantages in this respect:

The display

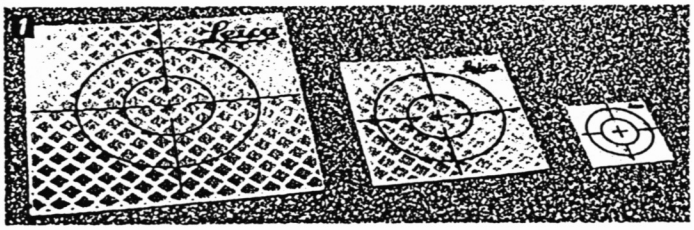
The large-format display has 8 lines of 35 characters, is graphics-compatible, fully alphanumeric and can be illuminated. It is directly in the viewer's field of vision and is set at a steep angle to avoid reflections from the environment.

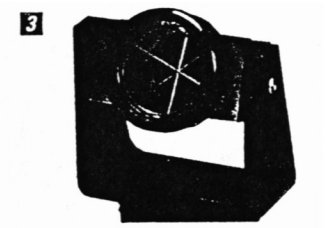
The industrial total station – TDM 5005

Angle + distance measurement = total station. 3D-coordinates can be measured with a single instrument – to an accuracy that meets the high standards of industry.

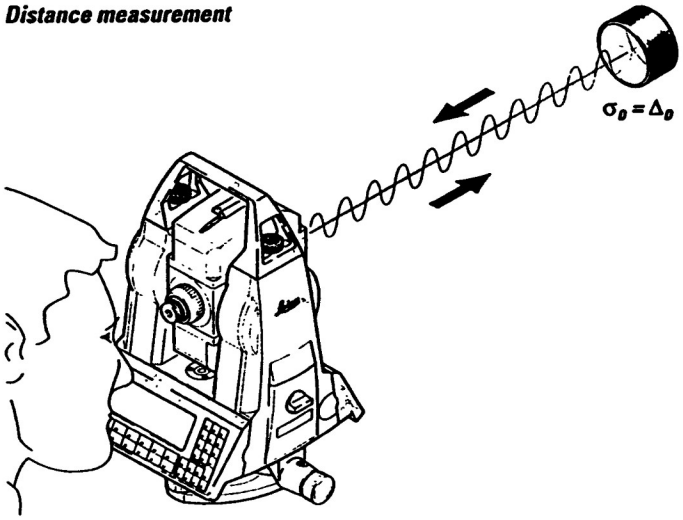


TDM 5005 – the "one-man total station"





Distance measurement



If the instrument is equipped with an integrated distance meter the distance to the target point can be measured in addition to the direction measurement. This is done by means of a reflector that doubles as target mark. Typical measuring accuracy in the close range up to 120 m is Δ 0.5 mm.

The distance meter

The TDM 5005 total station and the special version TDA 5005 are equipped with a distance meter so that distance measurements to many different types of reflector can be made in addition to angle measurement.

Measurement of the distance to the marked object points takes a matter of seconds, with a typical accuracy of 0.5 mm at distances up to 120 m.

The three-dimensional coordinates of the object point can be obtained equally fast.

Reflectors

The following reflector types can be used for the total stations of the TPS 5000 series.

1 Reflective tapes
2 Hollow corner cube reflector
3 Prism reflectors

All reflectors can be freely exchanged and maximum precision is retained. The same specified measuring accuracy is thus guaranteed regardless of the reflector type.