WHITE PAPER

TRIMBLE S6 WITH MAGDRIVE SERVO TECHNOLOGY

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ABSTRACT

The Trimble® S6 Total Station incorporates a revolutionary servo/angle system called MagDrive™ servo technology. MagDrive servo technology is based on a direct drive and frictionless electromagnetic drive technique. The direct drive system allows the servo motors to be mounted directly on the horizontal and vertical axis, removing the need for additional mechanical gearing. The integration with the angle sensor enhances the speed of the servo motors by providing fast angle values to be used by the servo processor. MagDrive servo technology provides high accuracy, high speed turning servo capabilities with low power consumption. The frictionless motion also removes servo noise and reduces instrument wear.

INTRODUCTION

The principle of Trimble's MagDrive servo technology is based upon using electromagnets for vehicular propulsion. This concept was first invented by Hermann Kemper in 1934 and forms the basis of maglev train development worldwide. During the late 1960s and early 1970s development began to create a high-speed train based upon the maglev concept.
In 1979 the world's first maglev train was operated at the International Transportation Exhibition in Hamburg, Germany. Long-term operation testing was conducted during the 1980s and 1990s with the first commercial operated maglev train commencing operations in 2002 from Shanghais Long Yang Road to Pudong International Airport, China. In December 2003, the Shanghai train set a new world record for commercial railway systems with a maximum speed of 501 km/h (311 mph). The speed and efficiency of

the maglev train is set to revolutionize the train and transportation industries. Countries, such as the United States, Germany, Japan, and China, are investing in maglev technology as transport systems for the future. For more information, see http://www.transrapid.de/en/index.html.

TRIMBLE'S MAGDRIVE SERVO TECHNOLOGY

Trimble MagDrive servo technology is an integrated servo and angle system that uses a direct drive and frictionless electromagnetic drive technique similar to those used in maglev trains. The direct drive system allows the servo motors to be mounted directly on the horizontal and vertical axis, removing the need for additional mechanical gearing.

The ability to provide fast accurate angles to the servo drive processor, without an additional encoder or tacheometer, provides the high speed capabilities of MagDrive.

SERVO DRIVE

The servo drive consists of a holder containing areas of magnets and soft iron that are distributed in two concentric cylindrical structures separated by an air gap. The air gap provides sufficient space for a cylindrical motor winding, which is divided into three phases to provide control over changing direction and fine control of the rotation (Figure 1).

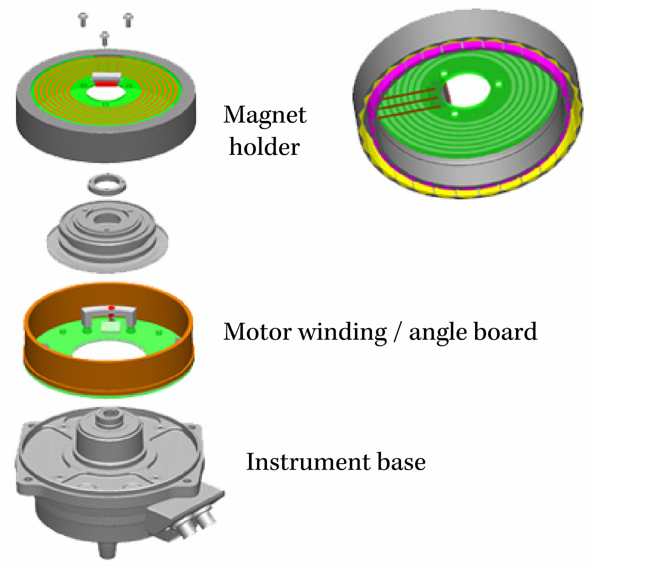

Figure 1: Integrated angle and servo system

The instrument is driven by applying a current through the motor winding. The motor's transmission of force, which drives the instrument, provides non-contacting, frictionless motion according to known electromagnetic field theory. The electromagnetic force enables the magnet holder to be rotated.

The force is created according to the known physical relation:

F = B x I x L x SIN(A), where

F is the force vector (Newton)

B is the magnetic field strength (Tesla)

I is the current in the winding (Amp)

L is wire length in the magnetic field

A is the angle between the current and magnetic field.

The working torque M is given by *F* multiplied by cylinder radius *R* (Figure 2).

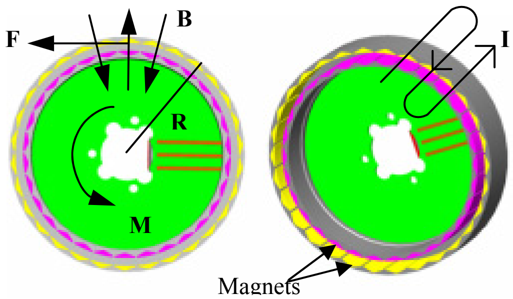

Figure 2: Servo drive in operation

This design enables force to be transmitted from the drive to the instrument with almost frictionless contact. The system provides endless motion horizontally and vertically, including endless fine adjustment without mechanical clutches.

The servo drive technology has three working modes, namely:

- Driving mode. Where movement is controlled by servo knobs or system process
- Friction mode. Where the drive allows the instrument to be turned manually
- Holding mode. Where the drive works as a clutch to lock the instrument position and prevent movements, e.g when pressing a push-button

The driving mode is controlled by the turning of the servo knobs. The servo knobs are configured to increase the speed of the instrument turn as they are continually turned. There are 5 speed increments of motion that are changed when the instrument has been continuously turned at a speed greater than 1 revolution per second. The amount of continuous turning, at 1 revolution per second to change speeds from slowest to fastest is specified below:

- less than ¾ of a turn (slowest)
- greater than ¾ turn
- greater than 1½ turn
- greater than 2¼ turn
- greater than 2¾ turn (fastest)

The last increment is ½ a turn to provide the user with easy access to the fastest speed. When the servo knob has stopped being turned the instrument will stay at the current speed increment for ½ a second to allow the user to continually move the instrument if required. After ½ a second the instrument will return to the slowest speed. Reverse motion of the servo knobs can also be used to change down the speeds.

The working modes and design of the direct drive system provide exceptional performance compared to conventional techniques. The performance can be easily shown by comparing the time required to transit the instrument from the face 1 to the face 2 position. A comparison of instrument performance is shown in Table 1.

The times shown are the average of 30 turns each instrument.

	Specified max turning speed	Average time to change face
Trimble S6	115°/sec	3.2 sec
Trimble 5600	60°/sec	9.9 sec
Other leading manufacturer	50°/sec	8.4 sec

Table 1: Trimble S6 performance changing face

The time was measured from the moment change face was selected to the time the angles were updated and the instrument was ready for use. Accuracy of the turns is all within the specifications of the instruments tested.

MagDrive servo technology in the Trimble S6 clearly provides accurate turning at exceptional speed.

ANGLE SENSOR

The Trimble S6 incorporates an improved optical-based angle sensor unit that is integrated with the servo drive (Figure 3). The angle sensor unit consists of glass circles that hold a coarse and fine code pattern. The code pattern is distributed in two tracks on a glass disk: one track with an absolute code and one with an incremental code. The use of two separate tracks provides a uniform accuracy and resolution around the circle. Both tracks are illuminated with a single laser light source, which is then projected onto two Complementary Metal Oxide Semiconductor (CMOS) image sensors.

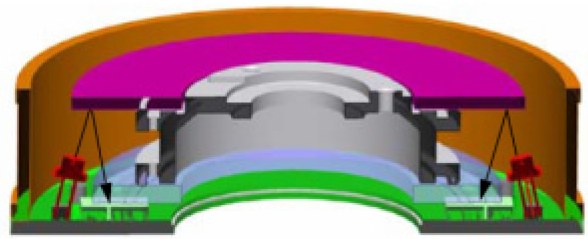

Figure 3: Cross-section of Angle Sensor Unit

To ensure that the absolute encoder is robust and less sensitive to eccentric mounting errors, the sensors are positioned on opposite sides of the disk. The image read from the incremental track is analyzed using a numerical Fourier phase-detection algorithm to create the high resolution angle from the fine code. The final angle value is calculated as the mean value of the two CMOS image sensor readings.

Mechanically, the angle sensor unit is integrated into the servo drive housing. The central unit contains the optical glass disc, laser transmitter, image area detectors and the servo drive windings. The angle sensor is designed not only for displaying and storing angle data but also to support the servo system with fast data for angular calculations.

In addition to the fast acquisition of accurate angles, the angle measurement system compensates for the following:

- Automatic correction for deviation of the plumb axis.
- Automatic correction for collimation errors.
- Automatic correction for trunnion axis tilt.
- Arithmetic averaging for reducing sighting errors.

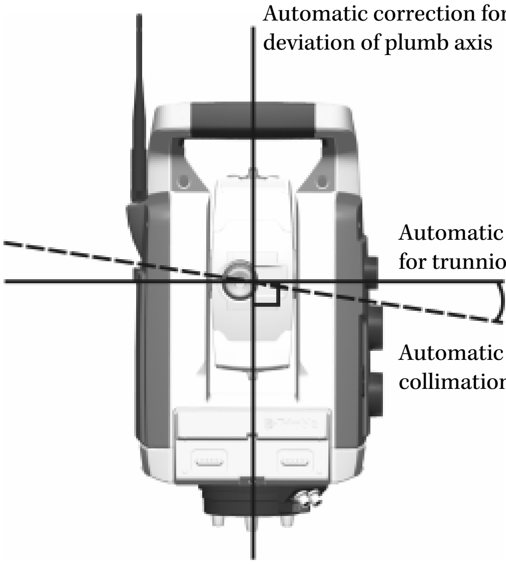

Figure 4: Automatic correction for deviation of the plumb axis

Deviations in the plumb axis may occur when one (or more) of the tripod legs move as a result of unstable ground or changes in ground viscosity, such as the heating of road tarmac. Corrections for this movement are essential to ensure that accurate measurements are obtained.

Most modern total stations are equipped with a dual-axis compensator that automatically corrects the horizontal and vertical angles for any deviations in the plumb axis caused by mislevelment. The principle of the dual-axis compensator in the Trimble S6 is to use a light beam that is reflected towards a free liquid surface via an optical lens. A CMOS image sensor is then used to detect the inclination of the light beam in the measuring direction and perpendicular to this direction.

The level compensator sensor is mounted in the centre of the instrument to minimize the sensitivity to vibrations and rotation of the instrument. The mounting facilities are designed for the highest stability that can provide an absolute level compensator value. This means that the compensator can be active with full accuracy directly after the instrument is powered up. In addition, an automatic procedure can be activated by the operator for the routine calibration of the compensator. The calibration process involves establishing a horizontal reference plane relative to the balanced vertical axis of the instrument during a 360° rotation of the instrument. The orientation of the reference plane may change slightly with large temperature variations or other mechanical stresses.

In contrast to most total stations, MagDrive allows the Trimble S6 to correct not only the horizontal and vertical angles for mislevelment, but also the aiming errors caused by mislevelment. The mislevelment correction is applied to the servo drive to re-aim the instrument. For example, correcting the aiming when extending a vertical line to ensure that a true vertical line can be obtained. The result is that horizontal and vertical angles are corrected for mislevelment while the instrument is accurately aimed at the correct location. This ability ensures that mislevelment errors are corrected to provide accurate angle measurements.

AUTOMATIC CORRECTION FOR COLLIMATION ERRORS

Collimation errors affect measured horizontal and vertical angles. The horizontal collimation error is the difference between the line of sight and the plane perpendicular to the trunnion axis; the vertical collimation error is the difference between the vertical circle zero and the plumb axis. Traditionally, collimation errors were eliminated by observing angles on both instrument faces. In the Trimble S6 the collimation errors can be predetermined by performing a pre-measurement collimation test. Angular measurements are observed on both instrument faces to enable the collimation errors to be calculated and the respective correction values to be stored in the instrument. The collimation correction values are then applied to all subsequent angle measurements. Angles observed on a single face are therefore corrected for collimation errors, thereby removing the need to measure on both instrument faces.

Trimble S6 instruments with Autolock® technology can automatically lock and track a target. Since the sighting to the target is performed by the instrument, the affects of horizontal and vertical collimation are similar to those experienced during manual sighting. To correct for the collimation errors in the tracker unit, an Autolock collimation test can be performed. The Autolock collimation test automatically observes angular measurements to a target on both instrument faces. The Autolock collimation errors are then calculated and the respective correction values are stored in the instrument. The Autolock collimation correction values are then applied to all subsequent angle measurements observed when Autolock is enabled. Angles observed on a single face are therefore corrected for collimation errors, thereby removing the need to measure on both instrument faces.

AUTOMATIC CORRECTION FOR TRUNNION AXIS TILT

The trunnion axis tilt error is the difference between the trunnion axis and the plane perpendicular to the plumb axis. In the Trimble S6 the trunnion axis tilt error can be determined by performing a pre-measurement trunnion axis tilt test. Angular measurements are observed on both instrument faces to enable the horizontal tilt axis error to be calculated and the respective correction value to be stored in the instrument. The horizontal tilt axis correction value is then applied to all subsequent horizontal angles.

AUTOMATIC MEASUREMENT AVERAGING REDUCES SIGHTING ERRORS

The Trimble S6 automatically reduces sighting errors caused by misaligning the instrument to the target or by movement during measurement. The sighting errors can be reduced by:

- Using Autolock technology. When Autolock is enabled the instrument will automatically lock to and track the target. Manual sighting errors are therefore reduced.
- SurePoint™ accuracy assurance. When the Trimble S6 is manually aimed at a target the servo motors are finely tuned to hold the aimed angle. SurePoint ensures that sighting errors due to unintentional small movements of the instrument are eliminated.
- Automatically averaging angles during distance measurement. When measuring in STD mode the instrument will take approximately 1.2 seconds to measure the distance. Fully synchronized angles and distances are averaged over the measurement period to obtain an averaged, highly accurate measurement.
- Using averaging measurement methods in the Trimble field software. Measurement methods are available, which allow a defined number of measurements to be observed and a resultant averaged measurement to be stored. In addition, multiple rounds of measurements can be observed to further reduce measurement errors.

MAGDRIVE SERVO TECHNOLOGY ADVANTAGES

In addition to providing high speed angles and servo control, MagDrive servo technology provides some distinct advantages over conventional total stations. These advantages include:

SUREPOINT ACCURACY ASSURANCE

SurePoint accuracy assurance allows the Trimble S6 to remain aimed at a target. Once the user manually aims the instrument at the target the servo drive is placed into the holding mode. If the instrument is unintentionally bumped, e.g. by pressing the trigger key with excessive force, then the instrument will make fine adjustments to turn back to the original aimed angle. SurePoint ensures that traditional sighting errors caused by unintentional small movements of the instrument are eliminated.

AIMING COMPENSATION FOR MISLEVELMENT

Conventional total stations use a dual-axis compensator to correct the horizontal and vertical angles for the effects of mislevelment. However, the angle correction does not compensate for the aiming error introduced by the mislevelment. MagDrive servo technology provides another valuable feature of SurePoint, which enables the Trimble S6 to correct not only the horizontal and vertical angles for mislevelment, but also the aiming errors caused by mislevelment. The mislevelment correction is applied to the servo drive to re-aim the instrument to the correct location. The result is horizontal and vertical angles that are corrected for mislevelment while the instrument is still accurately aimed at the correct location.

The correction of aiming for mislevelment errors provides the Trimble S6 with advanced error-correction techniques that further increase the ability to provide highly accurate measurements.

EXTENDING A VERTICAL LINE

A limitation of conventional total stations is the ability to extend a vertical line up or down, with the same horizontal angle, by simply moving the vertical control knob. This ability would demand an instrument that is perfectly levelled with all axes in perfectly adjusted. In practice, when you turn the instrument vertically, you can also see the horizontal angle slightly change. To obtain a true vertical line, the horizontal angle has to be adjusted. With the Trimble S6, SurePoint uses the compensation and error information to automatically adjust the horizontal angle and aiming to a fixed value when the vertical control knob is turned. Therefore, a perfect vertical line can be extended by simply turning the vertical control knob.

EXTENDING A HORIZONTAL LINE

Similar to the technique used for extending a vertical line, a traditional way of setting out a horizontal straight line in a direction exactly opposite to a given horizontal direction, is to transit the telescope 180° by simply turning the vertical control knob. With conventional instruments this technique requires a perfectly adjusted axis without horizontal collimation errors for an accurate result. The Trimble S6 removes this limitation by using the collimation and compensator error information to automatically adjust the horizontal angle to a fixed value when the vertical control knob is turned. The horizontal angle is adjusted to provide an accurate straight line direction by turning only the vertical control knob.

CONCLUSION

The Trimble S6 Total Station with MagDrive servo technology provides unprecedented speed and accuracy for all survey applications. MagDrive also provides distinct advantages over conventional total stations that allow the user to maximise accuracy and productivity.

To learn more about how Trimble total surveying solutions can help you and your business, or to see for yourself the Trimble S6 Total Station with MagDrive, please contact your local Trimble representative, who will be pleased to give you a demonstration. To locate your nearest Trimble authorized distribution partner, visit our website at http://www.trimble.com/locator/sales.asp.