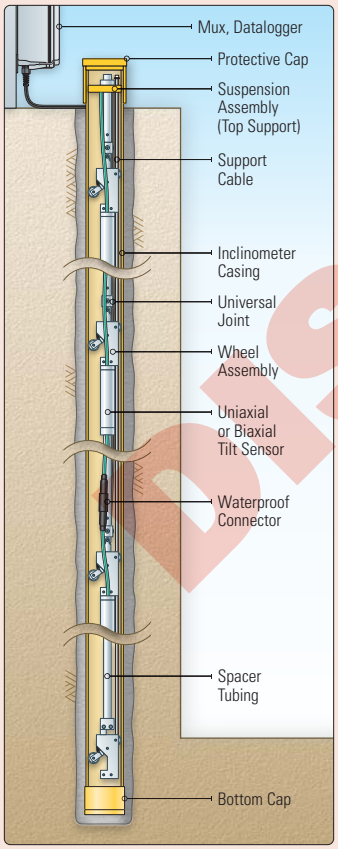
MEMS In-Place Inclinometer Systems

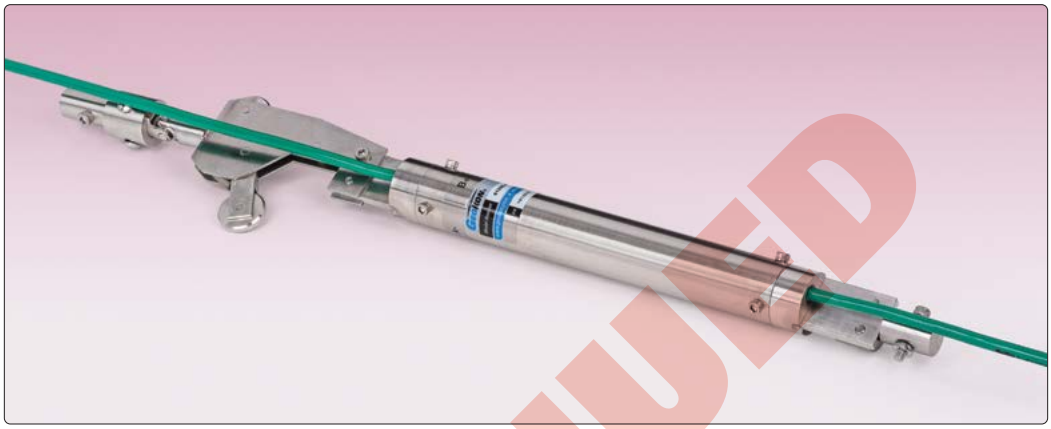
Applications

The remote, continuous, and automatic monitoring of…

- **Lateral deformation in dams and tailings**
- **The stability of natural slopes, landslides embankments and sub-sea marine sediments**
- **The stability of slurry walls, sheet piling and tieback walls**
- **Lateral ground movements in, around and above tunnels and underground openings**



Typical application to monitor the stability of a foundation wall.



6150E-1 Biaxial MEMS Tilt Sensor.

Introduction

The basic principle of operation is the utilization of MEMS (Micro-Electro-Mechanical System) tilt sensors to make accurate measurement of inclination, over segments of a borehole drilled into the structure being studied. Two versions are available: one is designed to be installed in grooved inclinometer casing and the other is a wheelless version, designed for use in standard 2" PVC pipe.

Operating Principle

The Model 6150E MEMS Digital In-Place Addressable Inclinometer consists of a string of biaxial MEMS tilt sensors mounted on lengths of stainless steel tubing, linked together by universal joints.

The tilt sensors are connected to each other by means of a four-wire bus cable. Each sensor has a length of this cable exiting from the top and bottom of the sensor housing. The same cable (customer specified length) connects the uppermost sensor to the chosen readout (PC, datalogger, SCADA system, etc.).

Movements of the ground deflect the casing or pipe causing one or more of the inclinometer segments (length L) to undergo changes of tilt (Δθ). Summation of all these tilts in the form $\Sigma L \sin\theta$, are plotted to give profiles of lateral deflection. Each tilt sensor also contains a thermistor to permit temperatures to be recorded.

Available versions

6150E-1 | This is the classic configuration in which biaxial MEMS tilt sensors are mounted on lengths of stainless steel tubing to provide customer specific gauge lengths, and linked together by universal joints. Spring-loaded wheel assemblies are located at each joint and allow the sensor string to positively engage in the grooves of conventional inclinometer casing.* The entire string is normally supported from the top of the casing by a suspension bracket.

**A wheeless version is available: please contact GEOKON for details.*

Advantages and Limitations

MEMS tilt sensors have a wide range combined with a high sensitivity, which makes them ideally suited for use in installations which deviate excessively from the vertical. Their long-term stability is excellent and they are resistant to shock loads.

Digital systems offer greater noise immunity than analog types and are capable of signal transmission over cables lengths up to 1200 m, depending on the number of sensors.

Limitations include cost, which may limit the number of sensors in any one installation. Because of this, the deflection profile obtained may not be as detailed as profiles obtained with conventional inclinometer probes. However, costs can be controlled by limiting the tilt sensor placement only to those zones where the deflections are anticipated.

● *Model 6150E-1 MEMS In-Place Inclinometer.*

Data Acquisition

The Model 6150E Addressable In-Place Inclinometers use the industry standard **Modbus®** Remote Terminal Unit (RTU) protocol to communicate. As the name suggests, **Modbus** was designed to work on what is known as a bus network. Model 6150E In-Place inclinometers use RS-485 (half duplex) as the electrical interface because of its prevalence, simplicity and success as a robust, industrial physical layer.

Automated monitoring is accomplished using the Model 8800 GeoNet Wireless Network Nodes, Model 8600 Series Dataloggers, sensemetrics Threads, Campbell Scientific Dataloggers or any other device capable of being a Modbus RTU client and having an RS-485 port.

Technical Specifications

Range	±15° (±54000 arcseconds)
Resolution[1]	±0.0001° (±0.2 arcseconds)
Precision[2]	±0.0018° (±6.5 arcseconds)
Nonlinearity[3]	±0.016° across ± 15° range (±59.3 arcseconds)
Temperature Dependent Uncertainty	±0.0054°/°C (±19.3 arcseconds/°C)
Cross axis sensitivity[4]	4%
Frequency Response	–3db @ 8-28 Hz
Thermistor Accuracy	±0.65 °C
Thermistor Precision	±0.06 °C
Operating Temperature	–40 °C to 80 °C (–40 °F to 176 °F)
Power Supply Voltage	12 VDC ±20%
Operating Current[5]	26 mA ±1 mA
Standby Current	1.2 mA ±0.1 mA
Maximum Supply Current[6]	500 mA
Housing Diameter	32 mm (1.250")
Housing Length	235 mm, (9.25")
Weight of 0.5 m Assembly[7]	1.5 kg (3.4 lb.)
Materials	316 Stainless Steel
Electrical Cable	Four Conductor, Foil shield, Polyurethane jacket, nominal OD = 6.3 mm
Minimum Sensor Spacing	0.5 m

[1]All but one in a hundred individual readings would fall within our published tolerance. (Most measuring devices are specified with only a 95% confidence interval, meaning one in twenty readings exceed the stated limit, on average.)
[2]Expanded uncertainty for 99.0% confidence interval includes angle random walk and incidental seismic noise during tests. Angle "random walk" describes the changes between consecutive readings that have no discernible cause.
[3]Typical, per MEMS device datasheet.
[4]Per MEMS device datasheet.
[5]Operating and standby current are for each individual sensor drop in a string.
[6]Per entire string.
[7]Weight of sensor without cable.

Legacy Versions

Limited legacy versions are available allowing for the repair and/or expansion of retired in-place inclinometer models previously available from **GEOKON;** legacy models include:

6150A | Analog Sensor

Where each sensor uses its own cable, up to 305 m (biaxial) or 610 m (uniaxial). Output is ±4 V at ±15°. The maximum number of sensors that can be used in this configuration is 24 (Uniaxial) or 16 (Biaxial) in 70 mm (2.75") inclinometer casing and 42 (Uniaxial) or 28 (Biaxial) in 85 mm (3.34") casing.

6150B | Analog Sensor, Addressable

Where all the sensors are connected together on a single 6-pair cable. The maximum number of sensors that can be used in this configuration is 16 and the maximum cable length is 305 m.

6150C | Digital Sensor, Addressable

With digital MEMS sensors connected to a 2-conductor Frequency Shift Keying (FSK) trunk line via waterproof connectors and where readout is accomplished via a modem interface. The maximum number of sensors that can be used in this configuration is 32.

6150D | Digital Sensor, Wheelless, Addressable

Similar to the 6150C but with sensors mounted on tubes at customer specific gauge lengths without wheel assemblies, flexibly linked with fixed U-joints, for use in standard 2" PVC pipe (without grooves).

Please contact **GEOKON** for details.

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