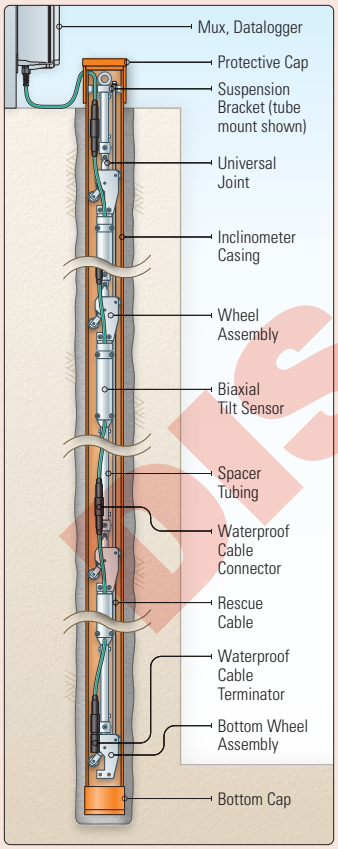
MEMS In-Place Inclinometer Systems

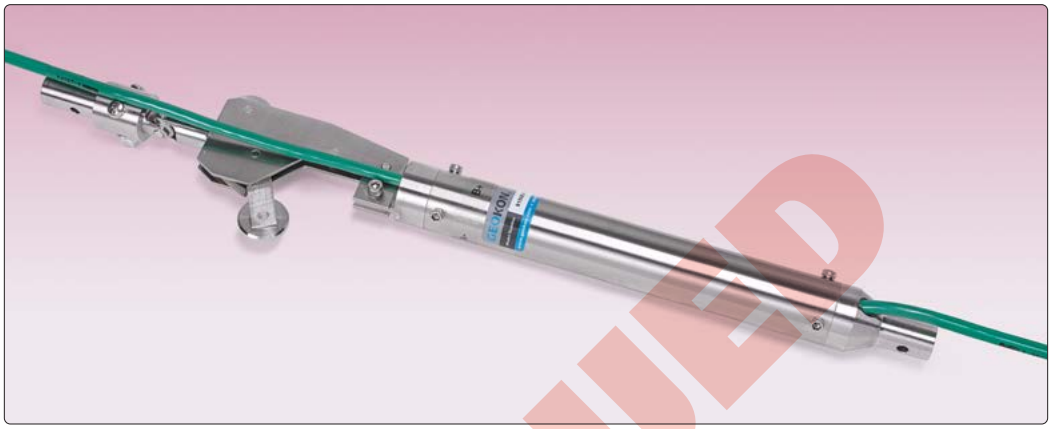
Applications

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.



6150F Series Biaxial MEMS Tilt Sensor.

Operating Principle

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.

The Model 6150F MEMS Digital In-Place Addressable Inclinometer consists of a string of Biaxial MEMS Tilt Sensors mounted on lengths of stainless steel tubing, which are cut to customer-specified segment lengths, and interconnected with 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.

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 (at the 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 ($\Delta\Theta$). 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.

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 6150F MEMS In-Place Inclinometer.*

Data Acquisition

The Model 6150F 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 6150F 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.

Ordering Information

6150F-0.5-M: MEMS Digital In-Place Addressable Inclinometer, RS-485, Vertical, Biaxial. Segment for 0.5 m spacing, includes connecting tube, connecting cables and intermediate wheel assembly.
6150F-1-M: as above, with 1 m spacing.
6150F-2-M: as above, with 2 m spacing.
6150F-3-M: as above, with 3 m spacing.
6150F-5-M: as above, with 5 m spacing.
6150F-2-E: as above, with 2 ft. spacing.
6150F-5-E: as above, with 5 ft. spacing.
6150F-10-E: as above, with 10 ft. spacing.
6150F-2: Termination assembly connector.*
6150F-3V: Readout cable, female connector to bare leads.
6150F-4V: Readout cable, female connector to 5-pin.
6150F-6: Suspension bracket for tube or cable mount.*
6300-5: Bottom wheel assembly.*
6300-6E/M: Rescue cable for in-place inclinometer, runs to bottom of assembly.

**One required per string.*

Technical Specifications

Range	±15° (±54000 arcseconds)
Resolution[1]	±0.0001° (±0.2 arcseconds)
Precision[2]	±0.0018° (±6.5 arcseconds)
Nonlinearity	±0.006° across ±8° range (±20.8 arcseconds) ±0.016° across ±15° range (±59.3 arcseconds)
Temperature Dependent Uncertainty	±0.0054°/°C (±19.3 arcseconds/°C)
Cross axis sensitivity[3]	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[4]	26 mA ±1 mA
Standby Current	1.2 mA ±0.1 mA
Maximum Supply Current[5]	500 mA
Weight: Sensor	1.08 kg (2.4 lb.) (0.5 m segment)
Weight: Tube and Cable	0.18 kg (0.4 lb.) (0.5 m segment)
Materials	316 Stainless Steel
Electrical Cable	Four-conductor, foil shield, Polyurethane jacket, nominal OD = 6.3 mm
Minimum Sensor Spacing	0.5 m
Sensor L × Ø	240 × 32 mm (9.50" × 1.25")

[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]Per MEMS device data sheet.
[4]Operating and standby current are for each individual sensor drop in a string.
[5]Per entire string.

Legacy Versions

Limited legacy versions are available allowing for the repair and/or expansion of retired in-place inclinometer models previously available from **GEOKON**. For more information, please visit: www.geokon.com/6150ABCDE

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