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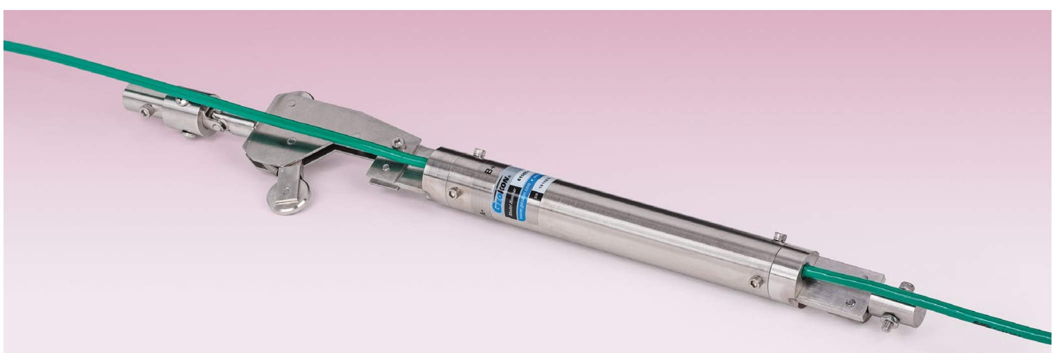
Instruction Manual

Model 6150E

MEMS Digital Addressable In-Place Inclinometer, RS-485



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EQUATIONS

1. INTRODUCTION

The Geokon Model 6150E MEMS Digital Addressable In-Place Inclinometer system enables long-term monitoring of deformations in structures such as dams, embankments, foundation walls, and similar applications. The basic principle of operation is the utilization of tilt sensors to make accurate measurement of inclination, over segments of a borehole, which is drilled into the structure being studied. The instrument is designed to be installed in standard grooved inclinometer casing, which is installed in the borehole. Constant monitoring by the instrument allows for very precise measurement of changes in the borehole profile. Each tilt sensor is individually serialized and calibrated. A calibration sheet for each sensor is provided, showing the relationship between sensor output and inclination.

Each tilt sensor is comprised of two addressable Micro-Electro-Mechanical Systems (MEMS) devices inside a sealed stainless steel housing. The devices measure the "A" and "B" axes of the borehole. Each sensor also contains a device for reading temperatures.

The tilt sensors are connected to each other by means of four-wire bus cable. Each sensor has a length of this cable exiting both the top and bottom of the housing. A male connector is attached to the cable exiting the top of the sensor and a female connector is attached to the cable exiting the bottom of the sensor. The uppermost sensor of the string does not have a male connector; instead, it will have the customer specified terminator for attachment to the chosen readout (PC, datalogger, SCADA system, etc.).

Stainless steel tubing is used to mechanically connect the sensors, as well as to fix them at the customer-designated intervals. The tilt sensor housing has a wheel assembly and universal joint on its upper end. This centralizes the sensors in the casing, allows unimpeded relative movement of the spacer tubing, and accommodates any spiraling of the casing. The entire string is normally supported from the top of the casing by a suspension bracket.

2. INSTALLATION

2.1 Preliminary Tests

Prior to installation, the sensors should be checked for proper operation. Complete the following:

1) Place the sensors in the correct order by referring to the labels on the sensors and the paperwork provided.

2) Connect the sensors together by plugging the cable exiting the underside of one sensor into the cable exiting the top of the next sensor.

   Caution! When connecting the sensors make sure to line up the two "bumps" on the outside of the female connector with the "bump" on the outside of the male connector. This will ensure that the pins and holes on the interior of the connectors align correctly. Push the male and female connectors together until they are completely mated (Figure 1).

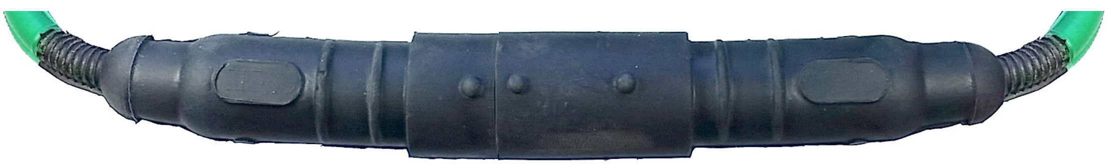

Figure 1 - Cable Connection Detail

3) Once all sensors have been connected, plug the end terminator (Figure 2) into female connector of the bottom sensor.

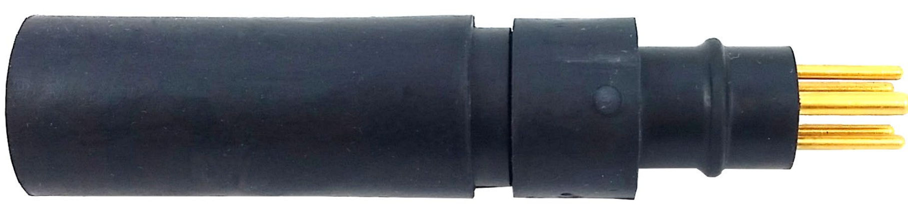

Figure 2 - End Terminator

4) Connect the completed string to a readout or datalogger.

5) Hold the first sensor in a vertical position and observe the reading. The tilt sensor must be held in a steady position while taking the reading. The observed reading should be close to the factory vertical reading. Tilts in a positive direction (A+ or B+, as marked on the sensor) should yield increasing readings. Tilts in a negative direction (A- or B-) should yield decreasing readings. The temperature indicated on the readout should be close to ambient. Repeat this process with the remaining sensors.

6) Once the preliminary tests have been completed, disconnect the string from the readout. Next, disconnect all of the sensor cables. (The end terminator may remain on the bottom sensor.)

Should any of these preliminary tests fail, see Section 5 for troubleshooting.

2.2 Assembly and Installation

PLEASE NOTE:

- The one-inch cap screws used in the following assembly procedure are installed in the wheel assemblies at the factory and must be removed before attaching the tubing.
- The string will ship with a few spare cap screws and nuts. The shorter 3/8” cap screws are spares for the screws that attach the wheel assembly to the sensor.
- The lengths of tubing that make up the IPI string are shown in a table supplied along with the calibration sheets. Where the spacing of the sensors is too long for a continuous length of tubing, two tubes are joined together by a special union. Use the one-inch cap screws and nuts to make this connection.
- **Use Loctite 222 thread locking compound on all threaded connections.**

2.2.1 Bottom Wheel Assembly

The bottom wheel assembly has no universal joint, only a swivel, and is labeled as “6300-5 BOTTOM”. Attach this wheel assembly to the appropriate section of tubing by using one of the 10-32 cap screws and a nut. *Remember to use Loctite 222 on all threaded connections*.

Attaching a safety cable to the bottom wheel assembly is strongly recommended. Not only can it be used to retrieve the assembly if one of the joints breaks loose, but it is also very helpful when lowering the assembly into the casing.

Safety cables purchased from Geokon will have an eyebolt on one end. Slide the eyebolt onto the 10-32 cap screw that was used to attach the first section of tubing to the bottom wheel assembly. Tighten another nut onto the cap screw; this will trap the safety cable between the two nuts. The completed bottom wheel assembly is shown in Figure 3.

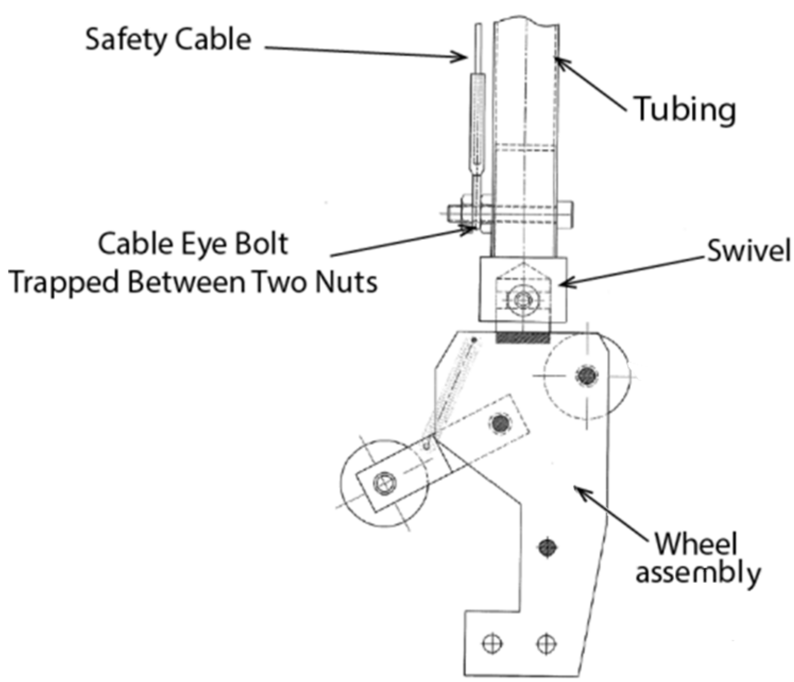

Figure 3 - Bottom Wheel Assembly

2.2.2 Sensor Orientation

All wheel assemblies should be oriented in the same direction when installed in the casing (as shown in Figure 6). The wheel assemblies are attached at the factory so that the fixed wheel is facing the A+ direction of the sensor (Figure 4).

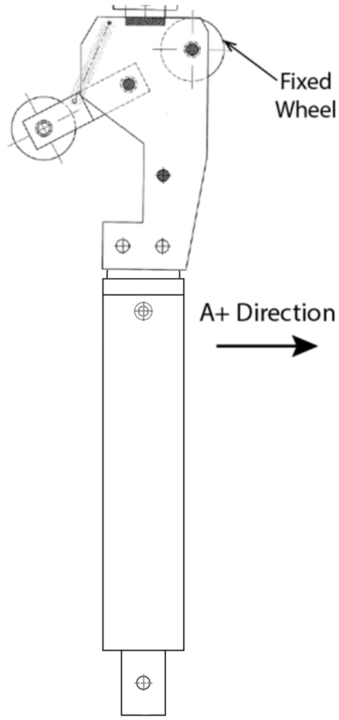

Figure 4 - A+ Direction

It is customary and recommended to point the A+ (fixed wheel) direction in the same direction as the anticipated movement, i.e., towards the excavation being monitored or downslope for slope stability applications.

A second MEMS device is included in the sensor and is attached with its positive direction 90° clockwise from the first device. This is the B+ direction of the sensor (Figure 5).

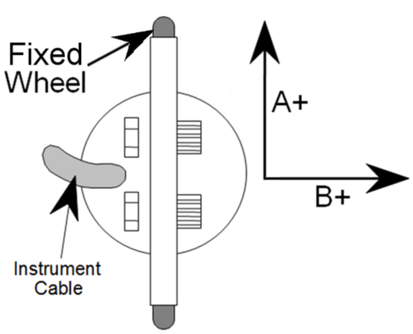

Figure 5 - Sensor Orientation

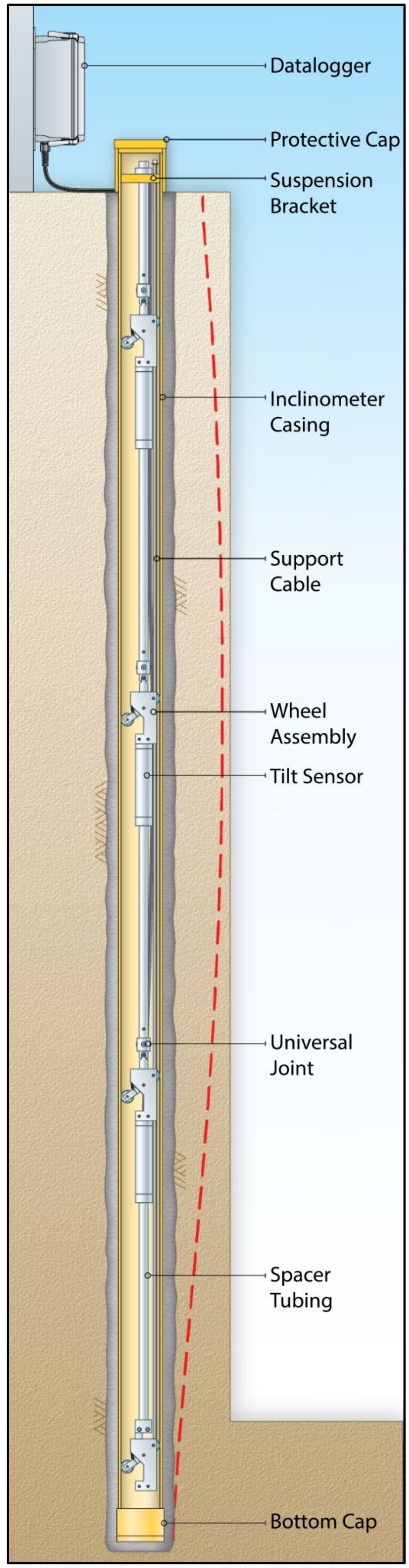

Figure 6 - Model 6150E Installation

2.2.3 Sensor Installation

Attach the tubing that is installed on the bottom wheel assembly to the underside of the lowest sensor in the string. Once again, use a long 10-32 cap screw and a nut. (*Remember to use Loctite 222 on all threaded connections.*)

Insert the bottom wheel assembly into the casing, making sure to orientate the fixed wheel correctly. (See Section 2.2.2 above.) Using the safety cable, lower the wheel assembly and tubing into the hole, until the bottom sensor is at the top of the casing.

A clamp of some sort (such as vice-grips attached to the tubing or a screwdriver placed under the sensor), should be used to hold the assembly in place at the top of the casing.

Using the same hardware as before, attach the next section of tubing to the bottom sensor's wheel assembly, and then attach it to the next sensor in the string.

Plug the male connector of the bottom sensor into the female connector of the sensor above it. **Caution! When connecting the sensors make sure to line up the two "bumps" on the outside of the female connector with the "bump" on the outside of the male connector. This will ensure that the pins and holes on the interior of the connectors align correctly. Push the male and female connectors together until they are completely mated (Figure 7).**

Figure 7 - Cable Connection Detail

If desired, the gage cable may be taped to the tubing. The connectors may be taped together for additional security.

Using the safety cable, lower the bottom sensor and tubing into the hole, until the next sensor is at the top of the casing. Make sure to orientate the A+ direction of the sensor correctly when inserting it into the casing.

Continue to add tubing to the sensors, connect the sensor cables together, and lower the string into the casing, until the uppermost sensor is aligned with the top of the casing.

Attach the suspension bracket to the top sensor's wheel assembly or to the final section of tubing as required. Lower the final sensor into the casing and position the suspension bracket on top of the casing. It is important that the top rim of the casing be relatively square to prevent any side interference with the wheel assembly of the top sensor.

The safety cable can now be tied off around the top of the casing and the signal cable can be run to the readout location. Readings can be taken immediately after installation, but it is recommended that the system be allowed to stabilize for a few hours before recording the zero readings.

2.3 6150E Wiring

Table 1 shows the function of each of the conductors of the instrument cable.

Instrument Cable Conductors	Description
Red	MEMS String Power
White	Communication RS-485+
Green	Communication RS-485-
Black	Ground
Shield	Analog Ground

Table 1 – 6150E Wiring

2.4 Six-Pin Waterproof Connector

The pinouts for the six-pin male and female connectors are shown in Figure 8 and Figure 9; the function of each wire is detailed in Table 2.

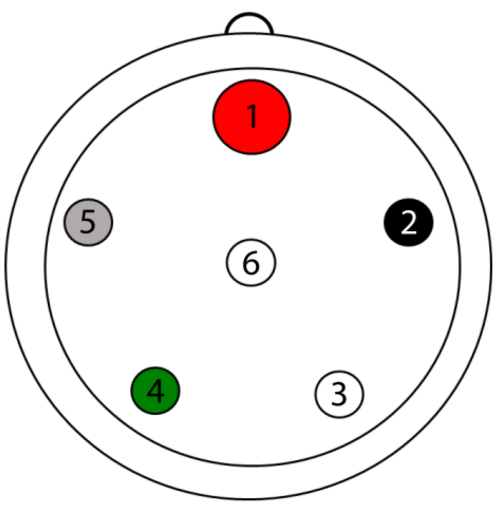

Figure 8 - Male Waterproof Connector

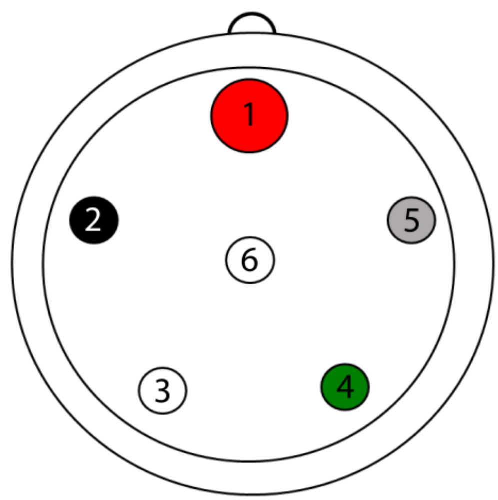

Figure 9 - Female Waterproof Connector

Pin	Wire Color	Function
1	Red	Power
2	Black	Ground
3	White	RS-485+ Data High
4	Green	RS-485- Data Low
5	Bare	Shield Drain
6	N/C	N/C

Table 2 - Six-Pin Wiring Chart

2.5 USB to RS-485 Converter

If a PC is to be interfaced to 6150E strings, a USB to RS-485 converter will be needed. Geokon can provide a small, convenient, USB dongle, which has screw terminals for connecting the 6150E signal cable. Figure 10 shows Geokon Model 3810A-2, USB to RS-485 Converter. Table 3 details the connections between the 6150E string and the USB to RS-485 Converter.

Figure 10 - Geokon Model 3810A-2, USB to RS-485 Converter

MEMS String	USB to RS-485 Converter	Description
Red	+5V	5 volt power to the string
Green	485-	Communication RS-485-
White	485+	Communication RS-485+
Black	GND	Ground

Table 3 - USB to RS-485 Wiring Chart

3. MODBUS RTU PROTOCOL

3.1 Introduction to Modbus

Model 6150E Addressable In-Place Inclinometers use the industry standard Modbus Remote Terminal Unit (RTU) protocol to communicate with the chosen readout method. As the name suggests, Modbus was designed to work on what is known as a *bused network*, meaning that every device receives every message that passes across the network. The Modbus standard does not specify a physical layer (connection type), but it will work with any interface that can communicate asynchronously with multiple devices (e.g., RS-485, RS-422, optical, radio, etc.). 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.

3.2 Modbus RTU Overview

The Modbus RTU protocol uses packets (messages made up of multiple sections) to communicate and transfer data between devices on the network. The general format of these packets is as follows:

1) Modbus Address (one byte) – the address of the specific device on the bus. (Labeled on the sensors as #1, #2, #3, etc.)
2) Function Code (one byte) – the action to be carried out by the slave device.
3) Data (multi-byte) – the payload of the function code being sent.
4) CRC (two bytes) – cyclic redundancy check; a 16-bit data integrity check calculated over the other byes in the packet.

3.3 Modbus Tables

The most recent sensor readings are stored in memory registers, read using a Modbus command. Angle and temperature readings are available in processed or precursor formats. Register addresses and formats are described in Table 4.

Table 5 shows device control addresses. Any nonzero value written to the trigger address initiates a measurement cycle, updating the angle and temperature measurement registers. Any anomalies detected during the most recent measurement cycle produce a nonzero error code. Refer to Appendix C.2 for an explanation of these codes.

The flash password prevents unintended writes to the nonvolatile memory in Table 6 and the preprogrammed device information in Table 7. Contact Geokon for instructions.

<table>
<tr><th>Register Address</th><th>Byte</th><th>Word</th><th>Parameter</th><th>Units</th><th>Type</th><th>Access</th></tr>
<tr><td rowspan="2">0x100</td><td>0</td><td rowspan="2">LSW</td><td rowspan="4">A-Axis</td><td rowspan="4">degrees</td><td rowspan="4">float</td><td rowspan="24">RO</td></tr>
<tr><td>1</td></tr>
<tr><td rowspan="2">0x101</td><td>2</td><td rowspan="2">MSW</td></tr>
<tr><td>3</td></tr>
<tr><td rowspan="2">0x102</td><td>4</td><td rowspan="2">LSW</td><td rowspan="4">B-Axis</td><td rowspan="4">degrees</td><td rowspan="4">float</td></tr>
<tr><td>5</td></tr>
<tr><td rowspan="2">0x103</td><td>6</td><td rowspan="2">MSW</td></tr>
<tr><td>7</td></tr>
<tr><td rowspan="2">0x106</td><td>12</td><td rowspan="2">LSW</td><td rowspan="4">Temperature</td><td rowspan="4">°C</td><td rowspan="4">float</td></tr>
<tr><td>13</td></tr>
<tr><td rowspan="2">0x107</td><td>14</td><td rowspan="2">MSW</td></tr>
<tr><td>15</td></tr>
<tr><td rowspan="2">0x108</td><td>16</td><td rowspan="2">LSW</td><td rowspan="4">Uncorrected A-Axis</td><td rowspan="4">degrees</td><td rowspan="4">float</td></tr>
<tr><td>17</td></tr>
<tr><td rowspan="2">0x109</td><td>18</td><td rowspan="2">MSW</td></tr>
<tr><td>19</td></tr>
<tr><td rowspan="2">0x10A</td><td>20</td><td rowspan="2">LSW</td><td rowspan="4">Uncorrected B-Axis</td><td rowspan="4">degrees</td><td rowspan="4">float</td></tr>
<tr><td>21</td></tr>
<tr><td rowspan="2">0x10B</td><td>22</td><td rowspan="2">MSW</td></tr>
<tr><td>23</td></tr>
<tr><td rowspan="2">0x10E</td><td>28</td><td rowspan="2">LSW</td><td rowspan="2">Thermistor ADC</td><td rowspan="2">N/A</td><td rowspan="2">uint16</td></tr>
<tr><td>29</td></tr>
<tr><td rowspan="2">0x117</td><td>46</td><td rowspan="2"></td><td rowspan="2">Error Code</td><td rowspan="2">N/A</td><td rowspan="2">uint16</td></tr>
<tr><td>47</td></tr>
</table>

Table 4 - Register Addresses and Formats

<table>
<tr><th>Register Address</th><th>Byte</th><th>Word</th><th>Parameter</th><th>Units</th><th>Type</th><th>Access</th></tr>
<tr><td rowspan="2">0x118</td><td>48</td><td rowspan="2"></td><td rowspan="2">Trigger</td><td rowspan="2">N/A</td><td rowspan="2">uint16</td><td rowspan="8">RW</td></tr>
<tr><td>49</td></tr>
<tr><td rowspan="2">0x119</td><td>50</td><td rowspan="2">LSW</td><td rowspan="4">Password</td><td rowspan="4">N/A</td><td rowspan="4">uint32</td></tr>
<tr><td>51</td></tr>
<tr><td rowspan="2">0x11A</td><td>52</td><td rowspan="2">MSW</td></tr>
<tr><td>53</td></tr>
<tr><td rowspan="2">0x11B</td><td>54</td><td rowspan="2"></td><td rowspan="2">Measure Cycle</td><td rowspan="2">N/A</td><td rowspan="2">uint16</td></tr>
<tr><td>55</td></tr>
</table>

Table 5 - Device Control Addresses

Register Address	Byte	Word	Parameter	Units	Type	Access
0x200	0		Drop Address	N/A	uint16	RO
	1					
0x201	2		Sensor Type	N/A	string	
	3					
0x202	4					
	5					
0x203	6					
	7					
0x204	8					
	9					
0x205	10					
	11					
0x206	12					
	13					
0x207	14					
	15					
0x208	16					
	17					
0x209	18	LSW	Serial Number	N/A	uint32	
	19					
0x20A	20	MSW				
	21					
0x20B	22		Software Version	N/A	uint16	
	23					
0x20C	24		Hardware Version	N/A	uint16	
	25					

Table 6 - Nonvolatile Memory

Register Address	Byte	Word	Parameter	Units	Type	Access
0x20D	26	LSW	A Offset	degrees	float	RO
	27					
0x20E	28	MSW				
	29					
0x20F	30	LSW	B Offset	degrees	float	
	31					
0x210	32	MSW				
	33					
0x213	38	LSW	A Gage Factor	degrees/ degree	float	
	39					
0x214	40	MSW				
	41					
0x215	42	LSW	B Gage Factor	degrees/ degree	float	
	43					
0x216	44	MSW				
	45					

Table 7 - Preprogrammed Device Information

4. DATA REDUCTION

4.1 Inclination Calculation

The output of the 6150E Inclinometer Sensor is angle of inclination. The standard Sensor has a full range of approximately ±15°.

Each Sensor is provided with a unique Gage Factor (G) that is used to calculate the corrected inclination angle (θ) of the sensor:

$$\theta = G(R)$$

Equation 1 - Corrected Inclination Angle

Where;
θ = Corrected inclination angle of the Sensor
G = Gage Factor
R = Reading from Sensor

To calculate the change in the inclination angle of the Sensor, the following equation is used:

$$\Delta\theta = G(R_1-R_0)$$

Equation 2 - Change in Inclination

Where;
$\Delta\theta$ = Change in the inclination angle of the sensor
G = Gage Factor
R_1 = Current reading from Sensor
R_0 = Initial or Zero reading from Sensor

Positive values are tilts in the direction of the arrows A+ and B+

4.2 Deflection Calculation

The lateral displacement (D) of the top of any segment relative to the vertical line running through the bottom of the segment is equal to:

$$D = L\sin\theta$$

Equation 3 - Lateral Displacement

Where;
L = The length of the segment.
θ = Inclination angle of the sensor.

Equation 3 can also be expressed as: $D = L\sin G(R)$

Where;
G = The gage factor.
R = Reading from the sensor.

The profile of the borehole is constructed by using the cumulative sum of these lateral displacements starting with the top segment (L_1). For instance, referring to Figure 12, the total lateral displacement of the top of the upper segment, (which is usually at the surface), from the vertical line drawn through the bottom of the lower segment, (located at the bottom of the borehole), is:

$$D = L_1\sin\theta_1 + L_2\sin\theta_2 + L_3\sin\theta_3 + L_4\sin\theta_4 + L_5\sin\theta_5$$

Equation 4 - Offset Calculation

Therefore;
$D = L_1\sin G(R)_1 + L_2\sin G(R)_2 + L_3\sin G(R)_3 + L_4\sin G(R)_4 + L_5\sin G(R)_5$
and the change in displacement (ΔD) is:

$$\Delta D_n = \sum_{1}^{n} L_n G_n \Delta R_n$$

Equation 5 - Deflection Calculation

Where;
ΔR_1 = Sensor's$_{(1)}$ current reading ($R_{1(1)}$) minus the Sensor's$_{(1)}$ initial, or Zero, reading ($R_{0(1)}$), or ($R_{1(1)}$-$R_{0(1)}$).
ΔR_2 = Sensor's$_{(2)}$ current reading ($R_{1(2)}$) minus Sensor's$_{(2)}$ initial, or Zero, reading ($R_{0(2)}$), or ($R_{1(2)}$-$R_{0(2)}$).

Repeat for all the other sensors in the string.

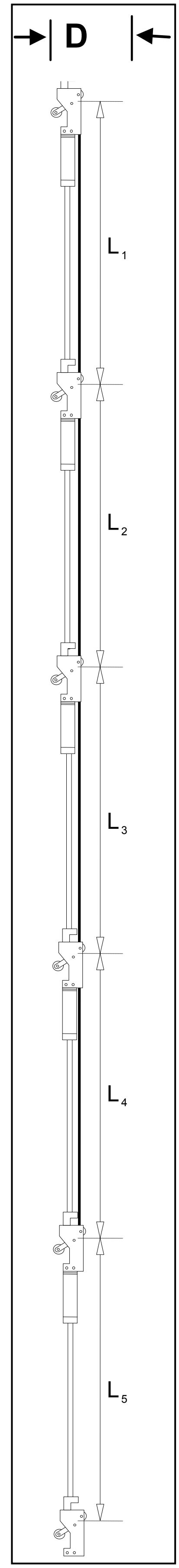

Figure 11 - Deflection Intervals

Although the system is designed for use in continuous segments with pivots, the sensors can be installed without interconnecting tubing in standard, round tubing or pipe using special friction anchors. In those systems, the assumption is made that the measured deflection occurs over the segment length, the midpoint of which is at the sensor location, and that L is the distance between adjacent midpoints.

4.3 Temperature Correction

Although the temperature dependence of the MEMS tilt meter is close to zero, and usually does not require compensation, it sometimes happens that temperature effects can cause real changes of tilt; therefore, each Sensor is equipped with a device for reading the Sensor temperature. This enables temperature-induced changes in inclination to be distinguished from inclination due to other sources. The device provides a digital output proportional to the temperature.

Normally, temperature corrections are not required. An important point to note is that sudden changes in temperature will cause both the structure and the Sensor to undergo transitory physical changes, which will show up in the readings. The Sensor temperature should always be recorded, and efforts should be made to obtain readings when the instrument and structure are at thermal equilibrium. The best time for this tends to be in the late evening or early morning hours.

4.4 Environmental Factors

Since the purpose of the inclinometer installation is to monitor site conditions, factors that may affect these conditions should be observed and recorded. Seemingly minor effects may have real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to, blasting, rainfall, tidal or reservoir levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

5. TROUBLESHOOTING

Maintenance and troubleshooting of Model 6150E In-Place Inclinometers is confined to periodic checks of the cable connections. The sensors are sealed and there are no user serviceable parts.

Should difficulties arise, consult the list of possible solutions shown below. Refer to Appendix C.2 for Modbus error codes. Consult the factory for additional troubleshooting help.

Symptom: Tilt Sensor Readings are Unstable or Fail to Read

- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, and antennas.
- ✓ Check all cable connections, terminals, and plugs.
- ✓ Water may have penetrated the interior of the tilt sensor. There is no remedial action.

APPENDIX A. SPECIFICATIONS

Range	±15° (±54000 arcseconds)
Resolution[1]	±0.0001° (±0.2 arcseconds)
Precision[2]	±0.0018° (±6.5 arcseconds)
Nonlinearity	±0.016° (±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 to +80 °C -40 to 176 °F
Power Supply Voltage	12 V_{DC} ±20%
Operating Current[4]	26 mA ±1 mA
Standby Current	1.2 mA ±0.1 mA
Maximum Supply Current[5]	500 mA
Housing Diameter	32 mm (1.250")
Housing Length	235 mm (9.25")
Weight of 0.5 m Assembly	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
Maximum Recommended String Design Weight	181 kg (400 lb.)
Maximum Test Load	Test to over 900 kg (2000 lb.) without breaking

Table 8 - Model 6150 MEMS Tilt Sensor Specifications

Notes:
[1] 99.0% confidence interval
[2] Includes angle random walk and seismic noise
[3] Per MEMS device datasheet.
[4] Per drop
[5] Full string

APPENDIX B. SAMPLE CALIBRATION SHEETS

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

MEMS Tilt Sensor Calibration

Model Number: 6150E-1

Calibration Date: January 17, 2018

This calibration has been verified/validated as of 02/05/2018

Serial Number: 1745224 Sensor A

Temperature: 23.1

Calibration Instruction: CI-Tiltmeter MEMS Sensor

Technician:

Inclination 1 (degrees)	Reading 1 (degrees)	Inclination 2 (degrees)	Reading 2 (degrees)	Reading Average (degrees)	Calculated Inclination (degrees)	Error (%FS)
-15.0015	-17.0786	-15.0011	-17.0767	-17.0777	-15.0107	-0.03
-8.0005	-10.1660	-8.0005	-10.1658	-10.1659	-7.9985	0.01
-3.9997	-6.2206	-3.9997	-6.2183	-6.2194	-3.9948	0.02
-1.9999	-4.2512	-1.9999	-4.2512	-4.2512	-1.9980	0.01
-0.9994	-3.2615	-0.9994	-3.2611	-3.2613	-0.9938	0.02
0.0000	-2.2805	-0.0003	-2.2792	-2.2798	0.0019	0.01
1.0001	-1.2956	1.0004	-1.2957	-1.2957	1.0004	0.00
1.9995	-0.3074	1.9995	-0.3067	-0.3070	2.0034	0.01
4.0004	1.6596	4.0004	1.6594	1.6595	3.9984	-0.01
8.0015	5.6028	8.0018	5.6037	5.6032	7.9994	-0.01
15.0011	12.4962	15.0008	12.4967	12.4964	14.9926	-0.03

6150E Deflection Gage Factor (G): 1.01451 (degrees/degree)

Deflection = L sin (G * (R_1 - R_0)) (mm or inches)

Tilt = G (R_1 - R_0) (degrees)

Wiring Code: See Manual for further information

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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Figure 12 - Sample Model 6150E Calibration Sheet, Sensor A

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

MEMS Tilt Sensor Calibration

Model Number: 6150E-1

Calibration Date: January 17, 2018

This calibration has been verified/validated as of 02/05/2018

Serial Number: 1745224 Sensor B

Temperature: 23.7

Calibration Instruction: CI-Tiltmeter MEMS Sensor

Technician:

Inclination 1 (degrees)	Reading 1 (degrees)	Inclination 2 (degrees)	Reading 2 (degrees)	Reading Average (degrees)	Calculated Inclination (degrees)	Error (%FS)
-15.0011	-14.4014	-15.0011	-14.4006	-14.4010	-15.0098	-0.03
-8.0001	-7.4959	-8.0005	-7.4963	-7.4961	-7.9986	0.01
-4.0004	-3.5528	-3.9997	-3.5504	-3.5516	-3.9934	0.02
-2.0002	-1.5866	-2.0002	-1.5866	-1.5866	-1.9982	0.01
-0.9994	-0.5982	-1.0001	-0.5994	-0.5988	-0.9952	0.02
-0.0007	0.3814	-0.0003	0.3827	0.3821	0.0008	0.00
1.0001	1.3659	1.0001	1.3659	1.3659	0.9997	0.00
2.0005	2.3530	2.0002	2.3543	2.3537	2.0027	0.01
4.0004	4.3184	4.0001	4.3190	4.3187	3.9980	-0.01
8.0005	8.2601	8.0008	8.2591	8.2596	7.9995	0.00
15.0005	15.1482	15.0008	15.1489	15.1485	14.9945	-0.02

6150E Deflection Gage Factor (G): 1.01539 (degrees/degree)

Deflection = L sin (G * (R_1 - R_0)) (mm or inches)

Tilt = G (R_1 - R_0) (degrees)

Wiring Code: See Manual for further information

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Figure 13 - Sample Model 6150E Calibration Sheet, Sensor B

APPENDIX C. MODBUS ADDRESSABLE SYSTEM

C.1 Modbus Communications Parameters

Port Setting	Required Value
Bits per Second	115,200
Data bits	8
Parity	None
Stop bits	1
Flow Control	None

Table 9 - Modbus Communications Parameters

C.2 Error Codes

Number	Name	Cause	Remedy
2	Temperature Sensor Range	Measured temperature out of range. Thermistor may be too hot or too cold, or it may be damaged.	Use adjacent sensors to validate or estimate temperature.
4	Temperature Sensor Verify	Secondary temperature sensor differed too much from high accuracy primary sensor.	Use adjacent sensors to validate or estimate temperature.
8	System Reset	Unexpected interruption in prior measurement cycle.	Ensure supply voltage is sufficient.

Table 10 - Error Codes

Note: The Sensor stores and transmits errors in binary code to compact the information. Though unlikely, two errors could occur in one measurement cycle. The resulting code will be the sum of the error numbers, e.g., error 4 plus error 8 appears as number 12.

APPENDIX D. PROGRAMMING THE 6150E RS-485 ADDRESSABLE IN-PLACE INCLINOMETER WITH CRBASIC

D.1 Sample CR1000 Program

The following sample program reads one 6160E Sensor string with three Biaxial sensors. The String in this example communicates with the CR1000 through the Control Ports C1 and C2, which are setup as COM1. RS-485 to TTL converter required:

```
Public ErrorCode              'Error Code sent back from ModBus Command
Public A_Axis_Degrees(3)      'A Axis Degree Output
Public B_Axis_Degrees(3)      'B Axis Degree Output
Public Celsius(3)             'Temperature Celsius
Public Count                  'Counter to increment through sensors

'Define Data Tables
DataTable (Test, 1,-1)
  Sample (3,A_Axis_Degrees(),IEEE4) 'Store Degree Reading for A Axis
  Sample (3,B_Axis_Degrees(),IEEE4) 'Store Degree Reading for B Axis
  Sample (3,Celsius(),IEEE4) 'Store Thermistor C Reading
EndTable

'Main Program
BeginProg

  'Open COMport with TTL communications at 115200 baud rate
  SerialOpen (Com1,115200,16,0,50)

  'Read 3 sensors in MEMS String every 10 seconds
  Scan (10,Sec,0,0)

    'Loop through addresses of connected String
    For Count = 1 To 3

      'Reset temporary storage for both Degrees and Temp so not to retain
      'previous reading
      A_Axis_Degrees(Count) = 0
      B_Axis_Degrees(Count) = 0
      Celsius(Count) = 0

      'Flush Serial between readings
      SerialFlush (Com1)

      'Write to register to begin reading MEMS String
'NOTE: ModbusMaster won't send 0x118 unless "&H119" is entered

      ModbusMaster (ErrorCode,Com1,115200,Count,6,1,&H119,1,1,50,0)
```

```
      'Delay after write register
      Delay (1,1,Sec)

      'Use Modbus command to retrieve A Axis and B Axis Degree Readings
     ModbusMaster (ErrorCode,Com1,115200,Count,3,A_Axis_Degrees(Count),&H101,1,1,50,0)
     ModbusMaster (ErrorCode,Com1,115200,Count,3,B_Axis_Degrees(Count),&H103,1,1,50,0)

      'Use Modbus command to retrieve Thermistor Celsius from string
      ModbusMaster (ErrorCode,Com1,115200,Count,3,Celsius(Count),&H107,1,1,550,0)

      'Delay before proceeding to next reading
      Delay (1,1,Sec)

    Next

    'Call Table to store Data
    CallTable Test

  NextScan
EndProg
```

D.2 Sample CR6 Program

The following Sample program reads one 6160E Sensor string with three addressable sensors. The String in this example communicates with the CR6 through the Control Ports C1 and C2, which are setup as ComC1:

```
Public ErrorCode            'Error Code sent back from ModBus Command
Public A_Axis_Degrees(3)    'A Axis Degree Output
Public B_Axis_Degrees(3)    'B Axis Degree Output
Public Celsius(3)           'Temperature Celsius
Public Count                'Counter to increment through sensors

'Define Data Tables
DataTable (Test, 1,-1)
  Sample (3,A_Axis_Degrees(),IEEE4) 'Store Degree Reading for A Axis
  Sample (3,B_Axis_Degrees(),IEEE4) 'Store Degree Reading for B Axis
  Sample (3,Celsius(),IEEE4) 'Store Thermistor C Reading
EndTable

'Main Program
BeginProg

  'Open COMport with RS-485 communications at 115200 baud rate
  SerialOpen (ComC1,115200,16,0,50,3)

  'Read 3 sensors in MEMS String every 10 seconds
  Scan (10,Sec,0,0)

    'Loop through addresses of connected String
    For Count = 1 To 3

      'Reset temporary storage for both Degrees and Temp so not to retain
      'previous reading
      A_Axis_Degrees(Count) = 0
      B_Axis_Degrees(Count) = 0
      Celsius(Count) = 0

      'Flush Serial between readings
      SerialFlush (ComC1)

          'Write to register 0x118 to trigger string
          'NOTE: ModbusMaster won't send 0x118 unless "&H119" is entered
      ModbusMaster (ErrorCode,ComC1,115200,Count,6,1,&H119,1,1,10,0)

      'Delay after write register
      Delay (1,1,Sec)
```

```
    'Use Modbus command to retrieve A Axis and B Axis Degree Readings
   ModbusMaster (ErrorCode,ComC1,115200,Count,3,A_Axis_Degrees(Count),&H101,1,1,10,0)
   ModbusMaster (ErrorCode,ComC1,115200,Count,3,B_Axis_Degrees(Count),&H103,1,1,10,0)

    'Use Modbus command to retrieve Thermistor Celsius from string
    ModbusMaster (ErrorCode,ComC1,115200,Count,3,Celsius(Count),&H107,1,1,10,0)

    'Delay before proceeding to next reading
    Delay (1,1,Sec)

   Next

   'Call Table to store Data
   CallTable Test

  NextScan
EndProg
```

APPENDIX E. DROPS VERSUS LENGTH

The number of allowed drops on a string is inversely proportional to the length of the cable along which they are placed. Longer cable means fewer drops can be supplied reliably by the power source, and shorter cable means more drops can be supported. Additionally the number of drops that a string of a certain length is capable of supporting is also dependent on the bus voltage, which must always remain between 9 and 15 volts DC. With a supply of less than nine volts, the drops on the string may not behave as expected, and with a supply of more than 15 volts, the drops may become damaged due to excessive voltage.

Provided the string is being supplied with 9 to 15 volts DC, the chart shown below may be used to estimate the number of drops that can be supported for a given cable length and supply voltage. This assumes that the drops are spaced evenly along the string. It is important to note that the curves on the chart begin at a 200-meter cable length.

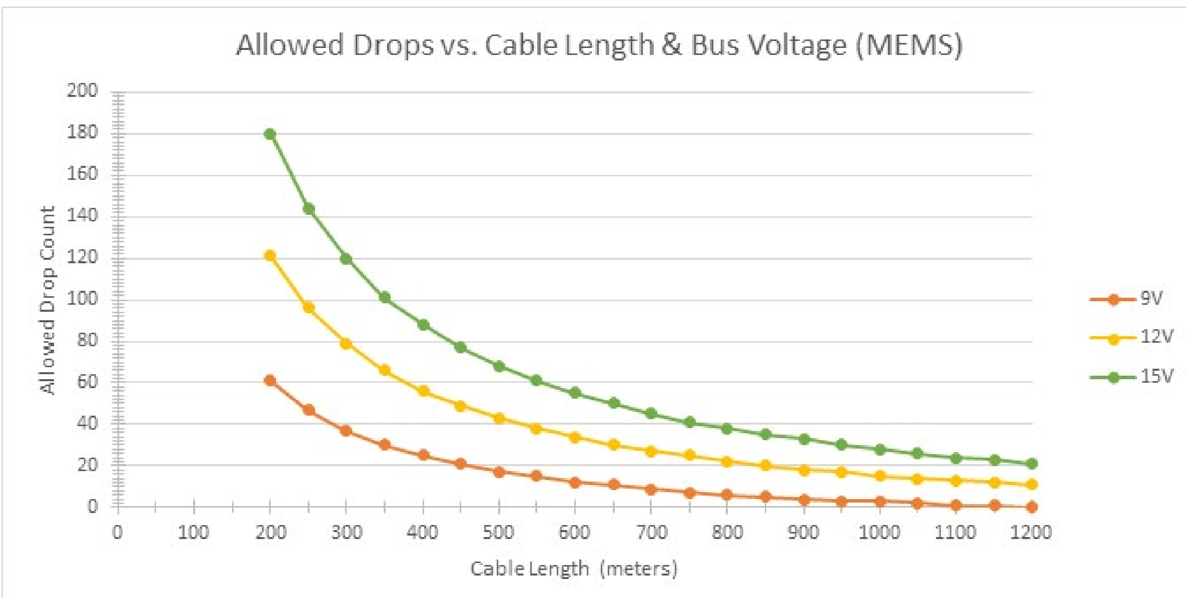

Figure 14 - Allowed Drops Graphic Representation

Note: The number of drops that can be supported on strings shorter than 200 meters must be handled on a case-by-case basis, and may require practical experimentation to obtain a reliable result.