

Model 6140

Vertical In-Place Inclinometer String

Instruction Manual







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1. INTRODUCTION

The operating principle of the GEOKON Model 6140 Vertical In-Place Inclinometer String is the utilization of MEMS (Micro-Electro-Mechanical Systems) tilt sensors to make accurate measurements of inclination over segments of an inclinometer casing.

The Model 6140 Vertical IPI String consists of a string of Biaxial MEMS tilt sensors, installed in rugged engineered polymer housings. One spring-loaded wheel and two fixed wheels allow the string to positively engage the grooves of conventional 70 or 85 mm inclinometer casing maintaining azimuth with depth. The entire string is held in tension by attaching a suspension weight from the bottom-most sensor and hanging the string from the top of the casing using a suspension cable and support bracket.

Sensors in the inclinometer string are mechanically connected with high-strength aircraft cable assemblies, which are free to pivot about the connection point. Sensors are electrically connected via a common bus cable, while the top-most sensor includes a waterproof connector that allows for easy assembly to the chosen readout device (PC, datalogger, SCADA system, etc.) through a customer-specified readout cable.

Each sensor outputs calibrated tilt (angular degrees) and temperature (degree Celsius) readings, which can be easily imported into MS Excel, or any inclinometer visualization software, without the need to convert raw data into engineering units.

The Model 6140 Vertical IPI String uses industry standard Modbus® Remote Terminal Unit (RTU) protocol to communicate. It employs an RS-485 (half duplex) electrical interface, recognized for its prevalence, simplicity, and success as a robust, industrial physical layer. Monitoring can be accomplished using GeoNet Digital High Power and Addressable Loggers, the Model 8020-38 Addressable Bus Converter, Model 8600 Series Dataloggers, Campbell Scientific Dataloggers, or any other device capable of operating as a Modbus RTU client and having an RS-485 port.

For strings of 50 sensors or more, the use of a Model 6140-HOIST Installation/Removal Hoist should be considered. For more information, see Appendix F.

2. INSTALLATION



For a visual demonstration watch the Model 6140 Installation Video.

2.1 CABLE CONNECTIONS

When making cable connections, line up the orientation dot on the outside of the male connector with the two orientation dots on the outside of the female connector (Figure 1). This will ensure the pins and receptacles of the connectors align correctly. To prevent water entry, be sure to push the connectors together until they are fully mated (Figure 2). For additional security, GEOKON recommends taping the connectors together with electrical or black mastic tape.

Note: To facilitate mating, the male connectors have dielectric grease applied. Do not remove this grease.

Caution! Care should be taken to avoid cutting or damaging the cable jacket, which could introduce moisture into the interior of the string, thereby causing irreparable damage to the sensors.



FIGURE 1: Cable Connection Detail



FIGURE 2: Connected Cables

2.2 PRELIMINARY TESTS

Prior to installation, check the sensors for proper operation by completing the steps below.

For strings containing fewer than 100 sensors, skip to Step 4.

- 1. Place the string sections in the correct order by referring to the labels on the shipping cartons. Do not remove from the cartons.
- Connect the string sections together by plugging the male cable connector of one section into the female connector of the next. Connectors are marked with color-coded tape between each section. Shipping cartons are labeled in order of sequence and by string identification if applicable. (See Section 2.1 for cable connection details.)
- 3. Repeat this process until the entire string is connected. The aircraft suspension cable does not need to be connected at this time.
- 4. Plug the male cable connector of the top-most sensor of the string into the female connector of the readout cable.
- 5. Connect the IPI string to a datalogger or PC (Refer to Section 2.6 for details.)
- Tilting the shipping carton from one side to another should yield increasing or decreasing readings for all sensors. The temperature indicated on the readout should be close to ambient. Repeat this process with the remaining shipping cartons. If any of these preliminary tests fail, refer to Section 6 for troubleshooting.

Once the preliminary tests are complete, disconnect the string from the readout device and disconnect the string sections from each other (if applicable). When disconnecting, do not pull by the cable, grip the connectors and pull apart carefully.

2.3 CONNECT THE SUSPENSION WEIGHT

1. Remove the locking pin from the suspension weight by depressing the barb and pulling on the ring.



FIGURE 3: Locking Pin Details

2. Retract the spring sleeve on the suspension weight.



FIGURE 4: Retract the Spring Sleeve

3. Mate the ball stud of the terminal sensor to the receiver on the weight, then release the spring sleeve.



FIGURE 5: Capture the Ball Stud

4. Reinsert the locking pin to prevent the sleeve from accidentally retracting during use.



FIGURE 6: Completed Connection

2.4 SENSOR ORIENTATION

All sensors should be oriented in the same direction when installed in the casing. The MEMS device monitors both A and B directions (Figure 7). The A+ and A- directions face the sensor wheels and are marked on the sensor housing. The B+ direction is 90 degrees clockwise from the A+ direction, as viewed from above.

Point the A+ direction in the same direction as the anticipated movement, e.g., towards the excavation being monitored or downslope for slope evaluation applications.

FIGURE 7: A & B Directions

2.5 INSTALLING THE SENSORS IN THE CASING

GEOKON recommends the height of the top of the casing from ground level be no higher than 0.5 meters (20 inches). This facilitates an easier install with less potential for twisting of the signal cable and sensors.

GEOKON also recommends the use of the Model 6140-HOIST Installation/Removal Hoist to support strings of 50 sensors or more (see Appendix F). The weight of the string will increase as more string sections are installed into the casing.

Important! Sensors must be held vertically above the casing so the weight of the string is placed on the aircraft cable. Hold the string by the sensors, not by the cable. Failure to do so will add stress to the signal cable and may damage the entire string (see Figure 8).



FIGURE 8: Sensor Orientation

- 1. Insert the suspension weight into the casing. Install the sensors directly from the shipping carton into the casing according to the following steps.
- 2. Insert the bottom sensor, make sure to position all three wheels of the sensor in the grooves of the casing. The sensor should be oriented in the casing as described in Section 2.4
- 3. Install the next sensor of the string into the borehole, and each sensor thereafter, as previously described, until the topmost sensor of the string is reached.
- 4. Insert the sensor hold into the casing, then insert top sensor into the holder.



FIGURE 9: Sensor Hold

For strings containing less than 100 sensors, skip to Step 6.

- 5. Connect the next section of the string to the section already in the borehole as follows:
 - a. Using the supplied screwdriver, remove the screw and washer holding the aircraft cable to the top sensor of the current string section.



FIGURE 10: Remove Screw

b. Take the aircraft cable eyelet from the bottom sensor of the next string section and arrange over the existing eyelet.



FIGURE 11: Arrange Eyelet from the Next String Section Over Existing Eyelet

c. Secure both eyelets to the top sensor by reinstalling the screw and washer. Figure 12 shows the completed connection.



FIGURE 12: Secure Aircraft Cable Eyelets, Completed Aircraft Cable Connection

- d. Mate the male and female cable connectors (matching color-to-color) of the two string sections. (See Section 2.1 for cable connection details.)
- e. Remove the sensor hold from the casing.
- f. Install the next section of the string into the borehole, and each section thereafter, as previously described, until the topmost sensor of the string is reached.
- g. Insert the sensor hold into the casing, then insert the top sensor into the holder.
- 6. Plug the male cable connector of the top sensor into the female connector of the readout cable. (See Section 2.1 for cable connection details.)
- 7. Connect the aircraft cable from the top sensor to the eye bolt on the bottom of the suspension bracket using the quick link connector.



FIGURE 13: Suspension Bracket Attachment

- 8. Remove the sensor hold from the casing and install the top sensor into the borehole.
- 9. Position the suspension bracket on top of the casing.

Note: In order for the suspension bracket to be properly seated on the casing, the top rim of the casing must be clean and flat.

- 10. Connect the readout cable to a datalogger or PC (Refer to Section 2.6 for details).
- 11. Readings may be taken immediately after installation; however, GEOKON recommends evaluating the data over a period of time to determine when the string has sufficiently stabilized to collect an accurate zero reading.

2.6 READOUT

If your datalogger has built-in RS-485 communications, connect the readout cable using the wiring diagram below. (The datalogger must have the appropriate port available.)

Datalogger	Sensor Conductor Color
485+	WHITE
485-	GREEN
12V	RED
GND	BLACK
SHD	BARE

TABLE 1: Digital High Power or Addressable (RS-485) Logger to Sensor Wiring Table

If your datalogger does not have built-in RS-485 communications, the converter below can be utilized.

MODEL 8020-38 ADDRESSABLE BUS CONVERTER

Model 8020-38 Addressable Bus Converter (Figure 14) can be utilized in a string with **50 sensors or less**. The Model 8020-38 allows addressable strings to be connected to personal computers, readouts, dataloggers, and programmable logic controllers. The converter acts as a bridge using the TTL or USB protocols between readers and the GEOKON RS-485-enabled sensor strings.



FIGURE 14: Model 8020-38 RS-485 to TTL/USB Converter

If utilizing a Model 8020-38 to connect the 6140 string to a readout, wire the connections as shown. (The dataloggers must have the appropriate port available.)

Datalogger Connection	Conductor Color	8020-38 Connection
/+	RED	12 V (IN)
X	WHITE	TX (IN)
XX	GREEN	RX (OUT)
GND	BLACK	GND
SHD	BARE	SHIELD

8020-38	Sensor
Connection	Conductor Color
12 V (OUT)	RED
485+	WHITE
485-	GREEN
GND	BLACK
SHIELD	BARE



TABLE 2: Datalogger to Model 8020-38 Wiring

ing TABLE 3: Model 8020-38 to Sensor Wiring

For more information, please refer to the Model 8020-38 Instruction Manual.

2.7 FOUR-PIN WATERPROOF CONNECTOR

The pinouts for the four-pin male and female connectors are shown below; the function of each wire is detailed in Table 4 below.



FIGURE 15: Male Waterproof Connector



FIGURE 16: 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

TABLE 4: Four-Pin Wiring Chart

3. MODBUS RTU PROTOCOL

3.1 INTRODUCTION TO MODBUS

Model 6140 inclinometers use the industry standard Modbus Remote Terminal Unit (RTU) protocol to communicate with the chosen readout method. Each 6140 is a Modbus server. As the name suggests, Modbus was designed to work on what is known as a **bus network**, meaning that every device receives every message on the bus. Model 6140 inclinometers use the RS-485 electrical interface because of its prevalence, simplicity, and success as a robust, industrial physical layer.

More information about Modbus can be found at the following website:

http://www.modbus.org/specs.php

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 server device.
- 3. Data (multi-byte) The payload of the function code being sent.
- 4. Cyclic Redundancy Check or CRC (two bytes): A 16-bit data integrity check calculated over the other bytes 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 5.

Note: GEOKON stores the gauge factor and offsets in the sensor during the factory calibration process. Therefore, the outputs of the A and B axes are both corrected values.

Table 6 shows device control addresses. Any non-zero 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 non-zero error code. Refer to Appendix D for an explanation of these codes.

Register Address	Byte	Word	Parameter	Units	Туре	Access
0x100	0 1	LSW	A Avia	dograaa	fleet	
0x101	2		A-AXIS	uegrees	nuar	
0x102	4	LSW	D Auia	4	flaat	
0x103	6 7	MSW	B-AXIS	degrees	noat	
0x106	12 13	LSW	т.,	00	a .	
0x107	14 15	MSW	Iemperature	°С	float	RO
0x108	16 17	LSW	Uncorrected	degrees	fleet	
0x109	18 19	MSW	A-Axis	uegrees	nuar	
0x10A	20 21	LSW	Uncorrected	dograaa	floot	
0x10B	22 23	MSW	B-Axis	uegrees	liuat	
0x117	46 47		Error Code	N/A	uint16	

TABLE 5: Register Addresses and Formats

Register Address	Byte	Word	Parameter	Units	Туре	Access
0110	48		Triggor		uin+16	D\\/
UX118	49		пцун	N/A	unitio	11VV

TABLE 6: Device Control Address

Register Address	Byte	Word	Parameter	Units	Туре	Access
0x200	0		Drop Address	N/A	uint16	
	1					
0x201	2					
	3	_				
0x202	4					
	5					
0x203	6	_				
	/	_				
0x204	8					
	10		Sensor Type	N/A	string	
0x205	10	_				
0,,206	12					DO
UX206	13					RU
0x207	14					
	15					
0v208	16					
07200	17					
0x209	18	lsw				
19	19		Serial Number	N/A	uint32	
0x20A	20	MSW			unitoz	
	21					
0x20B	22	_	Software Version	N/A	uint16	
	23	_				
0x20C	24	_	Hardware Version	N/A	uint16	
	25					

TABLE 7: Non-Volatile Memory

4.1 COMPATIBLE DATALOGGERS

GEOKON can provide several datalogger options. Devices compatible with this product are listed below. For further details and instruction consult the corresponding Manual(s) at <u>geokon.com/</u><u>Dataloggers</u>.



DATALOGGERS:

8600 Series

The MICRO-6000 Datalogger is designed to support the reading of a large number of GEOKON instruments for various unattended data collection applications through the use of GEOKON Model 8032 Multiplexers. Weatherproof packaging allows the unit to be installed in field environments where inhospitable conditions prevail. The Nema 4X enclosure also has a provision for locking to limit access to responsible field personnel.

GeoNet Series

The GeoNet series is designed to collect and transfer data from vibrating wire, RS-485, and analog instruments. GeoNet offers a wide range of telemetry options, including LoRa, cellular, Wi-fi, satellite, and local. Loggers can work together to operate in a network configuration, or be used separately as standalone units. GeoNet devices arrive from the factory ready for deployment and may commence with data acquisition in minutes.

Data is transferred to a secure cloud-based storage platform where it can be accessed through the GEOKON OpenAPI. Industry leading data visualization software, such as the free GEOKON Agent Software, can be used with the OpenAPI for data viewing and reporting. Dataloggers without network capabilities are also available.

5. DATA REDUCTION

5.1 INCLINATION CALCULATION

The 6140 Inclinometer Sensor outputs simple engineering units, degrees of tilt, which have been calibrated for both angular and temperature effects. Because of this, no further correction to the outputted data is required.

5.2 DISPLACEMENT CALCULATION

There are two equation sets available that calculate sensor displacement: **Lateral Sensor Displacement** and the **Simplified Lateral Sensor Displacement**. Review the descriptions below and perform the preferred calculation method. In both cases initial readings must be taken after installation to serve as a baseline. Initial measurements are then used as a reference and subtracted from any subsequent measurements in order to determine movement or change in a borehole position at various time intervals.

LATERAL SENSOR DISPLACEMENT CALCULATION

Developed specifically for the 6140 assembly, the equation below takes into account the angles of sensors at either end of any given gauge length. Utilizing this method gives the most accurate results and is recommended by GEOKON.

The relative lateral displacement (\mathbf{D}_{rel}) of each measuring point is found using the following equation:

$$D_{1rel} = Lsin\left(\frac{\theta_1 + \theta_2}{2}\right)$$

EQUATION 1: Relative Lateral Displacement

Where:

L = Gauge length (i.e. sensor spacing)

 θ = Inclination angle of the sensor, as described above

The profile of the borehole is approximated by accumulating these relative lateral displacements at each measuring point, starting with the bottom sensor. Refer to Figure 17 below.

The absolute lateral displacement (D_{abs}) at each measuring point is found using the following equation:

$$D_{3abs} = L \sin\left(\frac{\theta_1 + \theta_2}{2}\right) + L \sin\left(\frac{\theta_2 + \theta_3}{2}\right) + L \sin\left(\frac{\theta_3 + \theta_4}{2}\right)$$

OR

$$D_{3abs} = D_{1rel} + D_{2rel} + D_{3rel}$$

EQUATION 2: Absolute Lateral Displacement



FIGURE 17: Displacement Intervals

SIMPLIFIED LATERAL SENSOR DISPLACEMENT CALCULATION

The Simplified Lateral Sensor Displacement equation can be used as an alternative to Equation 1. This method will introduce a small amount of error.

The relative lateral displacement (\mathbf{D}_{rel}) of each measurement point is found using the following equation:

$$D_{1rel} = L \sin \theta_1$$

EQUATION 3: Simplified Relative Lateral Displacement

Where:

- L = Gauge length (i.e. sensor spacing)
- θ = Inclination angle of the sensor, as described above

The profile of the borehole is approximated by accumulating these relative lateral displacements at each measurement point, starting with the bottom sensor. Refer to Figure 17 above.

With this method, the topmost sensor of the string will be ignored and is not factored into the equation. The absolute lateral displacement (D_{abs}) at each measuring point is found using the following equation:

 $D_{3abs} = L\sin\theta_1 + L\sin\theta_2 + L\sin\theta_3$

OR

 $D_{3abs} = D_{1rel} + D_{2rel} + D_{3rel}$

EQUATION 4: Simplified Absolute Lateral Displacement

5.3 TEMPERATURE EFFECTS

In a given installation, temperature effects can cause real changes of tilt; therefore, each sensor is equipped with a device for measuring the sensor temperature. This enables temperature-induced changes in inclination to be distinguished from inclination due to other sources.

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.

5.4 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.

6. TROUBLESHOOTING



Maintenance and troubleshooting of Model 6140 Vertical IPI String 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. Visit <u>geokon.com/</u><u>Technical-Support</u> 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 or connectors. Contact GEOKON.

APPENDIX A. SPECIFICATIONS

A.1 MODEL 6140 VERTICAL IN-PLACE INCLINOMETER STRI
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Range ¹	±90°
Resolution ²	0.00025° (0.004 mm/m)
Precision ³	±0.0075° (±0.13 mm/m)
Nonlinearity	±0.005° across ±30° range (±0.09 mm/m)
Temperature Dependent Uncertainty	±0.001°/°C across ±5° angular range (±0.016 mm/m) ±0.0016°/°C across ±15° angular range (±0.026 mm/m) ±0.0026°/°C across ±30° angular range (±0.042 mm/m)
Operating Temperature	-40 °C to 65 °C (-40 °F to 149 °F)
Power Supply Voltage	12 VDC (+0%/-10%) for up to 250 sensors 15 VDC (+0%/-10%) for 251 to 500 sensors
Operating Current ⁴	20 mA ±1 mA Peak 5 mA Average
Standby Current ⁴	2 mA ±0.1 mA
Maximum Sensors per String ⁵	500
Datalogger Sensor Limits	Refer to the applicable datalogger manual
Maximum String Length	250 m (1,000 ft.)
Standard Sensor Length	0.5 m (2 ft)
Weight, Sensor	0.36 kg (0.8 lb)
Weight, Suspension Weight	1.6 kg (3.6 lb)
Materials	316 Stainless Steel, Engineered Polymer
Interface	RS-485
Protocol	MODBUS
Baud Rate	115,200 bps
Acquisition Cycle Time ⁶	350 ms
Temperature Accuracy	±0.5 °C
Ingress Protection	IP68 to 3 MPa (300 m head water)
Electrical Cable	Four Conductor, Foil shield, Polyurethane jacket, nominal OD = 7.9 mm

TABLE 8: Model 6140 Inclinometer Specifications

¹ Calibrated Range: ±30°

 2 99% confidence interval (i.e. 99 out of 100 individual readings fall within this tolerance).

³ Includes random walk (changes between consecutive readings that have no discernible cause) and seismic noise during testing.

⁴ Operating and standby current are for each individual sensor in a string.

⁵ Dependant on datalogger used. Consult datalogger manufacturer.

⁶ The time from a trigger write to when a new value is available for reading.

A.2 PARTS LIST

6140-1	Vertical IPI String Top, with readout cable connector
6140-0.5M	Vertical IPI String Middle, 0.5 m spacing
6140-2FT	Vertical IPI String Middle, 2 ft. spacing
6140-2	Vertical IPI String Bottom, with Suspension Weight connector
6140-5-1	Vertical IPI String Connector Bottom, 0.5 m spacing, for strings with >100 sensors, 1 required for every 100 sensors
6140-5-2	Vertical IPI String Connector Bottom, 2 ft. spacing, for strings with >100 sensors, 1 required for every 100 sensors
6140-3-1	Suspension Cable, <5 m length
6140-3-2	Suspension Cable, 6 to 10 m length
6140-3-3	Suspension Cable, 10 to 20 m length
6140-4	Suspension Weight
6140-6	Sensor Hold
6140-HOIST	Installation/Removal Hoist
6140-REEL-E	Reel for Model 6140-HOIST, English
6140-REEL-M	Ree I for Model 6140-HOIST, Metric
6180-2	Suspension Bracket
6180-3-1	Readout Cable, <15 m length bare leads
6180-3-2	Readout Cable, 16 to 30 m length, bare leads
6180-3V	Readout Cable, >30 m length, bare leads

TABLE 9: Model 6140 Parts List



FIGURE 18: Model 6140-1 Vertical IPI String Top, with readout cable connector



FIGURE 19: Model 6140-0.5M / 6140-2FT Vertical IPI String Middle, 0.5 m/2 ft. spacing



FIGURE 20: Model 6140-2 Vertical IPI String Bottom, with Model 6140-4 Suspension Weight attached



FIGURE 21: Model 6140-5-1, -2 Vertical IPI String Connector Bottom, 0.5 m/2 ft. spacing, for strings with >100 sensors, 1 required for every 100 sensors



FIGURE 22: Model 6140-3-1, -2, -3 Suspension Cable



FIGURE 23: Model 6140-6 Sensor Hold



FIGURE 24: Model 6180-2 Suspension Bracket



FIGURE 25: Model 6180-3-1, -3-2 Topside Readout Cable/Bare Leads, < 50FT



FIGURE 26: Model 6180-3V Topside Readout Cable/Bare Leads, > 100FT



B.1 MODEL 6140 VERTICAL IPI STRING STANDARD ASSEMBLY

FIGURE 27: Standard Assembly Diagram

B.2 MODEL 6140 VERTICAL IPI STRING EXTENSION ASSEMBLY

Strings can be extended as shown in the diagram below. For more information, contact GEOKON.



FIGURE 28: Extension Assembly Diagram

GEOKON 。			
	Calibration Re	port	
Model Number:	S-6140-1-CAL	Calibration Date:	December 20, 2023
Serial Number:	2330066 AAxisAngular	Temperature:	22.1 °C
Calibration Instruction: <u>CI-M</u>	EMS PCBA (IPI_TILT, Triaxial)	Technician:	Rhidd
			1 y civin
Reference Average (Angular Degrees)	Sensor Output (Angular Degrees)	E (Angula	rror Ir Degrees)
-30.0010	-30.0014	-0.	.0003
-20.0004	-19.9986	0.	0018
-14.9999	-15.0019	-0.	.0020
-10.0001	-9.9986	0.	0015
-4.9996	-5.0011	-0.	.0016
0.0002	-0.0011	-0.	.0014
5.0000	5.0020	0.	0020
9.9998	10.0015	0.	0017
15.0003	14.9989	-0.	.0015
20.0005	20.0000	-0.	.0005
30.0005	30.0007	0.	0002
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. This report shall not be reproduced except in full without written permission of Geokon.			

FIGURE 29: A Axis Angular Calibration Report

GEO	KON。			
		Calibration Re	eport	
	Model Number:	S-6140-1-CAL	Calibration Date:I	December 20, 2023
	Serial Number:	2330066 AAxisTemperature	Temperature:	21.2 °C
Ca	alibration Instruction: <u>CI-M</u>	IEMS PCBA (IPI_TILT, Triaxial)	Technician:	Obellavaree
	SetPoint	Sensor Output	Error	
1000	(Degrees Celsius)	(Angular Degrees)	(Angular Degrees/De	gree Celsius)
	-35	0.1596	0.0000	
	-20	0.1586	0.0000	
	-5	0.1611	-0.0001	
	10	0.1588	0.0000	
	25	0.1594	0.0000	
	40	0.1632	0.0003	
	55	0.1565	-0.0001	
	70	0.1605	0.0000	
	Th The above named instrument has b This rep	above instrument was found to be in tolerance in a een calibrated by comparison with standards tracea ort shall not be reproduced except in full without w	Il operating ranges. ble to the NIST, in compliance with ANSI ritten permission of Geokon.	Z540-1.

FIGURE 30: A Axis Temperature Calibration Report

	<u>Calibration Re</u>	port
Model Number:	S-6140-1-CAL	Calibration Date: December 20, 2023
Serial Number:	2330066 BAxisAngular	Temperature: 22.0
Calibration Instruction: <u>CI-1</u>	MEMS PCBA (IPI_TILT, Triaxial)	Technician: Rfrida
Reference Average	Sensor Output	Error
(Angular Degrees)	(Angular Degrees)	(Angular Degrees)
-30.0010	-30.0008	0.0002
-20.0004	-20.0011	-0.0007
-14.9999	-15.0001	-0.0003
-10.0001	-9.9993	0.0007
-4.9996	-4.9984	0.0012
0.0002	-0.0004	-0.0006
5.0000	4.9996	-0.0004
9.9998	9.9987	-0.0012
15.0003	15.0012	0.0009
20.0005	20.0009	0.0004
30.0005	30.0003	-0.0002
30.0005	30.0003	-0.0002
 The above named instrument has	he above instrument was found to be in tolerance in a been calibrated by comparison with standards traceal	II operating ranges. Je to the NIST, in compliance with ANSI Z540-1.

FIGURE 31: B Axis Angular Calibration Report

CEOVON				
GEOKON.				
	Calibration Re	eport		
Model Number:	S-6140-1-CAL	Calibration Date:	December 20, 2023	
Serial Number:2	330066 BAxisTemperature	Temperature:	21.2	°C
CLM	EMS PCBA (IPL TILT Triavial)			
Calibration Instruction:		Technician:	V.OBalla. n	10
		1	renau	hee
SetPoint (Degrees Celsius)	Sensor Output	(Angular Degrees	Degree Celsius)	
-35	-0 3092	(Angular Degrees)	00	
-20	-0.3095	0.00	00	
-5	-0.3089	0.00	00	
10	-0.3089	0.00	00	
25	-0.3092	0.00	00	
40	-0.3082	0.00	01	
55	-0.3098	0.00	00	
70	-0.3091	0.00	00	
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. This report shall not be reproduced except in full without written permission of Geokon.				

FIGURE 32: B Axis Temperature Calibration Report

D.1 MODBUS COMMUNICATIONS PARAMETERS

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

TABLE 10: Modbus Communications Parameters

D.2 ERROR CODES

Number	Name	Cause	Remedy
2	Temperature Sensor Range	Measured temperature out of range. Thermistor may be too hot, too cold, or 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 11: Error Codes

Note: The sensor stores the errors as a bit field to compact the information. If two errors 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.

SAMPLE CR1000 PROGRAM E.1

The following sample program reads one 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. A RS-485 to TTL converter required.

Public ErrorCode Public A_Axis_Degrees(3) Public B_Axis_Degrees(3) Public Celsius(3) Public Count

'Error Code sent back from ModBus Command 'A Axis Degree Output 'B Axis Degree Output Temperature Celsius 'Counter to increment through sensors

'Define Data Tables

Sample (3,A_Axis_Degrees(),IEEE4) Sample (3,B_Axis_Degrees(),IEEE4) Sample (3,Celsius(),IEEE4) EndTable	'Store Degree Reading for A Axis 'Store Degree Reading for B Axis 'Store Thermistor C Reading
Endlable	

'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 \dot{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

E.2 SAMPLE CR6 PROGRAM

The following sample program reads one 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. The CR6 has built in RS 485 capability, so no RS-485 to TTL converter is required.

Public ErrorCode Public A_Axis_Degrees(3) Public B_Axis_Degrees(3) Public Celsius(3) **Public Count**

'Error Code sent back from ModBus Command 'A Axis Degree Output 'B Axis Degree Output 'Temperature Celsius 'Counter to increment through sensors

'Define Data Tables

DataTable(Test, 1, -1) Sample (3,A_Axis_Degrees(),IEEE4) Sample (3,B_Axis_Degrees(),IEEE4) Sample (3,Celsius(),IEEE4) EndTable

'Store Degree Reading for A Axis

'Store Degree Reading for B Axis

'Store Thermistor C Reading

'Main Program

EndProg

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

APPENDIX F. INSTALLATION / REMOVAL HOIST SYSTEM

Model 6140 Vertical In-Place Inclinometer Strings over 50 sensors can become heavy as they are lowered into the casing. Along with casing and site conditions, this weight can increase the difficulty of installation and the risk of sensor damage due to mishandling. The Model 6140-HOIST is designed to facilitate the installation or removal of a string. Regardless of casing and site conditions, GEOKON strongly recommends the use of this hoist for strings exceeding 100 sensors.

The hoist consists of a pulley system, support cable coiled on a reel, a socket adapter set for use with a customer supplied drill, and a handle for optional manual use. Attachment points for the hoist (marked with a yellow tag) are installed on the sensors at the necessary intervals by the factory.

The quantity of support cable reels required will depend on the length of the string. Once the string exceeds 100 sensors, additional reels are generally required for each set of 50 subsequent sensors (Up to 100 sensors = 1 reel, 150 sensors = 2 reels, 200 sensors = 3 reels, etc.). The support cable is typically attached after the first 50 sensors have been installed in the casing. At this point, the support cable is used with the hoist to support the next 50 sensors.



FIGURE 33: Model 6140-HOIST Installation/Removal Hoist

F.1 INSTALLING A STRING USING THE HOIST SYSTEM

- 1. Install the string as indicated in Section 2.5 until the first attachment point, identified with a yellow tag, has been reached.
- 2. Insert the sensor hold into the casing, then insert the tag-marked sensor into the holder.

Note: All other installation steps (sensor cable connection, aircraft cable connection, etc.) must be performed in conjunction with the hoist system process.



FIGURE 34: Marked Sensor Attachment Point

- 3. On the hoist frame, depress the leg locking lever and unfold the legs until they lock in place.
- 4. Position the hoist frame so the pulley is directly above the casing.



FIGURE 35: Model 6140-HOIST Frame

5. Install the socket/adapter (used with a customer supplied drill) or the manual handle onto the winch port of the hoist frame (Figure 36).



FIGURE 36: Drill (Left) or Manual Handle (Right) Installed onto Winch Port

6. Rotate the winch port counterclockwise to unwind a length of support cable off the reel, enough to guide the cable over the pulley and down to the tag-marked sensor.

Important! Hold tension on the cable to prevent it from unraveling at the reel.

7. Lock the cable in place with the center clamp to keep tension on the reel.



FIGURE 37: Support Cable Aligned on Pulley and Secured in Center Clamp

8. Connect the cable to the sensor attachment point using the quick link connector.



FIGURE 38: Support Cable Secured to Attachment Point with Quick Link Connector

9. Release the center clamp.



FIGURE 39: Release the Center Clamp

10. Rotate the winch port clockwise to lift the sensor up slightly and remove the sensor hold.



FIGURE 40: Sensor Lifted off Sensor Hold

11. Rotate the winch port counterclockwise to lower the string into the casing. While lowering, continue to position and install the sensors as described in Section 2.5.

If no additional support cable reels are required, skip to Step 13.

- 12. When the next tag-marked sensor is reached:
 - a. Insert the sensor hold into the casing, then insert the tag-marked sensor into the holder.
 - b. Rotate the reel so the terminating loop pin is visible as shown in Figure 41 and remove the terminating loop from the pin on the outside of the reel.



FIGURE 41: Remove the Terminating Loop

c. Lay the excess support cable along the string and attach it to the sensor cable with wire ties, just above the furthest sensor it can reach.

Important! Do not trim the terminating loop from the support cable. Do not discard the reel. These will facilitate string removal if necessary (See Section F.2).



FIGURE 42: Secure Support Cable to the String

d. Remove the quick-release pin from the winch and remove the empty reel. Remove the guide tube from the reel and **place it inside a new reel**.



FIGURE 43: Remove the Empty Reel and Guide Tube

e. Install the new reel onto the hoist, with the cable hanging over the **top side**. Secure in place with the quick-release pin (Figure 44).



FIGURE 44: Install a new Reel using the Quick-Release Pin

- f. Repeat the procedure from Step 6 for each additional string section.
- 13. When the next tag-marked sensor is reached, insert the sensor hold into the casing, then insert the top sensor into the holder.
- 14. Rotate the reel so the terminating loop pin is visible as shown in Figure 46 and remove the terminating loop of the support cable from the pin on the outside of the reel. There will be excess cable at the top of the string.

Important! Do not trim the terminating loop from the support cable. Do not discard the reel. These will facilitate string removal if necessary (See Section F.2).



FIGURE 45: Remove the Terminating Loop

15. Attach the support cable to the suspension bracket with wire ties.



FIGURE 46: Secure Terminating End to the Suspension Bracket

16. Complete the installation as described in Section 2.5.

F.2 REMOVING A STRING USING THE HOIST SYSTEM

- 1. On the hoist frame, depress the leg locking lever and unfold the legs until locked in place.
- 2. Position the hoist frame with the pulley directly above the casing.
- 3. If not already in place, install an empty reel onto the hoist frame. Insert the guide tube into the reel and secure in the hoist with the quick-release pin.



FIGURE 47: Install an Empty Reel with the Quick-Release Pin

4. Install the socket/adapter (used with a customer supplied drill) or the manual handle onto the winch port of the hoist frame.



FIGURE 48: Drill (Left) or Manual Handle (Right) Installed onto Winch Port

- 5. Cut the wire ties securing the support cable to the suspension bracket or sensor cable.
- 6. Rotate the reel so the terminating loop pin is visible as shown in Figure 49. Guide the support cable over the pulley and insert the terminating loop of the support cable through the slot in the reel and onto the pin on the outside.



FIGURE 49: Support Cable over Pulley (Left) and Terminating Loop Installed on Empty Reel (Right)

- 7. Rotate the winch port clockwise to lift the string up slightly. Remove the suspension bracket or sensor hold from the casing.
- 8. Continue to rotate the winch port clockwise to lift the string from the casing, guiding the sensors out carefully.
- 9. When the first flag-marked sensor is reached, insert the sensor hold into the casing, then insert the sensor into the holder.



FIGURE 50: Marked Sensor Attachment Point

10. Lock the cable in place with the center clamp to keep tension and prevent unraveling at the reel.



FIGURE 51: Support Cable Secured in Center Clamp

- 11. Disconnect the support cable from the sensor attachment point.
- 12. Release the center clamp. Secure the support cable to the reel.



FIGURE 52: Release the Center Clamp (Left) and Secure the Support Cable to the Reel (Right)

- 13. If there are more support cable sections installed, remove the full reel and repeat the procedure from Step 3.
- 14. Once all support cables have been disconnected, remove the rest of the string by hand.

APPENDIX G. SUSPENSION CABLE ADJUSTMENT

The Model 6140-3 Suspension cable is shipped fully assembled to the specified length. The cable length can be shortened if required by following the instructions in this section.

G.1 CONNECTING THE SUSPENSION BRACKET

To ensure the string is installed to the correct depth, sum the length from the bottom of the weight to the tip of the top sensor and subtract this value from the desired string depth (measured from the top of the casing to the bottom of the string assembly); the resulting value is the Suspension Cable Length.

Note: GEOKON suggests suspending the sensor string at least 150 mm (six inches) above the bottom of the casing, to account for debris and settlement.

- 1. Measure the suspension cable out to the calculated length, minus 4.5 inches to account for the connecting clip and suspension bracket.
- 2. Form a loop at the measured location. Lightly secure with one of the supplied cable clamps. Do not fully tighten at this stage.



FIGURE 53: Loop and Clamp

3. Place the supplied thimble into the loop. Tighten the suspension cable to the thimble by sliding the cable clamp to the thimble.



FIGURE 54: Insert and Tighten Thimble in Loop

4. Connect the aircraft cable to the eye bolt on the bottom of the suspension bracket using the quick link connector.



FIGURE 55: Suspension Cable Installed with Quick Link Connector

- Adjust the suspension cable as needed so the distance from the recessed shoulder of the suspension bracket to the tip of the top sensor equals the calculated Suspension Cable Length. Secure the cable clamp fully to a torque specification of approximately 4.5 ft-lbs.
- 6. Secure a second cable clamp approximately 3 inches from the first cable clamp, tightening fully to the torque specification above.



FIGURE 56: Final Adjusted Cable Assembly

7. Secure the loose end of the suspension cable to the main length with tape.



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