Model 6180

Vertical In-Place

Inclinometer System

Instruction Manual

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1. INTRODUCTION

The GEOKON Model 6180 Vertical In-Place Inclinometer (IPI) System enables long-term monitoring of deformations in structures such as dams, embankments, foundation walls, and similar applications. The basic principle of operation uses MEMS accelerometers to measure static tilt at specified depths in a casing installed in the structure being studied. The instrument is designed to be installed in standard grooved inclinometer casing, which is installed in the borehole. Monitoring by the instrument allows for very precise measurement of changes in the borehole profile.

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

The sensors are mechanically joined with quick-connect ball joints, which allow for unimpeded relative movement between sensors and accommodate any spiraling of the casing. Electrically, sensors are connected to each other with four-wire bus cable and molded waterproof connectors.

Each sensor is individually serialized and calibrated. A calibration sheet for each sensor is provided, showing the relationship between sensor output and inclination.

Data is collected by connecting the IPI string to a readout device (PC, datalogger, SCADA system, etc.) via a customer-specified readout cable.

2. INSTALLATION

2.1 PRELIMINARY TESTS

Prior to installation, check the sensors for proper operation. Complete the following steps:

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

2. Starting with the first sensor, connect the sensors by plugging the male connector from the second sensor into the female connector from the first sensor. Proceed in this manner until the full string is connected.
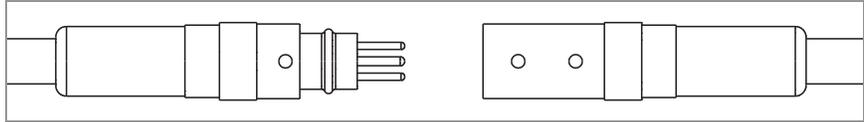
FIGURE 1: *Cable Connection Detail*

> **Caution!** When connecting the sensors, make sure to line up the orientation dot on the outside of the male connector with the two orientation dots on the outside of the female connector. This will ensure the pins and receptacles on the interior of the connectors align correctly. Push the connectors together until they are completely mated.
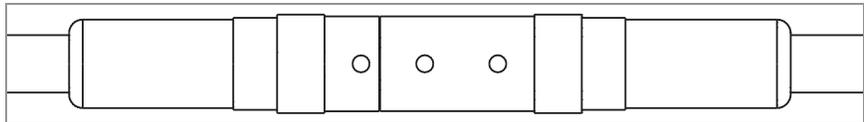
FIGURE 2: *Connected Cables*

3. Connect the completed string to a Model 8020-38 converter, PC, or datalogger (refer to Section 2.6).

4. Hold the first sensor in a vertical position and observe the reading. The tilt sensor must be held steady while taking the reading. The observed reading should be close to the factory vertical reading. Tilting the sensor in a positive direction (A+ or B+, as marked on the sensor) should yield increasing readings. Tilting the sensor 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.

5. Once the preliminary tests are complete, disconnect the string from the readout device and disconnect the sensors from each other.

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

2.2 SAFETY CABLE

GEOKON strongly recommends attaching a safety cable to the bottom-most (terminal) sensor, Model 6180T. This can be used to retrieve the assembly in the event of an accident, and it also can be helpful when lowering the assembly into the casing.

Model 6180-6 safety cable assemblies purchased from GEOKON consist of a customer-specified length of aircraft cable (07-125SS316-E/M) with eye bolt and hex nuts pre-attached for ease of installation, along with all hardware required to anchor the string.

To connect the safety cable to the terminal sensor, complete the following steps:

1. Fasten the upper end of the safety cable to a fixed object, or to something too large to enter the casing, to avoid accidentally dropping the entire cable into the casing.

2. Remove the two hex nuts from the eye bolt.

3. Insert the eye bolt through both connection holes on the terminal sensor.

4. Thread the two nuts back onto the bolt and tighten against one another using two 5/16" crescent wrenches; this will secure the safety cable to the terminal sensor.

The figure below shows a properly connected safety cable.
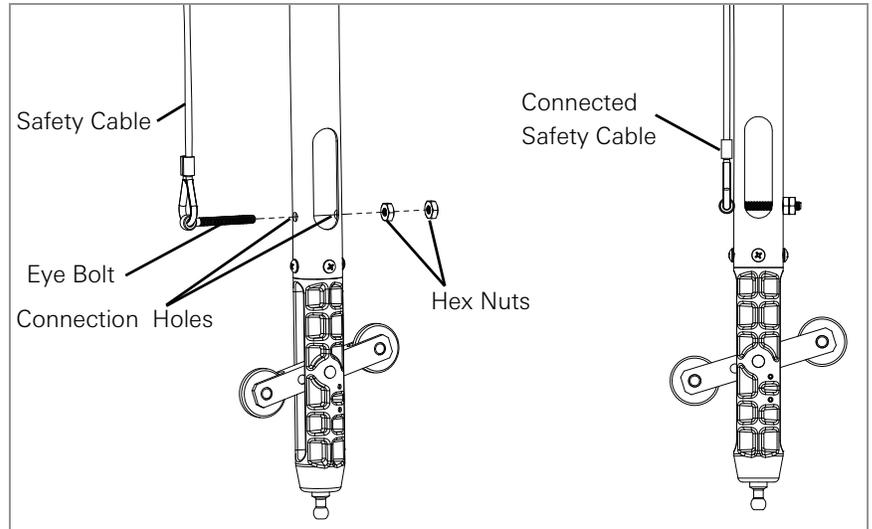
FIGURE 3: *Connecting a Safety Cable*

5. Tie off the top end of the safety cable by attaching it to an appropriate anchor point. Follow the procedure from Section 2.5.1 for proper installation of the cable clamps.

2.3 SENSOR ORIENTATION

All wheel assemblies should be oriented in the same direction when installed in the casing. The wheel assemblies are attached at the factory so the upper wheel is facing the A+ direction of the sensor (as shown in the figure to the left). Axis directions are also physically labeled on each sensor.

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

The MEMS device monitors both A and B directions. The B+ direction is 90 degrees clockwise from the A+ direction, as viewed from above.

2.4 SENSOR INSTALLATION

The first sensor to install is the Model 6180T terminal sensor, which includes two sets of wheels.

2.4.1 SUSPEND THE FIRST SENSOR

1. Insert the 6180T sensor into the casing, making sure to orient the wheels correctly for proper axis orientation (see Section 2.3), and with the male cable connector facing up toward the top of the casing.

FIGURE 4: *A & B Directions*

Support using rod or screwdriver
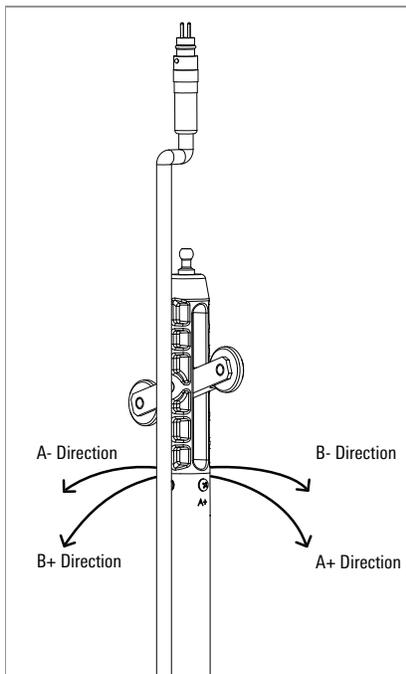
FIGURE 6: Support Sensor with Rod

2. With the safety cable attached, lower the first sensor into the casing hole, until the ¼" support holes are adjacent the top of the casing.

3. Suspend the sensor in place at the top of the casing by inserting a ¼" diameter screwdriver or rod through the support hole on the side of the sensor. Refer to the figures below and to the left.

Support Holes

Holes for Safety Cable Eye Bolt
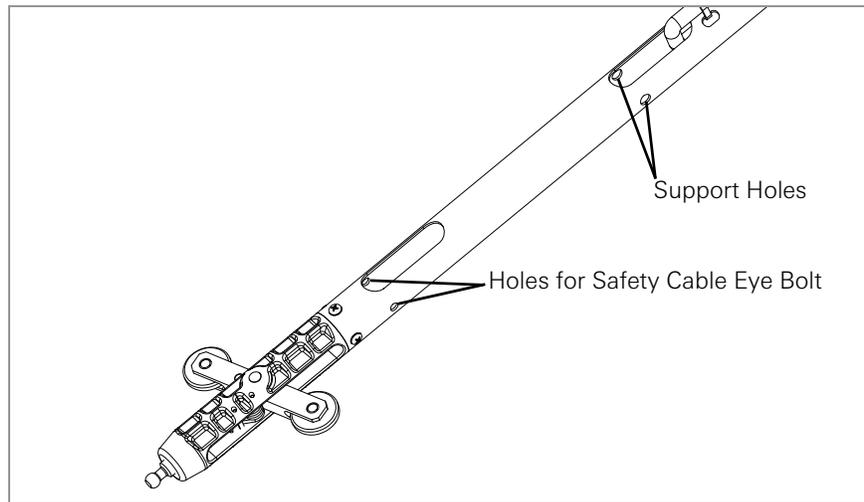
FIGURE 5: Holes for Safety Cable Eye Bolts vs Holes for Support Holes

2.4.2 CONNECT THE SECOND SENSOR TO THE FIRST SENSOR

1. Each 6180 segment is supplied with a barbed locking pin pre-installed.

Ring
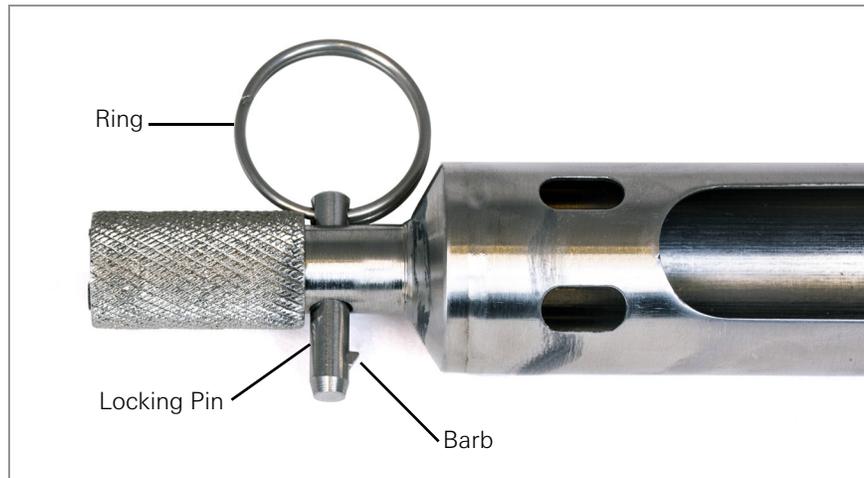
Locking Pin

Barb

FIGURE 7: Pre-inserted Locking Pin

2. Remove the locking pin by depressing the barb and pulling the ring at the same time.

FIGURE 8: Remove the Locking Pin

3. Retract the spring sleeve on the second sensor and mate the ball stud of the first sensor to the receiver of the second sensor by connecting them together using a lateral motion.
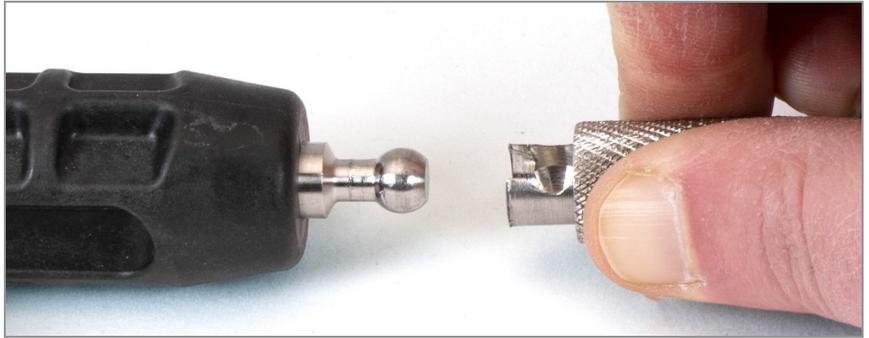
FIGURE 9: *Retract the Spring Sleeve*

4. Capture the ball stud by releasing the spring sleeve (make sure the sleeve returns to its initial position).
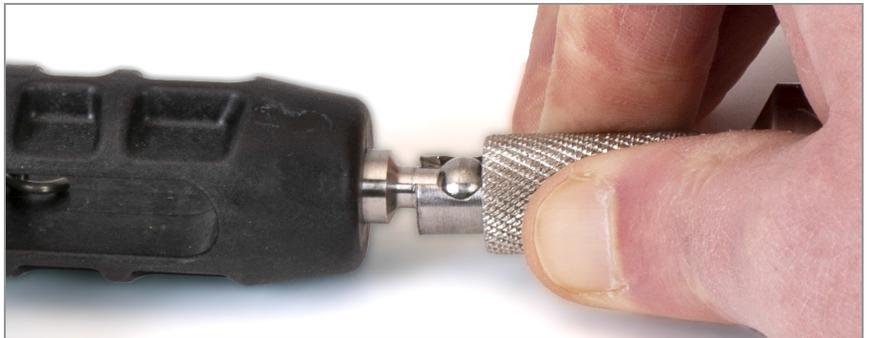
FIGURE 10: *Capture the Ball Stud*

5. Reinsert the locking pin to prevent the sleeve from retracting while in use.

FIGURE 11: *Completed Connection*

6. Plug the male connector of the first sensor's signal cable into the female connector of the second sensor's signal cable.

   Caution! When connecting the sensors, make sure to align the two orientation dots on the outside of the female connector with the orientation dot on the outside of the male connector. This will ensure the pins and receptacles on the interior of the connectors align correctly. Push the male and female connectors together until they are completely mated.
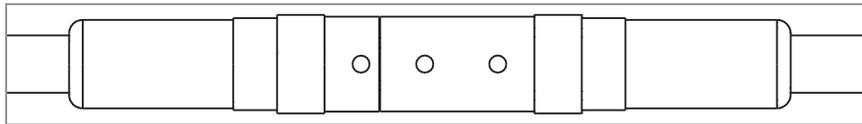
FIGURE 12: *Cable Connection Detail*

> **Note:** For additional security, tape the connectors together.

7. Using a provided tie wrap, secure the cable of the male connector to the tube of the second sensor by feeding the tie wrap through the parallel slots, around the cable, and back to itself; this will help provide strain relief for the connectors. Trim any length of excess tie wrap. See the figure below.
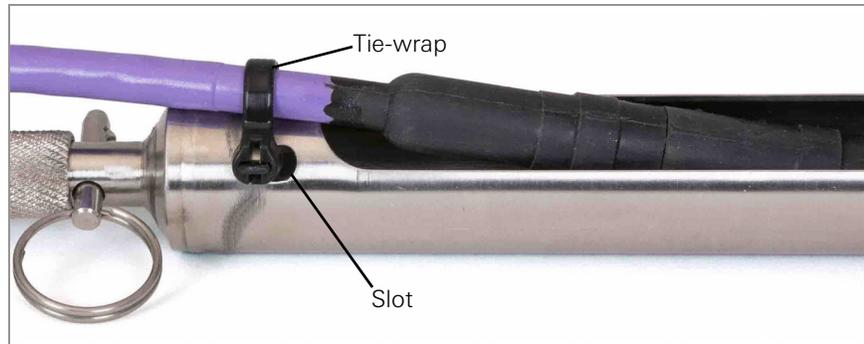
FIGURE 13: *Tie-Wrapped Cable*

8. Remove the screwdriver/rod from the first sensor and, with the safety cable attached, lower the second sensor into the casing hole, until the ¼" support holes are adjacent the top of the casing. Make sure to orient the A+ direction of each sensor correctly when inserting it into the casing.

9. Suspend the second sensor in place at the top of the casing by inserting a ¼" diameter screwdriver or rod through the the support hole on the side of the sensor.

10. Repeat steps 2 - 9 above for each subsequent sensor.

11. Plug the male connector of the top-most sensor to the female connector of the readout cable (6180-3-1, 6180-3-2, or 6180-3V). Connect the other end of the readout cable to the readout device or data-logger.

2.5 CONNECTING THE SUSPENSION BRACKET

To ensure the string is installed to the correct depth, sum the sensor lengths 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.

2.5.1 CONNECT THE CABLE ASSEMBLY TO THE BRACKET

1. Hook the supplied thimble through the bottom-side eyelet on the suspension bracket (6180-2).

2. Feed the bare cable end of the suspension cable assembly (6180-1) through the bottom-side eyelet on the suspension bracket.

3. Pull the cable through the eyelet until the distance from the suspension bracket support shoulder to the end of the suspension receiver is equal to the previously calculated Suspension Cable Length.

4. Fold the "dead end" of the cable back onto the "live end", then secure one of the supplied cable clamps onto the cable at a distance of approximately 3.5 inches from the bottom-side eyelet on the suspension bracket. (Install the cable clamp nuts firmly, but not tighten them down yet).

5. Orient the cable clamp with the two ends of the U-bolt facing toward the "live end" of the cable as shown below.
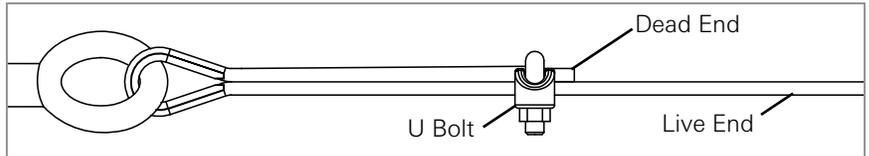
FIGURE 14: *Attach the First Cable Clamp*

6. Seat the loop formed by the cable into the channel of the thimble.

7. Install a second cable clamp onto the cable at the base of the thimble (see image below).
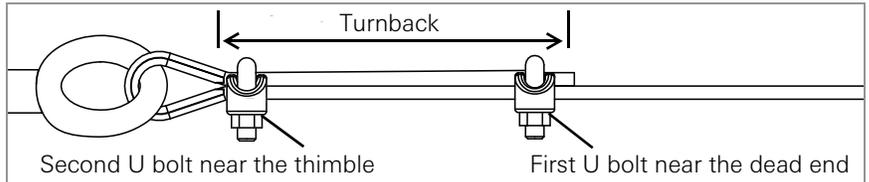
FIGURE 15: *Attach the Second Cable Clamp*

8. Adjust the first cable clamp so the "turnback length" measures approximately 3.25 inches.

9. Apply light tension to the cable to remove all slack. Tighten all four cable clamp nuts to a torque specification of approximately 4.5 ft-lbs.

10. If desired, the third supplied cable clamp may be installed in between the first and second cable clamps (make sure to tighten nuts to the previously mentioned torque specification).

11. Trim the excess cable from the "dead end", leaving at least 3/8 inch of length from the first cable clamp. Alternatively, wrap the end of the cable with tape and then tape it to the main length of the suspension cable.
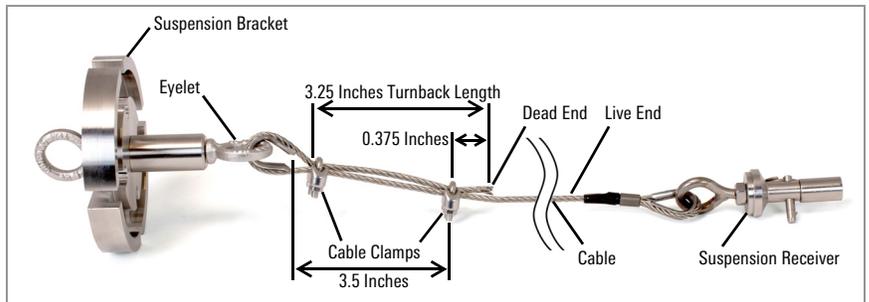
FIGURE 16: *Assembled Suspension Cable (Example)*

2.5.2 CONNECT THE CABLE ASSEMBLY TO THE SENSOR STRING

The suspension cable assembly attaches to the sensor string similar to how the sensors attach to each other. For illustrated steps refer to Section 2.4.2.

1. Remove the locking pin from the suspension receiver by depressing the barb and pulling the ring at the same time.

2. Retract the spring sleeve on the suspension receiver and mate the ball stud of the top-most sensor to the suspens0ion receiver by connecting them together using a lateral motion.

3. Release the spring sleeve to secure the ball stud inside the sleeve.

4. Reinsert the locking pin to prevent the sleeve from retracting while in use.

2.5.3 LOWER THE TOP-MOST SENSOR

Lower the top-most sensor into the casing and position the suspension bracket on top of the casing.

Important! Ensure the top rim of the casing is relatively square to properly seat the suspension bracket.

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 and when the zero readings should be established.

2.6 MODEL 8020-38 RS-485 TO TTL/USB CONVERTER

GEOKON makes the Model 8020-38 Addressable Bus Converter for connecting addressable strings 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.

For more information, please refer to the Model 8020-38 instruction manual.

FIGURE 17: Model 8020-38 RS-485 to TTL/USB Converter

Note: The datalogger you use must have the appropriate port available.

■ If your datalogger does not have built-in RS-485 communications, connect the wiring using the diagram to the left.

■ If your datalogger has built-in RS-485 communications, connect the wiring using the diagram in the figure below.
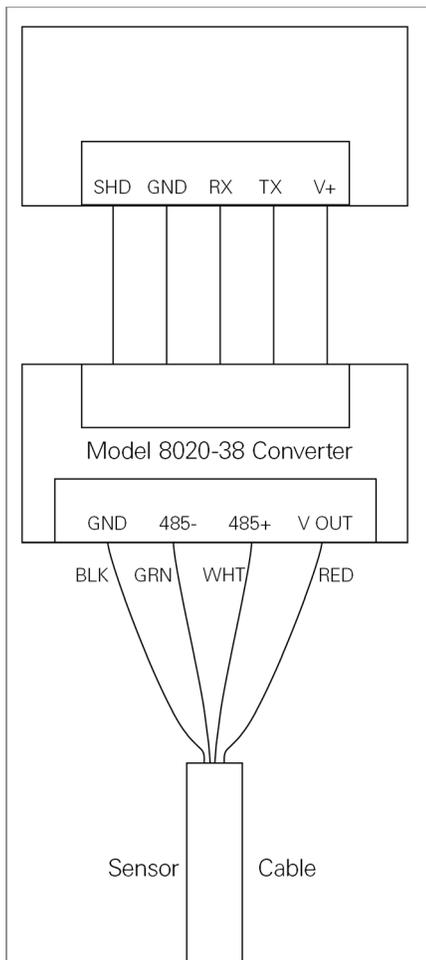
FIGURE 18: Wiring of Datalogger without built-in RS-485 Conversion
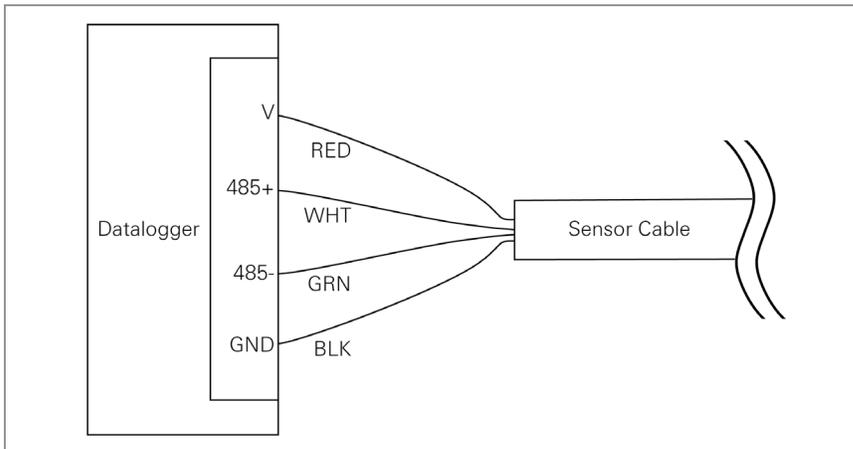
FIGURE 19: *Wiring of Datalogger with built-in RS-485 Conversion*

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 1 below.
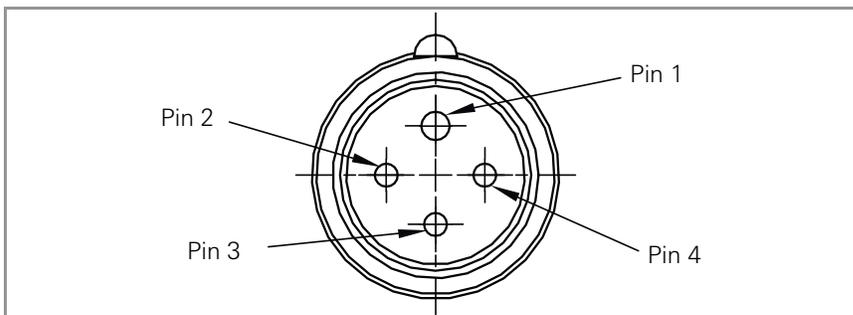
FIGURE 20: *Male Waterproof Connector*
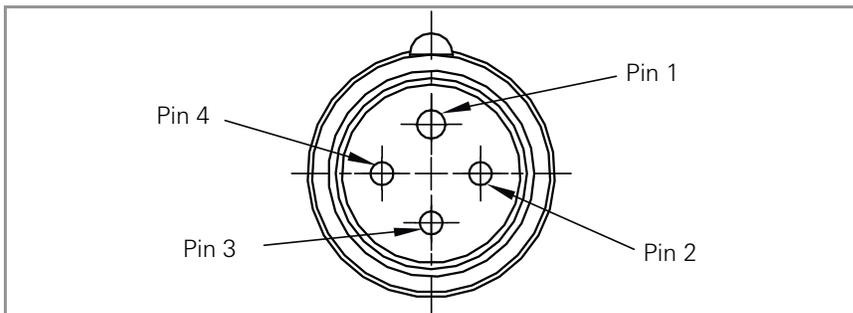
FIGURE 21: *Female Waterproof Connector*

Pin	Wire Color	Function
1	Red	Power
2	Black	Ground
3	White	RS-485+ Data High
4	Green	RS-485- Data Low

TABLE 1: *Four-Pin Wiring Chart*

3. MODBUS RTU PROTOCOL

3.1 INTRODUCTION TO MODBUS

Model 6180 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 **bus network**, meaning that every device receives every message that passes across the network. Model 6180 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 slave 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 2.

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 3 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 C for an explanation of these codes.

The flash password prevents unintended writes to the nonvolatile memory in Table 4. Contact GEOKON for instructions.

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

TABLE 2: *Register Addresses and Formats*

Register Address	Byte	Word	Parameter	Units	Type	Access
0x118	48		Trigger	N/A	uint16	RW
	49					
0x119	50	LSW	Password	N/A	uint32	
	51					
0x11A	52	MSW				
	53					
0x11B	54		Measure Cycle	N/A	uint16	
	55					

TABLE 3: *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 4: *Non-Volatile Memory*

FIGURE 22: *Installation Example*

4. DATA REDUCTION

4.1 INCLINATION CALCULATION

The output of the 6180 Inclinometer Sensor is a corrected angle of inclination. The standard sensor has a full range of ±90° and a calibrated range of ±30°. Register values for the Gauge Factor and Offset are factory-written to the Modbus registers for each sensor using calibration data.

4.2 DEFLECTION CALCULATION

The lateral displacement (D) of the wheel-end of any sensor relative to the vertical line running through the receiver-end of the sensor is equal to:

$D = Lsin\theta$
EQUATION 1: *Sensor Displacement*

Where:
L = The length of the sensor
θ = Inclination angle of the sensor, as described above

The profile of the borehole is constructed by using the cumulative sum of these displacements starting with the terminal sensor. For instance, refer to the figure to the left.

The total displacement of the wheel-end of the outermost sensor from the vertical line drawn through the end of the innermost sensor is:

$D_{total} = L_1sin\theta_1 + L_2sin\theta_2 + L_3sin\theta_3$
EQUATION 2: *Total Displacement*

4.3 TEMPERATURE CORRECTION

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.

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 6180 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 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 or connectors. There is no remedial action.

APPENDIX A. SPECIFICATIONS

A.1 INCLINOMETER SPECIFICATIONS

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	±0.019°/°C (±0.33 mm/m/°C)
Operating Temperature	-40 to 80 °C (-40 to 176 °F)
Power Supply Voltage	12 VDC ±20%
Operating Current[4]	12 mA ±1 mA
Standby Current[4]	2 mA ±0.1 mA
Maximum Supply Current[5]	500 mA
Sensor Diameter	25.4 mm (1")
Standard Sensor Length[6]	0.5 m, 1 m, 2 m, 3 m, 2 ft, 5 ft, 10 ft
Sensor Weight	0.5 m: 0.55 kg (1.22 lb), 1 m: 0.97 kg (2.14 lb), 2 m: 1.80 kg (3.98 lb), 3 m: 2.64 kg (5.82 lb), 2 ft: 0.64 kg (1.42 lb), 5 ft: 1.40 kg (3.10 lb), 10 ft: 2.67 kg (5.90 lb)
Materials	316 Stainless Steel, Engineered Polymer
Electrical Cable	Four Conductor, Foil shield, Polyurethane jacket, nominal OD = 7.9 mm
Minimum Sensor Spacing	0.5 m
Interface	RS-485
Protocol	Modbus
Baud Rate	115,200 bps
Temperature Accuracy	±0.5 °C
Ingress Protection	IP68 to 3 MPa (300 m/1000 ft of head)
Maximum Allowable String Weight	113 kg (250 lb)
Casing Diameter Range	58 mm to 90 mm

TABLE 5: *Model 6180 Inclinometer Specifications*

Notes:

[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 drop in a string

[5] Per entire string

[6] Custom spacing available upon request

A.2 PARTS LIST

6180-0.5M	IPI MEMS Addressable Vertical	Biaxial, Segment Length = 0.5 M
6180-1M	" " " "	Biaxial, Segment Length = 1M
6180-2M	" " " "	Biaxial, Segment Length = 2M
6180-3M	" " " "	Biaxial, Segment Length = 3M
6180-2FT	" " " "	Biaxial, Segment Length = 2FT
6180-5FT	" " " "	Biaxial, Segment Length = 5FT
6180-10FT	" " " "	Biaxial, Segment Length = 10FT
6180T-0.5M	IPI MEMS Addressable Vertical, Terminal	Biaxial, Segment Length = 0.5M
6180T-1M	" " " " "	Biaxial, Segment Length = 1M
6180T-2M	" " " " "	Biaxial, Segment Length = 2M
6180T-3M	" " " " "	Biaxial, Segment Length = 3M
6180T-2FT	" " " " "	Biaxial, Segment Length = 2FT
6180T-5FT	" " " " "	Biaxial, Segment Length = 5FT
6180T-10FT	" " " " "	Biaxial, Segment Length = 10FT
6180-1	Suspension Cable Assembly	Specify Length of 07-125SS316 Aircraft Cable Required
6180-2	Suspension Bracket	
6180-6	Safety Cable Assembly	Specify Length of 07-125SS316 Aircraft Cable Required
6180-3-1	Topside Readout Cable/Bare Leads, < 50 FT	Specify Length of 02-313P9LTD Signal Cable Required
6180-3-2	Topside Readout Cable/Bare Leads, 50 FT-100 FT	Specify Length of 02-313P9LTD Signal Cable Required
6180-3V	Topside Readout Cable/Bare Leads, > 100 FT	Specify Length of 02-313P9LTD Signal Cable Required
07-125SS316-E	Aircraft Cable, 1/8", English	
07-125SS316-M	Aircraft Cable, 1/8", Metric	
02-313P9LTD-M	Low Temp., Polyurethane Cable, 0.313", Violet	

TABLE 6: *Model 6180 Inclinometer Parts List*
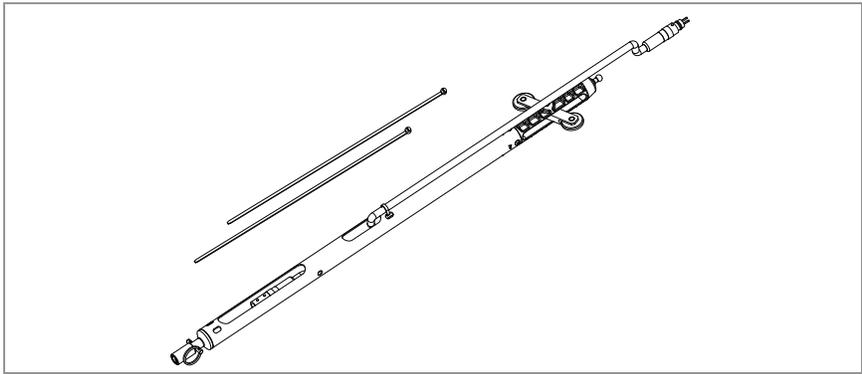
FIGURE 23: Model 6180-0.5M, -1M, -2M, -3M, -2FT, -5FT, -10FT
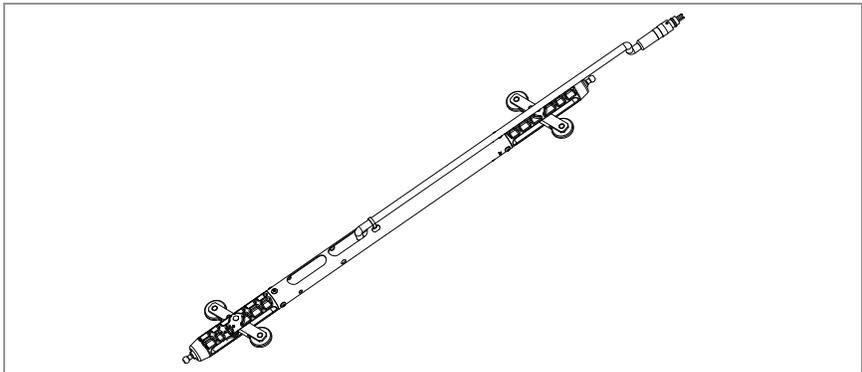

FIGURE 24: Model 6180T-0.5M, -1M, -2M, -3M, -2FT, -5FT, -10FT
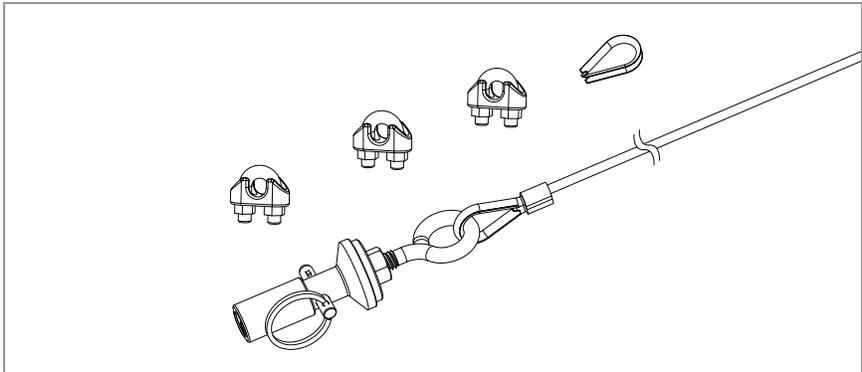

FIGURE 25: Model 6180-1 Suspension Cable Assembly
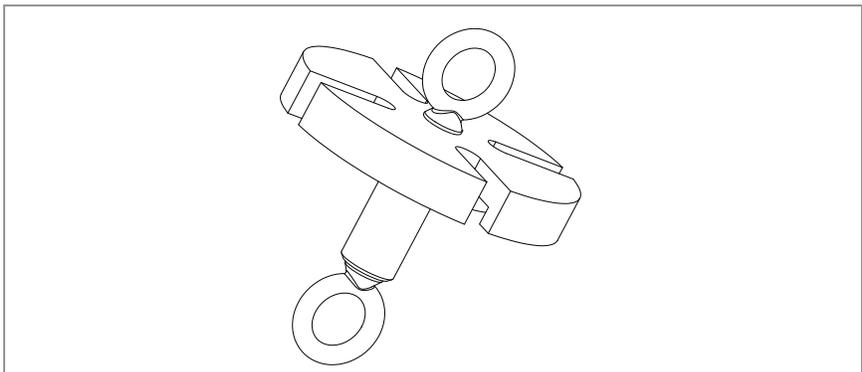
*FIGURE 26: Model 6180-2 Suspension Bracket*
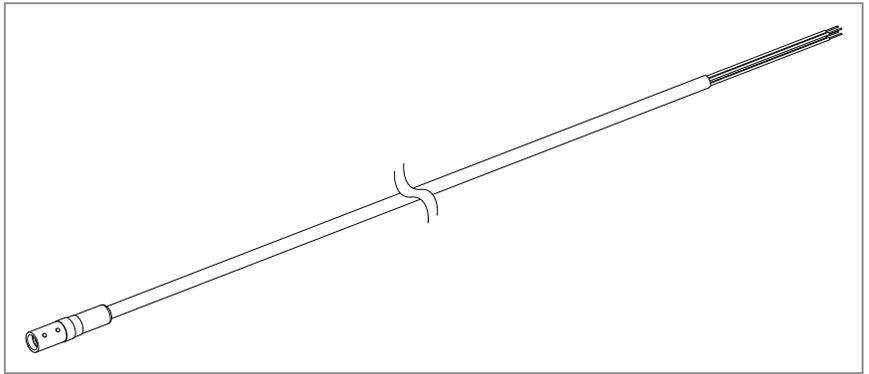
FIGURE 27: *Model 6180-3-1, -3-2 Topside Readout Cable/Bare Leads, < 50FT*
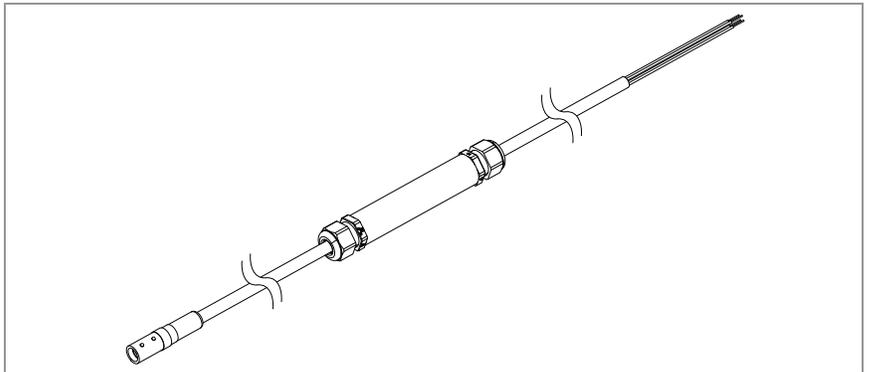
FIGURE 28: *Model 6180-3V Topside Readout Cable/Bare Leads, > 100FT*
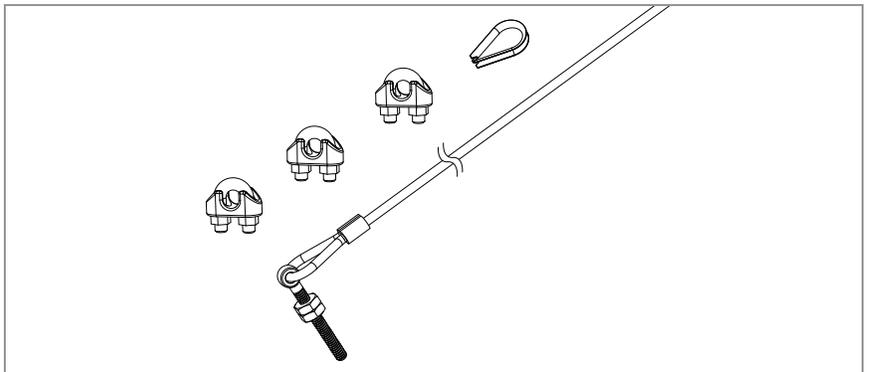
FIGURE 29: *Model 6180-6 Safety Cable Assembly*

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MEMS Tilt Sensor Calibration

Model Number: _____6180_____

Serial Number: _____2935603 Axis A_____

Calibration Instruction: CI-Tiltmeter MEMS Sensor

Calibration Date: _____July 27, 2020_____
This calibration has been verified/validated as of 07/06/2021

Temperature: _____23.3_____

Technician:

Inclination Angle (degrees)	Sensor Output Angle (degrees)	Error (degrees)
-20.0006	-19.9994	0.0012
-15.0003	-15.0024	-0.0021
-8.0003	-8.0000	0.0002
-4.0006	-4.0000	0.0006
-2.0002	-1.9990	0.0012
-0.0005	-0.0022	-0.0017
1.9999	2.0016	0.0017
3.9997	3.9985	-0.0012
7.9998	8.0004	0.0006
14.9998	14.9983	-0.0015
19.9998	20.0006	0.0008

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 30: Sample Model 6180 Calibration Sheet, Sensor A

MEMS Tilt Sensor Calibration

Model Number: _____6180_____

Serial Number: ___2935603 Axis B___

Calibration Instruction: ___CI-Tiltmeter MEMS Sensor___

Calibration Date: _____July 27, 2020_____
This calibration has been verified/validated as of 07/06/2021

Temperature: _____23.2_____

Technician:

Inclination Angle (degrees)	Sensor Output Angle (degrees)	Error (degrees)
-20.0004	-19.9997	0.0008
-15.0003	-15.0019	-0.0016
-8.0003	-7.9996	0.0007
-4.0004	-3.9995	0.0009
-2.0002	-2.0001	0.0001
-0.0003	-0.0023	-0.0019
1.9995	2.0008	0.0013
3.9997	3.9989	-0.0009
7.9998	8.0007	0.0009
14.9994	14.9989	-0.0006
19.9998	20.0001	0.0004

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 31: *Sample Model 6180 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 7: 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 8: 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.   CRBASIC PROGRAMMING

D.1 SAMPLE CR1000 PROGRAM

The following sample program reads one 6180 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              '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 6180 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                      '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
```