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Installation Manual

Model 6160/6161

MEMS Tilt Sensor

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1. INTRODUCTION

The Geokon Model 6160 MEMS Tilt Sensor is designed for permanent long-term monitoring of changes in tilt of structures such as dams, embankments, foundation walls, retaining walls, buildings, and the like. There are two main types of Tilt Sensors: The Model 6160 is an adaption of the tiltmeter used in Model 6150 In-Place Inclinometer, and the 6161 utilizes the same MEMS sensors inside a Nema 4 enclosure. Examples of each type are shown in the Figures below. Each style of housing contains either one or two Micro-Electro-Mechanical Systems (MEMS) sensors oriented at 90 degrees to measure biaxial tilts. All types include a thermistor for measuring temperatures.

They are designed to be attached to the structure so that they can sense and measure any tilting of the structure in uniaxial or biaxial directions. Angular changes of as little as two arc seconds can be detected.

Figure 1 - Model 6160 MEMS Tilt Sensor

Figure 2 - Mounting Bracket for the Model 6160 Tilt Sensor

Figure 3 - Model 6161A Tilt Sensor (Vertical Orientation, Biaxial model shown)

Figure 4 - Model 6161B Tilt Sensor (Vertical Orientation, Biaxial model shown)

2. INSTALLATION

2.1 Preliminary Tests

Prior to installation, the sensors need to be checked for proper operation. Each tilt sensor is supplied with a calibration report, which shows the relationship between output voltage and inclination. The tilt sensor electrical leads are connected to a Datalogger or the RB-500 readout box (see Section 3 for readout instructions) Hold the sensor in an approximately vertical position and observe the reading. The sensor must be held in a steady position. The current reading should be close to the factory vertical reading provided on the calibration report. (See Appendix C. for a sample calibration report.) The temperature indicated by the thermistor should be close to the ambient temperature.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between any conductor and the shield or the case should exceed two megohms.

2.2 Installing Model 6160 Sensors

2.2.1 Mounting Brackets

The first step is to install the uniaxial/biaxial mounting bracket (Figure 5), which is designed for mounting on vertical walls. The bracket may be mounted using a drop-in anchor or an anchor rod that is epoxied or grouted in place. See Section 2.2.1 for instructions using drop-in anchors, and Section 2.2.2 for anchor rods.

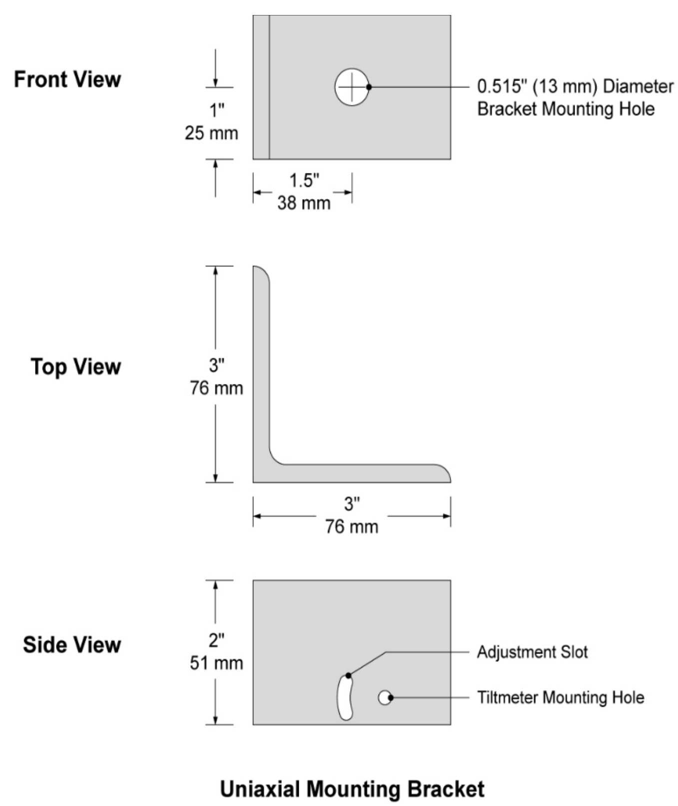


Figure 5 - Tiltmeter Mounting Brackets

2.2.1.1 Mounting with a Drop-in Anchor

1) Mark the location where the bracket will be installed.

2) Using a hammer drill, drill a 12 mm (0.5") hole approximately 37 mm (1.5") deep. Clean the hole thoroughly, blowing out with compressed air if possible.

3) Insert the 3/8" drop-in anchor with setting pin into the hole. The threaded end should be closest to the opening.

4) Insert the provided setting tool, small end first, into the anchor. Expand the anchor by hitting the large end of the setting tool with several sharp hammer blows.

5) Thread the supplied 3/8-16 anchor rod into the anchor.

6) Attach the mounting bracket to the bolt using the supplied hardware, as illustrated in Figure 6.

7) Use a leveling device to align the bracket vertically to the wall.

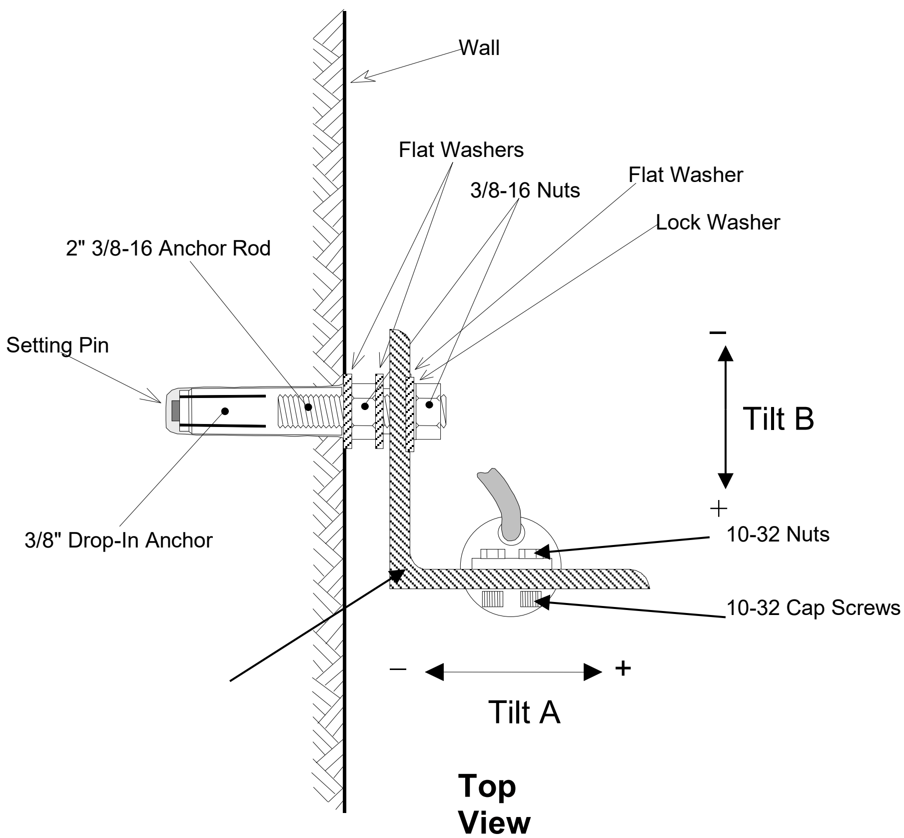


Figure 6 - Drop-in Anchor Installation

2.2.1.2 Mounting with an Anchor Rod

1) Mark the location where the bracket will be installed.

2) Using a hammer drill, drill a 12 mm (0.5") hole approximately 100 mm (4") deep.

3) Clean the hole thoroughly, blowing out with compressed air if possible.

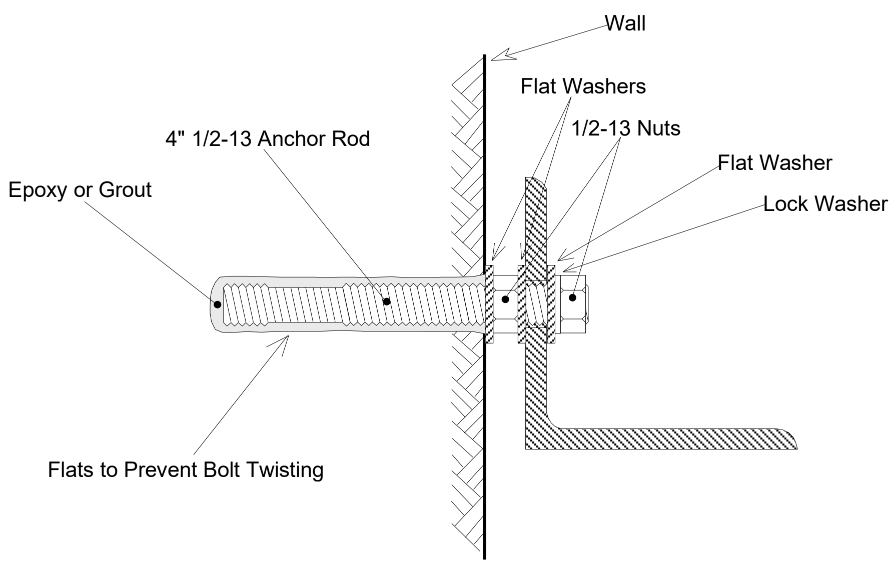
4) Mix the grout or epoxy and fill the hole.

5) Push the 1/2-13 threaded anchor rod into the hole. (Use a hammer if necessary to get the anchor to reach the bottom.)

6) Let the anchor rod set before continuing the installation.

7) After setting, attach the mounting bracket to the bolt using the supplied hardware as illustrated in Figure 7.

8) Use a bubble level or other leveling device to align the bracket vertically to the wall.



Top View

Figure 7 - Anchor Rod

2.2.2 Mounting the Sensor

1) Attach the tiltmeter to the mounting bracket using the supplied 10-32 cap screws, washers, and nuts. The cap screws should be installed finger-tight at this time.

2) Attach a portable readout such as the RB-500 to the tiltmeter and observe the reading. (See Section 3 for readout instructions.)

3) Adjust the sensor in the slot of the mounting bracket while observing the readout until the tiltmeter reads within ±0.15 volts of the zero reading shown on the calibration report supplied with the sensor. (See Appendix C for a sample calibration report.)

4) Tighten the cap screws to secure the tiltmeter in place.

5) Check the reading again after tightening to make sure it still reads within ±0.15 volts of the zero reading. Figure 8 shows the completed installation.

For biaxial sensors: Perform the steps above with the A axis reading. The positive direction of the B axis is 90° clockwise from the positive direction of the A axis. (When looking downwards in plan. See Figure 8 below.) Adjustment of the B axis is as follows:

1) Loosen the 3/8-16 nut on the mounting bracket.

2) Adjust the sensor position by rotating the bracket while observing the readout of the B axis until the tiltmeter reads within ±0.15 volts of the zero reading shown on the calibration report supplied with the sensor.

3) Tighten the nut to secure the mounting bracket in place.

4) Check the reading again after tightening to make sure it still reads within ±0.15 volts of the zero reading. Figure 8 shows the completed installation.

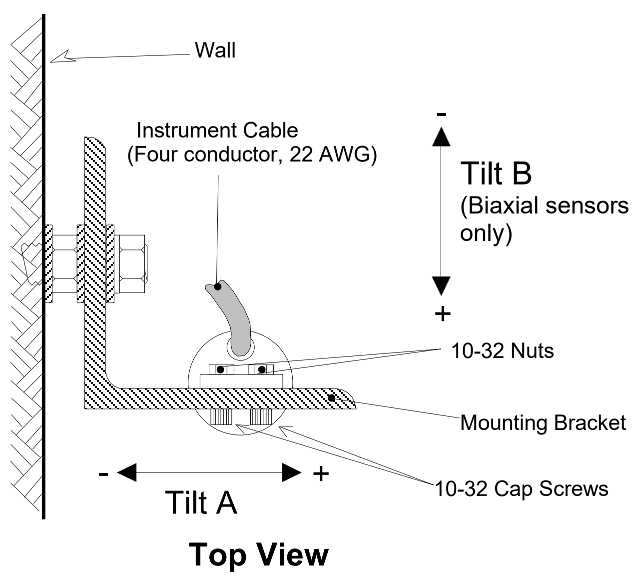


Figure 8 - Uniaxial or Biaxial Tiltmeter Installation Details

2.2.3 Sensor Protection

If the tiltmeter is installed in an exposed location where damage due to vandalism, construction, or other factors might occur, it should be covered with a protective enclosure and/or insulation.

For best results, the tiltmeter should be shielded from direct sunlight.

2.3 Installing Model 6161 Sensors

1) Place the tiltmeter on the mounting surface.

2) Align the tiltmeter so that the A axis (and B axis if applicable) is aligned with the direction of the expected tilt.

3) Use the holes in the tiltmeter mounting plate to mark where the drop-in anchors will be installed.

4) Using a hammer drill, drill four 9.5 mm (3/8”) diameter holes approximately 32 mm (1.25") deep. Clean the holes thoroughly, blowing out with compressed air if possible.

5) Insert the four 1/4" drop-in anchors with setting pin into the hole. The threaded end should be closest to the opening.

6) Insert the provided setting tool, small end first, into the anchor. Expand the anchor by hitting the large end of the setting tool with several sharp hammer blows.

7) Thread the supplied 1/4-20 threaded anchor rods into the anchors.

8) Slide the tiltmeter over the anchor rods until it is flush with the mounting surface.

9) Thread the 1/4-20 nuts onto the anchor rods until they are finger tight.

10) Attach a portable readout such as the RB-500 (see Section 3 for readout instructions) to the tiltmeter and observe the reading of the A axis (and B axis if applicable).

11) If the readings **are not within ±0.15 volts of the zero reading** shown on the calibration report supplied with the tiltmeter, **follow the instruction in Section 2.3.1 and 2.3.2** to adjust the position of the MEMS sensor(s). If the readings are within ±0.15 volts of the zero reading shown on the calibration report, tighten the 1/4-20 nuts to secure the tiltmeter in place. Check the reading again after tightening to make sure it still reads within ±0.15 volts of the zero reading. (A sample calibration report is shown in Appendix C.)

2.3.1 A Axis Tilt Adjustments

1) Use a Phillips head screwdriver to loosen the A axis adjustment screw (refer to Figure 9 below).

2) Adjust the position of the sensor mounting bracket until the A axis of the tiltmeter reads within ±0.15 volts of the zero reading shown on the calibration report supplied with the sensor. (See Appendix C for a sample calibration report.)

2.3.2 B Axis Tilt Adjustments

1) Open the tiltmeter by unscrewing the four captive screws on the front of the enclosure. **Make sure that no dirt, water or other contaminants are allowed to enter the enclosure.**

2) Use the Allen wrench provided to loosen the B axis adjustment screw (see Figure 9). (Note that on tiltmeters configured for horizontal orientation the B axis adjustment screw is located underneath the sensor mounting bracket.)

3) Adjust the position of the sensor mounting bracket until the B axis of the tiltmeter reads within ±0.15 volts of the zero reading shown on the calibration report supplied with the sensor. (See Appendix C for a sample calibration report.)

4) Make sure the gasket on the underside of the cover is clean and properly seated inside the groove.

5) Place the cover on the unit.

6) Tighten the cover screws a little at a time, working in a diagonal pattern, making sure the cover closes and tightly and evenly

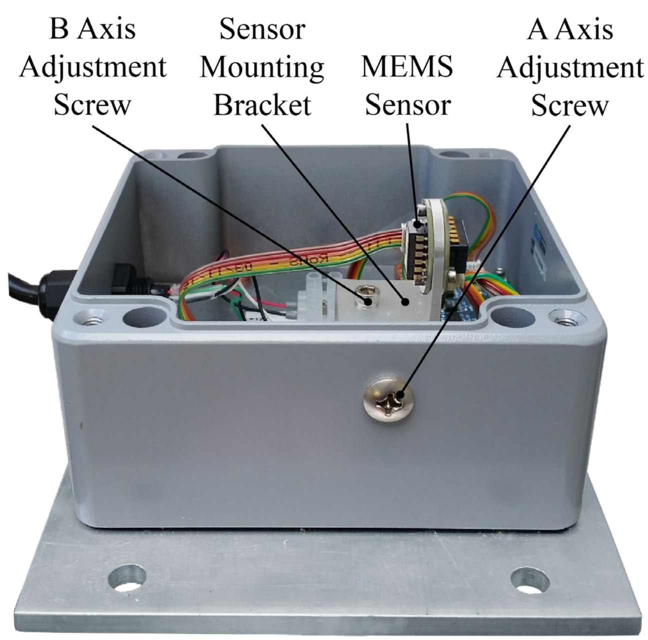


Figure 9 - Adjustment Screw Locations

2.4 Junction Boxes

For manual readout with an RB-500 readout box, cables from the individual sensors are connected to a switchbox. If a Datalogger is used the cables are connected directly to the Multiplexer. In both cases, the wiring code shown in Appendix D is used.

2.5 Splicing

The cable used for making splices should be a high-quality twisted pair type with 100% shielding (with integral shield drain wire). When splicing, it is very important that the shield drain wires be spliced together. Splice kits recommended by Geokon incorporate casts placed around the splice then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable in strength and electrical properties. Contact Geokon for splicing materials and additional cable splicing instructions.

3. TAKING READINGS

3.1 Dataloggers

In most cases the 6160 and 6161 MEMS Tiltmeters will be monitored continuously and automatically using a Datalogger. Connector pin designations for the various tiltmeter models are shown in Appendix D.

3.2 RB-500 Readout Box

The RB-500 readout box is designed to take readings for manually transcribing into a field book; it has no storage capabilities. This method is useful for reading systems that do not require continuous monitoring. The RB-500 readout box is also useful during initial installations and for setting up Datalogger systems. Connections to RB-500 are delineated on the readout.

3.3 Measuring Temperature

Although the temperature dependence of the MEMS tiltmeter is very small, the structure being monitored is usually affected by temperature to some degree; therefore, the gauge 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. (In landslide applications where the MEMS sensors are buried in the ground, temperature variations are very small or nonexistent and ground movements are unaffected by temperatures. In these situations, it is not necessary to measure temperatures.)

An important point to note is that sudden changes in temperature will cause both the structure and the Tiltmeter to undergo transitory physical changes, which will show up in the readings. For best results, the tiltmeter should be shielded from direct sunlight.

Each MEMS tilt sensor is equipped with a thermistor for reading temperature. This enables temperature-induced changes in tilt to be distinguished from tilts due to other sources. Section 4.2 provides an equation to correct the readout of the sensor for temperature.

Please note that Geokon model RB-500 cannot read temperatures; a separate digital ohmmeter is required. To read the temperature using an ohmmeter, connect the ohmmeter to the two thermistor leads of the tilt sensor. Use Appendix B to convert the measured resistance to temperature. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied, equal to approximately 14.7 Ω per one thousand feet [48.5Ω per km] of 22 AWG stranded copper leads. Multiply this factor by two to account for both directions.)

4. DATA REDUCTION

4.1 Tilt Calculation

The output of the MEMS Sensor is proportional to the sine of the angle of inclination from the vertical. For the ±15-degree sensor the FS output is approximately ±4 volts. The reading (R) in volts displayed on the RB-500 readout box, and the inclination (θ) is given by the equation:

$$\theta = (R_1 - R_{zero})\ G \text{ degrees}$$

Equation 1 - Inclination Versus Volts

Where;
R is the current reading in volts
R_{zero} is the reading at θ =zero
G is the Gauge Factor shown on the calibration report for the Model 6160 tiltmeter.

For measurements of tilt, i.e., changes of inclination, where R_0 is the initial reading and R_1 is a subsequent reading, the small zero reading, R_{zero} at zero inclination cancels out so that:

$$\text{Calculated Tilt} = G(R_1 - R_0)$$

Equation 2 - Tilt Versus Volts

4.2 Temperature Correction

The Model 6160 MEMS Tiltmeter has very small temperature sensitivity equal to +1 arc second per degree centigrade rise. The tilt corrected for temperature is:

$$\text{Tilt} = G(R_{1corr} - R_0) \text{ degrees}$$

Equation 3 - Tilt Versus Volts Corrected for Temperature

Where;
$R_{1corr} = R_1 - 0.0003\ (T_1 - T_0)$

4.3 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 a 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 the MEMS sensors used in the Model 6160 and 6161 Tiltmeters are confined to periodic checks of cable connections. The sensors are sealed and there are no user serviceable parts.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Tilt Sensor Readings are Unstable

- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger.
- ✓ Does the readout work with another tilt sensor? If not, the readout may have a low battery or be malfunctioning.

Symptom: Tilt Sensor Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. The nominal resistance of the thermistor is 3000 ohms at 25 degrees C. If the approximate temperature is known, the resistance of the thermistor leads can be estimated and used as a cable check. Remember to add cable resistance when checking. Resistance of 24 AWG stranded copper leads are approximately 25.7Ω per 1000 feet or 84.5Ω per km. Multiply this factor by two to account for both directions. If the resistance reads infinite or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<20Ω), a short in the cable is likely.
- ✓ Does the readout or datalogger work with another tilt sensor? If not, the readout or datalogger may be malfunctioning.

Symptom: Thermistor resistance is too high.

- ✓ Is there an open circuit? Check all connections, terminals, and plugs.

Symptom: Thermistor resistance is too low.

- ✓ Is there a short? Check all connections, terminals, and plugs.
- ✓ Water may have penetrated the interior of the tilt sensor. There is no remedial action.

APPENDIX A. SPECIFICATIONS

A.1 MEMS Tilt Sensor

Model:	6160	6161A	6161B	6161C
Range:	±15°	±15°	±15°	±15°
Full Scale Output:	±4 Volts	±4 Volts	±4 Volts	Digital
Frequency Response:	-3db @ 8-28 Hz	-3db @ 8-28 Hz	-3db @ 8-28 Hz	-3db @ 8-28 Hz
Resolution:[1]	±4 arc seconds (±0.01mm/m)	±4 arc seconds (±0.01mm/m)	±4 arc seconds (±0.01mm/m)	±4 arc seconds (±0.01mm/m)
Accuracy:[2]	±0.05mm/m (±10 arc seconds)	±0.05mm/m (±10 arc seconds)	±0.05mm/m (±10 arc seconds)	±0.05mm/m (±10 arc seconds)
Linearity:[3]	±0.07%FS	±0.07%FS	±0.07%FS	±0.07%FS
Thermal Zero Shift:	0.0003 volt/°C rise	0.0003 volt/°C rise	0.0003 volt/°C rise	0.0003 volt/°C rise
Operating Temperature	-20 to +80° C	-20 to +80° C	-20 to +80° C	-20 to +80° C
Dimensions:	Diameter: 32 mm Length:187 mm	L x W x H: 140 x 140 x 91 mm	L x W x H: 220 x 120 x 91 mm	L x W x H: 220 x 120 x 91 mm
Power Requirements:[4]	Uniaxial: +12V (nom) @ 30mA (9V min. / 15Vmax.) Biaxial: +12V (nom) @ 45mA (9V min. / 15Vmax.)			
Electrical Cable:	Uniaxial: Three twisted pair (Six conductor) 24 AWG Foil shield, Polyurethane jacket, nominal OD = 6.3 mm Biaxial: Six twisted pair (12 conductor) 24 AWG Foil shield, Polyurethane jacket, nominal OD = 7.9 mm			One twisted pair (two conductor) 22 AWG Foil shielded, Polyurethane jacket, Nominal OD = 6.3 mm

Table 1 - Model 6160 and 6161 Tilt Sensor Specifications

Notes:
[1] Depends on readout equipment. For best results requires a 4 ½ digit digital voltmeter. Averaging will yield resolution on the order of two arc seconds
[2] Based upon the use of a second order polynomial
[3] The output of the MEMS sensor is proportional to the sine of the angle of tilt
[4] **Voltages in excess of 18V will damage the circuitry and are to be avoided**

A.2 Thermistor

(see Appendix B also)

Range: -80 to +150° C
Accuracy: ±0.5° C

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3
Resistance to Temperature Equation:

$$T=\frac{1}{A+B(\mathrm{LnR})+C(\mathrm{LnR})^3}-273.15\ °C$$

Equation 4 - Resistance to Temperature

Where;
T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance.
$A = 1.4051 \times 10^{-3}$
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$
Note: Coefficients calculated over the −50 to +150° C. span.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Table 2 - Thermistor Resistance Versus Temperature

APPENDIX C. SAMPLE CALIBRATION REPORT

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

MEMS Tilt Sensor Calibration

Model Number: MEMS Tilt Sensor — Calibration Date: February 06, 2008

Serial Number: Sensor A 08-542 — Temperature: 25.5 °C

Technician:

Inclination (degrees)	Inclination (sinθ)	* Reading 1st Cycle (Volts)	* Reading 2nd Cycle (Volts)	* Average Reading (Volts)	Error in Calculated θ (%FS)	Error in Calculated sinθ (%FS)
10.00	0.1737	2.7616	2.7590	2.7603	-0.05	0.02
8.002	0.1392	2.2190	2.2165	2.2178	0.01	0.00
6.000	0.1045	1.6743	1.6727	1.6735	0.05	0.00
4.002	0.0698	1.1281	1.1280	1.1281	0.05	0.00
2.002	0.0349	0.5803	0.5802	0.5802	0.03	-0.01
0.000	0.0000	0.0322	0.0320	0.0321	0.00	0.00
-2.002	-0.0349	-0.5155	-0.5157	-0.5156	-0.02	0.02
-4.002	-0.0698	-1.0625	-1.0632	-1.0629	-0.03	0.02
-6.000	-0.1045	-1.6081	-1.6089	-1.6085	-0.03	0.02
-8.002	-0.1392	-2.1524	-2.1538	-2.1531	0.00	0.02
-10.00	-0.1737	-2.6947	-2.6958	-2.6953	0.07	0.00

6150 and 6155 In-Place Inclinometer Gage Factor (G): 0.06368 (sinθ/ Volt)

Temperature Correction Factor -0.0003 (T_1-T_0) Volts / °C

Deflection = GL(R_1-R_0) mm (inches)

6160 Tiltmeter Gage Factor (G): 3.6617 (degrees/ Volt)

Temperature Correction Factor -0.0003 (T_1-T_0) Volts / °C

Calculated 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 10 - Sample Model 6160 Calibration Report

APPENDIX D. WIRING CODES

03-250V0 cable	Connector Pin Designation	Uniaxial MEMS **with** Thermistor	Connector Pin Designation	Biaxial MEMS **without** Thermistor
Red	A	12VDC	A	12VDC
Red's Black	B	Ground	B	Ground
White	C	A Out Diff +	C	A Out Diff +
White's Black	D	A Out Diff -	D	A Out Diff -
Bare	E	Shield	E	Shield
Green	J	Thermistor	F	B Out Diff +
Green's Black	K	Thermistor	G	B Out Diff -

Table 3 - Cable 03-250V0 Wiring

06-312V0 Cable	Connector Pin Designation	Biaxial MEMS **with** Thermistor
Red	A	12VDC
Red's Black	B	Ground
White	C	A Out Diff +
White's Black	D	A Out Diff -
Bare	E	Shield
Green	F	B Out Diff +
Green's Black	G	B Out Diff -
Blue	J	Thermistor
Blue's Black	K	Thermistor

APPENDIX E. 6160 STANDARD ADDRESSABLE SYSTEMS

Description:

The standard 6160 addressable system incorporates a Distributed Multiplexer Circuit Board that allows multiple MEMS type tiltmeters, uniaxial or biaxial, to be connected as "drops" off of a single bus.

The tiltmeter "string" is addressed via ENABLE and CLOCK signals in the same manner as the Geokon Model 8032-16 Channel Multiplexer.

The addressable tiltmeter string is "enabled" by raising the appropriate Datalogger Control Port to 5V. After the string has been enabled, a delay of 125 mS is required before executing the 1st of the two clock pulses required to activate the 1st channel. Once the channel is selected, a delay of 100 mS is required for the sensor to warm up. The sensor's A-axis is read 100 times and then the average of these readings is stored. The sensors B-axis is then read. Finally, the sensor's thermistor is read through a bridge completion circuit and the temperature is calculated using a polynomial formula. Examples of CRBASIC programming can be found in Appendix F and AppendixG.

Wiring:

06-312V0 Cable Color	Connector Pin Designation	Addressable MEMS System (Logic Level Style)
Yellow	A	A-axis Output Differential +
Yellow's Black	B	A-axis Output Differential -
Brown	C	B-axis Output Differential +
Brown's Black	D	B-axis Output Differential -
Red	E	12VDC
Red's Black	F	Ground
White	G	Reset
White's Black	H	Ground
Green	J	Clock
Green's Black	K	Ground
Blue	L	Thermistor*
Blue's Black	M	Thermistor*
Bare	P	Shield

Table 4 - Addressable MEMS (Logic Level Style) Wiring

*1K and 5K precision resistors are used to complete the thermistor bridge circuit:

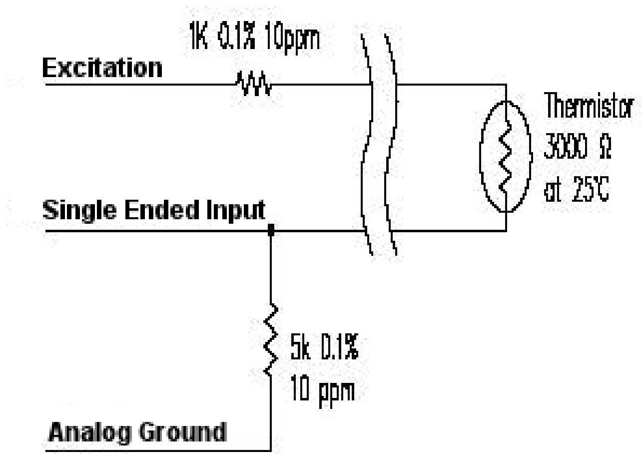


Table 5 - Thermistor Bridge Circuit

<u>Specifications for Addressable System (Logic Level Style) Circuit Board:</u>

Board Dimensions: 4.5"(L) x 1.155"(W) x 0.4"(H)

Power Requirements: +12V (± 3V)
110mA (max) when active
700uA (max) standby

Operating Temperature: -20 to +70° C

Contact Resistance: 100 mΩ (typ)

Contact Breakdown Voltage: 1500 Vrms

Relay open/close time: 4mS (max)

APPENDIX F. PROGRAMMING THE MEMS TILTMETER WITH CRBASIC

Description:

CRBASIC is the programming Language used with Campbell Scientific CRBASIC Dataloggers. Campbell's LoggerNet Software is typically used when programming in CRBASIC. The MEMS sensor should be read with the VoltDiff instruction and the output averaged 100x. (No Thermistor in this example.)

Sample Program:

```
'Declare Public Variables for Reading MEMS Sensor

Public MEMS_1
Public MEMS_2
Public MEMS_3
Public MEMS_Output  'Output of the MEMS Sensor

'Store MEMS Output every 2 minutes

DataTable (MEMS_EXAMPLE,1,-1)
    Sample (1,MEMS_Output,IEEE4)
EndTable

BeginProg

    '2 min scan interval

    Scan (2,min,0,0)

        'Read MEMS Sensor on Differential Channel 1 and average 100x Readings

        Delay(0,100,mSec)
        MEMS_3 = 0
        For MEMS_1 = 1 To 100
            VoltDiff (MEMS_2,1,mV5000,1,False,0,250,0.001,0)
            MEMS_3 = MEMS_3 + MEMS_2
        Next
        MEMS_Output = MEMS_3 / 100

        CallTable MEMS_EXAMPLE
    NextScan
EndProg
```

APPENDIX G. PROGRAMMING THE ADDRESSABLE MEMS TILTMETER WITH CRBASIC

Description:

CRBASIC is the programming Language used with Campbell Scientific CRBASIC Dataloggers. Campbell's Loggernet Software is typically used when programming in CRBASIC. The MEMS sensor should be read with the VoltDiff instruction and the output averaged 100x.

Sample Program:

```
'The following sample program reads 20 addressable Bi-Axial MEMS Gauges and
Thermistors. The A-Axis is read on Differential Channel 1, the B-Axis is read on Differential
Channel 2 and the Thermistors are read with Single Ended Channel 5 and the bridge excited
with EX1. The string is enabled with Control Port 1 and clocked with control port 8.

'Declare Public Variables for Reading MEMS Sensor and Thermistor

Public MEMS_1
Public MEMS_2
Public MEMS_3
Public THERM_1
Public THERM_2
Public THERM_3
Public Channel  'Counter
Public Reading_A  'Output of the A Axis
Public Reading_B  'Output of the B Axis
Public Reading_THERM  'Output of Thermistor

'Store MEMS Output every 5 minutes

DataTable (MEMS_EXAMPLE,1,-1)
   Sample (1,Reading_A,IEEE4)
   Sample (1,Reading_B,IEEE4)
   Sample (1,Reading_THERM,IEEE4)
EndTable

BeginProg

   '5 min scan interval

   Scan (5,min,0,0)

      'enable String using C1
      PortSet(1,1)

      'Delay
      Delay(0,125,MSEC)
```

```
'counter for number of sensors
For Channel = 1 To 20

    '1st clock using C8
    PortSet(8,1)
    Delay(0,10,MSEC)
    PortSet(8,0)
    Delay(0,10,MSEC)

    'Delay
    Delay(0,100,mSec)

    'Read the A-axis

    'Reset the temporary storage location
    MEMS_3 = 0

    'counter
    For MEMS_1 = 1 To 100

        'differential voltage measurement on DIFF1
        VoltDiff (MEMS_2,1,mV5000,1,False,0,1000,0.001,0)

        'Sum the readings
        MEMS_3 = MEMS_3 + MEMS_2

        'Increment To 100
    Next

    'Calculate the Average reading value
    Reading_A = MEMS_3 / 100

    'Read the B-axis

    'Reset the temporary storage location
    MEMS_3 = 0

    'counter
    For MEMS_1 = 1 To 100

        'differential voltage measurement on DIFF2
        VoltDiff (MEMS_2,1,mV5000,2,False,0,1000,0.001,0)

        'Sum the readings
        MEMS_3 = MEMS_3 + MEMS_2

        'Increment To 100
    Next
```

```
            'Calculate the Average reading value
            Reading_B = MEMS_3 / 100

            'Delay
            Delay(0,100,msec)

            'Read the thermistor

            'half bridge measurement - SE5 AND EX1
            BrHalf(THERM_1,1,mV2500,5,VX1,1,2500,0,1000,250,2.5,0.0)

            'Calculate the temperature
            THERM_2 = THERM_1 / 5000

            THERM_3 = (2.5 - (THERM_2*1000) - THERM_1)/THERM_2

            Reading_THERM = 1/(.0014051 + (.0002369*LOG(THERM_3)) +
(.0000001019*(LOG(THERM_3)^3))) - 273.2

            '2nd clock using C8
            PortSet(8,1)
            Delay(0,10,MSEC)
            PortSet(8,0)
            Delay(0,10,MSEC)

            'Next sensor
        Next

        'Disable String
        PortSet(1,0)

        CallTable MEMS_EXAMPLE
    NextScan
EndProg
```