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Installation Instructions

Model 6165

MEMS Tilt Beam

(Doc Rev G, 3/6/20)

Warranty Statement

Geokon warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by Geokon, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of Geokon's control. Components which wear or which are damaged by misuse are not warranted. This includes fuses and batteries.

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1. INTRODUCTION

Geokon's Model 6165 MEMS Tilt Beams are designed to be attached to structures, either vertically or horizontally, to measure any tilting or differential settlements that may occur. The tilt beams can be coupled together, in long horizontal strings, to measure differential settlement along embankments, railroad tracks, pipelines, tunnels, etc. They can also be used in vertical strings to measure the horizontal deformation of retaining walls, sheet piling, etc.

Each tilt beam contains a Micro-Electro-Mechanical-System (MEMS) sensor, which offers high sensitivity and accuracy over a range of ±15 degrees. MEMS tilt sensors have very good long-term stability, are virtually immune to shock loading, and have very low thermal coefficients. They are readily adaptable to automation and remote monitoring for profiling in real-time. The included signal conditioning yields a sensor output of ±3 volts at ±10 degrees and is designed to drive long cables without output signal degradation.

The MEMS sensor is mounted inside a fiberglass, aluminum, or anodized aluminum channel equipped with lugs for mounting to the structure under study. The beams are bolted to the structure using the supplied hardware, which includes two 3/8" expansion anchors. A thermistor mounted inside the sensor housing permits the measurement of temperatures. Readout of the tilt beams is accomplished by using a Geokon Model RB-500 Readout, or 8600 Series Datalogger.

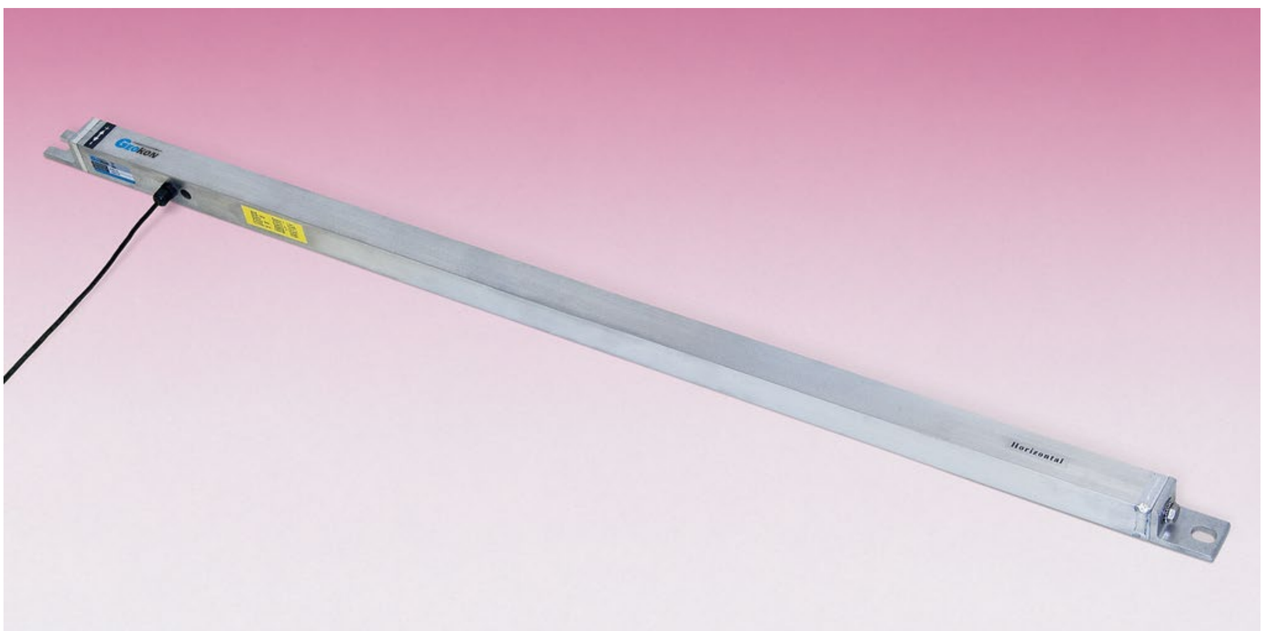

Figure 1 - Model 6165 MEMS Tilt Beam

2. INSTALLATION

2.1 Preliminary Tests

Prior to installation, each tilt beam should be checked for proper operation by completing the following:

1) Connect the beam to a readout or datalogger. (See Section 3 for readout and datalogger instructions.)

2) Depending upon which version of the tilt beam was purchased, hold the beam in a strictly horizontal or vertical position. The beam must be held in a steady position while taking readings. The observed reading should be close to the factory zero reading provided on the calibration report. **(Note that the RB-500 Readout Box uses a 2:1 voltage divider to halve the full-scale output of the MEMS sensor, which is ±4 volts. This is done so that the ±2-volt DVM in the RB-500 readout box can display the full output range of the MEMS sensor.)**

3) At one end of the beam there is a label that shows the sign of the change in readout voltage when that end of the beam is tilted in the direction shown. Tilts in a positive direction (+) should yield increasing readings. Tilts in a negative direction (-) should yield decreasing readings. The temperature indicated on the readout should be close to ambient.

4) Repeat this process with the remaining beams.

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

2.2 Attaching Mounting Brackets

Each beam is supplied with mounting brackets and associated hardware (Figure 2). To mount the brackets to the beam: Slide the external tooth lock washers (D) onto the bolts (C), followed by the flat washers (E). Use the bolts to attach the mounting brackets to the ends of the beam. Figure 3 shows the completed assembly.

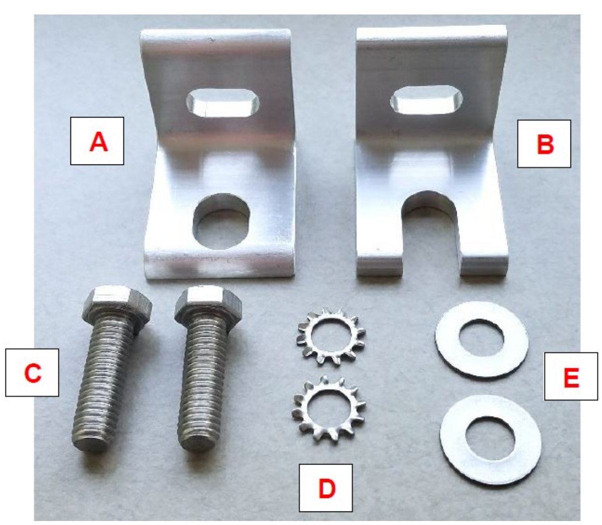

Figure 2 - Bracket Hardware

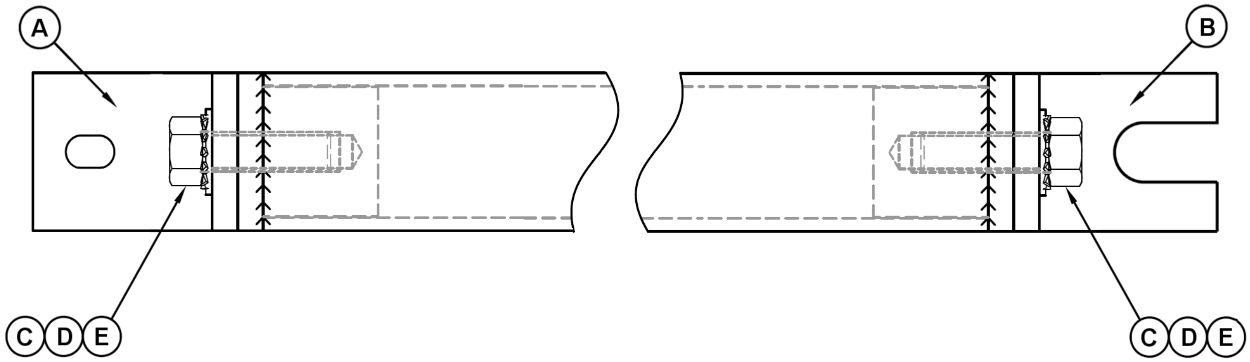

Figure 3 - Brackets Attached to Beam

Make sure the mounting brackets are orientated so that when the beam is mounted, the front of the beam will be facing out, as shown in Figure 4.

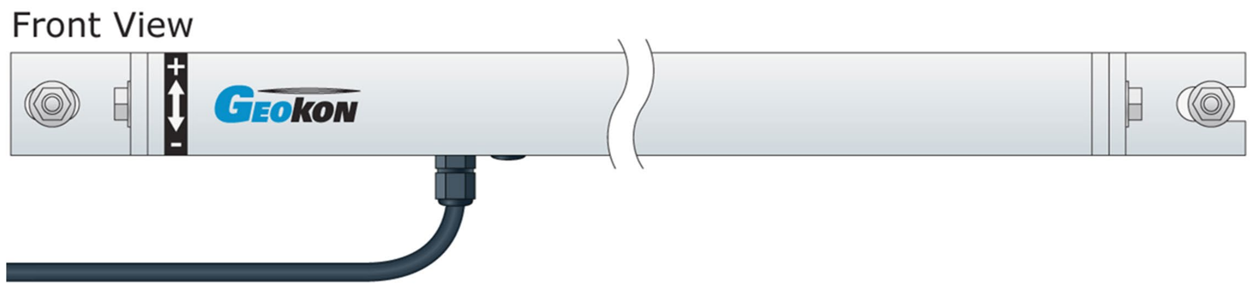

Figure 4 - Mounting Bracket Orientation

2.3 Mounting the Beam

1) Place the beam in the desired location.

2) Use a spirit level to make sure the beam is as close to a truly vertical or horizontal position as possible, depending upon the type of beam purchased.

3) Using the beam as a template, mark the locations of the holes in the mounting brackets on the mounting surface. The marks should be as close as possible to being in line on a horizontal or vertical plane.

4) Using a masonry drill (or other suitable equipment), drill two 12 mm (1/2") diameter holes, approximately 40 mm (1.6") deep at the marked locations.

5) Clean the holes thoroughly. (Blow them out with compressed air if possible.)

6) Insert the expansion anchors into the holes, with the slotted end down.

7) 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.

8) Thread the supplied 3/8-16 anchor rod into the anchor. Thread-locking cement can be used to ensure the hardware remains secure.

9) Attach the beam to the mounting surface by arranging the mounting hardware as shown in Figure 5. Use thread locking cement if desired.

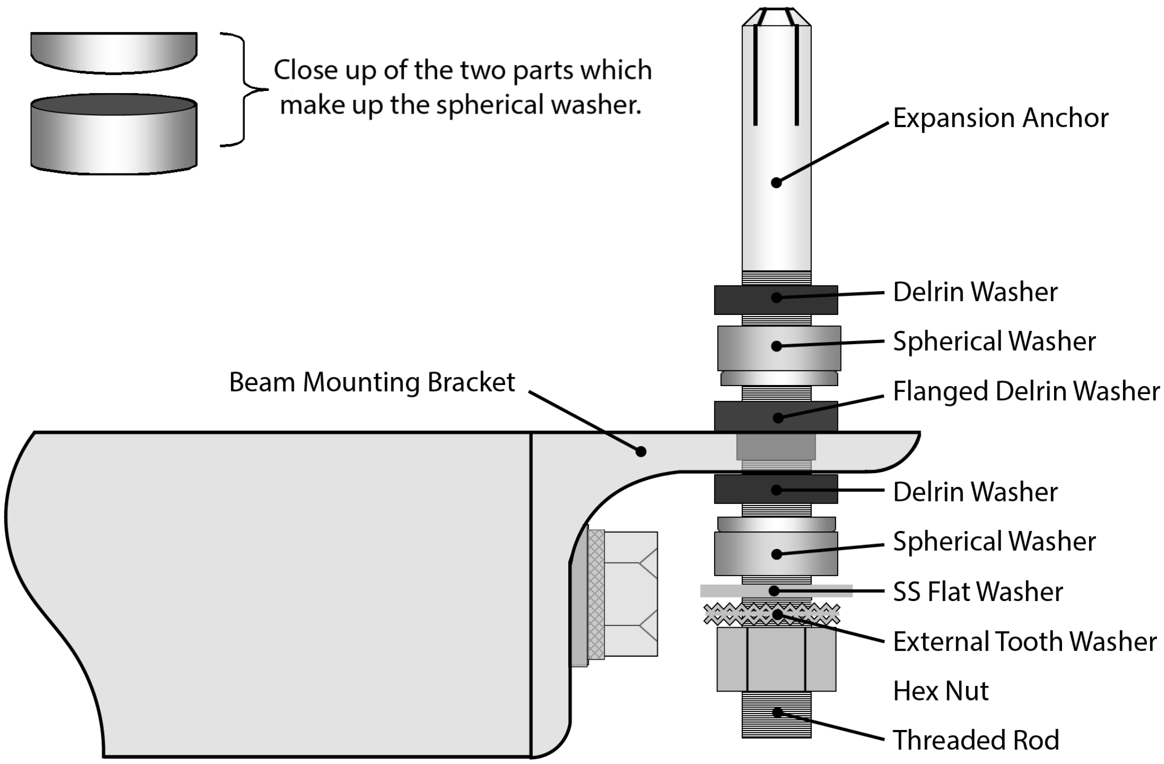

Figure 5 - Mounting Hardware

10) The beam must be level along the axis of the beam, as well as the perpendicular axis. This is to avoid any off-axis errors which can occur if the MEMS sensor is rotated axially too far away from a true horizontal or vertical position. The spherical washers allow the beam to be rotated in respect to the anchor bolt, thus adjustments can be made to avoid this type of error.

For vertical tilt beams, the axis of tilt can be either in the plane of the wall or perpendicular to the wall. The direction is selectable by slackening the bolts holding the mounting brackets to the ends of the beam and turning it 90 degrees.

3. TAKING READINGS

3.1 Initial Readings

The displayed output of the initial zero readings should be close to the factory zero reading provided on the calibration report. The sensor output at ±15 degrees is ±4 volts.

Note that the RB-500 Readout Box uses a 2:1 voltage divider to halve the full-scale output of the MEMS sensor, which is ±4 volts. This is done so that the ±2-volt DVM in the RB-500 readout box can display the full output range of the MEMS sensor.

3.2 Dataloggers

In most cases, the tilt beam will be monitored continuously and automatically using a Datalogger. Connections to Geokon 8600 series dataloggers, which uses Campbell Scientific CR6 MCU are shown in Table 1 below. For further information, consult the 8600 Series Instruction Manual.

03-250V0 Cable	Connector Pin Designation	Function
Red	A	12VDC
Red's Black	B	Ground
White	C	A Out Diff +
White's Black	D	A Out Diff -
Bare	E	Shield
Green	J	Thermistor
Green's Black	K	Thermistor

Table 1 - 03-250V0 Cable Wiring

3.3 RB-500 Readout Box

The RB-500 readout box is designed to display 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.

Connect the leads of the beam to the RB-500 as shown on the readout overlay.

Note that the RB-500 Readout Box uses a 2:1 voltage divider to halve the full-scale output of the MEMS sensor, which is ±4 volts. This is done so that the ±2-volt DVM in the RB-500 readout box can display the full output range of the MEMS sensor.

For further information, consult the RB-500 Instruction Manual.

3.4 Measuring Temperature

All tilt beams are equipped with a thermistor, which gives a varying resistance output as the temperature changes. Although the temperature dependence of the MEMS tilt beam is very small, and usually does not require compensation, it sometimes happens that temperature effects can cause real changes of tilt; therefore, 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. See Section 4.3)

The RB-500 will not read temperatures; a separate digital ohmmeter is required. (A Geokon GK-404 or GK-405 readout box can also be used; they can read the thermistor and display the temperature in degrees C.)

To read temperatures using an ohmmeter:

1) Connect an ohmmeter to the green and green's black conductors of the tilt beam. Since the resistance changes with temperature are 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). Multiply this factor by two to account for both directions.

2) Look up the temperature for the measured resistance in Appendix B, Table 3.

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 zero position. For the 15-degree MEMS sensor the full-scale output is approximately four volts. The reading (R) in volts displayed on the RB-500 readout box, and the inclination, (θ) is given by the equation:

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

Equation 1 - Inclination

Where;
R is the current reading in volts.
R_{zero} is the reading at θ = zero.
G_{tilt} is the Gauge Factor shown on the suppled calibration report (A typical 6165 calibration report is shown in Appendix C.)

Note that 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:

$$\text{Calculated Tilt (T)} = G_{tilt}(R_1 - R_0) \text{ degrees}$$

Equation 2 - Calculated Tilt

4.2 Displacement Calculation

To calculate the vertical or horizontal displacement (D) of one end of the beam relative to the other use the equation:

$$\text{Calculated Displacement (D)} = G_{\sin\theta} L(R_1 - R_0) \text{ mm(inches)}$$

Equation 3 - Calculated Displacement

Where;
L is length of the beam in mm or inches
$G_{\sin\theta}$ is the calibration factor in sinθ/volt as shown on the calibration report.

4.3 Temperature Correction

The Model 6165 MEMS Tilt Beam sensor has negligible temperature sensitivity equal to one arc second per degree C or 0.0003 volts/ degree C.

$$\text{Tilt corrected for temperature} = G_{tilt}[(R_1\text{-}R_0) - 0.0003(T_1\text{-}T_0)] \text{ degrees}$$

Equation 4 - Temperature Correction - Tilt

The corresponding correction for displacement is:

$$\text{Displacement corrected for temperature} = G_{\sin\theta}L[(R_1\text{-}R_0) - 0.0003(T_1\text{-}T_0)] \text{ mm(inches)}$$

Equation 5 - Temperature Correction - Displacement

The structure being monitored, and the tilt beam are both affected by temperature to some degree. An important point to note is that sudden changes in temperature will cause both the structure and the tilt beam to undergo transitory physical changes, which will show up in the readings. A system temperature correction factor can be calculated by taking readings of tilt and temperature over a short period of time and correlating the two. Alternatively, efforts can 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. **For best results, the Tilt Beam should be shielded from direct sunlight.**

4.4 Environmental Factors

Since the purpose of the tilt beam 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 Model 6165 Tilt Beams are confined to periodic checks of the 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? If the approximate temperature is known, the resistance of the thermistor leads can be estimated and used as a cable check. Connect an ohmmeter to the green and green's black conductors of the tilt beam. Since the resistance changes with temperature are 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). Multiply this factor by two to account for both directions. If the resistance reads very high or infinite (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

- ✓ It is likely that there is an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, contact Geokon for splicing information.

Symptom: Thermistor resistance is too low

- ✓ It is likely that there is a short. Check all connections, terminals, and plugs. If a short is located in the cable, contact Geokon for splicing information.
- ✓ Water may have penetrated the interior of the beam. There is no remedial action.

APPENDIX A. SPECIFICATIONS

A.1 Model 6165 MEMS Tilt Beam

Range:	±15°
FS Output:	± Four Volts
Resolution:[1]	±0.02 mm/m (±4 arc seconds)
Sensor Accuracy[2]:	±0.05 mm/m (±10 arc seconds)
Linearity:	0.2% F.S. (±5-degree range), 0.5% F.S. (±10-degree range). ±1.5% F.S.
Thermal Zero Shift:	0.0003 volt/°C rise
Operating Temperature:	-20 to +80° C
Power Requirements[3]:	+12V (nom) @ 30mA
Beam Dimensions:	1.5", 38 mm square cross section
Length:	Variable
Weight:	1.5 lb. / 0.7 kg (0.5 m beam)
Materials:	Aluminum
Electrical Cable:	Three twisted pair (Six conductor) 24 AWG for uniaxial Foil shield, PVC jacket, nominal OD = 6.3 mm

Table 2 - Model 6165 MEMS Tilt Beam Sensor Specifications

Notes:
[1] Depends on readout equipment. For best results, use a 4.5-digit digital voltmeter.
[2] Established under laboratory conditions.
[3] **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:

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

Equation 6 - Resistance to Temperature

Where;
T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = 1.4051×10^{-3}
B = 2.369×10^{-4}
C = 1.019×10^{-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 3 - 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: July 12, 2012

Serial Number: 1221794

Calibration Instruction: CI-Tiltmeter MEMS

Temperature: 24 °C

Technician:

Inclination (degrees)	Inclination (sinθ)	* Reading 1st Cycle (Volts)	* Reading 2nd Cycle (Volts)	* Average Reading (Volts)	Error in θ (%FS)	Calculated sinθ (%FS)
15.00	0.2588	4.176	4.177	4.1763	-0.07	0.09
14.00	0.2419	3.908	3.908	3.9078	0.00	0.09
12.00	0.2079	3.365	3.365	3.3654	0.08	0.05
10.00	0.1736	2.820	2.820	2.8197	0.13	0.03
8.00	0.1392	2.273	2.273	2.2728	0.15	0.03
6.00	0.1045	1.721	1.722	1.7216	0.13	0.00
4.00	0.0698	1.169	1.169	1.1694	0.09	0.00
2.00	0.0349	0.617	0.617	0.6173	0.06	0.01
0.00	0.0000	0.063	0.063	0.0631	0.00	0.00
-2.00	-0.0349	-0.489	-0.489	-0.4891	-0.04	0.02
-4.00	-0.0698	-1.040	-1.041	-1.0408	-0.07	0.03
-6.00	-0.1045	-1.592	-1.593	-1.5925	-0.10	0.03
-8.00	-0.1392	-2.141	-2.142	-2.1415	-0.09	0.04
-10.00	-0.1736	-2.686	-2.687	-2.6865	-0.04	0.06
-12.00	-0.2079	-3.229	-3.230	-3.2296	0.03	0.06
-14.00	-0.2419	-3.769	-3.769	-3.7691	0.15	0.06
-15.00	-0.2588	-4.038	-4.037	-4.0373	0.23	0.06

6150, 6155 and 6165 Deflection Gage Factor ($G_{sin\theta}$): 0.0630 (sinθ / Volt)

Deflection = $(G_{sin\theta})L(R_1-R_0)$ mm (inches)

6160 and 6165 Tilt Gage Factor (G_{tilt}): 3.642 (degrees/ Volt) over + / - 15° range

Calculated Tilt = $G(R_1 - R_0)$ degrees

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

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 6 - Sample Model 6165 Calibration Report

APPENDIX D. PROGRAMMING THE MEMS TILT BEAM WITH CRBASIC

D.1 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.

D.2 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
```