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Installation Instructions

Model 6165

MEMS Tilt Beam

(REV A 06/10)

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TABLE of CONTENTS

LIST of FIGURES, TABLES and EQUATIONS

1. Introduction

The Model 6165 MEMS Tilt Beam is designed for attachment to structures. on either vertical or horizontal surfaces, for the measurement of 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., or they can be used in vertical strings to measure the horizontal deformation of retaining walls, sheet piling, etc.

The Tilt Beam contains a Micro-Electro-Mechanical-System (MEMS) sensor which offers a range of ±15°, with high-sensitivity and accuracy. The MEMS sensor is mounted inside a fiberglass, aluminum or anodized aluminum channel equipped with lugs for mounting to the structure under study.

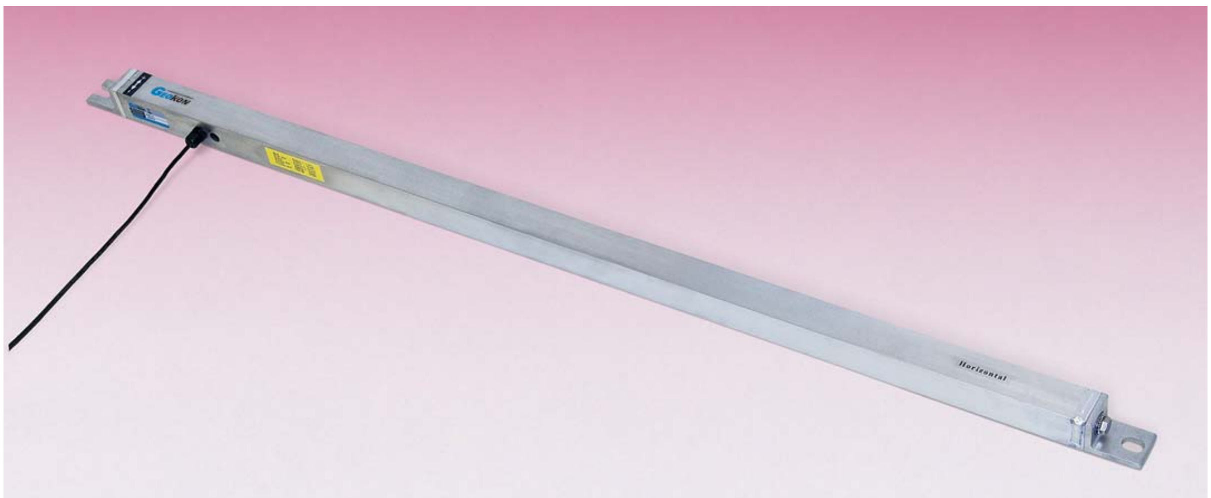


Figure 1 The Model 6165 MEMS Tilt Beam

2. Installation

2.1 Mounting A Horizontal Beam

Each Beam is supplied with two sets of mounting hardware for the two ends.

2.1.1 Use the beam as a template and mark two locations on the wall as close as possible in a horizontal plane, one of them opposite the hole in one end and the other in the center of the slot on the other end. Use a spirit level to make sure that the beam is level before marking the holes. (When installed the horizontal beam must be level both along the axis of the beam and also perpendicular to it: this is simply to avoid any off-axis errors which can occur if the MEMS sensor is rotated axially too far away from the horizontal).

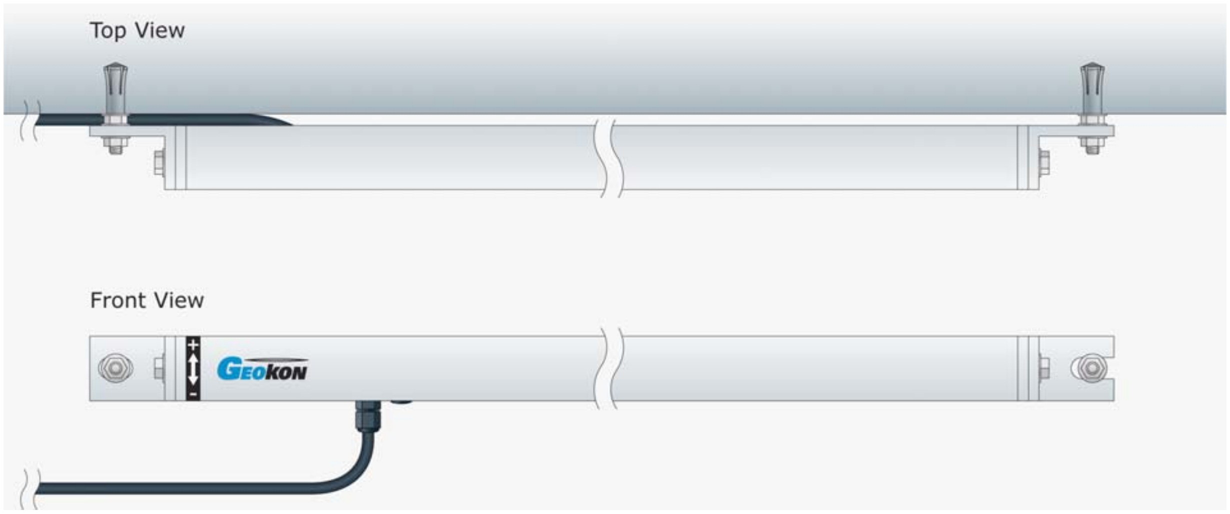
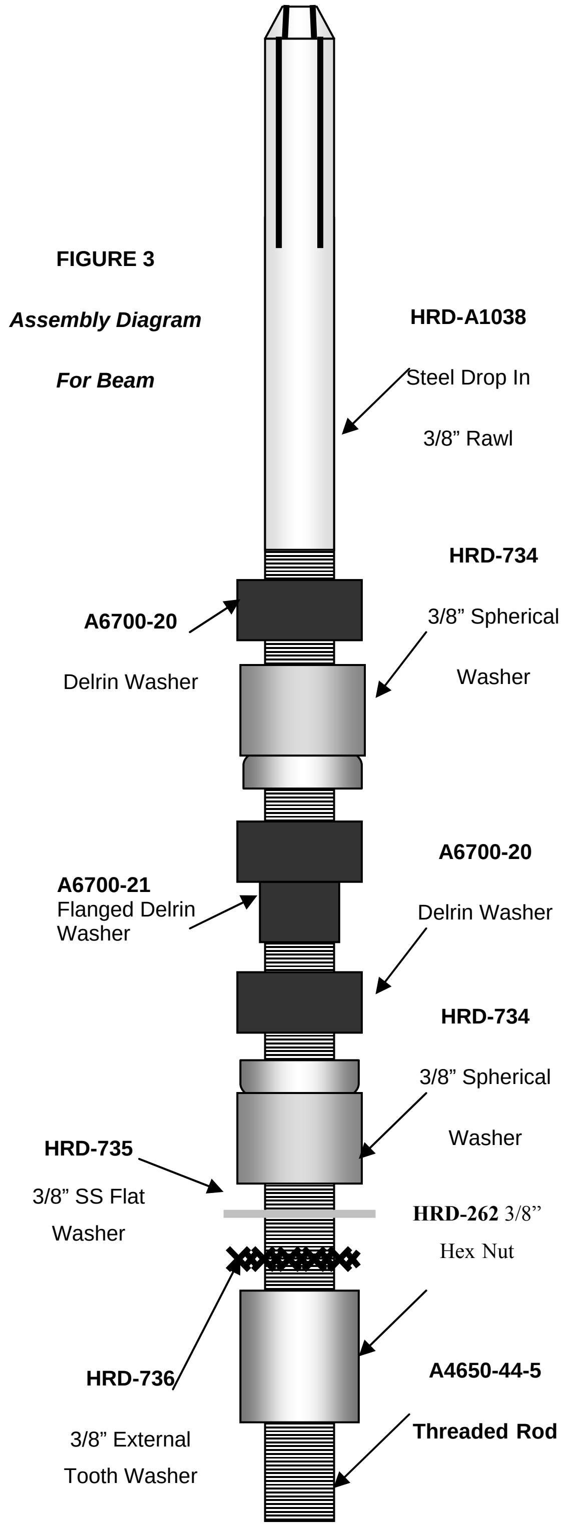
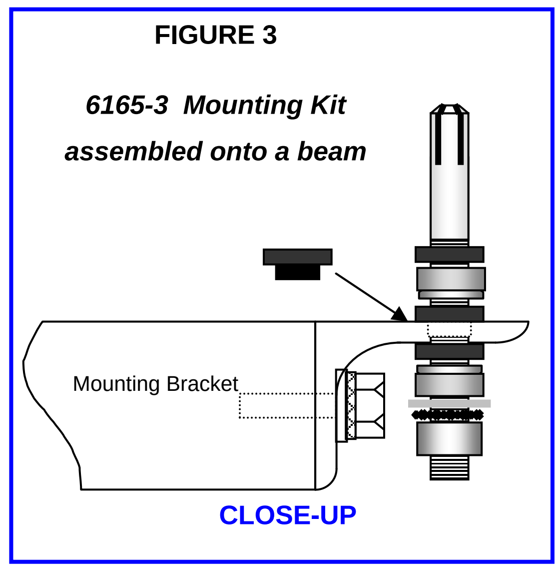


Figure 2. Mounting a horizontal beam to a vertical wall

2.1.2 Use a hammer drill to drill two 12mm (½") hole approximately 40 mm (1.6") deep. Clean the hole thoroughly, blowing out with compressed air if possible. Insert the 3/8" drop-in anchor with setting pin into the hole. The threaded end should be closest to the opening. Use the supplied setting-pin tool and a hammer to set the anchor with 2 or 3 sharp blows on the setting pin. Thread the supplied 3/8-16 anchor rod into the anchor. Attach the mounting brackets at the end of the beams using the hardware supplied following the sequence shown in Figure 3. The spherical washers allow the beam to be rotated with respect to the anchor bolt to assist in leveling the beam. Thread-locking cement can be used to ensure the hardware remains secure. The cable should issue out of the bottom of the beam and next to the Geokon Logo at one end of the beam is a label with a two-way arrow showing the sign of the change in the readout voltage when that end of the beam is tilted in the direction shown.





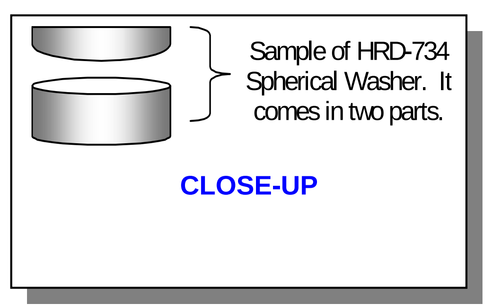


Figure 3. Mounting Hardware

2.2 Mounting A Vertical Beam

The vertical beam is installed in the same manner as the horizontal beam, using the beam itself as a template. The bolts should be installed as close as possible to in-line vertically. Also the mounting studs must be long enough to allow the sensor box to clear the wall or rock surface when leveling and zeroing is performed. Note that for vertical uniaxial 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 them through 90 degrees.

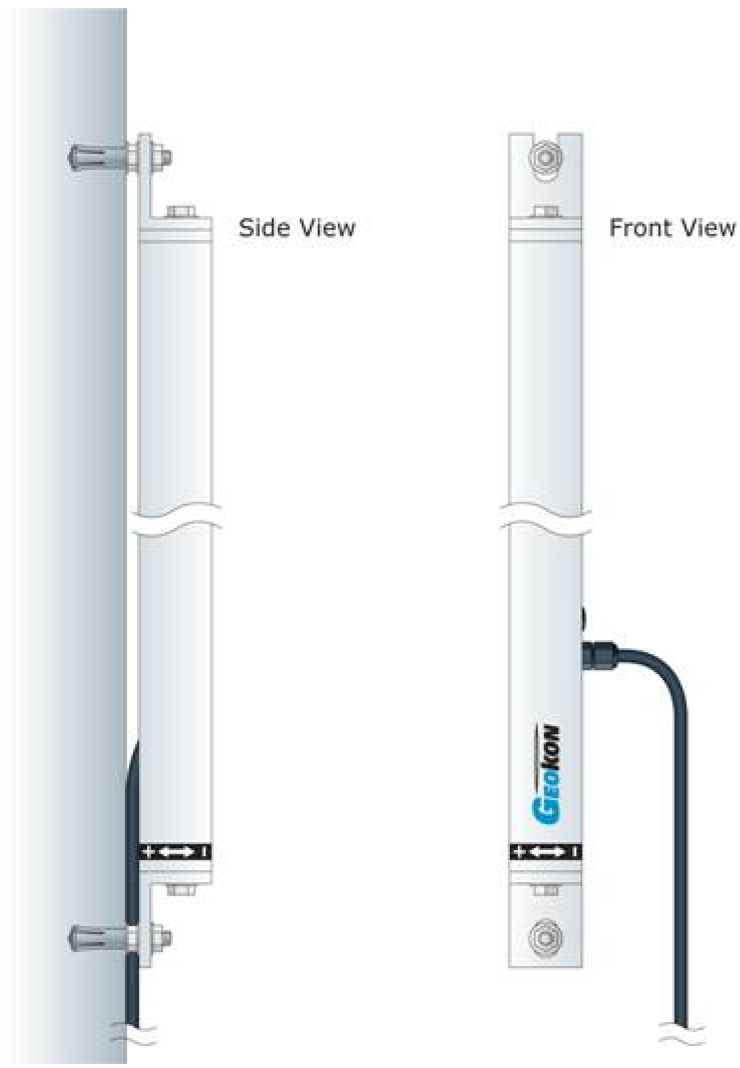


Figure 4. Mounting a vertical beam

Once again the direction of tilt corresponding to an increase in the readout voltage is shown by a label attached to one end of the beam.

3. Taking Readings

The initial zero reading of the MEMS sensor is taken using the RB-500 MEMS readout box. The displayed output should be close to zero volts. The output at +/- 15 degrees is +/- 4 volts. The MEMS sensor can also be read using the Model 8021 or 8025 dataloggers

3.1 Dataloggers

In most cases the 6165 MEMS Tiltmeter will be monitored continuously and automatically using a Datalogger.   Connections to the Geokon Model 8021 Micro-1000 Datalogger, which uses a Campbell Scientific CR1000 MCU are shown in Appendix C Page 11.

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.

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.

3.3 Measuring Temperature

Although the temperature dependence of the MEMS tilt meter is tiny, 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. **The RB-500 will not read temperatures:** a separate digital ohmmeter is required, (or a GK403 or GK 404)

The thermistor gives a varying resistance output as the temperature changes. See the wiring diagram in Appendix C, for the wiring code. Appendix B shows the conversion of resistance to temperature.

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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:

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

Where **R** is the current reading in volts, R_{zero} is the reading at θ =zero, and G_{tilt} is the Gage Factor shown on the calibration sheet for the Model 6165 Tilt Beam. (Example shown in Figure 5, Page 9) 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

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

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

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

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

4.3. Temperature Correction

The Model 6165 MEMS Tilt Beam has very small temperature sensitivity equal to +1 arc second per degree centigrade rise. The tilt corrected for temperature is:

$$\text{Tilt corrected for temperature} = G_{tilt} (R_{1corr} - R_0) \text{ degrees}$$

Where $R_{1corr} = R_1 - 0.0003 (T_1 - T_0)$. The corresponding correction for displacement is

$$\text{Displacement Corrected for temperature} = G_{\sin\theta} L (R_{1corr} - R_0) \text{ mm (inches)}$$

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

The structure being monitored usually is affected by temperature to some degree. 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. The gage 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. **For best results the Tilt Beam should be shielded from direct sunlight.**

4.3. 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 the MEMS sensors used in the Model 6165 Tilt Beams 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 (24 AWG stranded copper leads are approximately 25.7Ω/1000' or 84.5 Ω/km, multiply by 2 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.

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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	Inclination	* Reading 1st Cycle	* Reading 2nd Cycle	* Average Reading	Error in θ	Calculated sinθ
(degrees)	(sinθ)	(Volts)	(Volts)	(Volts)	(%FS)	(%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.

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Figure 5 - Sample Model 6165 Calibration Sheet

APPENDIX A - SPECIFICATIONS

A.1. MEMS Tilt Beam Sensor

Model:	6165
Range:	±15°
FS Output	+/- 4 Volts
Resolution:[1]	+/- 2arc seconds, (+/- 0.01mm/meter)
Accuracy:	0.1% FSR
Linearity:	0.2%F.S (+/- 5degrees range), 0.5% FS (+/- 10 degrees range). +/- 1.5% FSR
Thermal Zero Shift:	0.0003 volt/°C rise
Operating Temperature	-20 to +70° C
Beam Dimensions:	1.5", 38 mm square cross-section
Length:	Variable
Weight:	1.5 lbs., 0.7 kg.
Materials:	Aluminum
Electrical Cable:	3 twisted pair (6 conductor) 24 AWG for uniaxial Foil shield, PVC jacket, nominal OD = 6.3 mm

Table A-1 Model 6165 MEMS Tilt Beam Sensor Specifications

Notes: [1] Depends on readout equipment. For best results requires a 4 ½ digit digital voltmeter.

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:

$$T = \frac{1}{A + B(\mathrm{LnR}) + C(\mathrm{LnR})^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

Where; T = Temperature in °C.

LnR = Natural Log of Thermistor Resistance

$A = 1.4051 \times 10^{-3}$ (coefficients calculated over the −50 to +150° C. span)

$B = 2.369 \times 10^{-4}$

$C = 1.019 \times 10^{-7}$

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 B-1 Thermistor Resistance versus Temperature

APPENDIX C - WIRING CODE

03-250V0 cable	Connector Pin Designation	Uniaxial 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	Thermistor
Green's Black	G	Thermistor

Table C-1 Cable 03-250V0 Wiring

APPENDIX D - CRBASIC PROGRAMMING

Programming the MEMS Tilt Beam 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
```