GEOKON

The World Leader in Vibrating Wire Technology

48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603•448•1562
Fax: 603•448•3216
E-mail: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 6150B

Standard Analog Addressable MEMS In-Place Inclinometer

(REV D 9/19/17)

Warranty Statement

Geokon, Inc. 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.

Geokon manufactures scientific instruments whose misuse is potentially dangerous. The instruments are intended to be installed and used only by qualified personnel. There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Geokon, Inc. is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Geokon, Inc. or any breach of any warranty by Geokon, Inc. shall not exceed the purchase price paid by the purchaser to Geokon, Inc. for the unit or units, or equipment directly affected by such breach. Under no circumstances will Geokon reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon, Inc. neither assumes responsibility for any omissions or s that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

TABLE of CONTENTS

FIGURES, TABLES and EQUATIONS

1. INTRODUCTION

The Geokon Model 6150B Standard Analog Addressable MEMS In-Place Inclinometer system is designed for long term monitoring of deformations in structures such as dams, embankments, foundation walls and the like. The basic principle is the utilization of tilt sensors to make accurate measurement of inclination, over segments, in boreholes drilled into the structure being studied. The continuous nature of the instrument allows for very precise measurement of changes in the borehole profile to be measured. The instrument is installed in standard grooved inclinometer casing. As shown in Figure 1 below.

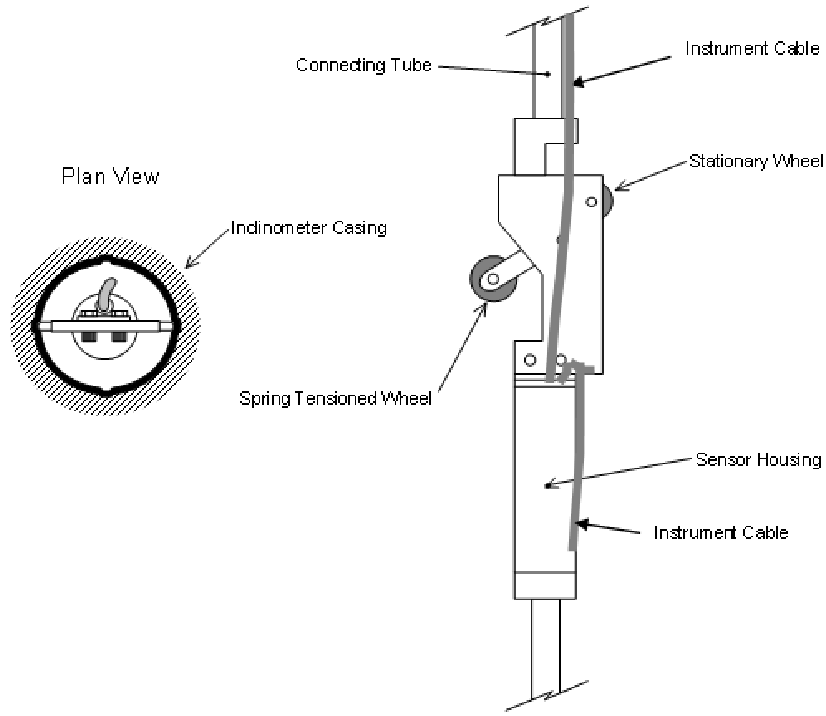


Figure 1 - Model 6150B MEMS Standard Analog addressable Tilt Sensor Assembly

1.1 Tilt Sensor Construction

The tilt sensor comprises one or two Micro-Electro-Mechanical Systems, (MEMS), sensors mounted inside a sealed housing. The Housing has a mounting bracket on its upper end for connecting the sensor to a wheel assembly that centralizes the sensor and orients the sensor when lowered into the casing grooves. A lug on the lower end connects to a universal coupling, which allows unimpeded relative movement between the spacing rods, and a swivel joint which prevents the wheel assemblies from running out of the casing grooves. Stainless steel tubing is used to connect and space apart the transducer and wheel assemblies. The whole string is normally suspended from the top of the casing. Biaxial systems use two transducers mounted at 90° to each other. Each housing contains a thermistor for reading temperatures.

The sensors are connected together by a single six pair cable that is permanently attached to each sensor as part of a string with the cable going in and out of the top of the sensor, one to the sensor above and one to the sensor below. Each string is custom made according to customer specifics. The maximum number of sensors is 16 and the maximum cable length is 305 meters. The assembly is read using the CR6 Datalogger.

2. INSTALLATION

2.1 Preliminary Tests

Prior to installation, the sensors can be checked for proper operation. Each tilt sensor is supplied with a calibration sheet, which shows the relationship between output voltage and inclination. The tilt sensor electrical leads are connected to a Datalogger, (see Appendix C.2 for the wiring diagram), and the current reading compared to the calibration readings.

Carefully hold the sensor in an approximately vertical position and observe the reading. The sensor must be held in a steady position. The readings should be close to the factory vertical reading. At a tilt angle of about ±15 degrees, the sensor output should be around ±4 Volts.

The temperature indicated by the thermistor, and readout on the green and white wires using an ohmmeter, should be close to ambient.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the Blue and Blue's Black pair should be approximately 3000 ohms at 25° (see Table 2 in Appendix B), and between any conductor and the shield or the case should exceed two megohms.

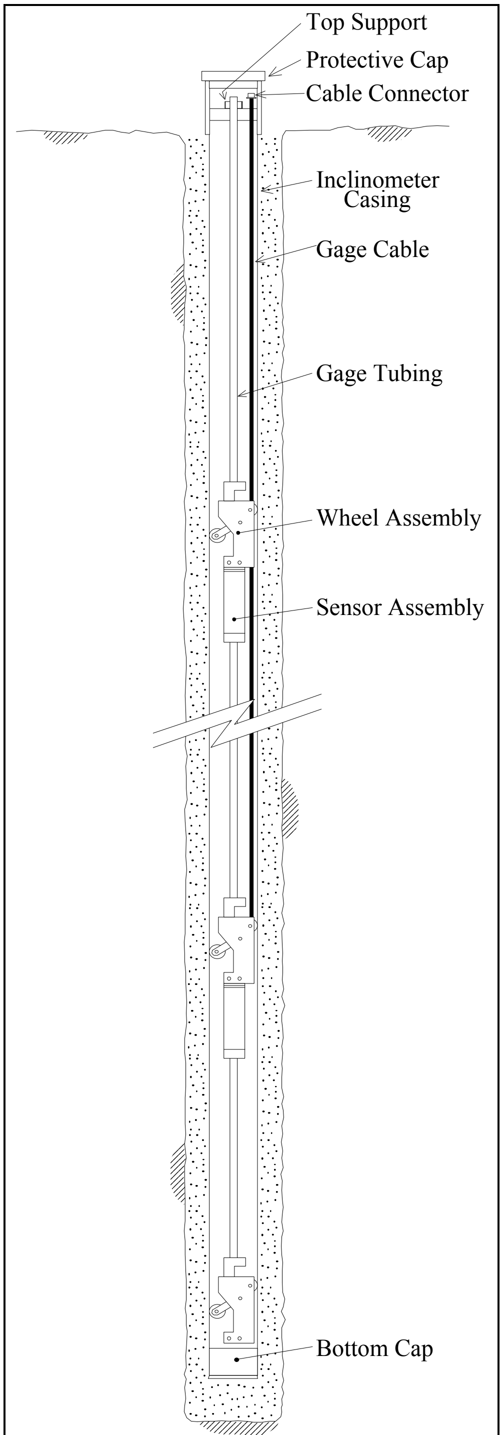


Figure 2 - Model 6150 Installation

2.2 Assembly and Installation

2.2.1 Connections to the bottom wheel assembly

Attach the bottom wheel assembly to the first tube section using a long 10-32 cap screw and nut. (*Use Loctite 222 on all threads.*) The lengths of tubing that make up the IPI string are shown in a table supplied along with the calibration sheets.

(Where the inter-anchor spacing is large, two tubes are joined together by a special union. Use 10-32 screws, nuts, and a thread locking cement to make this joint.)

Attaching a safety cable to the bottom wheel assembly is strongly recommended. Not only can it be used to retrieve the assembly in the event that one of the joints breaks loose, but it is also very useful in lowering the assembly into the casing. (The alternative to using the safety cable is to hold the tube sections with vice-grips at the top of the casing.)

The safety cable has a loop at its bottom end which fits over the long bolt used to hold the bottom wheel assembly to the first tube section. (The bottom wheel assembly is labeled, and it has no universal joint, just a swivel.) Slide the cable eyebolt onto the screw and attached a second nut, thus trapping the safety cable between the two nuts. See Figure 3.

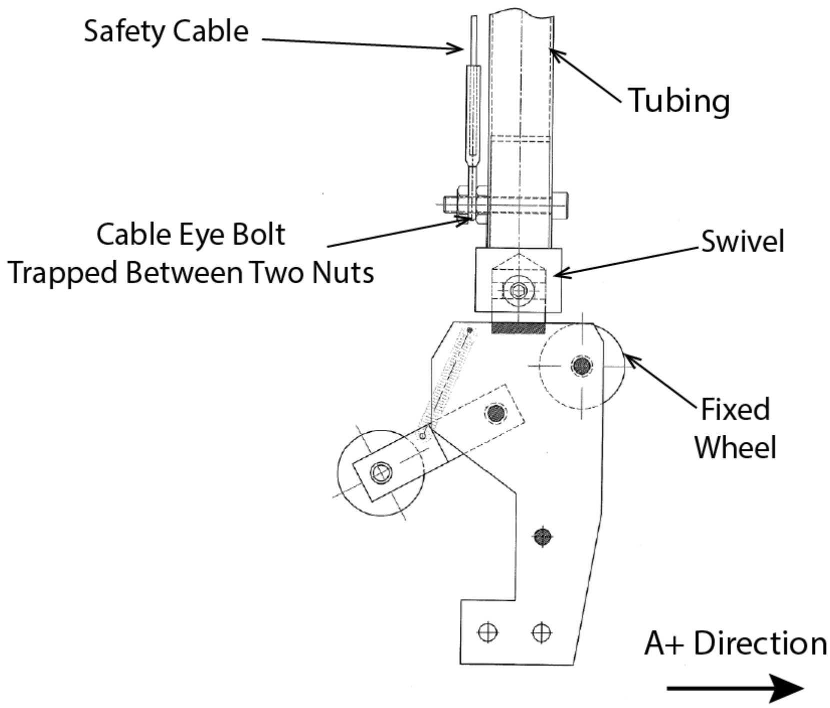


Figure 3 - Bottom Wheel Assembly

2.2.2 Connect the first sensor to the tubing and begin lowering the string

The bottom sensor with wheel assembly attached is connected to the next tube section using a long 10-32 cap screw and nut. (*Remember; use Loctite 222 on all threads.*)

The gage and tube assembly is now lowered into the borehole, using the safety cable, with the upper assembly fixed wheel aligned in the A+ direction (See Figure 3).

It is customary (and recommended) to point the A+ direction in the same direction as the anticipated movement, i.e., towards the excavation being monitored or downslope in the case of slope stability applications. Be sure that the lower wheel assembly and swivel are also aligned this way.

Both uniaxial and biaxial sensors are delivered with the orientation set such that the A+ direction marked on the sensor is aligned on the same side as the fixed wheel on the wheel assembly. (See Figure 3 above.) In a biaxial system, a second MEMS sensor is included in the housing and is attached with its positive direction 90° clockwise from the upper sensor (looking downwards in plan). This is the B+ direction. (See Figure 4.) Tilts in the positive direction yield increasing voltage readings.

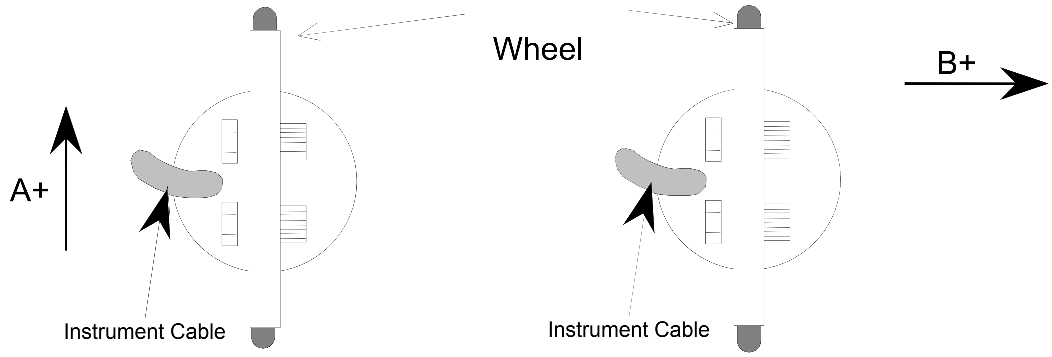


Figure 4 - Biaxial Sensor Orientation

2.2.3 Continue assembling and lowering the string

While holding the assembly at the top of the casing, the next tube segment is attached to the next sensor and lowered in the same orientation. The system can become quite heavy and a clamp of some sort (vice-grips) should be used to hold the rods in place while being assembled. The use of a winch to hold the safety cable can be of help. Note that the longer cables are on reels to facilitate handling. Something like two little saw horses (or even folding chairs) with a broom stick across them to act as an axle will allow the cable to spool off as needed, avoid entanglements and provide a holding point for extra cable.

The cables from the lower sensors should be taped or tie wrapped to the assembly at intervals to prevent interference as the system is built up and lowered down the borehole.

Continue to add gage tubing to the sensors and wheel assemblies until the last sensor has been installed.

At this point, the top suspension must be attached to the upper wheel assembly (or the gage tube). The assembly is bolted to the wheel assembly (or tube) as before, and then lowered into position on the casing. It is important that the casing be relatively square to prevent any side interference in the upper sensor wheel assembly.

After the sensor string is lowered into position, the safety cable can be tied off around the top of the casing and the signal cables can be run to the readout location and terminated at a switch box or otherwise fixed. Readings can be taken immediately after installation, but it is recommended that the system be allowed to stabilize for a few hours before recording zero conditions.

3. TAKING READINGS

3.1 Dataloggers

The 6150B MEMS Standard Analog Addressable In-place Inclinometer will be monitored continuously and automatically using a Datalogger. Connections to the Geokon Model 8600 Datalogger, which uses a Campbell Scientific CR6 Measurement and Control System, are shown in Appendix C.2. The CR6 datalogger supplied with the 6150B has been programmed to read the MEMS tiltmeter 100 times at each sample and calculate the average. If the user programs their own datalogger it is recommended that averaging be used to achieve better accuracies and more stable readings.

3.2 Measuring Temperature

Although the temperature dependence of the MEMS tilt meter is close to zero, 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 datalogger automatically measures the thermistor resistance and converts it into a temperature using Equation 6 in Appendix B.

The above remarks apply mainly to structures exposed to sunlight: in these situations, it is not uncommon for the structure to expand and contract differentially during the course of the day. For 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.

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 four volts.
The relationship between the reading, **R**, and the angle of inclination, **θ,** is given by the equation:

$$\theta = \mathrm{Sin}^{-1}(RG) \qquad \text{or} \qquad \mathrm{Sin}\theta = RG$$

Equation 1 - Inclination versus voltage

Where **R** is the reading in Volts and **G** is the Gage Factor (sinθ/volt) shown on the calibration sheet. Note that the small voltage reading at zero inclination can be ignored since it is only the tilting, i.e. change of inclination that is of interest. Note also that for small angles sinθ = θ radians.

The amount of tilt, in degrees, is given by the equation:

$$\mathrm{Tilt} = \mathrm{Sin}^{-1}\,(R_1 - R_0)G \text{ degrees}$$

Equation 2 - Tilt degrees versus voltage.

Positive values are tilts in the direction of the arrows A+ and B+

4.2 Temperature Correction

The Model 6150B Standard Analog Addressable MEMS Tiltmeter has very small temperature sensitivity equal to +1 arc second per degree centigrade rise. The tilt corrected for temperature is:

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

Equation 3 - Tilt versus voltage corrected for Temperature.

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

Normally, temperature corrections are not required. 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.

4.3 Deflection Calculation

The lateral offset, **D**, of the top of any segment relative to the vertical line running through the bottom of the segment is equal to **L**$\sin\theta$**,** where L is the length of the segment, between pivot points, and θ is the inclination of the segment to the vertical.

The length L_1, L_2, L_3, etc., can be calculated by adding **336 mm**, (both uniaxial and biaxial systems) to the individual lengths of tubing. This will give the correct distance between pivot points.

The profile of the borehole is constructed by using the cumulative sum of these lateral offsets starting with the bottom segment, $\mathbf{L_1}$. For instance, referring to Figure 5, the total lateral offset of the top of the upper segment, (which is usually at the surface), from the vertical line drawn through the bottom of the lower segment, (located at the bottom of the borehole), is

$$D_5 = L_1\sin\theta_1 + L_2\sin\theta_2 + L_3\sin\theta_3 + L_4\sin\theta_4 + L_5\sin\theta_5$$

Equation 4 - Offset Calculation

Therefore, ignoring temperature corrections,

$$D_5 = G_1L_1R_1 + G_2L_2R_2 + G_3L_3R_3 + G_4L_4R_4 + G_5L_5R_5$$

And the deflection, **ΔD,** i.e. the change in offset is

$$\Delta D_n = \sum_{1}^{n} G_nL_n\,\Delta R_n$$

Equation 5 - Deflection Calculation

Where $\mathbf{\Delta R_1 = (R_1 - R_0)}$ i.e. the present reading on Tiltmeter 1 minus the initial reading on Tiltmeter 1; and $\mathbf{\Delta R_2 = (R_2 - R_0)}$ i.e. the present reading on Tiltmeter 2 minus the initial reading on Tiltmeter 2; and similarly for all the other Tiltmeters.

Although the system is designed for use in continuous segments with pivots, the sensors can be installed without interconnecting tubing in standard, round tubing or pipe using special friction anchors. In those systems, the assumption is made that the measured deflection occurs over the segment length, the midpoint of which is at the sensor location, and that L is the distance between adjacent midpoints.

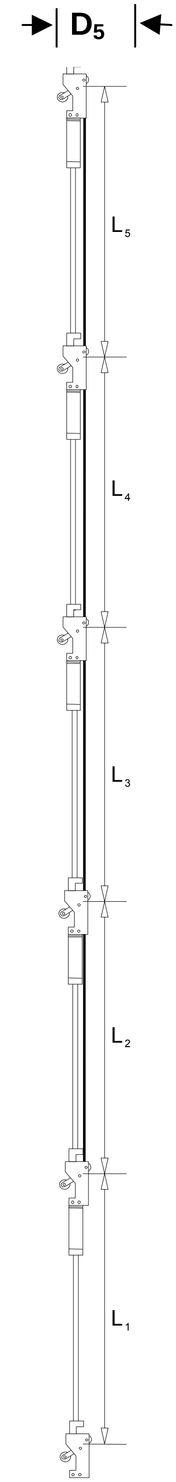


Figure 5 -Deflection Intervals

<u>NOTE</u>: The bottom sensor, though referred to as Tiltmeter 1 for deflection calculation, will be addressed per its position in the string, from the surface downward. In the above example, Tiltmeter 1 would be addressed as #5, and will be displayed as CH5 or Sensor 5 in the data file.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

MEMS Tilt Sensor Calibration

Model Number: 6150B-2

Calibration Date: March 16, 2017

This calibration has been verified/validated as of 09/19/2017

Serial Number: 1711352 Sensor A

Temperature: 22.8 °C

Calibration Instruction: CI-Tiltmeter MEMS Sensor

Technician:

Inclination (degrees)	Inclination (sinΘ)	Reading 1st Cycle	Reading 2nd Cycle	Average Reading	Error in calculated (% FS) Θ	sinΘ
15.00	0.2588	4.045	4.045	4.0450	-0.12	0.04
14.00	0.2419	3.775	3.775	3.7750	-0.07	0.02
12.00	0.2079	3.234	3.234	3.2340	0.04	0.01
10.00	0.1736	2.688	2.689	2.6885	0.09	-0.01
8.00	0.1392	2.140	2.140	2.1400	0.11	-0.02
6.00	0.1045	1.590	1.590	1.5900	0.11	-0.02
4.00	0.0698	1.037	1.037	1.0370	0.07	-0.03
2.00	0.0349	0.484	0.483	0.4835	0.02	-0.03
0.00	0.0000	-0.068	-0.068	-0.0680	0.00	0.00
-2.00	-0.0349	-0.622	-0.622	-0.6220	-0.05	0.00
-4.00	-0.0698	-1.176	-1.176	-1.1760	-0.10	0.00
-6.00	-0.1045	-1.726	-1.726	-1.7260	-0.11	0.02
-8.00	-0.1392	-2.277	-2.277	-2.2770	-0.12	0.01
-10.00	-0.1736	-2.824	-2.824	-2.8240	-0.09	0.01
-12.00	-0.2079	-3.368	-3.368	-3.3680	-0.02	0.01
-14.00	-0.2419	-3.910	-3.909	-3.9095	0.08	0.00
-15.00	-0.2588	-4.178	-4.177	-4.1775	0.17	0.00

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, 6161 and 6165 Tiltmeter Gage Factor (G_{tilt}): 3.638 (degrees/Volt) over +/-15° range

Calculated Tilt = G_{tilt} $(R_1 - R_0)$ 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.

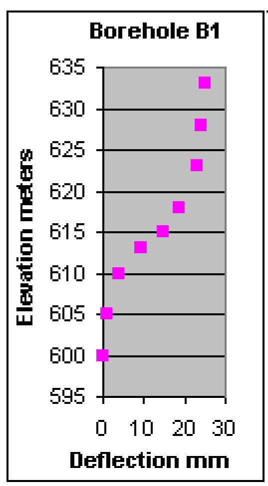
This report shall not be reproduced except in full without written permission of Geokon Inc.

Figure 6 - Sample Model 6150 MEMS Calibration Sheet

4.4 Sample Calculation

	MEMS DEFLECTION CALCULATION		Borehole#1					
SENSOR		L	Depth	Elevation	G	R0	T0	
		meters	meters	meters	Sinθ/V	Volts	° C	
Surface			0	633				
1		5	5	628	0.06271	0.582	20	
2		5	10	623	0.06303	0.5632	18	
3		5	15	618	0.06221	0.5495	18	
4		3	18	615	0.06295	0.532	17	
5		2	20	613	0.06284	0.5144	17	
6		3	23	610	0.06291	0.4883	17	
7		5	28	605	0.06273	0.4321	17	
8		5	33	600	0.06289	0.3962	17	

		R1	T1	$R1_{corr}$	$R1_{corr}$ -R0	GL(R1-R0)	Acc Defl	
		Volts	° C	Volts	Volts	mm	mm	
Surface								
1		0.5802	10	0.5832	0.0012	0.38	24.23	
2		0.5644	12	0.5662	0.003	0.95	23.85	
3		0.5632	17	0.5635	0.0140	4.35	22.90	
4		0.5514	17	0.5514	0.0194	3.66	18.55	
5		0.5602	17	0.5602	0.0458	5.76	14.89	
6		0.5169	17	0.5169	0.0286	5.40	9.13	
7		0.4404	17	0.4404	0.0083	2.60	3.74	
8		0.3998	17	0.3998	0.0036	1.13	1.13	



4.5 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 the vibrating wire tilt sensors used in the Model 6150B Standard Analog Addressable In-Place Inclinometer 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.

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 (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 52Ω/km, multiply by two 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 Datalogger work with another tilt sensor? If not, the 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:	6150B
Range	±15°
Resolution:[1]	±2 arc seconds, (±0.01 mm/m)
Accuracy[2]	±3 arc seconds
Linearity:[3]	±0.07% FS
Cross axis sensitivity	4%
Thermal Zero Shift:	-0.0003 volt/°C rise
Operating Temperature	-20 to +80° C -4 to 176° F
Power Requirements[4]:	6150B-1 (Uniaxial): +12V (nom) @ 30mA (9V min. / 15Vmax.) 6150B-2 (Biaxial): +12V (nom) @ 45mA (9V min. / 15Vmax.)
Sensor Output:	±4 Volts @ FS
Frequency Response:	-3db @ 8-28 Hz
Shock Resistance	2,000g
Thermistor Resistance:	3000Ω at 25 °C
Sensor Housing Dia.:	32 mm (1.250")
Length:	362 mm (14.25")
Weight:	0.7 kg (1.5 lb.)
Materials:	304 Stainless Steel
Electrical Cable:	Six twisted pair (12 conductor) 24 AWG Foil shield, Polyurethane jacket, nominal OD = 7.9 mm

Table 1 - Model 6150B Standard Analog Addressable MEMS Tilt Sensor Specifications

Notes:

[1] For best results requires a 4 1/2 digit, digital voltmeter.
Averaging 100 readings 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)

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:

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

Equation 6 - Convert Thermistor Resistance to Temperature

Where;
T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = 1.4051×10^{-3} (coefficients calculated over the −50 to +150° C. span)
B = 2.369×10^{-4}
C = 1.019×10^{-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 2 - Thermistor Resistance versus Temperature

APPENDIX C. 6150B STANDARD ANALOG ADDRESSABLE SYSTEMS

C.1 Description

The standard 6150B standard analog 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 Inclinometer "string" is addressed via ENABLE and CLOCK signals in the same manner as the Geokon Model 8032-16 Channel Multiplexer.

The addressable Inclinometer 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 warmup. 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 D.

C.2 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 3 - Addressable MEMS (Logic Level Style) Wiring

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

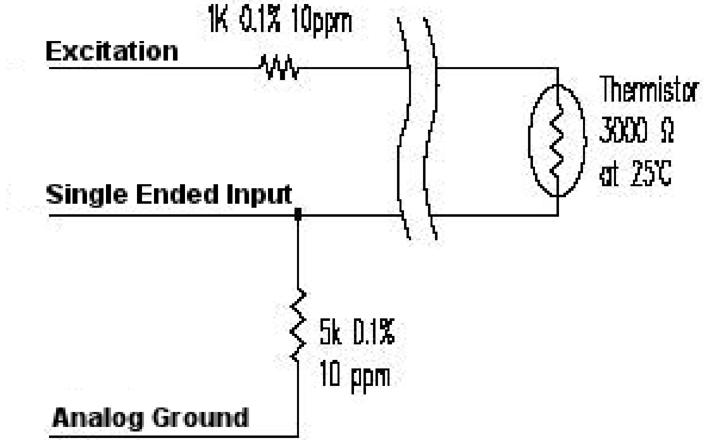


Figure 7 - Thermistor Bridge Circuit

C.3 Specifications for Addressable System (Logic Level Style) Circuit Board

Board Dimensions:	4.5"(L) x 1.155"(W) x 0.4"(H)
Operating Temperature:	-20 to +70° C
Contact Resistance:	100 mΩ (typ)
Contact Breakdown Voltage:	1500 Vrms
Relay open/close time:	4mS (max)
Power Requirements:	+12V (±3V) 35mA (max) when active 70uA (max) standby

Table 4 - Circuit Board Specifications

APPENDIX D. PROGRAMMING THE 6150B STANDARD ANALOG ADDRESSABLE MEMS IPI 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.

D.2 Sample Program:

The following sample program reads six addressable uniaxial MEMS Gages and Thermistors. The A-Axis is read on Differential Channel 1, the Thermistors are read with Single Ended Channel 5 and the bridge excited with VX1. The string is enabled with Control Port 1 and clocked with control port 8. A bridge completion circuit must be used to read Thermistors.

```
'Reads 1 uniaxial MEMS string with 6 Gages and 6 Thermistors

'Declare Public Variables for all gages and calculations

Public MEMS_1
Public MEMS_2
Public MEMS_3
Public THERM_1
Public THERM_2
Public THERM_3
Public Reading_IPI_1(6)  'IPI String Reading for 6 Gages
Public Reading_THERM_1(6)  'Thermistor Readings for 6 Gages

'Declare Constants for Thermistor Readings
'Coefficients for Steinhart-Hart equation

Const A = .0014051
Const B = .0002369
Const C = .0000001019

'Counter

Dim i

'Store MEMS outputs and Thermistors every Scan

DataTable (MEMS_IPI,1,-1)

Sample (6,Reading_IPI_1(),IEEE4)
Sample (6,Reading_THERM_1(),IEEE4)

EndTable
```

BeginProg

'30 second scan interval

Scan (30,sec,0,0)

'Enable String using C1

PortSet(1,1)
'Delay
Delay(0,125,MSEC)

'Counter to loop 6 times

For i = 1 To 6

'1st clock using C8 (there is two clock pulses required for each gage)

PortSet(8,1)
Delay(0,10,MSEC)
PortSet(8,0)
Delay(0,10,MSEC)

'Read the A-axis
'Reset the temporary storage location for the 100 average readings

MEMS_3 = 0

'Counter to take 100 readings

For MEMS_1 = 1 To 100

'Differential voltage measurement on Differential Channel 1

VoltDiff (MEMS_2,1,mV5000,1,False,0,1000,0.001,0)

'Take the average
'Sum the readings

MEMS_3 = MEMS_3 + MEMS_2
Next

'Calculate the Average reading value out of 100 readings

```
Reading_IPI_1(i) = MEMS_3 / 100
```

'Thermistor Reading

```
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(i) = (1/(A+B*LN(THERM_3)+C*(LN(THERM_3))^3)-273.15)
```

'2nd clock using C8 to advance to next gage and thermistor

```
PortSet(8,1)
Delay(0,10,MSEC)
PortSet(8,0)
Delay(0,10,MSEC)
```

'Next channel counter

```
Next i
```

'Disable string

```
PortSet (1,0)
```

'Store Data for the IPI string

```
CallTable MEMS_IPI

NextScan
EndProg
```