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Instruction Manual

Model 6300

Vibrating Wire In-Place Inclinometer

(Doc Rev Q, 05/01/19)

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EQUATIONS

1. INTRODUCTION

The Geokon Model 6300 Vibrating Wire 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 (Figure 1).

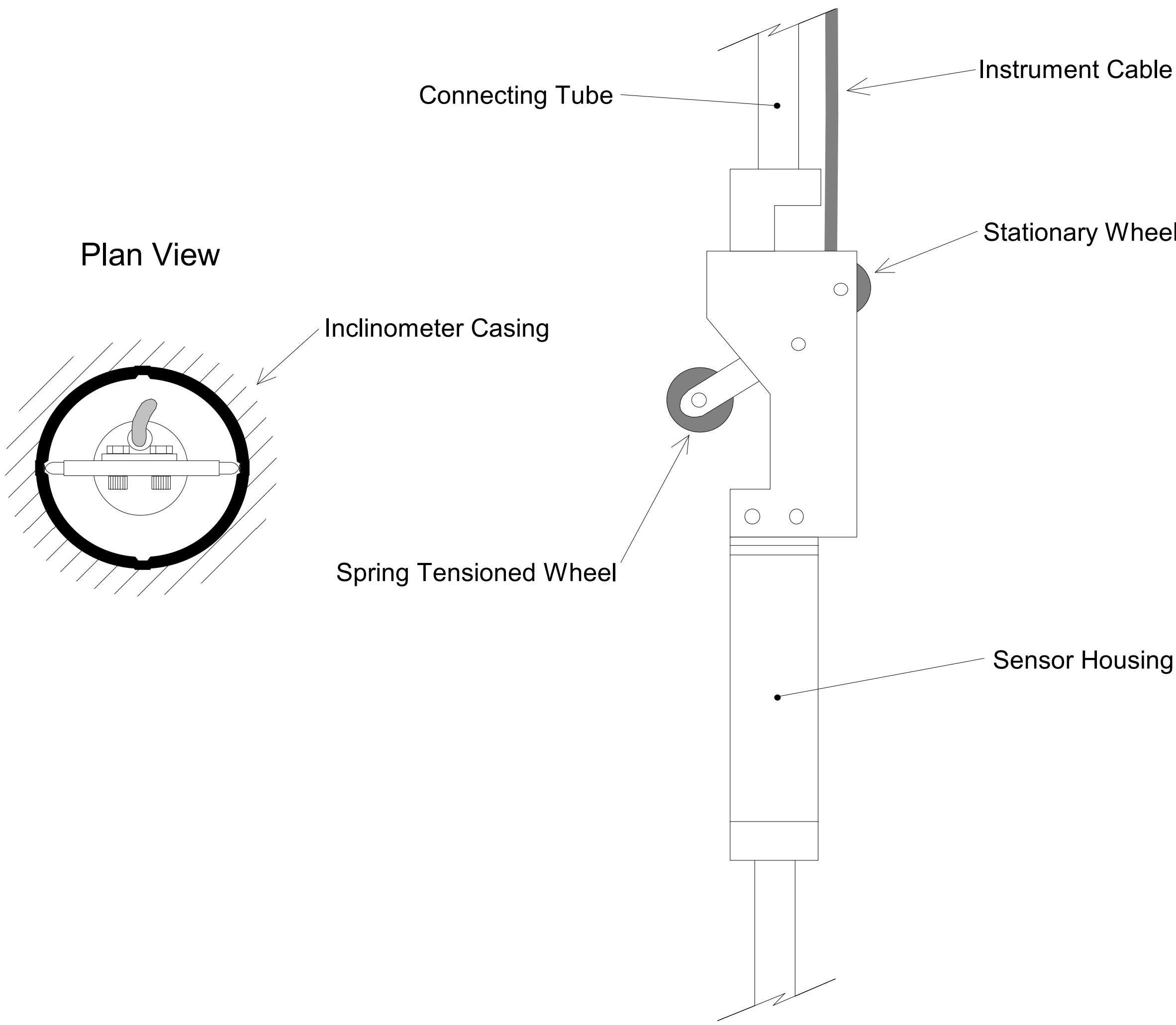

Figure 1 - Model 6300 Tilt Sensor Assembly

1.1 Tilt Sensor Construction

The sensor comprises a pendulous mass which is supported by a vibrating wire strain gauge and an elastic hinge (Figure 2). The strain gauge senses the changes in force caused by rotation of the center of gravity of the mass. The mass and sensor are enclosed in a waterproof housing which includes components for connecting the sensor to wheel assemblies and/or other sensors. The wheel assemblies centralize the sensors and allow the assembly to be lowered into the casing. Swivel joints are included to prevent the wheel assemblies from running out of the casing grooves due to spiral problems. Stainless steel tubing is used to connect the transducer and wheel assemblies together, and the whole string is normally supported from the top of the casing. Biaxial systems use two transducers mounted at 90° to each other.

To prevent damage during shipment the tilt sensors are locked in place by means of a locking clamp screw. This slotted-head clamp screw must be removed and replaced by a Phillips-head seal screw, (provided in the zip-lock bag), to render the tiltmeter operative.

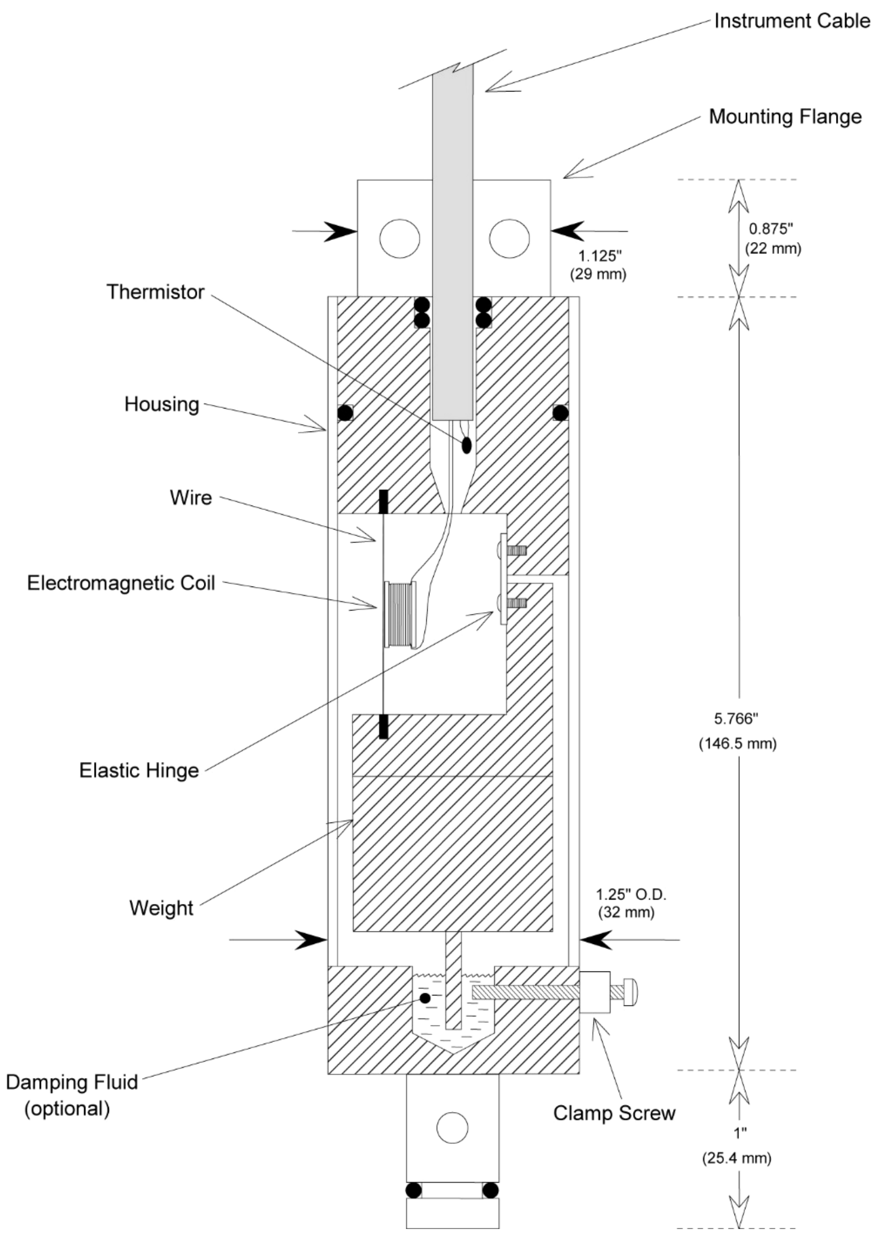

Figure 2 - Model 6300 Tilt Sensor

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 that shows the relationship between readout digits and inclination. The tilt sensor electrical leads (usually the red and black leads) are connected to a readout box (see Section 3 for readout instructions) and the current reading compared to the calibration readings. After backing-off the clamp screw three full turns, carefully position the sensor against a vertical surface and observe the reading. It will take a few seconds to come to equilibrium and the sensor must be held in a steady position. The readings should be within ±200 digits of the factory reading, re-tighten the clamp screw three turns.

Note: Vibrating wire tilt sensors are shock sensitive and severe shocks can cause a permanent offset or even break the suspension. (The unit will not survive a two foot (0.5 m) drop onto a hard surface). When transporting the tiltmeter tighten the locking clamp screw.

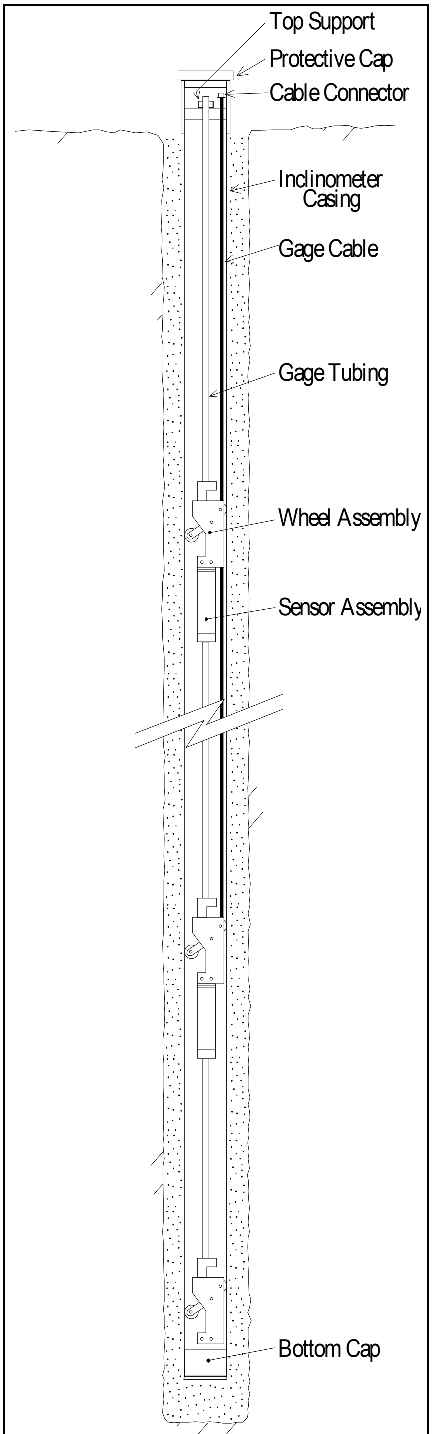

Figure 3 - Typical Installation

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gauge leads should be approximately 180 Ω, ±10 ohms. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by two for both directions). The resistance between the green and white leads varies with temperature. Compare the measured resistance and ambient temperature to the factors shown in Table 2 in Appendix B. The resistance between any conductor and the shield should exceed two megohm.

2.2 Model 6300 Assembly and Installation

1) Connect the safety cable to the bottom wheel assembly. (See Figure 3.) This 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 is to hold the tube sections with vice-grips at the top of the casing.

   The bottom anchor is labeled and has no Universal joint, just the swivel. The safety cable has a loop at its bottom end which fits over the long bolt used to hold the bottom anchor to the first tube section. This is shown in Figure 3. The cable eyebolt is trapped between two nuts.

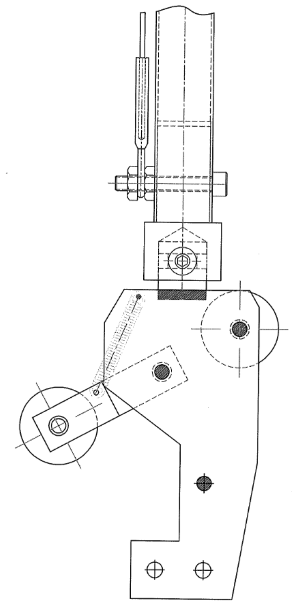

Figure 4 - Bottom Wheel Assembly with Safety Cable

2) Connect the first length of gauge tubing to the bottom wheel assembly. The length of tube is shown in the table supplied with this manual. (In some cases, two tubes are joined together by a special union.) Use the 10-32 screws and nuts, and a thread locking cement to make this joint.

3) The next step is to attach the uniaxial or biaxial sensor assembly.

2.2.1 Uniaxial System

The uniaxial sensor is delivered unattached to its wheel assembly and should be attached using the two 10-32 nuts and cap screws supplied. The tongue of the sensor fits inside the slot of the wheel assembly 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. Tilts in the positive direction yield increasing readings in digits.

Vibrating wire tilt sensors are shipped with a clamp screw holding the internal pendulum mechanism so that it is not damaged in shipment. A label is attached to each sensor emphasizing the importance of removing the slotted-head clamp screw completely and replacing it with the Phillips-head seal screw taped to the sensor. (Extra seal screws are provided in a zip-lock bag along with other accessories in case some become lost). This is very important for the sensor to be able to respond to tilting and remain waterproof.

The sensor and wheel assembly is now attached to the first tube section using a single long 10-32 cap screw. (Use Loctite 222 on all threads.)

2.2.2 Biaxial System

The biaxial sensors are delivered unattached to the wheel assembly and to each other. The upper sensor should be attached to the wheel assembly using the two 10-32 nuts and cap screws supplied. The tongue of the sensor fits inside the slot of the wheel assembly 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. (Tilts in the positive direction yield increasing readings in digits).

The adaptor piece is now bolted to the bottom of the sensor using a single 10-32 cap screw and thread locking compound (Loctite 222).

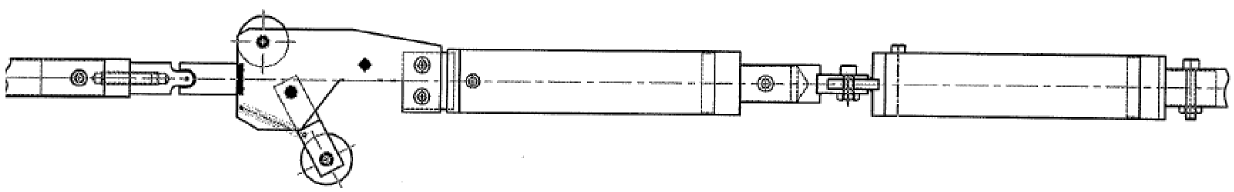

Figure 5 - Biaxial sensor assembly

Two short cap screws are used to attach the lower sensor via this adaptor with its positive direction (Marked A+ on the sensor body) at 90° clockwise from the upper sensor (in plan looking down the casing). This will be the B+ direction. See Figure 6.

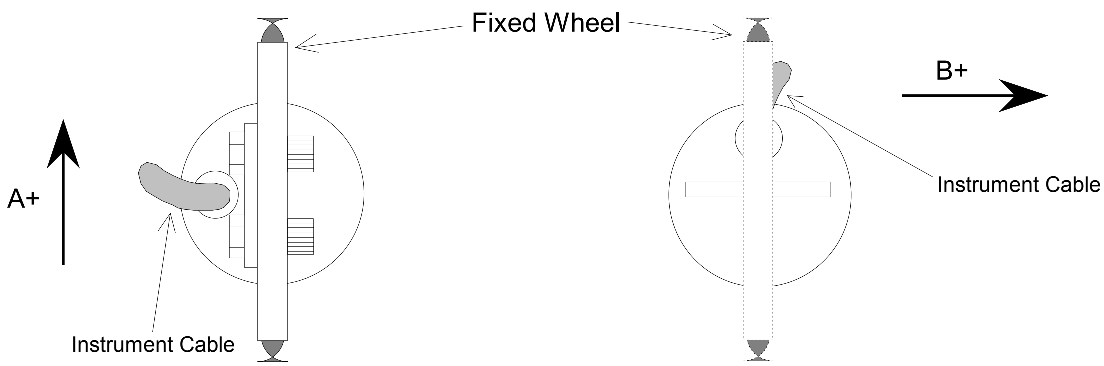

Figure 6 - Biaxial Sensor Orientation

Note that there is some clearance around the bolt holes which will allow for some manual alignment of the sensors (absolute alignment is not critical).

When the two sensors are connected, the lower one is joined to the previously prepared gauge tube. **Vibrating wire tilt sensors are shipped with a clamp screw holding the internal pendulum mechanism so that it is not damaged in shipment. A label is attached to each sensor emphasizing the importance of removing the slotted-head clamp screw completely and replacing it with the Phillips-head seal screw taped to the sensor. (Extra seal screws are provided in a zip-lock bag along with other accessories in case some become lost). This is very important for the sensor to be able to respond to tilting and remain waterproof.**

This assembly is now lowered into the borehole, using the safety cable, with the upper assembly fixed wheel aligned in the so-called A+ direction. 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 down-slope in the case of slope stability applications. Be sure that the lower wheel assembly and swivel are also aligned this way.

While holding the assembly at the top of the casing, using either the safety cable or vice grips on the tubing, the next segment with sensors, wheels and swivel are attached and lowered in the same orientation. The system can become quite heavy and a clamp of some sort may need to be used to hold the rods in place while being assembled. The use of a winch to hold the safety cable can be a 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 and provide a storage point for the rest of the cable.

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

Continue to add gauge tubing, sensors and wheel assemblies until the last sensor has been attached to the upper wheel assembly, which is pre-assembled to the top suspension (Figure 7). The Top suspension can then be lowered into position on the casing. It is important that the end of the casing be cut square to prevent any side pressure on the upper sensor wheel assembly.

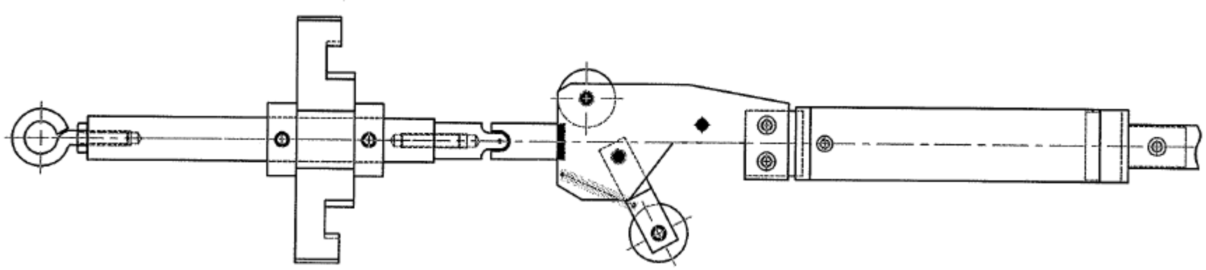

Figure 7 - Top Suspension

After the sensor string has been 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 or otherwise fixed. Readings should be taken immediately after installation, but it is recommended that the system be allowed to stabilize for a few hours before recording zero conditions.

For IPI strings that are going to measure only across a subsurface zone of interest and will not reach the surface, the cross-piece of the top suspension is omitted and the IPI string is suspended at the proper depth by a length of aircraft cable, attached to the eyebolt, and tied off at the top of the casing.

2.3 Fluid Damping

The vibrating wire tilt sensor acts as a self-damping system when used in vibration free environments. When external ground or structural vibrations exceed a certain threshold, the pendulous mass will continue to "dither" and stable readings may not be possible. In such cases, additional damping can be achieved by adding a viscous damping fluid to a small reservoir contained in the sensor. A thin, wide "paddle" is connected to the mass and when the fluid is added the pendulum is damped by the action of the paddle in the damping fluid.

Most in-place installations <u>will not</u> require this fluid. However, if the instrument gives unstable outputs, or it is known that the structure is constantly vibrating, the fluid can be added. The fluid is a high-viscosity silicone oil which must be injected into the sensor with a syringe.

The sensor must be held upright during the injection of the fluid and <u>at all</u> times following the injection. This makes it necessary to perform this operation in the field. The following applies for a typical in-place installation.

1) After connecting the sensor to the gauge tubing already in the casing, and after removal of the clamping screw, use the syringe applied, first pull the piston from the syringe and squeeze the silicone from the tube into the syringe. Replace the piston and start the silicone oil out of the "needle" end.

2) Now, inject 2.00 cc into the hole in the sensor. Immediately following this operation, the seal screw should be replaced in the sensor.

3) The sensor may now be lowered into the casing.

2.4 Splicing and Junction Boxes

Because the vibrating wire output signal is a frequency rather than current or voltage, variations in cable resistance have little effect on gauge readings and, therefore, splicing of cables has little effect and, in some case, may be beneficial. For example, if multiple sensors are installed in a borehole, and the distance from the borehole to the terminal box or datalogger is great, a splice could be made to connect the individual cables to a single multi-conductor cable. This multiconductor cable would then be run to the readout station. For such installations it is recommended that the transducer be supplied with enough cable to reach the top of the casing plus enough extra to make splicing possible.

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 itself in strength and electrical properties. Contact Geokon for splicing materials and additional cable splicing instructions.

Junction boxes and terminal boxes are available from Geokon for all types of applications. In addition, portable readout equipment and datalogging hardware are available. Contact Geokon for specific application information.

3. TAKING READINGS

3.1 GK-404 Readout Box

The Model GK-404 Vibrating Wire Readout is a portable, low-power, handheld unit that can run continuously for more than 20 hours on two AA batteries. It is designed for the readout of all Geokon vibrating wire gauges and transducers; and is capable of displaying the reading in either digits, frequency (Hz), period (μs), or microstrain (με). The GK-404 also displays the temperature of the transducer (embedded thermistor) with a resolution of 0.1 °C.

3.1.1 Operating the GK-404

Before use, attach the flying leads to the GK-404 by aligning the red circle on the silver "Lemo" connector of the flying leads with the red line on the top of the GK-404 (Figure 8). Insert the Lemo connector into the GK-404 until it locks into place.

Figure 8 - Lemo Connector to GK-404

Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

To turn the GK-404 on, press the "ON/OFF" button on the front panel of the unit. The initial startup screen will be displayed. After approximately one second, the GK-404 will start taking readings and display them based on the settings of the POS and MODE buttons.

The unit display (from left to right) is as follows:

- The current Position: Set by the **POS** button. Displayed as a letter A through F.
- The current Reading: Set by the **MODE** button. Displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached gauge in degrees Celsius.

Use the POS button to select position B and the MODE button to select Dg (digits). (Other functions can be selected as described in the GK-404 Manual.)

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually, or if enabled, by the Auto-Off timer. If the no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions.

For further information, please see the GK-404 manual.

3.2 GK-405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components: The Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application; and the GK-405 Remote Module, which is housed in a weatherproof enclosure and connects to the vibrating wire gauge to be measured. The two components communicate wirelessly. The Readout Unit can operate from the cradle of the Remote Module, or, if more convenient, can be removed and operated up to 20 meters from the Remote Module.

3.2.1 Connecting Sensors

Connecting sensors with 10-pin connectors:
Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

Connecting sensors with bare leads:
Attach the GK-403-2 flying leads to the bare leads of a Geokon vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.2.2 Operating the GK-405

Press the button labeled “POWER ON”. A blue light will begin blinking, signifying that the Remote Module is waiting to connect to the handheld unit. Launch the GK-405 VWRA program by tapping on “Start” from the handheld PC’s main window, then “Programs” then the GK-405 VWRA icon. After a few seconds, the blue light on the Remote Module should stop flashing and remain lit. The Live Readings Window will be displayed on the handheld PC. Choose display mode “B”. Figure 9 shows a typical vibrating wire output in digits and thermistor output in degrees Celsius. If no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions. For further information, consult the GK-405 Instruction Manual.

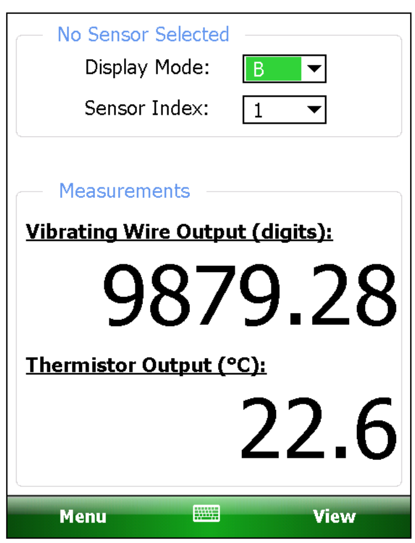

Figure 9 - Live Readings – Raw Readings

3.3 GK-403 Readout Box (Obsolete Model)

The GK-403 can store gauge readings and apply calibration factors to convert readings to engineering units. The following instructions explain taking gauge measurements using Mode "B". Consult the GK-403 Instruction Manual for additional information.

3.3.1 Connecting Sensors

Connecting sensors with 10-pin connectors:
Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

Connecting Sensors with Bare Leads:
Attach the GK-403-2 flying leads to the bare leads of a Geokon vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.3.2 Operating the GK-403

1) Turn the display selector to position "B".

2) Turn the unit on.

3) The readout will display the vibrating wire output in digits. The last digit may change one or two digits while reading.

4) The thermistor reading will be displayed above the gauge reading in degrees centigrade.

5) Press the "Store" button to record the value displayed.

If the no reading displays or the reading is unstable, see Section 5 for troubleshooting suggestions. The unit will turn off automatically after approximately two minutes to conserve power.

3.4 Measuring Temperatures

Each Vibrating tilt sensor is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Geokon readout boxes will read the thermistor and display temperature in °C automatically. To read the thermistor using an ohmmeter, complete the following:

1) Connect the ohmmeter to the two thermistor leads coming from the instrument. (Usually white and green.) Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant.

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

4. DATA REDUCTION

4.1 Inclination Calculation

Inclinations are measured in digits on Position B on the Geokon readout. The output of the VW tilt sensor is proportional to the sine of the angle of tilt. For small angles θ and $\sin\theta$ are the same, so the relationship between output digits and the amount of tilting, (change of the angle of inclination), **$\Delta\theta$,** is given by the equation:

$$\Delta\theta = \Delta\sin\theta = (R_1 - R_0)\ G \text{ degrees tilt}$$

Equation 1 - Calculation of Tilt (Linear)

Where;
R_1 is the current reading in digits
R_o is the initial reading in digits
G is the Linear Gauge Factor in degrees tilt/digit given on the calibration report supplied with the sensor. (A sample calibration report is shown in Appendix E.)

The linear equation works very well for inclinations of less than four degrees. More than this and the linearity errors start to increase beyond 0.5% FS. The error incurred by using the linear equation is shown on the calibration chart.

For better accuracy at larger inclinations use the polynomial equation: This uses a second order curve to approximate the sine curve.

$$\theta = R^2A + RB + C \text{ degrees tilt}$$

Equation 2 - Calculation of Tilt (Polynomial)

Where A, B and C are the coefficients supplied on the calibration report. Calculate θ_1 by substituting $R = R_1$ in the formula and then calculate θ_0 by substituting $R = R_0$ then subtract to find the difference $\Delta\theta = (\theta_1 - \theta_0)$.

4.2 Temperature Correction

The Model 6350 Tiltmeter has a slight temperature sensitivity on the order of -0.5 digit per °C rise, i.e. the reading falls by 0.5 digits for every one °C rise of temperature. The temperature correction is:

$$+0.5G(T_1\text{-}T_0) \text{ degrees tilt}$$

Equation 3 - Temperature Correction

Normally, corrections are not applied for this small effect because the structure being monitored usually is affected to a much greater degree. An important point to note, also, is that sudden changes in temperature will cause both the structure and the Tiltmeter to undergo transitory physical changes that will show up in the readings. The gauge temperature should always be recorded for comparison, 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

Now, the change in reading must be converted to a lateral deflection. The lateral deflection is defined as $L\sin\Delta\theta$ where L is the gauge length between pivot points and $\Delta\theta$ is the change in inclination (corrected for temperature) determined from Equation 3.

The length L_1, L_2, L_3,…. etc., can be calculated by adding **311 mm**, (uniaxial systems) or **524 mm**, (biaxial system), to the individual lengths of tubing. This will give the correct distance between pivot points.

The horizontal displacement profile can be constructed by using the cumulative sum of the displacement starting with the bottom segment. Subsequent readings over time will reveal changes in deflection, possible shear zones, etc. For example, referring to Figure 10 and Equation 4.

$$\mathbf{D_1 = L_1 \Delta\sin\theta_1}$$
$$\mathbf{D_2 = L_1 \Delta\sin\theta_1 + L_2 \Delta\sin\theta_2}$$
$$\mathbf{D_3 = L_1 \Delta\sin\theta_1 + L_2 \Delta\sin\theta_2 + L_3 \Delta\sin\theta_3}$$
$$\mathbf{D_4 = L_1 \Delta\sin\theta_1 + L_2 \Delta\sin\theta_2 + L_3 \Delta\sin\theta_3 + L_4 \Delta\sin\theta_4}$$
$$\mathbf{D_5 = L_1 \Delta\sin\theta_1 + L_2 \Delta\sin\theta_2 + L_3 \Delta\sin\theta_3 + L_4 \Delta\sin\theta_4 + L_5 \Delta\sin\theta_5}$$

Where, for small angles:

$$\Delta\sin\theta = (R_1 - R_0)\, G$$

Equation 4 - Horizontal Displacement Calculation

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

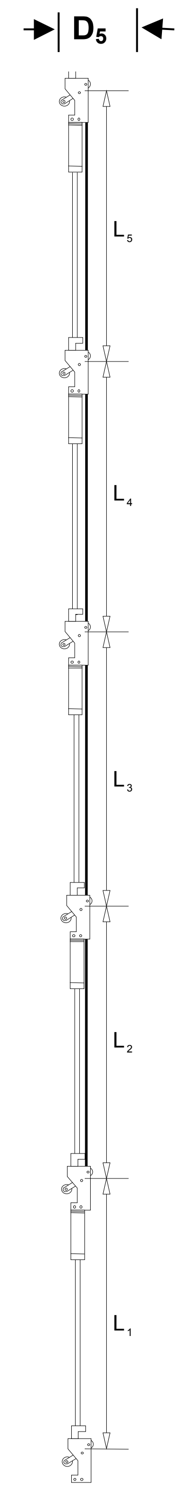

Figure 10 - Deflection Intervals

4.4 Environmental Factors

Since the purpose of the inclinometer installation is to monitor site conditions, factors that may affect these conditions should be observed and recorded. Seemingly minor effects may have 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 vibrating wire tilt sensors used in the Model 6300 Inclinometer are is 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 the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct?

- ✓ 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. If using the GK-403, GK-404, or GK-405 connect the clip with the blue boot to the shield drain wire. (Green for the GK-401)

- ✓ 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. Nominal resistance between the two gauge leads (usually red and black leads) is 180Ω, ±10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/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 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. If a cut is located in the cable, splice according to instructions in Section 2.4.

Symptom: Thermistor resistance is too low:

- ✓ Is there a short? Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions in Section 2.4.

- ✓ Water may have penetrated the interior of the tilt sensor. There is no remedial action.

APPENDIX A. SPECIFICATIONS

A.1 Vibrating Wire Tilt Sensor

Model:	**6300**
Range:[1]	±10°
Resolution:[2]	8 arc seconds
Accuracy:[3]	±8 arc seconds
Linearity:[4]	±0.3% FSR
Thermal Zero Shift:	±4 arc seconds/°C
Operating Temperature	-40 to +80° C -40 to 175° F
Operating Frequency:	1400-3500 Hz
Coil Resistance:	180 Ω
Diameter:	1.250", 32 mm
Length:	7.375", 187 mm
Weight:	1.5 lbs., 0.7 kg.
Materials:	304 Stainless Steel
Electrical Cable:	Two twisted pair (four conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")

Table 1 - Model 6300 Tilt Sensor Specifications

Notes:
[1] Consult the factory for other ranges.
[2] Depends on readout equipment. With averaging techniques, it is possible to achieve one arc second
[3] Derived using 2nd order polynomial.
[4] The output from the sensor is proportional to the sine of the angle of tilt

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:

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

Equation 5 - 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 2 - Thermistor Resistance Versus Temperature

APPENDIX C. EXCITATION AND READOUT PARAMETERS

The Micro-10 Datalogger which uses the Campbell Scientific Measurement and Control Module can be used to continuously monitor the Model 6300.

The following parameters are recommended:

C.1 Excitation

The 2.5-volt excitation directly off the wiring panel is ideal for these sensors. The 5-volt supply from the AVW-1 and AVW-4 modules is also usable, but the 12-volt excitation should be avoided as it tends to overdrive the sensor.

C.2 Excitation Frequency

The starting and ending frequencies of the excitation sweep should be kept in a relatively narrow band for these sensors to maximize the stability and resolution of the output.

The frequency band for the full range is shown on the calibration reports.

The frequencies can be determined from these. The highest and lowest frequencies shown can be used to determine the sweep parameters. After initial readings are obtained, parameters should be set to 200 Hz below the resonant frequency and 1-200 Hz above.

C.3 Offset

To maximize the five-digit, high resolution output, the offset parameter can be used to remove the zero offset of the sensor.

In other words, if the installed reading is 4,300, the offset parameter could be set at -4300 which would theoretically change the resolution from 0.1 digit to 0.0001 digit.

For assistance in programming these parameters contact Geokon, Inc.

Appendix D. Addressable Systems

The Addressable system allows all the borehole sensors to be connected to a single cable rather than have a separate cable for each sensor. The sensors are supplied in a string connected together by pre-determined lengths of cables specified by the customer.

The string of sensor is installed in a manner to that described in Section 2.

The cable is connected, via a 15-pin connector, to a special Geokon Model 8021-1X datalogger modified, by the addition of a Model 8031 Distributed Multiplexer, specifically for use with the addressable system

APPENDIX E. TYPICAL CALIBRATION REPORT

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

Vibrating Wire Tilt Sensor Calibration

Model Number: 6300 Series

Calibration Date: April 26, 2004

Serial Number: 04-4472

Temperature: 22.9 °C

Cal. Std. Control #(s): 406, 213, 260, 189, 524, 529, 333

Technician:

Inclination (sin)	Inclination (degrees)	* Reading 1st Cycle (digits)	* Reading 2nd Cycle (digits)	* Average Reading (digits)	Error (%FS) Linear	Error (%FS) Polynomial
0.0867	4.972	10469	10470	10470	-0.31	0.01
0.0667	3.823	9910	9912	9911	-0.20	0.01
0.0533	3.057	9540	9540	9540	-0.10	-0.02
0.0349	1.998	9023	9022	9023	-0.05	-0.01
0.0175	1.003	8535	8535	8535	-0.03	0.00
0.0087	0.497	8285	8287	8286	-0.04	0.02
0.0042	0.241	8161	8162	8162	-0.01	0.00
0.0000	0.000	8044	8044	8044	0.00	-0.01
-0.0042	-0.241	7926	7923	7925	-0.03	0.01
-0.0087	-0.497	7800	7800	7800	0.00	-0.01
-0.0175	-1.003	7551	7551	7551	-0.01	-0.01
-0.0349	-1.998	7059	7058	7059	-0.09	0.03
-0.0533	-3.057	6537	6536	6537	-0.14	0.00
-0.0667	-3.823	6159	6158	6159	-0.18	-0.02
-0.0867	-4.972	5587	5587	5587	-0.33	0.00

*Readings displayed in GK-401 Position B.

Linear Gage Factor (G): 0.002037 (degrees/ digit)

Polynomial Gage Factors: A: 5.084E-09 B: 1.955E-03 C: -16.053

Calculated Angle (degrees): Linear, q = $G(R_1 - R_0)+K(T_1-T_0)$

Polynomial, q = $AR^2 + BR + C$

Wiring Code: Red and Black: Gage White and Green: Thermistor Bare: Shield

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 11 - Sample Model 6300 Calibration Report