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Instruction Manual

Model 4151

Miniature Strain Gauge

(Doc Rev C, 04/30/19)

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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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EQUATIONS

1. INTRODUCTION

The Model 4151 is a modification of the 4150 strain gauge in which the spot-weldable tabs have been replaced by pins welded to the end blocks and designed to be grouted into two short holes drilled into the material under test. Special versions of the Model 4151 are available with extended ranges. These gauges are particularly useful for measurements in high strain regimes such as on plastic pipes or piles and on fiberglass structural members and rebars. A unique design allows these gauges to be manufactured without increasing their overall length, making them particularly suitable where space and or access is limited.

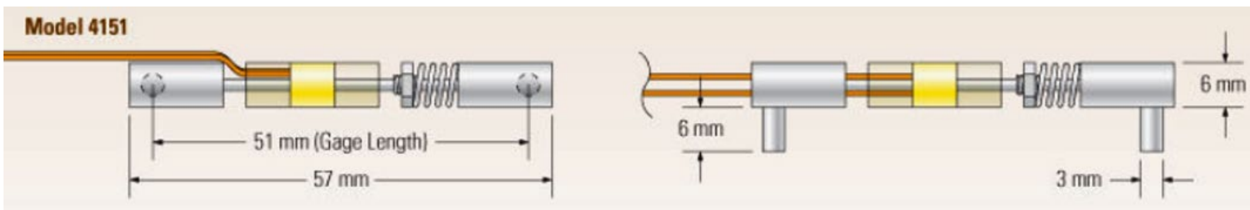


Figure 1 - Model 4151 Miniature Strain Gauge

2. INSTALLATION

2.1 Preliminary Tests

Upon receipt of the instrument, the gauge should be checked for proper operation (including the thermistor). The strain gauge normally arrives set at approximately 50% of its range. The midrange position should give a reading of about 2500 microstrains on Channel E. Gently pull on the ends of the gauge and the readings should increase. **CAUTION: Do not rotate the shaft of the strain gauge. This may cause irreparable damage to the instrument.**

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gauge leads should be approximately 50 ohms, ±10 ohms. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω per 1000 feet (48.5Ω per km) multiply by two for both directions). The resistance between the green and white conductors varies with temperature; see Table 5 in Appendix C. Resistance between any conductor and the shield should exceed two megohms.

2.2 Adjusting the Initial Wire Tension

Caution! Under no circumstances should the procedures described below be used after the gauge has been epoxied in place.

Gauges are supplied with an initial reading of between 2000 and 2500 microstrain. This gives a range of ±1250 microstrain. This range is adequate for most purposes and should not be altered except in unusual circumstances.

If the strain directions are known, the wire tension can be adjusted for greater range in either compression or tension. If the gauge is required to read large tensile strains then set the reading between 1500 and 2000 microstrains, if the gauge is to read large compressive strains set the initial reading to between 2500 and 3000 microstrains. Table 1 lists the wire tension readings.

Using the fingers rotate the nut on the threaded portion of the tube. The position of the nut controls the spring tension.

Place the gauge on a flat surface, take a reading, and note it. If it is desirable to increase the range for measurement of more compressive strain, the spring must be tightened. Hold the gauge by the coil assembly and turn the nut to tighten. A rotation of one-half turn will give a change of about 600 microstrains. The gauge end block will often turn as well; therefore, after the adjustment has been made, rotate the end block back to its original position so that the pins line up. Again, hold the tube while doing this. Check the reading. If okay, apply a spot of thread locking cement to preserve the nut position and the tension.

For more range in tension, the nut is rotated in the opposite direction using the same technique of holding the coil assembly, rotating the nut, and realigning the end blocks, etc.

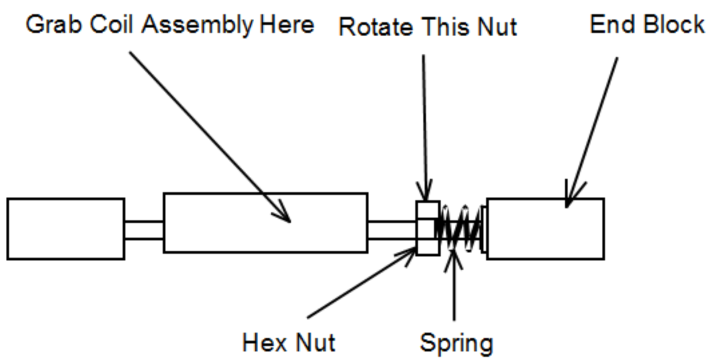


Figure 2 - Tension Adjustment

		Available Strain Range	
Setting Range	**Strain Reading**	**Tension**	**Compression**
Mid-range	2500	1250	1250
Tension (67% of range)	1775	1675	825
Compression (67% of range)	2625	825	1675

Table 1 - Guide to Initial Tension Settings

2.3 Strain Gauge Installation

The Strain gauge is provided with pins that can grouted in short drill holes. Two 5 mm (3/16 inch) diameter holes 13 mm (1/2 inch) deep should be drilled at a spacing of 51 mm (two inches). A drill hole spacer bar is provided to make this easier. Drill one hole then place a slightly smaller drill in the hole and use the spacer bar to locate the second hole.

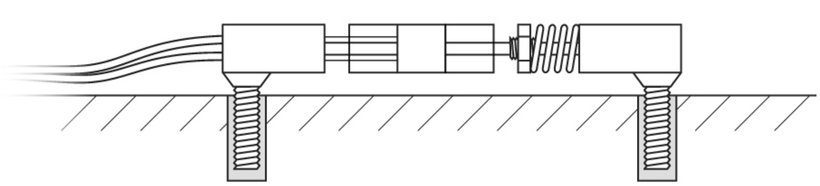


Figure 3 - Model 4151 Strain Gauge Installation

Fill the drill holes with epoxy or quick setting cement and push the pins into the grout or epoxy.

2.4 Protection from Mechanical Damage

Cables should be adequately restrained to ensure that there is no danger of the coil housing being ripped off (4100) or the lead wires torn out (4150) by tugging on the cable. Cables may be tagged down using pieces of stainless steel shim strips (supplied) spot welded in place over the top of the cable. Tie wraps, tape, or wire ties may also be used to secure the gauge cables.

The cable should also be protected from accidental damage caused by moving equipment or fly rock. This is best accomplished by putting the cable inside flexible conduit and positioning the conduit in as safe a place as possible. (Flexible conduit is available from Geokon.) The conduit can be connected via conduit bulkhead connectors to the cover plates and then to a readout.

2.5 Cable Splicing and Termination

Terminal boxes with sealed cable entries are available from Geokon for all types of applications. These allow many gauges to be terminated at one location with complete protection of the lead wires. The interior panel of the terminal box can have built-in jacks or a single connection with a rotary position selector switch. Contact Geokon for specific application information.

Because the vibrating wire output signal is a frequency rather than a current or voltage, variations in cable resistance have little effect on gauge readings; therefore, splicing of cables has no ill effects, and in some cases may in fact be beneficial. The cable used for making splices should be a high-quality twisted pair type, with 100% shielding and an integral shield drain wire. **When splicing, it is very important that the shield drain wires be spliced together.** Always maintain polarity by connecting color to color.

Splice kits recommended by Geokon incorporate casts that are placed around the splice and are then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable in strength and electrical properties. Contact Geokon for splicing materials and additional cable splicing instructions.

Cables may be terminated by stripping and tinning the individual conductors and then connecting them to the patch cord of a readout box. Alternatively, a connector may be used which will plug directly into the readout box or to a receptacle on a special patch cord.

2.6 Protection from Electrical Noise

Care should be exercised when installing instrument cables to keep them as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run alongside AC power lines as they will pick up the noise from the power cable, which will likely cause unstable readings. Contact the factory concerning filtering options available for use with the Geokon dataloggers and readouts.

2.7 Lightning Protection

Unlike numerous other types of instrumentation available from Geokon, vibrating wire strain gauges do not have any integral lightning protection components, such as transorbs or plasma surge arrestors.

Suggested Lightning Protection Options:

- If the gauge is connected to a terminal box or multiplexer, components such as plasma surge arrestors (spark gaps) may be installed in the terminal box/multiplexer to provide a measure of transient protection. Terminal boxes and multiplexers available from Geokon provide locations for the installation of these components.

- Lighting arrestor boards and enclosures are also available from Geokon. These units install where the instrument cable exits the structure being monitored. The enclosure has a removable top to allow the customer to service the components or replace the board if the unit is damaged by a lightning strike. A connection is made between the enclosure and earth ground to facilitate the passing of transients away from the gauge. See Figure 4.

- Plasma surge arrestors can be epoxied into the instrument cable, close to the sensor. A ground strap then connects the surge arrestor to an earth ground, such as a grounding stake or the steel structure.

Consult the factory for additional information on available lightning protection.

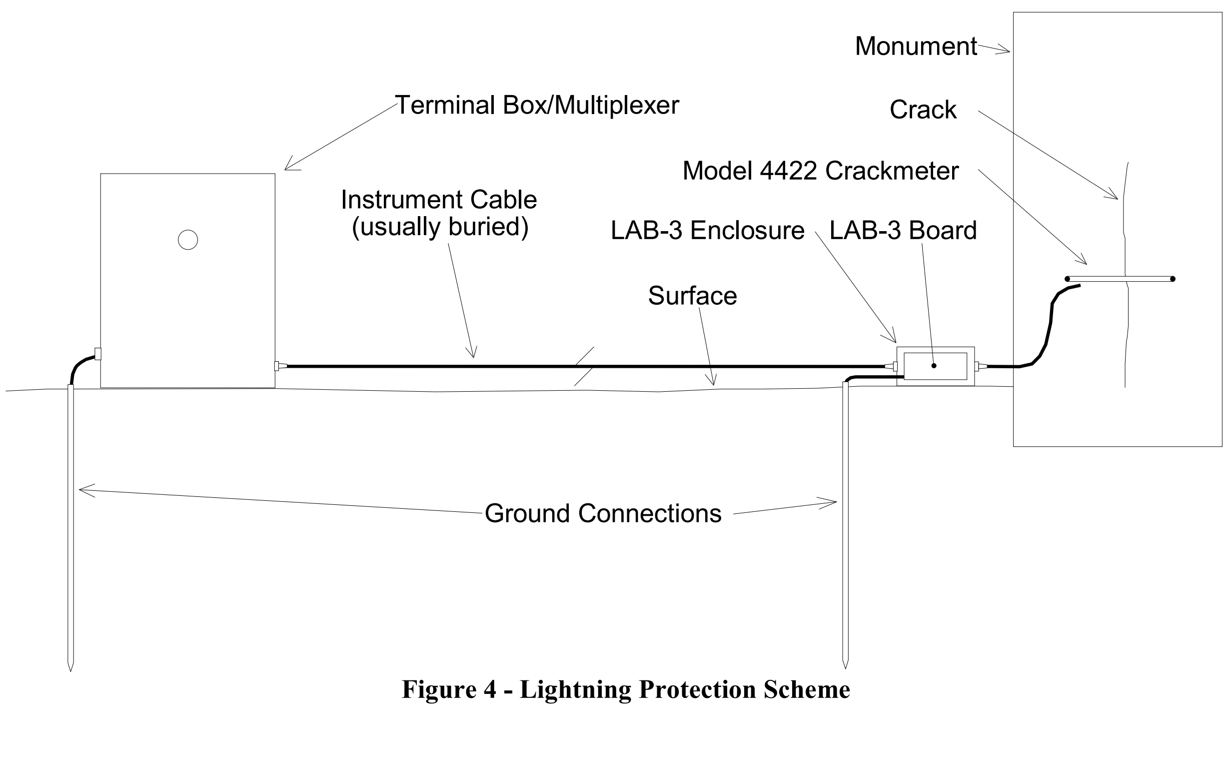


Figure 4 - Lightning Protection Scheme

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 strain gauge (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 5). Insert the Lemo connector into the GK-404 until it locks into place.

Figure 5 - 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 **E** 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 no reading displays or the reading is unstable, consult Section 5 for troubleshooting suggestions.

For further information, please refer to 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 via a cable 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 with 10-pin Bulkhead Connectors Attached

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.

3.2.2 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).

3.2.3 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 "E". Figure 6 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.

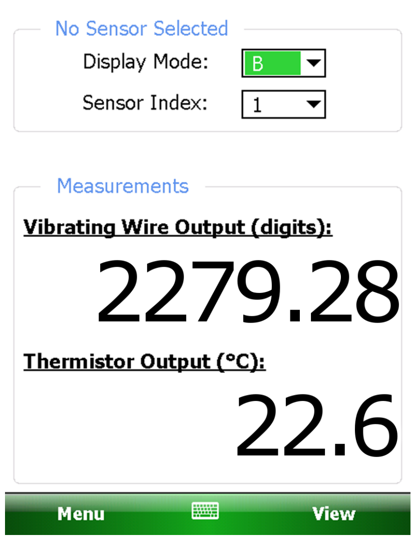


Figure 6 - Live Readings – Raw Readings

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 “E”. Consult the GK-403 Instruction Manual for additional information.

3.3.1 Connecting Sensors with 10-pin Bulkhead Connectors Attached

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.

3.3.2 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).

3.3.3 Operating the GK-403

1) Turn the display selector to position “E”.

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 automatically turn off after approximately two minutes to conserve power.

3.4 Measuring Temperatures

Each strain gauge is equipped with a thermistor, which gives a varying resistance output as the temperature changes. The white and green leads of the instrument cable are normally connected to the internal thermistor. Readout boxes will read the thermistor and display the temperature in degrees C.

To read temperatures using an ohmmeter: Connect an ohmmeter to the green and white thermistor leads coming from the strain gauge. 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 14.7Ω per 1000 feet (48.5Ω per km) at 20 °C. Multiply these factors by two to account for both directions. Look up the temperature for the measured resistance in Appendix C, Table 5.

4. DATA REDUCTION

Readings on Channel E of Geokon's readout boxes are displayed directly in microstrain based on the theoretical equation:

$$\mu\varepsilon_{theory} = 0.391\ (f^2 \times 10^{-3})$$

Equation 1 - Theoretical Microstrain

Where;
$\mu\varepsilon$ is the strain in the wire in microstrain.
f is the resonant frequency of the vibrating wire.

4.1 Conversion of the Readings to Strain Changes

In practice, the method of wire clamping effectively shortens the vibrating wire slightly, causing it to over-register the strain. This effect is removed by applying the batch gauge factor (B) from the calibration report supplied with the gauges.

$$\mu\varepsilon_{apparent} = (R_1 - R_0)B$$

Equation 2 - Strain Calculation

Where;
R_0 is the initial reading on Channel E
R_1 is a subsequent reading.
Note: when $(R_1 - R_0)$ is positive, the strain is tensile.

The value obtained from the above equation is required for computing stresses in equations two through four in Appendix B. The stresses thus computed are the total of those caused by both construction activity and by any temperature change that may have occurred.

4.2 Strain Resolution

When using the GK-403 or GK-404 Readout on display setting "E" the strain resolution is ±0.1 microstrains throughout the range of the gauge.

4.3 Environmental Factors

Since the purpose of the strain gauge installation is to monitor strains and stresses, factors that may affect these conditions should always 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 levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

Temperatures should be recorded at the time of each reading along with notes concerning the construction activity that is taking place. This data might supply logical reasons for observed changes in the readings. For temperature correction factors when used on concrete, see Appendix E.

4.4 Bending Effects

In the case of a structural member, a strain gauge measures the strain at one point on the surface, and this would be sufficient if it could be guaranteed that no bending was occurring in the member. In practice, this will occur near the center of long thin members subjected to tensile loads. Elsewhere, bending moments are the rule rather than the exception, and there will be a neutral axis around which bending takes place.

If bending effects are to be taken into account, then more than one strain gauge is required at each cross section of the structural member, and for a complete analysis at least three gauges are required and very often more. On a circular pipe strut, three gauges spaced 120° apart around the periphery of the strut would suffice (four would be preferable). (See Appendix D for analysis.) On an H pile or I beam at least four strain gauges would be called for, and on sheet piling two gauges back to back on either side of the pile would be required. (Where a member is subjected to bending and only the front surface is accessible, for instance, a steel tunnel lining or the outside of sheet pilings, the bending moments can be measured by installing two vibrating wire gauges at different distances from the neutral axis).

4.5 Converting Strains to Stresses

Whereas strain gauges measure strain or deformation of the structure, the designer is more interested in the structural loads or stresses. This requires a conversion from the measured strains to computed stresses.

Stresses are computed by multiplying the measured strain by the Young's Modulus for the material being instrumented. Loads are computed by multiplying the stress by the cross-sectional area of the structural member.

Strain changes with time are computed from strain gauge readings taken at various times, and by comparison with some initial readings taken at time zero. This initial reading is best taken when the structural member is under no load.

5. TROUBLESHOOTING

Maintenance and troubleshooting of Vibrating Wire Strain Gauges is confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gauges are usually inaccessible and remedial action is limited. Should difficulties arise, consult the following list of problems and possible solutions. Return any faulty gauges to the factory. **Gauges should not be opened in the field.** For additional troubleshooting and support, contact Geokon.

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, splice according to instructions in Section 2.5.

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, splice according to instructions in Section 2.5.

- ✓ Water may have penetrated the interior of the strain gauge. There is no remedial action.

Symptom: Strain Gauge 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 the strain reading outside the specified compressive or tensile range of the instrument?

- ✓ Is there a source of electrical noise nearby? Likely candidates are generators, motors, arc welding equipment, high voltage lines, etc. If possible, move the instrument cable away from power lines and electrical equipment or install electronic filtering.

- ✓ Make sure the shield drain wire is connected to ground.

- ✓ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

Symptom: Strain Gauge Fails to Read

- ✓ Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the sensor leads. Table 2 shows the expected resistance for the various wire combinations; Table 3 is provided for the user to record the observed values. Cable resistance is approximately 14.74Ω per 1000 feet (48.5Ω per km) of 22 AWG wire at 20 °C. Multiply these factors by two to account for both directions. If the resistance is very high or infinite, the cable is probably broken or cut. If the resistance is very low, the gauge conductors may be shorted. If a cut or a short is located in the cable, splice according to the instructions in Section 2.5.

- ✓ Does the readout or datalogger work with another gauge? If not, it may have a low battery or possibly be malfunctioning.

Vibrating Wire Sensor Lead Grid - SAMPLE VALUES					
	Red	**Black**	**White**	**Green**	**Shield**
Red	N/A	**≅50Ω**	infinite	infinite	infinite
Black	**≅50Ω**	N/A	infinite	infinite	infinite
White	infinite	infinite	N/A	**3000Ω at 25°C**	infinite
Green	infinite	infinite	**3000Ω at 25°C**	N/A	infinite
Shield	infinite	infinite	infinite	infinite	N/A

Table 2 - Sample Resistance

Vibrating Wire Sensor Lead Grid - SENSOR NAME/## :					
	Red	**Black**	**White**	**Green**	**Shield**
Red					
Black					
White					
Green					
Shield					

Table 3 - Resistance Work Sheet

APPENDIX A. SPECIFICATIONS

A.1 Strain Gauge

Range (nominal):	2500 $\mu\varepsilon$
Resolution:	0.1 $\mu\varepsilon$[1]
Calibration Accuracy	0.1% FS
System Accuracy:	2.0% FS[2]
Stability:	0.1% FS/yr
Linearity:	2.0% FSR
Thermal Coefficient:	12.2 $\mu\varepsilon$/°C
Frequency Range:	1400 – 3500 Hz
Dimensions (gauge): **(Length × Diameter)**	2.250 × 0.250" 57.2 × 6.4 mm
Dimensions (coil): **(L×W×H)**	0.750 × 0.250" (diameter) 19.1 × 6.4 mm (diameter)
Coil Resistance:	50 Ω
Temperature Range:	-20 to +80 °C

Table 4 - Specifications

Notes:

[1] Depends on the readout, above figure pertains to the GK-404 Readout.

[2] System Accuracy takes into account hysteresis, nonlinearity, misalignment, batch factor variations, and other aspects of the actual measurement program. System Accuracy to 1.0% FS may be achieved through individual calibration of each strain gauge.

A.2 Thermistor (See Appendix C also)

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

APPENDIX B. THEORY OF OPERATION

A vibrating wire attached to the surface of a deforming body will deform in a manner similar to that of the body to which it is attached. These deformations alter the tension of the wire, therefore altering its natural frequency of vibration (resonance).

The relationship between frequency (period) and deformation (strain) is described as follows:

1) The fundamental frequency (resonant frequency) of vibration of a wire is related to its tension, length, and mass. The fundamental frequency may be determined by the equation:

$$f = \frac{1}{2L_W}\sqrt{\frac{F}{m}}$$

Where;
L_W is the length of the wire in inches.
F is the wire tension in pounds.
m is the mass of the wire per unit length (pounds, sec.^{2}/in.^{2}).

2) Note that:

$$m = \frac{W}{L_w g}$$

Where;
W is the weight of L_W inches of wire (pounds).
g is the acceleration of gravity (386 in./sec.^{2}).

3) And:

$$W = \rho a L_w$$

Where;
ρ is the wire material density (0.283 lb./in.^{3}).
a is the cross-sectional area of the wire (in.^{2}).

4) Combining the equations from steps one, two, and three gives:

$$f = \frac{1}{2L_w}\sqrt{\frac{Fg}{\rho a}}$$

5) Note that the tension (F) can be expressed in terms of strain, i.e.:

$$F = \varepsilon_w E a$$

Where;
ε_w is the wire strain (in./in.).
E is the Young's Modulus of the wire (30 x 10^6 psi).

6) Combining the equations from steps four and five gives:

$$f = \frac{1}{2L_w}\sqrt{\frac{\varepsilon_w E g}{\rho}}$$

7) Substituting the given values for E, g, and ρ yields:

$$f = \frac{101142}{L_w}\sqrt{\varepsilon_w}$$

8) On channel 'A', (which displays the period of vibration, T,) multiplied by a factor of 10^6:

$$T = \frac{10^6}{f}$$

9) Combining the equations from steps seven and eight gives:

$$\varepsilon_w = \frac{97.75 L_w{}^2}{T^2}$$

10) The equation from step nine must now be expressed in terms of the strain in the surface of the body to which the gauge is attached. Since the deformation of the body must equal the deformation of the wire:

$$\varepsilon_w L_w = \varepsilon L_g$$

Where;
ε is the strain in the body.
Lg is the gauge length (in inches).

11) Combining the equations from steps nine and ten gives:

$$\varepsilon = \frac{97.75}{T^2} \cdot \frac{L_w{}^3}{L_g}$$

Where;
L_W is 2.000 inches.
Lg is 2.000 inches.

12*) Therefore:

$$\varepsilon = 0.391 \text{ x } 10^3 \left[\frac{1}{T^2} \right]$$

13*) The display on position "E" of the readout is based on the equation:

$$\varepsilon = 0.391 \text{ x } 10^9 \left[\frac{1}{T^2} \right]$$

The squaring, inverting, and multiplication by the factor 0.391×10^9 is all done internally by the microprocessor of the readout, so that the displayed reading on Channel E is given in microinches per inch (ε).

*Note that T is in seconds x 10^6 and ε is in microinches per inch

Alternatively;

$\varepsilon = 0.391 \text{ x } 10^{-3} f^2$ microstrain.

Where;
f is the frequency in Hz.

APPENDIX C. THERMISTOR TEMPERATURE DERIVATION

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

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

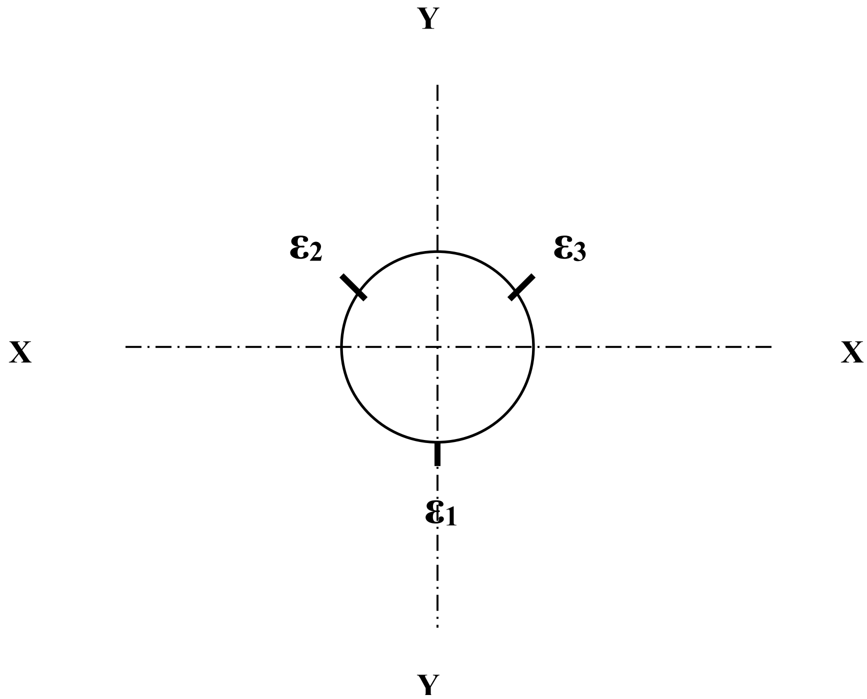
Equation 3 - Resistance to Temperature

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 5 - Thermistor Resistance versus Temperature

APPENDIX D. CALCULATION OF AXIAL LOADS AND BENDING STRAINS FROM THREE STRAIN GAUGES AT 120 DEGREES ON A CIRCULAR PIPE



$$\text{Average Axial Strain} = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3)/3$$

Equation 4 - Average Axial Strain

$$\text{Bending Strain around the YY Axis} = (\varepsilon_2 - \varepsilon_3)/1.732$$

Equation 5 - Bending Strain Around YY

$$\text{Bending Strain around the XX Axis} = (\varepsilon_2 + \varepsilon_3 - \varepsilon_1)/2$$

Equation 6 - Bending Strain Around XX

APPENDIX E. TEMPERATURE CORRECTION

The steel used for the vibrating wire has a thermal coefficient of expansion, (CF1), of +12.2 microstrains/°C. Therefore, the total (or true strain) in the structural element, corrected for thermal effects on the gauge, is given by the following equation:

$$\mu\varepsilon_{total} = (R_1 - R_0)B + (T_1 - T_0) \times CF_1$$

Equation 7 - Total Strain Corrected for Gauge Thermal Effects

In the above equation $(R_1 - R_0)B$ is the apparent stain and $\mu\varepsilon$total is the true strain or the actual strain and includes both thermally induced strains in the material plus those induced by changes in load.

In a free field, where no loads are acting, the thermal material strains are given by the following equation:

$$\mu\varepsilon_{thermal} = (T_1 - T_0) \times CF_2$$

Equation 8 - Thermal Material Strains

In Equation 8, CF2 represents the coefficient of expansion of the material.

Therefore, to calculate the strain in the material due to load changes only:

$$\mu\varepsilon_{load} = \mu\varepsilon_{total} - \mu\varepsilon_{thermal} = (R_1 - R_0)B + (T_1 - T_0) \times (CF_1 - CF_2)$$

Equation 9 - Strain Calculation due to Load Change

Example:

If;
The material is concrete with a temperature coefficient of 10.4 microstrain/°C
B = 0.91
R_0 = 3000 microstrain,
R_1 = 2900 microstrain,
T_0 = 20°C
T_1 = 30°C

Then;
$\mu\varepsilon_{apparent}$ = (2900 – 3000) × 0.91 = -91 (compressive)
$\mu\varepsilon_{total}$ = (2900 – 3000) × 0.91 + (30 – 20) × 12.2 = +31 (tensile)
$\mu\varepsilon_{thermal}$ = (30 – 20) × 10.4 = +104 (tensile)
$\mu\varepsilon_{load}$ = (2900 – 3000) × 0.91 + (30 – 20) × (12.2 – 10.4) = -73 (compressive)

Explanation of the above:

The apparent compressive strain, indicated by the readout box after application of the batch factor (B), is $(R_1-R_0) \times B = -91$ microstrain, but, if the strain in the concrete had not changed, the steel vibrating wire would have expanded and gone slack by the equivalent of (30-20) x 12.2 = -122 microstrains, therefore the concrete must have actually expanded by +31 microstrains to account for the observed apparent strain. However, the concrete would have expanded by (30 – 20) x 10.4 = +104 microstrain because of the temperature increase. The fact that it did not reach this value must mean that there has been a superimposed buildup of compressive strain equal to (104-31) = -73 microstrain. This multiplied by the Young's Modulus will give the actual compressive stress in the concrete caused by the imposed load change.