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 4151

Miniature Strain Gage

(Doc REV A, 06/13)

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 errors 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

Page

1. INTRODUCTION

The Model 4151 is a modification of the 4150 strain gage 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 gages 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 gages 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 Gage

2. INSTALLATION

2.1. Preliminary Tests

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

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gage leads should be approximately 50 ohms, ±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 2 for both directions). Between the green and white should be approximately 3000 ohms at 25° (see Table in Appendix 3), and between any conductor and the shield should exceed 2 megohms.

2.2 Adjusting the initial wire tension

Note. Under no circumstances should the procedures described below be used after the gage has been epoxied in place.

Gages are supplied with an initial reading of between 2000 and 2500 microstrain. This gives a range of +/- 1250 microstrain. This range is usually 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 gage is required to read large tensile strains then set the reading between 1500 and 2000 microstrains, if the gage 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 gage 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 gage by the coil assembly and turn the nut to tighten. A rotation of ½ turn will give a change of about 600 microstrain. The gage end block will often turn also, so after the adjustment the block should be turned back so that the pins line up. Again, hold the tube while doing this. Check the reading. If OK, 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.

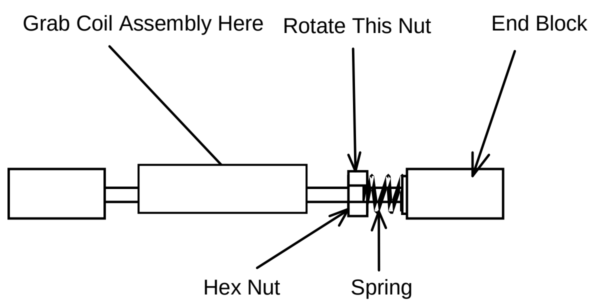


Figure 2 - Tension Adjustment

Setting Range	Strain Reading	Available Strain Range: Tension	Available Strain Range: 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 Gage Installation

The Strain gage is provided with pins that can grouted in short drill holes.Two 5mm (3/16 inch) diameter holes 13mm (1/2 inch) deep should be drilled at a spacing of 51mm (2 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.

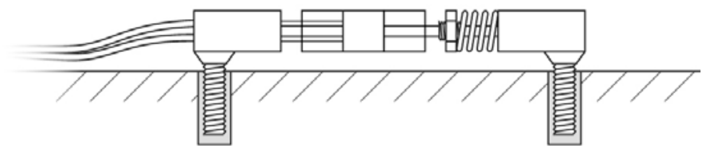


Figure 3: Model 4151 Strain Gage Instalation

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

2.4. Cable Installation

The cable should be routed in such a way so as to minimize the possibility of damage due to traffic or vandalism.
Cables may be spliced to lengthen them, without affecting gage readings. Always waterproof the splice completely, preferably using an epoxy based splice kit such the 3M Scotchcast™, model 82-A1. These kits are available from the factory.

2.5. 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 with AC power lines. The instrument cables will pick up the 50 or 60 Hz (or other frequency) noise from the power cable and this will likely cause a problem obtaining a stable reading. Contact the factory concerning filtering options available for use with the Geokon dataloggers and readouts should difficulties arise.

2.6. Lightning Protection

The Model 4151, unlike numerous other types of sensors available from Geokon, do not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors. Usually this is not a problem, however, if the instrument cable is exposed, it may be appropriate to install lightning protection components, as the transient could travel down the cable to the gage and possibly destroy it.

Note the following suggestions;

- If the gage 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 installation of these components.
- Lighting arrestor boards and enclosures are available from Geokon that install near the instrument. The enclosure has a removable top so, in the event the protection board (LAB-3) is damaged, the user may service the components (or replace the board). A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the gage. See Figure 7. Consult the factory for additional information on these or alternate lightning protection schemes.

- Plasma surge arrestors can be epoxy potted into the gage cable close to the sensor. A ground strap would connect the surge arrestor to earth ground, either a grounding stake or other suitable earth ground.

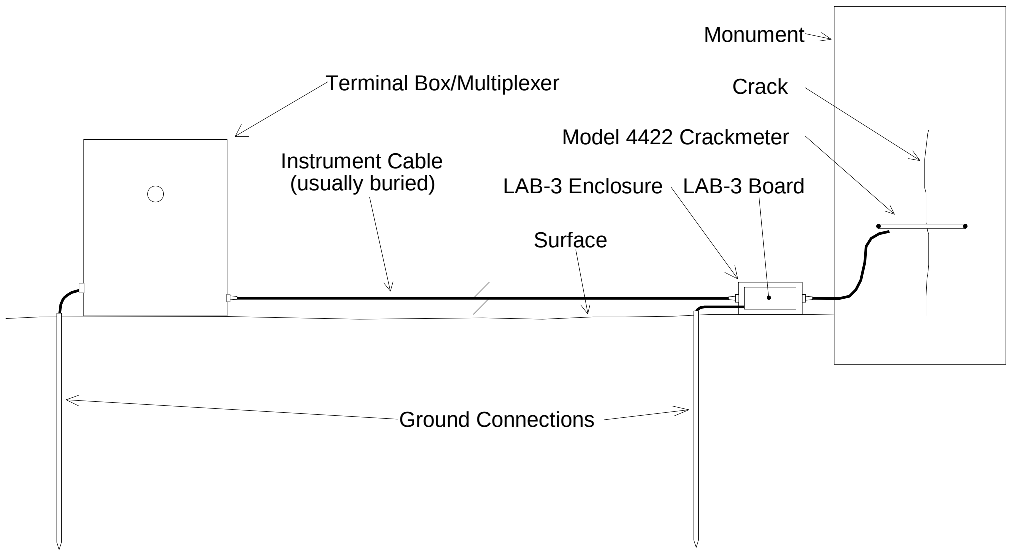


Figure 4 - Lightning Protection Scheme

3. TAKING READINGS

3.1. Operation of the GK-401 Readout Box

The GK-401 is a basic readout for all vibrating wire gages.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the green or blue clip for the shield drain wire. The GK-401 cannot read the thermistor (see Section 3.4).

1. Turn the display selector to position "B" (or "F"). Readout is in digits (Equation 4-1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Record the value displayed. If zeros are displayed or the reading is unstable see section 5 for troubleshooting suggestions.

3. The unit will automatically turn itself off after approximately 4 minutes to conserve power.

3.2. Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The following instructions will explain taking gage measurements using Modes "B" and "F" (similar to the GK-401 switch positions "B" and "F").

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green clips are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "B" (or "F"). Readout is in digits (Equation 4-1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. 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 thermistor will be read and output directly in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.3 Operation of the GK404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.
The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire (blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **B** and the MODE button to select **Dg** (digits).
Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.

The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

3.4 Operation of the GK405 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
- the GK-405 Remote Module which is housed in a weather-proof enclosure and connects to the vibrating wire sensor by means of:

1) Flying leads with alligator type clips when the sensor cable terminates in bare wires or,
2) by means of a 10 pin connector..

The two components communicate wirelessly using Bluetooth®, a reliable digital communications protocol. The Readout Unit can operate from the cradle of the Remote

Module (see Figure 5) or, if more convenient, can be removed and operated up to 20 meters from the Remote Module

Figure 5   GK405 Readout Unit

For further details consult the GK405 Instruction Manual.

3.5. Measuring Temperatures

Each Miniature Strain gage is equipped with a thermistor for reading temperature. The thermistor is located in the end of the large cable and gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor.

The GK 401 readout box will not read temperatures – an ohmmeter is required

1. Connect the ohmmeter to the two thermistor leads coming from the Strain Gage. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Table B-1. Alternately the temperature could be calculated using Equation B-1.

   Note: The GK-403, GK-404 and GK-505 readout boxes will read the thermistor and display temperature in °C automatically.

4. DATA INTERPRETATION

Readings on Channel E of either the GK-401, theGK-403 or the GK-404 Readout Box 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 and f is the resonant frequency of the vibrating wire.

4.1. Conversion of the Readings to Strain Changes

In practice the method of clamping the wire shortens it slightly causing the gage to over-register the strain. This effect is removed by applying a batch gage factor (B) supplied with each gage (a typical batch gage factor is 0.90 ± 0.01). Then

$$\text{The apparent strain, } \mu\varepsilon_{apparent} = (R_1 - R_0)B$$

Equation 2 – Apparent Strain Calculation

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

4.2. Strain Resolution

When using the GK-401, Readout Box on display channel 'E' the strain resolution is always 1 microinch/inch throughout the range of the gage. Greater resolution can be obtained by reading the gage in the period mode on display channel 'A'. At the upper end of the strain range (period 10,000) the resolution is 0.8 microstrain, whereas at the lower end (period 20,000) the resolution is 0.1 microstrain; in mid-range the sensitivity is 0.3 microstrain.

When using the GK-403 or GK404 Readout on display setting 'E' the strain resolution is ±0.1 microstrain throughout the range of the gage.

4.3. Environmental Factors

Since the purpose of the straingage installation is to monitor strains and stresses, factors which 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 memeber, a strain gage 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 gage is required at each cross section of the structural member,** and for a complete analysis at least three gages are required and very often more. On a **circular pipe strut three gages spaced 120^{o}** apart around the periphery of the strut would suffice (four would be preferable).**(See Appendix E for analysis)** On an H pile or I beam at least four strain gages would be called for, and on sheet piling two gages 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 gages at different distances from the neutral axis).

4.5. Converting Strains to Stresses

Whereas strain gages 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 structral member.

Strain changes with time are computed from strain gage 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 these strain gages are confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gages are usually inaccessible and remedial action is limited.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Strain Gage 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 readings outside the specified range (either compressive or tensile) of the instrument? Gage may have become too slack or too tight; inspection of the data might indicate that this is a possibility.

- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Move the equipment away from the installation or install electronic filtering. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger.
- ✓ Does the readout work with another gage? If not, the readout may have a low battery or be malfunctioning.
- ✓ Does the coil assembly work on another gage? If not, the coil assembly may be defective.

Symptom: Strain Gage Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads for the for the VK-4151, 50Ω, ±10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low (< 25Ω for the VK-4150) a short in the cable is likely. Splicing kits and instructions are available from the factory to repair broken or shorted cables. Consult the factory for additional information.
- ✓ Does the readout or datalogger work with another strain gage? If not, the readout or datalogger may be malfunctioning.
- ✓ Does the coil assembly work on another gage? If not, the coil assembly may be defective.

APPENDIX A - SPECIFICATIONS

A.1 Strain Gage

Model:	VK-4151
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 (gage): (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

Notes:
[1] Depends on the readout, above figure pertains to the GK-403 Readout.
[2] System Accuracy takes into account hysteresis, non-linearity, 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 gage.

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 like manner. The deformations alter the tension of the wire and hence also 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 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 equations 1, 2 and 3 gives:

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

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

$$F = \varepsilon_w E a$$

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 equations 4 and 5 gives:

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

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 equations 7 and 8 gives:

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

10. Equation 9 must now be expressed in terms of the strain in the surface of the body to which the gage 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 gage length (in inches).

11. Combining equations 9 and 10 gives:

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

Where; (for the VK-4100 or VK-4150 Strain Gage)
L_W is 2.000 inches.
Lg is 2.000 inches.

12. Therefore:

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

(Note that T is in seconds x 10^6 and ε is in inches per inch)

13. The display on position "E" of the GK-401/403 Readout is based on the equation:

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

Note that in this formula ε is in micro inches per inch and T is in seconds x 10^6

Alternatively $\varepsilon = 0.391 \times 10^{-3} f^2$ microstrain. Where f is the frequency in Hz

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

APPENDIX C - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation:

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

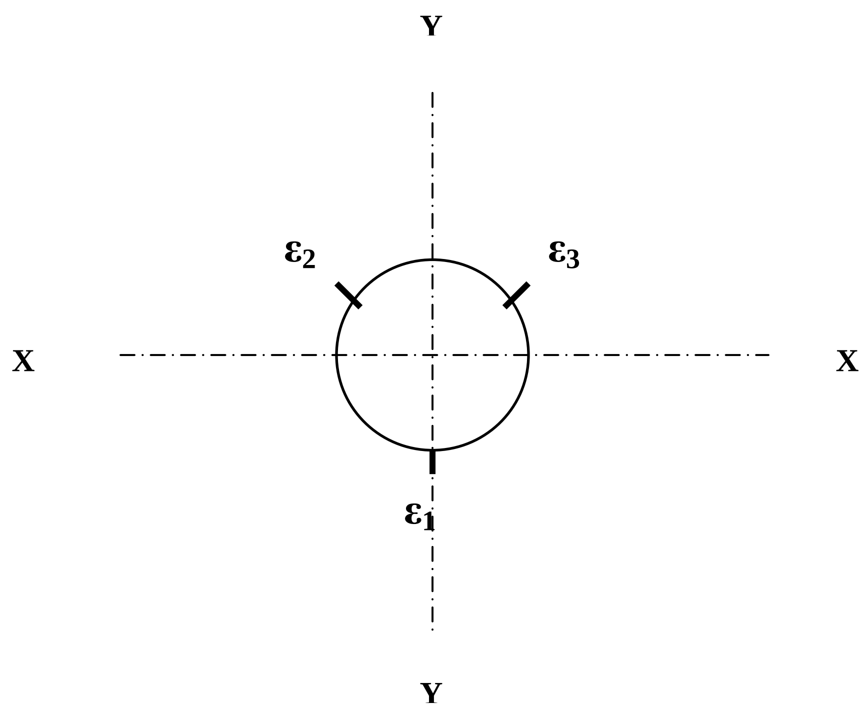
Equation C-1 Convert Thermistor Resistance to Temperature

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 C-1 Thermistor Resistance versus Temperature

APPENDIX D - Calculation of Axial Loads and Bending Strains
from
Three Strain gages at 120 degrees on a Circular Pipe



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

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

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

APPENDIX E - TEMPERATURE CORRECTION

The steel used for the vibrating wire has a thermal coefficient of expansion, (CF_1), of +12.2 microstrain/°C. Therefore the total, or true strain in the structural element, corrected for thermal effects on the gage, is given by the following equation.

$$\mu\varepsilon_{total} = (R_1 - R_0)B + (T_1 - T_0)xCF_1$$

Equation D-1 Total Strain Corrected for Gage Thermal Effects

In the above equation $(R_1\text{-}R_0)B$ 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 D-2 Thermal Material Strains

In Equation D-2, CF_2 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 D-3 Strain Calculation due to Load Change

Note the following example where the material is concrete with a temperature coefficient of 10.4 microstrain/°C and where B = 0.91

R_0 = 3000 microstrain, T_0 = 20°C

R_1 = 2900 microstrain, T_1 = 30°C

$$\mu\varepsilon_{apparent} = (2900 - 3000) \times 0.91 = -91(compressive)$$

$$\mu\varepsilon_{total} = (2900 - 3000) \times 0.91 + (30 - 20) \times 12.2 = +31(tensile)$$

$$\mu\varepsilon_{thermal} = (30 - 20) \times 10.4 = +104(tensile)$$

$$\mu\varepsilon_{load} = (2900 - 3000) \times 0.91 + (30 - 20) \times (12.2 - 10.4) = -73(compressive)$$

Explanation:

The apparent compressive strain, indicated by the readout box after application of the batch factor, B, is $(R_1\text{-}R_0)$ x B = –91microstrain, 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 microstrain so the concrete must have actually expanded by +31 microstrain to account for the observed apparent strain. But, the concrete itself would have expanded by (30 – 20) x 10.4 = +104 microstrain on account of the temperature increase, so the fact that it didn't reach this value must mean that there has been a superimposed build up of compressive strain equal to - (104-31) = -73 microstrain and this multiplied by the Young's Modulus will give the actual compressive stress in the concrete caused by the imposed load change.