The World Leader in Vibrating Wire Technology

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Instruction Manual

Model 4200ER

Extended Range
Vibrating Wire Strain Gage

(Doc Rev. A, 04/07/2017)

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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.

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TABLE of CONTENTS

LIST of FIGURES, TABLES and EQUATIONS

1. INTRODUCTION

The Geokon Model 4200ER Vibrating Wire Strain Gage is designed primarily for high range strain measurements in mass concrete, in structures such as foundations, piles, bridges, dams, containment vessels, tunnel liners, etc. See Figure 1. Strains as high as 10,000 mirostrain can be accomodated

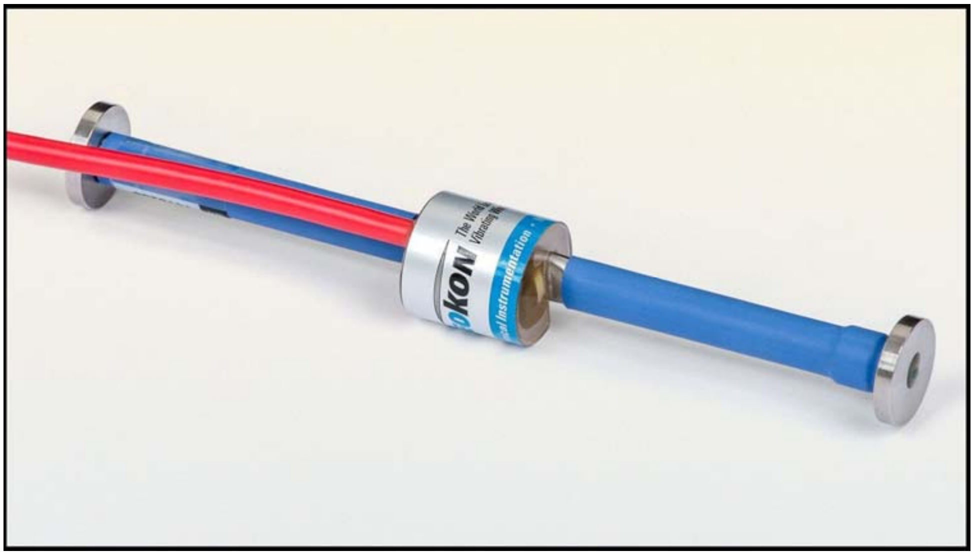

Figure 1 - Model 4200ER Vibrating Wire Strain Gage

Note the small collar under the shrink tube at one end.

The primary means of gage placement is direct embedment in concrete by pre-attaching the gage to rebar or tensioning cables, pre-casting the gage into a concrete briquette which is subsequently cast into the structure, or grouting into boreholes in the concrete.

Strains are measured using the vibrating wire principle: a length of steel wire is tensioned between two end blocks that are firmly in contact with the mass concrete. Deformations in the concrete will cause the two end blocks to move relative to one another, altering the tension in the steel wire. This change in tension is measured as a change in the resonant frequency of vibration of the wire. Electromagnetic coils that are located close to the wire accomplish excitation and readout of the gage frequency.

Portable readouts or dataloggers available from Geokon, such as the model, GK-403, GK 404 or MICRO-6000 datalogger, used in conjunction with any of these vibrating wire strain gages, will provide the necessary voltage pulses to pluck the wire and convert the measured frequencies so as to display the reading directly in digits which can then be converted into microstrain using the calibration coefficients supplied.

This manual contains installation instructions, readout and data reduction procedures, and troubleshooting guidelines.

PLEASE NOTE THE FOLLOWING:

- ***Do not rotate or pull on the gage end blocks as this will alter the readings and may cause permanent damage.***

2. GAGE INSTALLATION

The 4200ER strain gages are supplied fully sealed and pre-tensioned with the plucking coil mounted. A preliminary check is advisable and this is made by connecting to the readout box and observing the displayed readout (see readout instructions, Section 3). The observed reading should be around the mid-range position (see Table 1). Pressure on the gage ends should make this reading decrease.

Check the resistance between the two lead wires (usually red and black). For the model 4200ER it should be around 180 ohms. Remember to add the cable resistance at approximately 14.7Ω/1000' or 48.5Ω/km (at 20°C, multiply by 2 for both directions). If the gage contains a thermistor, check its resistance (usually the white and green lead wires) with an ohmmeter. Check the reading against that which should be obtained at the existing ambient temperature. See Appendix B for the resistance to temperature conversion and resistance v. temperature table.

Return any faulty gages to the factory. Gages should not be opened in the field.

2.1. Adjusting the Desired Range

Gages are supplied with the wire tension set in approximate rmid-range If the range needs to be at some other position this is accomplished by the following procedure: Attach the red and black leeds to a readout box with the channel position set in the D and the mode for microstrain. Grip the small collar under the shrink tube and rotate the end flange adjacent to it as shown in Figure 2

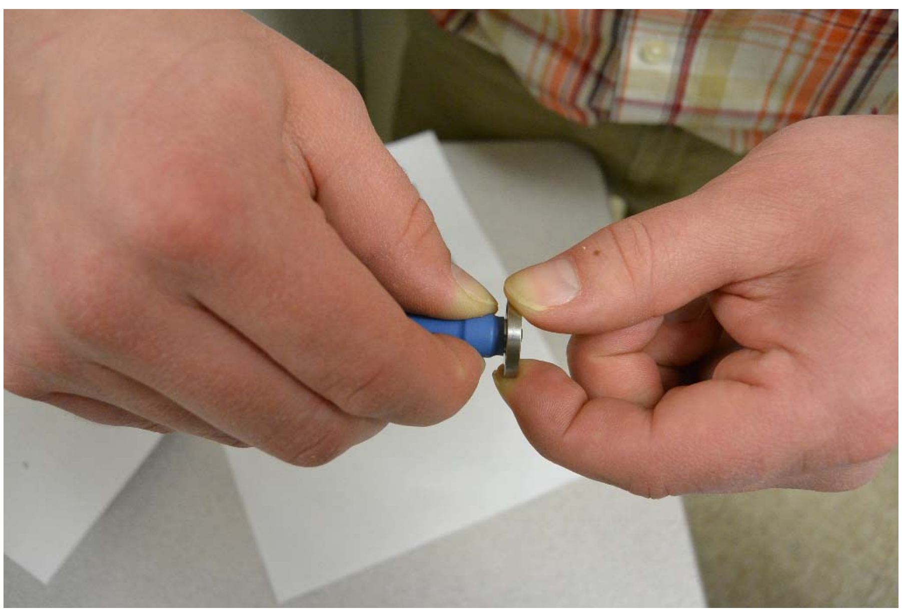

Figure 2 Adjusting the range

Rotate clockwise to decrease the initial reading and counter-clockwise to increase the reading. Please remember that although the readings are taken on Channel D, in the digits output mode, the digits shown are not directly in microstrain but must be converted to microstrain by multiplying the observed digits change by the gage factor given on the calibration sheet.

2.2. Placing the Gage in Concrete

The Model 4200ER strain gages are normally set into the concrete structure in one of two ways: either by casting the unit(s) into the concrete mix directly or by pre-casting the unit(s) into briquettes that are subsequently cast into the structure.

When casting the gage directly into the structure care must be taken to avoid applying any large forces to the end blocks during installation. The model 4200ERcan be wired into position by wiring directly to the tube (see Figure 3). The wires should not be tied too tightly since rebar and/or tension cables tend to move during concrete placement and vibration. Care should be taken not to damage the cable with the vibrator. The gage can also be placed directly into the mix if it can be assured that the orientation will be correct after the gage placement.

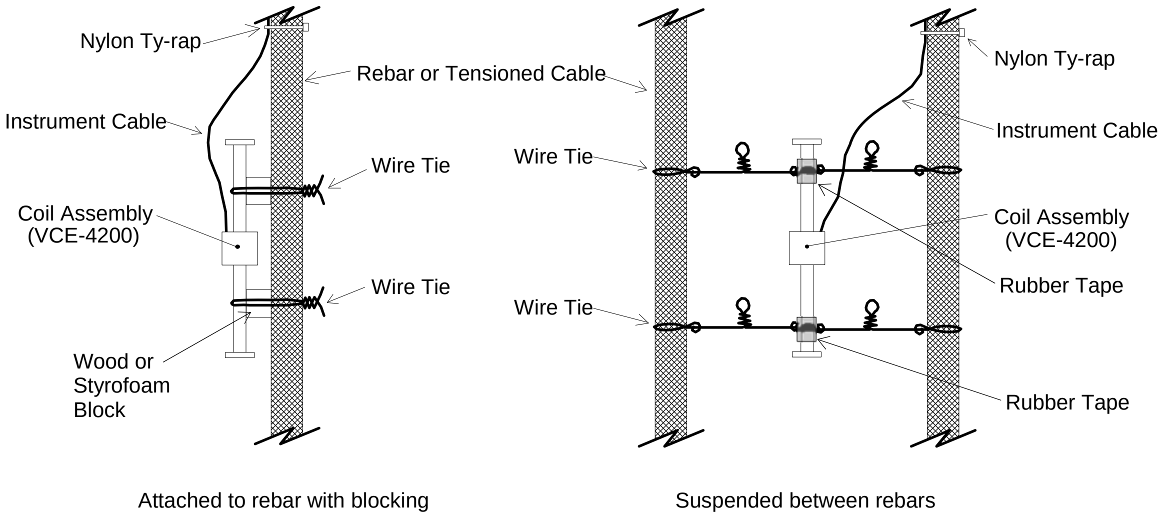

Figure 3 - Attaching VCE-4200X Strain Gages to Rebar

Note the following instructions to suspend the model VCE-4200X strain gage between rebar:

1. **Wrap a layer of self-vulcanizing rubber tape around the gage in the two places shown in Figure 3 (around the tie points). The rubber layer serves as a shock absorber, dampening any vibrations of the suspension system. Sometimes, without the rubber layers, as the tie wires are tightened the resonant frequency of the tie wires interferes with the resonant frequency of the gage. This results in unstable readings or no readings at all. This effect disappears once the concrete has been placed.**
2. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together. Twist it 2 times around the body of the strain gage, over the rubber strips, about 3 cm from the gage ends.
3. Twist two loops in the wire, one on either side of the gage, at a distance of about 3cm

   from the gage body. Repeat this process at the other end of the gage.
4. Position the gage between the rebar and twist the wire ends twice around the rebar, then around itself.
5. Tighten the wire and orient the gage by twisting on the loops.
6. Slip on the plucking coil and affix using a hose clamp. Tie the instrument cable off to one of the rebar using nylon Ty-Raps™.

Alternative Method:

Tie two short pieces of steel rebar to the existing rebar using nylon Tie-wraps, as shown in Figure 3B. Then tie the strain gage to the short pieces of rebar again using nylon tie wraps. This method avoids the resonance problems associated with the previous method.

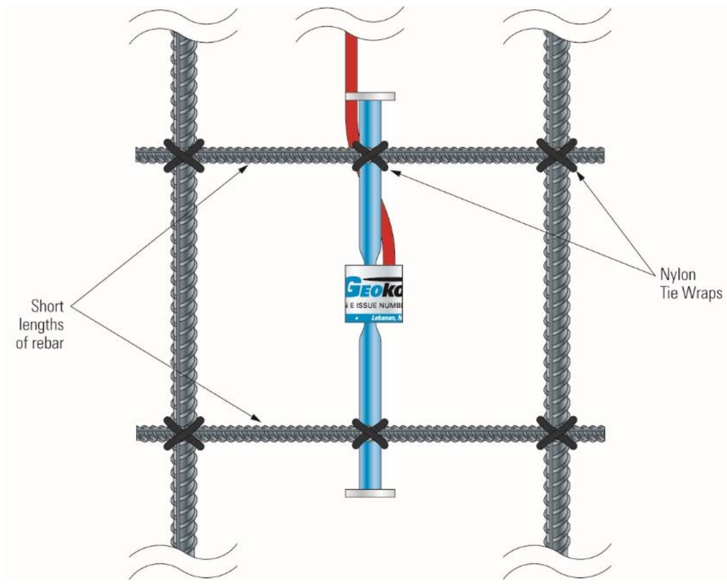

Figure 3B - Alternative Method for attaching VCE 4200X straingages to rebar.

2.3. Using Pre-cast Briquettes or Grouting

An alternate method to the above is to pre-cast the gages into briquettes of the same mix as the mass concrete and then place these in the structure prior to concrete placement. The briquettes should be constructed not more than 3 days and not less than 1 day prior to installation. The briquettes should be continuously cured with water prior to placement in the mass concrete.

Embedment gages can also be used in shotcrete and in drilled holes in rock or concrete that are subsequently grouted. When used in shotcrete special care should be taken to protect the lead wires. Encasing them in conduit or heavy tubing has been used effectively to protect the cable. The gages can be placed by packing the immediate area around the gage by hand and then proceeding with the shotcrete operation.

2.4. Cable Protection and Termination

The cable from the strain gages can be protected by the use of flexible conduit, which can be supplied by Geokon.

Terminal boxes with sealed cable entries and covers are also available, allowing many gages to be terminated at one location with complete protection of the lead wires. The panel can have built-in jacks or a single connection with a rotary position selector switch.

Cables may be spliced to lengthen them, without affecting the gage readings. Always maintain polarity by connecting color to color. Always waterproof the splice completely, preferably using a splice kit (epoxy based) such as the 3M Scotchcast™ kit, model 82-A1.

Cables may be terminated by stripping and tinning and connected by clipping to the patch cord from the readout box. Alternatively, a plug may be used which will connect directly into the readout box or to a receptacle on a special patch cord.

2.5. Lightning Protection

The 4200ER Embedment Strain Gage, unlike numerous other types of instrumentation available from Geokon, does not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors. Usually this is not a problem as the gages are installed within concrete or grout and somewhat isolated from potentially damaging electrical transients. However, there may be occasions where some sort of lightning protection is desirable, for example where the gage is in contact with rebar that may be exposed to direct or indirect lightning strikes. Also, 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 at the exit point of the instrument cable from the structure being monitored. 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 4. 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 the rebar itself.

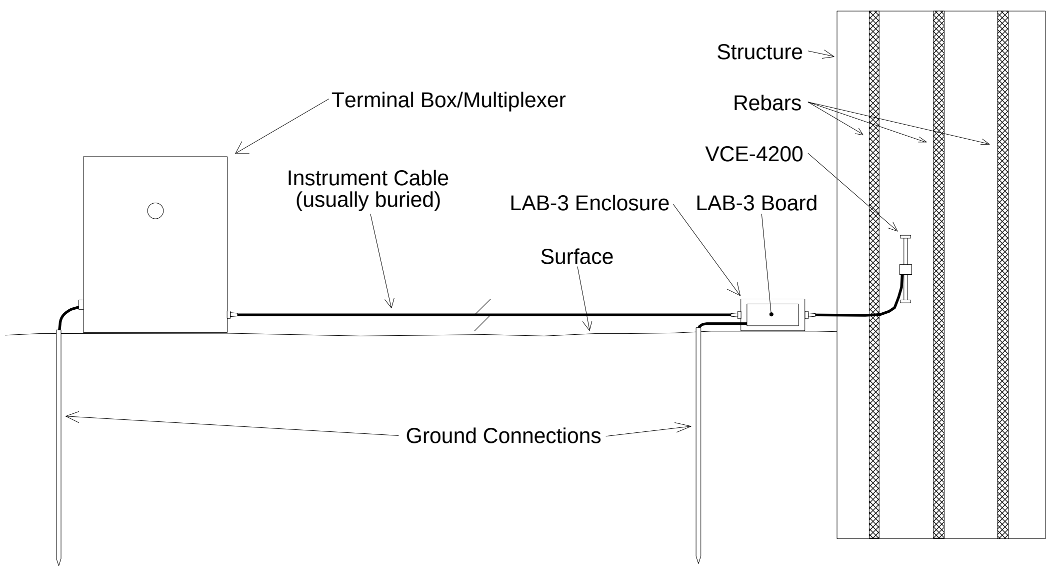

Figure 4 - Lightning Protection Scheme

3. TAKING READINGS

The following three sections describe how to take readings using readout equipment available from Geokon. Table 1 shows a 10,000 microstrain range gage, Other ranges are avialbale on request.

Model:	4200ER - 10,000
Readout Position:	D
Display Units:	Readout units
Frequency Range:	400-1200 Hz
Mid-Range Reading:	2000
Minimum Reading:	1000
Maximum Reading:	3000

Table 1 - Embedment Strain Gage Readout Positions

3.1. 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 GK-403 reads out the thermistor temperature directly in degrees C.

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 leads are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position ""D".
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 displayed on the screen above the gage reading in degrees centigrade.
3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.2. Operation of the GK-404 Readout Box

The GK404 is a palm sized readout box which diplays 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 **D** and the **MODE** button to select **µE**

(Note that the display, although marked μE is not directly in microstrains. The change in digits diplayed must be multiplied by the gage factor given on the calibration sheet to get the true microstrains)

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

3.3. Operation of the 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
- 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.

3.4. MICRO-6000 Datalogger

The following parameters are recommended when using the strain gages with the MICRO-1000 datalogger or any other CR1000 based datalogger:

See Table 2 for the recommended Gage Type selection and Gage Factor,G, entry to convert to microstrain when using the embedment strain gages with the MICRO-1000 Datalogger Configuration Software. Table 2 also lists the starting and ending frequency settings for the excitation sweep when writing a program for the CR1000 using the P28 vibrating wire measurement instruction. Alternately, if a calibration sheet is supplied with the strain gage the exact values can be calculated from the start and end frequencies of the calibration. To maximize the stability and resolution of the sensor a relatively narrow band of excitation frequency should be selected. One could calculate these settings by taking an initial reading and then setting the starting frequency to 200 Hz below and the ending frequency 200 Hz above.

Model:	**4200ER**
MICRO-6000 Gage Type:	4200
Gage Factor G:	Shown on cal sheet
Start Frequency (P28):	4 (400 Hz)
End Frequency (P28):	12 (1200 Hz)

Table 2 - Embedment Strain Gage Datalogger Parameters

3.5. Measuring Temperatures

All Vibrating Wire Strain Gages are equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor.

Note: All readout boxes will read the thermistor and display temperature in °C.

4.DATA REDUCTION FOR THE GK-403, GK-404 or GK-405 in POSITION D

4.1. Conversion of Readings to Strain Changes

Readings on channel D of all Readout Box are set up to display microstrain when used with a 6 inch long strain gage . But the 4200X strain gage is special in that it has unusually large range so that the displayed readout units, R, must be multiplied by the gage factor, G, on the calibration sheet to obtain true values of microstrain, $\mu\varepsilon$.

$$\mu\varepsilon = G(R_1 - R_0)$$

Equation 1 - Strain Calculation, channel D

Where R_0 and R_1 are the readout box readings in Pos D.

Note: when $(R_1 - R_0)$ is positive, the strain is tensile.

A typical calibration sheet is shown in Figure 6

It will be noted that the 4200Er output is not very linear varying as much a +/- 3%FS. Therefor it is advisable to use the polynomial expression to aceive greater accuracy.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Strain Gage Calibration Report

Model: 4200X

Calibration Date: August 04, 2015

This calibration has been verified/validated as of 08/06/2015

Serial Number: 1523715

Temperature: 22.8 °C

Calibration Instruction: CI-VW Strain Gage

Technician:

GK-401 Reading Position D

Actual Strain 1st Cycle	Gage Reading 1st Cycle	Actual Strain 2nd Cycle	Gage Reading 2nd Cycle	Average Actual Strain	Average Gage Reading	Calculated Strain (Linear)	Error Linear (%FS)	Calculated Strain (Polynomial)	Error Polynomial (%FS)
0	1009	0	1009	0	1009	322	3.22	2	0.02
1988	1355	1988	1354	1988	1355	1925	-0.63	1983	-0.05
4000	1742	4000	1742	4000	1742	3724	-2.76	4003	0.03
6000	2166	6000	2166	6000	2166	5693	-3.07	6002	0.02
8000	2635	8000	2635	8000	2635	7872	-1.28	7997	-0.03
10000	3155	10000	3157	10000	3156	10292	2.92	10001	0.01

Linear Gage Factor (G): 4.644 **(microstrain/digit)** **Regression Zero:** 940

Calculated Strain: **Linear, Strain** $= G(R_1 - R_0)$

Polynomial, Strain $= AR_1^3 + BR_1^2 + CR_1 + D$

Polynomial Gage Factors: A: 7.8638E-08 B: -0.001033

C: 7.849 D: -6948

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.

Figure 6 - Typical Calibration Sheet for the 4200ER Strain Gage

4.2. Temperature Corrections

Temperature variations of considerable magnitude are not uncommon, particularly during concrete curing; therefore it is always advisable to measure temperatures along with the measurement of strain. Temperature induced expansions and contractions can give rise to real changes of stress in the concrete if the concrete is restrained in any way, and these stresses are superimposed on any other load related stresses.
Temperature can also affect the strain gage itself since increasing temperatures will cause the vibrating wire to elongate and thus to go slack indicating what would appear to be a compressive strain in the concrete. This effect is balanced to some degree by a corresponding stretching of the wire caused by expansion of the concrete in which the gage is embedded or to which the gage is attached. If the concrete expanded by exactly the same amount as the wire then the wire tension would remain constant and no correction would be necessary.

The effect of temperature on the 4200ER strain gage is complex - it varies depending on the strain level.A Typical temperature correction factor to be applied to the 4200ER-10,000 is as follows:

Temperature Correction Factor = +(0.000401*R1 - 1.067)(T1-T0)

Where

R1 is the current gage reading,.

T1 is the current temperature in degrees C,

T0 is the initial temperature in degrees C.

This correction factor was developed by testing four gages at three different parts of their range (i.e., at microstrain levels of 4000, 8000 and 12000), at five different temperature levels, i.e., -40, -20, 0, 20, 40, and 60 degrees C).

When using the polynomial expression to calculate the strain, this correction factor must be applied to the current reading R1. The modified value of R1 is then inserted into the polynomial.

Thus the modified value of R1 to be inserted into the polynomial is

R1+ (0.000401*R1 – 1.067) x (T1 - T0)

4.3. Shrinkage Effects

A well know property of concrete is its propensity to shrink as the water content diminishes, or for the concrete to swell as it absorbs water. This shrinkage and swelling can give rise to large apparent strain changes that are not related to load or stress changes. The magnitude of the strains can be several hundred microstrain.

It is difficult to compensate for these unwanted strains. An attempt may be made, or it may occur naturally, to keep the concrete under a constant condition of water content. But this is frequently impossible on concrete structures exposed to varying weather conditions. Sometimes an attempt is made to measure the shrinkage and/or swelling effect by casting a strain gage inside a concrete block that remains unloaded but exposed to the same moisture conditions as the active gages. Strains measured on this gage may be used as a correction.

4.4. Creep Effects

It is also well known that concrete will creep under a sustained load. What may seem to be a gradually increasing load as evidenced by a gradually increasing strain may, in fact, be strain due to creeping under a constant sustained load.

On some projects, gages have been cast into concrete blocks in the laboratory and then kept loaded by means of springs inside a load frame so that the creep phenomenon can be quantified.

4.5. Effect of Autogenous Growth

In some old concrete, with a particular combination of aggregates and alkaline cements, the concrete may expand with time as it undergoes a chemical change and recrystallization. This expansion is rather like creep but in the opposite direction. It is difficult to account for.

5. TROUBLESHOOTING

Maintenance and troubleshooting of embedment 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 reading outside the specified range (either compressive or tensile) of the instrument?

- ✓ 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.

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 (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 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 (<100Ω) 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.

APPENDIX A - SPECIFICATIONS

A.1 4200ER Strain Gage

Model:	**4200ER**
Range (nominal):	10,000 $\mu\varepsilon$
Resolution:	5.0 $\mu\varepsilon$[1]
Calibration Accuracy	0.5%FSR
Sytem Accuracy:	2.0% FSR[2]
Stability:	0.1%FS/yr
Linearity:	+/-3.0% FSR
Thermal Coefficient:	variable
Frequency Range Hz:	400-1200
Dimensions (gage): (Length × Diameter)	6.00 x 0.750" 153× 19 mm
Dimensions (coil):	0.875 × 0.875" 22 × 22 mm
Coil Resistance:	50 Ω
Temperature Range:	-20 to +80° C

Table A-1 Strain Gage Specifications

Notes:
[1] Depends on the readout; figures in Table A-1 pertain to the GK-403 or GK-404 Readout.
[2] System Accuracy takes into account hysteresis, non-linearity, misalignment, batch factor variations, and other aspects of the actual measurement program.

A.2 Thermistor (see Appendix C 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:

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

Equation C-1 Convert Thermistor Resistance to Temperature

Where: T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
$A = 1.4051 \times 10^{-3}$ (coefficients calculated over the –50 to +150° C. span)
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Table C-1 Thermistor Resistance versus Temperature

APPENDIX C - HIGH-TEMPERATURE THERMISTOR LINEARIZATION

Resistance to Temperature Equation for *US Sensor 103JL1A*:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3 + D(LnR)^5} - 273.2$$

Where; T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
$A = 1.127670 \times 10^{-3}$
$B = 2.344442 \times 10^{-4}$
$C = 8.476921 \times 10^{-8}$
$D = 1.175122 \times 10^{-11}$
(Coefficients optimized for a curve "J" Thermistor over the temperature range of 0°C to +250°C.)

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
32,650	**0**	7,402	**32**	2,157	**64**	763.5	**96**	316.6	**128**	148.4	**160**	76.5	**192**	42.8	**224**
31,029	**1**	7,098	**33**	2,083	**65**	741.2	**97**	308.7	**129**	145.1	**161**	75.0	**193**	42.1	**225**
29,498	**2**	6,808	**34**	2,011	**66**	719.6	**98**	301.0	**130**	142.0	**162**	73.6	**194**	41.4	**226**
28,052	**3**	6,531	**35**	1,942	**67**	698.7	**99**	293.5	**131**	138.9	**163**	72.2	**195**	40.7	**227**
26,685	**4**	6,267	**36**	1,876	**68**	678.6	**100**	286.3	**132**	135.9	**164**	70.8	**196**	40.0	**228**
25,392	**5**	6,015	**37**	1,813	**69**	659.1	**101**	279.2	**133**	133.0	**165**	69.5	**197**	39.3	**229**
24,170	**6**	5,775	**38**	1,752	**70**	640.3	**102**	272.4	**134**	130.1	**166**	68.2	**198**	38.7	**230**
23,013	**7**	5,545	**39**	1,693	**71**	622.2	**103**	265.8	**135**	127.3	**167**	66.9	**199**	38.0	**231**
21,918	**8**	5,326	**40**	1,637	**72**	604.6	**104**	259.3	**136**	124.6	**168**	65.7	**200**	37.4	**232**
20,882	**9**	5,117	**41**	1,582	**73**	587.6	**105**	253.1	**137**	122.0	**169**	64.4	**201**	36.8	**233**
19,901	**10**	4,917	**42**	1,530	**74**	571.2	**106**	247.0	**138**	119.4	**170**	63.3	**202**	36.2	**234**
18,971	**11**	4,725	**43**	1,480	**75**	555.3	**107**	241.1	**139**	116.9	**171**	62.1	**203**	35.6	**235**
18,090	**12**	4,543	**44**	1,432	**76**	539.9	**108**	235.3	**140**	114.5	**172**	61.0	**204**	35.1	**236**
17,255	**13**	4,368	**45**	1,385	**77**	525.0	**109**	229.7	**141**	112.1	**173**	59.9	**205**	34.5	**237**
16,463	**14**	4,201	**46**	1,340	**78**	510.6	**110**	224.3	**142**	109.8	**174**	58.8	**206**	33.9	**238**
15,712	**15**	4,041	**47**	1,297	**79**	496.7	**111**	219.0	**143**	107.5	**175**	57.7	**207**	33.4	**239**
14,999	**16**	3,888	**48**	1,255	**80**	483.2	**112**	213.9	**144**	105.3	**176**	56.7	**208**	32.9	**240**
14,323	**17**	3,742	**49**	1,215	**81**	470.1	**113**	208.9	**145**	103.2	**177**	55.7	**209**	32.3	**241**
13,681	**18**	3,602	**50**	1,177	**82**	457.5	**114**	204.1	**146**	101.1	**178**	54.7	**210**	31.8	**242**
13,072	**19**	3,468	**51**	1,140	**83**	445.3	**115**	199.4	**147**	99.0	**179**	53.7	**211**	31.3	**243**
12,493	**20**	3,340	**52**	1,104	**84**	433.4	**116**	194.8	**148**	97.0	**180**	52.7	**212**	30.8	**244**
11,942	**21**	3,217	**53**	1,070	**85**	421.9	**117**	190.3	**149**	95.1	**181**	51.8	**213**	30.4	**245**
11,419	**22**	3,099	**54**	1,037	**86**	410.8	**118**	186.1	**150**	93.2	**182**	50.9	**214**	29.9	**246**
10,922	**23**	2,986	**55**	1,005	**87**	400.0	**119**	181.9	**151**	91.3	**183**	50.0	**215**	29.4	**247**
10,450	**24**	2,878	**56**	973.8	**88**	389.6	**120**	177.7	**152**	89.5	**184**	49.1	**216**	29.0	**248**
10,000	**25**	2,774	**57**	944.1	**89**	379.4	**121**	173.7	**153**	87.7	**185**	48.3	**217**	28.5	**249**
9,572	**26**	2,675	**58**	915.5	**90**	369.6	**122**	169.8	**154**	86.0	**186**	47.4	**218**	28.1	**250**
9,165	**27**	2,579	**59**	887.8	**91**	360.1	**123**	166.0	**155**	84.3	**187**	46.6	**219**		
8,777	**28**	2,488	**60**	861.2	**92**	350.9	**124**	162.3	**156**	82.7	**188**	45.8	**220**		
8,408	**29**	2,400	**61**	835.4	**93**	341.9	**125**	158.6	**157**	81.1	**189**	45.0	**221**		
8,057	**30**	2,316	**62**	810.6	**94**	333.2	**126**	155.1	**158**	79.5	**190**	44.3	**222**		
7,722	**31**	2,235	**63**	786.6	**95**	324.8	**127**	151.7	**159**	78.0	**191**	43.5	**223**		

Table B-2: High Temperature Thermistor Resistance versus Temperature.