

Vibrating Wire Rebar Strain Gauge User Manual



Man154	3.0.2	06/08/2014	Kim Malcolm	Phil Day	Chris Rasmussen
Manual No.	Revision	Date	Originator	Checked	Authorised for Issue

Contents

Section 1 : Foreword	3
Section 2 : Introduction	4
Section 3 : Installation	5
3.01 Preliminary Tests	5
3.02 Rebar Strain Gauge Installation	5
3.02.1 Model ST5 – 16 to 40	5
3.02.2 Model ST5 - 12 "Sister Bar"	7
3.03 Cable Installation	8
Section 4 : Taking Readings	9
4.01 Operation of the Vibrating Wire Readout/Logger	9
4.02 Measuring Temperatures (Alternative Method)	9
Section 5 : Data Reduction	10
5.01 Strain Calculation	10
5.02 Temperature Correction	11
5.03 Environmental Factors	11
Section 6 : Troubleshooting	12
Section 7 : Thermistor Temperature Derivation	14
Section 8 : Data Reduction	16
8.01 Converting from Hz to microstrain	16
Section 9 : Temperature Effects	18

Section 1 : Foreword

Soil Instruments Vibrating Wire Rebar Strain Gauge, as with all our equipment, has been designed to operate consistently in a construction site environment and is, therefore, relatively robust.

However, it is essential that the equipment covered by this manual is both operated and maintained by competent and suitably qualified personnel. They must **READ AND UNDERSTAND** the procedures outlined in this manual before attempting installation or operation of the equipment on site.

Soil Instruments will not accept for repair under guarantee, instruments that have been neglected or mishandled in any way.

Section 2 : Introduction

Vibrating Wire Rebar Strain Gauges are designed primarily for monitoring the stresses in reinforcing steel in concrete structures, such as bridges, concrete piles and diaphragm walls. The strain meter is comprised of a length of high strength steel, bored along its central axis to accommodate a miniature vibrating wire strain gauge. Readout of load or stress is achieved remotely using a portable readout or datalogging system.

The Model ST5 - 16 to 40 Vibrating Wire Rebar Strain Gauge consists of a short length of high strength steel welded between two sections of reinforcing bar. It is designed to be welded between sections of structural concrete reinforcing bar. The cable exits from the strain meter via a compression fitting. See Figure 1.

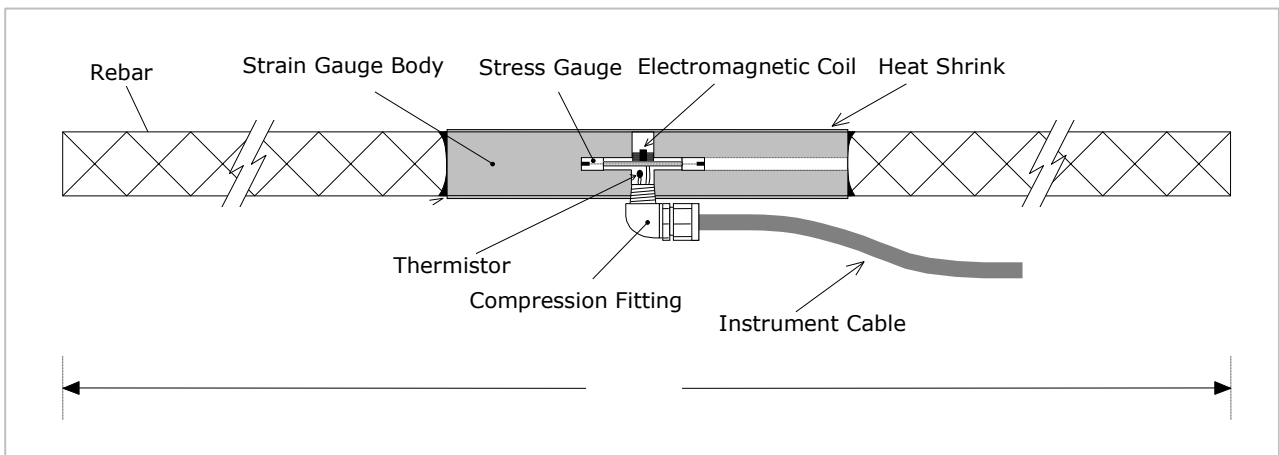


Figure 1 - Model ST5 -16 to 40 Rebar Strain Gauge

The Model ST5 - 12 Vibrating Wire Rebar Strain Gauge or "Sister Bar" consists of a short length of high strength steel welded between two long sections of reinforcing bar. It is designed to be wire tied in parallel with the structural rebar. The small diameter of the bar minimises its effect on of the sectional modulus of the concrete. The cable exits from the strain meter through a small gland of protective epoxy. See Figure 2.

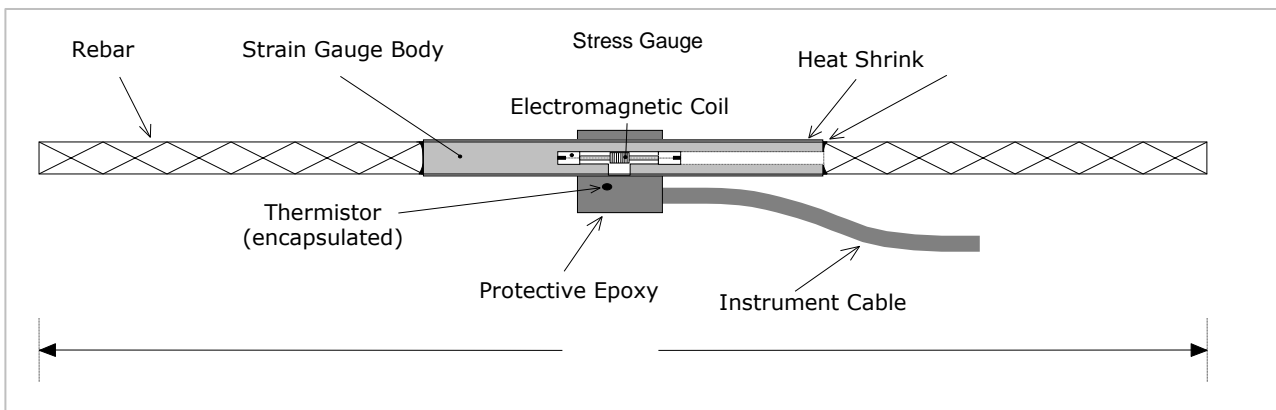


Figure 2 - Model ST5 - 12 Rebar Strain Gauge

Both models of strain meters are robust, reliable and easy to install and read and are unaffected by moisture, cable length or contact resistance. The long term stability of these instruments has proven to be excellent.

Section 3 : Installation

3.01 Preliminary Tests

It is always wise, before installation commences, to check the strain meters for proper function. Each strain meter is supplied with a calibration sheet which shows the relationship between readout digits and microstrain and also shows the initial no load zero reading. The strain meter electrical leads (usually the red and black leads) are connected to a readout box (see section 3) and the zero reading given on the sheet is now compared to a current zero reading. The two readings should not differ by more than approx 25 digits after due regard to correction for temperature.

Checks of electrical continuity can also be made using an ohmmeter. The resistance between the gauge leads should be approximately 170Ω , $\pm 10\Omega$. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately $14.7\Omega/1000'$ or $48.5\Omega/\text{km}$, multiply by 2 for both directions). Between the green and white should be approximately 3000 ohms at 25° (see Table B-1) and between any conductor and the shield should exceed 2 megohm.

NOTE: Do not lift the strain meter by the cable

3.02 Rebar Strain Gauge Installation

3.02.1 Model ST5 – 16 to 40

The normal procedure is to weld the strain meter in series with the reinforcing steel that is to be instrumented on the site. For a typical installation see Figure 3. The strain meter is long enough so that it may be welded in place without damaging the internal strain gauge element (Figure 1). However, care should still be taken to ensure that the central portion of the strain meter does not become too hot as the plucking coil and protective epoxy could melt. In order to prevent this it may be necessary to place wet rags between the weld area and the coil housing. Also, take care not to damage or burn the instrument cable when welding. After welding, route the instrument cable along the rebar system and tie it off at metre intervals using nylon cable ties. Avoid using iron tie wire to secure the cable as the cable could be cut.

Be sure when installing the strain meters to note the location and serial numbers of all instruments. This is necessary for applying the proper calibration factors and determining strain characteristics when reducing data.

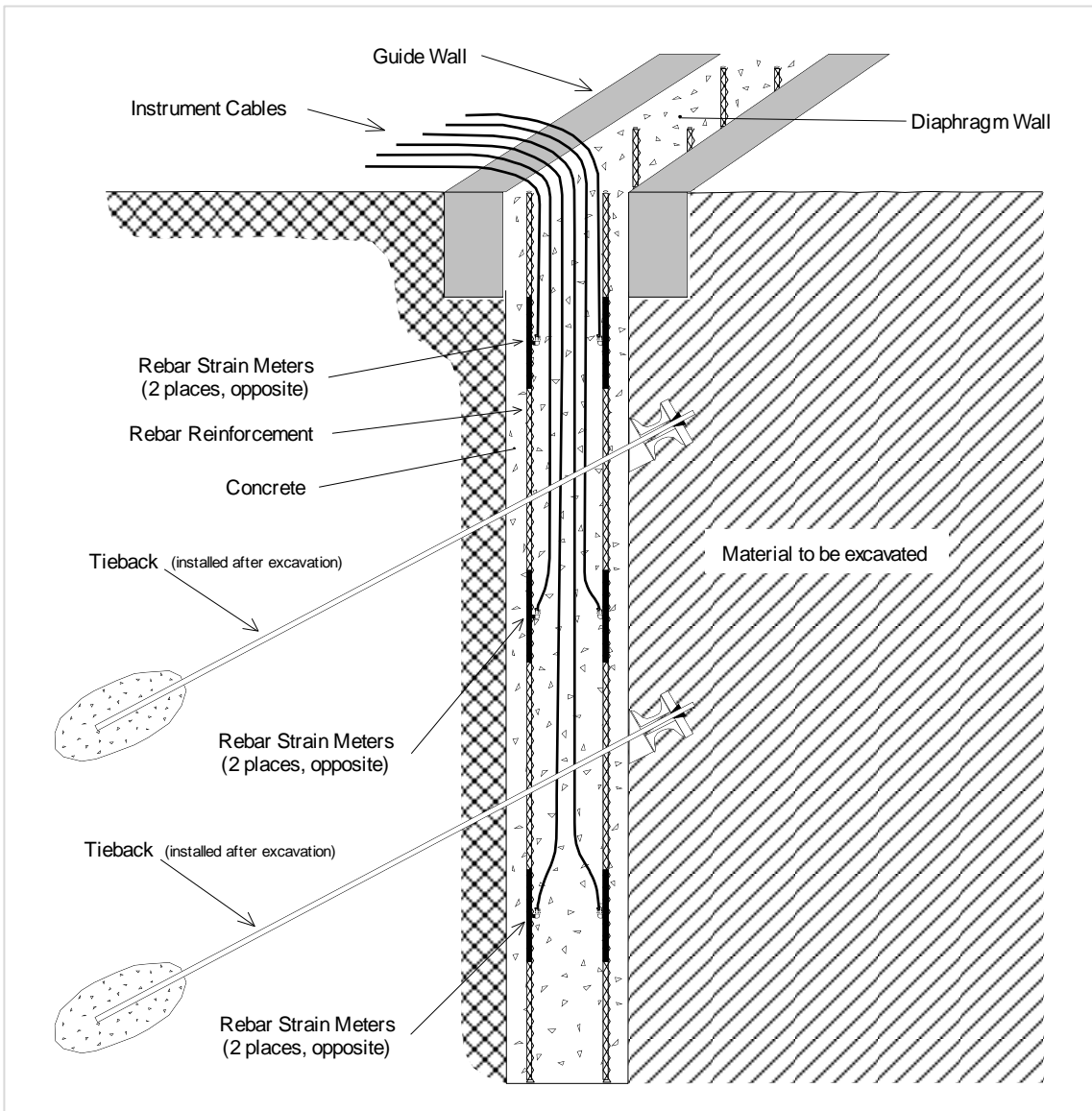


Figure 3 - Model ST5 – 16 to 40 Installation

3.02.2 Model ST5 - 12 "Sister Bar"

The "Sister Bar" is usually installed using standard iron tie wire. Normally ties near the ends and at the one third points are sufficient if the gauge is being wired to a larger section of rebar or to horizontal bars. Wiring at the one third points alone is sufficient if the gauge is being wired in parallel to the structural rebar. See Figures 4 and 5. Route the instrument cable along the rebar system and tie it off at metre intervals using nylon cable ties. Avoid using the tie wire on the instrument cable as it could cut the cable.

Be sure when installing the strain meters to note the location and serial numbers of all instruments. This is necessary for applying the proper calibration factors and determining load characteristics when reducing data.

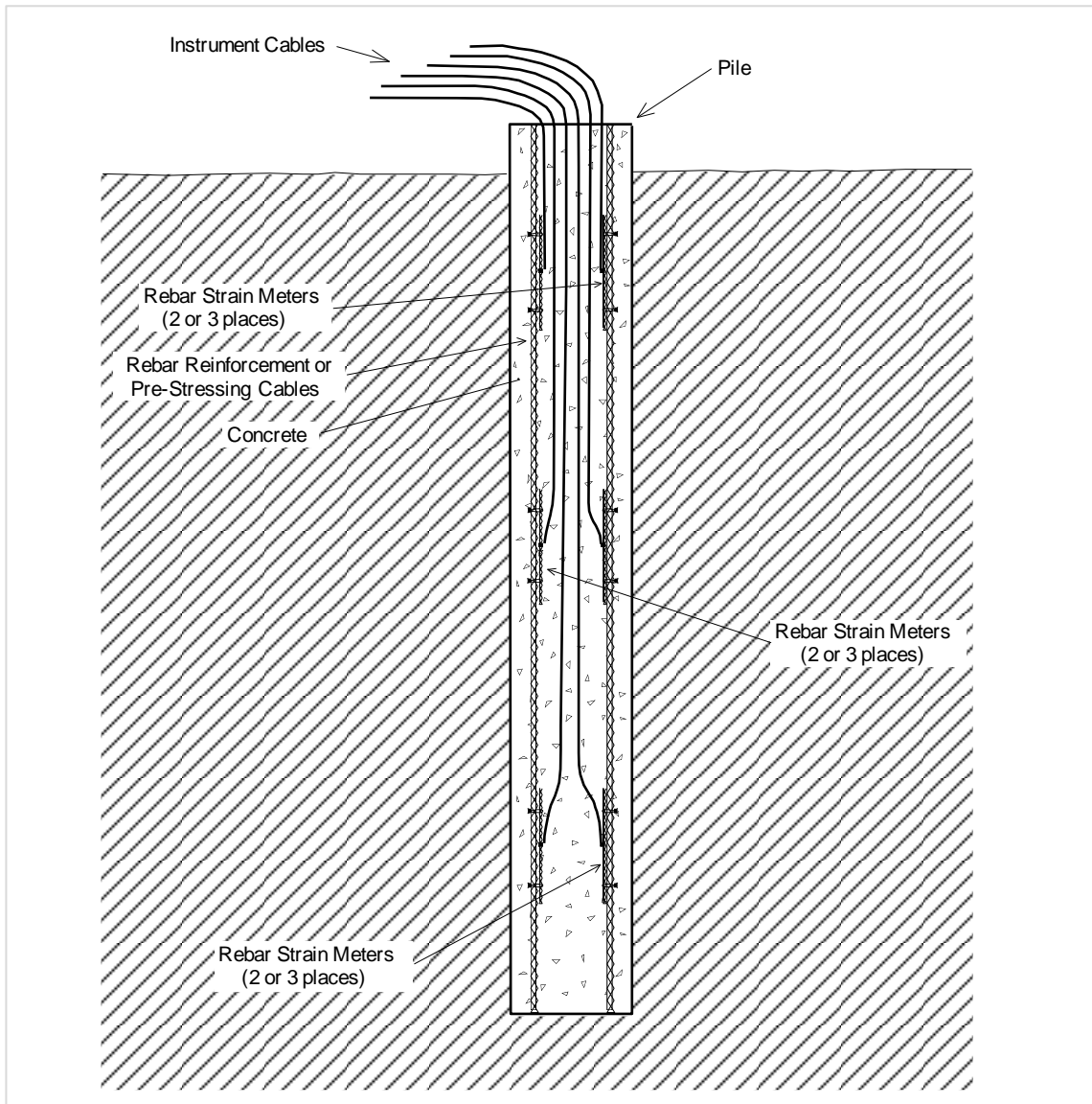


Figure 4 – ST5 - 12 "Sister Bar" Installation

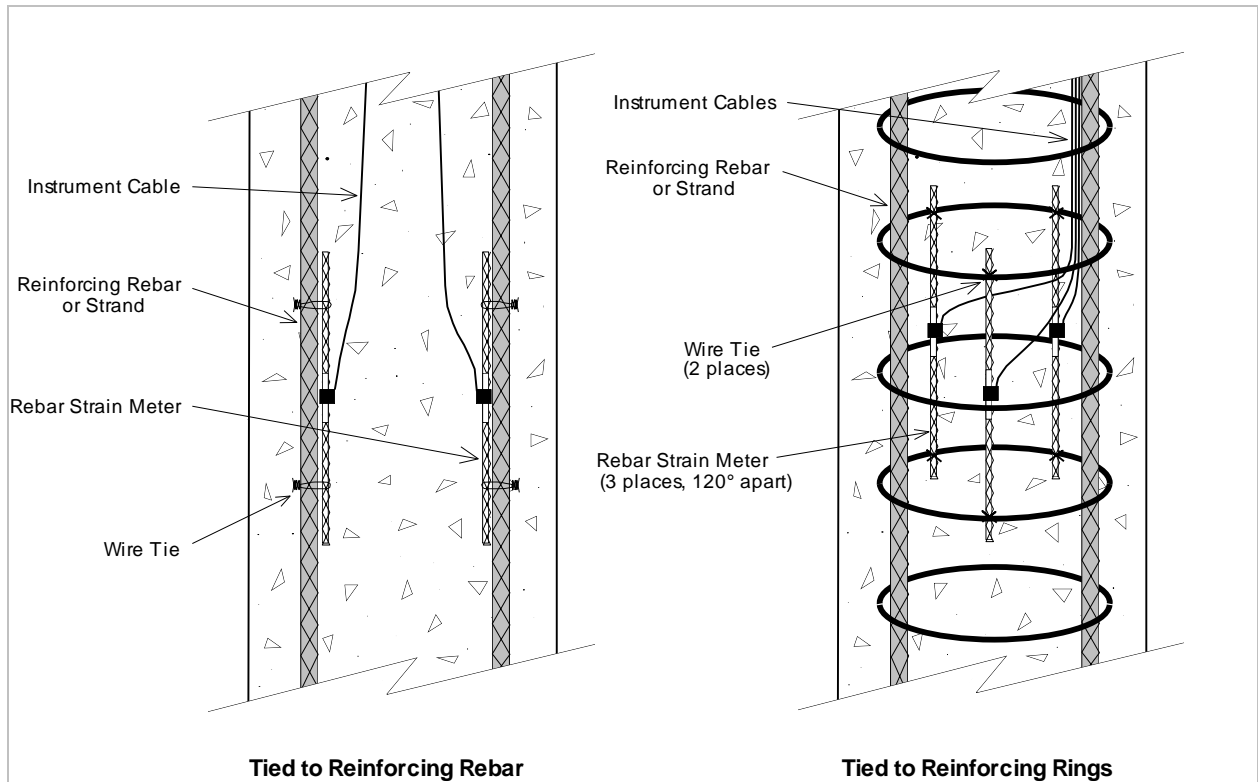


Figure 5 - Model ST5 - 12 "Sister Bar" Installation Detail

3.03 Cable Installation

As noted in the installation sections, route the instrument cables along the structural rebar and tie off using nylon cable ties every 1 metre to secure. Outside of the instrumented structure, the cable should be protected from accidental damage caused by moving equipment or other construction activity.

Cables may be spliced to lengthen them, without affecting gauge readings. Always waterproof the splice completely, especially when embedding within the concrete, preferably using an epoxy based splice kit such as Soil Instruments Cable Jointing Kit.

Section 4 : Taking Readings

4.01 Operation of the Vibrating Wire Readout/Logger

Connect the Readout using the flying leads or in the case of a Switchable Terminal Unit, with a connector. The red and black conductors are for the vibrating wire gauge, the white and green conductors are for the thermistor.

4.02 Measuring Temperatures (Alternative Method)

Each Vibrating Wire Rebar Strain Gauge is 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.

1. Connect an ohmmeter to the two thermistor leads coming from the strain meter. (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.

Section 5 : Data Reduction

5.01 Strain Calculation

The basic units utilised by Soil Instruments for measurement and reduction of data from Vibrating Wire Rebar Strain Gauges are Frequency Squared divided by 1000 ($F^2/1000$) units. Two types of calibration constants and a Thermal Factor are provided on the calibration sheet. The Vibrating Wire Strain Meter is calibrated in kN and the constants calculated for strain/

Equation 1:

To reduce $F^2/1000$ units to strain using Linear Factors
$$\mu\epsilon = G(R^1 - R^0) + K(T^1 - T^0)$$

Where;

- G is the Linear Gauge Factor from the calibration sheet
- R^1 is the current $F^2/1000$ reading
- R^0 is the initial (baseline) $F^2/1000$ reading
- K is the thermal factor
- T^1 is the current temperature in degrees C.
- T^0 is the initial temperature in degrees C.

Equation 2:

To reduce $F^2/1000$ units to strain using Polynomial Factors
$$\mu\epsilon = AR_1^2 + BR_1 + C + K(T^1 - T^0)$$

Where;

- A is the A Polynomial Factor from the calibration sheet
- B is the B Polynomial Factor from the calibration sheet
- C is the C Polynomial Factor from the calibration sheet
- R^1 is the current $F^2/1000$ reading
- K is the thermal factor
- T^1 is the current temperature in degrees C.
- T^0 is the initial temperature in degrees C.

5.02 Temperature Correction

Rebar strain Gauges are usually embedded in concrete and strained by the concrete, the assumption being that the strain in the meter is equal to the strain in the concrete. When the temperature changes, the concrete may expand and contract at a slightly different rate to that of the steel of the vibrating wire. The coefficients of expansion are:

Steel:	12.2 $\mu\text{M}/^\circ\text{C}$
Concrete:	10 to 14 $\mu\text{M}/^\circ\text{C}$
Difference (c):	2.2 to 1.8 $\mu\text{M}/^\circ\text{C}$

Table 1

Thermal Coefficients

Hence a correction is required to the observed strains equal to the difference of these two coefficients. See Equation 3.

Equation 3:

$$\text{Thermal Correction} \\ \varepsilon + C(T_1 - T_0)$$

Where:

- ε is the resultant from Equation 1 or 2
- T_0 is the initial temperature recorded at the time of installation.
- T_1 is the current temperature.
- C is the thermal coefficient from Table 1.

NOTE: For most practical purposes the temperature effects on the embedded gauges are considered to be the same as those on the concrete.

5.03 Environmental Factors

Since the purpose of the strain meter installation is to monitor site conditions, factors which may affect these conditions should be observed and recorded. Seemingly minor effects may have a real influence on the behaviour of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to, blasting, rainfall, tidal or reservoir levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

Section 6 : Troubleshooting

Maintenance and troubleshooting of Vibrating Wire Rebar Strain Gauges are confined to periodic checks of cable connections. Once installed, the meters 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 Gauge Readings are Unstable

- If using a datalogger to record readings automatically, are the swept frequency excitation settings correct?
- Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger.
- Does the readout work with another strain meter? If not, the readout may have a low battery or be malfunctioning.

Symptom: Strain Gauge Fails to Read

- Is the cable cut or crushed? This can be checked with an ohmmeter. The nominal resistance between the two gauge leads (usually red and black leads) is $170\Omega, \pm 10\Omega$. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately $48.5\Omega/\text{km}$, 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 ($<20\Omega$) a short in the cable is likely.
- Does the readout or datalogger work with another strain meter? If not, the readout or datalogger may be malfunctioning.

Symptom: Thermistor resistance is too high

- Is there an open circuit? Check all connections, terminals and plugs. If a cut is located in the cable, splice according to instructions in Section 2.3.

Symptom: Thermistor resistance is too low

- Is there a short? Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions in Section 2.3.

Section 7 : Thermistor Temperature Derivation

Thermistor Type: NTC 3000 ohm.

Resistance to Temperature Equation:

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

Equation B-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	524.4	+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 B-1 Thermistor Resistance versus Temperature

Section 8 : Data Reduction

8.01 Converting from Hz to microstrain

Data from strain gauges is generally presented in micro strain ($\mu\epsilon$) where strain is the ratio of the change in length per unit length:-

$$\left(\frac{\Delta L}{L}\right) \text{ Practical K factor} = 3920 \text{ (Gauge calibration constant)}$$

Conversion of Period and Linear Units to microstrain is carried out using either of the formulae detailed below:-

Period Units

$$\mu\epsilon = K * \left[\frac{10^7}{(T_1)^2} - \frac{10^7}{(T_0)^2} \right]$$

Where $\mu\epsilon$ = Change in strain in micro-strain

K = Gauge Calibration Constant

T_0 = Base reading in Period units x 10^7

T_1 = Current reading in Period units x 10^7

Please note: when $\frac{10^7}{(T_1)^2} - \frac{10^7}{(T_0)^2}$ is positive the resultant strain is tensile.

Linear Units

$$\mu\epsilon = K (F_1 - F_0) \times 10^{-4}$$

Where $\mu\epsilon$ = Change in micro-strain

K = Gauge Calibration Constant

F_0 = Base reading in $f^2/1000$ units

F_1 = Current reading in $f^2/1000$ units

Please note: when $(F_1 - F_0)$ is positive the resultant strain is tensile.

The calculation of Load in a member using data from strain gauges is often complex. The fundamental problem is determining the composite Young Modulus (E) of the member, since it is often difficult to accurately determine the properties of the insitu materials.

Once a Young Modulus is calculated, the following equations can be used to calculate the loading on the structural member at the location of the Strain Gauge.

$$\text{Force (F)} = \text{Stress (S)} \times \text{Area (A)}$$

Where A = Cross sectional area in m^2

Where F units = Newton's

Where S units = N/m^2

$$\text{Stress (S)} = \text{Young Modulus of Elasticity (E)} \times \text{Strain } (\epsilon)$$

Where E units = N/m^2

Example calculation

Steel pipe outside diameter = 1.016m

Steel pipe inside diameter = 0.984m

Calculated change from the strain gauges = $54.688_{\mu\epsilon}$

Young Modulus of Elasticity of the steel pipe = 200,000,000,000 N/m²

$$\text{Stress} = E \times \epsilon$$

$$= 200,000,000,000 \times 0.000054688$$

$$= 10937600 \text{ N/m}^2$$

$$\text{Area} = \pi r^2$$

$$= \pi \times (\text{outside diameter} / 2)^2 - \pi \times (\text{inside diameter} / 2)^2$$

$$= \pi \times (1.016 / 2)^2 - \pi \times (0.984 / 2)^2$$

$$= \pi \times (0.508)^2 - \pi \times (0.492)^2$$

$$= \pi \times 0.258064 - \pi \times 0.242064$$

$$= 0.810732 \text{ m}^2 - 0.760466 \text{ m}^2$$

$$= 0.050266 \text{ m}^2$$

$$\text{Force} = S \times A$$

$$= 10937600 \times 0.050266$$

$$= 549789.4 \text{ N}$$

Section 9 : Temperature Effects

It is best practice to record temperature when you record strain readings. You can then use the temperature data as well as strain data to analyse the behaviour of the structure.

The steel used for the wire in the strain gauge has a thermal coefficient of expansion similar to that of structural steel. Thus, if the gauge and the steel have the same thermal coefficient of expansion and are subjected to the same temperature change, corrections for temperature change are not required.

If the gauge is heated by direct sunlight, so that its temperature increases faster than that of the structural steel, you may see large changes in apparent strain. It is difficult to correct for this, so try to shield gauges from direct sunlight using thermally insulated covers.

If the steel in the structure has a thermal coefficient that is quite different from that of the gauge, the following temperature correction might be appropriate.

$$\Delta\mu\varepsilon \text{ corrected} = \Delta\mu\varepsilon - (TC_m - TC_g)(Temp_1 - Temp_0)$$

Where;

$\Delta\mu\varepsilon$ is the change in strain,

TC_m is the thermal coefficient of the member

TC_g is the thermal coefficient of the gauge: $11.0 \mu\varepsilon / ^\circ\text{C}$

$Temp_1$ is the current temperature

$Temp_0$ is the initial temperature



Bell Lane, Uckfield, East Sussex
TN22 1QL United Kingdom

t: +44 (0) 1825 765044
f: +44 (0) 1825 744398

e: info@itmsoil.com
w: www.itmsoil.com

Soil Instruments Ltd. Registered in England. Number: 07960087. Registered Office: 5th Floor, 24 Old Bond Street, London, W1S 4AW