RST INSTRUMENTS LTD.

Vibrating Wire Strain Gauge
Model VWSG-A
Instruction Manual

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Vibrating Wire Strain Gauge Model VWSG-A

Product: Vibrating Wire Strain Gauge Model VWSG-A
Instruction Manual

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1 INTRODUCTION

RST VWSG-A, Vibrating Wire Strain Gauge is intended primarily for long-term strain measurements on structural steel members such as tunnel linings, arches, struts, piles, sheet piling, etc.

The primary means of attachment is by conventional arc welding, but they may also be used to monitor strain changes on concrete or rock surfaces using anchors grouted into boreholes.

Strains are measured using the vibrating wire principle: a length of steel wire is tensioned between two mounting blocks that are welded to the steel surface being studied.

Deformations (i.e. strain changes) of the surface will cause the two mounting blocks to move relative to one another, thus altering the tension in the steel wire. The tension is measured by plucking the wire and measuring its resonant frequency of vibration by means of an electromagnetic coil positioned next to the wire. See Figure 1.

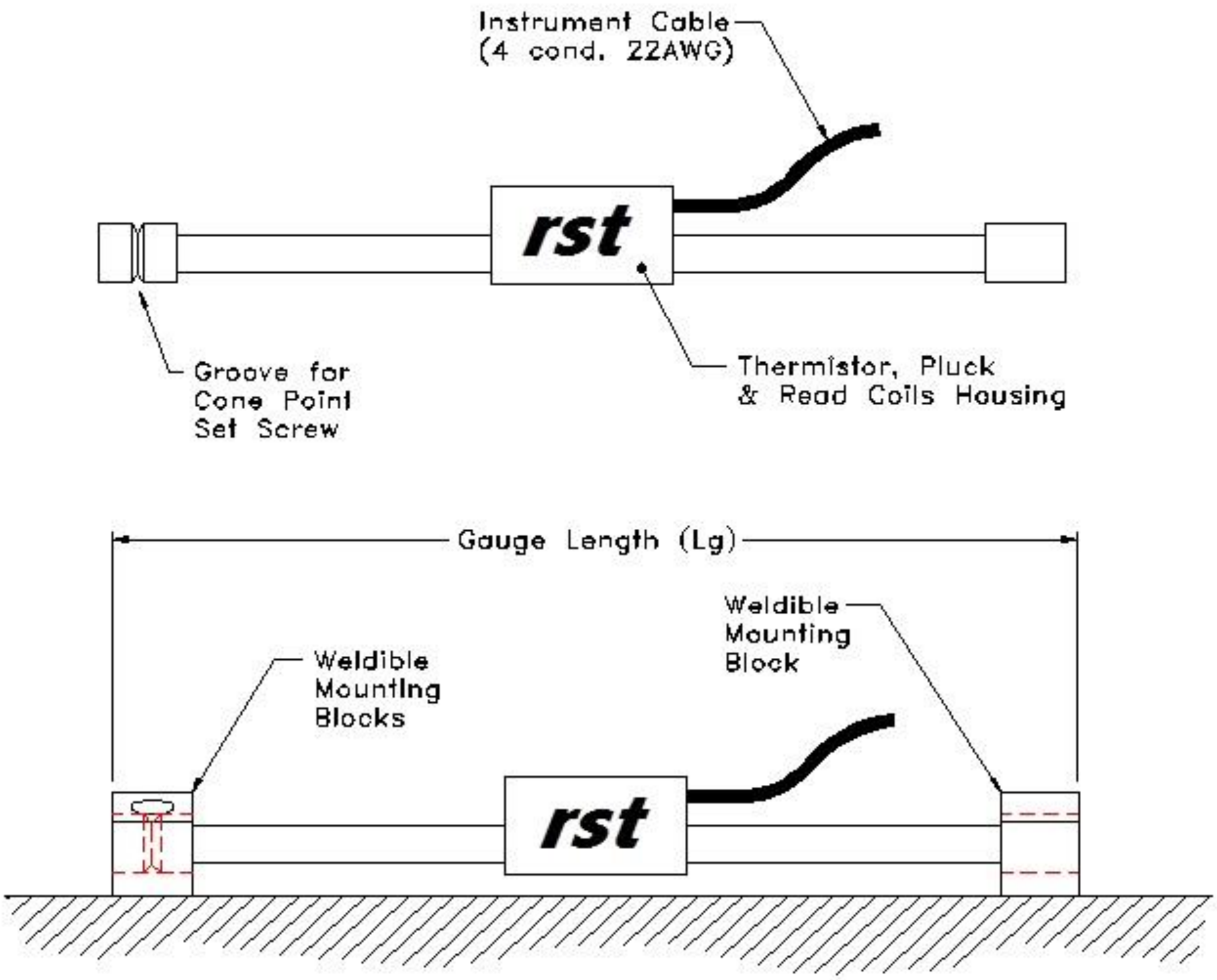


Figure 1 - Model VWSG-A Vibrating Wire Strain Gauge

Portable readouts available from RST, used in conjunction with the Vibrating Wire Strain Gauge, will provide the necessary excitation to pluck the wire and will convert the measured frequency so as to display the reading directly in microstrain.

This manual contains installation instructions, readout instructions and recommended maintenance and troubleshooting procedures. The theory of the gauge is also given, along with some suggestions for data interpretation.

PLEASE NOTE THE FOLLOWING:

The VWSG-A Vibrating Wire Strain Gauge is not suitable for measurement of dynamic or rapidly changing strains.

2 GAUGE INSTALLATION

2.1 PRELIMINARY TESTS

A preliminary check is advisable, and this is made by placing the coil assembly onto the gauge and connecting it to the VW2102 or VW2104 Readout Box. Switch the position selector “C” and turn the unit on. While gently pulling on the gauge end blocks, observe the reading; it should be seen to increase with increased tension. Do no apply excessive tension, as the wire could break. The nominal reading range is 1000 to 4000 microstrain. Mid-range is approximately 2500 microstrain.

Check the resistance between the two lead wires (red and black). It should be around 150 ohms. If the gauge contains a thermistor, check its resistance between the white and green lead wires. Check the reading against that which should be obtained at the existing ambient temperature. See Appendix C of the resistance versus temperature correlation.

Return any faulty gauges to the factory. Gauges should not be opened in the field.

2.2 ARC WELDING THE MOUNTING BLOCKS

The VWSG-A Vibrating Wire Strain Gauge is attached to mounting blocks which must first be arc welded to the steel surface to be studied. A spacer bar and spacing jig are used to correctly space the two blocks. Figure 2 illustrates the procedure: the two mounting blocks are fitted over the ends of the spacer bar, and the jig is used to position them correctly, while the set screws in the mounting blocks are tightened down onto the spacer bar. Avoid excessive tightening as this only damages the spacer bar unduly.

The mounting blocks are supplied in pairs; one has a single cone point set screw, the other has two oval point set screws.

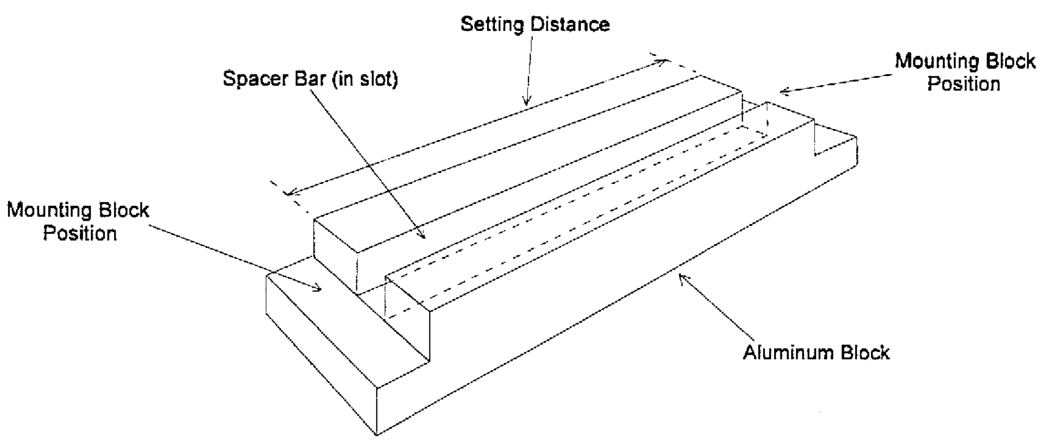


Figure 2 - Spacing Jig

The steel surface is cleaned using a wire brush to remove all scale, rust, dirt and oil. The blocks are then removed from the spacing jig and pressed firmly against the steel surface using the spacer bar as handle. The edges of the mounting blocks are now welded in the order as shown in Figure 3.

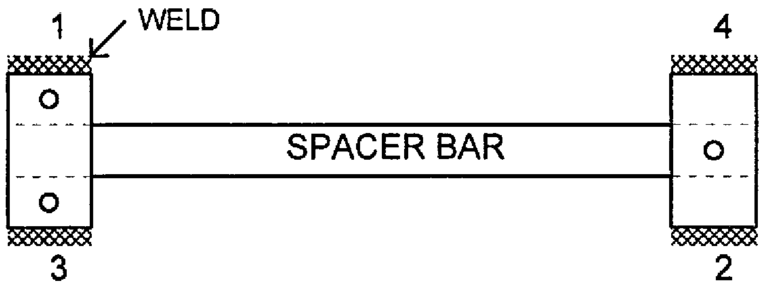
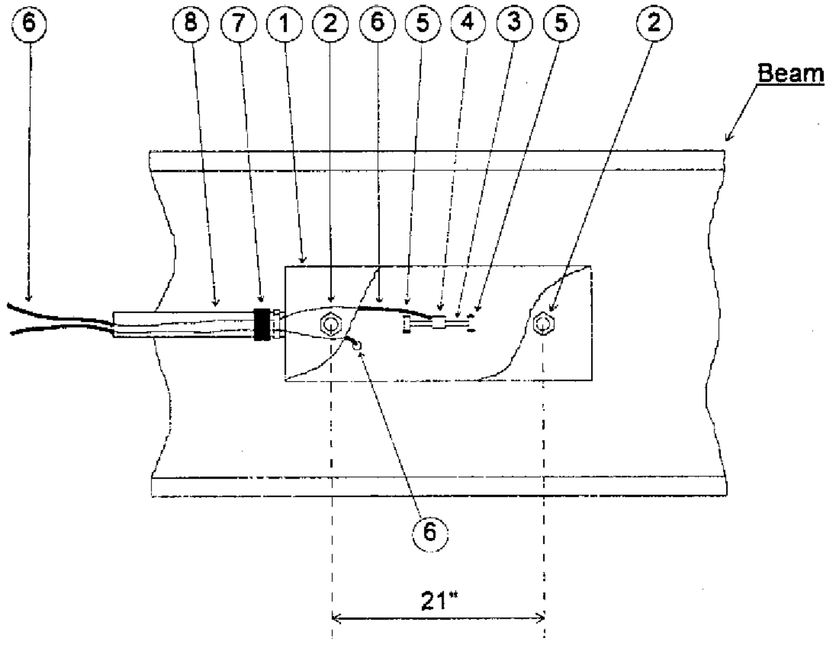


Figure 3 - Welding Sequence for the Mounting Blocks

Avoid excessive heat and DO NOT WELD THE FLAT END SURFACES as this will prevent removal of the spacer bar. To speed things up, where many gauges are being installed, it is advantageous to have more than one spacer bar.

After welding, cool the mounting blocks with a water soaked rag, then slacken the set screws and remove the spacer bar. Clean away all welding slag using a chipping hammer and wire brush.

If the gauges are to be protected by cover plates, then the studs which will hold the cover plates should be welded in place now using a special welding jig to get the correct stud spacing. Either a special stud welder can be used, or an arc welder can be used to weld the head of a hex head bolt to the steel surface.



KEY	DESCRIPTION	MANUFACUTURER
1	Cover Channel 4”-5.4”x2	RST
2	Bolt 1/2-13x3”	RST
3	VWSG-A Strain Gauge	RST
4	Strain Gauge Plucking Coil	RST
5	Strain Gauge Mounting Blocks	RST
6	Gauge Cables	RST
7	Conduit Connector	RST
8	Flex Conduit	RST

Figure 4 - Typical Installation

2.3 INSTALLATION TO MEASURE CONCRETE SURFACE STRAINS

Concrete surface strains can be measured utilizing the VWSG-A Vibrating wire Strain Gauge by attaching the strain gauge to the concrete surface using one of the following methods:

1) Grouting stud mounted end blocks into drilled holes in the concrete (the usual method). A template is provided for drilling two 2½" deep holes in the concrete at the proper spacing. The holes should be a minimum ½" in diameter. The mounting blocks are connected to the spacer bar using the spacer block to position them properly. The studs are then grouted into the pre-drilled holes using either a fast setting hydraulic cement or a high strength epoxy.

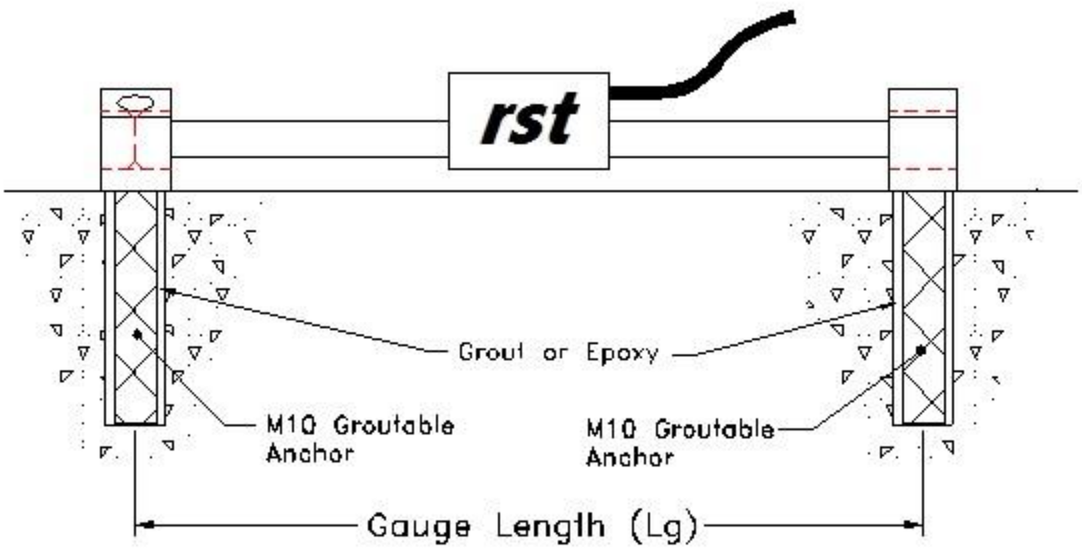


Figure 5 - Installation on Concrete using Groutable Anchors

2) In some cases, with proper care, the standard mounting blocks can be epoxied to the concrete surface. If this procedure is used, the plating should be removed from the underside of the mounting blocks and concrete surface carefully sanded and cleaned. Room temperature curing epoxy is recommended.

2.4 SETTING THE STRAIN GAUGE

When the mounting blocks are welded in place the strain gauge is now uncoupled from the coil and is slid into the holes in the mounting blocks, being careful to see that the grooved end of the gauge lies inside the mounting block which has the single cone point set screw. A little time will be saved if the hose clamp, which holds the plucking coil, is now positioned around the gauge. The cone point set screw is tightened firmly into in the V groove in the one end of the gauge.

Clip the plucking coil over the gauge, secure with a hose clamp and connect it to the readout box. Switch the box on with the display switch on 'C'. The mid-range position of the gauge occurs at a reading of 2500. If the gauge will measure mainly compressive readings then it should be set to a reading of 3500. If the gauge will measure mainly tensile strains it should be set to a reading of 1500. The relationship between the period, as displayed on channel 'A' of the Readouts, and the measured strain, as displayed on channel 'c' is shown in Figure 6.

Readings can be made to increase by grabbing the coil assembly and pushing in the direction of the free end. When the desired reading is obtained, the free end is secured inside the mounting block by tightening down firmly on the two cone point set screws. The reading may alter slightly during this operation, which is normal.

Applying a coat of rust preventative paint can inhibit corrosion at the weld points.

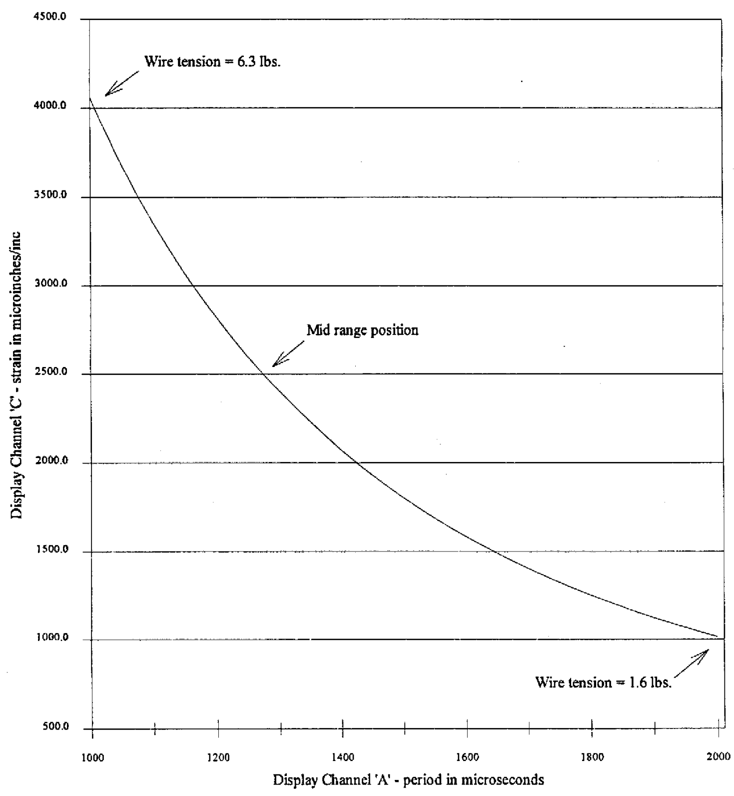


Figure 6 - Readout Modes

2.5 Initial Readings

All readings are relative to the initial reading, so it is important that this initial reading be carefully taken. It is preferable to install gauges on steel members which are still in an unloaded condition, i.e., prior to their assembly into the structure. In this way, the initial readings correspond to zero loads. Otherwise the initial readings will correspond to some unknown load level.

2.6 Gauge and Lead Wire Protection

Gauge and lead wires must be protected from mechanical damage and from water. A typical system is shown in Figure 4.

Gauges are protected by cover plates manufactured from angle iron or channel iron, bolted over the top of the gauge. Studs may be welded directly onto the surface using an automatic stud welder or hex head bolts can be arc welded head down. In this latter case, a special cover plate bolt welding jig is available to achieve the correct spacing. Cover plates fit over these studs or bolts, and nuts are tightened down to hold them in place. Studs should not be positioned within 6 inches of the strain gauge and excessive force should not be used when tightening the cover retaining nuts as this will distort the underlying steel surface and give rise to spurious readings. Also avoid welding anywhere near the gauge as this also will cause large local distortions of the metal.

2.7 Cables and Connectors

The cable should be protected from accidental damage by moving equipment or fly rock. This is best done by putting the cable inside flex-conduit and by positioning the conduit in as safe a place as possible. Conduit can be connected via conduit bulkhead connectors to the cover plates and to readout enclosure (see Figure 4). The readout enclosure has a gasket lid which can be removed to read the gauges. In this way, the ends of the lead wires and/or plugs are kept clean and dry. A special panel may be incorporated if many strain gauges are to be read out from the same terminal box. The panel has built-in jacks or plug-ins which facilitate the connection of the various gauges to the patch cord from the readout box.

Cables may be spliced to lengthen them without affecting gauge readings. Always waterproof the splice completely, preferably using an epoxy based splice kit such as the 3M Scotchcast™, model 82-A1.

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

2.8 Lightning Protection

The VWSG-A Vibrating Wire Strain Gauge, unlike numerous other types of instrumentation available from RST, does not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors.

Here are few suggestions:

- 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 RST provide locations for installation of these components.
- Lightning arrestor boards and enclosures are available from RST 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 (Surge 4C) 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 gauge. See Figure 7. Consult the factory for additional information on these or alternate lightning protection schemes.

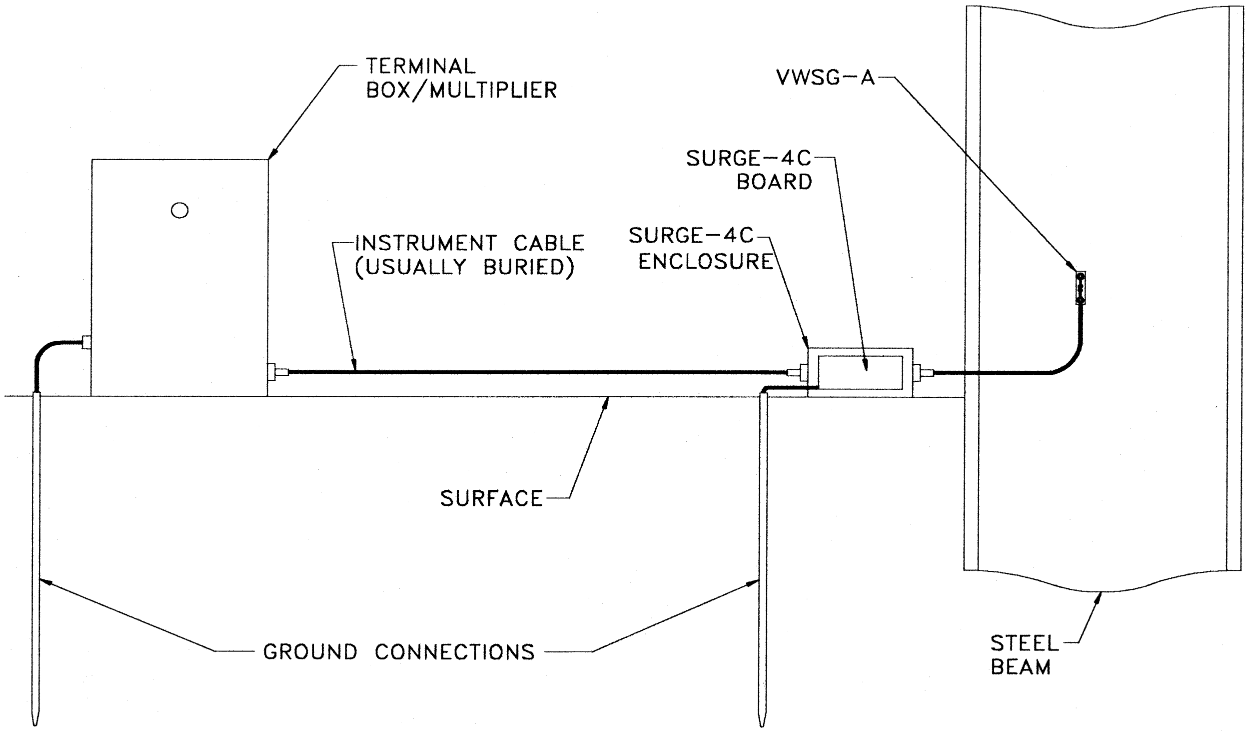


Figure 7 - Lighting Protection Scheme

3 TAKING READINGS

The following three sections describe how to take readings using either of the two readouts available from RST.

MODEL	VWSG-A
Readout Position:	C
Display Units:	Microstrain (με)
Frequency Range:	400-1000 Hz
Mid-Range Reading:	2500 με
Minimum Reading	1000με
Maximum Reading:	4000με

Table 1 – Strain Gauge Readout Positions

3.1 OPERATION OF THE VW2102 READOUT BOX

The VW2102 is a basic readout for all vibrating wire gauges.

Connect the Readout using the flying leads in the case of the terminal station, with a connector. The red black clips are for the vibrating wire gauge, the green lead for the shield drain wire. The VW2102 cannot read the thermistor (see section 3.3).

Turn the display selector to position "C". See Table 1 for correct position.

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.

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

3.2 Operation of the VW2104 Readout Box

The VW2104 can store gauge readings and also apply calibration factors to convert readings to engineering units. Consult the VW2104 Instruction Manual for additional information on Mode "G" of the Readout. The VW2104 reads 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 gauge, the white and green leads are for the thermistor. The cable shield drain wire (blue) should be connected to the shield wire or it can be connected to the black clip lead.

1. Turn the display selector to position "C". See Table 1 for correct position.
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 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 gauge reading in degrees centigrade.
3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.3 Measuring Temperatures

All Vibrating Wire Strain Gauges 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.

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

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

Note: The VW2104 readout box will read the thermistor and display temperature in °C automatically.

4 DATA INTERPRETATION

Readings on Channel C of either the VW2102 or VW2104 Readout Box are displayed directly in microstrain based on the theoretical equation.

$$\mu\varepsilon_{theory} = 4.062\ (f^2 \times 10^{-3})$$

Where με is the microstrain and f is the resonant frequency of the vibrating wire.

4.1 CONVERSION OF READINGS TO STRAIN CHANGES

Channel 'C' on the VW2102 and VW2104 Readouts, used for reading the Strain Gauges, will display readings = $f^2 x\ 10^{-3}$ x 4.062 (where 4.062 is the default Gauge Factor, F_0). Thus, the change in strain between the initial reading (R_0) and any subsequent reading (R_1) can be calculated by simply subtracting the initial strain from the subsequent strain, multiplied by the corrected Gauge Factor. Note that compressive strains give rise to decreasing readings (difference $R_1 - R_0$ is negative), while tensile strains give increasing readings (difference $R_1 - R_0$ is positive).

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

Equation 1 - True Strain Calculation

4.2 STRAIN RESOLUTION

When using the VW2102 Readout on display channel 'C' the strain resolution is always 1 microinch/inch throughout the range of the gauge. Greater resolution can be obtained by reading the gauge in the period mode on display channel 'A'. In the period mode the relationship between period and strain is non-linear (see Figure 6). 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 VW2104 Readout on display setting 'C' the strain resolution is $\pm$ 0.1 microstrain throughout the range of the gauge.

4.3 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.

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. These initial readings are best taken when the structural member is under no load, i.e., the gauges should be mounted while the member is still in the steel yard or warehouse.

This is not always possible and often strain gauges are installed on members which are under some existing load, so that subsequent strain changes always take off from some unknown datum. However, a technique exists, namely the "Blind Hole Drilling Method" (Photolastic 1977), whereby residual or existing stresses can be measured. The procedure is to cement a strain gauge rosette to the surface and then to analyze the strains caused by drilling a short blind hole in the center of the rosette. However, it is a well known fact that strains can be locked into steel during its manufacture.

Sometimes it is possible, especially where temporary supports are being monitored, to measure the strain in the structural member after the structure has been dismantled. This no load reading should agree with the initial no load reading if one was obtained. Any lack of agreement would be an indication of gauge zero drift although the possibility of some permanent plastic deformation of the member should not be overlooked, particularly where measured strain were high enough to approach the yield point.

Temperatures should be recorded at the time of each reading along with notes concerning the construction activity taking place. This data might supply logical reasons for observed changes in the readings.

In the case of a steel structure, 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 exception, and there will be a neutral axis around which bending takes place.

If bending effects are to be taken in to account then more than one strain gauge is required at each cross section of the structural member. 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). 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 gauges at different distances from the neutral axis.

Consider the example of an I beam shown in Figure 8. Four strain gauges (1,2,3 and 4) are welded in two pairs back to back on the central web. The gauges are at a height (d) above the center of the web (axis yy) and at a distance (2c) apart. The I beam has a flange (2b wide) and a web (2a deep).

The axial stress is given by averaging the strain reading from all four strain gauges and multiplying by the modulus.

$$\sigma_{axial} = \frac{(\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4)}{4} * E$$

Equation 2 - Axial Stress Calculation

The stress due to bending is calculated by looking at the difference between pairs of gauges mounted on opposite sides of the neutral axis. Thus the maximum stress due to bending about axis yy is given by:

$$\sigma_{yy} = \frac{(\varepsilon_1 + \varepsilon_3) - (\varepsilon_2 + \varepsilon_4)}{4} * \frac{b}{d} * E$$

Equation 3 - Stress due to bending on Axis yy

The maximum stress due to bending about axis xx is given by:

$$\sigma_{xx} = \frac{(\varepsilon_1 + \varepsilon_2) - (\varepsilon_3 + \varepsilon_4)}{4} * \frac{a}{c} * E$$

Equation 4 - Stress due to bending on Axis xx

$$\sigma_{\max imum} = \sigma_{axial} + \sigma_{xx} + \sigma_{yy}$$

Equation 5 - Maximum Stress

In all of the above calculations pay careful attention to the sign of the strain.

Note that the total strain, at any point in the cross section, is the algebraic sum of the bending strains and axial strain. It will be seen that the strains in the outer corners of the flange can be a lot higher than the strains measured on the web and that failure of the section can be initiated at these points. Hence the importance of analyzing the bending moments.

The above consideration would also seem to lead to the conclusion that, from the point of view of obtaining the greatest accuracy, the best location for the strain gauges would be on the outer corners of the flanges as shown in Figure 9. The disadvantage of having the gauges located here lies in the difficulty of protecting the gauges and cables from accidental damage. But a much more serious problem arises from the fact that each of the 4 gauges can be subjected to localized bending forces which affect only one gauge, but not the others. It is always necessary to locate gauges in pairs. One on either side of the neutral axis of the part of the I beam to which the gauge is attached. This is why the configuration in Figure 8 is preferable. There is the added advantage the gauges located on the web as shown in Figure 8 are much easier to protect.

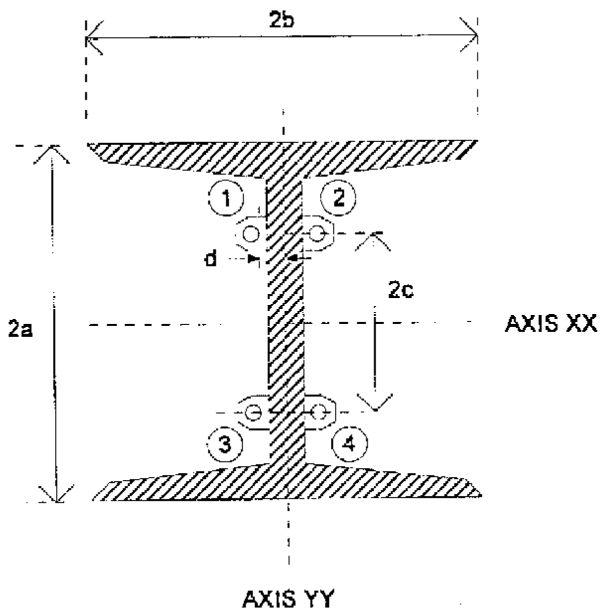


Figure 8 - Strain Gauges Mounted on Central Web

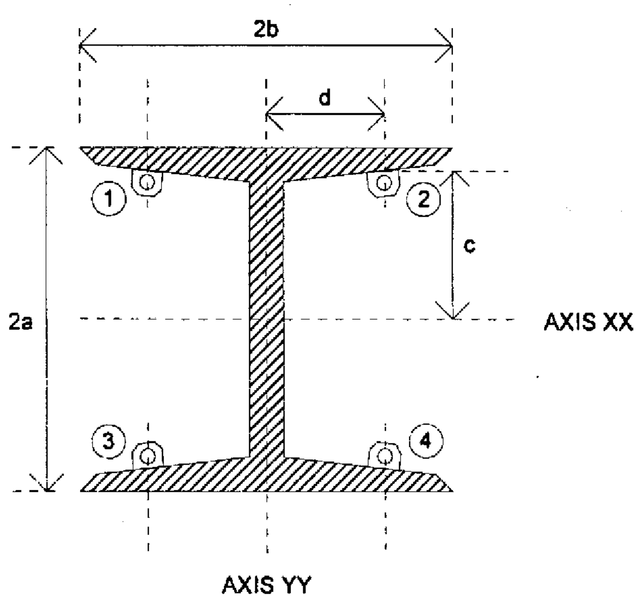


Figure 9 - Strain Gauges Mounted on Flanges

Figure 10 illustrates an alternate arrangement using 2 gauges to measure axial strain only.

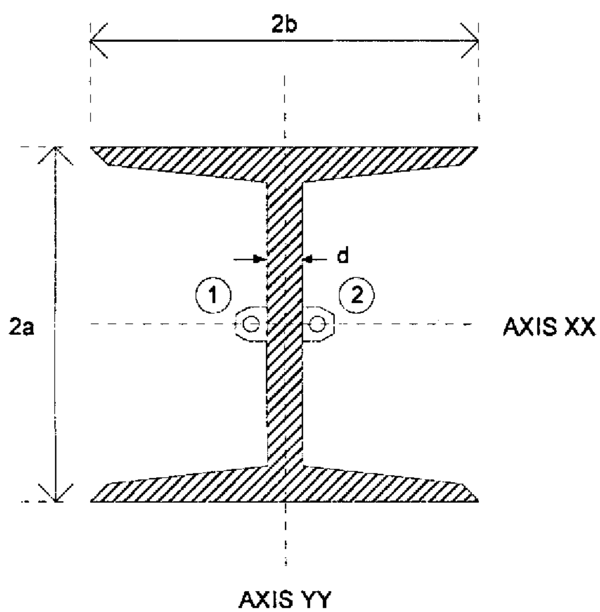


Figure 10 - Axial Strain Measurement

4.4 TEMPERATURE EFFECTS

The thermal coefficient of expansion of the steel vibrating wire is the same as that for the steel of the structure to which the gauge is attached, so that no temperature correction to the measured strain is required. However, this is only true if the wire and underlying steel structure are at the same temperature. If sunlight is allowed to impinge directly onto the gauge, then this could elevate the temperature of the wire above the surrounding steel and cause large changes in apparent strain. Therefore, always shield strain gauges from direct sunlight. Also, avoid excessive handling of the gauge prior to reading. Either a) take the reading quickly or b) allow sufficient time for the gauge temperature to re-stabilize before reading. In any case, it is always a good idea to record the temperature every time the strain reading is made so that any real strain effects, caused by temperature changes, can be assessed. In order to facilitate the measurement of temperature, each strain gauge has a thermistor encapsulated along with the plucking coil. The thermistor is read out on the green and white conductors using an ohmmeter or the RST Model VW2104 Readout box. If an ohmmeter is used the relationship between resistance (ohms) and temperature is shown in Appendix C.

4.5 WELDING EFFECTS

Arc welding close to the gauges can cause very large strain on the steel structure. Thus, welding studs onto stronger piles to support lagging or shortcrete reinforcing mesh can cause big strain changes as can welding cover plates or protective channels, etc. over the gauges and cables. Always take gauge readings before and after any arc welding on the steel structure so that corrections can be applied to any apparent strain shifts.

4.6 END EFFECTS

If end effects are to be avoided then strain gauges should be placed away from the ends of struts where they may be influenced by localized clamping or bolting distortions. For most structural members a distance of 5 feet is sufficient.

On the other hand, end effects may be of some interest because they add to the load induced effects and may be large enough to initiate failure at the ends rather than in the middle of the structural member.

5 TROUBLESHOOTING

Maintenance and troubleshooting of VWSG-A Vibrating Wire Strain Gauges are confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gauges 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.

5.1 SYMPTOM: STRAIN GAUGE READINGS ARE UNSTABLE

1) Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct?
2) Are the strain readings outside the specified range (either compressive or tensile) of the instrument? The gauge may have become too slack or too tight; inspection of the data might indicate that this is a possibility. Loosen the two oval point set screws in one of the mounting blocks. This will permit the internal spring to re-tension the gauge and the gauge will read again. Set the gauge to some new datum and retighten the set screws. If the gauge does not respond to re-setting and if the old plucking coil will pluck a new gauge, then the gauge should be replaced.
3) 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.

4) Does the readout work with another gauge? If not, the readout may have a low battery or be malfunctioning.

5.2 SYMPTOM: STRAIN GAUGE FAILS TO READ

1) Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gauge leads (usually red and black leads) is 180Ω, $\pm$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.
2) Does the readout or datalogger work with another strain gauge? If not, the readout or datalogger may be malfunctioning.

6 CALCULATIONS

The fundamental relationship between stain and period is as follows:-

Microstrain = $F * 10^9/T^2$

Where F is the gauge factor (for the Strain Gauge)

T is the reading in microseconds for one oscillation.

Alternatively, for readout units which display readings in frequency^2 * 10^{-3} units.

Microstrain = F * R

Where F is the gauge factor (for the Strain Gauge)

R is the reading in frequency^2 * 10^{-3} units.

As described earlier, the VW2102 and VW2104 readouts have excitation sweep frequencies which are particularly suitable for VWSG-A and VWSG-E gauges (Channel C). This channel has a default gauge factor (F_0 = 4.029 which may differ for other readouts).

To calculate microstrain of VWS gauges using these channels:

Microstrain = R (F/F_0)

Where R is the reading in microstrain from a channel with an embedded gauge factor

F is the gauge factor of the VWS gauge

F_0 is the embedded gauge factor of the readout (4.029 for VW2102 & VW2104 readouts).

For example, if a reading of 2000 was taken from a VW2102 or VW2104 readout on Channel C, for a surface mount gauge, this would translate into a microstrain reading of;

=2000*(3.810/4.062) = 2000 * 0.938

=1876.

Surface mount gauge factor = 3.810 (mean value)
Embedment gauge factor = 3.405 (mean value)

APPENDIX A - SPECIFICATIONS

A.1 Strain Gauge

Range (nominal):	3000με
Resolution:	0.1με[1]
Accuracy:	2.0% FSR[2]
Stability:	0.1%FS/yr
Linearity:	2.0%FSR
Thermal Coefficient	12.2με/°C
Dimensions (gauge):	6.125x0.750” (155 x 19mm)
Dimensions (coil):	0.875 x 0.875” (22 x 22mm)
Coil Resistance:	150Ω
Temperature Range:	-20 to + 80°C

Note:

[1]Depends on the readout, above figure pertains to the 2104 Readout.

[2]Accuracy to 1.0% FSR may be achieved through calibration.

A.2 Thermistor (also see Appendix C)

Range: -80 to +150°C

Accuracy: ±0.5°C

Appendix B- THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSE 44005, Date #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 = 1.4051×10^{-3} (coefficient 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	141.11	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
77.99K	-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	-35	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	282.4	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	56.92	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.	53	250.9	93	83.6	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