RST INSTRUMENTS LTD.

Vibrating Wire Strain Gauge Model VWSG-S Instruction Manual

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Vibrating Wire Strain Gauge Model VWSG-S Instruction Manual

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1 INTRODUCTION

The VWSG-S Vibrating Wire Strain Gauges are designed for measuring strains on structural steel members such as bridges, piles, tunnel linings, buildings, etc. The VWSG-S consists of a vibrating wire gauge element and removable coil assembly as shown in Fig.1. The VWSG-S-LP (Low Profile) consists of a vibrating wire gauge element and an integral coil in a lower profile configuration.

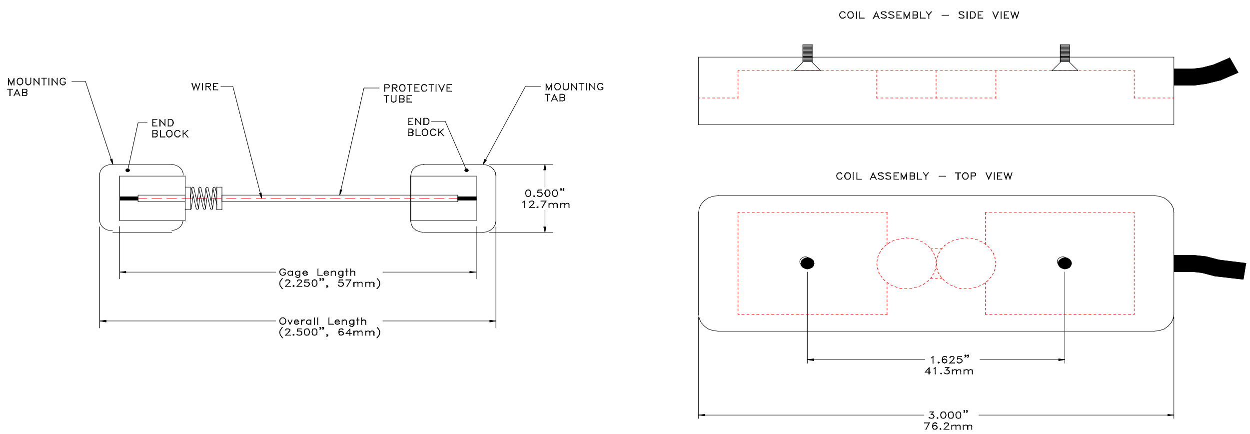


Figure 1 - VWSG-S Vibrating Wire Strain Gauge and Coil Assembly

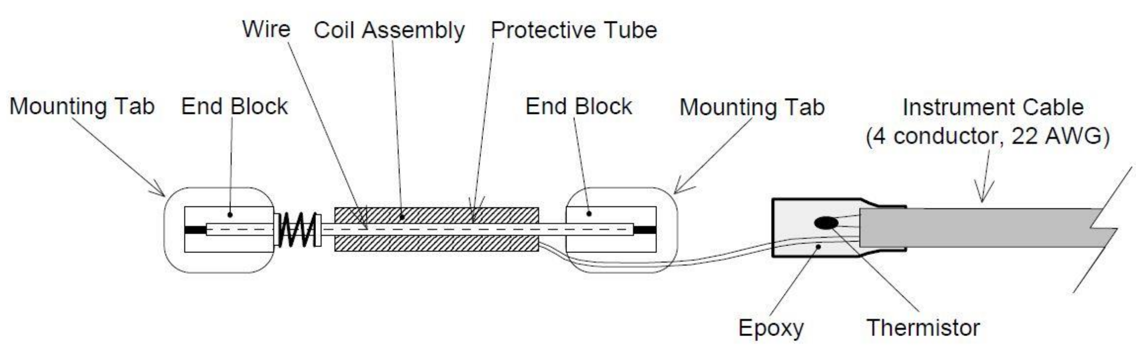


Figure 2 - VWSG-S-LP Vibrating Wire Strain Gauge and Coil Assembly

The primary means of attachment is by spot welding, but they may also be epoxy bonded to the surface.

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. The wire is plucked and its resonant frequency measured by means of an electromagnetic coil positioned next to the wire.

Vibrating Wire Readouts used in conjunction with the vibrating wire strain gauge, provide the necessary excitation to pluck the wire and display the period of the resulting vibration in microstrain units directly.

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

2 GAUGE INSTALLATION

2.1 PRELIMINARY TESTS

The VWSG-S and VWSG-S-LP Strain Gauge assemblies are supplied fully sealed and tensioned. A preliminary gauge reading is advisable and this is made by connecting the plucking coil wires (turn the coil assembly housing upside down and set the gauge element inside) to the readout box, and observing the displayed readout. See section 3 for more information on readout operation and reading position. The strain gauges are supplied with the wire tension set at mid-range (i.e. 2500 μstrain, ±200) which gives approximately ±1250 microstrain, suitable for most applications. (See Appendix E if adjustment to the strain range is necessary.) Light pressure on the gauge ends should make microstrain readings decrease. Pull on the gauge element ends to increase the displayed reading. **Do not pull too hard** (> 10 lbs., 4.5 kg) on the ends of the gauge or the wire may break!

Check the resistance between the two vibrating wire gauge lead wires (usually red and black wires). Nominal coil assembly resistance for the VWSG-S is 180Ω, ±10Ω. For the VWSG-S-LP the nominal coil assembly resistance is 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). The resistance of the thermistor (temperature sensing element) may also be checked (usually the white green wires). Check the resistance with the table in Appendix C.

Contact and return any faulty gauges to RST Instruments Ltd.

2.2 INSTALLATION OF STRAIN GAUGES BY SPOT WELDING

(USE SAFETY GLASSES)

The following tools and accessories are needed to install the VWSG-S onto steel by spot welding;

- Power grinder or sander, files, wire brush, sandpaper, de-greaser.
- Test mounting strips.
- Spot welder and hand probe (RST Instruments Mode: VWSG-S-1000). Refer to Figure 3.

Figure 3 - VWSG-S-1000 Capacitive Discharge Spot Welder

- Cyanoacrylate adhesive.
- A spray can of self-etching primer.
- And spray can of rust paint.
- Waterproofing compound such as Dow Corning RTV-3145 and/or aqua seal.
- Coil assembly and stainless steel shim stock.
- Heat shrink, solder, cable ties, wire ties, and/or duct tape (quantity as required).

Note the following instructions.

1. ***Prepare the Surface*** **-** The surface of the steel member should be flat and clean, free from rust, grease and pitting. Degrease the surface using an appropriate cleaning agent, then use a power grinder or sander, file, wire brush or sandpaper, to achieve a flat, smooth surface.

2. ***Spot Weld Test Strips*** **-** Before welding the gauge it is necessary to test the spot welder to make sure that it is functioning properly and that the correct weld energy is used. Weld energy, and to a certain extent, contact pressure determines the quality of the weld. Approximately 20-40 watt-seconds weld energy is required to properly weld VWSG-S strain gauges to structural steel. Using the test material supplied with the gauges, run a series of tests to determine the correct weld energy. Then perform a peel test as shown in Fig. 3 below.

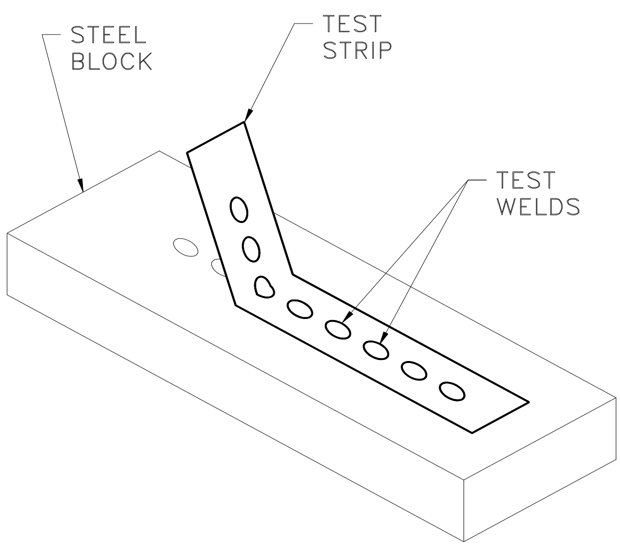


Figure 4 - Peel Test

When the correct weld energy is being used, the test strip, when peeled back from the steel surface with pliers, will show a series of holes where the welded strip has been left behind on the substrate. If insufficient weld energy is used the test strip pulls loose without holes being torn in it. If excessive weld energy is used, the test strip will discolor, melt and be ejected away from the spot.

Sparking is usually an indication of dirt between test and substrate, or it may be an indication of insufficient force, in which case the hand probe force setting should be adjusted.

Excessive deformation of the weld area calls for either a decrease of the force applied by the hand probe and/or a decrease of weld energy.

3. ***Spot Welding the Gauge***

Initial Readings

It is important that the gauge has the correct initial reading. Gauges are supplied with an initial reading of approximately 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 a different range is required, please refer to Appendix E. If the gauge is required to read large tensile strains then set the reading between 1500 and 2000 microstrains, if the gauge is to read large compressive strains set the initial reading between 2500 and 3000 microstrains.

Note

Under no circumstances should the procedures described in Appendix E be used after the gauge has been welded down.

Spot weld one end of the gauge using the weld pattern and the sequence shown in Figure 4. Starting in the middle of the back row, complete the spot welds toward the outside edge. Then continue on to the two sides (3 and 4).

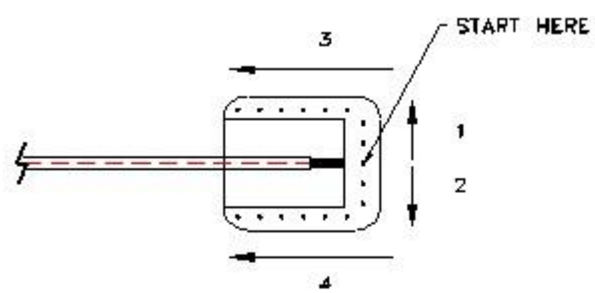


Figure 5 - Spot Welding Sequence

When all the dots on the first flange have been welded, prepare to weld the other end, as follows. Place the alignment tool over the two ends of the gauge as shown in Fig 5 below. This will ensure that the two ends of the gauge are properly aligned.

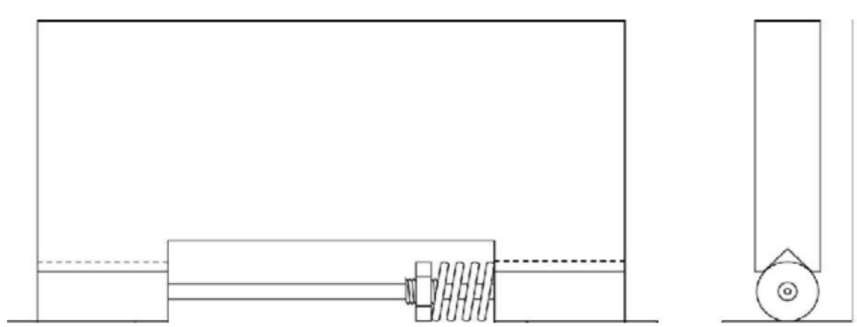


Figure 6 - Spot Welding Sequence

With the alignment tool held in place, spot weld the preliminary spot located at the center of the back edge of the second tab. When the first spot has been welded, connect the strain gauge to the readout box and confirm that this initial reading is within the required range. Assuming that the reading is acceptable, commence with the spot welding of the tab as per the initial tab. If the reading is unacceptable, the first spot weld can be removed using a sharp razor blade placed under the tab, close to the weld.

Welds should have a slight depression and be uniform in appearance. Keep the hand probe weld tip clean and burr free. Periodically sand it gently with 400 grit paper. Care should be taken to keep the tip surface to a well rounded point. Proper dressing will keep the tip from sticking to the mounting tab during welding.

Note
When the gauge is used on curved surfaces it is recommended that a second row of welds be made on the periphery of the mounting tab (between the stenciled row and edge). This is also a good practice on flat surfaces.

When both ends of the gauge have been spot welded, take a small screwdriver and lightly tap both end blocks with the handle of the screwdriver at points over the flanges only. See Figure 6 below. The purpose of the tapping is to relieve any local stresses induced by the welding procedure.

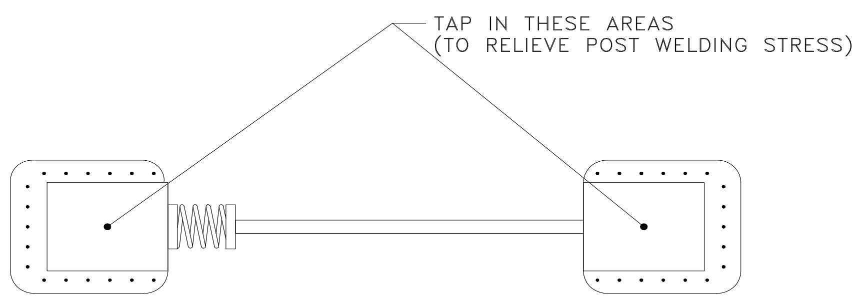


Figure 7 - Tap Points

4. ***Installing the Collar Shims***

The strain gage performance is enhanced by the addition of collar shims. These shims are supplied preformed in the shape of an L and are spot welded over the top of the end blocks.

Take the shim and position it over the end block so that the edge of the ¼ inch (6mm) wide shim is flush with the back edge of the end block. Use the tip of the spot welder probe to press the angle in the collar shim tightly into the corner between the end block and the base tab as shown in Fig. 7. Now weld the small end of the collar shim L down onto the tab using three welds all positioned as close to the corner as possible. Now add another three welds at the outer edge of the collar shim.

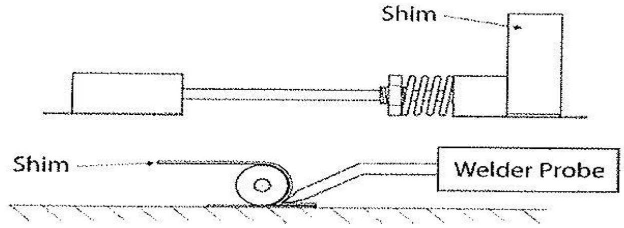


Figure 8 - Welding the Collar Shim in Place

Now bend the collar shim over the end block and force it into the corner on the other side of the end block. Weld it into the corner as before using a total of six welds. Now spot weld the collar shim to the end block using three welds along the highest point of the end block. Refer to Fig. 8 for an example of a completed installation.

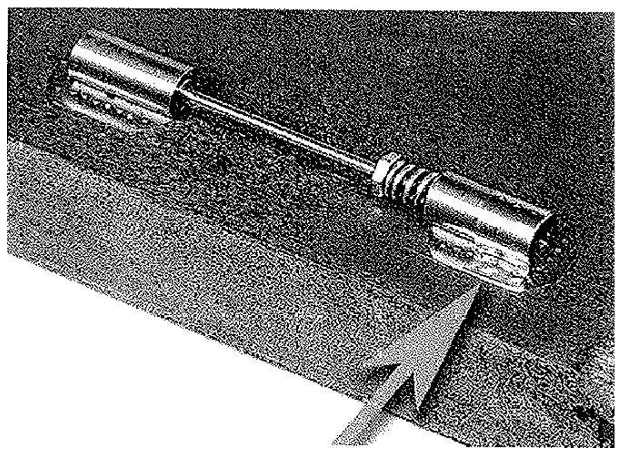


Figure 9 - The Completed Collar Shim

Tap and additional four or five times on each end block to ensure all stresses are relieved. Refer to Fig. 6. Read the gauge with the readout device to confirm the initial reading. Continue the tapping procedure until the readings settle down and do not change more than a few digits.

5. ***Gauge Protection*** - With the gauge now installed, it is imperative that the gauge weld points be protected from corrosion. The gauge itself will not corrode since it is made of stainless steel but the substrate can corrode, especially at the weld points, unless they are protected by a water-proofing compound. The recommended procedure is as follows:

   1 Apply several drops of cyanoacrylate adhesive to the edge of the mounting tab. The glue will wick into the gap between the mounting tab and the substrate and provide the first line of defense.

   2. Mask off the areas where the spot welds will be required to hold the plucking coil housing of model VWSG-S or the cover plate of model VWSG-S-LP.

   3. Spray a coat of Self Etching Primer (available at any auto-parts store), over the mounting tab areas and all exposed bare metal areas. The purpose is to protect the substrate weld points. Ensure to get complete coverage of the mounting tab edges, paying particular attention to the point where the tab is under the gauge tube. Ensure to spray beneath the coil housing on the VWSG-S-LP gauge. Don't worry if the primer also coats the gauge.

4. Apply a layer of waterproofing compound over the mounting tab area. Again, the idea is to protect the substrate weld points, so be careful to get complete coverage of the mounting tab edges, paying particular attention to the point where the tab is under the gauge tube.

6A. ***VWSG-S Only - Install the Plucking Coil Housing*** - Before the waterproofing layer has hardened it is necessary to install the plucking coil housing over the strain gauge. Do not use an excessive amount of the waterproofing compound. Keep the waterproofing compound away from the gauge tube so as not to impede its freedom to move relative to the end blocks.

If the plucking coil housing is to be kept portable, use it now to squeeze excess waterproofing compound out of the way so that when it sets up it will not prevent the proper seating of the plucking coil housing.

If the plucking coil housing is to be fixed permanently in place, position it over the gauge and look through the transparent housing, moving it until it is clear of the gauge. In this position, use the spot welder to weld the tabs holding the coil housing to the substrate. Naturally the area of the substrate to which the tabs are welded will require surface preparation as before, and again, the tabs should be protected from corrosion as before.

6B. ***VWSG-* LP Only – Install the Strain Gauge Cover** - The Strain Gauge is provided with a semi-cylindrical metal cover, which must be spot welded in place over the gauge. The cover welding tabs must be protected as per step 5 above.

Figure 10 - Welding the Collar Shim in Place

7. ***Secure the Gauge Cable*** – Subject to the requirements of the installation, the gauge cables can be secured to the steel member by a variety of methods including steel anchor points, cable ties, welded shim stock or duct tape.

8. ***Check the Gauge Reading*** - Connect a Vibrating Wire Readout Box and check that the gauge is reading within the desired reading range. Follow the instructions in the Troubleshooting section if the gauge will not read or exhibits unexpected readings.

2.3 INSTALLATION OF STRAIN GAUGES BY EPOXY WELDING

The following tools and accessories are needed to install the VWSG-S onto steel by epoxy bonding;

- Power grinder or sander, files, wire brush, sandpaper.
- Quick setting 2 part adhesive such as M-Bond AE10 epoxy (Micro-Measurments).
- Strain gauge setting jig.
- Waterproofing compound such as Dow Corning RTV-3145.
- Cable ties and/or duct tape (quantity as required).

See the following instructions;

1. ***Prepare the Surface*** - Follow the instructions outlined in the spot welding section.
2. ***Epoxy Bond the Gauge*** - *Position* the gauge in the slot of the setting jig. Apply epoxy base to the mounting tabs of the strain gauge. Apply activator to the steel at the approximate locations for the mounting tabs. Press the gauge firmly against the beam and hold for at least 30 seconds or until the epoxy has set.
3. ***Gauge Protection*** - *Apply* a layer of waterproofing compound over the mounting tab area.
4. ***Install the Plucking Coil Housing*** - Before the waterproofing layer has hardened it is necessary to install the plucking coil housing over the strain gauge. Do not use an excessive amount of the waterproofing compound. Keep the waterproofing compound away from the gauge tube so as not to impede its freedom to move relative to the end blocks.

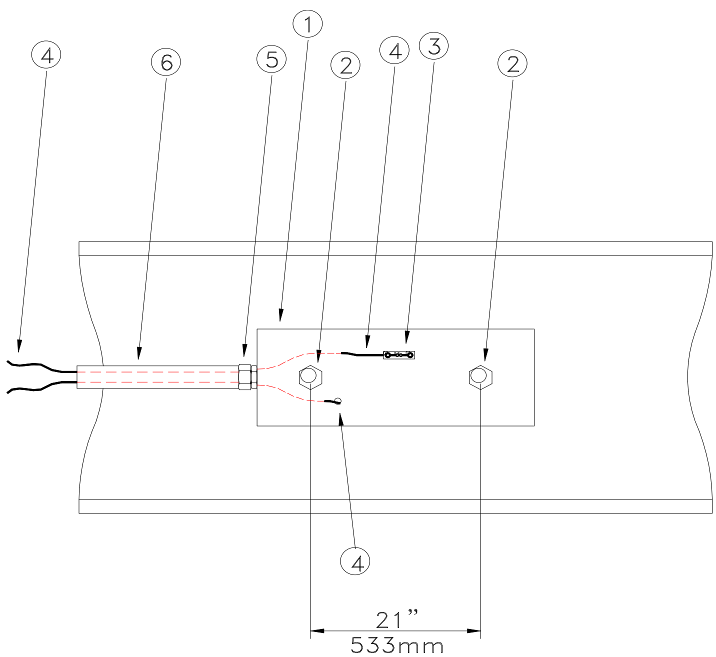
   If the plucking coil housing is to be kept portable use it now to squeeze excess waterproofing compound out of the way so that when it sets up it will not prevent the proper seating of the plucking coil housing.

   If the plucking coil housing is to be fixed permanently in place, position it over the gauge and look through the transparent housing, moving it until it is clear of the gauge. In this position, use the spot welder to weld the tabs holding the coil housing to the substrate. The area of the substrate to which the tabs are welded will require surface preparation as before, and again, the tabs should be protected from corrosion.
5. ***Secure the Gauge Cable*** - Use cable ties or duct tape to secure the gauge cable to the steel member.
6. ***Check the Gauge Reading*** - *Connect* a portable readout (Section 3) and check that the gauge is reading at the desired reading. Follow the instructions in the Troubleshooting section if the gauge will not read.

2.4 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 10.

Gauges and their associated wiring can be protected by cover plates manufactured from angle 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 welded head down. In this latter case, a special cover plate bolt welding jig is available from the factory 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 will cause large local distortions of the metal. A typical cover plate arrangement is shown in Figure 7.



Key	Description	Manufacturer
0	VWSG-S Strain Gauge - under coil assembly	RST
1	Cover Channel (L x W x H) 21 x 4 x 2", 533 x 101 x 50mm	RST
2	Bolt ½ - 13 x 3"	RST
3	Strain Gauge Plucking Coil	RST
4	Gauge Cables, 4 conductor shielded, PVC jacket	RST
5	Conduit Connector	RST
6	Flex Conduit	RST

Figure 11 - Typical Installation

Such protection as described above may not be practical if an arc welder is not available. The coil housing provides a measure of protection which may be adequate. The installer should best judgment to ensure that the adequate level of protection is installed.

2.5 Cables and Connectors

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

The cable should 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 a readout enclosure (see Figure 5). The readout enclosure has a gasketed 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 connectors or posts 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 the 3M Scotchcast™, model 82-A1. These kits are available from RST Instruments Ltd.

2.6 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 RST for shielding and filtering options.

2.7 Lightning Protection

The VWSG-S and VWSG-S-LP Vibrating Wire Strain Gauges, unlike numerous other types of instrumentation available from RST, do not have any integral lightning protection components, i.e. tranzorbs or plasma surge arrestors.

Here are a 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 11. Consult the factory for additional information on these or alternate lightning protection schemes.

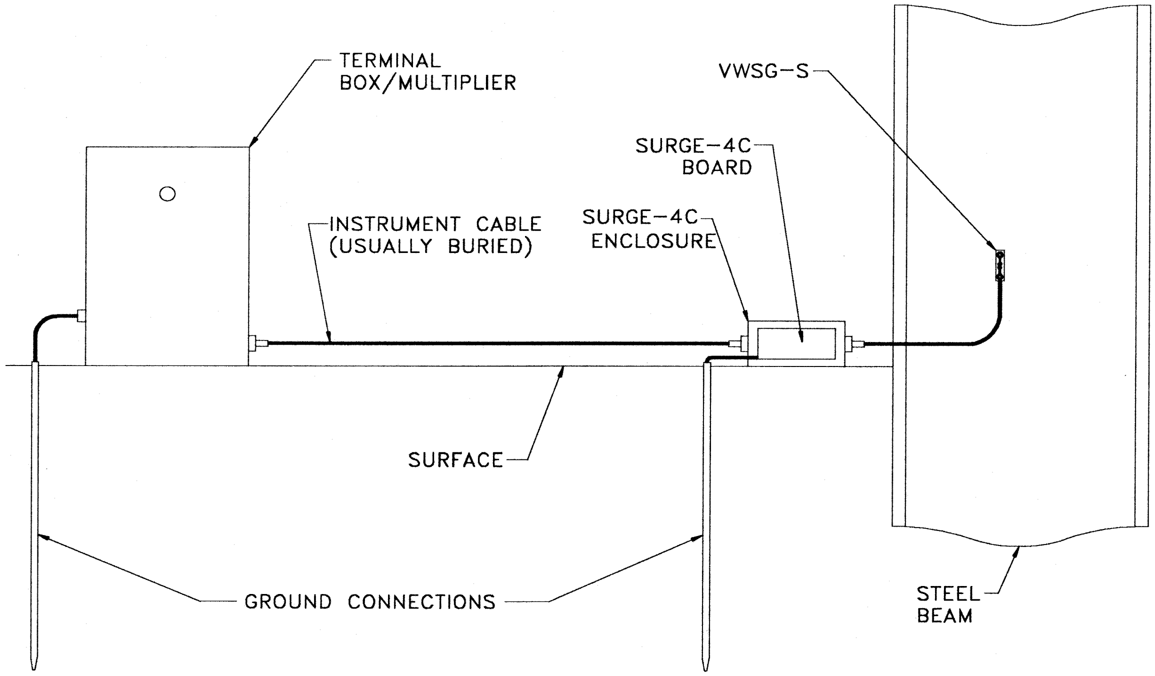


Figure 12 - Lightning Protection Scheme

Plasma surge arrestors can be epoxy potted into the gauge cable close to the sensor. A ground strap would connect the surge arrestor to earth ground, either a grounding stake or the steel structure itself.

3 TAKING READINGS

The following section describes how to take readings using a VW2106 readout box available from RST.

Model:	**VWSG-S or VWSG-S-LP**
Frequency Range:	1200-3550 Hz
Mid-Range Reading:	2500 $\mu\varepsilon$
Minimum Reading:	1000 $\mu\varepsilon$
Maximum Reading:	4000 $\mu\varepsilon$

Table 1 - Strain Gauge Readout Positions

3.1 OPERATION OF THE VW2106 READOUT BOX

The VW2106 can store gauge readings and also apply calibration factors to convert readings to engineering units. Consult the VW2106 Instruction Manual for additional information on inputting calibration constants. The VW2106 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 and the blue for the shield drain wire.

1. Turn the display selector to position "B".
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. The B unit reading can be converted to strain by using the formula in section 4. Consult the VW2106 manual for directly displaying the values in strain. 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 gauge reading in degrees centigrade.
3. The unit will automatically turn itself off after approximately 5 minutes to conserve power.

3.2 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.

1. Connect an ohmmeter to the two thermistor leads coming from the strain gauge. (Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant.)
2. Look up the temperature for the measured resistance in Table C-1. Alternately the temperature could be calculated using Equation C-1.

Note: The VW2106 readout box will read the thermistor and display temperature in °C.

3.3 INITIAL READINGS

All readings are relative to an initial reading, therefore 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 load. Otherwise the initial readings will correspond to some unknown load level.

4 DATA INTERPRETATION

Readings on channel E of either the VW2102 or VW2104 Readout Box are displayed directly in microstrain based on the theoretical equation:

$$\mu\varepsilon = 0.391\left(f^2 x 10^{-3}\right)$$

Equation 1 – Theoretical Microstrain

Where;

$\mu\varepsilon$ is mocrostrain and f is the resonant frequency of the vibrating wire.

4.1 CONVERSION OF READINGS TO STRAIN CHANGES

In practice the method of clamping the wire shortens it slightly causing the gauge to over-register the strain. This effect is removed by applying a batch gauge factor (B) supplied with each gauge (a typical batch gauge factor is 0.915 ± 0.01). Then

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

Equation 2 - True 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 VW2102 Readout on display channel 'E' 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. 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 'E' the strain resolution is ±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. This initial reading is 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, called 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 the 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 strains 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 the exception, and there will be a neutral axis around which bending takes place.

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

Consider the example of an I beam shown in Figure 7A. 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 3 - 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 4 - 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 5 - Stress due to bending on Axis xx

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

Equation 6 - Maximum Stress

In all of the above calculations pay strict regard 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 the 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 comers of the flanges as shown in Figure 8. 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 of Figure 7 is preferable. There is the added advantage that gauges located on the web as shown in Figure 7 are much easier to protect.

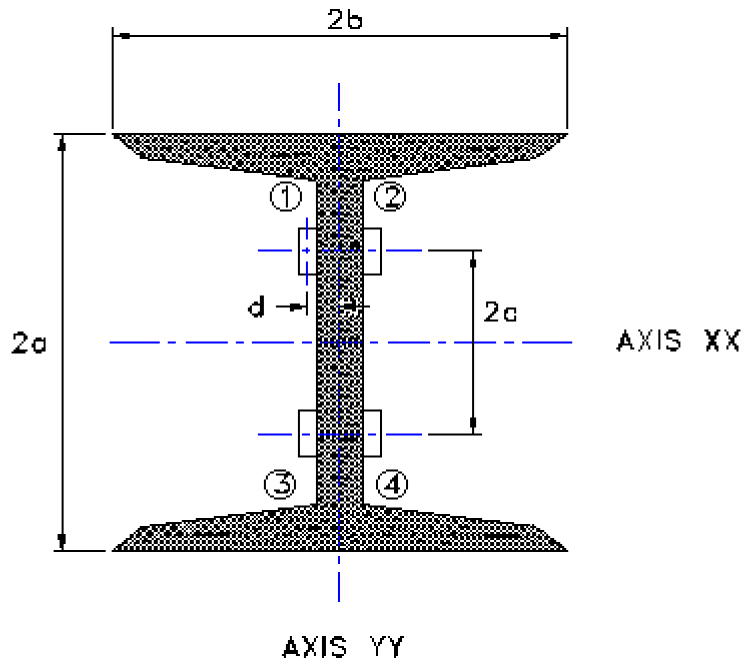


Figure 13 - Strain Gauges Mounted on Central Web. Axial Strain and Bending Moments about both XX and YY Axes

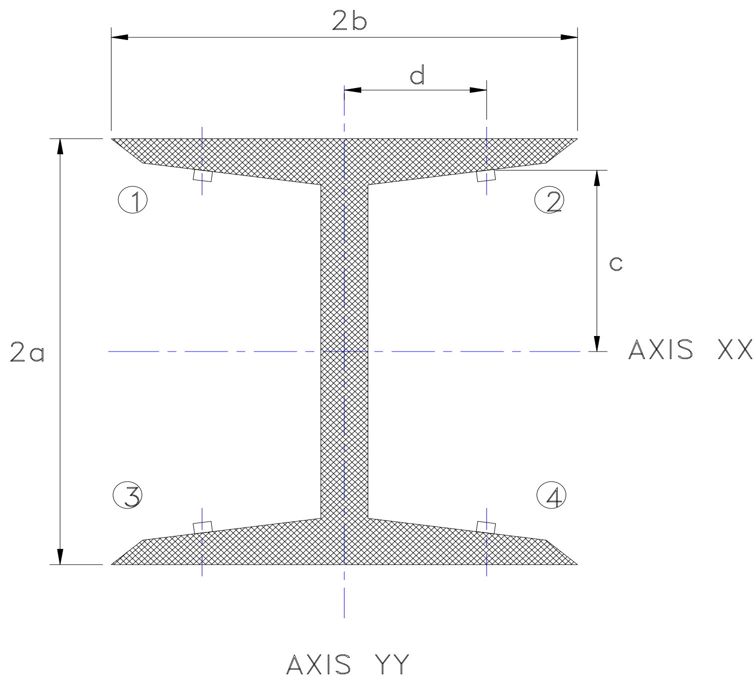


Figure 14 - Strain Gauges Mounted on Flanges (Not Recommended)

If, for reasons of economy, it is decided that only two strain gauges per cross-section are to be used, then the configuration of figure 9 will give the axial strains and the bending moment around the minor YY axis only.

Figure 9 illustrates an alternate arrangement using 2 gauges to measure axial strain only.

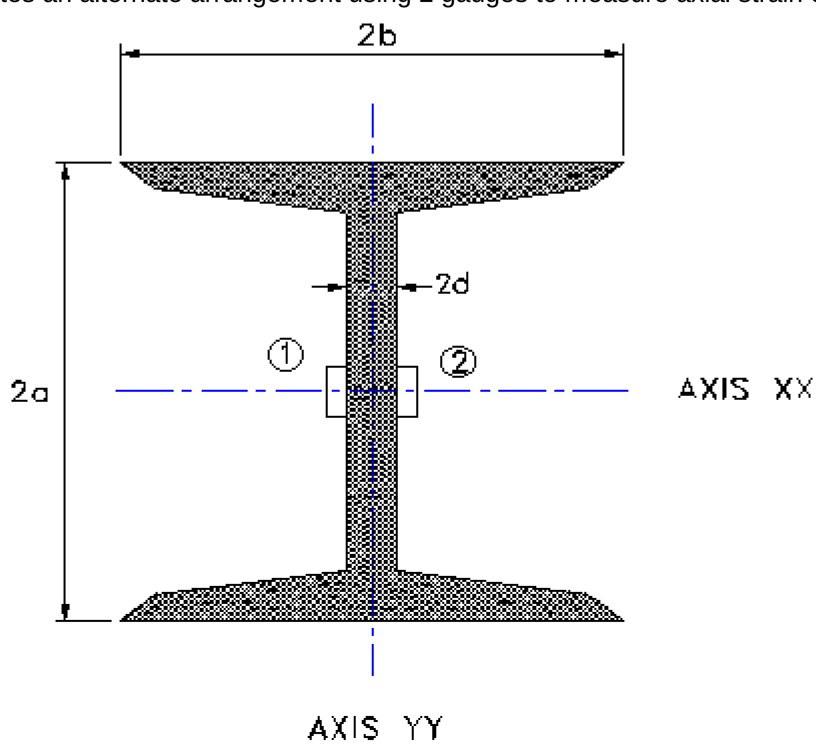


Figure 15 - Axial Strain Measurement and Bending Moment about YY axis only

This configuration has the advantage of positioning the gauges and cables where they are easy to protect. In fact the cable from one gauge can be passed through a hole drilled in the web, so that the two cables can be protected easily be a single conduit.

Another configuration of 2 gauges that has been used successfully is shown in figure 10.

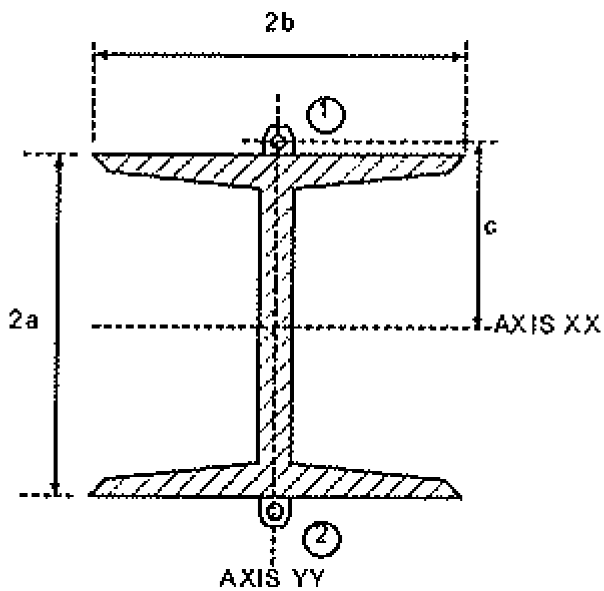


Figure 16 - Axial Strain and Bending Moments about XX axis only

This configuration allows the calculation of the axial strains and the bending moment around the major XX Axis. The disadvantage lies in the exposed position of the gauges on the outside of the flanges which will require a greater degree of protection for the gauges and cables.

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, and as a result no temperature correction to the measured strain is required. However, this is only true if the wire and the 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 it can be read directly if using the VW2104 readout. If an ohmmeter is used the relationship between resistance (ohms) and temperature is shown in Appendix C. If the strain gauges are bonded to concrete see Appendix D.

4.5 Welding Effects

Arc welding close to the gauges can cause very large strain on the steel structure. Thus, welding studs onto more solid piles to support lagging or shotcrete 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 VWGS-S 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.

Symptom: Strain Gauge Readings are Unstable

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct?
- ✓ Is the strain reading outside the specified range (either compressive or tensile) of the instrument? Gauge 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 gauge? If not, the readout may have a low battery or be malfunctioning.
- ✓ Does the coil assembly work on another gauge? If not, the coil assembly may be defective.

Symptom: Strain Gauge Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gauge leads for the VWSG-S (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 gauge? If not, the readout or datalogger may be malfunctioning.
- ✓ Does the coil assembly work on another gauge? If not, the coil assembly may be defective.

Appendix A - SPECIFICATIONS

A1 Strain Gauge

Model:	VWSG-S
Range (nominal):	2500 μ□
Resolution:	0. 1 μ□[1]
Calibration Accuracy:	0.1% FS
Batch Factor Accuracy:	0.5% FS
System Accuracy:	2.0% FS[2]
Stability:	0.1%FS / yr
Linearity:	2.0% FSR
Thermal Coefficient:	12.2 μ□□□□°C
Dimensions (Gauge): Length x Diameter	2.250 x 0.250” 57.2 x 6.4mm
Dimensions (Coil): (Length x Diameter)	3.000 x 0.875 x 0.500” 76.2 x 22.2 x 12.7mm
Coil Resistance:	180Ω
Temperature Range:	-20 to +80°C

Notes:

[1] Depends on the readout, above figure pertains to the VW2104 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 gauge.

A.2 Thermistor (also see Appendix C)

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.:

$$F = \varepsilon_W Ea$$

Where;

ε_W is the wire strain (in./in.).

E is the Young's Modulus of the wire (30 x 10^6 Psi).

a is the acceleration due to gravity (386 in./sec.^{2}).

6. Combining equations 4 and 5 gives:

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

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

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

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

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

9. Combining 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 gauge is attached. Since the deformation of the body must equal the deformation of the wire:

$$\varepsilon_w L_w = \varepsilon L_g$$

Where;

ε is the strain in the body.

L_g is the gauge length (in inches).

11. Combining equations 9 and 10 gives:

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

Where;

L_w is 2.000 inches.

L_g is 2.250 inches.

12. Therefore :

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

(Note that T is in seconds x 106 and ε is in inches per inch)

13. The display on position “E” of the VW2102/2104 Readout is based on the equation:

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

Not 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 is given in terms of microinches per inch (ε).

Appendix C - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale 41C3001-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 = $1.019 \text{ X } 10^{-7}$

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

Table 2 Thermistor Resistance versus Temperature

Appendix D - TEMPERATURE CORRECTION WHEN USED ON CONCRETE

The steel used for the vibrating wire has a thermal coefficient of expansion of 12.2 microstrain/°C. Therefore the *total strain in the concrete* corrected for thermal effects on the gauge is given by the following equation.

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

Equation 7 - Total Concrete Strain Corrected for Gauge Thermal Effects

In the above equation (R –R0)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 concrete plus those induced by changes in load.

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

$$\mu\varepsilon_{thermal} = (T_1 - T_0)xCF_2$$

Equation 8 - Thermal Concrete Strains

In Equation 8, CF_2 represents the coefficient of expansion of concrete. Unless this figure is known assume a nominal value of 10.4 micro strain/°C.

Therefore, to calculate the strain in the concrete due to load changes only;

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

Equation 9 - Strain Calculation due to Load Change

Note the following example, where B = 0.91

R_0 = 3000 microstrain, T_0 = 20°C

R_1 = 2900 microstrain, T_1 = 30°C

1 $\mu\varepsilon_{apparent}$ =(2900 - 3000) x 0.91= -91(compressive)

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

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

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

Note

Since assumptions have been made regarding the thermal coefficients for the concrete, these equations should only be used as a general guide. Also, if the modulus is known, the total stress can be calculated regardless of temperature (assuming that there is no creep).

Appendix E - ADJUSTING THE GAUGE WIRE TENSION

Note

Under no circumstances should the procedures described in Appendix E be used after the gauge has been welded down.

Gauges 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 gauge is required to read large tensile strains then set the reading between 1500 and 2000 microstrains, if the gauge is to read large compressive strains set the initial reading to between 2500 and 3000 microstrains. Table 3 lists the wire tension readings.

A mini wrench is used to rotate a nut on a threaded tube. The position of the nut controls the spring tension.

E.1. Adjusting the Gauge

Place the gauge in a coil housing, 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. Grab the gauge by the tube and turn the nut in a clockwise direction to tighten. A rotation of ½ turn will give a change of about 600 microstrain. The gauge end block will often turn also, so after the adjustment the block should be turned back so that the flats 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 tube, rotating the nut and realigning the end blocks, etc.

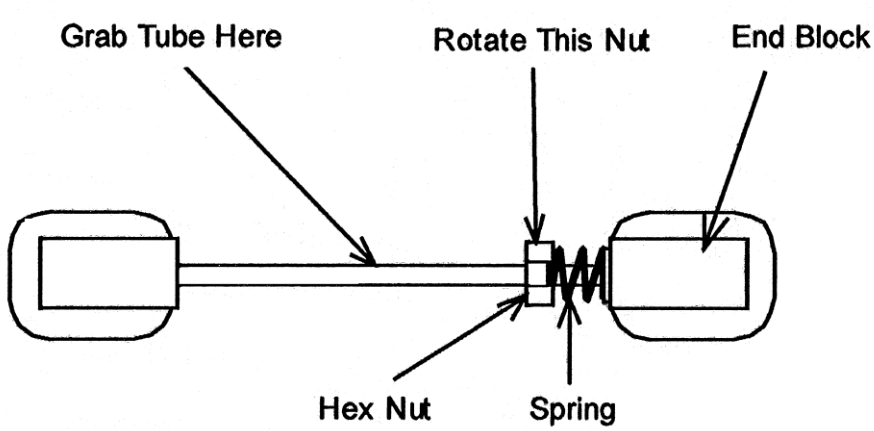


Figure 17 - Tension Adjustment

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

Table 3 - Guide to Initial Tension Settings

Appendix F - MEASUREMENT AND CORRECTION FOR TEMPERATURE EFFECTS

If the ends of the steel or concrete structural member are restrained by some semi-rigid medium, then any increase in temperature of the structural member will result in a build-up of compressive strain in the member. The magnitude of this temperature-induced strain increase will be measured accurately by the strain gauge (Because, while the member is restrained from expansion, the vibrating wire is not restrained and the expansion of the wire will cause a reduction in wire tension and a resulting decrease in the vibrational frequency. This can be interpreted as an increase in compressive strain, which is exactly equal to the temperature-induced increase in compressive strain in the member).

The temperature-induced strains can be separated from the load-induced strains by reading both the strain and temperature of the strain gauges at frequent intervals over a period of time in which the external loading from construction activity can be assumed to be constant. From these readings it is possible to calculate the changes of temperature and the corresponding changes of strain over the same time intervals. When these strain changes are plotted against the corresponding temperature changes, the resulting graph shows a straight-line relationship, the slope of which yields a correction factor. This correction factor can be applied to the total strain and temperature data to remove the temperature-induced strains leaving only those strains produced by changing loads.

Note that the correction factor may change with time and with construction activity due to the fact that the rigidity of the restraint may change. It would then be a good idea to repeat the above procedure in order to calculate a new temperature correction factor.

The steel used for the vibrating wire has a thermal coefficient of expansion, (CF_1), of +12.2 microstrain/^{0}C. Therefore **the actual, or true strain in the steel**, corrected for thermal effects on the gauge, is given by the following equation.

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

Equation 10 - Actual Strain after Correction for Gauge Thermal Effects

In the above equation (R_1-R_0)B is the apparent strain and $\mu\varepsilon_{actual}$ is the true strain or the actual strain after the thermal effect on the gauge wire has been corrected for. **It includes both the thermally induced strains in the steel, superimposed on those induced by changes in load**.

In a free field, where no loads are acting, the thermal strains in the steel are given by the following equation;

$$\mu\varepsilon_{thermal} = (T_1 - T_0)xCF_1$$

Equation 11 - Thermal concrete Strains

In Equation 11, CF_1 represents the coefficient of expansion of steel.