RST INSTRUMENTS LTD.

Vibrating Wire Strain Gauges

VWSG-E(M), VWSG-A(M)

Instruction Manual

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Vibrating Wire Strain Gauges VWSG-E(M), VWSG-A(M)

Product: Vibrating Wire Strain Gauges VWSG-E(M), VWSG-A(M)
Instruction Manual

Document number: ELM0025F
Revision: 2.2
Date: June 28, 2017

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1 INTRODUCTION

RST VWSG-A(M) and VWSG-E(M) Vibrating Wire Strain Gauges are designed for the measurement of strains in Civil and Structural Engineering. Strain Gauges may be directly attached to steelwork and concrete surfaces (VWSG-A(M) Type) or embedded within mass concrete (VWSG-E(M) Type). Stress changes within these materials can then be calculated, based on the strain measurement changes, if the modulus of the material is known.

Vibrating Wire Strain Gauges consist of a length of high tensile steel wire anchored into, and tensioned between, two end blocks. An encapsulating sealed stainless steel tube protects the Vibrating Wire from the external environment. Relative movements of the end blocks result in a change in the tension of the Vibrating Wire causing a change in the resonant frequency of the wire when it vibrates.

Vibrating Wire Strain Gauge (VWSG) instruments measure strains using the vibrating wire principle. A length of special steel wire is pre-tensioned between two mounts located within the body of the VWSG instrument. The VWSG instrument is then securely attached between two mounting blocks that have been welded to the steel surface which is being studied. Deformations (i.e.- strain changes) along the steel surface will cause the two welded mounting blocks to move slightly relative to one another, thus altering the tension of the Vibrating Wire within the VWSG instrument. The tension in the Vibrating Wire is measured by plucking the wire and then measuring it's resonant frequency of vibration. In practice, the Vibrating Wire is plucked periodically by an electromagnetic coil positioned next to the wire and it's resonant frequency is measured by means of the same electromagnetic coil.

There is a linear relationship between the change in length of the Vibrating Wire Strain Gauge and the square of the resonant frequency of the Vibrating Wire. A Vibrating Wire Readout Unit (RST Model VW2106) supplies an excitation pulse (frequency sweep) to the Strain Gauge Vibrating Wire. The resulting Strain Gauge output resonant frequency is read by the VW2106 Vibrating Wire Readout Unit which is displayed in B Units on the Readout Unit display.

RST VWSG-A(M) and VWSG-E(M) Vibrating Wire Strain Gauges can be read using other manufacturers Vibrating Wire Readout Units and/or dataloggers equipped with vibrating wire excitation modules. However, care must be taken to ensure that the correct frequency sweep is being applied to the VW sensors by the Vibrating Wire Readout Unit, otherwise false readings will result.

VWSG-A(M) and E(M) Vibrating Wire Strain Gauges are manufactured in various configurations to suit particular mechanical applications and are supplied with various types of end blocks and terminations to enable the Strain Gauges to be attached onto or embedded into a variety of materials and in many different configurations.

This manual contains general information concerning Vibrating Wire Strain Gauge installation, set-up, troubleshooting and data reduction, together with typical installation details.

The user is directed to read this manual thoroughly before undertaking any installation work with RST Vibrating Wire Strain Gauges.

1.1 NOTES ON VIBRATING WIRE READOUT UNITS

Vibrating Wire readout units and Vibrating Wire datalogger excitation modules, supply an excitation pulse or frequency sweep to the coils of the Vibrating Wire Strain Gauge, which causes the Vibrating Wire to oscillate at its resonant frequency. The coils of the Strain Gauge transform this frequency into a sinusoidal output, with the output frequency corresponding to the resonant frequency of the Strain Gauge Vibrating Wire. This output frequency is detected by the readout or the datalogger unit and may be displayed in various parameters, dependent upon the particular manufacturers' readout unit design.

Note: Strain Gauge readings are normally displayed in B units (Frequency^2 * 10^{-3}) on RST VW2106 Readout Units. Users must consult the Instruction Manual for the RST VW2106 VW Readout Unit (RST Manual ELM0042H) for detailed reading instructions.

Depending on the date of manufacture, RST VWSG-A(M) and VWSG-E(M) Vibrating Wire Strain Gauges may require different sweep frequency ranges in order to provide correct B Unit output readings. The operator must consult the Strain Gauge Calibration Record Sheet for the instrument to be read, in order to confirm these requirements.

In general, RST VWSG-A(M) and VWSG-E(M) Vibrating Wire Strain Gauge instruments use a sweep frequency of 450 to 1200 Hz. However, the operator must always refer to the VW Calibration Record Sheet for the VWSG-A(M) or VWSG-E(M) Strain Gauge sensor to be read, in order to determine the correct sweep frequency required to obtain a correct reading.

The sweep frequency for the VW2106 VW Readout Unit can be easily changed in the field. Refer to the VW2106 VW Readout Unit Instruction Manual (ELM0042H) which provides instructions on how to change the sweep frequency setting.

VW Readout Units use set sweep frequencies to pluck the Vibrating Wire in the sensor. The VW Readouts Units include options for several different sweep frequencies. A higher sweep frequency is required to read VW sensors which will have higher resonant frequencies readings. While a lower sweep frequency is required to read VW sensors which will have lower resonant frequencies readings.

If the sweep frequency applied, is inappropriate to the natural resonance of the VW sensor being read, the output readings will be erratic and unstable. If this problem is noted to be occurring, the sensor sweep frequency should be checked on sensor VW Calibration Record sheet.

2 SURFACE INSTALLATION

2.1 VWSG-A(M) VIBRATING WIRE STRAIN GAUGES FOR SURFACE ATTACHMENT

VWSG-A(M) Strain Gauges are used primarily for attachment to steel or concrete structures where they will measure long term strains. Application examples would include driven steel piles, steel struts, steel props, steel or concrete tunnel linings, etc.

VWSG-A(M) Strain Gauges are supplied in an un-tensioned state and require the initial tension to be pre-set, by the installer, in the direction of the expected strain movement so that a reading lag does not occur.

The end fittings of VWSG-A(M) Strain Gauges are sealed within a protective steel outer tube by a pair of Viton "0" rings so that the Strain Gauge is totally waterproof to protect against external fluid pressures in excess of 50 bar.

VWSG-A(M) Strain Gauges can be supplied with a wide range of steel Mounting Block types to enable the Strain Gauge to be fixed to steel structures by arc welding or onto concrete surfaces using drill-in anchors or epoxy glue.

Irrespective of the exact mounting method, the basic mounting arrangement consists of a pair of steel Mounting Blocks holding the ends of the Strain Gauge securely in place as shown in Figure 1.

One Mounting Block has a single M4 cone point set screw that locates into a circumferential "Vee" groove at one end of the Strain Gauge. The other Mounting Block has a milled slot at top to allow the plain end of the Strain Gauge to be clamped in place using two M4 dome point set screws placed through the block at opposing angles.

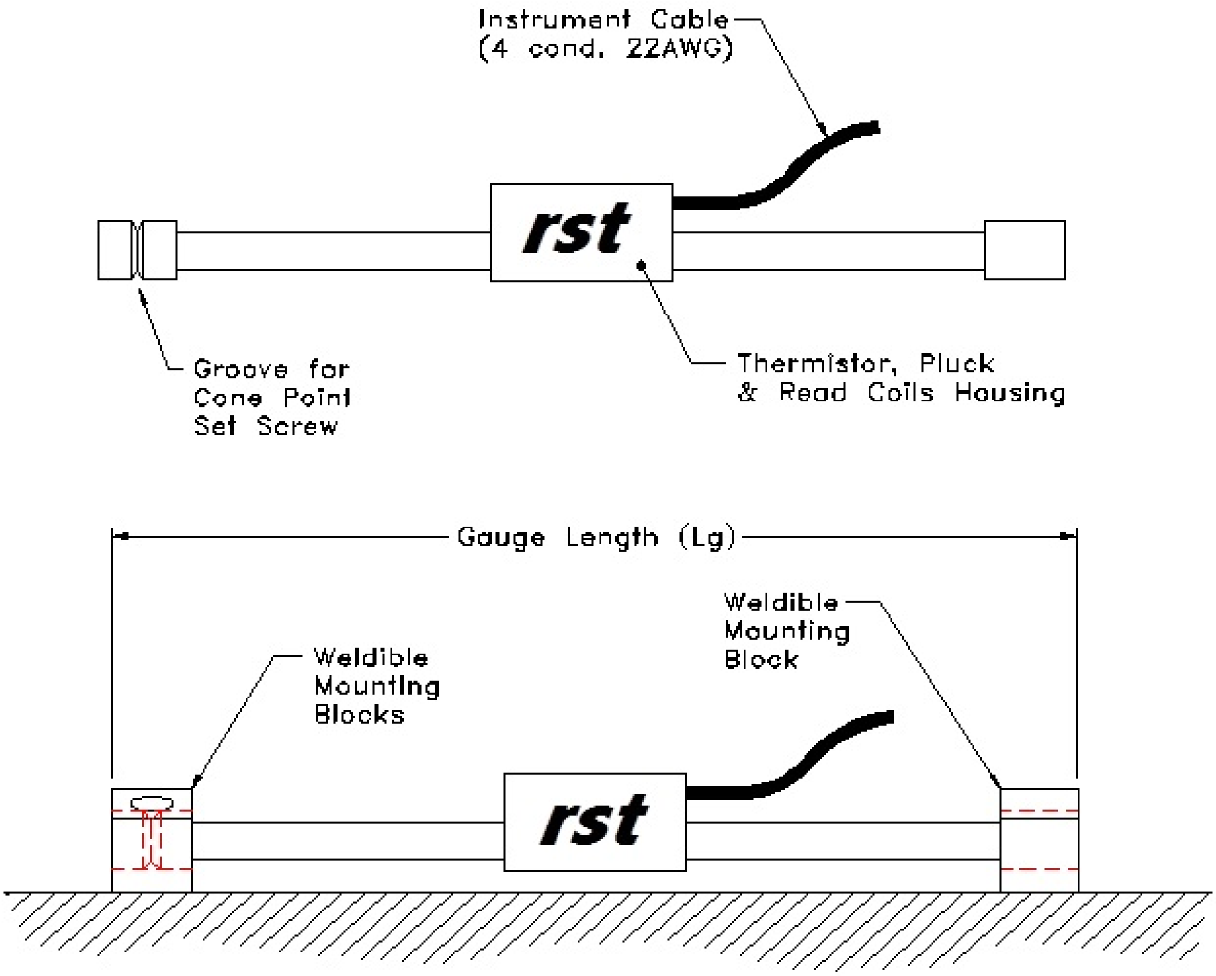

Figure 1 - VWSG-A(M) General Arrangement

2.2 INSTALLATION OF MOUNTING BLOCKS

The two steel Mounting Blocks must be located in perfect alignment on the steel surface where the installation is to occur and they must be set at an exact distance apart from each other. If the steel Mounting Blocks are not installed at the correct distance apart, there will be a resultant error in the calculation of the measured strain.

Installation of the steel Mounting Blocks, in exact alignment and at the require distance, is accomplished using a temporary steel Spacer Bar which is installed between the two mounting blocks. This steel Spacer Bar, which is sufficiently rigid to resist any bending or displacement caused by the welding installation process. It is noted that the VWSG-A(M) Strain Gauges are not rigid enough to withstand the forces which could be induced by the welding process, and could result in damage to the instrument and subsequent incorrect readings.

A Spacing Jig is used to set the steel Spacer Bar in alignment with the two steel Mounting Blocks and at the correct length, as shown in Figure 2. The Mounting Block set screws are tightened into place on the steel Spacer Bar. The locked Strain Gauge assembly is then removed from the Spacer Jig and set in place on the prepared steel surface, ready to be arc welded in place.

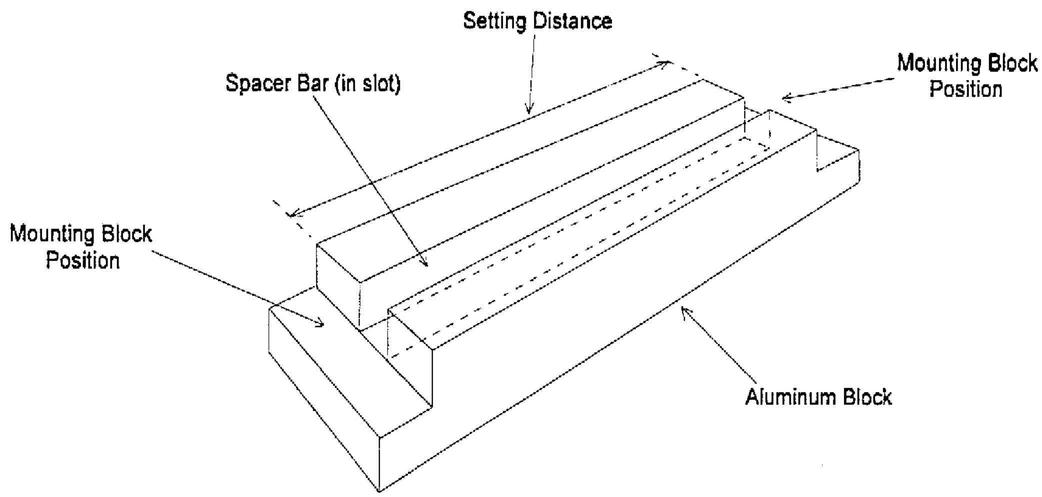

Figure 2 - Spacing Jig

2.3 Arc Welding the Mounting Blocks

The steel surface where the VWSG-A(M) Strain Gauge installation is planned, must be cleaned using a wire brush to remove all scale, rust and dirt. If oil or grease contamination is evident, the surface must also be cleaned with a solvent, prior to the final preparation with a clean wire brush. The assembled steel Spacer Bar and steel Mounting Blocks are then removed from the Spacing Jig and pressed firmly against the steel surface, The Spacer Bar can be used as a handle to hold the assembly in place during the welding work.

The outer edges of the Mounting Blocks are now arc welded to the steel surface in the order shown in Figure 3.

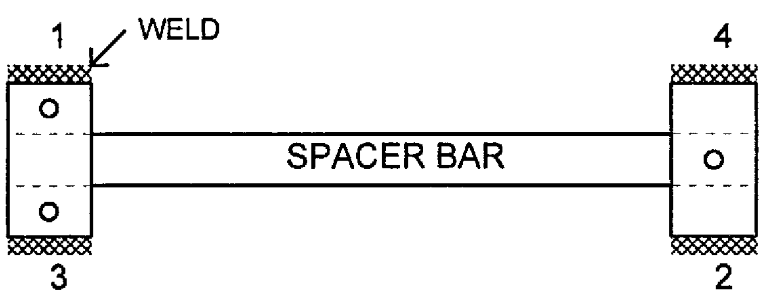

Figure 3 - Welding Sequence for the Mounting Blocks

It is important to avoid the build-up of excessive heat which could result in deformation of the intended mount alignment. Following each weld pass, cooling should be carried out with a wet rag. The welds must be secure, but should not be excessively large in order avoid the introduction of stresses and distortion into the surrounding steel..

<u>Note</u>: Care must be taken to not place any weld on the flat end surfaces of the steel Mounting Blocks which could prevent the later removal of the Spacer Bar.

After welding, cool the welds and the Mounting Blocks with a water soaked rag, then slacken the three set screws and remove the temporary Spacer Bar. Clean away all welding slag and splatter using a wire brush and welding hammer, being careful not to damage the steel Mounting Blocks.

If the Strain Gauge is to be protected by a cover plate, then threaded studs, which are intended to hold the cover plates in place, need to be welded in place at this time, before the VWSG-A(M) Strain Gauge is installed.

Stud welding can be accomplished with either a special stud welder, or a low power arc welder. The hex head of small bolts (approx. 3/16" to 1/4" size) are welded flush to the steel surface. In some cases, a special welding jig may be devised to place the studs at the exact locations required for a prefabricated cover plate.

The application of a coat of rust preventative paint is recommended at all the weld points, to inhibit corrosion that could occur over time.

To speed up the installation process, when many Strain Gauges are being installed at one site, it may be advantageous to have additional manpower and multiple spacer bars available for use.

2.4 INSTALLATION TO MEASURE CONCRETE SURFACE STRAINS

Concrete surface strains can be measured utilizing the VWSG-A(M) Vibrating Wire Strain Gauge by attaching the Strain Gauge to the concrete surface using one of the following methods:

1) Vibrating Wire Strain Gauges for mounting on concrete surfaces will normally be supplied with M10 steel anchor bars welded onto the bottoms of the Strain Gauge Mounting Blocks. The Mounting Blocks are connected to the steel Spacer Bar using the same general procedure described in Section 2.2 above, for welded Mounting Blocks. The Spacing Jig is used to position and space the Mounting Blocks properly. A template is then used for drilling two 70mm deep by M12 holes in the concrete surface, at the required spacing, for the M10 anchors. The anchors are then grouted into the pre-drilled holes using either a fast setting hydraulic cement or a high strength epoxy, as shown in Figure 4.

   After a full grout set is achieved, the Spacer Bar is removed and the VWSG-A(M) Strain Gauge is installed.

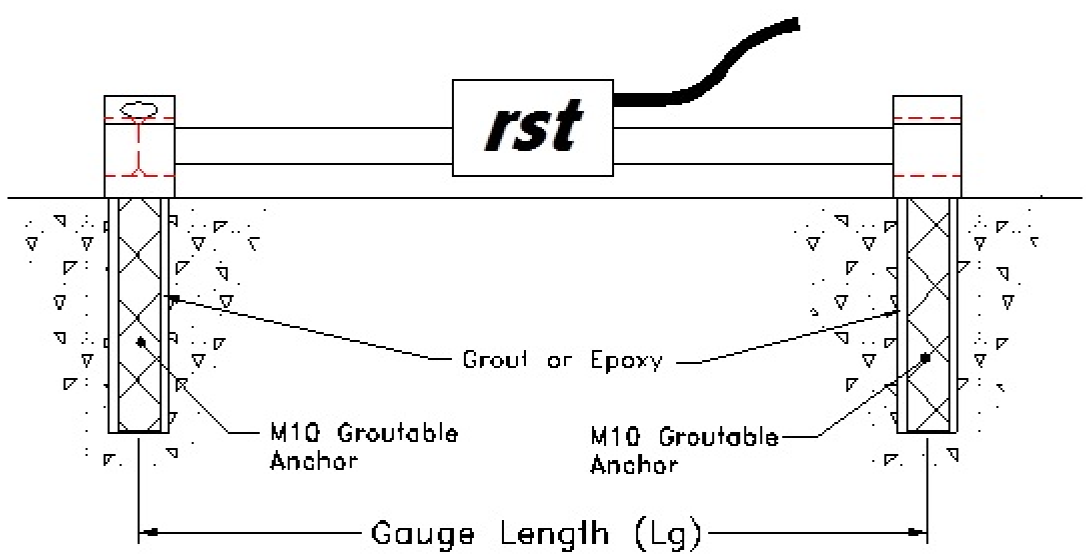

Figure 4 - Installation on Concrete using Groutable Anchors

2) In some cases, with proper care, the standard steel Mounting Blocks can be epoxied directly on to a concrete surface. The concrete surface must be clean and dry and have a certain amount of roughness to allow epoxy bonding. Sanding, minor chipping and cleaning will likely be required. If this procedure is used, the plating on the underside of the Mounting Blocks must also be removed and the steel surface roughened with coarse emery cloth.

   Epoxy capable of curing at the temperature of the location is required. Note that the concrete surface may be cooler than the surrounding ambient air temperature.

2.5 Setting the Initial Tension of the Strain Gauge

Once the steel Mounting Blocks have been fixed, welded or glued to the surface, the VWSG-A(M) Strain Gauge must be installed into the mounting blocks and set to the correct tension prior to use.

In advance of the installation, the operator will need to determine whether the Strain Gauge will be measuring compressive or tensile strains.

The first installation step is to insert the Strain Gauge instrument into the aligned Mounting Blocks with the end with the circumferential "Vee" groove, located in the Mounting Block with the single set screw. Slide the Strain Gauge into the mounting block holes and tighten the single set screw into the "Vee" groove, at the one end only. This will locate the Strain Gauge.

Note: The VW Calibration Record Sheet must be consulted for each VWSG-A(M) Strain Gauge being installed to determine the calibration of the instrument and the reading frequency to strain relationship which is required for set-up of the initial tension of the Strain Gauge, between the two fixed Mounting Blocks.

Attach the VWSG-A(M Strain Gauge readout wires to a manual VW readout unit. Gently push or pull the free end of the Strain Gauge to set a preload tension in the Strain Gauge in the direction that either compressive or tensile strains are expect to occur.

The usable range of a VWSG-A(M) Strain Gauge is approximately 3000 micro-strains between 1000 and 4000 micro-strains. And the mid-range reading is at approximately 2500 micro-strains. For the monitoring of expected compressive strains, the Strain Gauge should be initially set between 3000 and 3500 micro-strains. For the monitoring of expected tensile strains, the Strain Gauge should be set between 1500 and 2000 micro-strains.

Note: During the installation work, direct Strain Gauge readings will be provided to the Operator in B Units [(VW frequency)^2 x 10^{-3})] from the RST VW2106 Readout Box. Section 7 of this manual provides a details explanation of how the micro-strain values are calculated from the vibration frequency of the Vibrating Wire Strain Gauges. However, processing this information into micro-strain data is an involved process which is not practical to be doing as the instrument installation work proceeds.

To simplify the installation process for the Operator, and so that the Operator will be able to work effectively in the field, it is recommended that the Operator prepare a field spreadsheet, in advance of the field installation work, which will provide quick correlations between B Units Readings, Frequency and micro-strain at quarterly points throughout the Strain Gauge ranges. This preparatory work will greatly simplify and clarify the field installation task.

When the desired micro-strain reading (B Unit equivalent) has been achieved, tighten the two cone point set screws at the opposite end mounting block to retain the desired initial Strain Gauge reading. Noted that the micro-strain reading will likely change slightly during this operation, as the strain setting are very sensitive to extremely minor mechanical changes. If the Strain Gauge reading changes significantly from the targeted level, a re-set may be required.

Secure all the output wiring from the Strain Gauge. Gently tap the end blocks with the plastic handle of a small screwdriver to relieve any residual stresses or mechanical hang-ups. Gentle tapping should be repeated until a stable B Unit output reading is achieved.

Re-check the output reading from the Strain Gauge. If it has moved too much from the desired initial setting point, it may be necessary to perform a second re-set the Strain Gauge, until an acceptable setting is achieved.

In normal Civil Engineering monitoring work, strains are generally well within the working range of the Strain Gauge being used. Therefore, in practice, setting the Strain Gauge to the approximate mid-range value will be sufficient for practically all cases.

However, for cases where more range is required in either the compressive or the tensile directions, the Strain Gauge set point can be offset from the center of the range in the desired direction, as required. The following is noted:

- For the monitoring of higher compressive strains, the Strain Gauge would be set at a higher frequency than 50% of range so that more range would be available in the negative direction.
- For the monitoring of higher tensile strains, the Strain Gauge would be set at a lower frequency than 50% of range so that more range would be available in the positive direction.

2.6 Initial Readings

All future Strain Gauge Readings will be compared back to the initial reading set, so it is important that the initial reading be taken very carefully and be fully documented. In some cases it may be advisable to take several baseline readings over several days. Noted that temperature differentials will impact strain gauge readings, so it will be best to take the initial reading set in the early morning hours, when temperatures are the most iso-thermic and the instruments will be the most stable.

For a steel structure, initial strain reading need to be carried out before any loading is carried out, so that there is a clear understanding of the initial strain regime in the structure. Subsequent readings sets will indicate the strain differential that has been caused by the loading of the structure.

2.7 Gauge Protection

2.7.1 Corrosion Protection

If the Strain Gauge instrument installations are intended for long term use, rust inhibiting paint should be applied to all weld points. Over time, unchecked corrosion can impact the connection of the Strain Gauge instrument to the underlying steel structure, which could alter the instrument output.

2.7.2 Thermal Protection

The thermal coefficient of expansion of the steel vibrating wire is virtually the same as that for the steel structure which the gauge is attached to. So in theory, no temperature correction will be required to the Strain Gauge output data, due to temperature changes. However, in reality this theory only holds true if the instrument and the attached steel structure will always be maintained at the exact same temperature, at all times. This will likely never occur in the real world, due to the various thermal inputs from the surrounding environment. The only true iso-thermal environment might be found within a deep underground structure or opening.

The thermal input from direct sunlight on Strain Gauge instruments must be avoided because the resulting heat rise on the steel body will have a large impact on the instrument output and mechanical function. Heat shields and insulation can be installed in an attempt to provide protection from thermal input, but even then, the heat influence at certain times of the day, and under certain weather conditions, may render a portion of the daily output data unusable.

A key strategy for dealing with large diurnal temperatures changes and shifting direct sunlight, is to ensure that a full set of daily base readings are established each day just prior to dawn, when everything at the site will be the most isothermal. This daily base data set will help to interpret changes that are actually occurring at a site and will indicate when and where reading inputs ae not to be trusted.

All temperature data needs to be logged and archived for later use. To clearly establish the influence of temperature, the temperature data should be plotted with movement data which will indicate any relationships.

2.7.3 Mechanical Protection

Strain Gauge instruments are very sensitive to mechanical interference. To avoid unwanted mechanical influence or disturbance, it is highly recommended that guards and cover plates be installed over and around instruments that could be at risk. If a Strain Gauge instrument is noted to have experienced a sudden reading change, it would be advisable to carry out an inspection to check for any obvious signs of an external mechanical event, such as being struck, lifted or have a vertical load applied.

The cables from mounted Strain Gauges need to be adequately protected from mechanical damage and excessive wear over time. This can be accomplished by the installation of rigid or flexible conduit, steel guards, barriers or covers. Most of these items can be supplied by RST as custom parts..

3 INSTALLATION INTO CONCRETE

3.1 VWSG-E(M) Strain Gauge For Concrete Embedment

VWSG-E(M) Embedment Strain Gauges are used for the determination of strains in mass concrete structures such as bored piles, diaphragm walls, concrete dams etc.

These Strain Gauges are fully sealed by laser welding and are supplied pre-tensioned. Since their intended use is for concrete embedment, the initial wire tension is set up for the measurement of compressive strains. Each Strain Gauge is fitted with a pair of coils and a thermistor.

No adjustment of the initial wire tension is possible by the User, without specialized equipment and instructions.

VWSG-E(M) and VWSG-E(M) HT Strain Gauges are normally installed into concrete pours by tying the Strain Gauges to adjacent reinforcing bar or alternatively casting the Strain Gauges into briquettes, which are subsequently tied to reinforcing bar. The preferred method is to directly install the Strain Gauge into concrete rather than using the briquette method, which may reduce reading accuracy due to boundary effects.

In many cases, the end user will require the conversion of the strain readings into stress values. To do this requires knowledge of the modulus of the placed concrete. It is noted that the concrete modulus does vary, and it cannot be assumed that briquette modulus and the mass concrete modulus will be the same.

If accurate stress values are required, irrespective of the method chosen, it is important that concrete samples are taken of the mass concrete pour to establish the modulus of that concrete. Note that care must be taken to ensure correct techniques in sampling, curing and subsequent testing are followed.

It is often useful to cast a reference Strain Gauge into a concrete sample, which can be cured in similar conditions to that of the mass concrete, and which can be loaded in a test machine to directly establish the stress/strain relationship.

When casting a Strain Gauge directly into the structure, care must be taken to avoid applying any large forces to the end blocks during the installation. The instrument can be wired into position as depicted in Figure 5. The tie wires should not be tied too tightly since re-bar and/or the instrument cables tend to move during concrete placement and vibration. Care should be taken not to damage the instrument cable with a vibrator or other placement tools. Also placement of the concrete from height could easily result in damage to an installed Strain Gauge.

<u>Note:</u> For concrete pours where the concrete will be consolidated using power vibrators, the construction labour MUST be made aware of Strain Gauge locations and supervised at all times to prevent damage to the instruments or wiring from the vibrator equipment.

A Strain Gauge can also be placed directly into placed concrete, if it can be assured that the gauge orientation will remain unchanged.

3.2 VWSG-E(M) Strain Gauge Attachment

The following directions are provided for attaching model VWSG-E(M) Strain Gauges within a re-bar cage.

Direct Attachment to Re-Bar with Blocking

1. Wrap a layer of self-vulcanizing rubber tape around the Strain Gauge at the two locations where the gauge will be mounted to the re-bar (refer to Figure 5).
2. The rubber tape layer serves as a shock absorber, dampening any vibrations coming from the suspension system and the re-bar Sometimes, without the use of rubber tape layers, as the tie wires are tightened, the resonant frequency of the tie wires interferes with the resonant frequency of the Strain Gauge. This results in unstable readings or no readings at all prior to the placement of the concrete. Noted that this effect will disappear once the concrete has been placed and has attained an initial set.
3. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together (not high tensile stainless steel wire). Twist it 2 to 3 times around the body of the Strain Gauge, over the rubber strips, about 3 cm from the gauge ends.
4. Wire two spacer blocks onto the re-bar cage at the installation location. The blocks should be located in alignment with the upper and lower rubber tape layers.
5. Tightly secure the Strain Gauge to the two spacer blocks and re-bar using the soft iron wire.
6. Tie the instrument cable off to a nearby re-bar using nylon Ty-Raps™.

Suspended Attachment to Re-Bar Mat

1. Wrap a layer of self-vulcanizing rubber tape around the Stain Gauge at the two locations where the gauge will be mounted to the re-bar mat (refer to Figure 5).
2. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together (not high tensile stainless steel wire). Twist it 2 to 3 times around the body of the Strain Gauge, over the rubber strips, about 3 cm from the gauge ends.
3. Twist two loops in the upper wire, one on either side of the Strain Gauge, at a distance of about 3cm from the gauge body. Repeat this process at the lower end of the gauge.
4. Position the Strain Gauge between two vertical re-bars and twist the wire ends twice around the re-bar, then around itself.
5. Tighten the wire by twisting on the loops, and orient the Strain Gauge.
6. Tie the instrument cable off to a nearby re-bar using nylon Ty-Raps™.

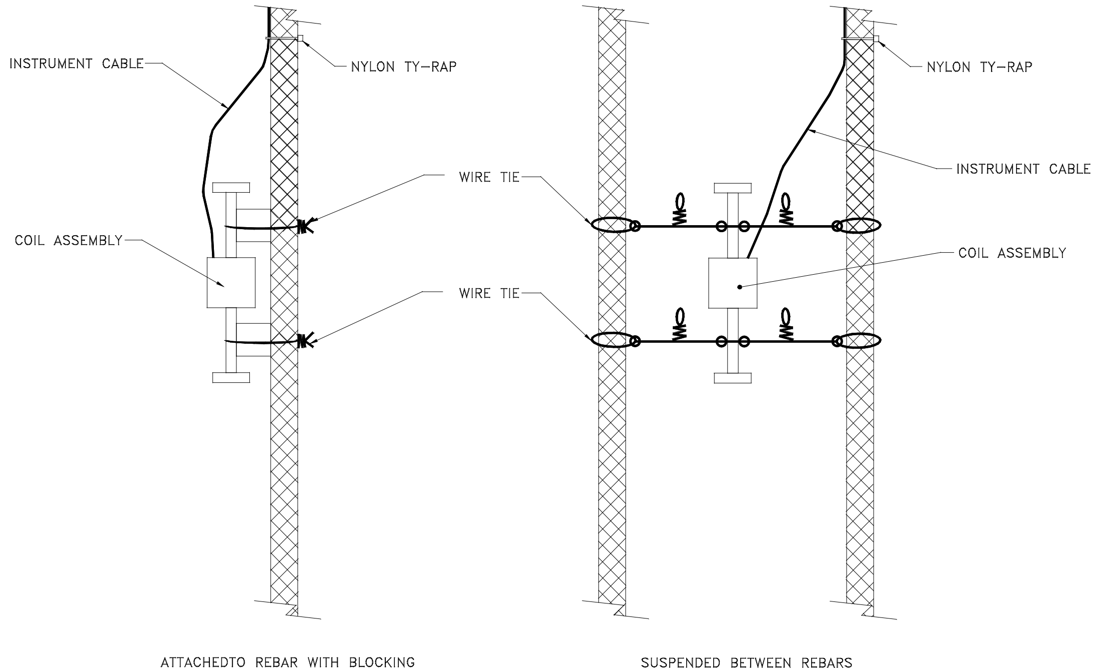

Figure 5 – Attaching VWSG-E(M) Strain Gauges to Re-bar

3.3 Using Pre-cast Briquettes or Grouting

An alternate instrumentation method is to pre-cast Strain Gauges into briquettes of the same concrete mix as the future concrete batch and then place these instrumented briquettes into the structure prior to the concrete placement. The briquettes should be between 24 and 48 hours old when they are installed and the new concrete is placed. Prior to installation and concrete placement the briquettes should be continuously cured with water.

Embedment Strain Gauges can also be installed in shotcrete and in drilled holes in rock or concrete, which are subsequently backfill grouted.

When used in shotcrete special care needs to be taken to protect the lead wires from damage due to the shotcreting process. Encasing the wiring in conduit or heavy tubing has been used effectively for protection. The Strain Gauges can also be placed by hand-packing the immediate area around the Strain Gauge and then proceeding with the shotcrete placement operation.

3.4 Cable Protection and Termination

The cables from embedded Strain Gauges need to be adequately protected from mechanical damage during installation and concrete placement. This can be accomplished by the use of rigid or flexible conduit, guards and covers. Most of these items can be custom supplied by RST.

Cables may be terminated by stripping and tinning the ends. Connection to a VW 2106 Vibrating Wire Readout Unit or a datalogger unit is usually done with bare wire connection to terminal strips. In some cases, a special patch cord is supplied to connect the VW output wires directly into a port on the VW 2106 Readout Unit.

Terminal boxes with sealed cable entries and covers are also available. This will allow many Strain Gauges to be terminated at one location, with complete protection of the lead wires. To facilitate readings, the Strain Gauge wiring can be terminated as built-in jack connectors or as a single connection with a rotary position selector switch.

Cables may be spliced to lengthen them without affecting the Strain Gauge readings. When splicing, always maintain polarity by connecting same color to same color. Always ensure the splice is completely sealed and waterproofed. Use of an RST CT-1100 Epoxy Splice Kit is recommended for all splices.

3.5 VWSG-E(M) HT CONCRETE EMBEDMENT STRAIN GAUGE

VWSG-E(M) HT Strain Gauges have a Strain Gauge element identical to VWSG-E(M). The only discernible difference is the appearance of the coil housing and the use of Teflon/Kaptan connecting cable. Within the coil housing, the coils themselves are constructed using high temperature materials.

Prior to shipment, the entire gauge will have been subjected to testing at elevated temperatures of 260 to 300 degrees Centigrade (dependent upon the specific application). Consequently, the Strain Gauge element will have a slight coloration. Unlike the VWSG-E(M) Strain Gauge, VWSG-E(M) HT Strain Gauges are NOT fitted with a thermistor.

3.6 SPECIAL PRECAUTIONS

The coil housing of the VWSG-E(M) HT is constructed using advanced aerospace materials and techniques, resulting in an extremely hard material with properties similar to glass. Like glass, this material has high internal stresses, and will shatter if subject to impact. Similarly, it is important if the User wishes to undertake temperature testing of the Strain Gauge (i.e. Not embedded or confined in concrete), that temperature should be applied gradually to minimize excessive thermal stress.

4 LIGHTNING PROTECTION

VWSG-A(M) and VWSG-E(M) Vibrating Wire Strain Gauges, unlike numerous other types of Vibrating Wire instruments available from RST, do not have any integral lightning protection components included. Integral surge protection devices are normally not required because the installation environment, which is usually well grounded, provides adequate protection.

However, to be effective isolated, the entire instrumentation system needs to be considered. This is of particular concern when multiple instruments are connected into a network which covers a large area. In this case, the network could be subject to transient and/or induced currents which could damage sensors and/or data acquisition equipment.

In this case, external surge protection may be required to reduce the risk of damage and data loss. The following suggestions for surge protection are provided:

- If the Strain 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 built-in locations for installation of these surge protection devices.
- 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 easily 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 Strain Gauges. See Figure 6.
- Additional information is available from RST on surge protection schemes and other alternatives.

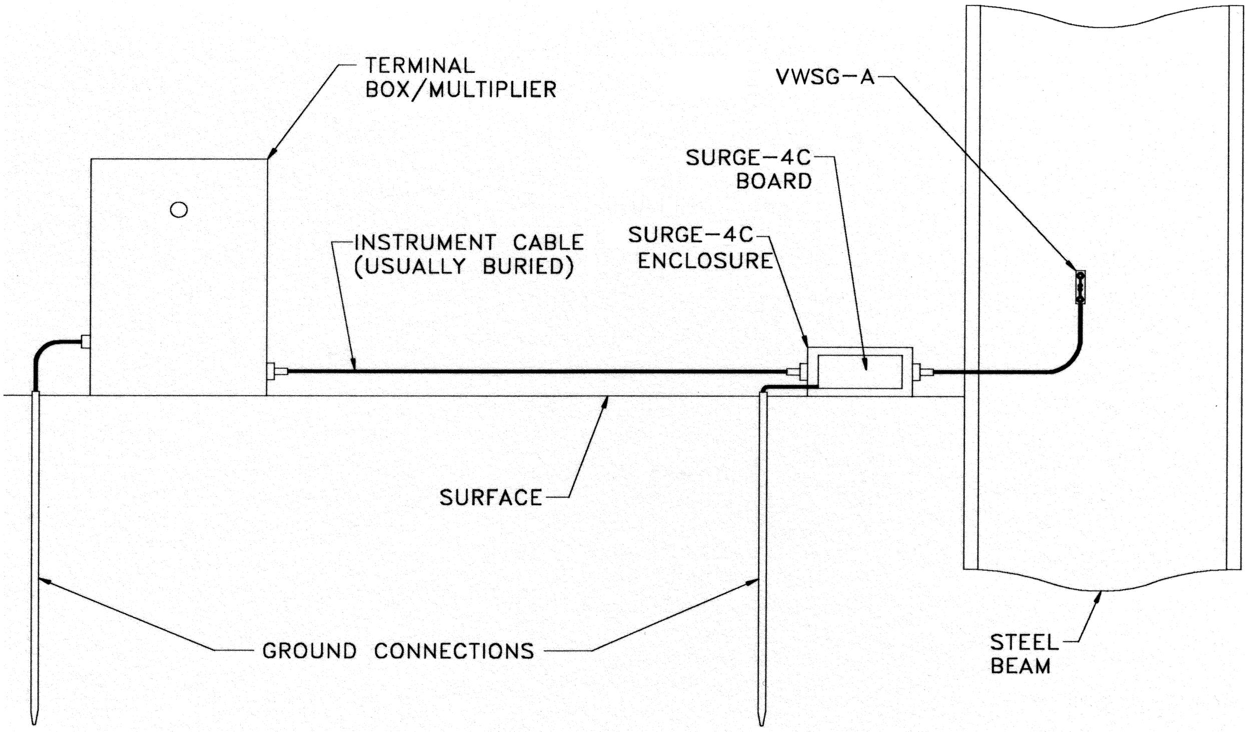

Figure 6 - Lighting Protection Scheme

5 GENERAL INSTALLATION GUIDELINES

Golden Rule Number 1: CHECK, CHECK AND CHECK AGAIN!

For every Strain Gauge installation, the installer needs to identify the key construction sequence events and the key instrument installation steps that will occur at the site. A successful installation must take into account both of these interdependent activities in detail.

The Strain Gauges must be checked before and after each key construction sequence events and each instrument installation step to ensure that the instrument function has not been disrupted. The installer must also investigate the ongoing work at site to identify any unforeseen site construction procedures or problems that could potentially put the installation at risk.

For example; The installation of an Embedment VW Strain Gauge in a reinforced concrete pile would typically encounter the following checkpoints to ensure the instrument function and to be able to immediately troubleshoot any problems, before proceeding with the next step of the construction work or the installation.

Manual readings and Strain Gauge function checks would occur at the following pre-determined points:

1) Prior to shipping to the job site; Pre-shipping by RST

2) Immediately upon receipt at site; By the client

2) Immediately prior to installation in the field

3) Immediately following installation of the Strain Gauge onto the re-bar cage

4) During and following addition of extension cabling to the instrument

5) Following installation of protective ducting/conduit

6) Following attachment ducting/conduit to re-bar cage

7) Following installation of first re-bar cage into the excavation

8) Following splicing of second re-bar cage onto the first re-bar cage
9) Following installation of second re-bar cage into the excavation
10) Following subsequent re-bar cage splices and installations (multiple)
11) Immediately prior to and following the initial concrete backfill placement
12) Immediately prior to and following each successive concrete backfill lift
13) Immediately following the completion of the concrete backfill work
13) Periodically during curing of the pile concrete
14) Immediately before breakout of the pile top
15) Immediately after breakout of the pile top
16) Immediately after forming of the pile cap
17) Immediately prior to and following the concrete placement of the pile cap.

A similar schedule of key construction and instrumentation steps/events should be prepared for all installations.

This type of planning, based on critical steps/events in the construction schedule and the instrument installation, should form a key component of a correctly planned installation.

6 TAKING READINGS WITH VW2106 READOUT UNIT

6.1 CABLE AND WIRING

VWSG-E(M) & VWSG-A(M) gauges:

- Red: Strain Gauge excitation
- Black: Strain Gauge excitation
- White: Thermistor
- Green: Thermistor
- No Shield Wire

VWSG-E(M) HT gauge:

- White: Strain Gauge excitation
- White: Strain Gauge excitation
- Red: Not used; No Thermister
- Red: Not used; No Thermister
- No Shield Wire

Cables supplied with the Strain Gauges may be readily extended using electrical wire/cable of the same or greater gauge size. Cable extension does not affect the output or affect the accuracy of VW Strain Gauges since the gauge outputs a frequency signal which is unaffected by the resistance of an additional cable length.

However, it is noted that all wire/cable splices must be properly insulated and protected. And to due to the inherit risks that splices pose to the overall wiring integrity of an installation, it is recommended that the number of splices be minimized.

When splicing, always maintain the polarity identification of the sensor by connecting same color wires to the same color.

All cable joints should be protected by a fully waterproofed epoxy based splice. Use of an RST CT-1100 Epoxy Splice Kit is recommended.

Cable runs in difficult locations such as deep bored piles and diaphragm walls should be fully protected from damage by tremied concrete and tremie pipes. Running cables in thick wall UPVC ducting and tying the ducting to adjacent reinforcing bar has been found to be very effective.

If VWSG-A(M) surface mount gauges are to be used on steel driven piles, cable protection from high accelerations is particularly important. Please contact RST for advice on these applications.

6.2 Operation of the VW2106 VW Readout Box

The VW2106 is the basic manual readout box for all Vibrating Wire type instruments, including Vibrating Wire Strain Gauges. Details of the operation and use of the VW2106 readout box is found in RST Instruction Manual (ELM0042H).

The VW2106 Readout can be programmed to log VW instrument readings. Instructions can be found in the RST Instruction Manual (ELM0042H).

The VW2106 Readout is also able to apply calibration constants which will convert frequency readings into engineering units. Instructions for this application can be found in the VW2106 Host Software, as detailed in the VW2106 Host Software Instruction Manual (ELM0053D).

6.3 VW2106 Readout Operation

The following instructions outline the basic steps needed to take a manual reading with the VW2106 Readout Unit:

- Connect the VW instrument leads to the VW 2106 terminal strip quick-connects. Match the VW wire colors to the colors indicated at the terminal strip. Red and Black are from the VW coils. Green and White are from the Thermister sensor.
- Turn on the readout unit by pressing any key.
- The readout will go through its startup procedure, and automatically default to the reading screen.
- The operator must refer to the VW Calibration Record sheet for the VWSG-E(M) Strain Gauge sensor which is to be read in order to determine correct sweep frequency to use to obtain a correct reading. The sweep frequency for the VW2106 VW readout unit can be easily changed in the field. Refer to the VW2106 VW Readout Unit Instruction Manual (ELM0042H) which provides instructions on how to change the sweep frequency settings.
- The VW B-unit reading (f^2x10^{-3}) will appear at the top or the screen, along with the temperature ($^oC/^oF$) at the bottom of the screen.
- Record the reading and move onto the next instrument, connecting the VW sensor wire to the terminal strip quick-connects, in the same manner.
- If required, the operator can listen to the plucking of the VW coil by simultaneously pressing the up/down arrows for several seconds. A speaker icon will appear on the display. This will verify if the VW coil is functional and is being plucked.
- Manual readings on sensors which contain multiple gauges (i.e. load cells) are performed by connecting the instrument to the *Expansion* port with the appropriate connector. For details on this function, refer to the VW2106 VW Readout Instruction Manual (ELM0042H).
- To conserve power, the VW2106 Readout unit will automatically turn itself off after approximately 5 minutes, if there is no input provided at the user interface.

Refer to the below table indicating the various sweep frequencies provided by the RST VW2106 VW Readout Box for reading VW sensors.

Note the following Sweep Frequencies used for reading Strain Gauge instruments:

C Sweep – Used for Arc Weldable Strain Gauges

D Sweep – Used for Embedment Strain Gauges

E Sweep - Used for Spot Weldable Strain Gauges

A Sweep	450-6000Hz	Wide Sweep
B Sweep	1200-3550Hz	Piezometer, Strain Gauge, Borehole Stressmeter, Jointmeter, Crackmeter, Displacement, Settlement, Temperature, Load Cells
C Sweep	450-1200Hz	Strain Gauge (Arc Weldable)
D Sweep	450-1200Hz	Strain Gauge (Embedment)
E Sweep	1000-3600Hz	Strain Gauge (Spot Weldable)
F Sweep	2500-6000Hz	Borehole Stressmeter
U Sweep	1200-3550Hz	User Specified Frequency

6.4 INITIAL READINGS

Subsequent Strain Gauge readings will always be referenced to some initial or inferred zero strain reading. Normally, the initial reading should be taken when the structure is in an unloaded or unstressed state.

For example, in the case of driven piles, the initial readings may not take place until sometime well after the pile installation, but just before additional loading is added. Extreme care must be taken with the establishment of the initial reading set, not only to ensure that the readings are valid, but also to ensure that the details of the load state are clearly known and recorded at that time. Care must be taken to ensure that ostensibly unloaded structures are not being influenced by the ambient temperatures, bending moments within the structure or other physical stresses at the time that the initial readings are being taken.

To understand how the ambient temperatures may be effecting the base strain readings, it is always good practice to take a set of readings late in the afternoon, immediately following the heat of day, and another set in the early morning, before sunrise.

If these issues are not understood and taken into account by the initial readings, it will be impossible to properly evaluate or interpret the later loaded results.

7 DATA INTERPRETATION VWSG-A(M) – (ARC WELDABLE TYPE)

7.1 CONVERSION OF B UNIT READINGS TO THEORETICAL MICROSTRAIN

The VW2106 Vibrating Wire Readout unit provides B Unit readings which are related to the resonant vibration frequency of the Vibrating Wire sensor. This relationship to reading frequency is provided in the following equation.

$$B\ Unit = \left(f^2 x 10^{-3}\right)$$

Equation 1 – Vibration Frequency to B Unit Relationship

Conversion of the B Unit reading to theoretical microstrain is carried out using a Vibrating Wire Calibration Factor (CF_T), as show in the below equation. For each type and design of Vibrating Wire Strain Gauge, a theoretical CF_T is established based on the design of the instrument, which includes the vibrating wire type used and the length of the installed wire. This theoretical initial CF_T is called the Theoretical Gauge Factor for that instrument type and is applied to all VWSG instruments manufacture using the same design.

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

$$\mu\varepsilon = \mathrm{CF_T}\left(B \ \mathrm{Unit}\right)$$

Equation 2 – Theoretical Microstrain

Where; $\mu\varepsilon$ - microstrain units – Theoretical

- Where one microstrain is the strain which will produce a deformation of one part per million

CF_T - Strain Gauge Calibration Factor – Theoretical for the sensor design

- Equals 4.062 $\mu\varepsilon$ / B Unit

f - Resonant frequency of the Vibrating Wire

However, in practice the actual physical properties of the Vibrating Wire used and the manufacturing process, which effectively slightly shortens the free strain length of the Vibrating Wire, will cause the instrument to slightly over register an applied strain. This manufacturing effect is removed by carrying out batch calibrations of completed VWSG instruments and establishing a Batch Calibration Factor. For the sensors used for RST Vibrating Wire Strain Gauges the Batch Calibration Factor is typically around 0.943 +/- 0.010 (0.933 to 0.953).

$$CF = \mathrm{CF_T} \ \mathrm{x} \ \mathrm{BCF}$$

Equation 3 – Batch Calibration Factor Correction

Where; CF - Strain Gauge Calibration Factor - Corrected by the Batch Calibration Factor

- Where one microstrain is the strain which will produce a deformation of one part per million

CF_T - Strain Gauge Calibration Factor - Theoretical for the sensor design

- Equals 4.062 $\mu\varepsilon$ / B Unit

BCF - Batch Calibration Factor – From the Sensor Calibration Sheet

- Varies from batch to batch, but is generally around 0.943 +/- 0.010

- Subject to change, if the manufacturing process changes

The user must ensure that copies of the VW Calibration Record sheet are available for each installed VW Stain Gauge Sensor. Care must be taken to understand the Calibration Factors which are provided on the Calibration Sheet and the relationship which exists between the Theoretical Calibration Factor and the Batch Calibration Factor.

Example Calculation - Change in Strain

- For a Model VWSG-A(M) Arc Weldable Strain Gauge
- VW Readings taken using Sweep C at 450 to 1200 Hz

Initial B Unit Reading = 684 B Units — - Before load is applied - Frequency f = 827 Hz

Strain = 684 B Units x CF — - CF = 3.830 $\mu\varepsilon$ / B Unit

Strain = 684 B Units x 3.830 $\mu\varepsilon$ / B Unit = 2619.7 $\mu\varepsilon$

Final B Unit Reading = 724 B Units — - After load is applied - Frequency f = 851 Hz

Strain = 724 B Units x CF — - CF = 3.830 $\mu\varepsilon$ / B Unit

Strain = 724 B Units x 3.830 $\mu\varepsilon$ / B Unit = 2772.9 $\mu\varepsilon$

Net Strain Change:

Net B Unit Reading Change = + 40 B Units
Net Strain Change = B Unit Change x CF
Net Strain Change = + 40 B Units x 3.830 $\mu\varepsilon$ / B Unit = **+ 153.2** $\mu\varepsilon$

Net Strain Change = Initial Strain Reading – Final Strain Reading
= 2619.7 $\mu\varepsilon$ - 2772.9 $\mu\varepsilon$ = **+ 153.2** $\mu\varepsilon$

7.2 Conversion of Readings to Strain Changes

In reality, Vibrating Wire Strain Gauges are built registering an initial strain due to the manufacturing process, which fixes the Vibrating Wire at an initial tension. This initial strain setting is removed by carefully establishing base reading as part of the installation procedure and then comparing all subsequent readings, back to the original base reading. The True Strain is calculated by the following equation.

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

Equation 3 - True Strain Calculation

Where; R_0 is the initial strain reading - $\mu\varepsilon$

R_1 is a subsequent strain reading - $\mu\varepsilon$

Note: When ($R_1 - R_0$) is positive; The strain is tensile

When ($R_1 - R_0$) is negative; The strain is compressive

7.3 Strain Resolution

The VW2106 Vibrating Wire Readout unit provides B Unit readings with a resolution of 0.1 B Units. Using Equation 2, the resolution of the microstrain measurements can be calculated as follows:

$$\mu\varepsilon = CF\left(B \text{ Unit}\right)$$

$$\mu\varepsilon = CF\left(0.1\right)$$ - Strain Reading Resolution

Equation 4 - Microstrain Resolution

Where; $\mu\varepsilon$ is microstrain

CF is the Strain Gauge Calibration Factor ($\mu\varepsilon$ / B Unit)

7.4 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 7. 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 5 - 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 6 - 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 7 - Stress due to bending on Axis xx

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

Equation 8 - 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.

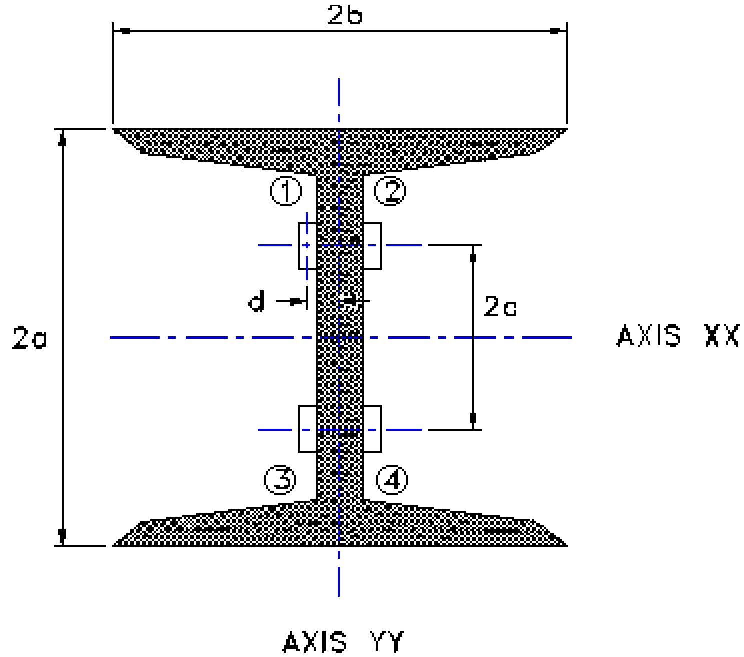

Figure 7 - Strain Gauges Mounted on Central Web. Axial Strain and Bending Moments about both XX and YY Axes

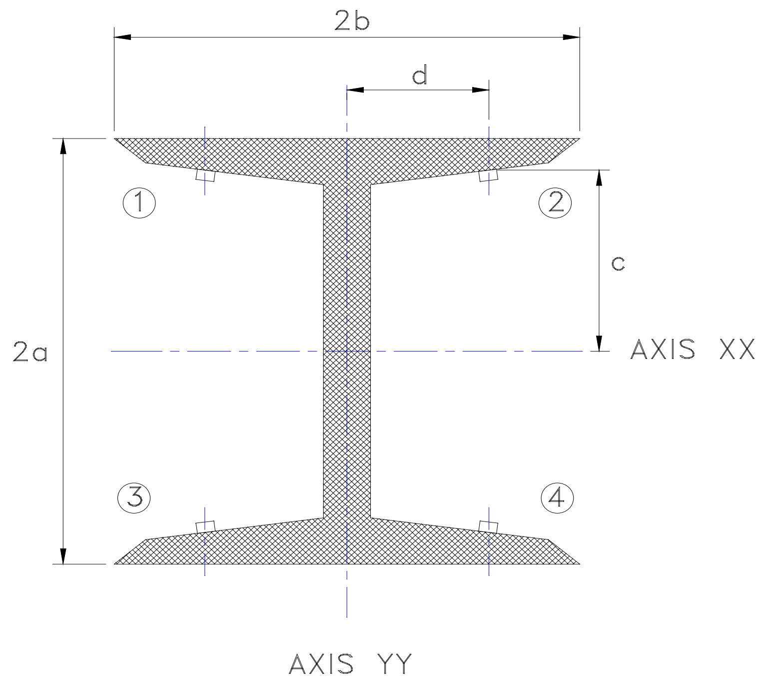

Figure 8 - Strain Gauges Mounted on Flanges (Not Recommended)

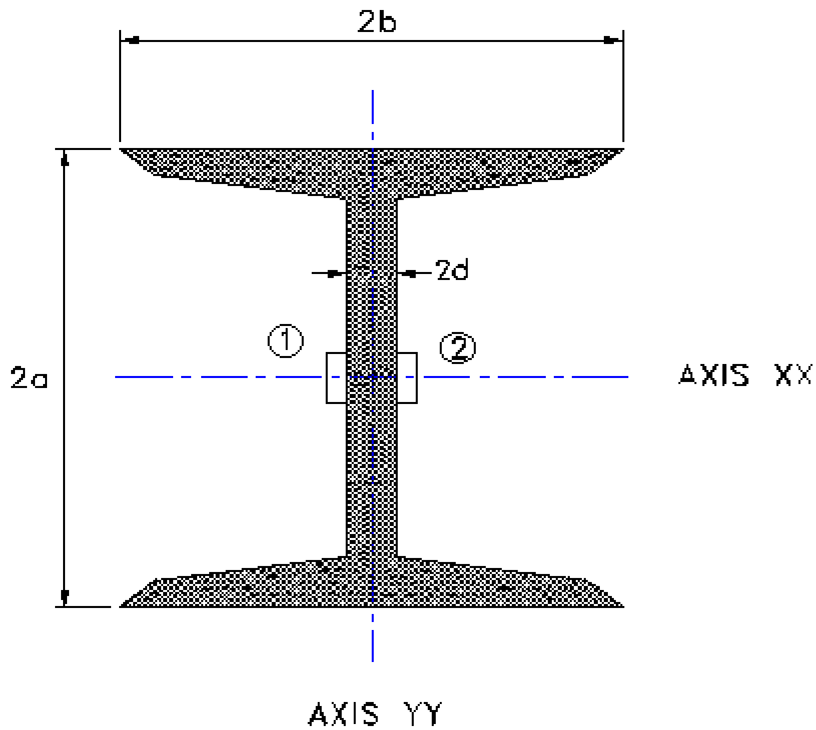

Figure 9 - Axial Strain Measurement and Bending Moment about YY axis only

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

This configuration has the advantage of positioning the Strain 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.

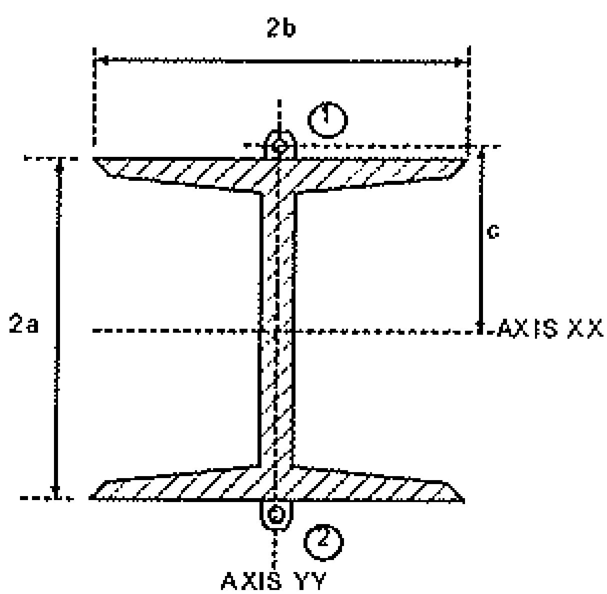

Figure 10 - Axial Strain and Bending Moments about XX axis only

Another alternative Strain Gauge configuration, using only 2 Strain Gauges, is shown in Figure 10. This configuration allows the calculation of the axial strains and the bending moment around the major XX Axis only. 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.

7.5 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 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 B.

7.6 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 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.

7.7 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.

8 DATA INTERPRETATION VWSG-E(M) – (CONCRETE EMBEDMENT TYPE)

8.1 CONVERSION OF B UNIT READINGS TO THEORETICAL MICROSTRAIN

Refer to Section 7.2 for VWSG-A(M) Strain Gauges.

8.2 CONVERSION OF READINGS TO STRAIN CHANGES

Refer to Section 7.2 for VWSG-A(M) Strain Gauges.

Noted that the True Strain may need correction for temperature changes. Refer to Section 8.3.

8.3 TEMPERATURE CORRECTIONS

Temperature variations of considerable magnitude are not uncommon in concrete, particularly during the curing period with may take up to several weeks, or longer. Therefore, it is always advisable to measure and record temperature along with every Strain Gauge measurement. Temperature induced expansions and contractions can give rise to real changes of stress within mass concrete. If the concrete is restrained or anchored in any way, the related stresses will be superimposed on any stresses due to temperature. This makes the analysis and interpretation of stresses in concrete structures very complicated and difficult to ascertain with certainty.

Temperature can also affect the Strain Gauge function and accuracy, since increasing temperatures will cause the vibrating wire to elongate slightly and thus provide a lower frequency reading than the external stress field may actually be exerting on the VWSG instrument. This would give a false indication that the concrete is undergoing compressive strain. The coefficient of expansion of the Vibrating Wire Strain Gauge (C_1), which is for steel, is approximately 12.2 microstrain / ^oC.

The effect of the Vibrating Wire within the Strain Gauge expanding due to higher ambient temperature would be offset to some degree by an expansion of the concrete in which the Strain Gauge is embedded or attached. If the concrete expanded by exactly the same amount as the Vibrating Wire, then the wire tension would remain constant and no correction would be necessary. However, the coefficient of expansion of concrete (C_2), is approximately 10.4 microstrain / ºC. This means that a correction for temperature is required which would be equal to:

$$\text{Temp Correction} = (T_1 - T_0) \times (C_1 - C_2)$$

Equation 9 – Correction for Temperature

And the true load related to the strain in the concrete is given by:

$$\mu_{true} = (R_1 - R_0)\,B + \left[(T_1 - T_0) \times (C_1 - C_2)\right]$$

Equation 10 – True Load Related Strain Calculation

Example Calculation:

T_0 = 20 ºC – Initial Temperature

T_1 = 30 ºC – Final Temperature

C_1 = Coefficient of Expansion for Strain Gauge Steel = 12.2 microstrain / ºC

C_2 = Coefficient of Expansion for Concrete = 10.4 microstrain / ºC

R_0 = 3000 – Initial Strain – microstrain

R_1 = 2900 - Final Strain - microstrain

F_0 = 4.062 – CF_T – Strain Gauge Calibration Factor – Initial Theoretical - microstrain / B Unit

F_1 = 3.830 – CF – Strain Gauge Calibration Factor – Corrected by calibration - microstrain / B Unit

B = 0.943 - BCF – Batch Calibration Factor = F_1 / F_0 = 3.830 / 4.062

Example Using Equation 10:

Apparent Strain =

$(2900\ \mu\varepsilon\ -\ 3000\ \mu\varepsilon)\ \times\ 0.838\ =$

$-100\ \mu\varepsilon\ \times\ 0.838\ =\ -83.8\ \mu\varepsilon$ (compression)

Temperature Related Strain =

$(30\ ^{o}C\ -\ 20\ ^{o}C)\ \times\ (12.2\ \mu\varepsilon / ^{o}C\ -\ 10.4\ \mu\varepsilon / ^{o}C) =$

$10\ ^{o}C\ \times\ 1.8\ \mu\varepsilon / ^{o}C\ =\ 18.0\ \mu\varepsilon$ (tension)

True Load Related Strain = $-83.8\ \mu\varepsilon\ +\ 18.0\ \mu\varepsilon\ =\ -65.8\ \mu\varepsilon$ (compression)

8.4 SHRINKAGE EFFECTS

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

This physical property of concrete makes it very difficult to determine the internal strains, if random wetting and drying cycles are occurring. To compensate for these unwanted strains, an attempt can be made to keep the concrete at relatively constant water content. However, at most sites, this is frequently impossible to do, as most concrete structures are large and are exposed to varying weather conditions.

In some cases, an attempt is made to measure the shrinkage and/or swelling effects due to water content by casting a Strain Gauge inside of a concrete test block, which remains unloaded, but is exposed to the same moisture conditions as the main concrete structure which is instrumented by active Strain Gauges. Strain changes measured by the VW Strain Gauge installed in the reference block, may be used as a correction to other Strain Gauge readings from the main concrete structure.

8.5 CREEP EFFECTS

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

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

8.6 EFFECT OF AUTOGENOUS CONCRETE GROWTH

In some old concretes, which have a particular combination of alkaline and silicate aggregates, and alkaline cements, an internal reaction may occur within the concrete mass which will cause very minor expansion over time, as the concrete undergoes subtle chemical changes and recrystallization. This slow reaction can result in minor expansion and cracking within the concrete mass which can present similar to a slow creep movement. In extreme cases, occurring over many years, the affected mass concrete may eventually breakdown and crumble completely, to some depth below the surface.

This type of internal chemical reaction proceeds very slowly and is therefore very difficult to account for when attempting to accurately measure small strains occurring within concrete structures.

9 TROUBLESHOOTING

1) No reading obtained from a VW Strain Gauge. Display shows “00000” on RST VW2106 VW readout:

   a) Strain Gauge red/black wires are disconnected or loose. Check the connections and ensure both wires are correctly connected and tight.

   b) Check the resistance between these two wires with a low voltage multi-meter. The resistance of the Strain Gauge should be about 135 Ohms. High or low resistance could indicate a damaged VW Strain Gauge sensor or connecting cable. Contact RST for further advice.

   c) Incorrect excitation sweep frequency is being used which will not produce a stable reading. Check the VW Calibration Record sheet for the installed VW sensor to determine the recommended sweep frequency for the sensor. Change the sweep frequency settings in the VW2106 Readout and re-take the reading.

   d) Check to ensure the VW2106 Readout is functional by taking a reading from another Strain Gauge.

2) Fluctuating readings from a VW Strain Gauge:

   a) Check the resistance between the red/black wires which should be nominally about 135 Ohms. Less than 135 Ohms could indicate water ingress into the cable joints or a short circuit. (Note that for VWSG-E(M) HT Strain Gauges, the output wires are both white.)

   b) Incorrect excitation sweep frequency used. Check sweep frequency recommended on the VW Calibration Record sheet.

   c) For VWSG-A(M): Was the Strain Gauge correctly tensioned as part of the installation?

   d) For VWSG-A(M) and VWSG-E(M): The Strain Gauges should be pre-installation tested on a solid surface, otherwise the entire gauge may oscillate, causing erroneous and unstable output values.

   e) Does the VW2106 Readout unit work with another Strain Gauge?

   f) Are the strain values provided by the Readout, outside of the specified range?

   g) Is there a source of electrical interference nearby? Noted that problems can be caused by the local presence of power generating equipment or DC to AC Current Inverters. Must move data acquisition and electronic readout equipment away from the source of potential interference, install filtering at the datalogger and connect drain wires to a good quality grounding.

Contact RST directly for additional help on troubleshooting issues, if required.

Appendix A - 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 11 - 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

Figure 11 - Thermistor Resistance versus Temperature