GEOKON

Instruction Manual

Model VK-4100/4150

Vibrating Wire Strain Gages

CE

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1. INTRODUCTION

The VK-4100 and VK-4150 Vibrating Wire Strain Gages are designed for measuring strains on structural steel members such as bridges, piles, tunnel linings, buildings, etc. The VK-4100 consists of a vibrating wire gage element and removable coil assembly. The VK-4150 consists of a vibrating wire gage element and integral coil assembly. (The VK4150-5 Model differs from the standard VK4150: in that it has a range of 10,000 microstrain (See Appendix J))
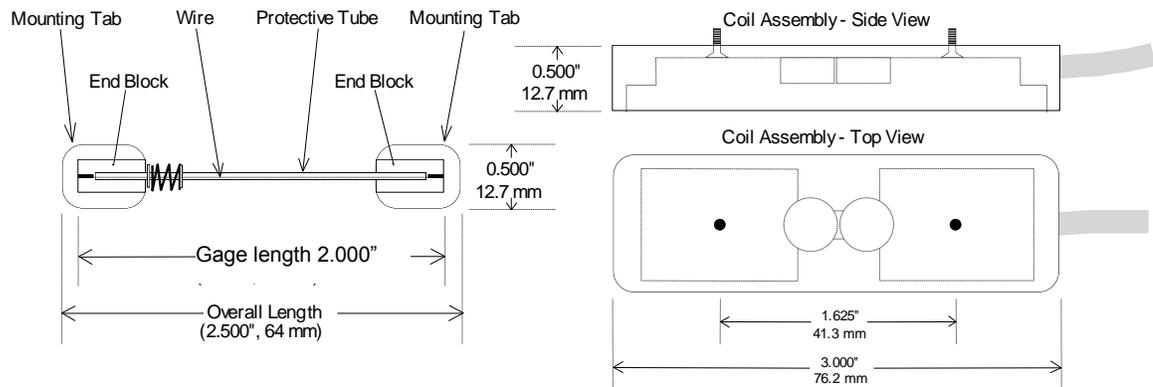
Figure 1 - VK-4100 Vibrating Wire Strain Gage and Coil Assembly
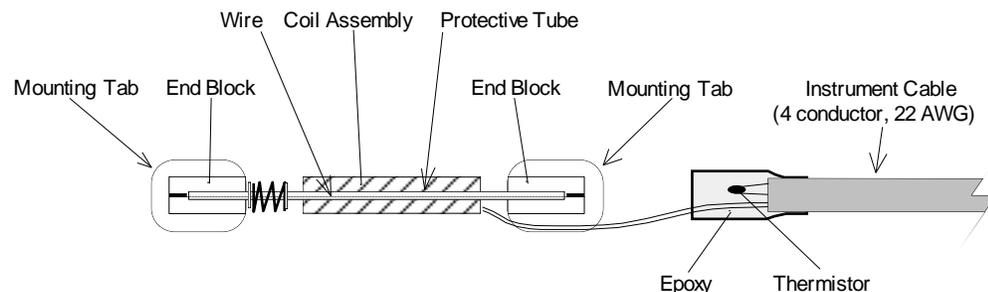
Figure 2 - VK-4150 Vibrating Wire Strain Gage

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

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 gage, 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 gage is also given along with some suggestions for data interpretation.

2. GAGE INSTALLATION

2.1. Preliminary Tests

The VK-4100 and VK-4150 Strain Gages are supplied fully sealed and tensioned. The VK-4100 has a detachable plucking coil while the VK-4150 contains an integral one. A preliminary gage reading is advisable and this is made by connecting the plucking coil wires (for the VK-4100 turn the coil assembly housing upside down and set the gage 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 gages are supplied with the wire tension set at mid-range (i.e. 2500 μstrain, $\pm$200) which gives approximately 1250 microstrain range in both tension and compression, suitable for most applications. See Appendix E if adjustment to the strain range is necessary. But note: **Under no circumstances should the procedures described in Appendix E be used after the gage has been welded down.** If the gage is required to read large tensile strains then set the reading between 1500 and 2000 microstrains, if the gage is to read large compressive strains set the initial reading to between 2500 and 3000 microstrains.
 Light pressure on the gage ends should make microstrain readings decrease. Pull on the gage element ends to increase the displayed reading. Do not pull too hard (> 10 lbs., 4.5 kg) on the ends of the gage or the wire may break!

Check the resistance between the two vibrating wire gage lead wires (usually red and black wires). Nominal coil assembly resistance for the VK-4100 is 180Ω, $\pm$10Ω, for the VK-4150, 50Ω, $\pm$10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). 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.

2.2. Installation of Strain Gages by Spot Welding

 (USE SAFETY GLASSES!)

The following tools and accessories are needed to install the VK-4100 or VK4150 onto steel by spot welding;
- Power grinder or sander, files, wire brush, sandpaper, de-greaser.
- Test mounting strips.
- Spot welder and hand probe.
- Cyanoacrylate adhesive.
- A spray can of Self Etching Primer and spray paint. (Available at auto stores)
- Stainless steel shim stock for the collar shim, (supplied).
- Shim stock for securing the gage cable (VK-4150), (supplied).
- Cable ties, wire ties, and/or duct tape (quantity as required).
- Masking tape.

Note the following instructions.

2.2.1   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.

2.2.2 ***Spot Weld Test Strips*** - Before welding the gage 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 VK-4100 or VK4150 strain gages to structural steel. Using the test material supplied with the gages run a series of tests to determine the correct weld energy. Then perform a peel test as shown in the figure below.
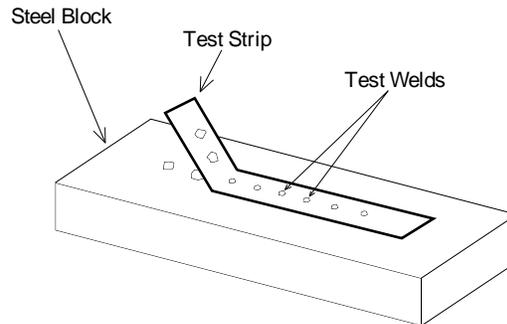
Figure 3 - Peel Test

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.

2.2.3 Spot welding the gages

Spot weld one end of the gage using the weld pattern and the sequence shown in Fig 4.
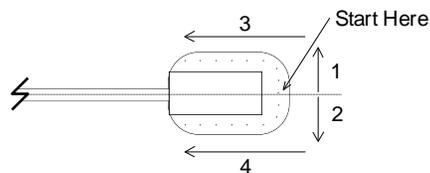
Figure 4 - Spot Welding Sequence - Outer Rows

If spot welding the VK-4150, start with the end where the cable comes out. Carefully move the lead wires out of the way. Start in the middle of the back row of dots marked on the mounting tab, complete the back row, working in a direction away from the center. Place a weld point at each of the marked dots down the sides of the block.
Now add another row of welds on both sides of the gage block as close to gage block as possible and between the welds of the previous rows. As shown in Figure 5.
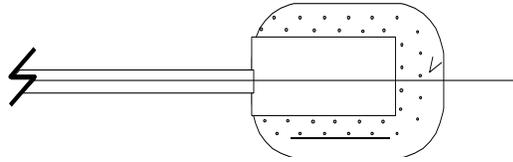
Figure 5 - Spot Welding Sequence – Inner Rows

When all the dots on the flange have been welded, proceed to weld the other end as follows: Place the alignment tool over the two ends of the gage as shown in figure 6 below. This will make sure that the two ends of the gage are in a straight line.
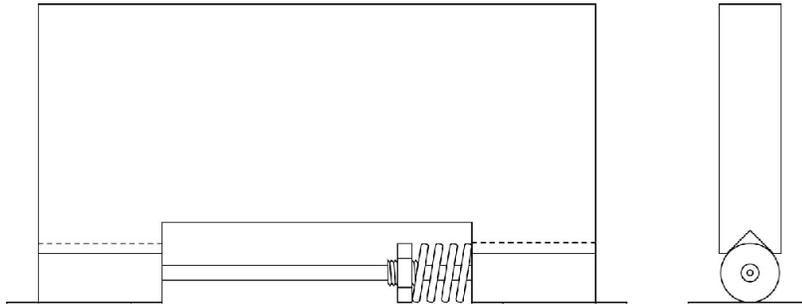
Figure 6 Using the Alignment Tool.

With this jig held in place, spot-weld a preliminary spot, in the center of the second tab but outside the back row and close to the edge of the tab. When this spot has been welded, connect the gage to the readout box and check the reading. If the reading is within the acceptable range then proceed to spot weld two more welds along the back line then remove the alignment tool and weld the rest of the tab following the same pattern and sequence as before. If the reading is not acceptable then the spot can be undone by using a sharp razor blade pried under the tab at a point 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 sandpaper. 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 gage is used on curved surfaces it is recommended that a third row of welds be made on the periphery of the mounting tab (between the stenciled row and edge).

2.2.4 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. Now weld the small end of the collar shim L down onto the tab using

three welds all position as close to the corner as possible. Now add another three welds at the outer edge of the collar shim.
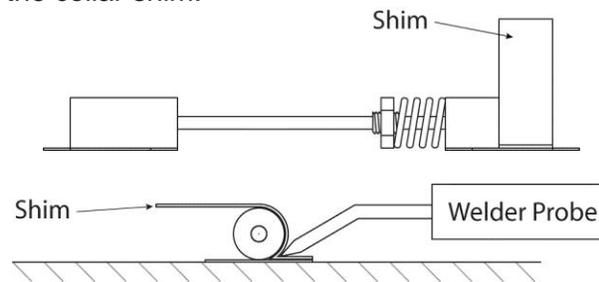
Figure 7 Welding the Collar Shim in Place.

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.

Figure 8 The Completed Collar Shim.

Repeat the process on the other end block. When both ends of the gage have been spot welded in this way, take a small screwdriver and lightly tap both end blocks with the handle of the screwdriver at points over the flanges only.
 The purpose of the tapping is to relieve any local stresses induced by the welding procedure.

After tapping four or five times on each end block read the gage again. Continue the tapping procedure until the readings settle down and do not change more than a few digits.

2.2.5   Secure the Gage Cable - For the VK-4150

Use the shim stock provided, spot-weld the cable-to-lead-wire junction firmly to the steel substrate. Be sure to leave some slack in the lead-wires. Use the second shim stock spot weld the cable to the steel approximately 1" (25 mm) behind the lead-wire junction.

2.3   Corrosion Protection

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

1.   Apply several drops of cyano-acrylate adhesive to the edge of all the spot-welded mounting tabs. The glue will wick into the gap between the mounting tabs 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 the Model 4100 or the cover plate of the Model 4150.

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. 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 gage tube. Be careful to spray beneath the coil housing on the 4150 gage. Don't worry if the primer also coats the gage

3.   Spray a coat of paint over the primed areas. (Available from any auto parts store)

2.4 Install the Plucking Coil Housing (for the VK-4100)

Remove the masking taped areas and place the plucking coil housing over the gage. Connect the gage to the readout box and move the housing until a steady reading is obtained. In this position, use the spot welder to weld the tabs holding the coild housing to the substrate. The tabs and surrounding bare metal should be protected from corrosion as before.

2.5   Installing the cover of the model 4150 gage

The VK-4150 is provided with a semi-cylindrical metal cover, which can be spot-welded in place over the gage and will be adequate in most cases. (Figure 9). Waterproof the spot welding tabs as before.

Figure 9 - Spot welded cover plate

2.6 Additional Gage and Lead Wire Protection

The cover of the VK-4100 coil housing provides a measure of protection for the strain gage, and this may be adequate in most cases.
In extreme environments and/or where long term performance is required gage and lead wires may require additional protection from corrosion and mechanical damage.

2.6.1 Additional protection from mechanical damage

Gages can be further protected by cover plates manufactured from angle iron, (2 ½ inch minimum) or channel iron, (4" x 1 ½ inch), bolted over the top of the gage. A typical system for the 4100 gage is shown in Figure 10.
  Studs may be welded directly onto the surface using an automatic stud welder, or hex head bolts can be arc-welded head down. In this latter case, a special cover plate bolt, welding jig is available 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 gage, 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 gage as this will cause large local distortions of the metal.
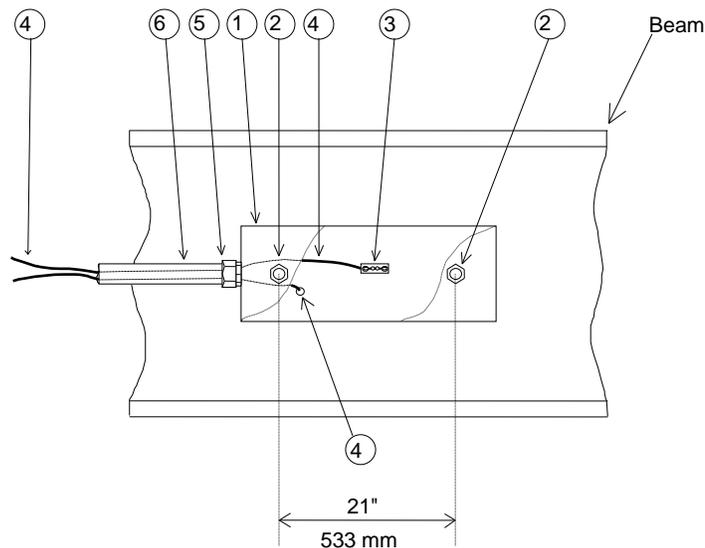
Key	Description	Manufacturer	Part Number
	VK-4100 Strain Gage (under coil)	Geokon	4100-2
1	Cover Channel (L×W×H) 21 × 4 × 1 1/2", 533 × 101 × 37mm	Geokon	4100-7
2	Bolt ½-13 × 3"		
3	Strain Gage Plucking Coil	Geokon	4100-3
4	Gage Cables, 4 conductor shielded, PVC jacket	Geokon	2-187V3
5	Conduit Connector	T&B	5231
6	Flex Conduit	SealTite	3/8"

Figure 10 – Channel Iron Cover Plate

2.6.2 Additional protection from corrosion.

In severe environments and for long term protection, The space between the coil housing and the Model 4100 gage and the space between the cover plate and the model 4150 gage can be filled with a stiff grease (e.g. axle grease). For further protection the entire assembly – gage, coil housing or cover plate can be covered by a layer of insulating mastic. (e.g. Plymouth 10 Plyseal which comes in a roll 3 ¾" x 1/8" x 10ft. (Available from Geokon.)).

2.6.3 Protection from Sunlight.

The thermal coefficient of expansion of the steel vibrating wire is the same as that for the steel of the structure to which the gage is attached, and as a result no temperature correction to the measured strain is required when calculating load induced strains. 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 gage, then this could elevate the temperature of the wire above the surrounding steel and cause large changes in apparent strain. Therefore, **always shield strain gages from direct sunlight** by covering the gage with insulation material such as Styrofoam or fiberglass.

3. CABLES AND CONNECTORS

3.1. Protection from Mechanical Damage

Cables should be adequately restrained so that there is no danger of the coil housing being ripped off (VK-4100) or the lead wires torn out (VK-4150) by tugging on the cable. Cables may be tagged down using pieces of 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 gage 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 10). The readout enclosure has a gasketed lid that can be removed to read the gages. In this way, the ends of the lead wires and/or plugs are kept clean and dry. A manual switch type terminal box , (Model 4911-16VTS), may be incorporated if many strain gages are to be read out from the same location: the face panel has built-in connectors or posts to connect to the patch cord of readout box and a manual rotary switch or switches to rapidly connect to the various gages.

Cables may be spliced to lengthen them, without affecting gage 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 Geokon..

3.2. Protection from 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 the factory for shielding and filtering options available for use with the VK-4100 and VK-4150 strain gages.

3.3. Lightning Protection

The VK-4100 and VK-4150 Vibrating Wire Strain Gages, unlike numerous other types of instrumentation available from Geokon, do not have any integral lightning protection components, i.e. transorbs or plasma surge arrestors.
Here are a few suggestions:

- If the gage is connected to a terminal box or multiplexer components such as plasma surge arrestors (spark gaps) may be installed in the terminal box/multiplexer to provide a measure of transient protection. Terminal boxes and multiplexers available from Geokon provide locations for installation of these components.

- Lighting arrestor boards and enclosures are available from Geokon that install at the exit point of the instrument cable from the structure being monitored. The enclosure has a removable top so, in the event the protection board (LAB-3) is damaged, the user may service the components (or replace the board). A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the gage. See Figure 11. Consult the factory for additional information on these or alternate lightning protection schemes.
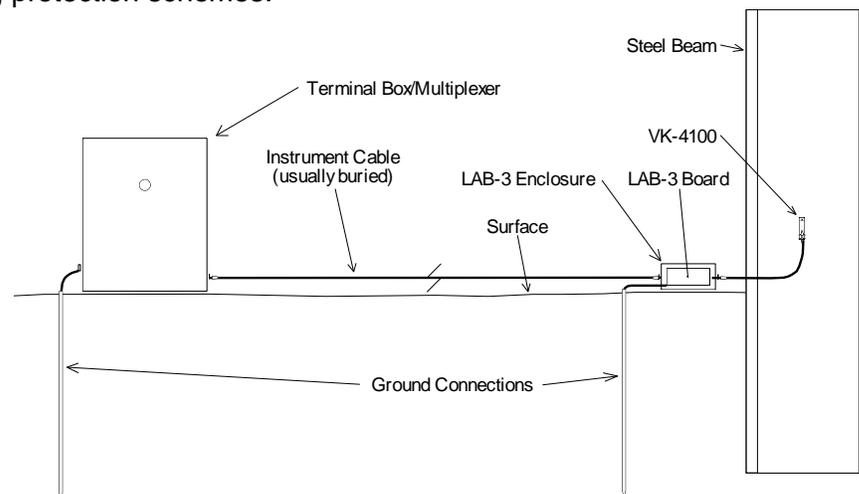

Figure 11 - Lightning Protection Scheme

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

4. TAKING READINGS

The following three sections describe how to take readings using any one of the readouts available from Geokon.

Model:	VK-4100	VK-4150	VK-4150-5
Readout Position:	E	E	E
Display Units:	microstrain ($\mu\epsilon$)	microstrain ($\mu\epsilon$)	Digits
Frequency Range:	1400-3500 Hz	1400-3500 Hz	1400-3500 Hz
Mid-Range Reading:	2500 $\mu\epsilon$	2500 $\mu\epsilon$	6000
Minimum Reading:	1000 $\mu\epsilon$	1000 $\mu\epsilon$	2500
Maximum Reading:	4000 $\mu\epsilon$	4000 $\mu\epsilon$	10,000

Table 1 - Strain Gage Readout Positions

Note: When reading the VK-4150 the reading may continue to change slightly due to a coil heating effect. Record the reading in the first few seconds.

4.1. Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The GK-403 reads out the thermistor temperature directly in degrees C.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green leads are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "E".

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Press the "Store" button to record the value displayed. If the no reading displays or the reading is unstable see section 5 for troubleshooting suggestions. The thermistor will be read and displayed on the screen above the gage reading in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

4.2 Operation of the GK404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.

The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire (blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **E** and the MODE button to select **µE**
Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.

The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

4.3 Operation of the GK405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components:

- the Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application
- the GK-405 Remote Module which is housed in a weather-proof enclosure and connects to the vibrating wire sensor by means of:
1) Flying leads with alligator type clips when the sensor cable terminates in bare wires or,
2) by means of a 10 pin connector..

The two components communicate wirelessly using Bluetooth®, a reliable digital communications protocol. The Readout Unit can operate from the cradle of the Remote Module (see Figure 12) or, if more convenient, can be removed and operated up to 20 meters from the Remote Module

Figure12 GK405 Readout Unit

For further details consult the GK405 Instruction Manual.

5. MEASURING TEMPERATURES

All Vibrating Wire Strain Gages are equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor. The GK-403 and GK-404 readout boxes will read the thermistor automatically and display the temperature in °C.

The relationship between temperature and resistance is shown in Table C-1 of Appendix C. The temperature can also be calculated using Equation C-1.

6. DATA INTERPRETATION

Readings on Channel E of either the GK-403 or GK-404 Readout Box are displayed directly in microstrain based on the theoretical equation:

$$\mu\varepsilon_{theory} \ = \ 0.391 \ (f^2 \times 10^{-3})$$

Equation 1 - Theoretical Microstrain

Where $\mu\varepsilon$ is the strain in the wire in microstrain and, f, is the resonant frequency of the vibrating wire.

6.1. Initial Readings

All readings are referred to an initial reading, so it is important that this initial reading be carefully taken. It is preferable to install gages on steel members that 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.

6.2. Conversion of the Readings to Strain Changes

In practice the method of clamping the wire has the effect of shortening it slightly causing the gage to over-register the strain. This effect is removed by applying a batch gage factor (B) supplied with each gage.

$$\text{The apparent strain, } \mu\varepsilon_{apparent} = \ (R_1 - R_0)B$$

Equation 2 – Apparent 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.

6.3. Converting Strains to Stresses

Whereas strain gages 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.

Stresses are computed by multiplying the measured strain by the Young's Modulus for steel, which varies between 190 to 206 Gpa, (28 to 30 x 10^6 psi). Loads are computed by multiplying the stress by the cross-sectional area of the steel member.

Strain changes with time are computed from strain gage 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 gages should be mounted while the member is still in the steel yard or warehouse.

 Temperatures should be recorded at the time of each reading along with notes concerning the construction activity that is taking place. This data might supply logical reasons for observed changes in the readings. For temperature correction factors when used on concrete, see Appendix D.

6.4. Bending Effects

In the case of a steel structure, a strain gage 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 only occur near the center of long thin members subjected to purely 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 gage is required at each cross section of the structural member,** and for a complete analysis at least three gages are required and very often more. On a **circular pipe strut three gages spaced 120$^\mathbf{O}$** apart around the periphery of the strut would suffice (four would be preferable).**(See Appendix G for analysis)** On an H pile or I beam at least four strain gages would be called for, and on sheet piling two gages 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 gages at different distances from the neutral axis).

Consider the example of an I beam shown in Figure 12A. Four strain gages (1, 2, 3 and 4) are welded in two pairs back to back on the central web. The gages 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 gages and multiplying by the modulus.

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

Equation 3 - Axial Stress Calculation

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

$$\sigma_{yy} = \frac{\left(\varepsilon_1 + \varepsilon_3\right) - \left(\varepsilon_2 + \varepsilon_4\right)}{2} \times \frac{b}{d} \times E$$

Equation 4 - Stress due to bending on Axis yy

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

$$\sigma_{xx} = \frac{\left(\varepsilon_1 + \varepsilon_2\right) - \left(\varepsilon_3 + \varepsilon_4\right)}{2} \times \frac{a}{c} \times E$$

Equation 5 - Stress due to bending on Axis xx

$$\sigma_{maximum} = \sigma_{axial} + \sigma_{xx} + \sigma_{yy}$$

Equation 6 - Maximum Stress

In all of the above calculations pay strict regard to the sign of the strain change. A positive change is tensile and a negative change is compressive.

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 <u>strains in the outer corners of the flange can be a lot higher than the strains measured on the web</u> and that failure of the section can be initiated at these points, hence the importance of analyzing the bending moments.
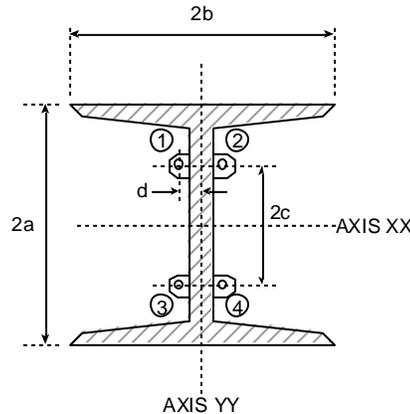
<u>Figure 13A - Strain Gages Mounted on Central Web Axial Strain and Bending Moments about both XX and YY Axes (Recommended)</u>

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 gages would be on the outer corners of the flanges as shown in Figure 13B. The disadvantage of having the gages located here lies in the difficulty of protecting the gages and cables from accidental damage. **But a much more serious problem arises from the fact that each of the 4 gages can be subjected to localized bending forces which affect only that one gage, but not the others**. Such as might happen if the flanges are impacted by wooden lagging or blocking; or if there is welding on one of the flanges. Or if cross-bracing is welded to only part of the flange
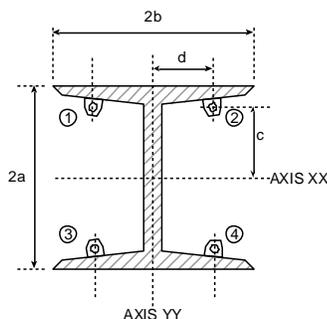
<u>Figure 13B - Strain Gages Mounted on Flanges (Recommended only for axially loaded beams in pure bending).</u>

This is why, for an accurate analysis of the stresses acting in the beam, it is always necessary to locate gages in pairs, one on either side of the neutral axis of the part of the I beam to which the gage is attached. Also it is necessary to locate the gages at least four

beam heights away from any end effects, and from any other object that applies a force to the beam. This is why the configuration of Figure 13A is preferable. There is the added advantage that gages located on the web as shown in Figure 13A are much easier to protect.

If, for reasons of economy, it is decided that only two strain gages per cross-section are to be used, then the configuration of figure **13Ca** is sometimes used but will give the axial strains and the bending moment around the minor YY axis only. Gages in **13Cb** will give some measure of bending around the major XX axis but will also be affected by bending in the YY axis.
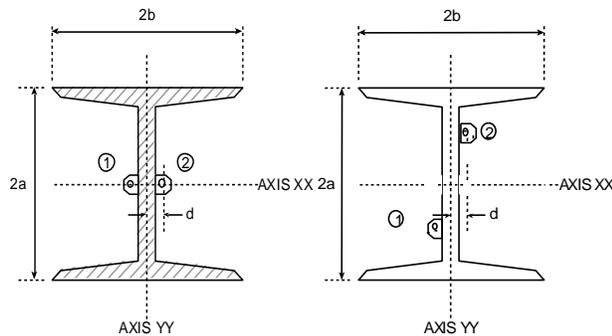
Figure 13Ca (Recommended)   **Figure 13Cb**

Figure 13Ca - Axial Strain Measurement and Bending Moment about YY axis only.

This configuration has the advantage of positioning the gages and cables where they are easy to protect. In fact, using the **12Ca** configuration, the cable from one gage can be passed through a hole drilled in the web, so that, the two cables can be protected easily by a single conduit. Configuration **12Cb** suffers from the possibility that local warping and distortions producing bending at one gage may not be sensed by the other gage.

Another configuration of 2 gages that has been used with some success is shown in fig. **13D**.
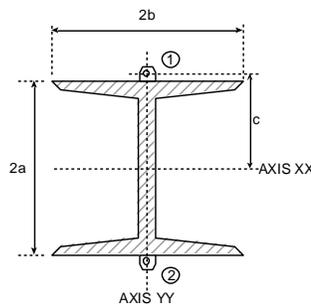

Figure 13D - Axial Strain and Bending Moments about XX axis only

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 gages on the outside of the flanges which will require a greater degree of protection for the gages and cables.

6.5. 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 gage is attached, and as a result **no temperature correction to the measured strain is required when calculating load induced strains on steel.** 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 gage, then this could elevate the temperature of the wire above the surrounding steel and cause large changes in apparent strain. Therefore, **always shield strain gages from direct sunlight**. Also, avoid excessive handling of the gage prior to reading. Either a) take the reading quickly or b) allow sufficient time for the gage 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 stress changes, caused by temperature changes, can be assessed. (For further details on this topic see Appendix D and F). In order to facilitate the measurement of temperature, each strain gage has a thermistor encapsulated along with the plucking coil. The thermistor is read out on the green and white conductors using an ohmmeter or any of the Geokon Readout Boxes. If an ohmmeter is used the relationship between resistance (ohms) and temperature is shown in Appendix C. If the strain gages are bonded to concrete see Appendix D.

6.6. Welding Effects

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

6.7. End Effects

If end effects are to be avoided then strain gages 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.

7. TROUBLESHOOTING

Maintenance and troubleshooting of these strain gages are confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gages are usually inaccessible and remedial action is limited.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Strain Gage Readings are Unstable

✓ Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct?

✓ Is the strain readings outside the specified range (either compressive or tensile) of the instrument? Gage 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 gage? If not, the readout may have a low battery or be malfunctioning.

✓ Does the coil assembly work on another gage? If not, the coil assembly may be defective.

Symptom: Strain Gage Fails to Read

✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads for the VK-4100 (usually red and black leads) is 180Ω, $\pm10\Omega$ for the VK-4150, 50Ω, $\pm10\Omega$. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately $14.7\Omega/1000'$ or $48.5\Omega/km$, 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 ($<100\Omega$ for the VK-4100, $<25\Omega$ for the VK-4150) a short in the cable is likely. Splicing kits and instructions are available from the factory to repair broken or shorted cables. Consult the factory for additional information.

✓ Does the readout or datalogger work with another strain gage? If not, the readout or datalogger may be malfunctioning.

✓ Does the coil assembly work on another gage? If not, the coil assembly may be defective.

APPENDIX A - SPECIFICATIONS

A.1 Strain Gage

Model:	VK-4100	VK-4150	VK4150-5
Range (nominal):	3000 µε		10,000 µε
Resolution:	0.4 µε[1]		1.3 µε
Calibration Accuracy	0.1%FS		0.1%FS
System Accuracy:	2.0% FS[2]		2.0% FS[3]
Stability:	0.1%FS/yr		0.1%FS/yr
Linearity:	+/-2.0% FSR		+/-7.5% FSR
Thermal Coefficient:	12.2 µε/°C		See Appendix J
Frequency Range:	1400 – 3500 Hz		1400 – 3500 Hz
Dimensions (gage): (Length × Diameter)	2.250 × 0.250" 57.2 × 6.4 mm		2.250 × 0.250" 57.2 × 6.4 mm
Dimensions (coil): (L×W×H)	3.000 × 0.875 × 0.500" 76.2 × 22.2 × 12.7 mm	0.750 × 0.250" (diameter) 19.1 × 6.4 mm (diameter)	0.750 × 0.250" (diameter) 19.1 × 6.4 mm (diameter
Coil Resistance:	180 Ω	50 Ω	50 Ω
Temperature Range:	-20 to +80° C		-20 to +80° C

Notes:
[1] Depends on the readout, above figure pertains to the GK-403 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 gage.
[3] Using the polynomial equation

A.2 Thermistor (see Appendix C also)

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.:

$$F = \varepsilon_w E a$$

Where;
ε_W is the wire strain (in./in.).
E is the Young's Modulus of the wire (30 x 10^6 Psi).

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 gage 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.
Lg is the gage length (in inches).

11. Combining equations 9 and 10 gives:

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

Where; (for the VK-4100 or VK-4150 Strain Gage)
L_w is 2.000 inches.
Lg is 2.000 inches.

12. Therefore: $\varepsilon = 0.391 \times 10^3 \left[\dfrac{1}{T^2}\right]$

(Note that T is in seconds x 10^6 and ε is in inches per inch)

13. The display on position "E" of the GK-401/403 Readout is based on the equation:

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

Note 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 on Channel E is given in terms of microinches per inch (ε).

APPENDIX C - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation:

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

Equation C-1 Convert Thermistor Resistance to Temperature

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

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

Table C-1 Thermistor Resistance versus Temperature

APPENDIX D - TEMPERATURE CORRECTION WHEN USED ON CONCRETE

The steel used for the vibrating wire has a thermal coefficient of expansion, (CF_1), of +12.2 microstrain/°C. Therefore <u>the total, or true strain in the concrete,</u> corrected for thermal effects on the gage, is given by the following equation.

$$\mu\varepsilon_{total} = (R_1 - R_0)B + (T_1 - T_0)xCF_1$$
<u>Equation D-1 Total Concrete Strain Corrected for Gage Thermal Effects</u>

In the above equation $(R_1-R_0)B$ is the apparent stain and $\mu\varepsilon_{total}$ is the true strain or the actual strain, (i.e that which would be measured by a tape measure) 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:

$$\mu\varepsilon_{thermal} = (T_1 - T_0) \times CF_2$$
<u>Equation D-2 Thermal Concrete Strains</u>

In Equation D-2, CF_2 represents the coefficient of expansion of concrete. Unless this figure is known, assume a nominal value of +10.4 microstrain/°C.

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

$$\mu\varepsilon_{load} = \mu\varepsilon_{total} - \mu\varepsilon_{thermal} = (R_1 - R_0)B + (T_1 - T_0) \times (CF_1 - CF_2)$$
<u>Equation D-3 Strain Calculation due to Load Change</u>

Note the following example, where B = 0.91

R_0 = 3000 microstrain, T_0 = 20°C
R_1 = 2900 microstrain, T_1 = 30°C

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

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

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

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

Explanation:
The apparent compressive strain, indicated by the readout box after application of the batch factor, B, is $(R_1-R_0) \times B$ = –91microstrain, but, if the strain in the concrete had not changed the steel vibrating wire would have expanded and gone slack by the equivalent of (30-20) x 12.2 = -122 microstrain so the concrete must have actually expanded by +31 microstrain to account for the observed apparent strain. But, the concrete itself would have expanded by (30 – 20) x 10.4 = +104 microstrain on account of the temperature increase, so the fact that it didn't reach this value must mean that there has been a superimposed build up of compressive strain equal to 104-31 = -73 microstrain and this multiplied by the Young's Modulus will give the actual stress in the concrete caused by the imposed load change.

APPENDIX E - ADJUSTING THE GAGE WIRE TENSION

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

Gages 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 gage is required to read large tensile strains then set the reading between 1500 and 2000 microstrains, if the gage is to read large compressive strains set the initial reading to between 2500 and 3000 microstrains. Table E-1 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 Gage

Place the gage 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 gage by the tube (or, in the 4150, by the coil assembly) and turn the nut in a clockwise direction to tighten. A rotation of ½ turn will give a change of about 600 microstrain. The gage 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.
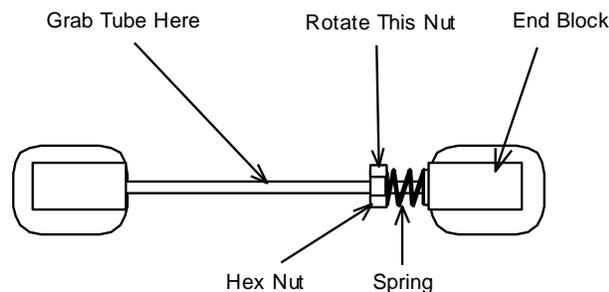
Figure E-1 - Tension Adjustment

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

Table E-1 - Guide to Initial Tension Settings

APPENDIX F - SEPARATION OF STRAINS INDUCED BY EXTERNAL LOADS AND STRAINS INDUCED BY TEMPERATURE CHANGES

If the ends of the structural member are free to expand or contract without restraint then strain changes can take place without any change in stress. And in these situations the strain gage would indeed show no change in reading. Conversely, 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 stress in the member. The magnitude of this temperature-induced stress increase will be measured accurately by the strain gage. (Because the structural member is restrained from expanding, but the vibrating wire is not restrained, and the expansion of the vibrating wire will cause a reduction in wire tension and a resulting decrease in the vibrational frequency. This will be indicated on the readout box as a decrease in strain readings, corresponding to an increase in compressive stress/strain, the magnitude of which is exactly equal to the temperature-induced increase in compressive stress/strain in the member.)

 The temperature-induced stresses can be separated from the stresses produced by external structural loading, by reading both the strain and temperature of the strain gages at frequent intervals over a period of time during 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 an empirical correction factor, CF_{emp}. microstrain /degree This empirical correction factor can be applied to the total strain and temperature data to remove the temperature-induced stresses leaving only those stresses produced by changing external loads, i.e.

Stress induced by external load only = [(R1-R0)B + (T1-T0) CF_{emp}]E

Note that the correction factor, CF_{emp} 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.

In a free field, where no loads are acting, and the steel is free to expand or contract without restraint, then R1 would equal R0 and the thermal strains in the steel are given by the following equation;

$$\mu\varepsilon_{thermal} = (T_1 - T_0) \times CF_1$$
Equation F-1 Free Field Thermal Strains

In Equation F-1, CF_1 represents the coefficient of expansion of steel = +12.2 microstrain/°C.

The total strain in the structural steel member, due to both changes of load and changes of temperature, is given by the following equation.

$$\mu\varepsilon_{total} = (R_1 - R_0)B + (T_1 - T_0)xCF_1$$
Equation F-2 Total Strain after Compensation for Thermal Effects on the Wire

Where the ends of the structural member are perfectly restrained then $(R_1-R_0)B$ the compressive strain induced by temperature change alone would be exactly cancelled by (T_1-T_0) x CF_1, the expansive strain and $\mu\varepsilon_{total}$ would be zero.

APPENDIX G - CALCULATION OF AXIAL LOADS AND BENDING STRAINS FROM THREE STRAIN GAGES, AT 60 DEGREES, ON A CIRCULAR PIPE
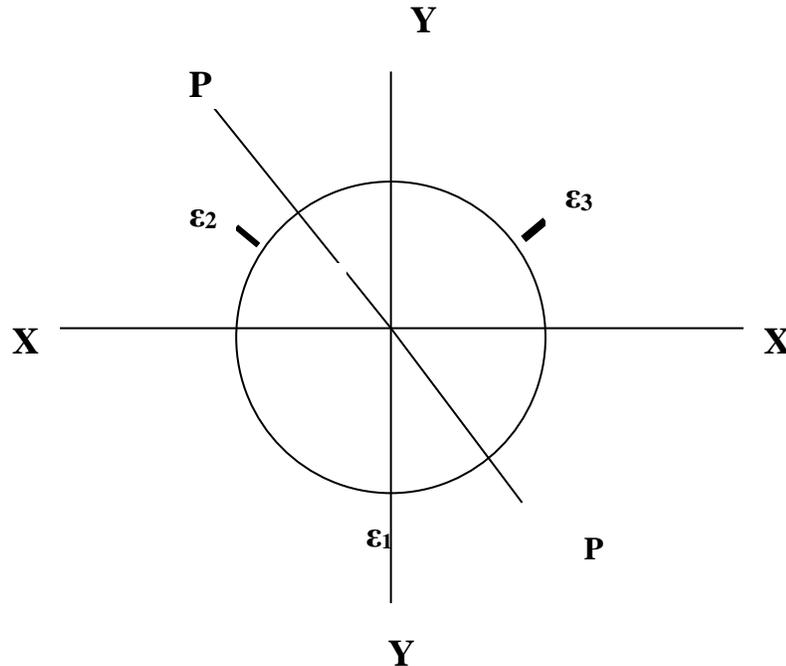
Average Axial Strain   **A =   (ε₁ + ε₂ + ε₃)/3**

Maximum Bending Strain around the YY Axis, **(X) = +/- [(ε₂ ‑ ε₃)/1.732]**

Maximum Bending Strain around the XX Axis, **(Y) =   +/- [((ε₁ + ε₂ + ε₃)/3) ‑ ε₁]**

The maximum strain, **P, = +/- [Xcosθ + Ysinθ] +A** and **tanθ = Y/X**

Example:

Let ε₁ = 20, ε₂ = 192 and ε₃ = 88 (all tensile strains)

Average Axial Strain, A = (20 +192 + 88)/3 = +100 microstrain tension

X= +/- (104/1.732) = +/- 60

Y = +/- (300/3 - 20) = +/- 80

Tanθ = 80/60 = 1.333 and **θ** = 53 **degrees from the X axis**

P=+/- [60 x 0.60 +80 x 0.8] + 100 = +200 microstrain. tensile. (and +0 microstrain

minimum)

APPENDIX H - GAGE INSTALLATION BY EPOXY BONDING.

2.3. Installation of Strain Gages by Epoxy Bonding

The following tools and accessories are needed to install the VK-4100 or VK4150 onto steel by epoxy bonding;

- Power grinder or sander, files, wire brush, sandpaper.

- Quick setting 2 part adhesive such as Loctite$^{®}$ 410 with accelerator.

- Strain gage 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 Gage* - Position the gage in the slot of the setting jig. Apply epoxy base to the mounting tabs of the strain gage. Apply activator to the steel at the approximate locations for the mounting tabs. Press the gage firmly against the beam and hold for at least 30 seconds or until the epoxy has set.

3. *Gage Protection* - Apply a layer of waterproofing compound over the mounting tab area.

4. *Install the Plucking Coil Housing (for the VK-4100)* - Before the waterproofing layer has hardened it is necessary to install the plucking coil housing over the strain gage. Do not use an excessive amount of the waterproofing compound. Keep the waterproofing compound away from the gage 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 gage and look through the transparent housing, moving it until it is clear of the gage. 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 Gage Cable* - For the VK-4150, using the shim stock provided, spot-weld the cable-to-lead-wire junction firmly to the steel. Be sure to leave some slack in the lead-wires. Using the second shim stock spot weld the cable to the steel approximately 1" (25 mm) behind the lead-wire junction. For the VK-4100 or VK-4150 use cable ties or duct tape to secure the gage cable to the steel member.

6. *Check the Gage Reading* - Connect a portable readout (section 3) and check that the gage is reading at the desired reading. Follow the instructions in the Troubleshooting section if the gage will not read.

7. *Spot-weld the 4150 cover plate* using the special shim stock strips provided. Spot weld the strips to the split tube first and then to the steel member.

APPENDIX I - THE MODEL 4150-5 EXTENDED RANGE STRAIN GAGE.

The Model 4150-5 strain gage differs slightly from the Standard 4150 gage in that it has a 10,000 microstrain range and there are a few other details that are noted here.

The gages must be individually calibrated due to the technique used to obtain the required range.

The gage is installed in the same manner as the standard VK-4150 gage but the position within the range should be set by the user, using the calibration sheet for each gage as a guide. Push or pull on the gage before spot welding the second tab,

For maximum accuracy the polynomial data reduction equations should be used.

The thermal coefficient of the gage is also different from the standard in that it varies throughout the range of readings and the instructions below should be used to make the corrections for temperature effects.

The temperature correction for the special 10,000 microstrain range model 4150-5 is as follows:

Using the Linear Equation.

Strain = $G[(R1-R0)+ K(T1-T0)]$

$K= (M*R1+B)$

Where M is 0.0002205

B= -0.03886

G is the linear gage factor = 1.0296 microstrain /digit (Position B)

R1 is the current reading

R0 is the initial reading

T1 is the temperature of R1

T0 is the temperature of R0

Example:

R1= 6682

R0 = 6596

T1= 30.13C

T0 = 20.09C

K = [(0.0002205*6682)-0.03886] = 1.4345

And the strain, after temperature correction, is

Strain = 1.0296[(6682-6596) +1.4345(30.13-20.09)] =+ 103 microstrain.

Using the Polynomial Equation

If the polynomial expression is used then you must first correct the value of R1 for temperature before using the polynomial.

So, using the same example,

The correction to R1 is K(T1-T0) = 1.4345(10.04) = +14.4

So if the current value of R1 is 6682 the value, corrected for temperature that must be entered into the polynomial is 6682+14.4 = 6696.4