Model 4450

VW Displacement Transducer

Instruction Manual

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GEOKON warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by GEOKON, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY IS VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of GEOKON's control. Components that wear or are damaged by misuse are not warranted. This includes fuses and batteries.

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1. INTRODUCTION

THEORY OF OPERATION

GEOKON Model 4450 Vibrating Wire Displacement Transducers consist of a vibrating wire sensing element, in series with a heat treated, stress relieved spring. One end of the spring is connected to a vibrating wire, the other end to the transducer shaft. As the transducer shaft is pulled out from the gauge body, the spring is elongated, causing an increase in tension in the vibrating wire. The increase in tension (strain) of the wire is directly proportional to the extension of the shaft. This change in strain allows the Model 4450 to measure displacement very accurately.

Model 4450 Displacement Transducers are fully sealed and can operate at pressures of up to 250 psi. They are designed to be read by one of the various readout boxes available from GEOKON.

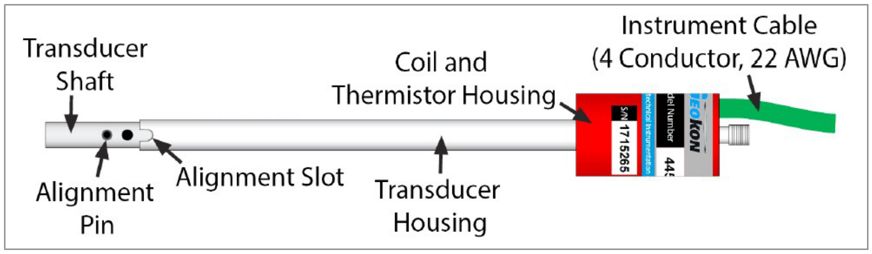

FIGURE 1: *Model 4450 Displacement Transducer*

2. INSTALLATION

2.1 PRELIMINARY TESTS

Most sensors are shipped with shipping spacer(s) installed that maintain tension to prevent damage during transportation. Installed spacers are different depending on the range of the sensor:

- **Ranges 12.5 mm (0.50”) through 50 mm (2"):** Sensors are secured using a shipping wire inserted into a machined hole and coiled around the shaft.
- **Ranges of 100 mm (4") or More:** Sensors are secured using stackable slotted sleeves around the shaft.

GEOKON recommends that each sensor is function tested before installing in the field. To perform this preliminary check complete the following steps:

1. Carefully remove the shipping spacer(s) or wire.

Important! Care should be taken to not rotate the push rod in relation to the sensor housing or to let the push rod snap back uncontrolled into the housing.

2. Connect the sensor to a readout. This could be a portable, handheld readout or the system that will be used in the final installation.

3. The sensor should have a strong, stable signal. When the push rod of the sensor is pulled, the frequency or digits should increase. When retracted into the sensor housing, the readings should decrease. The temperature reading should match the ambient temperature.

Important! Do not extend the push rod so that the full range of the sensor as indicted in the supplied calibration sheet is exceeded.

4. Check electrical continuity using an ohmmeter. Resistance between the gauge leads (usually red and black) should be approximately 180 ohms (128 ohms for Model 4420HT). Remember to add cable resistance, which is approximately 48.5 ohms per km (14.7 ohms per 1000 feet) of 22 AWG stranded copper leads at 20 °C. Multiply this factor by two to account for both directions. Resistance between thermistor leads (usually green and white) will vary based on temperature (see Appendix B). Resistance between any conductor and the shield should exceed two megaohms.

Should any of these preliminary tests fail, see Section 5 for troubleshooting tips.

2.2 DISPLACEMENT TRANSDUCER INSTALLATION

1. Be sure to place the alignment pin of the transducer shaft into the alignment slot during installation. This will prevent the internal wire from twisting.
2. With the #10-32 thread of the transducer shaft pressed against the shaft-mounting device, rotate the transducer approximately 16 turns to tighten the transducer shaft onto the mounting device. **Do not rotate the gauge tube relative to the shaft while securing.**
3. Attach the red and black gauge leads to the readout box. Select position B. (See Section 3 for readout instructions.)
4. The desired initial reading (setpoint) must be determined. Each sensor is provided with a unique calibration sheet. The calibration sheet indicates how the digit readings vary with the extension of the transducer shaft. The lowest digit readings correspond to a minimal extension of the transducer shaft, while the highest digit readings correspond to the maximum extension of the shaft. The desired initial reading (setpoint) will be determined based on the expected movement of the transducer shaft after installation. For applications where extension of the shaft is expected, choose a lower initial setpoint and vice versa.

Expected movement	Expect only extension	Expect mostly extension	Expect equal extension and compression	Expect mostly compression	Expect only compression
Initial reading (setpoint), in digits	3000	4250	5500	6750	8000
Target position in 0-100 mm range	0 mm	25 mm	50 mm	75 mm	100 mm

The digit readings above are only an example and must be adjusted based on individual calibration sheets as received from GEOKON.

TABLE 1: *Example for Determining Initial Reading (Setpoint)*

5. Gently pull on the transducer housing until the desired reading is obtained. **Never extend the shaft further than the range of the gauge.** The transducer also may be damaged if it is allowed to free fall through its stroke.

6. Hold the desired reading and secure the cable side of the gauge against or inside the mounting device. The transducer can be secured by using a Swagelok male connector with nylon front and back ferrules. Tighten the Swagelok connector per the instructions in Section 2.3. **Do not rotate the gauge tube relative to the shaft while securing.**

7. Initial readings must be taken and carefully recorded along with the temperature at the time of installation. These readings serve as a reference for subsequent deformation calculations.

2.3 SWAGELOK TUBE FITTING INSTRUCTIONS

These instructions apply to 25 mm (1") and smaller fittings.

2.3.1 INSTALLATION

1. Fully insert the tube into the fitting until it bumps against the shoulder.

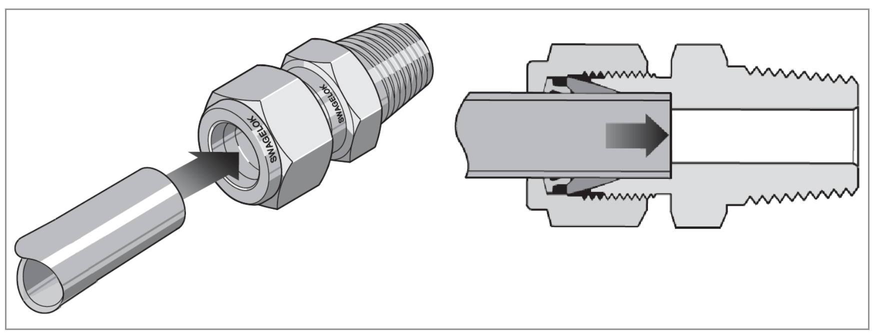

FIGURE 2: *Tube Insertion*

2. Rotate the nut until it is finger-tight. (For high-pressure applications as well as high-safety-factor systems, further tighten the nut until the tube will not turn by hand or move axially in the fitting.)
3. Mark the nut at the six o'clock position.

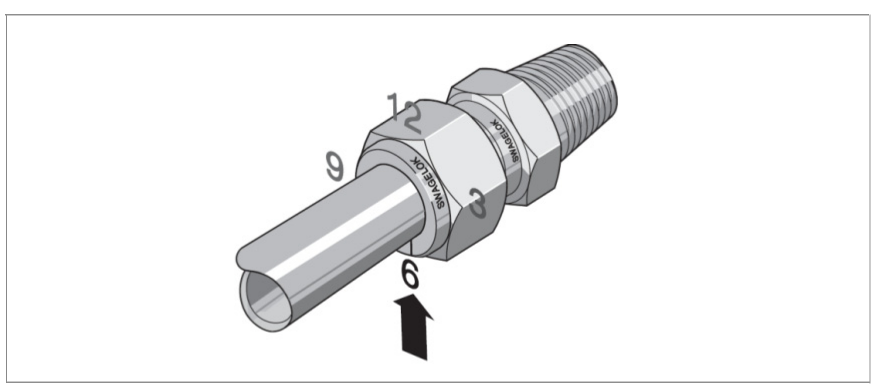

FIGURE 3: *Make a mark at six o'clock*

4. While holding the fitting body steady, tighten the nut one and one-quarter turns until the mark is at the nine o'clock position.

   Note: For 1/16", 1/8", 3/16", and 2, 3, and 4 mm fittings, tighten the nut three-quarters of a turn until the mark is at the 3 o'clock position

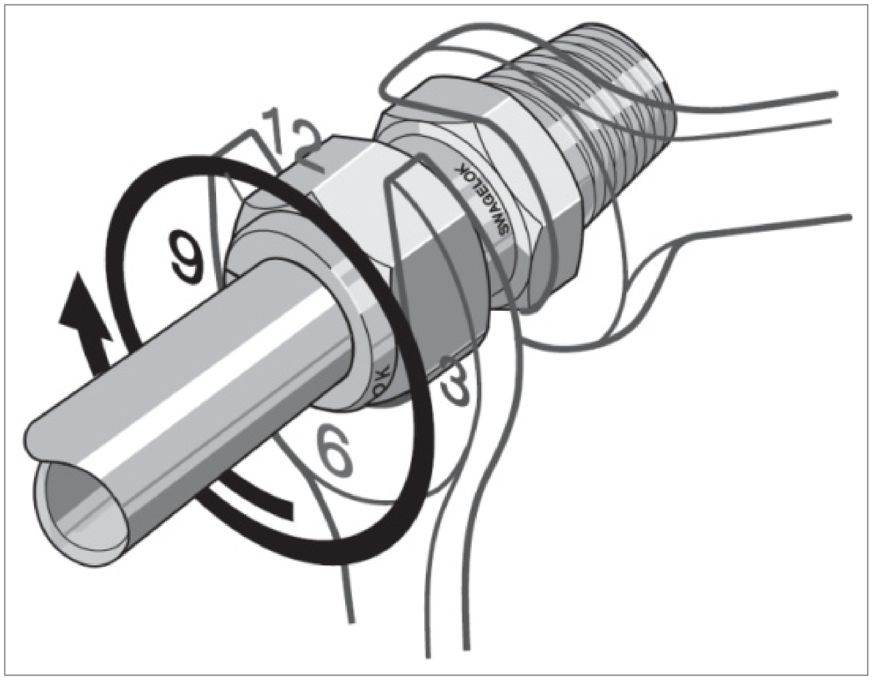

FIGURE 4: *Tighten One and On Quarter Turns*

2.3.2 REASSEMBLY INSTRUCTIONS

Swagelok tube fittings may be disassembled and reassembled many times.

Warning: Always depressurize the system before disassembling a Swagelok tube fitting.

1. Prior to disassembly, mark the tube at the back of the nut, then make a line along the nut and fitting body flats. These marks will be used during reassembly to ensure the nut is returned to its current position.

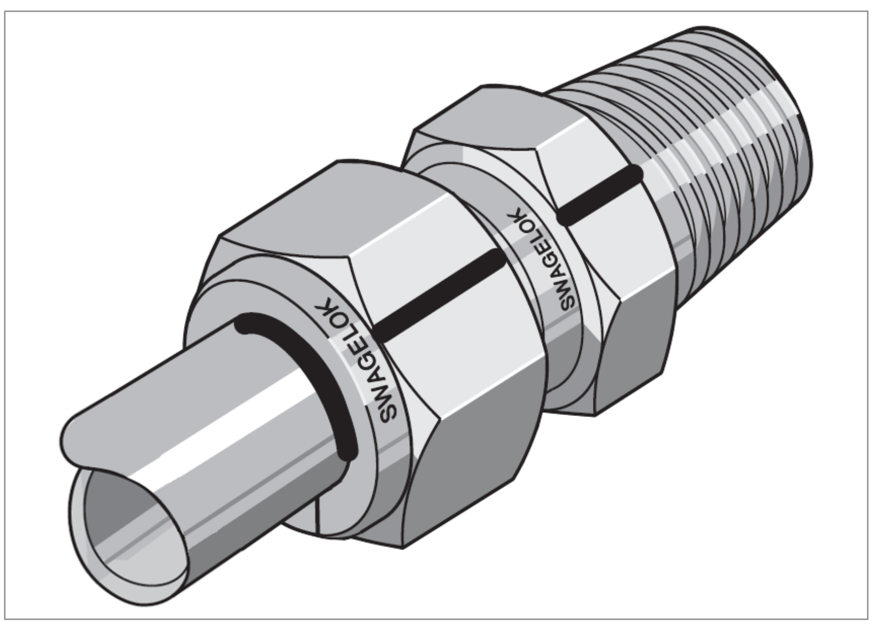

FIGURE 5: Marks for Reassembly

2. Disassemble the fitting
3. Inspect the ferrules for damage and replace if necessary. If the ferrules are replaced the connector should be treated as a new assembly. Refer to the previous section for installation instructions.
4. Reassemble the fitting by inserting the tube with pre-swaged ferrules into the fitting until the front ferrule seats against the fitting body.

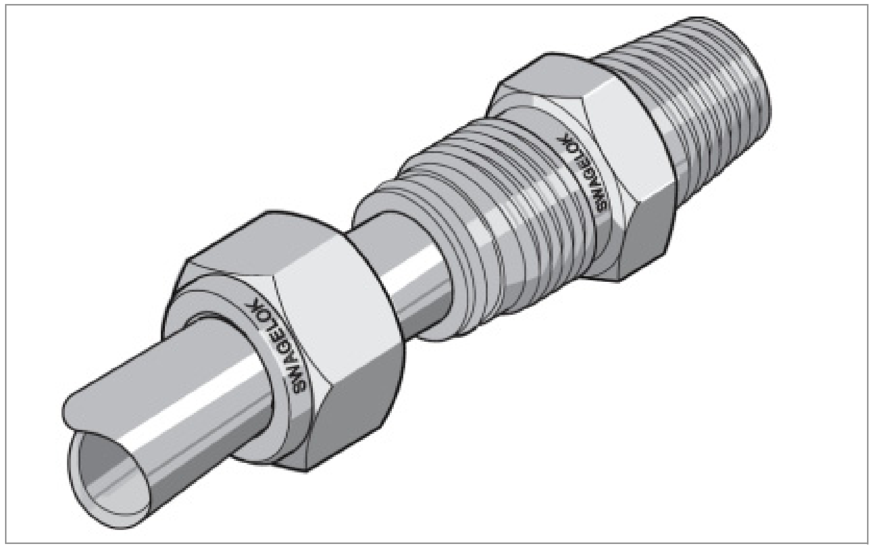

***FIGURE 6:** Ferrules Seated Against Fitting Body*

5. While holding the fitting body steady, rotate the nut with a wrench to the previous position as indicated by the marks on the tube and the connector. At this point, there will be a significant increase in resistance.
6. Tighten the nut slightly.

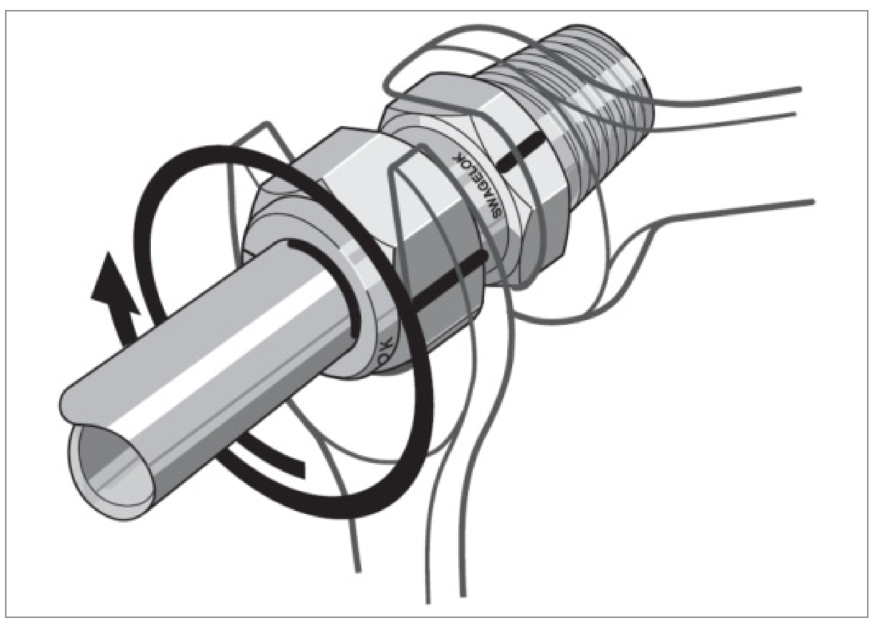

***FIGURE 7:** Tighten Nut Slightly*

2.4 CABLE INSTALLATION AND SPLICING

The cable should be routed to minimize the possibility of damage due to moving equipment, debris or other causes. The cable can be protected by the use of flexible conduit, which can be supplied by GEOKON.

Terminal boxes with sealed cable entries are available from GEOKON for all types of applications. These allow many gauges to be terminated at one location with complete protection of the lead wires. The interior panel of the terminal box can have built-in jacks or a single connection with a rotary position selector switch. Contact GEOKON for specific application information.

Because the vibrating wire output signal is a frequency rather than a current or voltage, variations in cable resistance have little effect on gauge readings; therefore, splicing of cables has no ill effects, and in some cases may in fact be beneficial. The cable used for making splices should be a high quality twisted pair type, with 100% shielding and an integral shield drain wire. **When splicing, it is very important that the shield drain wires be spliced together.** Always maintain polarity by connecting color to color.

Splice kits recommended by GEOKON incorporate casts, which are placed around the splice and are then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable itself in strength and electrical properties. Contact GEOKON for splicing materials and additional cable splicing instructions.

Cables may be terminated by stripping and tinning the individual conductors and then connecting them to the patch cord of a readout box. Alternatively, a connector may be used which will plug directly into the readout box or to a receptacle on a special patch cord.

2.5 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 alongside AC power lines; they will pick up the noise from the power cable, which will likely cause unstable readings. Contact the factory concerning filtering options available for use with the GEOKON dataloggers and readouts.

2.6 LIGHTNING PROTECTION

Unlike numerous other types of instrumentation available from GEOKON, displacement transducers do not have any integral lightning protection components, such as transorbs or plasma surge arrestors. Usually this is not a problem, however, if the instrument cable is exposed, it may be appropriate to install lightning protection components, as the transient could travel down the cable to the gauge and possibly destroy it.

SUGGESTED LIGHTNING PROTECTION OPTIONS:

- If the instrument 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 the installation of these components.
- Lighting arrestor boards and enclosures are also available from GEOKON. These units install where the instrument cable exits the structure being monitored. The enclosure has a removable top to allow the customer to

service the components or replace the board in the event that the unit is damaged by a lightning strike. A connection is made between the enclosure and earth ground to facilitate the passing of transients away from the displacement transducer. See Figure 8.

- Plasma surge arrestors can be epoxied into the instrument cable, close to the transducer. A ground strap then connects the surge arrestor to an earth ground, such as a grounding stake or the rebar itself.

Consult the factory for additional information on available lightning protection.

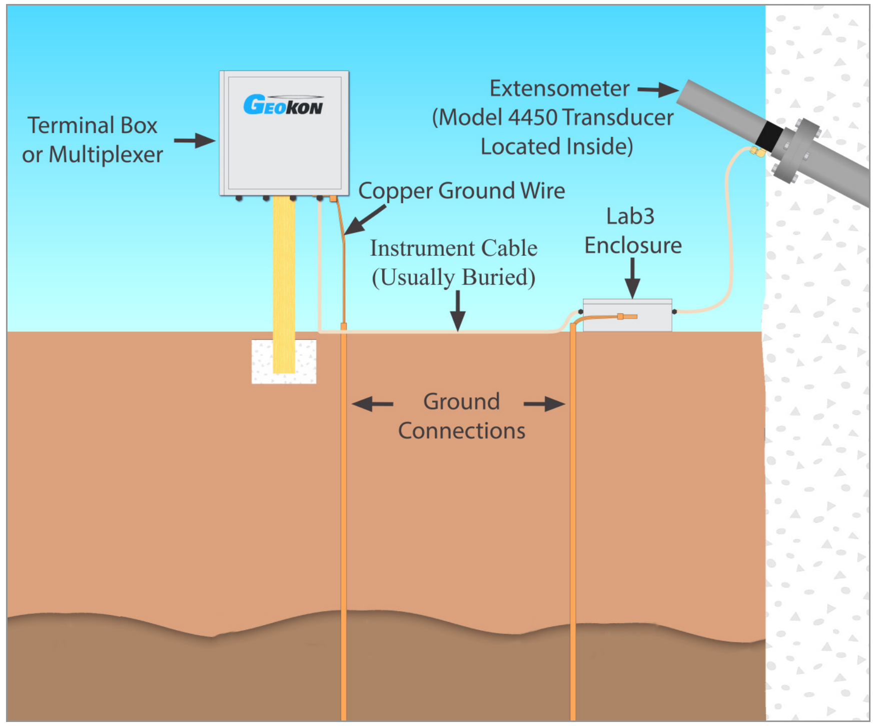

FIGURE 8: *Lightning Protection Scheme*

3. TAKING READINGS

3.1 GK-404 VIBRATING WIRE READOUT

The Model GK-404 VW Readout is a portable, low-power, hand-held unit that is capable of running for more than 20 hours continuously on two AA batteries. It is designed for the readout of all GEOKON vibrating wire instruments, and is capable of displaying the reading in digits, frequency (Hz), period (μs), or microstrain (με). The GK-404 also displays the temperature of the transducer (embedded thermistor) with a resolution of 0.1 °C.

***FIGURE 9:** GK-404 Readout*

3.1.1 OPERATING THE GK-404

***FIGURE 10:** Lemo Connector to GK-404*

1. Attach the flying leads by aligning the red circle on the silver Lemo connector with the red line on the top of the GK-404 (see Figure 10). Insert the Lemo connector into the GK-404 until it locks into place.
2. Connect each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).
3. To turn on the GK-404, press the **On/Off** button on the front panel of the unit. The initial startup screen will display.
4. After a delay, the GK-404 will start taking readings and display them based on the settings of the **Pos** and **Mode** buttons.

The unit display (from left to right) is as follows:

- The current position: set by the **Pos** button, displayed as A through F.
- The current reading: set by the **Mode** button, displayed as a numeric value followed by the unit of measure.
- Temperature reading of the attached instrument in degrees Celsius.

Use the **Pos** and **Mode** buttons to select the correct position and display units for the model of equipment purchased.

The GK-404 will continue to take measurements and display readings until the unit is turned off, either manually or by the Auto-Off timer (if enabled).

For more information, consult the GK-404 manual.

3.2 GK-405 VIBRATING WIRE READOUT

The GK-405 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.

The remote module can be wire-connected to the sensor by means of:

- Flying leads with alligator clips, if the sensor cable terminates in bare wires.
- A 10 pin connector.

The two units communicate wirelessly using Bluetooth®, a reliable digital communications protocol. Using Bluetooth, the unit can operate from the cradle of the remote module, or, if more convenient, can be removed and operated up to 20 meters away from the remote module.

The GK-405 displays the thermistor temperature in degrees Celsius.

For further details, consult the GK-405 Instruction Manual.

FIGURE 11: *GK-405 Readout*

3.2.1 CONNECTING SENSORS WITH 10-PIN BULKHEAD CONNECTORS ATTACHED

Align the grooves on the sensor connector (male), with the appropriate connector on the readout (female connector, labeled senor or load cell). Push the connector into place, and then twist the outer ring of the male connector until it locks into place.

3.2.2 CONNECTING SENSORS WITH BARE LEADS

Attach the flying leads to the bare leads of a GEOKON vibrating wire sensor by connecting each of the clips on the leads to the matching colors of the sensor conductors, with blue representing the shield (bare).

3.2.3 OPERATING THE GK-405

Press the power button on the Readout Unit. After start-up completes, a blue light will begin flashing, signifying that the two components are ready to connect wirelessly. Launch the GK-405 VWRA program by doing the following:

1. Tap Start on the hand-held PC's main window.
2. Select Programs.
3. Tap the GK-405 VWRA icon.

After a few seconds, the blue light should stop flashing and remain lit. The Live Readings window will display on the hand-held PC.

Set the Display mode to the correct letter required by your equipment. For more information, consult the GK-405 Instruction Manual.

3.3 MEASURING TEMPERATURES

All GEOKON vibrating wire instruments are equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. The white and green leads of the instrument cable are normally connected to the internal thermistor.

The GK-404 and GK-405 readouts will read the thermistor and display the temperature in degrees Celsius.

TO READ TEMPERATURES USING AN OHMMETER:

1. Connect an ohmmeter to the green and white thermistor leads coming from the instrument. Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied equal to approximately 48.5Ω per km (14.7Ω per 1000') at 20 °C. Multiply these factors by two to account for both directions.
2. Look up the temperature for the measured resistance in Appendix B.

4. DATA REDUCTION

4.1 DISPLACEMENT CALCULATION

The basic units utilized by GEOKON for measurement and reduction of data from vibrating wire displacement transducers are digits. Calculation of digits is based on the following equation:

$$\text{digits} = \left(\frac{1}{\text{Period}}\right)^2 \text{ x } 10^{-3} \text{ or digits} = \frac{\text{Hz}^2}{1000}$$

EQUATION 1: *Digits Calculation*

To convert digits to displacement the following equation applies:

$D_{uncorrected} = (R_1 - R_0) \text{ x } G \text{ x } F$

EQUATION 2: *Displacement Calculation*

Where:

R_1 is the current reading.
R_0 is the initial reading, usually obtained at installation.
G is the gauge factor, usually millimeters or inches per digit.
F is an optional engineering units conversion factor (see the table below).

From / To	Inches	Feet	Millimeters	Centimeters	Meters
Inches	1	12	0.03937	0.3937	39.37
Feet	0.0833	1	0.003281	0.03281	3.281
Millimeters	25.4	304.8	1	10	1000
Centimeters	2.54	30.48	0.10	1	100
Meters	0.0254	0.3048	0.001	0.01	1

TABLE 2: *Engineering Units Conversion Multipliers*

For example, if the initial reading R_0 is 6783 digits, the current reading, R_1, is 7228. The calibration factor, G, is 0.011906 mm/digit. The displacement change is:

$+5.3 \text{ mm} = (7228 - 6783) \text{ x } 0.011906$

EQUATION 3: *Displacement Change*

Note that increasing readings (digits) indicate increasing extension.

4.2 TEMPERATURE CORRECTION

GEOKON's vibrating wire displacement transducers have a small coefficient of thermal expansion. Correction may not be necessary in most cases. However, to achieve maximum accuracy, there are corrections that you can apply.

Use the following equation to provide thermal correction of the instrument:

$D_{corrected} = G(R_1 - R_0) + K(T_1 - T_0)$

EQUATION 4: *Thermally-Corrected Displacement Calculation*

Where:
R_1 is the current reading
R_0 is the initial reading
G is the linear gauge factor
T_1 is the current temperature
T_0 is the initial temperature
K is the thermal coefficient (see Equation 5)

Tests have determined that the thermal coefficient, K, changes with the position of the transducer shaft. The first step in the temperature correction process is determination of the proper thermal coefficient based on the following equation:

$$K = ((R_1 \times M) + B) \times G$$

EQUATION 5: *Thermal Coefficient Calculation*

Where:
R_1 is the current reading
M is the multiplier
B is the constant
G is the linear gauge factor from the supplied calibration sheet.

Model:	**Multiplier (M):**	**Constant (B):**
4450-3 mm (0.125")	0.000520	3.567
4450-12 mm (0.5")	0.000375	1.08
4450-25 mm (1")	0.000369	0.572
4450-50 mm (2")	0.000376	0.328
4450-100 mm (4")	0.000398	0.0864
4450-150 mm (6")	0.000384	-0.3482
4450-200 mm (8")	0.000396	-0.4428
4450-230 mm (9")	0.000403	-0.5016
4450-300 mm (12")	0.000424	-0.6778

TABLE 3: *Thermal Coefficient Calculation Constants*

Consider the following example using a Model 4450-25 mm displacement transducer:

R_0 = 4250 digits
R_1 = 5875 digits
T_0 = 10 °C
T_1 = 20 °C
G = 0.06152 mm/digit
K = (((5875 x 0.000369) + 0.572) x 0.06152) = 0.0168
$D_{corrected} = ((R_1 - R_0) \times G) + ((T_1 - T_0) \times K)$
$D_{corrected} = ((5875 - 4250) \times 0.06152) + ((20 - 10) \times 0.0168)$
$D_{corrected} = 99.97 + 0.168$
$D_{corrected} = +100.138$ mm

The temperature coefficient of the mass or member to which the displacement transducer is attached should also be taken into account. Use the temperature coefficient of the mass or member, combined with the changes in temperature from initial to current readings, to determine thermal effects of the mass or member.

4.3 ENVIRONMENTAL FACTORS

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

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 25 mm

Serial Number: 1720191

Calibration Instruction: CI-4400

Cable Length: 11.6 meters

Calibration Date: June 15, 2017

This calibration has been verified/validated as of 07/17/2017

Temperature: 22.7 °C

Technician: Kathy Rogers

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2672	2672	2672	-0.04	-0.15	0.00	0.00
5.0	3492	3491	3492	5.00	0.02	5.00	0.00
10.0	4308	4308	4308	10.03	0.11	10.00	0.01
15.0	5120	5120	5120	15.02	0.10	15.00	0.00
20.0	5929	5929	5929	20.00	0.00	20.00	-0.01
25.0	6736	6736	6736	24.97	-0.14	25.00	0.01

(mm) Linear Gage Factor (G): 0.006152 **(mm/ digit)** **Regression Zero:** 2678

Polynomial Gage Factors: **A:** 1.5386E-08 **B:** 0.006008 **C:** ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.0002422 **(inches/digit)**

Polynomial Gage Factors: **A:** 6.0574E-10 **B:** 0.0002365 **C:** ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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FIGURE 12: *Typical Calibration Sheet*

5. TROUBLESHOOTING

Maintenance and troubleshooting is confined to periodic checks of cable connections and maintenance of terminals. Once installed, these instruments are usually inaccessible and remedial action is limited. Should difficulties arise, consult the following list of problems and possible solutions. Return any faulty gauges to the factory. **Instruments should not be opened in the field.** For additional troubleshooting and support, contact GEOKON.

SYMPTOM: THERMISTOR RESISTANCE IS TOO HIGH

☐ Check for an open circuit. Check all connections, terminals, and plugs. If a cut is located in the cable, splice according to instructions in Section 2.4.

SYMPTOM: THERMISTOR RESISTANCE IS TOO LOW

☐ Check for a short circuit. Check all connections, terminals, and plugs. If a short is located in the cable, splice according to instructions in Section 2.4.

☐ Water may have penetrated the interior of the instrument. There is no remedial action.

SYMPTOM: INSTRUMENT 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 instrument shaft positioned outside the specified range (either extension or retraction) of the instrument? When the shaft is fully retracted with the alignment pin inside the alignment slot, the readings will likely be unstable because the vibrating wire is under-tensioned.Is there a source of electrical noise nearby? Likely candidates are generators, motors, arc welding equipment, high voltage lines, etc. If possible, move the instrument cable away from power lines and electrical equipment or install electronic filtering.

☐ Make sure the shield drain wire is connected to ground. Connect the shield drain wire to the readout using the blue clip.

☐ Does the readout or datalogger work with another instrument? If not, it may have a low battery or possibly be malfunctioning.

SYMPTOM: INSTRUMENT FAILS TO READ

☐ Does the readout or datalogger work with another instrument? If not, it may have a low battery or possibly be malfunctioning.

☐ Is the cable cut or crushed? Check the resistance of the cable by connecting an ohmmeter to the sensor leads; resistance is approximately 48.5Ω per km (14.7Ω per 1000') of 22 AWG wire.

If the resistance is very high or infinite, the cable is probably broken. If the resistance is very low, the conductors may be shorted. If a break or a short is present, splice according to the instructions in Section 2.4.

Refer to the expected resistance for the various wire combinations below.

Vibrating Wire Sensor Lead Resistance Levels

Red/Black	≅180Ω
Green/White	3000 at 25 °C

Any other wire combination will result in a measurement of infinite resistance.

APPENDIX A. SPECIFICATIONS

A.1 MODEL 4450 DISPLACEMENT TRANSDUCER

Range:	12 mm/0.50"	25 mm/1"	50 mm/2"	100 mm/4"	150 mm/6"	200 mm/8"
Resolution:[1]	0.025% FSR					
Linearity:	0.25% FSR					
Thermal Zero Shift:[2]	< 0.05% FSR/°C					
Stability:	< 0.2% / yr (under static conditions)					
Overrange:	115% FSR					
Temperature Range:	–40 to +80 °C (–40 +176 °F)					
Frequency Range (standard model):	1400-3500 Hz					
Frequency Range (small dia. model):	1700-3600 Hz					
Coil Resistance:	180Ω, +10Ω					
Cable Type:[3]	Two twisted pair (four conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")					
Dimensions:	See Sections A.2 and A.3 below for dimensions					

TABLE 4: *Model 4450 Displacement Transducer Specifications*

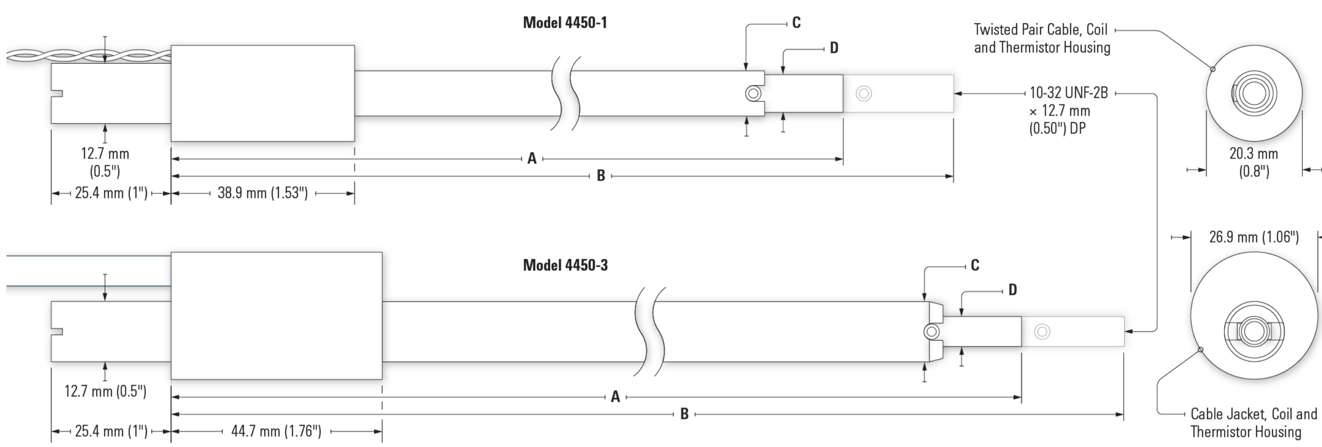
Notes:

[1] Minimum, greater resolution possible depending on readout.

[2] Depends on application.

[3] Polyurethane jacket cable available.

A.2 DIMENSIONS



Model 4450 Range ▶	3 mm (0.125")	12.5 mm (0.5")	25 mm (1")	50 mm (2")	100 mm (4")	150 mm (6")	200 mm (8")	230 mm (9")	300 mm (12")
A: Full Compression	174.6 mm (6.875")	177.1 mm (6.971")	196.2 mm (7.726")	262.8 mm (10.348")	399.2 mm (15.718")	464.3 mm (18.28")	662.8 mm (26.093")	688.2 mm (27.093")	929.5 mm (36.593")
B: Full Extension	177.6 mm (7.000")	189.6 mm (7.471")	221.2 mm (8.726")	312.8 mm (12.348")	499.2 mm (19.718")	614.3 mm (24.280")	862.8 mm (34.093")	918.2 mm (36.093")	1229.5 mm (48.593")
C:	9.5 mm (0.375")	9.5 mm (0.375")	9.5 mm (0.375")	9.5 mm (0.375")	12.7 mm (0.500")	12.7 mm (0.500")	12.7 mm (0.500")	12.7 mm (0.500")	12.7 mm (0.500")
D: Shaft Ø	7.9 mm (0.312")	7.9 mm (0.312")	7.9 mm (0.312")	7.9 mm (0.312")	6.4 mm (0.250")	6.4 mm (0.250")	6.4 mm (0.250")	6.4 mm (0.250")	6.4 mm (0.250")

Please Note: Dimensions are for reference only.

APPENDIX B. THERMISTOR TEMPERATURE DERIVATION

B.1 3KΩ THERMISTOR RESISTANCE

Thermistor Types:

- YSI 44005, Dale #1C3001–B3, Alpha #13A3001–B3
- Honeywell 192–302LET–A01

Resistance to Temperature Equation:

$$T = \frac{1}{A+B(LnR)+C(LnR)^3} - 273.15$$

EQUATION 6: *3kΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

$A = 1.4051 \times 10^{-3}$

$B = 2.369 \times 10^{-4}$

$C = 1.019 \times 10^{-7}$

Note: Coefficients calculated over the –50 to +150 °C span.

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

TABLE 5: *3KΩ Thermistor Resistance*

B.2 10KΩ THERMISTOR RESISTANCE

Thermistor Type: US Sensor 103JL1A

Resistance to Temperature Equation:

$$T = \frac{1}{A+B(LnR)+C(LnR)^3+D(LnR)^5} - 273.15$$

EQUATION 7: *10KΩ Thermistor Resistance*

Where:

T = Temperature in °C

LnR = Natural Log of Thermistor Resistance

A = 1.127670 x 10^{-3}

B = 2.344442 x 10^{-4}

C = 8.476921 x 10^{-8}

D = 1.175122 x 10^{-11}

Note: Coefficients optimized for a curve **J** Thermistor over the temperature range of 0 °C to +250 °C.

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
32,650	0	7,402	32	2,157	64	763.5	96	316.6	128	148.4	160	76.5	192	42.8	224
31,029	1	7,098	33	2,083	65	741.2	97	308.7	129	145.1	161	75.0	193	42.1	225
29,498	2	6,808	34	2,011	66	719.6	98	301.0	130	142.0	162	73.6	194	41.4	226
28,052	3	6,531	35	1,942	67	698.7	99	293.5	131	138.9	163	72.2	195	40.7	227
26,685	4	6,267	36	1,876	68	678.6	100	286.3	132	135.9	164	70.8	196	40.0	228
25,392	5	6,015	37	1,813	69	659.1	101	279.2	133	133.0	165	69.5	197	39.3	229
24,170	6	5,775	38	1,752	70	640.3	102	272.4	134	130.1	166	68.2	198	38.7	230
23,013	7	5,545	39	1,693	71	622.2	103	265.8	135	127.3	167	66.9	199	38.0	231
21,918	8	5,326	40	1,637	72	604.6	104	259.3	136	124.6	168	65.7	200	37.4	232
20,882	9	5,117	41	1,582	73	587.6	105	253.1	137	122.0	169	64.4	201	36.8	233
19,901	10	4,917	42	1,530	74	571.2	106	247.0	138	119.4	170	63.3	202	36.2	234
18,971	11	4,725	43	1,480	75	555.3	107	241.1	139	116.9	171	62.1	203	35.6	235
18,090	12	4,543	44	1,432	76	539.9	108	235.3	140	114.5	172	61.0	204	35.1	236
17,255	13	4,368	45	1,385	77	525.0	109	229.7	141	112.1	173	59.9	205	34.5	237
16,463	14	4,201	46	1,340	78	510.6	110	224.3	142	109.8	174	58.8	206	33.9	238
15,712	15	4,041	47	1,297	79	496.7	111	219.0	143	107.5	175	57.7	207	33.4	239
14,999	16	3,888	48	1,255	80	483.2	112	213.9	144	105.3	176	56.7	208	32.9	240
14,323	17	3,742	49	1,215	81	470.1	113	208.9	145	103.2	177	55.7	209	32.3	241
13,681	18	3,602	50	1,177	82	457.5	114	204.1	146	101.1	178	54.7	210	31.8	242
13,072	19	3,468	51	1,140	83	445.3	115	199.4	147	99.0	179	53.7	211	31.3	243
12,493	20	3,340	52	1,104	84	433.4	116	194.8	148	97.0	180	52.7	212	30.8	244
11,942	21	3,217	53	1,070	85	421.9	117	190.3	149	95.1	181	51.8	213	30.4	245
11,419	22	3,099	54	1,037	86	410.8	118	186.1	150	93.2	182	50.9	214	29.9	246
10,922	23	2,986	55	1,005	87	400.0	119	181.9	151	91.3	183	50.0	215	29.4	247
10,450	24	2,878	56	973.8	88	389.6	120	177.7	152	89.5	184	49.1	216	29.0	248
10,000	**25**	2,774	57	944.1	89	379.4	121	173.7	153	87.7	185	48.3	217	28.5	249
9,572	26	2,675	58	915.5	90	369.6	122	169.8	154	86.0	186	47.4	218	28.1	250
9,165	27	2,579	59	887.8	91	360.1	123	166.0	155	84.3	187	46.6	219		
8,777	28	2,488	60	861.2	92	350.9	124	162.3	156	82.7	188	45.8	220		
8,408	29	2,400	61	835.4	93	341.9	125	158.6	157	81.1	189	45.0	221		
8,057	30	2,316	62	810.6	94	333.2	126	155.1	158	79.5	190	44.3	222		
7,722	31	2,235	63	786.6	95	324.8	127	151.7	159	78.0	191	43.5	223		

TABLE 6: *10KΩ Thermistor Resistance*

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