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*Instruction Manual*

# Model 4500MLP

## Multi-level Vibrating Wire Piezometer

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## 1. THEORY OF OPERATION

Geokon Model 4500 Vibrating Wire Piezometers are intended primarily for long-term measurements of fluid and/or pore pressures in standpipes, boreholes, embankments, pipelines and pressure vessels. The Model 4500MLP is designed to permit the easy installation of several piezometers inside a single borehole. **The method eliminates the need for alternating sand and bentonite zones by permitting the entire hole to be backfilled using a bentonite grout tremied in through a grout pipe**.

The basic Model 4500S piezometer, shown in Figure 1, utilizes a sensitive stainless steel diaphragm to which a vibrating wire element is connected. In use, changing pressures on the diaphragm cause it to deflect, and this deflection is measured as a change in tension and frequency of vibration of the vibrating wire element. The square of the vibration frequency is directly proportional to the pressure applied to the diaphragm. Two coils, one with a magnet, another with a pole piece, are located close to the wire. In use, a pulse of varying frequency (swept frequency) is applied to the coils and this causes the wire to vibrate primarily at its resonant frequency. When excitation ends the wire continues to vibrate and a sinusoidal signal, at the resonant frequency, is induced in the coils and transmitted to the readout box where it is conditioned and displayed.

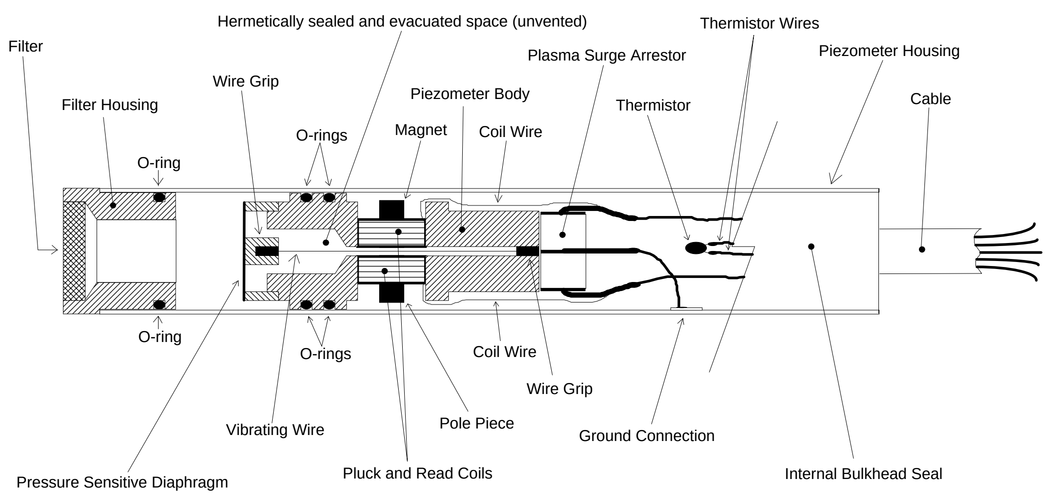


**Figure 1 Model 4500S Vibrating Wire Piezometer**

For the Model 4500MLP, the filter stone in the figure above is replaced by a tube leading to a much larger, curved, porous filter stone that can be forced against the walls of the borehole by a spring mechanism actuated remotely after the piezometer, in its closed configuration, has been lowered to its desired location. This is shown schematically in figures 2 and 3.

With all the filter stones pressed against the wall of the borehole in this manner the borehole can now be filled completely with a bentonite cement grout without running the risk of getting the filter stone plugged with bentonite or having substantial amounts of highly impervious bentonite interposed between the piezometer diaphragm and the ground water in the surrounding soil.


**Figure 2. The 4500MLP System**

**Figure 3. Close up of the 4500MLP Deployed in the Borehole.**

# 2. INSTALLATION

## 2.1 Preliminary Tests

Upon receipt of the piezometer the zero reading should be checked and noted (see Sections 3.1 and 3.2 for readout instructions). A thermistor is included inside the body of the piezometer (Figure 1-1) for the measurement of temperature. (See Section 3.3 for instructions).

Calibration data are supplied with each gage and a zero reading, at a specific temperature and absolute barometric pressure, is included. Zero readings at the site should coincide with the factory readings within 20 digits after barometric and temperature corrections are made. (Barometric pressures change with elevation at a rate of about 3.45kPa (½ psi) per 300meters (1,000 ft.)) See Figure 4 for a sample calibration sheet.

GEOKON

**Vibrating Wire Pressure Transducer Calibration**

Model Number: 4500S-100 Pressure Range: 100 psi

Serial Number: 48056 Mfg. Number: 8-3275

Customer: Temperature: 21.1 °C

Cust. I.D. #: n/a Barometric Pressure: 998.1 mbar

Job Number: 13053 Date: Nov. 7, 1998

Cal. Std. Control #(s): 183, 468 Technician:

| Pressure (psi) | Reading 1st Cycle | Pressure (psi) | Reading 2nd Cycle | Average Pressure | Average Reading | Change | Linearity (%FS) | Polynomial Fit (%FS) |
|---|---|---|---|---|---|---|---|---|
| 0 | 9136 | 0 | 9141 | 0 | 9139 | | 0.18 | -0.04 |
| 20 | 8453 | 20 | 8456 | 20 | 8455 | 684 | 0.03 | 0.08 |
| 40 | 7772 | 40 | 7774 | 40 | 7773 | 682 | -0.19 | -0.01 |
| 60 | 7085 | 60 | 7083 | 60 | 7084 | 689 | -0.19 | -0.01 |
| 80 | 6392 | 80 | 6390 | 80 | 6391 | 693 | -0.08 | -0.03 |
| 100 | 5694 | 100 | 5687 | 100 | 5691 | 701 | 0.25 | 0.03 |

**Linear Gage Factor (G): 0.029021 (psi/digit) Regression Zero: 9145**

**Polynomial Gage Factors: A: -1.40E-07 B: -0.026943 C:* 257.8826**

**Thermal Factor (K): -0.004326 (psi/°C)**

**Calculated Pressures:** **Linear,** $P = G(R_0 - R_1) + K(T_1 - T_0) - (S_1 - S_0)$**

**Polynomial,** $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)$**

***Barometric compensation is not required with vented transducers.*

**Factory Zero Reading:**

GK-401 Pos. B or F($R_0$): 9128 Temp($T_0$): 21.8 °C Baro($S_0$): 1001.4mbar Date: Jan. 27, 1997

**The user is advised to establish zero conditions in the field by recording the reading at a known temperature and barometric pressure.*

Wiring Code: Red and Black: Gage White and Green: Thermistor Bare: Shield

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

**Figure 4 Sample Calibration Sheet**

Care needs to be exercised in choosing the pressure range of the piezometer. During Installation the full pressure of the wet bentonite grout will be felt by the piezometer. Geokon piezometers can withstand over-ranging to100 percent of the calibrated range without damage and without affecting the calibration or shifting the zero reading. However, at the higher over-range pressures the piezometer may temporarily cease reading until the grout sets up and the pressure returns to normal.

### 2.2 Saturating the Filter Stone

The filter stone is saturated by first, disconnecting the Swagelok Union at the transducer, and then, by immersing the whole assembly, upside down, in a bucket of water. A vacuum is then applied to the nylon filter tube using the large syringe supplied with the system. This removes the entrapped air from the large filter stone. The transducer itself must be purged of air by injecting water into the Swagelok fitting using the small diameter tube (supplied) attached to the syringe and poked all the way down inside the Swagelok fitting and into the piezometer cavity. Then, while still under water, the nylon tube from the filter stone is reconnected to the transducer. Keep the assembly under water until ready to lower into the borehole.
**Caution. – do not allow the piezometer to freeze once it has been filled with water.**

### 2.3 Establishing an Initial Zero Reading

Vibrating Wire Piezometers differ from other types of pressure sensors in that they indicate a reading with no pressure exerted. **It is imperative that an accurate initial zero reading be obtained for each piezometer as this reading will be used for all subsequent data reduction.** Generally, it is obtained by reading the instrument prior to installation (with no pressure applied). The procedure is as follows: With the assembly under water in the bucket allow 5 to 15 minutes for the temperature to stabilize. For this purpose it would be best for the water temperature to be the same as the water temperature in the borehole. Use the thermistor inside the piezometer to measure the water temperature.
When stabilized take a zero reading. Note also the barometric pressure, if possible, or record the time for later referral to local weather station data.
For maximum accuracy record the depth of the piezometer below the water surface at the time of the reading. The piezometer diaphragm is at the same level as the lowest leaf spring.

### 2.4 Checking the Calibration

The following procedure could be used to verify the calibration factor as supplied on the calibration sheet (Figure 4);

1. Saturate the filter stone and fill the space between it and the diaphragm with water (Section 2.2).

2. Lower the piezometer to the bottom of a water-filled borehole using the cable to measure the actual depth.

3. Allow 15-20 minutes for the piezometer to come to thermal equilibrium. Using a readout box record the reading at that level.

4. Raise the piezometer a known amount. Record the reading. Calculate the factor given the change in pressure and reading. Compare to the calibration sheet value. The two values should agree within ± 0.5%.

Note: when doing this test be aware that the actual water level inside the borehole might change due to displacement of water by the different lengths of submerged cable. This is especially critical where the cable length is long and the borehole diameter small. Allowing sufficient time for the level to equilibrate may solve this problem. Or keep the borehole full to the top.

## 2.5 Installation in Boreholes

**Borehole sizes** are not critical but they should be **at least 100mm (4inch**) in diameter and not more than 30mm larger than the nominal size for which the spring loaded mechanism was designed.

### 2.5.1 The Drop Weight Method

In steeply inclined boreholes directed downwards the drop-weight method of installation is recommended. For shallow inclinations and upward directed holes, and for other situations where the drop weight method is not desired or possible, the pneumatic cutter method or the pull-pin method can be used, see (Sections 2.5.2 and 2.5.3). Note that the **drop-weight method cannot be used in holes which will not stay open and which require casing to be removed as the piezometers are installed**. This is because in the drop-hammer method the top piezometers are released first.

The 4500MLP sensors are designed to be installed around **flush-coupled 1”schd 80 PVC** grout pipe. Begin by connecting the grout pipe sections together and laying them out along the ground. Mark the desired locations of the piezometers at the calculated depths and then drill a single 7/32 or ¼ inch drill hole diametrically through the pipe.

Each piezometer assembly is held to the grout pipe by means of a single 50lb nylon Ty-rap, (supplied), that passes diametrally through two holes on opposite sides of the grout pipe. The Ty-rap also holds the piezometer assembly in its closed position.

The tying sequence is as follows: Pass the Ty-rap through the grout pipe, then through the spaces between the leaf springs, then around the two platens and then back to itself and pull it tight around the grout pipe. Keep the cables from lower piezometers **inside** the Ty-rap and leaf springs. The Ty-rap should pass just **below** the center leaf spring such that the bottom of the platen assemblies will be held tight to the grout pipe. See Figure 5

**Figure 5 4500MLP Ty-wrapped for Drop Weight Method**

As the grout pipe is assembled and pushed into the borehole the assemblies are added and the electrical cables fed into the hole. When the assembly is completed and the grout tube has reached its final position, a special weight, provided with the equipment, is tied to a length of aircraft cable and is then allowed to fall freely down the inside of the grout pipe. As the weight hits each of the Ty-raps stretching across the pipe the Ty-rap is snapped, allowing the filter stone to be forced against the walls of the borehole.

### 2.5.2 Pneumatic Cutter Method

The system is designed for installation around **flush-coupled 1”schd 80 PVC** grout pipe, although other grouting arrangements may be used. The assembly is held in its closed position, for installation, by two nylon Ty-raps,(supplied), which are installed through the eyebolts in the platens and through the holes in the cutting tool. Keep the cables from lower piezometers **inside** the Ty-rap and leaf springs. Orient the tool such that it will be above the assembly when pushed into the borehole, and that the grout tube is between the platens, Ty-rap the body of the piezometer to the grout pipe. *See Figure 6.*

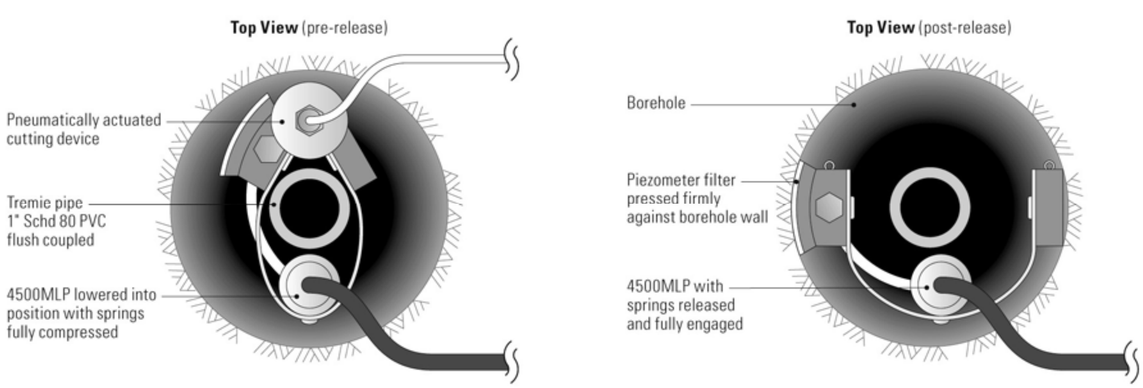

**Figure 6  Pneumatic Cutter Method of Installation.**

Piezometers are installed sequentially from the bottom of the borehole to the mouth. If the **grout pipe** is going to be **removed** from the borehole, the grout pipe is assembled and pushed into the borehole first and then each piezometer assembly must be pushed around the grout pipe, (and any lower piezometer cables), down to the desired elevation. If the grout pipe is to be left in place the piezomters can be taped to the grout pipe, making sure not to put the tape around the outside of the filter stone and spring mechanism.

When the desired elevation is reached the cutting tool is activated by connecting the pneumatic tube from the piezometer to a bottle of $CO_2$ (obtained locally from any welding supply outlet), The $CO_2$ bottle should have a pressure regulator which is set to a pressure of at least 2.5MPa, (350 psi), with the shut-off valve closed.  (See figure 7). The shut off valve is then opened suddenly allowing the pressure to reach the cutting tool, cutting the ty-wraps and releasing the spring-loaded platens against the borehole walls.

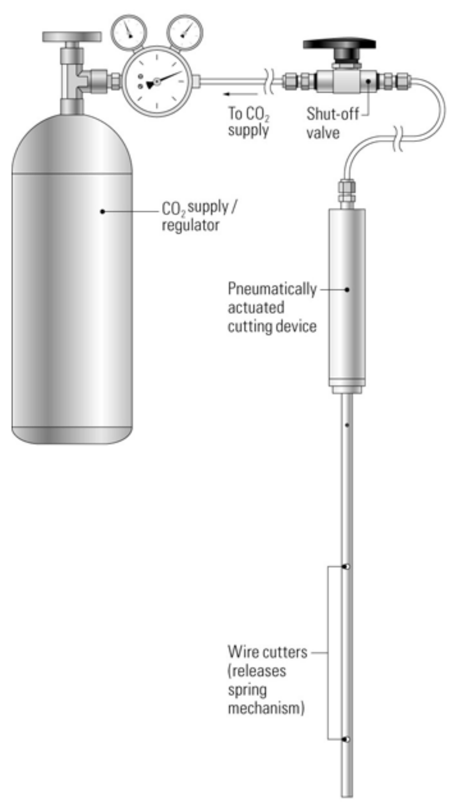


**Figure 7.  Pneumatic Cutter Equipment**

If installed in drill casing, the sensor is lowered to the proposed elevation and the casing is pulled just above this elevation before the assembly is released. The cutting tool is then removed from the drill hole and the next assembly prepared for installation. When lowering the next and subsequent piezometers down the hole, feed the cables from the lower piezometers through the middle of the assembled piezometer rather than around the outside. (This will prevent the cables from interfering with the filter and preventing its close contact with the borehole wall).
When all the assemblies are installed the hole can be grouted from the bottom up using a bentonite cement grout.

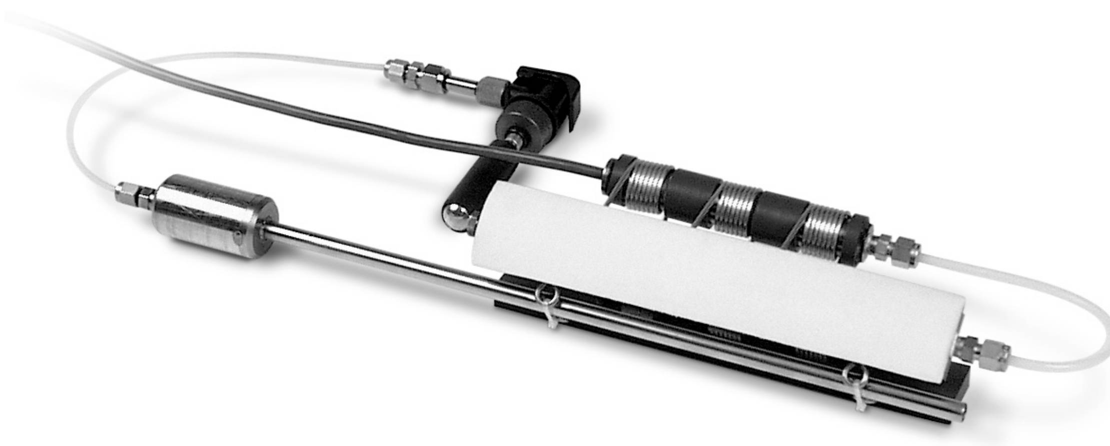

**Figure 8 . Model 4500MLP Multilevel Piezometer shown in closed, pre-installed configuration** ***(Note that the picture shows a small $CO_2$ cartridge which is no longer available.)***

### 2.5.3 Pull-Pin Method

In this method the piezometer assembly is held in its closed position by means of a pull-pin, which, after the filter stone and the platen are squeezed together, passes through both sets of three eyebolts mounted on the filter stone and the platen.

If the **grout pipe** is going to be **removed** from the borehole, the piezometer assembly must be pushed around the grout pipe down to the desired elevation using a second push pipe, which can be another length of the grout tube. While holding the piezometer in position by the push-in pipe, the pull-pin cable should be pulled gently until all the slack is taken out, and then pulled with a sudden strong jerk, which will release the platens without changing the position of the piezometer relative to the borehole. **A bit of practice pulling the pins before the actual installation will give some "feeling" and confidence as to how the system works.**

Piezometers should be installed sequentially from the bottom(top) of the borehole to the mouth.

If the **grout pipe** is going to be **left in** the borehole the piezometer assemblies can be attached to it in a manner that does not restrict the movement of the platens. The grout pipe can be assembled, length-by-length, and the piezometer assemblies, each with its own pull-pin, can be attached to it by taping the electrical cable to the grout tube close to the piezometer. The grout pipe and piezometer assemblies can then be pushed down the hole as a unit. When the final position is reached the pull-pins can then be pulled, activating the platens.

If installed in drill casing, the sensor is lowered to the proposed elevation and the casing is pulled just above this elevation before the assembly is released. The tool is then removed from the drillhole and the next assembly prepared for installation. When lowering or pushing the next and subsequent piezometers down the hole, feed the cables from the lower piezometers through the middle of the assembled piezometer rather than around the outside. This will prevent the cables from interfering with the filter and preventing close contact with the borehole wall.

When all the assemblies are installed the hole can be grouted from the bottom up using a bentonite cement grout. The grout pipe can be either removed from the hole or left in place.

## 2.6 Grouting requirements

*For more details on this topic, refer to "Piezometers in Fully Grouted Boreholes" by Mikkelson and Green, FMGM proceedings Oslo 2003. A copy is available from Geokon.*

The general rule for grouting multi level piezometers is to mimic the strength of the surrounding soil. The emphasis should be on controlling the water-cement ratio. This is accomplished **by mixing the cement with the water first.**
The most effective way of mixing is in a 50 to 200 gallon barrel or tub using the drill-rig pump to circulate the mix. Any kind of bentonite powder used to make drilling mud, combined with Type 1 or 2 Portland cement can be used. The exact amount of bentonite added will vary somewhat. The table below shows 2 possible mixes for strengths of 50 psi and 4 psi.
Add the measured amount of clean water to the barrel then gradually add the cement in the correct weight ratio. Next add the bentonite powder, slowly, so clumps do not form. Keep adding bentonite until the watery mix turns to an oily/slimy consistency. Let the grout thicken for another five to ten minutes. Add more bentonite as required until it is a smooth thick cream like pancake batter. It is now as heavy as it is feasible to pump.
When pumping grout, unless the tremie-pipe is to be left in place, withdraw the tremie-pipe after each batch, by an amount corresponding to the grout level in the borehole.

| **Application** | **Grout for Medium to Hard Soils** | | **Grout for Soft Soils** | |
|---|---|---|---|---|
| Materials | Weight | Ratio by Weight | Weight | Ratio by Weight |
| Water | 30 gallons | 2.5 | 75 gallons | 6.6 |

| | | | | |
|---|---|---|---|---|
| Portland Cement | 94 lbs (1 sack) | 1 | 94 lbs (1 sack) | 1 |
| Bentonite | 25 lbs (as required) | 0.3 | 39 lbs (as required) | 0.4 |
| Notes | The 28 day compressive strength of this mix is about 50 psi, similar to very stiff to hard clay. The modulus is about 10,000 psi | | The 28 day strength of this mix is about 4psi, similar to very soft clay. | |

**Table 1 showing Cement/bentonite/water ratios for two grout mixes.**

## 2.7 Splicing and Junction Boxes

Because the vibrating wire output signal is a frequency rather than current or voltage, variations in cable resistance have little effect on gage readings and, therefore, splicing of cables has no effect either and, in some cases, may be beneficial. For example, if multiple piezometers are installed in a borehole, and the distance from the borehole to the terminal box or datalogger is great, a splice (or junction box, see Figure 6) could be made to connect the individual cables to a single multi-conductor cable. This multi-conductor cable would then be run to the readout station. For such installations it is recommended that the piezometer be supplied with enough cable to reach the installation depth plus extra cable to pass through drilling equipment (rods, casing, etc.).

The cable used for making splices should be a high quality twisted pair type with 100% shielding (with integral shield drain wire). When splicing, it is very important that the shield drain wires be spliced together! Splice kits recommended by Geokon incorporate casts placed around the splice 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.

Junction boxes and terminal boxes are available from Geokon for all types of applications. In addition, portable readout equipment and datalogging hardware are available. See Figure 9. Contact Geokon for specific application information.

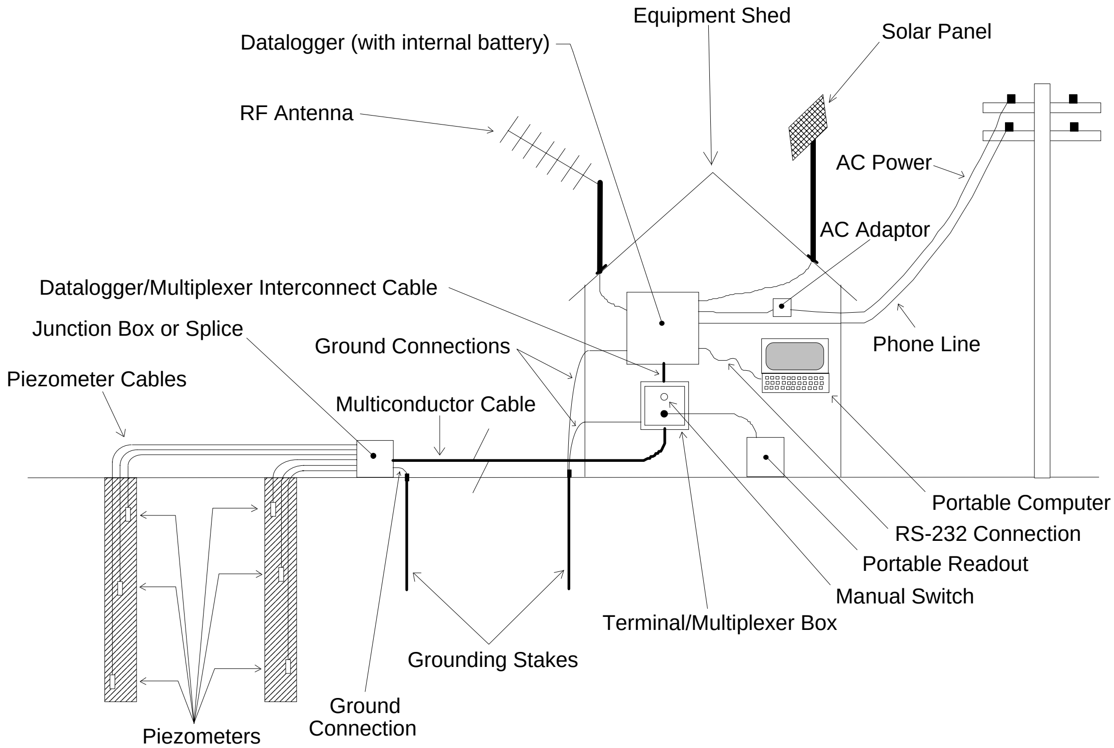


**Figure 9  Typical Multi-Piezometer Lightning Protection**

## 2.8  Lightning Protection

In exposed locations it is vital that the piezometer be protected against lightning strikes.

A tripolar plasma surge arrestor (see Figure 1) is built into the body of the piezometer and protects against voltage spikes across the input leads.  Following are additional lightning protection measures available;

1. If the instruments will be read manually with a portable readout (no terminal box) a simple way to help protect against lightning damage is to connect the cable leads to a good earth ground when not in use.  This will help shunt transients induced in the cable to ground thereby protecting the instrument.

2. Terminal boxes available from Geokon can be ordered with lightning protection built in.  There are two levels of protection;

    - The terminal board used to make the gage connections has provision for installation of plasma surge arrestors (similar to the device inside the piezometer).

    - Lightning Arrestor Boards (LAB-3) can be incorporated into the terminal box. These units utilize surge arrestors and transzorbs to further protect the piezometer.

    In the above cases the terminal box would be connected to an earth ground.

3. Improved protection using the LAB-3 can be had by placing the board in line with the cable as close as possible to the installed piezometer (see Figure 10). This is the recommended method of lightning protection.

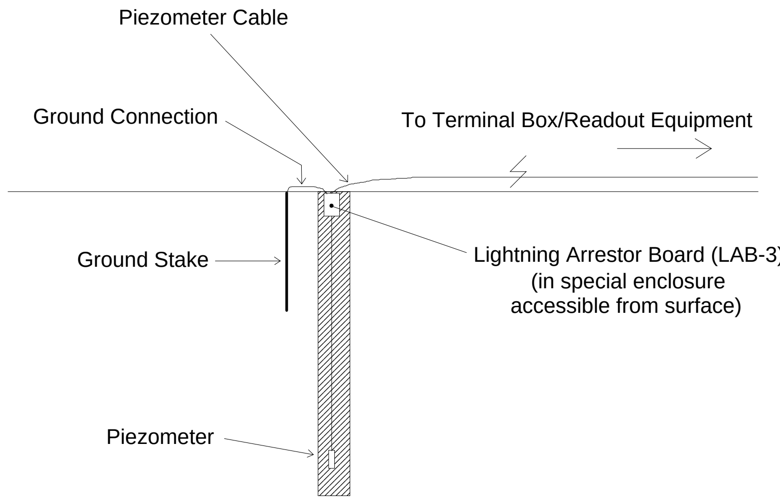


**Figure 10 Recommended Lab-3 Lightning Protection Scheme**

## 3. TAKING READINGS

### 3.1 Operation of the GK-401 Readout Box

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 green lead for the shield drain wire. The GK-401 cannot read the thermistor (see Section 3.4).

1. Turn the display selector to position "B" (or "F"). Readout is in digits (Equation 4-1).

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. Record the value displayed. If zeros are displayed or the reading is unstable see section 5 for troubleshooting suggestions.

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

### 3.1 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 following instructions will explain taking gage measurements using Modes "B" and "F" (similar to the GK-401 switch positions "B" and "F").

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 "B" (or "F"). Readout is in digits (Equation 4-1).

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 output directly in degrees centigrade.

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

**3.2 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 **B** and the MODE button to select **Dg** (digits).
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

**3.4 Measuring Temperatures**

Each vibrating wire piezometer is 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. High temperature versions use a different thermistor than the standard versions.

The GK-403 and GK-404 readout boxes when used with the **standard** temperature thermistor will display the temperature in °C automatically. It will **not** do this with high temperature thermistors.

The GK 401 readout box will not read temperatures directly, instead an ohmmeter must be used:

1. Connect the ohmmeter to the green and white thermistor leads coming from the piezometer. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied – equal to 22 ohms per thousand feet.)

2. For standard temperature models, look up the temperature for the measured resistance in Table B-1.Page 17. Alternatively the temperature could be calculated using Equation B-1. For high temperature models use Table B2 or the equation B2 given on page 18.

# 4. DATA REDUCTION

## 4.1 Pressure Calculation

The digits displayed by the Geokon Models GK-401, GK-403 or GK404 Readout Boxes on channel B are based on the equation

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

**Equation 4-1 Digits Calculation**

For example, a piezometer reading 8000 digits corresponds to a period of 354μs and a frequency of 2828 Hz. Note that in the above equation, the period is in seconds: the readout boxes display microseconds.
Since digits are directly proportional to the applied pressure,

**Pressure = (Initial Reading - Current Reading) × Calibration Factor**
**or**
$$P = (R_0 - R_1) \times G$$

## Equation 4-2 Convert Digits to Pressure

Since the linearity of most sensors is within 0.2% FS the errors associated with non-linearity are of minor consequence. However, for those situations requiring the highest accuracy it may be desirable to use a second order polynomial to get a better fit of the data points. The use of a second order polynomial is explained in Appendix C. Page 19.

The calibration sheet, a typical example of which is shown in figure 4 on page 5, shows the data from which the linear gage factor and the second order polynomial coefficients are derived. Columns on the right show the size of the error incurred by assuming a linear coefficient and the improvement, which can be expected by going to a second order polynomial. In many cases the difference is minor. The calibration sheet gives the pressure in specific engineering units. These can be converted to other engineering units using the multiplication factors shown in the table below.

| From → To ↓ | psi | "$H_2O$ | '$H_2O$ | mm $H_20$ | m $H_20$ | "HG | mm HG | atm | mbar | bar | kPa | MPa |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| psi | 1 | .036127 | .43275 | .0014223 | 1.4223 | .49116 | .019337 | 14.696 | .014503 | 14.5039 | .14503 | 145.03 |
| "$H_2O$ | 27.730 | 1 | 12 | .039372 | 39.372 | 13.596 | .53525 | 406.78 | .40147 | 401.47 | 4.0147 | 4016.1 |
| '$H_2O$ | 2.3108 | .08333 | 1 | .003281 | 3.281 | 1.133 | .044604 | 33.8983 | .033456 | 33.4558 | .3346 | 334.6 |
| mm $H_20$ | 704.32 | 25.399 | 304.788 | 1 | 1000 | 345.32 | 13.595 | 10332 | 10.197 | 10197 | 101.97 | 101970 |
| m $H_20$ | .70432 | .025399 | .304788 | .001 | 1 | .34532 | .013595 | 10.332 | .010197 | 10.197 | .10197 | 101.97 |
| "HG | 2.036 | .073552 | .882624 | .0028959 | 2.8959 | 1 | .03937 | 29.920 | .029529 | 29.529 | .2953 | 295.3 |
| mm HG | 51.706 | 1.8683 | 22.4196 | .073558 | 73.558 | 25.4 | 1 | 760 | .75008 | 750.08 | 7.5008 | 7500.8 |
| atm | .06805 | .0024583 | .0294996 | .0000968 | .0968 | .03342 | .0013158 | 1 | .0009869 | .98692 | .009869 | 9.869 |
| mbar | 68.947 | 2.4908 | 29.8896 | .098068 | 98.068 | 33.863 | 1.3332 | 1013.2 | 1 | 1000 | 10 | 10000 |
| bar | .068947 | .0024908 | .0298896 | .0000981 | .098068 | .033863 | .001333 | 1.0132 | .001 | 1 | .01 | 10 |
| kPa | 6.8947 | .24908 | 2.98896 | .0098068 | 9.8068 | 3.3863 | .13332 | 101.320 | .1 | 100 | 1 | 1000 |
| MPa | .006895 | .000249 | .002988 | .00000981 | .009807 | .003386 | .000133 | .101320 | .0001 | .1 | .001 | 1 |

## Table 2: Engineering Units Multiplication Factors

Note: Due to changes in specific gravity with temperature the factors for mercury and water in the above table are approximations!

## 4.2 Temperature Correction

Careful selection of materials is made in constructing the vibrating wire piezometer to minimize thermal effects, however, most units still have a slight temperature coefficient. Consult the supplied calibration sheet to obtain the coefficient for a given piezometer. Since piezometers are normally installed in a tranquil and constant temperature environment, corrections are not normally required. If however, that is not the case for a selected installation, corrections can be made using the internal thermistor ( see Figure 1) for temperature measurement. See Section 3.3 for instructions regarding obtaining the piezometer temperature.

Temperature correction equation is as follows;

**Temperature Correction = (Current Temperature - Initial Temperature) × Thermal Factor**

**or**

$$P_T = (T_1 - T_0) \times K$$

**Equation 4-3 Temperature Correction**

The calculated correction would then be **added** to the Pressure calculated using Equation 4-2. If the engineering units were converted remember to apply the same conversion to the calculated temperature correction!

For example, assume the initial temperature was 22° C, the current temperature is 15° C, and the thermal coefficient is –0.004326 PSI per °C rise (Figure 4). The temperature correction is +0.03 PSI

## 4.3 Barometric Correction (required only on <u>non</u>-vented transducers)

Since the standard piezometer is hermetically sealed and unvented, it responds to changes in atmospheric pressure. That being the case, corrections may be necessary, particularly for the sensitive, low pressure models. For example, a barometric pressure change from 29 to 31 inches of mercury would result in ≈1 PSI of error (or ≈2.3 feet if monitoring water level in a well!). Thus it is advisable to read and record the barometric pressure every time the piezometer is read. A separate pressure transducer (piezometer), kept out of the water, may be used for this purpose.
Barometric correction equation is as follows;

**Barometric Correction = (Current Barometer - Initial Barometer) × Conversion Factor**

or

$$P_B = (S_1 - S_0) \times F$$

**Equation 4-4 Barometric Correction**

Since barometric pressure is usually recorded in inches of mercury a Conversion Factor is necessary to convert to PSI. The Conversion Factor for inches of mercury to PSI is .491. Table 2 lists other common Conversion Factors.

The calculated barometric correction is **subtracted** from the Pressure calculated using Equation 4-2. If the engineering units were converted remember to apply the same conversion to the calculated barometric correction!

The user should be cautioned that this correction scheme assumes ideal conditions. In reality, conditions are not always ideal. For example, if the well is sealed, barometric effects at the piezometer level may be minimal or attenuated from the actual changes at the surface. Thus errors may result when applying a correction, which is not required. We recommend, in these cases, to independently record barometric pressure changes and correlate these with observed pressure changes to arrive at a correction factor.

An alternative to making barometric correction is to use piezometers that are vented to the atmosphere. Note section 4.3.1.

Equation 4-5 describes the pressure calculation with temperature and barometric correction applied.

$$P_{corrected} = ((R_0 - R_1)\times G) + ((T_1 - T_0) \text{ x } K) - ((S_1 - S_0) \text{ x } F)$$

**Equation 4-5 Corrected Pressure Calculation**

### 4.3.1 Vented Piezometers

Vented piezometers are designed to eliminate barometric effects. The space inside the transducer is not hermetically sealed and evacuated (see Figure 1), but is connected via a tube (integral with the cable) to the atmosphere. A chamber, containing desiccant capsules, is attached to the end of the tube to prevent moisture from entered the transducer cavity. Vented piezometers require more maintenance then non-vented types, and there is always a danger that water can find its way into the inside of the transducer and ruin it.

As supplied, the outer end of the desiccant chamber is closed by means of a seal screw to keep the desiccant fresh during storage and transportation. **THE SEAL SCREW MUST BE REMOVED BEFORE THE PIEZOMETER IS PUT INTO SERVICE!** The desiccant capsules are blue when fresh. They will gradually turn pink as they absorb moisture. When they have turned light pink in color they should be replaced. Contact Geokon for replacement capsules.

### 4.4 Environmental Factors

Since the purpose of the piezometer installation 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 the factors include, but are not limited to; blasting, rainfall, tidal levels, excavation and fill levels and sequences, traffic, temperature and barometric changes (and other weather conditions), changes in personnel, nearby construction activities, seasonal changes, etc.

## 5. TROUBLESHOOTING

Maintenance and troubleshooting of vibrating wire piezometers is confined to periodic checks of cable connections and maintenance of terminals. The transducers themselves are sealed and not user serviceable. Following are typical problems and suggested remedial action.

- **Piezometer fails to give a reading**

1. Check the resistance of the coils by connecting an ohmmeter across the gage terminals. Nominal resistance is 180Ω (±5%), plus cable resistance at approximately 15Ω per 1000' of 22 AWG wire. If the resistance is very high or infinite the cable is probably broken or cut. If the resistance is very low the gage conductors may be shorted. If a cut or a short is located in the cable, splice according to instructions in Section 2.7.
2. Check the readout with another gage.
3. The Piezometer may have been over-ranged or shocked. Inspect the diaphragm and housing for damage. Contact the factory.

- **Piezometer reading unstable**

1. Connect the shield drain wire to the readout using the green (GK-401) or the blue (GK-403) clip.
2. Isolate the readout from the ground by placing it on a piece of wood or similar non-conductive material.
3. Check for sources of nearby noise such as motors, generators, antennas or electrical cables. Move the piezometer cables if possible. Contact the factory for filtering and shielding equipment available.
4. The Piezometer may have been damaged by over-ranging or shock.
5. The body of the Piezometer may be shorted to the shield. Check the resistance between the shield drain wire and the Piezometer housing.

- **Thermistor resistance is too high**

1. Likely there is an open circuit. Check all connections, terminals and plugs. If a cut is located in the cable, splice according to instructions in Section 2.7.

- **Thermistor resistance is too low**

1. Likely there is a short. Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions in Section 2.7.
2. Water may have penetrated the interior of the piezometer. There is no remedial action.

## APPENDIX A - SPECIFICATIONS

| Model | 4500S | 4500AL[1] | 4500B | 4500C | 4580[2] |
|---|---|---|---|---|---|
| Available Ranges (psi) | 0-50<br>0-100<br>0-150<br>0-250<br>0-500<br>0-750<br>0-1000<br>0-1500<br>0-3000<br>0-5000<br>0-10000<br>0-15000 | 0-5<br>0-10<br>0-25 | 0-50<br>0-100<br>0-250 | 0-50<br>0-100<br>0-250 | 0-1<br>0-5 |
| Resolution | 0.025% FS | 0.025% FS | 0.025% FS | 0.05% FS | 0.01% FS |
| Linearity | 0.5% FS[3] | 0.5% FS[3] | 0.5% FS[3] | 0.5% FS[3] | 0.5% FS[3] |
| Accuracy | 0.1% FS[4] | 0.1% FS[4] | 0.1% FS[4] | 0.1% FS[4] | 0.1% FS |
| Over-Range | 2 × FS | 2 × FS | 2 × FS | 2 × FS | 2 × FS |
| Thermal Coefficient | <0.025% FS/°C | <0.05% FS/°C | <0.025% FS/°C | <0.05% FS/°C | <0.025% FS/°C |
| OD | .75"<br>19.05 mm | 1"<br>25.40 mm | .687"<br>17.45 mm | .437"<br>11.10 mm | 1.5"<br>38.10 mm |
| Length | 5.25"<br>133.35 mm | 5.25"<br>133.35 mm | 5.25"<br>133.35 mm | 6.5"<br>165.10 mm | 6.5"<br>165.10 mm |
| Frequency Range Hz | 1400-3500 | 1400-3500 | 1400-3500 | 1400-3500 | 1400-3500 |

**Table A-1 Vibrating Wire Piezometer Specifications**

Notes:

[1] Accuracy of test apparatus: 0.05%

[2] Other ranges available upon request.

[3] 0.1% FS linearity available upon request.

[4] Derived using 2$^{nd}$ order polynomial.

## APPENDIX B – STANDARD TEMPERATURE THERMISTOR TEMPERATURE DERIVATION

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

**Resistance to Temperature Equation B1:**

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

Where; T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = $1.4051 \times 10^{-3}$ (coefficients calculated over the –50 to +150° C. span)
B = $2.369 \times 10^{-4}$
C = $1.019 \times 10^{-7}$

| 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 B-1 STANDARD TEMPERATURE Thermistor Resistance versus Temperature**

## High Temperature Thermistor Linearization using SteinHart-Hart Log Equation

**Thermistor Type: Thermometrics BR55KA822J**

**Basic Equation B2:**

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

Where: T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = $1.02569 \times 10^{-3}$
B = $2.478265 \times 10^{-4}$
C = $1.289498 \times 10^{-7}$

Note: Coefficients calculated over -30° to +260° C. span.

**Table B2**

| Temp | R (ohms) | LnR | $LnR^3$ | Calculated Temp | Diff | FS Error | Temp | R (ohms) | LnR | $LnR^3$ | Calculated Temp | Diff | FS Error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -30 | 113898 | 11.643 | 1578.342 | -30.17 | 0.17 | 0.06 | 120 | 407.62 | 6.010 | 217.118 | 120.00 | 0.00 | 0.00 |
| -25 | 86182 | 11.364 | 1467.637 | -25.14 | 0.14 | 0.05 | 125 | 360.8 | 5.888 | 204.162 | 125.00 | 0.00 | 0.00 |
| -20 | 65805 | 11.094 | 1365.581 | -20.12 | 0.12 | 0.04 | 130 | 320.21 | 5.769 | 191.998 | 130.00 | 0.00 | 0.00 |
| -15 | 50684.2 | 10.833 | 1271.425 | -15.10 | 0.10 | 0.03 | 135 | 284.95 | 5.652 | 180.584 | 135.00 | 0.00 | 0.00 |
| -10 | 39360 | 10.581 | 1184.457 | -10.08 | 0.08 | 0.03 | 140 | 254.2 | 5.538 | 169.859 | 140.01 | -0.01 | 0.00 |
| -5 | 30807.4 | 10.336 | 1104.068 | -5.07 | 0.07 | 0.02 | 145 | 227.3 | 5.426 | 159.773 | 145.02 | -0.02 | -0.01 |
| 0 | 24288.4 | 10.098 | 1029.614 | -0.05 | 0.05 | 0.02 | 150 | 203.77 | 5.317 | 150.314 | 150.03 | -0.03 | -0.01 |
| 5 | 19294.6 | 9.868 | 960.798 | 4.96 | 0.04 | 0.01 | 155 | 183.11 | 5.210 | 141.428 | 155.04 | -0.04 | -0.01 |
| 10 | 15424.2 | 9.644 | 896.871 | 9.98 | 0.02 | 0.01 | 160 | 164.9 | 5.105 | 133.068 | 160.06 | -0.06 | -0.02 |
| 15 | 12423 | 9.427 | 837.843 | 14.98 | 0.02 | 0.01 | 165 | 148.83 | 5.003 | 125.210 | 165.08 | -0.08 | -0.03 |
| 20 | 10061.4 | 9.216 | 782.875 | 19.99 | 0.01 | 0.00 | 170 | 134.64 | 4.903 | 117.837 | 170.09 | -0.09 | -0.03 |
| 25 | 8200 | 9.012 | 731.893 | 25.00 | 0.00 | 0.00 | 175 | 122.1 | 4.805 | 110.927 | 175.08 | -0.08 | -0.03 |
| 30 | 6721.54 | 8.813 | 684.514 | 30.01 | -0.01 | 0.00 | 180 | 110.95 | 4.709 | 104.426 | 180.07 | -0.07 | -0.02 |
| 35 | 5540.74 | 8.620 | 640.478 | 35.01 | -0.01 | 0.00 | 185 | 100.94 | 4.615 | 98.261 | 185.10 | -0.10 | -0.04 |
| 40 | 4592 | 8.432 | 599.519 | 40.02 | -0.02 | -0.01 | 190 | 92.086 | 4.523 | 92.512 | 190.09 | -0.09 | -0.03 |
| 45 | 3825.3 | 8.249 | 561.392 | 45.02 | -0.02 | -0.01 | 195 | 84.214 | 4.433 | 87.136 | 195.05 | -0.05 | -0.02 |
| 50 | 3202.92 | 8.072 | 525.913 | 50.01 | -0.01 | -0.01 | 200 | 77.088 | 4.345 | 82.026 | 200.05 | -0.05 | -0.02 |
| 55 | 2693.7 | 7.899 | 492.790 | 55.02 | -0.02 | -0.01 | 205 | 70.717 | 4.259 | 77.237 | 205.02 | -0.02 | -0.01 |
| 60 | 2276.32 | 7.730 | 461.946 | 60.02 | -0.02 | -0.01 | 210 | 64.985 | 4.174 | 72.729 | 210.00 | 0.00 | 0.00 |
| 65 | 1931.92 | 7.566 | 433.157 | 65.02 | -0.02 | -0.01 | 215 | 59.819 | 4.091 | 68.484 | 214.97 | 0.03 | 0.01 |
| 70 | 1646.56 | 7.406 | 406.283 | 70.02 | -0.02 | -0.01 | 220 | 55.161 | 4.010 | 64.494 | 219.93 | 0.07 | 0.02 |
| 75 | 1409.58 | 7.251 | 381.243 | 75.01 | -0.01 | 0.00 | 225 | 50.955 | 3.931 | 60.742 | 224.88 | 0.12 | 0.04 |
| 80 | 1211.14 | 7.099 | 357.808 | 80.00 | 0.00 | 0.00 | 230 | 47.142 | 3.853 | 57.207 | 229.82 | 0.18 | 0.06 |
| 85 | 1044.68 | 6.951 | 335.915 | 85.00 | 0.00 | 0.00 | 235 | 43.673 | 3.777 | 53.870 | 234.77 | 0.23 | 0.08 |
| 90 | 903.64 | 6.806 | 315.325 | 90.02 | -0.02 | -0.01 | 240 | 40.533 | 3.702 | 50.740 | 239.69 | 0.31 | 0.11 |
| 95 | 785.15 | 6.666 | 296.191 | 95.01 | -0.01 | 0.00 | 245 | 37.671 | 3.629 | 47.788 | 244.62 | 0.38 | 0.13 |
| 100 | 684.37 | 6.528 | 278.253 | 100.00 | 0.00 | 0.00 | 250 | 35.055 | 3.557 | 45.001 | 249.54 | 0.46 | 0.16 |
| 105 | 598.44 | 6.394 | 261.447 | 105.00 | 0.00 | 0.00 | 255 | 32.677 | 3.487 | 42.387 | 254.44 | 0.56 | 0.19 |
| 110 | 524.96 | 6.263 | 245.705 | 110.00 | 0.00 | 0.00 | 260 | 30.496 | 3.418 | 39.917 | 259.34 | 0.66 | 0.23 |
| 115 | 461.91 | 6.135 | 230.952 | 115.00 | 0.00 | 0.00 | | | | | | | |

**Table B2 High Temperature. Temperature v Thermistor Resistance**

## APPENDIX C- NON LINEARITY AND THE USE OF A SECOND ORDER POLYNOMIAL TO IMPROVE THE ACCURACY OF THE CALCULATED PRESSURE

Most vibrating wire pressure transducers are sufficiently linear, ( ± 0.2 % FS), that use of the linear calibration factor satisfies normal requirements. However, it should be noted that the accuracy of the calibration data points, which is dictated by the accuracy of the calibration apparatus, is always ± 0.1 % FS.

This level of accuracy can be recaptured even where the transducer is non-linear, by the use of a second order polynomial expression, which gives a better fit to the data then does a straight line.

The polynomial expression has the form:

$$\text{Pressure} = AR^2 + BR + C$$

where R is the reading (digits channel B) and A,B,C, are coefficients. The figure on page 24 shows a calibration sheet of a transducer, which has a comparatively high non-linearity. The figure under the “Linearity (%FS)” column is

$$\frac{\text{Calculated pressure- True pressure}}{\text{Full-scale Pressure}} \times 100\% = \frac{G(R_0 - R_1) - P}{\text{F.S.}} \times 100\%$$

**Note: The linearity is calculated using the regression zero for $R_0$**

For example when P= 40 psi, G ($R_0$ - $R_1$) = 0.029021( 9145-7773), gives a calculated pressure of 39.817 psi. The error is 0.183 psi equal to 5 inches of water.
Whereas the polynomial expression gives a calculated pressure of A $(7773)^2$ + B (7773) + C = 39.996 psi and the actual error is only 0.004 psi or 0.1 inch of water.

Note. If the polynomial equation is used it is important that the value of C, in the polynomial equation, be taken in the field, following the procedures described in section 2.1.1. The field value of C is calculated by inserting the initial zero reading into the polynomial equation with the pressure, P, set to zero.

It should be noted that where changes of water levels are being monitored it makes little difference whether the linear coefficient or the polynomial expression is used.