The World Leader in Vibrating Wire Technology

48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603•448•1562
Fax: 603•448•3216
E-mail: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 6101

MEMS
Portable Tiltmeter

(Doc REV B 8/14)

Warranty Statement

Geokon, Inc. 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 which wear or which are damaged by misuse are not warranted. This includes fuses and batteries.

Geokon manufactures scientific instruments whose misuse is potentially dangerous. The instruments are intended to be installed and used only by qualified personnel. There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Geokon, Inc. is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Geokon, Inc. or any breach of any warranty by Geokon, Inc. shall not exceed the purchase price paid by the purchaser to Geokon, Inc. for the unit or units, or equipment directly affected by such breach. Under no circumstances will Geokon reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon, Inc. neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

TABLE of CONTENTS

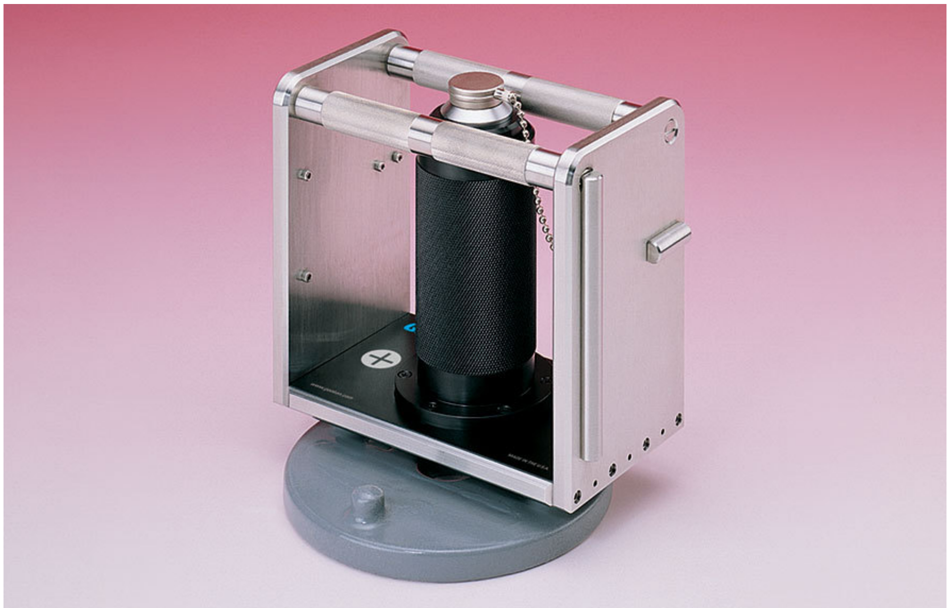


Figure 1. Model 6101 Portable Tiltmeter

1. Introduction

The Geokon Model 6101 MEMS Portable Tiltmeter is a precise, portable instrument designed to make rapid determinations of tilt in the monitoring of structures and soil and rock masses. It has applications in landslide monitoring, subsidence adjacent to excavations, tilting in buildings, retaining walls, bridge abutments, dams, etc.

2. Description

The MEMS tiltmeter system usually consists of three main components. They are the tiltmeter, the readout box and the tilt plate.

Tilt plates are designed to be permanently attached to the structure, either by epoxy bonding (ceramic plates) or by bolting, (stainless steel plates), (copper-coated aluminum plates).

The sensing element of the tiltmeter is a uniaxial MEMS sensor sealed in a waterproof housing. The output of the Geokon Model 6101 MEMS tiltmeter is equal to approximately +/- 4 volts at +/- 15°.The sensor is aligned on the tiltplate using alignment bars so that the same position and orientation is guaranteed for every reading.

The Readout Box may be either a Model GK604 Inclinometer Readout Box (plus the Model GK604-4 Bluetooth interface), or, the RB500 MEMS Readout Box

3. Installation and Use of the Tiltplates

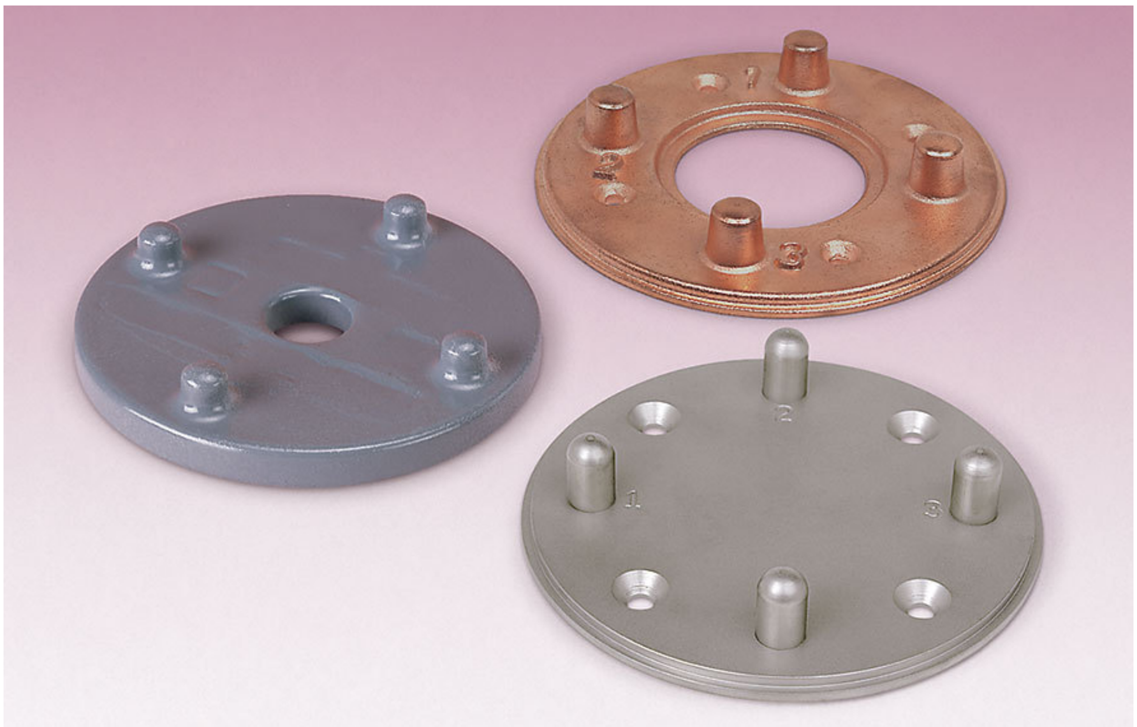


Figure 2. Tiltplates

Portable tiltmeters must be manually read so the location of the tiltmeter plate must be both protected and accessible. Covers are available for installations in areas where heavy construction is ongoing or where vandalism may be a problem.

The tiltplates should be installed on firm, clean surfaces as close to flat as is possible. Most installations utilize epoxy as the body-bonding medium. A resin such as Devcon VW 11800 can be used. The epoxy should be allowed to fully cure before readings commence.

The tilt plate that is being observed should have an I.D. number written on it

Some tiltplates are numbered 1 to 4 counter-clockwise and others **clockwise**. In the following the number in **bold** pertains to the **clockwise** numbering

For vertical installations such as building walls, bridge abutments, etc., the tilt plate pegs must be aligned as close to vertical as possible with Peg #1 at the top. See Figure 3

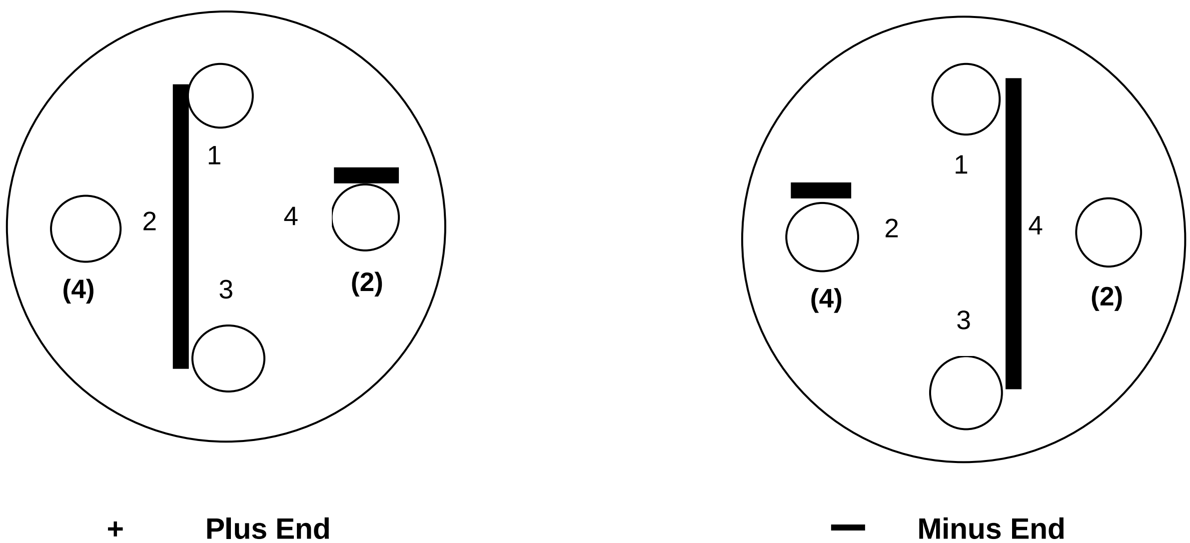


Figure 3. Measurements in the Vertical Plane

When taking readings in the **vertical plane** first hold the + end of the tiltmeter against the tiltplate so that the long bar lies to the left of pegs 1 and 3 and the short bar lies on top of peg 4,(**2**). Now take the first reading. Turn the tiltmeter end for end and position the long bar to the right of pins 1 and 3 with the short bar resting on top of peg 2(**4**). Now take the second reading. The second reading is the reverse (180°) of the first reading. Taking the difference of the two readings and dividing by two yields a number that eliminates any zero offset in the sensor. See Figure 3 for the positioning of the bars relative to the pegs.

For Horizontal installations point the Peg #1 in the same direction as the expected tilt. See Figure 4

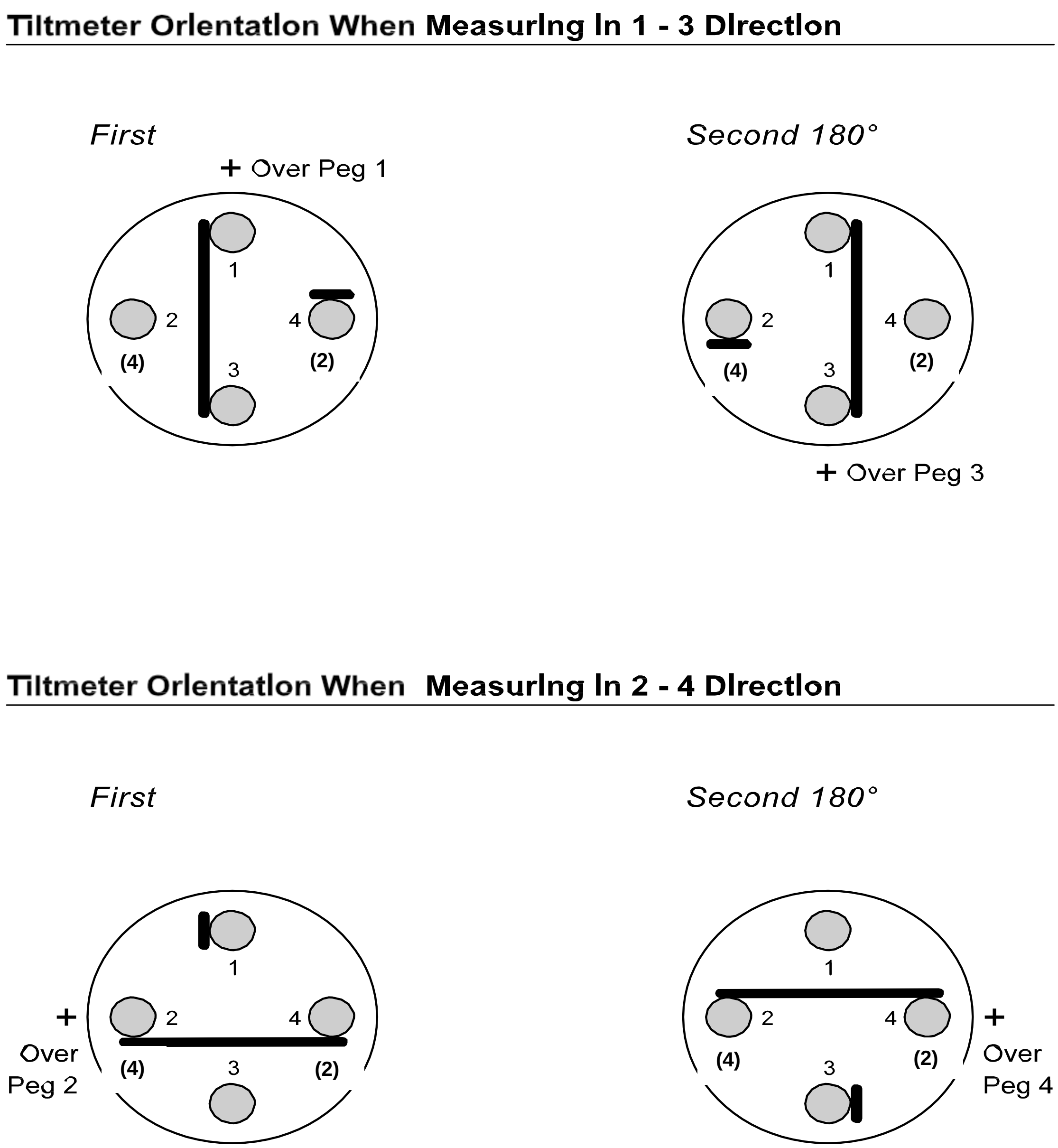


Figure 4. Measurements in the Horizontal Plane

When taking readings in the **horizontal plane** the tilt can be measured in two orthogonal directions. First hold the + end of the tiltmeter over peg 1, so that the long bar on the underside of the tiltmeter lies to the left of pegs 1 and 3 and the short bar lies against peg 4(**2**), as shown in figure 4 Now take the first reading. Turn the tiltmeter end for end so that the + end of the tiltmeter is over peg 3 and position the long bar to the right of pins 1 and 3 with the short bar resting against peg 2(**4**), as shown in figure 4. Now take the second reading. The second reading is the reverse (180°) of the first reading. This procedure eliminates any zero offset in the sensor.

Repeat the procedure for pegs 2 and 4 referring to figure 4 for the positioning of the long and short bars on the underside of the tiltmeter. Begin with the plus end of the tiltmeter over peg 2(**4**).

Note: If using ceramic tiltmeter plates care should be taken to avoid nicking or cracking the ceramic surface of the tiltplate pegs. The ceramic material is very brittle.

4. Taking Readings

4.1 Using the RB500 Readout Box

When using the RB500 readout Box the displayed reading is in Volts which can be converted to degrees tilt using the gage factor shown on the calibration sheet supplied with the tiltmeter. A typical Calibration Sheet is shown in Figure 5. The RB500 Readout Box does not store data so the readings must be entered into a field book. A typical Tiltmeter Data Sheet is shown in Figure 6

The polarity of the tiltmeter is set such that if tilted downward in the positive (+) direction the output will increase positively.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

MEMS Tilt Sensor Calibration

Model Number: MEMS Tilt Sensor

Calibration Date: November 22, 2013

Serial Number: 1333640

Calibration Instruction: CI-Tiltmeter MEMS

Temperature: 22.5 °C

Technician: K.D.Bellavance

Inclination (degrees)	Inclination (sinθ)	* Reading 1st Cycle (Volts)	* Reading 2nd Cycle (Volts)	* Average Reading (Volts)	Error in θ (%FS)	Calculated sinθ (%FS)
15.00	0.2588	4.084	4.084	4.0841	-0.16	0.01
14.00	0.2419	3.815	3.815	3.8150	-0.09	0.00
12.00	0.2079	3.274	3.275	3.2746	0.02	-0.01
10.00	0.1736	2.730	2.730	2.7298	0.08	-0.02
8.00	0.1392	2.182	2.182	2.1821	0.11	-0.02
6.00	0.1045	1.632	1.632	1.6321	0.11	-0.02
4.00	0.0698	1.080	1.080	1.0796	0.07	-0.02
2.00	0.0349	0.527	0.527	0.5266	0.03	-0.02
0.00	0.0000	-0.026	-0.026	-0.0259	0.00	0.00
-2.00	-0.0349	-0.581	-0.580	-0.5803	-0.06	0.00
-4.00	-0.0698	-1.134	-1.133	-1.1335	-0.10	0.00
-6.00	-0.1045	-1.685	-1.685	-1.6854	-0.12	0.00
-8.00	-0.1392	-2.236	-2.236	-2.2362	-0.14	-0.01
-10.00	-0.1736	-2.783	-2.783	-2.7829	-0.10	0.00
-12.00	-0.2079	-3.328	-3.327	-3.3277	-0.04	-0.01
-14.00	-0.2419	-3.869	-3.869	-3.8690	0.07	-0.02
-15.00	-0.2588	-4.137	-4.137	-4.1373	0.15	-0.02

6150, 6155 and 6170 In-Place Inclinometer Gage Factor (D): 0.0630 (sinθ/ Volt)

Deflection = DL(R_1-R_0) mm (inches)

6101, 6160 and 6165 Tiltmeter Gage Factor (G): 3.638 (degrees/ Volt) over + / - 15° range

Calculated Tilt = G(R_1 - R_0) degrees

Temperature Correction Factor -0.0003 (T_1-T_0) Volts / °C

Wiring Code: See manual for further 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.

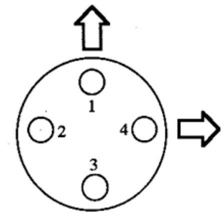
Figure 5. A Typical Tiltmeter Calibration Sheet

Tiltmeter Data Sheet

Instrument S/N ______________________ Readout Type ____________ S/N ______________

Tilt Plate Number ________________________

Location ____



Date	Time	Temp	Direction ____________				Direction ____________			
			Peg 1	Peg 3	Diff	Change	Peg 4	Peg 2	Diff	Change

Note: + Sign in the **Diff** and **Change** columns indicates tilt in the direction shown by arrows at top of page.

Figure 6. A Typical Tiltmeter Data Sheet

Connect the MEMS sensor to the Model RB500 readout box and check to see that the system is operating. Clean all dirt from both the sensor and the tiltplate. It is a good idea to let the sensor warm up for 2-3 minutes before taking readings. Follow the instructions of the RB500 readout box:

1) Connect the uniaxial MEMS Sensor to the readout box by means of the 10 pin plug or, if bare leads, by means of the terminal strip on the face panel following the printed color code on the panel.

RED:	+12V Power
RED'S BLACK:	GROUND
WHITE:	Channel A +Voltage Output
WHITE'S BLACK:	Channel A –Voltage Output
SHIELD:	Cable overall shield
GREEN:	Channel B +Voltage Output (Biaxial sensors only) or Thermistor + (Uniaxial sensors)
GREEN'S BLACK:	Channel B –Voltage Output (Biaxial sensors only) or Thermistor – (Uniaxial sensors)

Warning

Do not allow the RED and RED"S BLACK leads to touch each other, if the leads do touch each other it will blow the internal 0.6A Slo-Blo fuse. Additional fuses are supplied with the readout box.

2) Switch the power switch to the "ON" position.
3) Switch the selector switch to the "A" position.
4) Read the display and record the reading.
5) If a Biaxial sensor is connected, switch the selector switch to the "B" position.
6) Read the display and record the reading.
7) Power the unit off with the "OFF" switch.

4.2 When using a GK-603, or GK-604 readout box,

set the Gage Factor to the exact gage factor shown on the calibration sheet of the Model 6101 tiltmeter, (A typical calibration sheet is shown in Figure 5). the display will then be 20,000 sin θ such that at +/- 15 ° the readout box will display ± 5176 (make sure that in the "Configure Probe" screen the units are set to 2.0 sin θ and not 2.5 sin θ).

Connect the tilt meter to the GK 604 Bluetooth interface box using the cable supplied. Follow the instructions of the GK 604 inclinometer Readout Box.

5. Data Recording and Reduction

The data should be recorded on field sheets that have columns for the readings as in Figure 6. Position the tiltmeter such that the + is over peg 1. Record this number in the column labeled Peg 1. Rotate the unit 180° placing the plus (+) end over Peg 3. Record this data in the column headed Peg 3.

For Horizontal Tiltplates repeat the above for column pegs 2 and 4, always locating the plus (+) end of the sensor over the respective peg.

Note: *It is advisable to take the pairs of readings, one immediately after the other, to avoid the effects of temperature drift, etc.*

5.1 Example: of readings from a vertical tiltplate using a RB500 readout box

Peg 1 reading, (R1), = 0.0082 and Peg 3 reading, (R3), = –0.0099

(R1-R3) = (0.0082) – (–0.0099) = +0.0181

The conversion of this difference to degrees of angle is done as follows:

Tilt in degrees = G x (R1-R2)/2, where G is the Gage Factor shown on the tiltmeter calibration sheet – using the example in Figure 5, if G = 3.638 degrees /volt then the tilt = 3.638 x +0.0181/2 = +0.0329 degrees or +119 arc seconds. If a subsequent reading yields a tilt of say +142 arc seconds then the change of tilt is +23 arc seconds.

The change of tilt can be converted into a deflection using the conversion factor:

1 arc second = 0.0048mm/meter

or **1 arc second = 0.000058inches/ft**

Subsequent readings will show different values of tilting and the change can be recorded in the ‘Change’ column of figure 6.

5.2 **Example of readings taken from a horizontal tiltplate**

Four readings are taken; two each for Pin 1 and 3 and two each from Pins 2 and 4, following the instructions
of Section 4.

Reading Peg 1 to 3, (R1)	+0.0060 Volts
Reading Peg 3 to 1, (R3),	–0.0078 Volts
Reading Peg 2 to 4, (R2),	–0.0063 Volts
Reading Peg 4 to 2, (R4),	+0.0046 Volts

Peg 1 and 3. Tilt in this direction, (T13), is given by the difference,

$$(R1\text{-}R3) = +0.0060 - (-0.0078) = +\ 0.0138$$

Peg 2 and 4. Tilt in this direction, (T24) is given by the difference,

$$(R2\text{-}R4) = -0.0063 - (+0.0046) = -\ 0.0107$$

Note that the tilt is towards Peg 1 (positive) and towards Peg 4. (negative). (A positive figure for both T13 and T24 means that the tilt is towards Pin 1 and Pin 2.)

The magnitude of the tilt can be calculated in degrees from the formula:

$$\boldsymbol{\theta \text{ degrees} = G(R1\text{-}R3)/2 \text{ and } G(R2\text{-}R4)/2}$$

Using the G factor example as before

The tilt in the Peg 1 direction, (T13), is 3.638(+0.0138)/2 = +0.0251 degrees

The tilt in the Peg 4 direction, (T24), is 3.638(-0.0107)/2 = -0.0195 degrees

These two tilts can be combined, to give the maximum resultant tilt and its direction. This is done by first calculating the deflections, (D13) and (D24), This is done using the relationships 1 arc second = 0.0048mm/m or 1 arc second = 0.00062 inches/ft

In the above example (D13) = (T13) x 3600 x 0.0048 =+ 0.43mm/m and

(D24) = (T24) x 3600 x 0.0048 = - 0.34mm/m

The maximum deflection, Dmax, is given by the equation

$$Dmax = \sqrt{[(D13)^2 + (D24)^2]}$$

And the angle **θ,** the angle between the direction of Peg 1 and the direction of the maximum tilt, is given by the formula

$$\theta = Tan^{-1}[(D24)/(D13)$$

In the above example the maximum deflection would be

$$Dmax = \sqrt{[(0.43)^2 + (-0.34)^2]} = 0.55mm/m$$

And the direction is 38 degrees from the direction of Peg 1 in the direction of Peg 4

To convert Dmax into Tmax use the formula

$$Tmax = Dmax /0.0048 \times 3600$$

In this case the maximum tilt would be 0.032 degrees

5.3 Vertical Tiltplates with dual axes

In order to measure tilting in two axes with a vertical tiltplate it is necessary to have two tiltplates oriented at 90 degrees to each other, e.g. mounted on adjacent faces of a square column. In this case the reasoning of section 5.2 can be used to calculate the maximum tilt and direction.

6. Troubleshooting

The main concerns of tiltmeter surveys are the measurement of change in magnitude and direction of rotational movement. The zero offset of the sensor is not critical because the algebraic difference of the two readings eliminates the effect. A tiltplate tilted at an angle and located on a stable surface can be read periodically to check the calibration of the instrument. The sensor itself should not be opened in the field and if the unit fails to work it should be returned to Geokon for repair.

7. Specifications Model 6101 MEMS Portable Tiltmeter

Range	±15°
Output at +/- 15º	+/- 4 Volts DC (Nominal)
Input Supply Voltage[3]	9 to18 Volts DC
Input Supply Current	25 mA
Resolution[1]	± 2 arc seconds (+/- 0.05mm/m)
Accuracy[2]	± 5 arc seconds.
Thermal zero shift	0.0003volts/ºC rise
Temperature Range, Operating	-0 to+ 50°C
Temperature Range, Storage	–25 to +70°C
Shock Survival	20,000g
Dimensions	Sensor: 159 x 89 x 143mm
Weight	6.5Kg(including case)
Connector	Lemo ERA 3E30CNL

Notes:

[1] Depends on readout equipment. For best results requires a 4 ½ digit digital voltmeter. Averaging will yield resolution on the order of 2 arc seconds

[2] Based upon the use of a second order polynomial

[3] Voltages in excess of 18V will damage the circuitry and are to be avoided