RST INSTRUMENTS LTD.

NATM Style
Vibrating Wire Concrete
Stress Cells
Instruction Manual

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Vibrating Wire Concrete Stress Cells
NATM Style

Product: Vibrating Wire Concrete Stress Cells (NATM Style)
Instruction Manual

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1 INTRODUCTION

1.1 THEORY OF OPERATION

The "New Austrian Tunneling Method", N.A.T.M., calls for the support of a tunnel by the rapid application of shotcrete to freshly exposed ground. The theory behind this method of support, which is particularly useful in weaker ground, is that if the inherent strength of the ground can be preserved, it will be almost self-supporting and will require much less artificial support in the form of concrete or steel. To preserve the inherent cohesion of the ground it is necessary to prevent it from breading up the first place and, hence, the need for a rapidly applied layer of shotcrete.

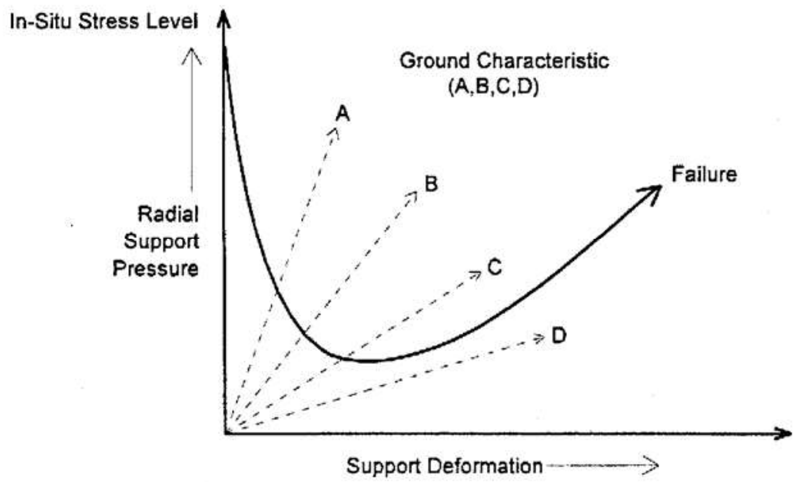

Figure 1 Ground Reaction Curve

The above figure graphically shows the ground reaction curve, i.e., the amount of support required versus the amount of inherent support and ground deformation. Thus, to prevent any support deformation (or tunnel closure) at all, would require a support pressure exerted-on the tunnel walls equal to the original in-situ ground stress.

A strong lining with characteristics of curve A would allow only a small amount of ground deformation, but might, because it is too strong, is uneconomical. A thinner lining which would allow more deformation would have characteristics of curves B or C. However, a lining which is too thin, with characteristics shown by curve D, would allow too much deformation of the rock allowing it to weaken and ultimately fail.

The task of the N.A.T.M. stress cells is to provide a measure of the support pressure which, when coupled with a measurement of tunnel closure, using a tape extensometer, will allow an assessment to be made of the adequacy of the shotcrete lining, indicating the need for perhaps more or less shotcrete to maintain stability. It is this ability to monitor the performance of the shotcrete lining that can lead to significant reductions in tunnel support costs.

1.2 STRESS CELL DESIGN AND CONSTRUCTION

The cell is comprised of 4 parts, the Diaphragm, Sensor Body, Fluid Body, and Pinch Tube. The Diaphragm consists of two stainless steel rectangular plates welded together around their perimeter, leaving a thin void between the plates. The Fluid Body is the volume of de-aired fluid in the system. It is the medium through which the pressure, witnessed by the plates, is transmitted to the Transducer, housed within the Sensor Body. In addition to protecting the sensor, the Sensor Body also provides a sealed chamber for attaching the Instrument Cable, and a Thermistor. The Pinch Tube provides a means to inflate the cell after the Shotcrete has cured. Inflating the cell is necessary, to fill any voids that may have been created, due to thermal expansion of the cell as the Shotcrete begins to cure and thermal contraction as the cell stabilizes at ambient temperature.

Mounting ears are provided at the corners of the Diaphragm to provide a means of securing the Cell while the shotcrete is applied.

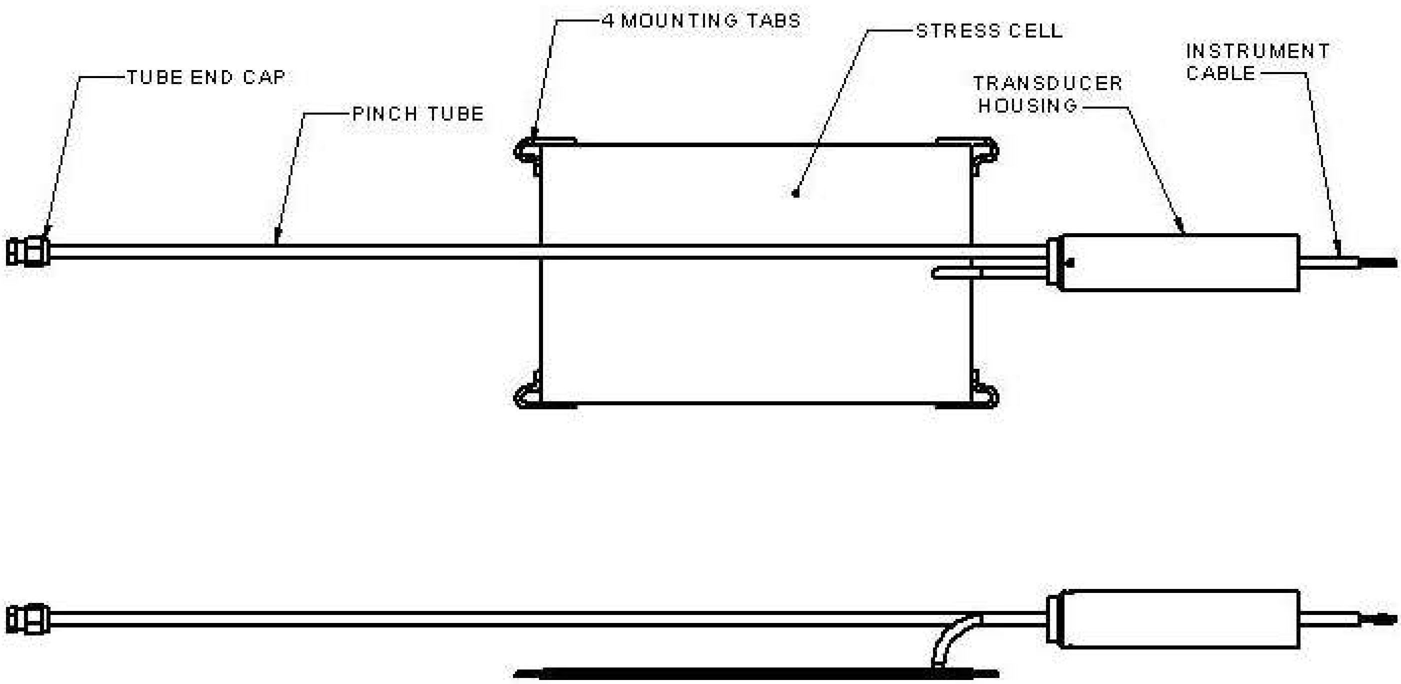

Figure 2 Concrete Stress Cell GA

2 INSTALLATION

2.1 PRELIMINARY TESTS

Prior to installing the Cell, a few function checks should be performed. Each Cell is supplied with a calibration sheet showing electrical connections, and the relationship between readout digits and pressure. After making the electrical connections, compare the current zero reading with the zero reading on the Cells Calibration Sheet. The two readings should not differ by more than ~50 counts. Now apply a load to the Cell, by pressing down on Diaphragm Plates, and verify a corresponding change on the readout. Witness the readout returning to the zero reading when the load is removed.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gauge leads should be approximately 150 ohms ±20 ohms. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000” or 48.5Ω/km, multiply by 2 for both directions). Between the green and white should be approximately 3000 ohms at 25^o (see Table B-1), and between any conductor and the shield should exceed 20 MΩ.

2.2 STRESS CELL INSTALLATION

Cells are positioned on the wall of the tunnel in two ways, one way to measure tangential stresses and the other to measure radial.

2.2.1 TANGENTIAL CELL (VW3201) INSTALLATION

The Tangential Cell is designed to measure *tangential* stresses in the lining, and must be installed perpendicular to the tunnel lining. One way of achieving this, would be to grout short pieces of rebar into the tunnel lining and tie, the cells mounting tabs, onto the rebar using soft iron wire. The cable should be routed to the junction box securing it to other pieces of rebar or to the reinforcing mesh. The cable is terminated inside this box.

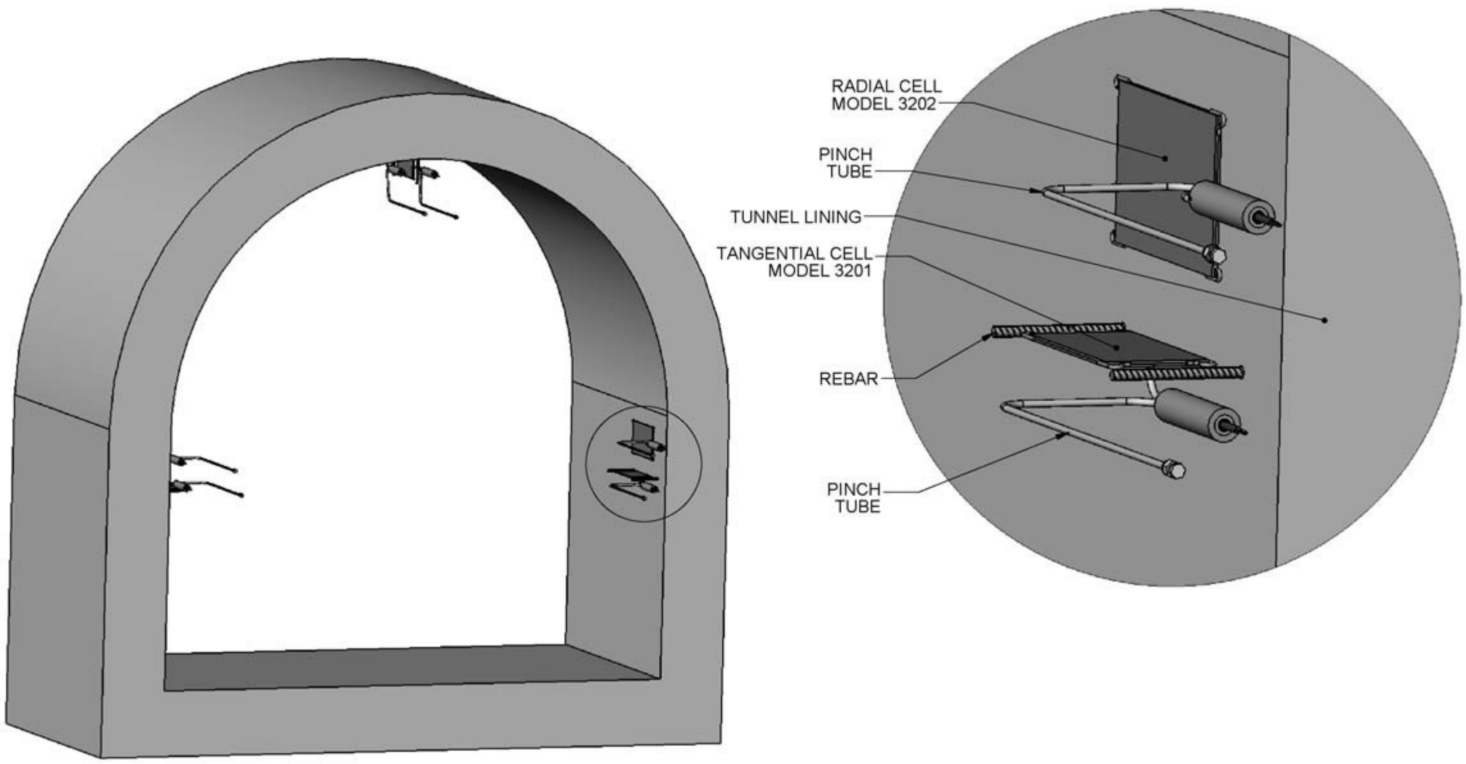

Figure 3 – General Arrangement

The pinch tube should be bent so that it will protrude from the lining of shotcrete after it has been applied. Or it can be wrapped in foam, plastic, etc. so that it can be dug out and accessed after shotcreting.

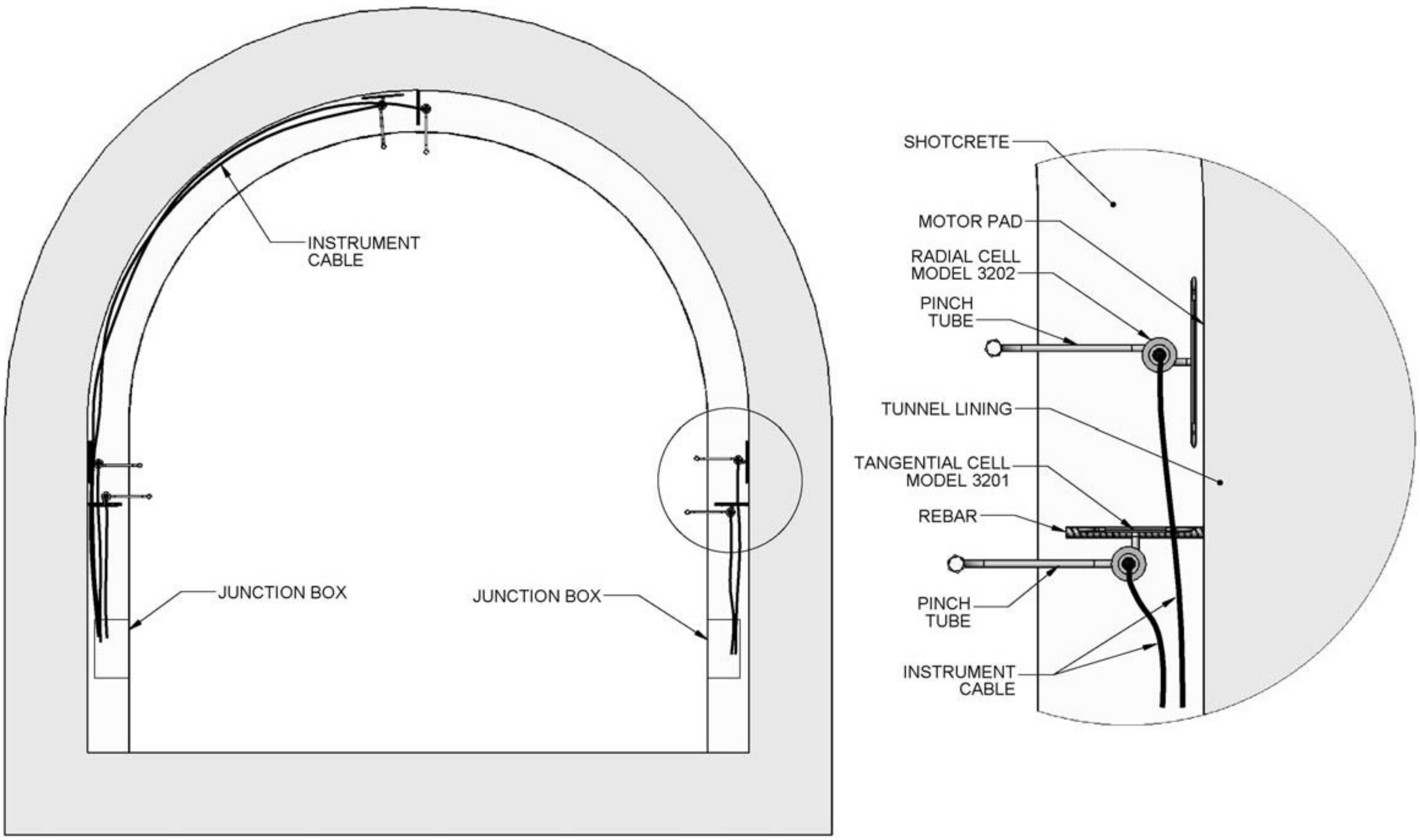

Figure 4 –Post Shotcrete General Arrangement

2.2.2 Radial Cell (VW-3202) Installation

The Radial Cell is designed to measure *radial* pressures in the tunnel lining. To compensate for any irregularities in the rock surface, a pad of quick setting mortar should be used in between the rock surface and the Cell.

Install nails, pins, spades, or pieces of rebar, adjacent to the cell location, so that the cell can be secured in position when necessary. Make a pad of quick setting mortar on the surface of the tunnel. Place the Cell onto the pad and then press down on the cell causing the mortar to extrude from beneath the cell. Secure the cell in place using the previously installed hardware.

The cable is routed to the readout location and secured intermittently along the way to installed hardware (rebar, nails, etc.) or to the reinforcing mesh (Refer to Sections 2.3 & 2.4).

The pinch tube should be bent so that it will protrude from the lining of shotcrete after it has been applied. Or it can be wrapped in foam, plastic, etc. so that it can be dug out and accessed after shotcreting.

2.3 Cable Handling

The cable should be protected from accidental damage caused by moving equipment or flying rock. This is best done by putting the excess cable inside a junction box.

Cables may be spliced to lengthen them, without affecting gauge readings. Always waterproof the splice completely, preferably using an epoxy based splice kit such as the 3M Scotchcast™, model 82-A1. These kits are available through RST Instruments Ltd.

2.4 Electrical Noise

Care should be exercised when installing instrument cables to keep them as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run with AC Power lines. The instrument cables will pick up the 50 or 60Hz (or other frequency) noise from the power cable and this will likely cause a problem obtaining a stable reading. Contact RST Instruments concerning filtering options available for use with RST dataloggers and readouts should difficulties arise.

2.5 Initial Readings

Before shotcreting, take initial readings on all the cells and record in the field book. Take all initial temperatures also using either a VW2104 Readout Box or a digital ohmmeter (if necessary refer to the respective Readouts Operating Manual).

2.6 Re-Pressurizing the Cell

Due to thermal expansion and contraction of the Cell as the Shotcrete cures, a process known as Heat of Hydration, voids may be created between the Cell and the cured Shotcrete. To eliminate these voids, and ensure data integrity, the Cell must be inflated which can be achieved by displacing the fluid in the pinch tube and forcing it into the Cell.

After shotcreting, record the cell's temperature and initial reading again. Once the temperature has stabilized to ambient, the cell can be inflated by squeezing the Pinch Tube using the Pinch Tube Crimper tool. The cell is first connected to the readout (see section 4) and then the Crimpers are used to squeeze the pinch tube flat beginning at the capped end.

> **Caution:** Do not crimp the pinch tube closer than one inch from the Tube End Cap.

As the tube is progressively flattened, the de-aired fluid is forced out of the tube and into the cell. As the cell expands, the pressure rise accompanying each pinch will be small (only one or two digits). If this is the case, cease pinching immediately. Once all of the voids between the cured shotcrete and the Cell are eliminated, the readings will begin to increase sharply, with every additional squeeze of the Pinch Tube.

> **Caution:** It is also possible that the cell is already in good contact with the shotcrete, so pinching the tube, will immediately cause a sharp rise in the cell pressure. Continued pinching after the cell has made good contact could cause the concrete around the cell to split open.

Graphing the relationship between the length of flattened pinch tube and the corresponding reading on the readout box will help to indicate when the voids are eliminated and its time to stop squeezing the Pinch Tube.

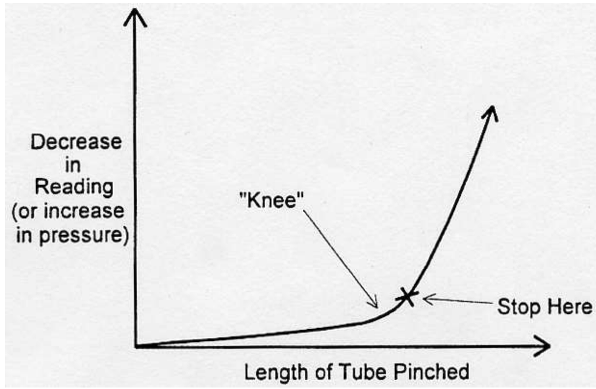

Figure 5 – Cell Re-Pressurization Graph

3 TAKING READINGS

3.1 OPERATION OF THE VW2102 READOUT BOX

The VW2102 is a basic readout for all vibrating wire gauges.

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 gauge, the green or blue clip for the shield drain wire. The VW2102 cannot read the thermistor (see section 3.4).

1. Turn the display selector to position “B”. Readout is in digits (Equation 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.

3.2 OPERATION OF THE VW2104 READOUT BOX

The VW2104 can store gauge readings and also apply calibration factors to convert readings to engineering units. Consult the VW2104 Instruction Manual for additional information on Mode “G” of the Readout. The following instructions will explain taking gauge measurements using Mode “B”.

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

1. Turn the display selector to position “B”. Readout is in digits (Equation 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 no reading displays or the reading is unstable, see section 5 for troubleshooting suggestions. The thermistor will be read and output directly in degrees Celsius.
3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.3 MEASURING TEMPERATURES

Each Vibrating Wire Concrete Stress Cell 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.

1. Connect an ohmmeter to the two thermistor leads coming from the stress cell. Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.
2. Look up the temperature for the measured resistance in Table B-1. Alternately the temperature could be calculated using Equation B-1.

Note
The VW2104 readout box will read the thermistor and display temperature in ^{o}C automatically.

4 DATA REDUCTION

4.1 PRESSURE CALCULATION

The basic units utilized by RST for measurement and reduction of data from Vibrating Wire Concrete Stress Cells are "digits". Calculation of digits is based on the following equation:

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

Equation 1 – Digits Calculation

To convert digits to pressure the following equation applies:

Pressure = (Initial Reading – Current Reading) x Calibration Factor

or

$P = (R_o - R_1) \times C$

Equation 2 – Convert Digits to Pressure

The *Initial Reading* is normally obtained during installation (usually the zero reading). The *Calibration Factor* (usually in terms of psi or MPa per digit) comes from the supplied calibration sheet.

4.2 TEMPERATURE CORRECTION

The vibrating wire sensor is relatively insensitive to temperature fluctuations and usually the effect of temperature is insignificant and can be ignored. But, if desired, correction for temperature effects on the sensor can be made using the factors supplied on the calibration sheet. See Equation 3. Also, there are spurious temperature effects caused by the mismatch between temperature coefficients of the cell and surrounding concrete. This effect is not quantifiable in the laboratory and hence no correction factor for this effect can be supplied.

Temperature Correction = (Current Temperature – Initial Temperature) x Thermal Factor

or

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

Equation 3 – Temperature Correction

5 TROUBLESHOOTING

Maintenance and troubleshooting of Vibrating Wire Concrete Stress Cells is confined to periodic checks of cable connections. Once installed, the cells are usually inaccessible and remedial action is limited.

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

Symptom: Stress Cell Readings are Unstable

- ✓ Is the readout box position set correctly? If using the datalogger to record readings automatically are the swept frequency excitation settings correct? Channel A or the VW2102 and VW2104 can be used to read the stress cells. To convert the Channel A period display to digits use Equation 1.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the VW2102 Readout connect the clip with the green boot to the bare shield drain wire of the stress cell cable. If using the VW2104 connect the clip with the blue boot to the shield drain wire.
- ✓ Does the readout work with another stress cell? If not, the readout may have a low battery or may be malfunctioning.

Symptom: Stress Cell Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gauge leads (usually red and black leads) is 150Ω, ±20Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance read infinite, or very high (megaohms), a cut wire must be suspected. If the resistance reads very low (<100Ω) a short in the cable is likely.
- ✓ Does the readout or datalogger work with another stress cell? If not, the readout or datalogger may be malfunctioning.

6 APPENDIX A – SPECIFICATIONS

Model:	Tangential Cell	Radial Cell
Ranges:	7 MPa (1000psi) 20 MPa (3000psi)	2 MPa (300psi) 3.5 MPa (500psi) 5 MPa (750psi)
Sensitivity:	0.025% F.S.	
Accuracy:	0.10% F.S.	
Linearity:	0.25% F.S. (standard) 0.1% F.S. (optional)	
Dimensions:	100 x 200mm (4x8")	150 x 250mm (6x10")
Pinch Tube Length:	600mm	
Material:	303 & 304 Stainless Steel	
Electrical Cable:	2 twisted pair (4 conductor) 22 AWG Foil shield, PU jacket, nominal OD = 6.3mm (0.250")	

Please consult RST Instruments Ltd. for other sizes or options available.

6.1 THERMISTOR (SEE ALSO APPENDIX B)

Range: -80 to +150°C

Accuracy: ±0.5°C

7 APPENDIX B – THERMISTOR TEMPERATURE DERIVATION

Temperature calculated using:

Steinhart-Hart Linearization

$$T_C = \frac{1}{C_0 + C_1(\ln R) + C_3(\ln R)^3} - 273.15$$

3000 Ohm @ 25C NTC Thermistor

C_0= 0.0014051
C_1= 0.0002369
C_3= 0.0000001019
lnR= Natural Log of Resistance
T_c= Temperature in ^oC

3000 Ohm NTC Thermistors

Ohms	Temp º C	Ohms	Temp º C	Ohms	Temp ºC	Ohms	Temp º C	Ohms	Temp º C
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
77.99K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-35	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	282.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	56.92	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965	53	250.9	93	83.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	3000	25	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150