Technical Note – TN-3
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Temperature Compensation of a Wheatstone Bridge

Introduction

If semiconductor strain gages are directly installed into a constant voltage Wheatstone bridge, it is likely that the null balance, i.e. the bridge output at no load, would be non-zero. Also, the bridge output would be very sensitive to any temperature changes the strain gages may experience. To bring the bridge to a near zero output condition at no load and to have the bridge self-compensate for changes in temperature, the bridge can be nulled and compensated using a set of series and shunt resistors in the bridge circuit.

Temperature Compensation Scheme

Figure 1 shows the possible null-balance and temperature compensation resistors which could be added to the basic Wheatstone bridge circuit. The resistors consist of series resistor, RS, and parallel resistor, RP, before the bridge, the RZ1 and RZ4 shunt resistors acting on gages G1 and G4, respectively, and RB2 and RB3 series resistors acting on the left and right branches, respectively, in the bridge. Only one shunt resistor, RZ1 or RZ4, is needed and only one series resistor, RB2 or RB3, is needed.

To wire up the bridge, the RED is connected to the positive source, the BLK and YEL are connected to the negative source, the GRN is connected to the positive signal line and the WHT is connected to the negative signal line.

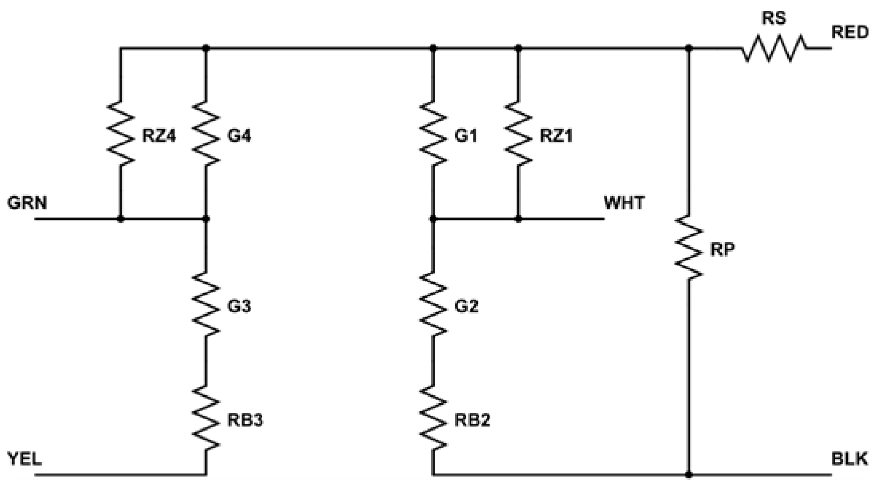

Figure 1: Compensation resistors to achieve null output at zero load and compensation for temperature changes in a constant voltage bridge. Yellow and Black leads are connected together in the final bridge configuration.

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Experimental Temperature Compensation for New Users

The information in this section is presented for the benefit of a user who has no prior experience with semiconductor strain gages and temperature compensation of Wheatstone bridges that use semiconductor strain gages. The user can use the default resistance values given in this section to get a better understanding of bridge behavior.

It has been found that the temperature coefficient of resistance of Piezo-Metrics gages are quite well matched. This matching means that the gages change resistance with temperature at the same rate. So, in general, no shunt resistor, RZ1 or RZ4, is needed.

Also, it has been found that a RS and RP equal to 1000 or 3000 ohms allows a good degree of temperature compensation to be obtained for strain gage resistances less than 1000 ohms. The null condition can be achieved by selecting the proper series resistor RB2 or RB3.

It should be noted that these values of RS, RP, RZ1, RZ4 and RB2 or RB3 will not scale the bridge output to a desired value. Calibration of the bridge output is found by measuring the bridge output at full-scale load. The calibration factor is in terms of unit load per volt.

The value of RB2 and RB3 can be calculated using the following equations,

assuming RB2 = 0,

$$RB3 = \frac{RG2 \cdot RG4 - RG1 \cdot RG3}{RG1} \tag{1}$$

assuming RB3 = 0,

$$RB2 = \frac{-RG2 \cdot RG4 + RG1 \cdot RG3}{RG4} \tag{2}$$

where RBn and RGn are resistance values of the series resistor and gage resistance, respectively. The proper series resistor, RB2 or RB3, will be indicated by a positive value for either equation 1 or 2.

NOTE: It is recommended to measure the higher strains with gages G1 and G3 and the lower strains with gages G2 and G4. For example, in a tension sensor, assign the gages oriented in the axial direction to positions G1 and G3 and assign the gages oriented in the transverse direction positions G2 and G4.

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The output of the bridge at full load is determined by,

$$\frac{e_0}{E_{exc}} = \frac{1}{4}\left(\frac{\Delta R_1}{R} - \frac{\Delta R_2}{R} + \frac{\Delta R_3}{R} - \frac{\Delta R_4}{R}\right) \qquad (3)$$

where

- e_0 is the bridge output,
- E_{exc} is the bridge excitation voltage,
- R is the nominal strain gage resistance,
- ΔR_n is the change in resistance of strain gage n.

The power dissipated, P, by each strain gage in a standard full-bridge configuration with a nominal resistance of R is calculated by,

$$P = \frac{1}{4}\frac{E_{exc}^2}{R} \qquad (4)$$

The power dissipated by the strain gage should be kept to 5 mW or lower to prevent too much self-heating.

The relationship between the change in gage resistance and the structural strain is,

$$\frac{\Delta R}{R} = GF \cdot \varepsilon \qquad (5)$$

where

- GF is the gage factor,
- ε is the structural strain.

Therefore, the full scale bridge output, e0, is determined by the amplitude of structural strain at full load, the strain gage’s gage factor, the positioning of the four strain gages in regions of tension and compression, and the bridge excitation voltage.

The instrumentation used to measure e0 must have sufficient resolution and noise suppression to obtain high signal-to-noise results.

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Worked Example

RG1 (ohms)	RG2 (ohms)	RG3 (ohms)	RG4 (ohms)
478.0	487.7	480.2	490.3

Inserting the resistance values of G1 to G4 into equations 1 and 2, RB3 is equal to 20 ohms and RB2 is equal to -19.5 ohms. Therefore, a 20 ohm resistor is needed in the RB3 position.

The final Wheatstone bridge configuration is:

RS = 1000 ohms
RP = 3000 ohms
RZ1 = infinite
RZ3 = infinite
RB2 = 0 ohms
RB3 = 20 ohms

Typically, a 5 VDC excitation voltage is used. For the above bridge configuration where the average gage resistance is 484 ohms and accounting for the RS only as an approximation of the circuit, the excitation voltage across the bridge is 695 mV. The power dissipated by the strain gage is therefore 0.25 mW which will minimize changes in gage resistance due to self-heating.

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Experimental Temperature Compensation for Experienced Users

The information in this section is presented assuming the user is familiar with temperature compensation of Wheatstone bridges using semiconductor strain gages and is interested in obtaining a temperature compensation solution for the user's sensor that is zero balanced and linearized to the full-scale load. Piezo-Metrics works with the client to deliver the temperature compensation solution.

The client wires the sensor using the 5-wire open bridge configuration. For a full-bridge implementation, the client makes 24 measurements consisting of 4 resistances x 3 temperatures x 2 loads.

NOTE: It is recommended to measure the higher strains with gages G1 and G3 and the lower strains with gages G2 and G4. For example, in a tension sensor, assign the gages oriented in the axial direction to positions G1 and G3 and assign the gages oriented in the transverse direction positions G2 and G4. The Piezo-Metrics online temperature compensation calculator is set-up for this configuration.

Client measurements:

1. Condition the gaged structure to ambient temperature conditions and then:

1.1 Apply zero load to the structure.

1.2 Measure the G1, G2, G3, G4 gage resistances and record the structure ID and data in the format defined by Piezo-Metrics.

1.3 Apply full-scale load to the structure.

1.4 Measure the G1, G2, G3, G4 gage resistances and record the structure ID and data in the format defined by Piezo-Metrics.

2. Condition structure to cold temperature conditions, repeat steps 1.1 to 1.4.

3. Condition structure to hot temperature conditions, repeat steps 1.1 to 1.4.

Temperature Compensation solution:

1. Enter the measured strain gage values into the Piezo-Metrics online temperature compensation calculator is available at www.piezo-metrics.com/services.

2. Piezo-Metrics calculator app solves the values of the series resistors, RB2 and RB3, and shunt resistors, RZ1 and RZ4, along with the bridge series and shunt resistors, RS and RP, which constitute the passive resistor network that temperature compensates the client's sensor.

3. (Optional) Piezo-Metrics can deliver to the client, for a nominal fee, a small PCB containing the temperature compensation resistors for direct hook-up to the sensor's Wheatstone bridge and to the client's instrumentation.

Additional Information

For more information about temperature compensation, please visit the Piezo-Metrics website at www.piezo-metrics.com and enter questions into the Customer Service Agent. Questions can be similar to:

‘tell me more about temperature compensation’

‘tell me how to use the temperature compensation calculator’

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