Bondable Resistance Temperature Sensors and Associated Circuitry

1.0 Introduction

Vishay Micro-Measurements manufactures a line of resistance temperature sensors that are constructed much like wide-temperature-range strain gages, but which utilize high-purity nickel-foil sensing grids. These temperature sensors are bonded to structures using standard strain gage installation techniques, and can measure surface temperatures from –320° to approximately +500°F [–195° to +260°C].

This Tech Note discusses the operational characteristics of nickel temperature sensors, as well as various methods of data readout. The standard line of temperature sensors and matching networks for use with strain indicators is listed in the Precision Strain Gages Data Book.

The resistance of high-purity nickel increases rapidly with temperature, following a repeatable and stable curve to over +500°F [+260°C]. As shown in Figure 1, the resistance changes are quite large, resulting in high signal levels. Figure 1 also includes a curve for Balco® alloy, discussed in Section 6. Note that a reference value of 50.0 ohms occurs at a temperature of +75.0°F [+23.9°C] in Figure 1. All standard Vishay Micro-Measurements TG temperature sensors are manufactured to this nominal value, but gages of other resistance values are available on special order. The resistance-versus-temperature characteristic of sensors having nonstandard reference resistances can be expressed directly as a percentage of the nominal +75.0°F [+23.9°C] value by multiplying the ordinate in Figure 1 by a factor of 2.0.

Tables are given later in this Tech Note for obtaining resistance values of TG sensors at various temperatures to a higher accuracy than is readable in Figure 1. These tables are also referenced to a value of 50.0 ohms at +75.0°F [+23.9°C] and can be multiplied by a factor of 2.0 to obtain resistances of nonstandard sensors as a percentage of their +75.0°F [+23.9°C] value.

2.0 Sensor Installation

TG temperature sensors are installed with the same techniques and materials used for installation of wide-temperature-range strain gages. M-Bond 600 or 610 adhesives are usually employed because they are useful over the entire temperature range of the sensor itself. Surface preparation techniques are given in Instruction Bulletin B-129, and specific installation procedures are included in the selected adhesive kit.

Balco is a Trademark of W.B. Driver Co.

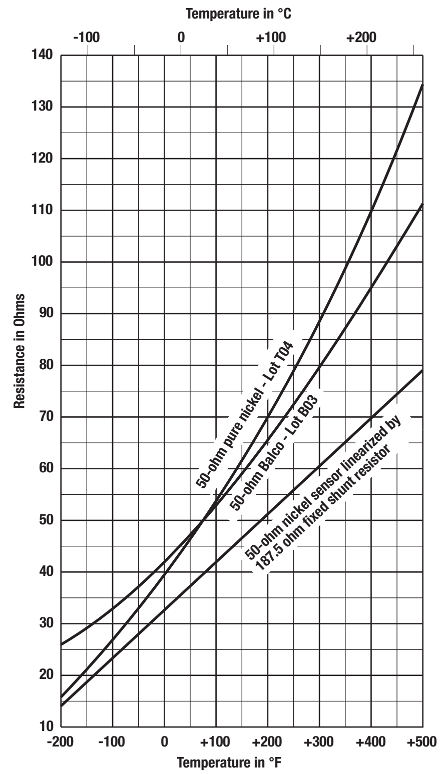

Figure 1. Variation of resistance with temperature for 50-ohm sensors mounted on 1018 steel.

Leadwires are normally handled in the same way as those for strain gages, with one significant difference. The three-wire system used with strain gages to eliminate errors due to temperature-induced resistance changes in the leadwires is not generally effective with TG sensors. This subject is treated at greater length in Sections 3 and 5.

3.0 Readout Methods

One method of reading temperature with TG temperature sensors is to connect the sensor to a Wheatstone resistance bridge, and convert the resistance readings to equivalent temperatures with the tables given in this Tech Note. But, the leadwires can cause two different errors in a Wheatstone bridge. First, the resistance of the leads, which can be appreciable with remote gages, produces an initial offset error, and desensitizes the arm of the bridge containing the temperature sensor. The second error is the result of resistance change in the leads caused by temperature variations. Except under unusual conditions, errors of this type are very small. In cases where long leadwires are necessary, special calibration techniques or compensation systems can be used.[1,2*]

A variation of the above method is capable of providing accurate compensation for leadwire resistances with a three-wire system. The circuit is shown in Figure 2, in which a precision decade box is used in place of one resistor in the Wheatstone bridge.

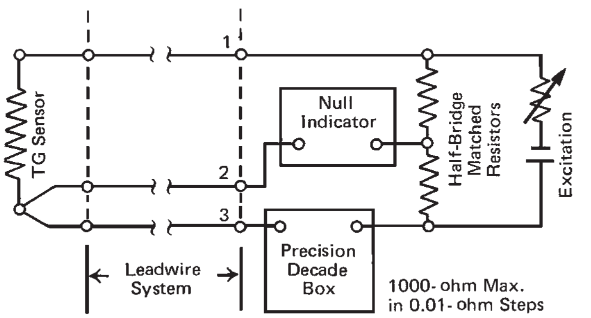

Figure 2. Three-wire null-balance circuit for TG sensor.

The decade box in this circuit is varied to keep the output at null, and the indicated decade resistance is therefore the same as the sensor resistance. Provided leads 1 and 3 are of the same length and size, resistance changes in the leadwire circuit caused by temperature changes common to all wires will not create errors in the reading. Three-wire compensation is effective in this case because this is a true null-balance system in which the bridge arm adjacent to the sensor (the decade box) is always set to the sensor resistance at the time of readout.

Excitation power can be either dc or ac, depending on the null indicator chosen. Excessive excitation can create errors due to self-heating in the sensor, but this error is easily avoided or corrected as discussed in Section 5.5.

A more sophisticated readout system, which eliminates the need for manual rebalance, is shown in Figure 3. This arrangement eliminates leadwire errors by use of a four-wire system.

If the digital voltmeter has a high enough input impedance, the readings will be a known function of sensor resistance, regardless of resistance change in any of the leadwires. A current level of one mA will allow the voltmeter to read sensor resistance in terms of mV (50.0 ohms reads as 50.0 mV).

3.1 Linearization of Sensor Response

The readout methods shown in Figures 2 and 3 can be

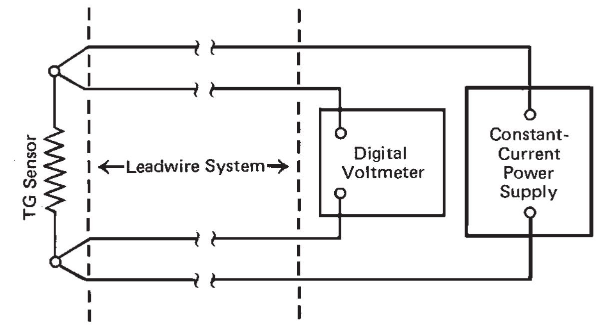

Figure 3. Four-wire circuit for TG sensor.

quite accurate, but are somewhat awkward to use in that they read sensor resistance directly, and the nonlinear characteristic of sensor resistance-versus-temperature requires the use of tabulated data to convert resistance values to the equivalent temperatures. A very simple method exists for converting the nonlinear sensor to a linear resistance change with temperature with good practical accuracy. This is accomplished by shunting the sensor with a fixed resistor equal in value to 3.75 times the +75.0°F [+23.9°C] value of sensor resistance, or 187.5 ohms for standard TG sensors. The resultant resistance change with temperature has a lower slope, but is quite linear as shown in Figure 1. Figure 4 is a plot of deviation from linearity for this circuit, and provides much higher error readability than Figure 1.

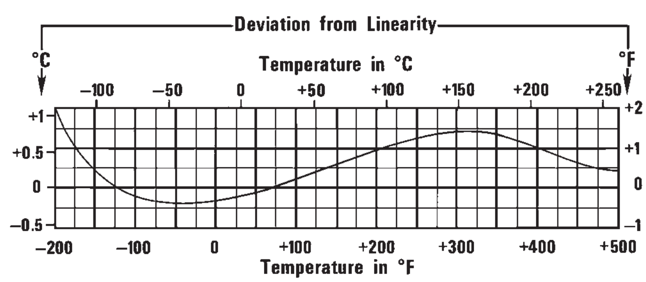

Figure 4. Deviation from linearity for shunted TG sensor of Figure 1.

A useful application of shunt linearization is to provide an asymmetrical bridge circuit that has a linear output voltage with temperature. This circuit can be used with a digital voltmeter for direct temperature readings (expressed in mV) or to drive one axis of an X-Y recorder for directly plotting temperature against another variable. A simplified version of this circuit is shown in Figure 5.

This linearization circuit requires a constant-voltage excitation source, and this can be conveniently provided by a single silver-oxide battery. The output factor is 0.5 mV/V/°F [0.9 mV/V/°C], which can be scaled down by use of a high-

*Superscript numbers refer to references appended to this Tech Note.

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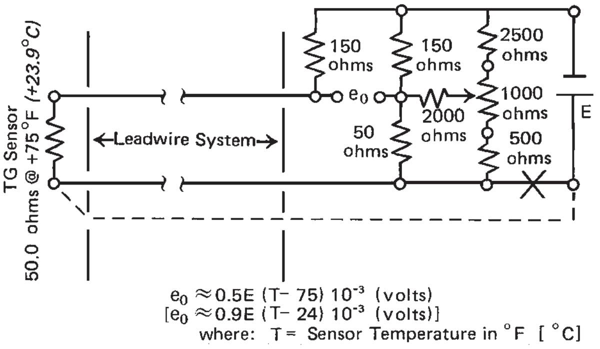

Figure 5. Linearization circuit.

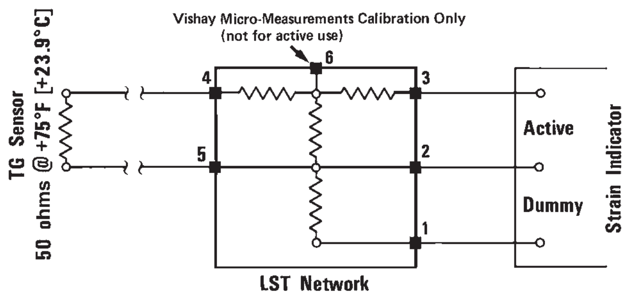

Figure 6. LST network circuit.

resistance voltage divider at the output terminals. A balance potentiometer is incorporated for balancing out the tolerance on the nominal sensor resistance and the offset caused by leadwire resistance. (When the Celsius temperature scale is used, it is more convenient to balance at +24°C, rather than +23.9°C, so that the readings are in round numbers.) Calibration can be checked by substituting a precision decade box for the TG sensor and dialing in resistances equivalent to various temperatures from the resistance-versus-temperature tables.

Because of the asymmetrical bridge, a three-wire lead system cannot be used effectively with the circuit in Figure 5 to eliminate the errors from a temperature-induced leadwire resistance change. However, it is possible to use the three-wire method for the more limited purpose of compensating the initial offset error caused by the leadwire resistance. This is accomplished by adding the third wire (shown dashed) and breaking the connection at the point marked X.

4.0 LST Matching Networks

Commercial single- or multiple-channel strain indicators are excellent readout devices for TG temperature sensors, and are particularly convenient when combinations of strain and temperature are to be measured or recorded simultaneously. This readout method requires the use of an interface signal conditioning network, referred to as an LST network, to “match” the temperature sensor response to that of the strain indicator. The arrangement is shown in Figure 6.

The LST network is a small, completely encapsulated unit consisting of four special precision resistors. When used with standard 50-ohm nickel TG temperature sensors, it performs the following three functions:

1. Provides a linear resistance change at the output terminals.
2. Attenuates the resistance change slope to the equivalent of 10 or 100$\mu\epsilon$/deg for a gage factor setting of 2.00 on the strain indicator. It is usually most practical to use 10$\mu\epsilon$/deg networks when a large temperature range is involved, and 100$\mu\epsilon$/deg networks for high resolution of small temperature spans.
3. Presents a complete 350-ohm half-bridge circuit to the strain indicator.

Differential temperature measurements can be made by combining two TG sensors and two LST networks. The arrangement in Figure 7a provides a half-bridge circuit to the strain indicator in which the ACTIVE arm responds to sensor 1, and the DUMMY arm to sensor 2. An alternate method is to arrange the networks to form a full-bridge circuit as shown in Figure 7b, which may be preferred for some types of readout equipment.

Calibration and balancing of circuits containing LST networks can be handled in various ways. Initial balance is usually obtained by setting the BALANCE of the strain indicator channel so that the instrument reading corresponds to the initial temperature of the TG sensor. When it is not possible to control or measure the initial temperature of the sensor, it can be temporarily replaced by a precision 50.0-ohm resistor. The BALANCE is then set to create an equivalent readout of +75.0°F (Fahrenheit networks) or +23.9°C (Celsius networks). The sensor can then be reconnected to the network. The first procedure has the obvious advantage of correcting for the error due to tolerance limits on initial TG-sensor resistance.

Resistance shunt calibration[3] can be applied to the output terminals of the LST network in order to verify linearity and span accuracy of the associated instrumentation. It is also useful in setting GAGE FACTOR or in correcting for leadwire desensitization when the LST network is near the sensor and remote from the readout instrument. In this latter case, note that shunt resistors must be placed across terminals 2 and 3 at the network, *not* at the instrument.

Because of significant resistance changes in the ACTIVE arm with temperature, shunt calibration across network terminals 2 and 3 will be correct only when the sensor temperature is near +75°F [+24°C]. So, it is preferable that

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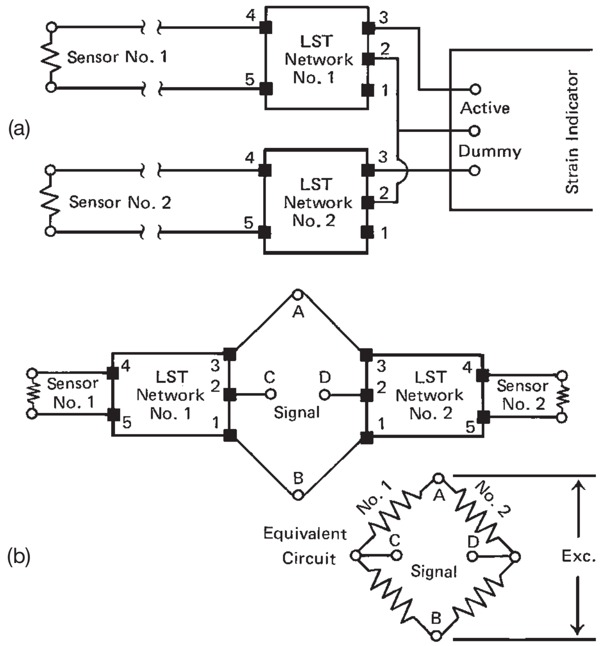

Figure 7. Differential temperature measurement using two TG sensors and two LST networks — (a) half-bridge arrangement and (b) full-bridge arrangement.

calibration resistors be shunted across the DUMMY arm (network terminals 1 and 2). When it is desired to calibrate across both arms to simulate both plus and minus temperature changes, and it is not convenient to stabilize sensor temperature near +75°F [+24°C], the sensor can be replaced by a precision 50.0-ohm resistor during calibration.

When applying shunt calibration to the differential temperature measurement circuit shown in Figure 7a, it will be necessary to calibrate across the ACTIVE arms (network terminals 2 and 3). Shunting network 1 will simulate a temperature decrease for sensor 1 or an increase for sensor 2. Under these conditions the nominal or common-mode temperature for both sensors must be near +75°F [+24°C] if it is desired to calibrate across both networks. If this cannot be conveniently arranged, the sensors should be temporarily replaced by 50.0-ohm resistors during calibration. If the alternate full-bridge connection of Figure 7b is used for a differential operation, shunt calibration steps can be applied to either DUMMY arm, terminals 1 and 2, regardless of temperature.

For best accuracy, it is always advisable to select shunt calibration values that are close to the temperature span of greatest interest. When the instrument readings are not in agreement with the simulated calibration temperature, the GAGE FACTOR can be adjusted to eliminate the error.

Custom LST networks can be tailored for special temperature ranges or output slopes, and for impedance matching. Contact our Applications Engineering Department for details.

5.0 Sources of Error

5.1 Deviations from Linearity

Linearization of TG-Series sensors with passive resistance circuits characteristically leaves small deviations from true linearity. To assure optimum correction for nonlinearity of the nickel, the user may select from four temperature ranges:

–200° to +500°F, use LST-10F/100F-350D
–320° to +100°F, use LST-10F/100F-350C
–150° to +260°C, use LST-10C/100C-350D
–200° to +25°C, use LST-10C/100C-350C

Deviations from linearity for these networks are shown in Figure 8.

The expansion coefficient of the structure to which the temperature sensor is bonded will affect linearity, and Figure 9 shows the deviation of TG sensors with LST-10F-350D conditioning networks on 1018 steel and 2024 aluminum alloy. For highest accuracy it is necessary to calibrate sensor/LST systems on the material to be used. In most work, however, the average curves of Figure 8 are satisfactory.

5.2 Leadwire Effects and Related Errors

Leadwires are a source of error in all circuits using TG sensors, except those of the type shown in Figures 2 and 3. To minimize these errors, leadwires between the sensor and the readout device (or LST network) should be of low resistance and no longer than necessary. A total two-wire resistance of 0.5 ohm will introduce a shift or offset of about +4°F [+2°C] at room temperature. This leadwire resistance corresponds to 25 ft [7.5 m] of AWG No. 20 [0.8-mm diameter] copper double leads, or 100 ft [30 m] of AWG No. 14 [1.6-mm diameter] double leads.

Changes in leadwire temperature are normally a minor source of error. A change of 50°F [28°C] over the entire length of a 0.5-ohm copper leadwire circuit will create an offset error of approximately 0.4°F [0.2°C] when the sensor temperature is near +75°F [+24°C]. This error decreases at higher sensor temperatures and increases at lower sensor temperatures. Accurate measurements in the cryogenic temperature region may require the approach of Figures 2 or 3 when long lengths of small diameter leadwire must be employed.

Initial "zero" errors or offsets due to the tolerances applicable to LST networks and the TG sensors themselves can be eliminated by stabilizing the sensor installation at any known temperature close to +75°F [+24°C], and then setting the instrument BALANCE so that the reading corresponds to this known temperature. This procedure also eliminates offset error caused by initial leadwire resistance.

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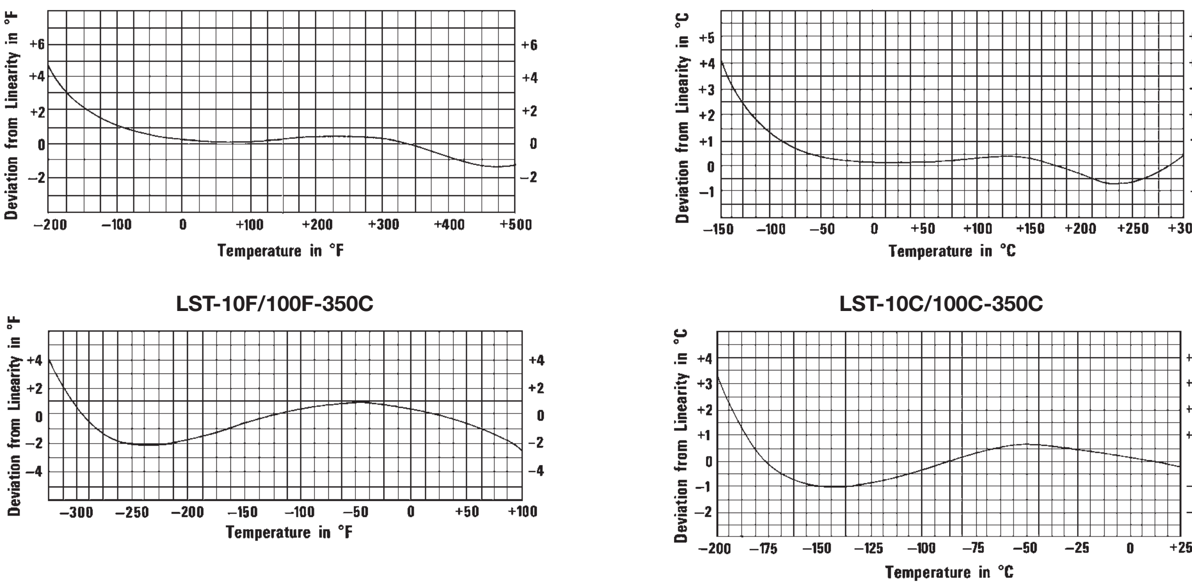

Figure 8. Typical deviation from linearity for TG-Series sensors and LST networks.

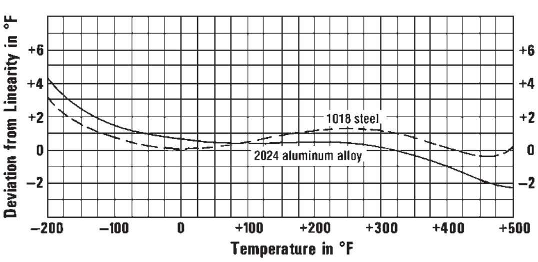

Figure 9. Typical deviation from linearity for TG-Series sensors mounted on 1018 steel and on 2024 aluminum alloy.

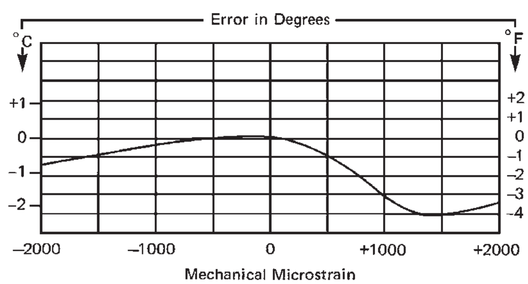

Figure 10. Typical error signal caused by strain applied to TG sensor. Data applies to sensor temperatures near +75°F [+24°C].

In certain circumstances it may be necessary to locate the instrumentation at a long distance from the sensor installations. When LST networks are employed under these conditions, it is preferable to position the network close to its associated sensor and use a three-wire lead circuit between the network and the remote indicator (this should not be done if the test temperature exceeds the temperature capability of the LST network). This type of hookup will eliminate first-order offset errors due to leadwire resistance and leadwire temperature changes. Desensitization or slope-change error is greatly reduced and can be eliminated by setting the strain indicator GAGE FACTOR properly. The correct setting can be calculated on the basis of known leadwire resistance, or directly determined by applying shunt calibration to the remote network terminals.

5.3 Strain Sensitivity Errors

The strain sensitivity of pure nickel can create error signals when TG sensors are installed in areas of high mechanical strain. The magnitude of this effect is fairly small, however, as shown in Figure 10.

The shape of this curve is caused by the nonlinear response of pure nickel. The strain-sensitivity coefficient has a high negative value in the central portion of the elastic region and tends toward a much smaller positive value on either side of this region. It will be observed that compressive strains result in smaller error signals, and this strain field orientation should therefore be selected for sensor placement when possible. The center of symmetry of this curve is located at approximately $+750\mu\epsilon$, because the manufacturing process leaves the sensor with a residual compression of this value.

It is important to realize that the center of symmetry can be shifted by installing the gage on materials of different thermal expansion coefficients and/or with different adhesive cure temperatures. It is for this reason that gage

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response when mounted on aluminum alloy will differ slightly from that obtained when mounted on steel. The tables on the following pages demonstrate the change in resistance-versus-temperature characteristic created by these two mounting conditions.

It has been shown that repeatability of properly installed TG sensors can be better than ±0.05% of applied temperature span. To take full advantage of this repeatability, and of the other intrinsic features of TG temperature sensors, it is always advisable to conduct a calibration run of the sensor mounted on a specific material when highest measurement accuracy is required.

5.4 Stability

In common with most other organic resin systems, the matrix of TG sensors will slowly sublimate and lose strength when aged at elevated temperatures. When properly installed, life will be essentially infinite below +250°F [+120°C], and will be approximately 10 000 hours at +400°F [+205°C]. At +500°F [+260°C], life can be estimated at 1000 hours in the presence of air, and will be considerably extended if an inert atmosphere is used.

The sensing grids are quite stable under the aging conditions described above. If exposed to temperatures above +500°F [+260°C], however, a slight shift in resistivity will occur, together with a small change in temperature coefficient. For example, if the WTG-Series sensor is exposed to a temperature of +600°F [+315°C] for one hour, the +75.0°F [+23.9°C] resistance will shift from 50 ohms to approximately 50.6 ohms. On a normalized basis, the resistance increase from +75.0° to +450°F [+23.9° to +232°C] will become 140% instead of the previous 143%. Operation at temperatures below +550°F [+290°C] will thereafter be stable and repeatable.

5.5 Self-Heating

In order to obtain a useful output from passive transducers such as TG temperature sensors, it is necessary to apply an excitation voltage, which results in self-heating of the sensors. This will cause a certain temperature rise in the surface to which the sensor is bonded, thus creating an error signal. Since TG sensors have a high temperature coefficient of resistance, it is not necessary to utilize high excitation levels to develop large outputs, and self-heating errors can easily be kept to insignificant values. When it is necessary to use high excitation levels to obtain maximum output signals, it should be noted that the largest practical sensor grid size should be chosen. The thermal conductivity and thermal capacity of the specimen will then determine the highest excitation level that can be used for a given self-heating error.

It is usually very simple to measure self-heating errors directly with TG sensors because the excitation can be varied under constant ambient temperature conditions while observing the change in output indication in degrees. A bridge excitation of 0.25V or less will usually produce self-heating errors of a fraction of one degree for standard sensors mounted on metallic specimens. Special attention should be given to self-heating errors when accurate measurements must be made on low thermal conductivity materials such as plastic or glass.

The attenuation factor incorporated into LST networks greatly reduces the excitation voltage from strain gage instrumentation, and self-heating errors are seldom encountered when this readout method is used with TG sensors.

6.0 Special Sensors

In addition to the standard line of TG sensors described in the Vishay Micro-Measurements Precision Strain Gages Data Book can furnish almost any sensor pattern desired, and a wide range of resistances. Setup charges will be minimized when the special pattern design corresponds to one of the patterns in the line of EA-Series strain gages, although resistances available are sometimes limited.

Balco, an alloy of nickel and iron with a high temperature-coefficient-of-resistance and a resistivity 2.4 times that of pure nickel, can also be furnished on special order for measurement or control functions. This alloy is frequently used for temperature compensation of transducer gage circuits.

Two fixed bondable Balco resistors are commonly inserted in the excitation leadwires of a transducer bridge circuit to provide automatic compensation for the combined effects of elastic modulus variation (in the transducer) and gage factor variation (in the strain gage) with temperature. A series of adjustable, bondable resistor patterns is available, and permits trimming to the exact value of resistance required. Both resistor types are also available in nickel.

While Balco has a slightly lower temperature coefficient of resistance than high-purity nickel, its lower cost and higher resistivity permit smaller size and better economy. Figure 1 shows the resistance-versus-temperature characteristic of Balco compared to that for nickel.

7.0 Calibration

Nickel foil lots are calibrated with specially designed test equipment consisting of a carefully controlled, uniform temperature bath, and a platinum resistance standard having calibration results traceable to the National Institute of Standards and Technology. Accuracy of calibration during these tests is +0.5°F [+0.3°C]. The temperature range used is –320° to +500°F [–195° to +260°C]. The test data from TG

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sensors shows that their behavior can be described generally by a polynomial equation of the form:

$$R = A + BT + CT^2 + DT^3 + ET^4 + FT^5 + GT^6 \quad (1)$$

where: R = Resistance of the gage
T = Temperature
A through G = Constants determined using regression analysis curve fitting

When the RTD's are being used to indicate temperature, the equation must be entered in the transposed form:

$$T = A' + B'R + C'R^2 + D'R^3 + E'R^4 + F'R^5 + G'R^6 \quad (2)$$

Values of the constants for Eqs. (1) and (2) for 50-ohm (at +75°F [+23.9°C]) nickel TG sensors are listed in Tables 1A and 1B.

Notes

1. The constants A' through G' in Eq. (2) are not the same as A through G in Eq. (1).
2. Curve-fit Eqs. 1 and 2 are best-fit equations, and may not produce exactly the data in Tables 2 through 5.

8.0 Resistance-versus-Temperature Tables

The following section gives the resistance of standard Vishay Micro-Measurements 50-ohm TG nickel temperature sensors from the boiling point of liquid nitrogen (–320.4°F [–195.8°C] to +500°F [+260°C]). Tables are provided for both Fahrenheit (in two-degree increments) and Celsius (in one-degree increments) scales, and for sensors mounted on both steel and aluminum alloy. It is worth noting that different types of substrate material (as discussed in Section 5.1), or even the same type of substrate material obtained from different sources, may have different thermal expansion properties, and may affect sensor response.

References

1. Watson, Robert B., James Dorsey, James E. Starr, "Conditioning Circuits for Bondable RTD's," 30th International Instrumentation Symposium, *Instrument Society of America*, Denver, Colorado, May 1984.
2. American National Standard ASTM E-644, "Standard Methods for Testing Industrial Resistance Thermometers." American Society for Testing and Materials. 1916 Race Street, Philadelphia, Pennsylvania 19103, 1978.
3. Vishay Micro-Measurements, Tech Note TN-514, "Shunt Calibration of Strain Gage Instrumentation," 1988.

Table 1A—Regression Analysis Constants for Calculating Resistance (Lot T04 Nickel)

Constants	Material	
	1018 Steel	2024-T4 Aluminum Alloy
A	3.946795×10^{1} [4.384157×10^{1}]	3.939097×10^{1} [4.378630×10^{1}]
B	1.33972×10^{-1} [2.50996×10^{-1}]	1.34525×10^{-1} [2.52373×10^{-1}]
C	8.31445×10^{-5} [2.84885×10^{-4}]	8.63411×10^{-5} [2.95290×10^{-4}]
D	4.72396×10^{-8} [3.00807×10^{-7}]	5.02142×10^{-8} [2.88453×10^{-7}]
E	4.93933×10^{-11} [2.03720×10^{-10}]	1.21108×10^{-11} [2.13625×10^{-10}]
F	-2.16840×10^{-13} [-2.95460×10^{-12}]	-2.51606×10^{-13} [-2.97514×10^{-12}]
G	3.15935×10^{-16} [1.07663×10^{-14}]	4.88934×10^{-16} [1.65922×10^{-14}]
Coefficients in brackets are °C.		

Table 1B—Regression Analysis Constants for Calculating Temperature (Lot T04 Nickel)

Constants	Material	
	1018 Steel	2024-T4 Aluminum Alloy
A´	-3.87148×10^{2} [-2.32852×10^{2}]	-3.85275×10^{2} [-2.31809×10^{2}]
B´	1.437356×10^{1} [79.8384×10^{-1}]	1.423312×10^{1} [79.0495×10^{-1}]
C´	-20.6576×10^{-2} [-11.4693×10^{-2}]	-1.96463×10^{-1} [-1.09006×10^{-1}]
D´	3.47019×10^{-3} [1.92684×10^{-3}]	3.14370×10^{-3} [1.74321×10^{-3}]
E´	-3.70193×10^{-5} [-2.05640×10^{-5}]	-3.23587×10^{-5} [-1.79412×10^{-5}]
F´	2.05767×10^{-7} [1.14362×10^{-7}]	1.75570×10^{-7} [9.73545×10^{-8}]
G´	-4.55192×10^{-10} [-2.53118×10^{-10}]	-3.82500×10^{-10} [-2.12139×10^{-10}]
Coefficients in brackets are °C.		

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Table 2—Resistance versus Temperature in Degrees Fahrenheit

Type TG Nickel Sensors Mounted on 1018 Steel—Lot No. T04AH

°F	R	°F	R	°F	R	°F	R	°F	R	°F	R
+500	134.27	+362	101.06	+224	74.15	+86	51.65	– 50	32.77	– 188	16.74
+498	133.73	+360	100.63	+222	73.79	+84	51.35	– 52	32.51	– 190	16.54
+496	133.19	+358	100.20	+220	73.44	+82	51.05	– 54	32.26	– 192	16.33
+494	132.66	+356	99.78	+218	73.09	+80	50.75	– 56	32.01	– 194	16.13
+492	132.13	+354	99.35	+216	72.73	+78	50.45	– 58	31.75	– 196	15.92
+490	131.60	+352	98.93	+214	72.38	+76	50.15	– 60	31.50	– 198	15.72
+488	131.07	+350	98.50	+212	72.03	+75.0	50.00	– 62	31.25	– 200	15.51
+486	130.54	+348	98.08	+210	71.69	+74	49.86	– 64	31.00	– 202	15.31
+484	130.02	+346	97.66	+208	71.34	+72	49.56	– 66	30.75	– 204	15.11
+482	129.49	+344	97.24	+206	70.99	+70	49.27	– 68	30.50	– 206	14.91
+480	128.97	+342	96.82	+204	70.64	+68	48.97	– 70	30.25	– 208	14.71
+478	128.45	+340	96.41	+202	70.30	+66	48.68	– 72	30.00	– 210	14.51
+476	127.93	+338	95.99	+200	69.96	+64	48.38	– 74	29.75	– 212	14.31
+474	127.42	+336	95.58	+198	69.61	+62	48.09	– 76	29.50	– 214	14.11
+472	126.90	+334	95.16	+196	69.27	+60	47.80	– 78	29.26	– 216	13.92
+470	126.39	+332	94.75	+194	68.93	+58	47.51	– 80	29.01	– 218	13.72
+468	125.88	+330	94.34	+192	68.59	+56	47.22	– 82	28.76	– 220	13.53
+466	125.37	+328	93.93	+190	68.25	+54	46.93	– 84	28.52	– 222	13.33
+464	124.86	+326	93.52	+188	67.91	+52	46.64	– 86	28.27	– 224	13.14
+462	124.36	+324	93.12	+186	67.57	+50	46.35	– 88	28.03	– 226	12.95
+460	123.85	+322	92.71	+184	67.23	+48	46.07	– 90	27.79	– 228	12.75
+458	123.35	+320	92.31	+182	66.89	+46	45.78	– 92	27.55	– 230	12.56
+456	122.85	+318	91.90	+180	66.56	+44	45.49	– 94	27.31	– 232	12.37
+454	122.35	+316	91.50	+178	66.22	+42	45.21	– 96	27.06	– 234	12.18
+452	121.85	+314	91.10	+176	65.89	+40	44.92	– 98	26.82	– 236	12.00
+450	121.36	+312	90.70	+174	65.56	+38	44.64	– 100	26.58	– 238	11.81
+448	120.86	+310	90.30	+172	65.22	+36	44.35	– 102	26.35	– 240	11.62
+446	120.37	+308	89.90	+170	64.89	+34	44.07	– 104	26.11	– 242	11.44
+444	119.88	+306	89.50	+168	64.56	+32	43.79	– 106	25.87	– 244	11.25
+442	119.39	+304	89.11	+166	64.23	+30	43.51	– 108	25.63	– 246	11.07
+440	118.90	+302	88.71	+164	63.90	+28	43.23	– 110	25.40	– 248	10.88
+438	118.42	+300	88.32	+162	63.57	+26	42.94	– 112	25.16	– 250	10.70
+436	117.93	+298	87.93	+160	63.24	+24	42.67	– 114	24.93	– 252	10.52
+434	117.45	+296	87.54	+158	62.92	+22	42.39	– 116	24.69	– 254	10.34
+432	116.97	+294	87.15	+156	62.59	+20	42.11	– 118	24.46	– 256	10.16
+430	116.49	+292	86.76	+154	62.27	+18	41.83	– 120	24.23	– 258	9.98
+428	116.01	+290	86.37	+152	61.94	+16	41.55	– 122	24.00	– 260	9.80
+426	115.53	+288	85.98	+150	61.62	+14	41.28	– 124	23.76	– 262	9.63
+424	115.06	+286	85.60	+148	61.29	+12	41.00	– 126	23.53	– 264	9.45
+422	114.59	+284	85.21	+146	60.97	+10	40.73	– 128	23.30	– 266	9.28
+420	114.11	+282	84.83	+144	60.65	+ 8	40.45	– 130	23.08	– 268	9.10
+418	113.64	+280	84.45	+142	60.33	+ 6	40.18	– 132	22.85	– 270	8.93
+416	113.17	+278	84.07	+140	60.01	+ 4	39.90	– 134	22.62	– 272	8.76
+414	112.71	+276	83.69	+138	59.69	+ 2	39.63	– 136	22.39	– 274	8.58
+412	112.24	+274	83.31	+136	59.37	+ 0	39.36	– 138	22.17	– 276	8.41
+410	111.78	+272	82.93	+134	59.05	– 2	39.09	– 140	21.94	– 278	8.24
+408	111.31	+270	82.55	+132	58.74	– 4	38.82	– 142	21.72	– 280	8.08
+406	110.85	+268	82.17	+130	58.42	– 6	38.55	– 144	21.49	– 282	7.91
+404	110.39	+266	81.80	+128	58.10	– 8	38.28	– 146	21.27	– 284	7.74
+402	109.93	+264	81.43	+126	57.79	–10	38.01	– 148	21.04	– 286	7.58
+400	109.48	+262	81.05	+124	57.48	–12	37.74	– 150	20.82	– 288	7.41
+398	109.02	+260	80.68	+122	57.16	–14	37.47	– 152	20.60	– 290	7.25
+396	108.57	+258	80.31	+120	56.85	–16	37.21	– 154	20.38	– 292	7.09
+394	108.12	+256	79.94	+118	56.54	–18	36.94	– 156	20.16	– 294	6.92
+392	107.66	+254	79.57	+116	56.23	–20	36.67	– 158	19.94	– 296	6.76
+390	107.21	+252	79.20	+114	55.92	–22	36.41	– 160	19.72	– 298	6.60
+388	106.77	+250	78.83	+112	55.61	–24	36.15	– 162	19.51	– 300	6.44
+386	106.32	+248	78.47	+110	55.30	–26	35.88	– 164	19.29	– 302	6.29
+384	105.87	+246	78.10	+108	54.99	–28	35.62	– 166	19.07	– 304	6.13
+382	105.43	+244	77.74	+106	54.68	–30	35.36	– 168	18.86	– 306	5.97
+380	104.99	+242	77.37	+104	54.37	–32	35.10	– 170	18.64	– 308	5.82
+378	104.54	+240	77.01	+102	54.07	–34	34.83	– 172	18.43	– 310	5.67
+376	104.10	+238	76.65	+100	53.76	–36	34.57	– 174	18.22	– 312	5.51
+374	103.67	+236	76.29	+ 98	53.46	–38	34.31	– 176	18.00	– 314	5.36
+372	103.23	+234	75.93	+ 96	53.15	–40	34.05	– 178	17.79	– 316	5.21
+370	102.79	+232	75.57	+ 94	52.85	–42	33.80	– 180	17.58	– 318	5.06
+368	102.36	+230	75.21	+ 92	52.55	–44	33.54	– 182	17.37	– 320	4.91
+366	101.92	+228	74.86	+ 90	52.25	–46	33.28	– 184	17.16	– 320.4	4.88
+364	101.49	+226	74.50	+ 88	51.95	–48	33.02	– 186	16.95		

Bondable Resistance Temperature Sensors and Associated Circuitry

Table 3—Resistance versus Temperature in Degrees Fahrenheit

Type TG Nickel Sensors Mounted on 2024-T4 Aluminum Alloy—Lot No. T04AH

°F	R	°F	R	°F	R	°F	R	°F	R	°F	R
+500	134.14	+362	100.54	+224	73.83	+86	51.62	– 50	32.77	– 188	16.74
+498	133.59	+360	100.12	+222	73.48	+84	51.33	– 52	32.51	– 190	16.54
+496	133.04	+358	99.69	+220	73.13	+82	51.03	– 54	32.26	– 192	16.33
+494	132.49	+356	99.26	+218	72.78	+80	50.73	– 56	32.01	– 194	16.13
+492	131.95	+354	98.84	+216	72.43	+78	50.44	– 58	31.75	– 196	15.92
+490	131.40	+352	98.41	+214	72.09	+76	50.15	– 60	31.50	– 198	15.72
+488	130.86	+350	97.99	+212	71.74	+75.0	50.00	– 62	31.25	– 200	15.51
+486	130.33	+348	97.57	+210	71.40	+74	49.86	– 64	31.00	– 202	15.31
+484	129.79	+346	97.15	+208	71.06	+72	49.56	– 66	30.75	– 204	15.11
+482	129.26	+344	96.73	+206	70.71	+70	49.27	– 68	30.50	– 206	14.91
+480	128.72	+342	96.31	+204	70.37	+68	48.97	– 70	30.25	– 208	14.71
+478	128.19	+340	95.90	+202	70.03	+66	48.68	– 72	30.00	– 210	14.51
+476	127.67	+338	95.48	+200	69.69	+64	48.38	– 74	29.75	– 212	14.31
+474	127.14	+336	95.07	+198	69.35	+62	48.09	– 76	29.50	– 214	14.11
+472	126.62	+334	94.66	+196	69.01	+60	47.80	– 78	29.26	– 216	13.92
+470	126.09	+332	94.25	+194	68.68	+58	47.51	– 80	29.01	– 218	13.72
+468	125.57	+330	93.84	+192	68.34	+56	47.22	– 82	28.76	– 220	13.53
+466	125.05	+328	93.43	+190	68.01	+54	46.93	– 84	28.52	– 222	13.33
+464	124.54	+326	93.03	+188	67.67	+52	46.64	– 86	28.27	– 224	13.14
+462	124.02	+324	92.62	+186	67.34	+50	46.35	– 88	28.03	– 226	12.95
+460	123.51	+322	92.22	+184	67.00	+48	46.07	– 90	27.79	– 228	12.75
+458	123.00	+320	91.82	+182	66.67	+46	45.78	– 92	27.55	– 230	12.56
+456	122.49	+318	91.41	+180	66.34	+44	45.49	– 94	27.31	– 232	12.37
+454	121.99	+316	91.01	+178	66.01	+42	45.21	– 96	27.06	– 234	12.18
+452	121.48	+314	90.61	+176	65.68	+40	44.92	– 98	26.82	– 236	12.00
+450	120.98	+312	90.22	+174	65.35	+38	44.64	– 100	26.58	– 238	11.81
+448	120.48	+310	89.82	+172	65.02	+36	44.35	– 102	26.35	– 240	11.62
+446	119.98	+308	89.43	+170	64.70	+34	44.07	– 104	26.11	– 242	11.44
+444	119.48	+306	89.03	+168	64.37	+32	43.79	– 106	25.87	– 244	11.25
+442	118.99	+304	88.64	+166	64.04	+30	43.51	– 108	25.63	– 246	11.07
+440	118.49	+302	88.25	+164	63.72	+28	43.23	– 110	25.40	– 248	10.88
+438	118.00	+300	87.86	+162	63.39	+26	42.94	– 112	25.16	– 250	10.70
+436	117.51	+298	87.47	+160	63.07	+24	42.67	– 114	24.93	– 252	10.52
+434	117.02	+296	87.08	+158	62.75	+22	42.39	– 116	24.69	– 254	10.34
+432	116.54	+294	86.69	+156	62.43	+20	42.11	– 118	24.46	– 256	10.16
+430	116.05	+292	86.31	+154	62.11	+18	41.83	– 120	24.23	– 258	9.98
+428	115.57	+290	85.92	+152	61.79	+16	41.55	– 122	24.00	– 260	9.80
+426	115.09	+288	85.54	+150	61.47	+14	41.28	– 124	23.76	– 262	9.63
+424	114.61	+286	85.16	+148	61.15	+12	41.00	– 126	23.53	– 264	9.45
+422	114.13	+284	84.77	+146	60.83	+10	40.73	– 128	23.30	– 266	9.28
+420	113.65	+282	84.39	+144	60.51	+ 8	40.45	– 130	23.08	– 268	9.10
+418	113.18	+280	84.02	+142	60.20	+ 6	40.18	– 132	22.85	– 270	8.93
+416	112.71	+278	83.64	+140	59.88	+ 4	39.90	– 134	22.62	– 272	8.76
+414	112.23	+276	83.26	+138	59.57	+ 2	39.63	– 136	22.39	– 274	8.58
+412	111.77	+274	82.89	+136	59.25	+ 0	39.36	– 138	22.17	– 276	8.41
+410	111.30	+272	82.51	+134	58.94	– 2	39.09	– 140	21.94	– 278	8.24
+408	110.83	+270	82.14	+132	58.62	– 4	38.82	– 142	21.72	– 280	8.08
+406	110.37	+268	81.76	+130	58.31	– 6	38.55	– 144	21.49	– 282	7.91
+404	109.90	+266	81.39	+128	58.00	– 8	38.28	– 146	21.27	– 284	7.74
+402	109.44	+264	81.02	+126	57.69	–10	38.01	– 148	21.04	– 286	7.58
+400	108.98	+262	80.65	+124	57.38	–12	37.74	– 150	20.82	– 288	7.41
+398	108.53	+260	80.28	+122	57.07	–14	37.47	– 152	20.60	– 290	7.25
+396	108.07	+258	79.92	+120	56.76	–16	37.21	– 154	20.38	– 292	7.09
+394	107.61	+256	79.55	+118	56.45	–18	36.94	– 156	20.16	– 294	6.92
+392	107.16	+254	79.19	+116	56.15	–20	36.67	– 158	19.94	– 296	6.76
+390	106.71	+252	78.82	+114	55.84	–22	36.41	– 160	19.72	– 298	6.60
+388	106.26	+250	78.46	+112	55.53	–24	36.15	– 162	19.51	– 300	6.44
+386	105.81	+248	78.10	+110	55.23	–26	35.88	– 164	19.29	– 302	6.29
+384	105.36	+246	77.74	+108	54.93	–28	35.62	– 166	19.07	– 304	6.13
+382	104.92	+244	77.38	+106	54.62	–30	35.36	– 168	18.86	– 306	5.97
+380	104.47	+242	77.02	+104	54.32	–32	35.10	– 170	18.64	– 308	5.82
+378	104.03	+240	76.66	+102	54.02	–34	34.83	– 172	18.43	– 310	5.67
+376	103.59	+238	76.30	+100	53.71	–36	34.57	– 174	18.22	– 312	5.51
+374	103.15	+236	75.94	+ 98	53.41	–38	34.31	– 176	18.00	– 314	5.36
+372	102.71	+234	75.59	+ 96	53.11	–40	34.05	– 178	17.79	– 316	5.21
+370	102.28	+232	75.24	+ 94	52.81	–42	33.80	– 180	17.58	– 318	5.06
+368	101.84	+230	74.88	+ 92	52.51	–44	33.54	– 182	17.37	– 320	4.91
+366	101.41	+228	74.53	+ 90	52.22	–46	33.28	– 184	17.16	– 320.4	4.88
+364	100.98	+226	74.18	+ 88	51.92	–48	33.02	– 186	16.95		

TECH NOTE

Bondable Resistance Temperature Sensors and Associated Circuitry

Table 4—Resistance versus Temperature in Degrees Celcius

Type TG Nickel Sensors Mounted on 1018 Steel—Lot No. T04AH

°C	R	°C	R	°C	R	°C	R	°C	R	°C	R	°C	R
+260	134.27	+194	105.25	+128	81.13	+62	60.59	– 3	43.03	– 69	27.52	–135	14.41
+259	133.78	+193	104.85	+127	80.79	+61	60.30	– 4	42.78	– 70	27.31	–136	14.23
+258	133.30	+192	104.46	+126	80.46	+60	60.01	– 5	42.53	– 71	27.09	–137	14.05
+257	132.82	+191	104.06	+125	80.12	+59	59.72	– 6	42.27	– 72	26.87	–138	13.88
+256	132.34	+190	103.67	+124	79.79	+58	59.43	– 7	42.02	– 73	26.66	–139	13.70
+255	131.86	+189	103.27	+123	79.46	+57	59.15	– 8	41.77	– 74	26.44	–140	13.53
+254	131.39	+188	102.88	+122	79.13	+56	58.86	– 9	41.52	– 75	26.23	–141	13.35
+253	130.91	+187	102.49	+121	78.80	+55	58.58	–10	41.28	– 76	26.01	–142	13.18
+252	130.44	+186	102.10	+120	78.47	+54	58.29	–11	41.03	– 77	25.80	–143	13.00
+251	129.96	+185	101.71	+119	78.14	+53	58.01	–12	40.78	– 78	25.59	–144	12.83
+250	129.49	+184	101.32	+118	77.81	+52	57.73	–13	40.53	– 79	25.37	–145	12.66
+249	129.02	+183	100.93	+117	77.48	+51	57.44	–14	40.29	– 80	25.16	–146	12.49
+248	128.56	+182	100.55	+116	77.16	+50	57.16	–15	40.04	– 81	24.95	–147	12.32
+247	128.09	+181	100.16	+115	76.83	+49	56.88	–16	39.79	– 82	24.74	–148	12.15
+246	127.62	+180	99.78	+114	76.51	+48	56.60	–17	39.55	– 83	24.53	–149	11.98
+245	127.16	+179	99.39	+113	76.18	+47	56.32	–18	39.30	– 84	24.32	–150	11.81
+244	126.70	+178	99.01	+112	75.86	+46	56.04	–19	39.06	– 85	24.11	–151	11.64
+243	126.24	+177	98.63	+111	75.54	+45	55.76	–20	38.82	– 86	23.90	–152	11.47
+242	125.78	+176	98.25	+110	75.21	+44	55.48	–21	38.57	– 87	23.70	–153	11.31
+241	125.32	+175	97.87	+109	74.89	+43	55.20	–22	38.33	– 88	23.49	–154	11.14
+240	124.86	+174	97.49	+108	74.57	+42	54.93	–23	38.09	– 89	23.28	–155	10.97
+239	124.41	+173	97.12	+107	74.25	+41	54.65	–24	37.85	– 90	23.08	–156	10.81
+238	123.95	+172	96.74	+106	73.93	+40	54.37	–25	37.61	– 91	22.87	–157	10.65
+237	123.50	+171	96.37	+105	73.61	+39	54.10	–26	37.37	– 92	22.66	–158	10.48
+236	123.05	+170	95.99	+104	73.30	+38	53.82	–27	37.13	– 93	22.46	–159	10.32
+235	122.60	+169	95.62	+103	72.98	+37	53.55	–28	36.89	– 94	22.26	–160	10.16
+234	122.15	+168	95.25	+102	72.66	+36	53.28	–29	36.65	– 95	22.05	–161	10.00
+233	121.70	+167	94.88	+101	72.35	+35	53.00	–30	36.41	– 96	21.85	–162	9.84
+232	121.26	+166	94.51	+100	72.03	+34	52.73	–31	36.17	– 97	21.65	–163	9.68
+231	120.81	+165	94.14	+ 99	71.72	+33	52.46	–32	35.93	– 98	21.45	–164	9.52
+230	120.37	+164	93.77	+ 98	71.41	+32	52.19	–33	35.70	– 99	21.25	–165	9.36
+229	119.93	+163	93.40	+ 97	71.09	+31	51.92	–34	35.46	–100	21.04	–166	9.21
+228	119.49	+162	93.04	+ 96	70.78	+30	51.65	–35	35.23	–101	20.85	–167	9.05
+227	119.05	+161	92.67	+ 95	70.47	+29	51.38	–36	34.99	–102	20.65	–168	8.89
+226	118.61	+160	92.31	+ 94	70.16	+28	51.11	–37	34.76	–103	20.45	–169	8.74
+225	118.17	+159	91.94	+ 93	69.85	+27	50.84	–38	34.52	–104	20.25	–170	8.58
+224	117.74	+158	91.58	+ 92	69.54	+26	50.57	–39	34.29	–105	20.05	–171	8.43
+223	117.31	+157	91.22	+ 91	69.23	+25	50.30	–40	34.05	–106	19.85	–172	8.28
+222	116.87	+156	90.86	+ 90	68.93	+24	50.03	–41	33.82	–107	19.66	–173	8.13
+221	116.44	+155	90.50	+ 89	68.62	+23.9	50.00	–42	33.59	–108	19.46	–174	7.98
+220	116.01	+154	90.14	+ 88	68.31	+23	49.77	–43	33.36	–109	19.27	–175	7.83
+219	115.58	+153	89.78	+ 87	68.01	+22	49.50	–44	33.13	–110	19.07	–176	7.68
+218	115.15	+152	89.43	+ 86	67.70	+21	49.24	–45	32.90	–111	18.88	–177	7.53
+217	114.73	+151	89.07	+ 85	67.40	+20	48.97	–46	32.67	–112	18.69	–178	7.38
+216	114.30	+150	88.71	+ 84	67.10	+19	48.71	–47	32.44	–113	18.49	–179	7.23
+215	113.88	+149	88.36	+ 83	66.79	+18	48.44	–48	32.21	–114	18.30	–180	7.09
+214	113.46	+148	88.01	+ 82	66.49	+17	48.18	–49	31.98	–115	18.11	–181	6.94
+213	113.03	+147	87.66	+ 81	66.19	+16	47.92	–50	31.75	–116	17.92	–182	6.80
+212	112.61	+146	87.30	+ 80	65.89	+15	47.66	–51	31.52	–117	17.73	–183	6.65
+211	112.20	+145	86.95	+ 79	65.59	+14	47.39	–52	31.30	–118	17.54	–184	6.51
+210	111.78	+144	86.60	+ 78	65.29	+13	47.13	–53	31.07	–119	17.35	–185	6.37
+209	111.36	+143	86.26	+ 77	64.99	+12	46.87	–54	30.85	–120	17.16	–186	6.22
+208	110.95	+142	85.91	+ 76	64.69	+11	46.61	–55	30.62	–121	16.97	–187	6.08
+207	110.53	+141	85.56	+ 75	64.40	+10	46.35	–56	30.40	–122	16.79	–188	5.94
+206	110.12	+140	85.21	+ 74	64.10	+ 9	46.09	–57	30.17	–123	16.60	–189	5.80
+205	109.71	+139	84.87	+ 73	63.80	+ 8	45.84	–58	29.95	–124	16.41	–190	5.67
+204	109.30	+138	84.52	+ 72	63.51	+ 7	45.58	–59	29.72	–125	16.23	–191	5.53
+203	108.89	+137	84.18	+ 71	63.21	+ 6	45.32	–60	29.50	–126	16.04	–192	5.39
+202	108.48	+136	83.84	+ 70	62.92	+ 5	45.06	–61	29.28	–127	15.86	–193	5.26
+201	108.07	+135	83.50	+ 69	62.62	+ 4	44.81	–62	29.06	–128	15.68	–194	5.12
+200	107.66	+134	83.16	+ 68	62.33	+ 3	44.55	–63	28.84	–129	15.49	–195	4.99
+199	107.26	+133	82.82	+ 67	62.04	+ 2	44.30	–64	28.62	–130	15.31	–195.8	4.88
+198	106.86	+132	82.48	+ 66	61.75	+ 1	44.04	–65	28.40	–131	15.13		
+197	106.45	+131	82.14	+ 65	61.46	+ 0	43.79	–66	28.18	–132	14.95		
+196	106.05	+130	81.80	+ 64	61.16	– 1	43.53	–67	27.96	–133	14.77		
+195	105.65	+129	81.46	+ 63	60.87	– 2	43.28	–68	27.74	–134	14.59		

Bondable Resistance Temperature Sensors and Associated Circuitry

Table 5—Resistance versus Temperature in Degrees Celcius

Type TG Nickel Sensors Mounted on 2024-T4 Aluminum Alloy—Lot No. T04AH

°C	R	°C	R	°C	R	°C	R	°C	R	°C	R	°C	R
+260	134.14	+194	104.74	+128	80.73	+62	60.45	– 3	43.03	– 69	27.52	–135	14.41
+259	133.64	+193	104.34	+127	80.40	+61	60.16	– 4	42.78	– 70	27.31	–136	14.23
+258	133.15	+192	103.94	+126	80.06	+60	59.88	– 5	42.53	– 71	27.09	–137	14.05
+257	132.65	+191	103.55	+125	79.73	+59	59.60	– 6	42.27	– 72	26.87	–138	13.88
+256	132.16	+190	103.15	+124	79.41	+58	59.31	– 7	42.02	– 73	26.66	–139	13.70
+255	131.68	+189	102.76	+123	79.08	+57	59.03	– 8	41.77	– 74	26.44	–140	13.53
+254	131.19	+188	102.36	+122	78.75	+56	58.75	– 9	41.52	– 75	26.23	–141	13.35
+253	130.70	+187	101.97	+121	78.42	+55	58.47	–10	41.28	– 76	26.01	–142	13.18
+252	130.22	+186	101.58	+120	78.10	+54	58.19	–11	41.03	– 77	25.80	–143	13.00
+251	129.74	+185	101.19	+119	77.77	+53	57.91	–12	40.78	– 78	25.59	–144	12.83
+250	129.26	+184	100.80	+118	77.45	+52	57.63	–13	40.53	– 79	25.37	–145	12.66
+249	128.78	+183	100.42	+117	77.12	+51	57.35	–14	40.29	– 80	25.16	–146	12.49
+248	128.30	+182	100.03	+116	76.80	+50	57.07	–15	40.04	– 81	24.95	–147	12.32
+247	127.82	+181	99.64	+115	76.48	+49	56.79	–16	39.79	– 82	24.74	–148	12.15
+246	127.35	+180	99.26	+114	76.16	+48	56.52	–17	39.55	– 83	24.53	–149	11.98
+245	126.88	+179	98.88	+113	75.84	+47	56.24	–18	39.30	– 84	24.32	–150	11.81
+244	126.41	+178	98.50	+112	75.52	+46	55.96	–19	39.06	– 85	24.11	–151	11.64
+243	125.94	+177	98.12	+111	75.20	+45	55.69	–20	38.82	– 86	23.90	–152	11.47
+242	125.47	+176	97.74	+110	74.88	+44	55.41	–21	38.57	– 87	23.70	–153	11.31
+241	125.00	+175	97.36	+109	74.56	+43	55.14	–22	38.33	– 88	23.49	–154	11.14
+240	124.54	+174	96.98	+108	74.25	+42	54.86	–23	38.09	– 89	23.28	–155	10.97
+239	124.08	+173	96.61	+107	73.93	+41	54.59	–24	37.85	– 90	23.08	–156	10.81
+238	123.61	+172	96.23	+106	73.62	+40	54.32	–25	37.61	– 91	22.87	–157	10.65
+237	123.15	+171	95.86	+105	73.30	+39	54.05	–26	37.37	– 92	22.66	–158	10.48
+236	122.70	+170	95.48	+104	72.99	+38	53.77	–27	37.13	– 93	22.46	–159	10.32
+235	122.24	+169	95.11	+103	72.68	+37	53.50	–28	36.89	– 94	22.26	–160	10.16
+234	121.78	+168	94.74	+102	72.36	+36	53.23	–29	36.65	– 95	22.05	–161	10.00
+233	121.33	+167	94.37	+101	72.05	+35	52.96	–30	36.41	– 96	21.85	–162	9.84
+232	120.88	+166	94.00	+100	71.74	+34	52.69	–31	36.17	– 97	21.65	–163	9.68
+231	120.43	+165	93.64	+ 99	71.43	+33	52.42	–32	35.93	– 98	21.45	–164	9.52
+230	119.98	+164	93.27	+ 98	71.12	+32	52.16	–33	35.70	– 99	21.25	–165	9.36
+229	119.53	+163	92.90	+ 97	70.82	+31	51.89	–34	35.46	–100	21.04	–166	9.21
+228	119.08	+162	92.54	+ 96	70.51	+30	51.62	–35	35.23	–101	20.85	–167	9.05
+227	118.64	+161	92.18	+ 95	70.20	+29	51.35	–36	34.99	–102	20.65	–168	8.89
+226	118.20	+160	91.82	+ 94	69.90	+28	51.09	–37	34.76	–103	20.45	–169	8.74
+225	117.75	+159	91.45	+ 93	69.59	+27	50.82	–38	34.52	–104	20.25	–170	8.58
+224	117.31	+158	91.09	+ 92	69.28	+26	50.56	–39	34.29	–105	20.05	–171	8.43
+223	116.88	+157	90.73	+ 91	68.98	+25	50.29	–40	34.05	–106	19.85	–172	8.28
+222	116.44	+156	90.38	+ 90	68.68	+24	50.03	–41	33.82	–107	19.66	–173	8.13
+221	116.00	+155	90.02	+ 89	68.37	+23.9	50.00	–42	33.59	–108	19.46	–174	7.98
+220	115.57	+154	89.66	+ 88	68.07	+23	49.77	–43	33.36	–109	19.27	–175	7.83
+219	115.13	+153	89.31	+ 87	67.77	+22	49.50	–44	33.13	–110	19.07	–176	7.68
+218	114.70	+152	88.95	+ 86	67.47	+21	49.24	–45	32.90	–111	18.88	–177	7.53
+217	114.27	+151	88.60	+ 85	67.17	+20	48.97	–46	32.67	–112	18.69	–178	7.38
+216	113.84	+150	88.25	+ 84	66.87	+19	48.71	–47	32.44	–113	18.49	–179	7.23
+215	113.42	+149	87.90	+ 83	66.57	+18	48.44	–48	32.21	–114	18.30	–180	7.09
+214	112.99	+148	87.55	+ 82	66.27	+17	48.18	–49	31.98	–115	18.11	–181	6.94
+213	112.56	+147	87.20	+ 81	65.98	+16	47.92	–50	31.75	–116	17.92	–182	6.80
+212	112.14	+146	86.85	+ 80	65.68	+15	47.66	–51	31.52	–117	17.73	–183	6.65
+211	111.72	+145	86.50	+ 79	65.38	+14	47.39	–52	31.30	–118	17.54	–184	6.51
+210	111.30	+144	86.15	+ 78	65.09	+13	47.13	–53	31.07	–119	17.35	–185	6.37
+209	110.88	+143	85.81	+ 77	64.79	+12	46.87	–54	30.85	–120	17.16	–186	6.22
+208	110.46	+142	85.46	+ 76	64.50	+11	46.61	–55	30.62	–121	16.97	–187	6.08
+207	110.04	+141	85.12	+ 75	64.21	+10	46.35	–56	30.40	–122	16.79	–188	5.94
+206	109.63	+140	84.77	+ 74	63.91	+ 9	46.09	–57	30.17	–123	16.60	–189	5.80
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+204	108.80	+138	84.09	+ 72	63.33	+ 7	45.58	–59	29.72	–125	16.23	–191	5.53
+203	108.39	+137	83.75	+ 71	63.04	+ 6	45.32	–60	29.50	–126	16.04	–192	5.39
+202	107.98	+136	83.41	+ 70	62.75	+ 5	45.06	–61	29.28	–127	15.86	–193	5.26
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+199	106.75	+133	82.40	+ 67	61.88	+ 2	44.30	–64	28.62	–130	15.31	–195.8	4.88
+198	106.35	+132	82.06	+ 66	61.59	+ 1	44.04	–65	28.40	–131	15.13		
+197	105.94	+131	81.73	+ 65	61.31	+ 0	43.79	–66	28.18	–132	14.95		
+196	105.54	+130	81.39	+ 64	61.02	– 1	43.53	–67	27.96	–133	14.77		
+195	105.14	+129	81.06	+ 63	60.73	– 2	43.28	–68	27.74	–134	14.59		