

## Section 13: Technical Reference

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## RTD, Thermocouple, or Thermistor?

### Resistance temperature detectors (RTDs)

An RTD sensing element consists of a wire coil or deposited film of pure metal. The element's resistance increases with temperature in a known and repeatable manner. RTDs exhibit excellent accuracy over a wide temperature range and represent the fastest growing segment among industrial temperature sensors. Their advantages include:

- **Temperature range:** Models in this bulletin cover temperatures from -260 to 850°C (-436 to 1582°F).
- **Repeatability and stability:** The platinum resistance thermometer is the primary interpolation instrument used by the National Institute of Standards and Technology from -260 to 962°C. Minco offers laboratory models stable within 0.0025°C per year. Even ordinary industrial RTDs typically drift less than 0.1°C/year.
- **Sensitivity:** The voltage drop across an RTD provides a much larger output than a thermocouple.
- **Linearity:** Platinum and copper RTDs produce a more linear response than thermocouples or thermistors. RTD non-linearities can be corrected through proper design of resistive bridge networks.
- **Low system cost:** RTDs use ordinary copper extension leads and require no cold junction compensation.
- **Standardization:** Manufacturers offer RTDs to industry standard curves, most commonly 100 Ω platinum to EN60751 (Minco element code PD or PE).

### Thermocouples

A thermocouple consists of two wires of dissimilar metals welded together into a junction. At the other end of the signal wires, usually as part of the input instrument, is another junction called the reference junction. Heating the sensing junction generates a thermoelectric potential (emf) proportional to the temperature difference between the two junctions. This millivolt-level emf, when compensated for the known temperature of the reference junction, indicates the temperature at the sensing tip. Published millivolt tables assume the reference junction is at 0°C.

Thermocouples are simple and familiar. Designing them into systems, however, is complicated by the need for special extension wires and reference junction compensation. Thermocouple advantages include:

- **Extremely high temperature capability:** Thermocouples with precious metal junctions may be rated as high as 1800°C (3272°F).
- **Ruggedness:** The inherent simplicity of thermocouples makes them resistant to shock and vibration.
- **Small size/fast response:** A fine-wire thermocouple junction takes up little space and has low mass, making it suitable for point sensing and fast response. Note, however, that many Minco RTDs have time constants faster than equivalent thermocouples.

### Thermistors

A thermistor is a resistive device composed of metal oxides formed into a bead and encapsulated in epoxy or glass. A typical thermistor shows a large negative temperature coefficient. Resistance drops dramatically and non-linearly with temperature. Sensitivity is many times that of RTDs but useful temperature range is limited. Some manufacturers offer thermistors with positive coefficients. Linearized models are also available.

There are wide variations of performance and price between thermistors from different sources. Typical benefits are:

- **Low sensor cost:** Basic thermistors are quite inexpensive. However, models with tighter interchangeability or extended temperature ranges often cost more than RTDs.
- **High sensitivity:** A thermistor may change resistance by tens of ohms per degree temperature change, versus a fraction of an ohm for RTDs.
- **Point sensing:** A thermistor bead can be made the size of a pin head for small area sensing.

Sensor type	Temperature range	Sensor cost	System cost	Stability	Sensitivity	Linearity	Specify for:
RTD	-260 to 850°C (-436 to 1562°F)	Moderate	Moderate	Best	Moderate	Best	<ul style="list-style-type: none"> <li>• General purpose sensing</li> <li>• Highest accuracy</li> <li>• Temperature averaging</li> </ul>
Thermocouple	-270 to 1800°C (-454 to 3272°F)	Low	High	Low	Low	Moderate	<ul style="list-style-type: none"> <li>• Highest temperatures</li> </ul>
Thermistor	-80 to 150°C (-112 to 302°F) (typical)	Low	Moderate	Moderate	Best	Poor	<ul style="list-style-type: none"> <li>• Best sensitivity</li> <li>• Narrow ranges (e.g. medical)</li> <li>• Point sensing</li> </ul>

## Choosing Sensor Elements

### RTD element types

Platinum is the most widely specified RTD element type, due to its wide temperature range, stability, and standardization between manufacturers. Copper, nickel, and nickel-iron can offer comparable accuracy at lower cost in many applications.

Element material	Temperature range	Resistivity ( $\Omega$ per circular mil foot at 20°C)	Benefits	Typical base resistance	Sensitivity (Avg. $\Omega/^\circ\text{C}$ , 0 to 100°C)	TCR $\Omega/\Omega/^\circ\text{C}$
Platinum	-260 to 850°C (-436 to 1562°F)	63.8	<ul style="list-style-type: none"> <li>•Greatest range</li> <li>•Best stability</li> <li>•Good linearity</li> </ul>	100 $\Omega$ at 0°C 1000 $\Omega$ at 0°C	0.39 3.90	0.00375 to 0.003927
Copper	-100 to 260°C (-148 to 500°F)	10.7	<ul style="list-style-type: none"> <li>•Best linearity</li> </ul>	10 $\Omega$ at 25°C	0.04	0.00427
Nickel	-100 to 260°C (-148 to 500°F)	41.5	<ul style="list-style-type: none"> <li>•Low cost</li> <li>•High sensitivity</li> </ul>	120 $\Omega$ at 0°C	0.81	0.00672
Nickel-iron	-100 to 204°C (-148 to 400°F)	120.0	<ul style="list-style-type: none"> <li>•Low cost</li> <li>•Highest sensitivity</li> </ul>	604 $\Omega$ at 0°C 1000 $\Omega$ at 70°F 2000 $\Omega$ at 70°F	3.13 4.79 9.58	0.00518 to 0.00527

### RTD and thermistor interchangeability

The tables below show temperature tolerance — the allowable deviation from nominal curves — for RTDs and thermistors in this catalog. Minco can supply sensors with tighter overall tolerance, or with the narrowest tolerance at a point other than 0°C.

Temperature °C	Interchangeability						
	Platinum RTD						
	0.06% at 0°C	0.1% at 0°C	0.22% at 0°C	0.36% at 0°C	0.5% at 0°C	0.1% at 70°F	0.24% at 70°F
-200	±0.55°C	±1.3°C			±2.1°C		
-100	±0.35°C	±0.8°C	±1.3°C		±1.7°C		
0	±0.15°C	±0.3°C	±0.5°C	±0.9°C	±1.3°C	±0.3°C	±0.7°C
20	±0.19°C	±0.4°C	±0.7°C	±1.3°C	±1.6°C	±0.3°C	±0.6°C
100	±0.35°C	±0.8°C	±1.8°C	±2.3°C	±2.9°C	±0.7°C	±1.1°C
200	±0.55°C	±1.3°C	±3.1°C	±3.7°C	±4.4°C	±1.3°C	±1.8°C
260	±0.67°C	±1.6°C	±3.7°C	±4.6°C	±5.5°C		
300	±0.75°C	±1.8°C					
400	±0.95°C	±2.3°C					
500	±1.15°C	±2.8°C					
600	±1.35°C	±3.3°C					
700		±3.8°C					
800		±4.3°C					
850		±4.6°C					

Temperature °C	Interchangeability									
	Copper RTD		Nickel RTD		Nickel-iron RTD				Thermistor	
	±0.2% at 25°C	±0.5% at 25°C	±0.3% at 25°C	±0.5% at 0°C	±0.26% at 0°C	±0.5% at 0°C	±0.5% at 25°C	±0.12% at 70°F	±0.25% at 70°F	±0.1% at 0°C
-100	±1.5°C	±2.2°C				±2.5°C	±2.9°C			
0	±0.7°C	±1.5°C	±0.5°C	±0.8°C	±0.6°C	±1.1°C	±1.4°C	±0.5°C	±1.4°C	±0.2°C
20	±0.5°C	±1.3°C	±0.8°C	±1.2°C	±0.8°C	±1.4°C	±1.2°C	±0.3°C	±0.7°C	±0.2°C
100	±1.5°C	±2.5°C	±1.8°C	±2.2°C	±1.7°C	±2.4°C	±2.2°C	±1.1°C	±2.0°C	±0.3°C
150	±2.2°C	±3.3°C	±2.5°C	±3.0°C	±2.3°C	±3.1°C	±2.9°C	±1.6°C	±2.9°C	±1.0°C
200	±2.8°C	±4.1°C	±3.1°C	±3.7°C	±2.9°C	±3.8°C	±3.6°C	±2.1°C	±3.8°C	
260	±3.6°C	±5.1°C	±3.4°C	±4.0°C						

### Thermocouple limits of error per ANSI-MC96.1-1982

Junction type:	E (Chromel-Constantan)	J (Iron-Constantan)	K (Chromel-Alumel)	T (Copper-Constantan)
Limits of error:	±1.7°C or ±0.5% 0 to 900°C	±2.2°C or ±0.75% 0 to 750°C	±2.2°C or ±0.75% 0 to 1250°C	±1.0°C or ±0.75% 0 to 350°C

## RTD Connections: 2-Wire, 3-Wire, 4-Wire?

Because an RTD is a resistance type sensor, resistance introduced by connecting extension wires between the RTD and control instrument will add to readings. Furthermore, this additional resistance is not constant but increases with ambient temperature. To estimate leadwire error in 2-wire circuits, multiply the total length of the extension leads times the resistance per foot in the table below. Then divide by the sensitivity of the RTD, given in the next two pages, to obtain an error figure in °C. For example, assume you have connected 100 feet of AWG 22 wires to a 100 Ω platinum RTD (PD element). Lead resistance is:

$$R = (200 \text{ ft.}) \times (0.0165 \Omega / \text{ft.}) = 3.3 \Omega$$

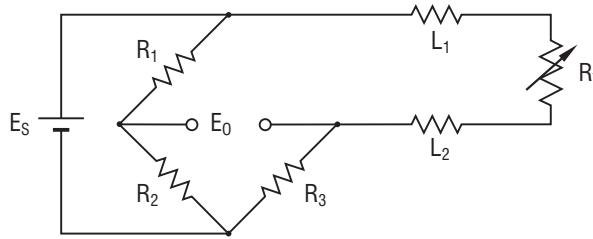
Approximate error is:

$$E = \frac{3.3 \Omega}{0.385 \Omega / ^\circ\text{C}} = 8.6^\circ\text{C}$$

Leadwire AWG	Ohms/ft. at 25°C
12	0.0016
14	0.0026
16	0.0041
18	0.0065
20	0.0103
22	0.0165
24	0.0262
26	0.0418
28	0.0666
30	0.1058

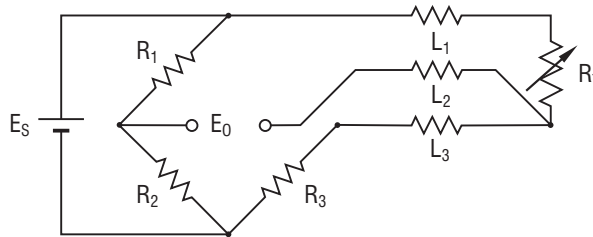
You can reduce leadwire error by:

- Using larger gauge extension wires.
- Specifying an RTD with greater sensitivity; 1000 Ω instead of 100 Ω, for example.
- Employing a 3 or 4-wire resistance canceling circuit as shown at right. Common leads, connected to the same end of the sensing element, are the same color.
- Using a 2-wire current transmitter. Its linearized signal is immune to electrical noise as well as resistance and can maintain accuracy over runs of several thousand feet. See Section 5 for transmitters.



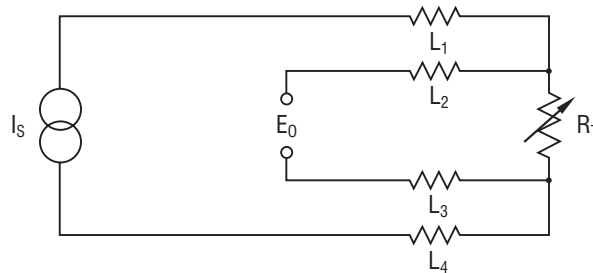
### 2-wire circuit

Shown above is a 2-wire RTD connected to a typical Wheatstone bridge circuit.  $E_S$  is the supply voltage;  $E_O$  is the output voltage;  $R_1$ ,  $R_2$ , and  $R_3$  are fixed resistors; and  $R_T$  is the RTD. In this uncompensated circuit, lead resistances  $L_1$  and  $L_2$  add directly to  $R_T$ .



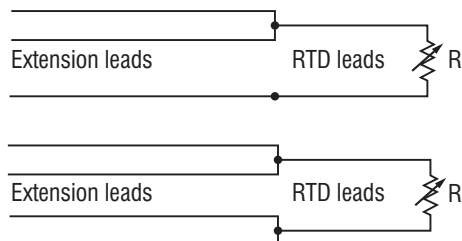
### 3-wire circuit

In this circuit there are three leads coming from the RTD instead of two.  $L_1$  and  $L_3$  carry the measuring current while  $L_2$  acts only as a potential lead. No current flows through it while the bridge is in balance. Since  $L_1$  and  $L_3$  are in separate arms of the bridge, resistance is canceled. This circuit assumes high impedance at  $E_O$  and close matching of resistance between wires  $L_1$  and  $L_3$ . Minco matches RTD leads within 5%.



### 4-wire circuit

4-wire RTD circuits not only cancel leadwires but remove the effects of mismatched resistances such as contact points. A common version is the constant current circuit shown above.  $I_S$  drives a precise measuring current through  $L_1$  and  $L_4$ .  $L_2$  and  $L_3$  measure the voltage drop across the RTD element.  $E_O$  must have high impedance to prevent current flow in the potential leads. 4-wire circuits may be usable over longer distances than 3-wire, but you should consider using a transmitter in electrically noisy environments.



If necessary you can connect a 2-wire RTD to a 3-wire circuit or 4-wire circuit, as shown above. As long as the junctions are near the RTD, as in a connection head, errors are negligible.

# Technical Reference

## Resistance/Temperature Tables

Complete tables in 1°C or 1°F increments are available from Minco at [www.minco.com/sensorcalc](http://www.minco.com/sensorcalc).

Platinum elements												
Element code	PJ	PA	PB	PD, PE	PN	PL	PH	PP	PG	PF	PW	PS
Resistance at 0°C	25.5 Ω	100 Ω	100 Ω	100 Ω	200 Ω	470 Ω	500 Ω	500 Ω	500 Ω	1000 Ω	1000 Ω	10k Ω
TCR (Ω/Ω/°C)	.00392	.00392	.00391	.00385	.00385	.00392	.00392	.00391	.00385	.00385	.00375	.00385
Sensitivity (Average Ω/°C)	0.100	0.392	0.391	0.385	0.770	1.845	1.963	1.955	1.925	3.850	3.750	38.50
Temperature (°C)	Resistance (ohms)											
-200	4.33	17.00	17.26	18.52	37.04	79.88	84.98	86.30	92.60	185.20		1,852
-180	6.56	25.72	25.97	27.10	54.19	120.88	128.59	129.84	135.48	270.96		2,710
-160	8.75	34.31	34.54	35.54	71.09	161.28	171.57	172.72	177.72	355.43		3,554
-140	10.91	42.80	43.01	43.88	87.75	201.15	213.99	215.03	219.38	438.76		4,388
-120	13.05	51.19	51.37	52.11	104.22	240.57	255.93	256.83	260.55	521.10		5,211
-100	15.17	59.49	59.64	60.26	120.51	279.58	297.43	298.19	301.28	602.56		6,026
-80	17.27	67.71	67.83	68.33	136.65	318.23	338.55	339.17	341.63	683.25		6,833
-60	19.35	75.87	75.96	76.33	152.66	356.57	379.53	379.80	381.64	763.28		7,633
-40	21.41	83.96	84.03	84.27	168.54	394.63	419.82	420.13	421.35	842.71	846.57	8,427
-20	23.46	92.01	92.04	92.16	184.32	432.43	460.03	460.19	460.80	921.60	923.55	9,216
0	25.50	100.00	100.00	100.00	200.00	470.00	500.00	500.00	500.00	1000.00	1000.00	10,000
20	27.53	107.95	107.92	107.79	215.59	507.35	539.73	539.58	538.96	1077.94	1075.96	10,779
40	29.54	115.85	115.78	115.54	231.08	544.47	579.23	578.92	577.70	1155.41	1151.44	11,554
60	31.54	123.70	123.60	123.24	246.48	581.38	618.49	618.02	616.21	1232.42	1226.44	12,324
80	33.53	131.50	131.38	130.90	261.79	618.06	657.51	656.90	654.48	1308.97	1300.96	13,090
100	35.51	139.26	139.11	138.51	277.01	654.53	696.31	695.54	692.53	1385.06	1375.00	13,851
120	37.48	146.97	146.79	146.07	292.14	690.77	734.86	733.94	730.34	1460.68	1448.56	14,607
140	39.43	154.64	154.42	153.58	307.17	726.79	773.18	772.11	767.92	1535.84	1521.63	15,358
160	41.37	162.25	162.01	161.05	322.11	762.59	811.27	810.05	805.27	1610.54	1594.22	16,105
180	43.31	169.82	169.55	168.48	336.96	798.18	849.12	847.75	842.39	1684.78	1666.33	16,848
200	45.22	177.35	177.04	175.86	351.71	833.54	886.74	885.22	879.28	1758.56	1737.96	17,586
220	47.13	184.82	184.49	183.19	366.38	868.68	924.12	922.46	915.94	1831.88	1809.11	18,319
240	49.02	192.25	191.89	190.47	380.95	903.59	961.27	959.46	952.36	1904.73	1879.78	19,047
260	50.91	199.64	199.24	197.71	395.42	938.29	998.18	996.22	988.56	1977.12	1949.96	19,771
280	52.78	206.97	206.55	204.91	409.81	972.77	1034.86	1032.76	1024.52	2049.05	2019.67	20,490
300	54.64	214.26	213.81	212.05	424.10	1007.03	1071.31	1069.06	1060.26	2120.52	2088.89	21,205
320	56.48	221.50	221.02	219.15	438.30	1041.06	1107.51	1105.12	1095.76	2191.52	2157.63	21,915
340	58.32	228.70	228.19	226.21	452.41	1074.88	1143.49	1140.95	1131.03	2262.06	2225.89	22,621
360	60.14	235.85	235.31	233.21	466.43	1108.47	1179.23	1176.55	1166.07	2332.14	2293.67	23,321
380	61.95	242.95	242.38	240.18	480.35	1141.85	1214.73	1211.91	1200.88	2401.76	2360.96	24,018
400	63.75	250.00	249.41	247.09	494.18	1175.00	1250.00	1247.04	1235.46	2470.92	2427.78	24,709
420	65.54	257.01	256.39	253.96	507.92	1207.93	1285.03	1281.94	1269.81	2539.62	2494.11	25,396
440	67.31	263.97	263.32	260.79	521.57	1240.64	1319.83	1316.60	1303.92	2607.85	2559.96	26,078
460	69.07	270.88	270.21	267.56	535.12	1273.14	1354.40	1351.03	1337.81	2674.62	2625.33	26,756
480	70.83	277.75	277.04	274.29	548.59	1305.41	1388.73	1385.22	1371.46	2742.93	2690.22	27,429
500	72.56	284.57	283.84	280.98	561.96	1337.46	1422.83	1419.18	1404.89	2808.78	2754.63	28,098
520	74.29	291.34	290.58	287.62	575.23	1369.28	1456.69	1452.91	1438.08	2876.16		28,762
540	76.01	298.06	297.28	294.21	588.42	1400.89	1490.31	1486.40	1471.04	2942.08		29,421
560	77.71	304.74	303.93	300.75	601.51	1432.28	1523.70	1519.66	1503.77	3007.54		30,075
580	79.40	311.37	310.54	307.25	614.51	1463.45	1556.86	1552.68	1536.27	3072.54		30,725
600	81.08	317.96	317.09	313.71	627.42	1494.39	1589.78	1585.47	1568.54	3137.08		31,371
620	82.75	324.49	323.60	320.12	640.23	1525.12	1622.47	1618.02	1600.58	3201.16		
640	84.40	330.98	330.07	326.48		1555.62	1654.92	1650.35				
660	86.04	337.43	336.49	332.79		1585.91	1687.14	1682.43				
680	87.67	343.82	342.86	339.06		1615.97	1719.12	1714.29				
700	89.29	350.17	349.18	345.28		1645.81	1750.87	1745.91				
720				351.46								
740				357.59								
760				363.67								
780				369.71								
800				375.70								
820				381.65								
840				387.55								
850				390.48								

# Technical Reference

	Copper	Nickel	Nickel-iron			Thermistors*	
Element code	CA	NA	FA	FB	FC	TA	TB
Base resistance	10 Ω at 25°C	120 Ω at 0°C	604 Ω at 0°C	1000 Ω at 70°F	2000 Ω at 70°F	2252 Ω at 25°C	10k Ω at 25°C
TCR (Ω/Ω/°C)	.00427	.00672	.00518	.00527	.00527	$\frac{R_{25}}{R_{125}} = 29.2$	$\frac{R_{25}}{R_{125}} = 23.5$
Sensitivity (Average Ω/°C)	0.039	0.806	3.133	4.788	9.576	-72	-287
Temperature (°C)	Resistance (ohms)						
-100	5.128		372.79				
-80	5.923	66.60	410.73			1660 K	3558 K
-60	6.712	79.62	452.82			316.5 K	845.9 K
-40	7.490	92.76	499.06			75.79 K	239.8 K
-20	8.263	106.15	549.46	826.90	1653.81	21.87 K	78.91 K
0	9.035	120.00	604.00	908.40	1816.81	7355	29.49 K
20	9.807	134.52	660.97	995.04	1990.09	2814	12.26 K
40	10.580	149.79	720.79	1086.49	2172.99	1200	5592
60	11.352	165.90	783.45	1182.50	2365.01	560.3	2760
80	12.124	182.84	848.97	1282.83	2565.66	282.7	1458
100	12.897	200.64	917.33	1387.21	2774.44	152.8	816.8
120	13.669	219.29	988.54	1495.42	2990.84	87.7	481.8
140	14.442	238.85	1062.60	1607.18	3214.37	53.0	297.2
160	15.217	259.30	1139.50	1722.26	3444.54		
180	15.996	280.77	1219.26	1840.41	3680.84		
200	16.776	303.46	1301.86	1961.38	3922.77		
220	17.555	327.53					
240	18.335	353.14					
260	19.116	380.31					

## Resistance/temperature calculations

Most RTD tables follow the Callendar-Van Dusen equation or some variation thereof:

$$R_t = R_0 [1 + At + Bt^2 + Ct^3]$$

where  $R_t$  is the resistance at temperature  $t$ ,  $R_0$  is the ice point resistance, and  $A$ ,  $B$ , and  $C$  are coefficients describing a given thermometer.

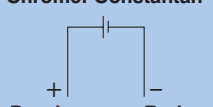
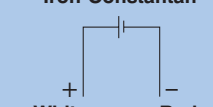
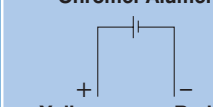

Request Application Aid #18 for a complete set of equations and coefficients for numerical calculation of resistance vs temperature.

## SensorCalc program

RTD and thermocouple tables are available on-line at [www.minco.com/sensorcalc](http://www.minco.com/sensorcalc). You can create and store tables in a variety of formats. You can also enter resistances and coefficients for custom tables, using Callendar-Van Dusen or ITS-90 equations.

\*See [www.minco.com/support](http://www.minco.com/support) for additional thermistor resistance tables.

## Thermocouples

Junction type:	E Chromel-Constantan	J Iron-Constantan	K Chromel-Alumel	T Copper-Constantan
				
Sensitivity (mV/°C):	0.063	0.053	0.041	0.043
Temperature (°C)	Millivolts			
-200	-8.824	-7.890	-5.891	-5.603
-150	-7.279	-6.499	-4.912	-4.648
-100	-5.237	-4.632	-3.553	-3.378
-50	-2.787	-2.431	-1.889	-1.819
0	0.000	0.000	0.000	0.000
50	3.047	2.585	2.022	2.035
100	6.317	5.268	4.095	4.277
150	9.787	8.008	6.137	6.702
200	13.419	10.777	8.137	9.286
250	17.178	13.553	10.151	12.011
300	21.033	16.325	12.207	14.860
350	24.961	19.089	14.292	17.816
400	28.943	21.846	16.395	20.869
450	32.960	24.607	18.513	
500	36.999	27.388	20.640	
550	41.045	30.210	22.772	

## Specifications for Temperature Sensors

Listed below are national and international specifications for RTDs and thermocouples.

### ANSI-MC96.1-1982

**Issued by:** Instrument Society of America  
**Date:** 1982

Sets general standards for thermocouples, including millivolt tables, limits of error, and wire color codes. All Minco thermocouples conform to this specification.

### CENELEC EN50014, EN50019:

**Issued by:** European Committee for Electrotechnical Standardization

**Date:** 2003

Minco has qualified specific models of sensors and accessories used in potentially hazardous areas to these international requirements.

### CSA

**Issued by:** Canadian Standards Assn.

**Date:** 2002

CSA Standards are met through recognized testing labs, such as Underwriters Labs, whose testing covers both the U.S. and Canada (see UL).

### DIN 43760

**Issued by:** Deutsches Institut für Normung (Germany)

**Date:** 1987

Specifies resistance curves and tolerance for nickel RTDs. Platinum curves are now covered under EN60751.

### FM

**Issued by:** Factory Mutual

**Date:** 1989

Selected temperature sensor and Temtran™ models are certified compliant to FM specifications and requirements for use in hazardous areas, for the purposes of safety and property loss prevention.

### IEC EN60751 (IEC 751)

**Issued by:** International Electrotechnical Commission

**Date:** 1983

IEC 751 has the widest international scope of any RTD standard. It calls for platinum RTDs, 100 Ω at 0°C, TCR 0.00385 Ω/Ω/°C, in one of two tolerance classes:

Class A: ±0.06% at 0°C.

Class B: ±0.12% at 0°C.

All Minco RTDs with PD element code meet Class B. Selected models have Class A as an option.

### ISO 9001: 2000 certified by TÜV Management Services

Minco's Quality Assurance system has been audited and certified to this internationally recognized standard.

### Additional Quality system standards

Minco also has the capability of meeting MIL-Q-9858, MIL-I-45208, FDA-GMP, and 10CFR50 and -21.

### ITS-90

**Issued by:** Comité International des Poids et Mesures

**Date:** 1990

ITS-90 defines temperature itself. It specifies the temperature in Kelvins of various physical constants, such as the triple point of water. ITS-90 also names the interpolating instruments to be used between the fixed points. Minco laboratory thermometers in Section 12 are suitable for use as secondary transfer standards, but do not have the stability required for primary standards.

### JIS C 1604-1989

**Issued by:** Japanese Standards Assn.  
**Date:** 1989

Specifies 100 Ω 0.00385 platinum thermometers in accordance with EN60751, but also makes provision for 0.003916 TCR. Minco can supply RTDs to either curve.

### MIL-T-24388C(SH)

**Issued by:** U.S. Naval Sea Systems Command

**Date:** 1990

RTDs and thermocouples for shipboard use. Included are platinum RTDs with 0.00392 TCR and nickel models with 0.00672 TCR. See Section 7 for bearing embedment RTDs qualified to this specification. Minco does not currently offer probe or thermowell models to MIL-T-24388.

### SAMA RC21-4-1966

**Issued by:** Scientific Apparatus Makers Association

**Date:** 1966

Specifies various curves for platinum, nickel, and copper RTDs. The platinum curve, available from Minco, has a resistance of 98.129 Ω at 0°C and TCR of 0.003923. Placing a fixed resistor of 1.871 Ω in series with this element makes it fit the EN60751 curve.

### UL

**Issued by:** Underwriters Laboratories

**Date:** 1995

Selected Minco temperature controllers and temperature transmitters are UL-Listed, and/or UL Recognized Components (see catalog listings for details).

## What is Temperature Coefficient of Resistance (TCR)?

TCR differentiates RTDs by their resistance/temperature curves. Sometimes called alpha ( $\alpha$ ), it is specified in various ways by different manufacturers.

In this bulletin TCR is the RTD's resistance change from 0 to 100°C, divided by the resistance at 0°C, divided by 100°C:

$$TCR (\Omega / \Omega / ^\circ C) = \frac{R_{100^\circ C} - R_{0^\circ C}}{R_{0^\circ C} \times 100^\circ C}$$

For example, a platinum thermometer measuring 100 Ω at 0°C and 139.11 Ω at 100°C has TCR 0.00391 Ω/Ω/°C:

$$TCR = \frac{139.11\Omega - 100\Omega}{100\Omega \times 100^\circ C} = 0.003911$$

For a copper RTD, 10 Ω at 25°C, TCR is:

$$TCR = \frac{12.897\Omega - 9.035\Omega}{9.035\Omega \times 100^\circ C} = 0.00427$$

Stated another way, TCR is the average resistance increase per degree of a hypothetical RTD measuring 1 Ω at 0°C.

The most common use of TCR is to distinguish between curves for platinum,

which is available with TCRs ranging from 0.00375 to 0.003927. The highest TCR indicates the highest purity platinum, and is mandated by ITS-90 for standard platinum thermometers.

There are no technical advantages of one TCR versus another in practical industrial applications. 0.00385 platinum is the most popular worldwide standard and is available in both wire-wound and thin-film elements.

In most cases, all you need to know about TCR is that it must be properly matched when replacing RTDs or connecting them to instruments.

## Material Selection Guide

This guide lists the least expensive materials compatible with various corrosive media. The user should also consider unusual temperatures or levels of concentration. Consult Minco for assistance.

Medium	(°F)	Material
Acetic acid	212	Monel
Acetic anhydride	300	Nickel
Acetone	212	304 SS
Acetylene	400	304 SS
Alcohols	212	304 SS
Alum. (Potassium or sodium)	300	Hastelloy C
Aluminum chloride	212	Hastelloy B
Aluminum sulfate	212	316 SS
Ammonia, dry	212	316 SS
Ammonium hydroxide	212	316 SS
Ammonium chloride 50%	300	Monel
Ammonium nitrate	300	304 SS
Ammonium sulfate	212	316 SS
Amyl acetate	300	304 SS
Aniline	25	Monel
Asphalt	250	304 SS
Atmosphere (industrial and marine)		304 SS
Barium compounds	<i>See calcium</i>	
Beer	70	304 SS
Benzene	212	Steel
Benzoic acid	212	316 SS
Bleaching powder 15%	70	Monel
Borax	212	Brass
Bordeaux mixture	200	304 SS
Boric acid	400	316 SS
Bromine, dry	125	Monel
Butane	400	Steel
Butyric acid	212	Hastelloy C
Calcium bisulphite	75	Hastelloy C
Calcium chloride	212	Hastelloy C
Calcium hydroxide 20%	300	Hastelloy C
Calcium hypochlorite	<i>See bleaching powder</i>	
Carbolic acid	<i>See phenol</i>	
Carbon dioxide, dry	800	Brass
Carbonated water	212	304 SS
Carbonated beverages	212	304 SS
Carbon disulfide	200	304 SS
Carbon tetrachloride	125	Monel
Chlorine, dry	100	Monel
Chlorine, moist	100	Monel
Chloroacetic acid	212	Monel
Chloroform, dry	212	Monel
Chromic acid	300	Hastelloy C
Cider	300	304 SS
Citric acid	212	Hastelloy C
Copper (10) chloride	212	Hastelloy C
Copper (10) nitrate	300	316 SS
Copper (10) sulfate	300	316 SS
Copper plating solution (cyanide)	180	304 SS

Medium	(°F)	Material
Copper plating solution (acid)	75	304 SS
Corn oil	200	304 SS
Creosote	200	304 SS
Crude oil	300	Monel
Ethyl acetate	<i>See lacquer thinner</i>	
Ethyl chloride, dry	500	Steel
Ethylene glycol (uninhibited)	212	304 SS
Ethylene oxide	75	Steel
Fatty acids	500	316 SS
Ferric chloride	75	Hastelloy C
Ferric sulphate	300	304 SS
Formaldehyde 40%	212	316 SS
Formic acid	300	316 SS
Freon	300	Steel
Fluorine, anhydrous	100	304 SS
Furfural	450	316 SS
Gasoline	300	Steel
Glucose	300	304 SS
Glue, pH 6-8	300	304 SS
Glycerine	212	Brass
Hydrobromic acid	212	Hastelloy C
Hydrochloric acid 37-38%	225	Hastelloy B
Hydrogen chloride, dry	500	304 SS
Hydrocyanic acid	212	304 SS
Hydrofluoric acid 60%	212	Monel
Hydrogen fluoride, dry	175	Steel
Hydrofluogilicic acid 40%	212	Monel
Hydrogen peroxide 10-100%	125	304 SS
Kerosene	300	Steel
Lacquers & thinners	300	304 SS
Lactic acid	300	316 SS
Lime	212	316 SS
Linseed oil	75	Steel
Magnesium chloride 50%	212	Nickel
Magnesium hydroxide (or oxide)	75	304 SS
Magnesium sulphate 40%	212	304 SS
Mercuric chloride 10%	75	Hastelloy C
Mercury 100%	700	Steel
Methylene chloride	212	304 SS
Methyl chloride, dry	75	Steel
Milk, fresh or sour	180	304 SS
Molasses	<i>See glucose</i>	
Natural gas	70	304 SS
Nitric acid	75	304 SS
Nitric acid	300	316 SS
Oxygen	75	Steel
Oleic acid	<i>See fatty acids</i>	
Oxalic acid	212	Monel
Photographic bleaching	100	304 SS

Medium	(°F)	Material
Palmitic acid	<i>See fatty acids</i>	
Phosphoric acid	212	316 SS
Phenol	212	316 SS
Potassium compounds	<i>See sodium compounds</i>	
Propane	300	Steel
Rosin 100%	700	316 SS
Sea water	75	Monel
Soap & detergents	212	304 SS
Sodium bicarbonate 20%	212	316 SS
Sodium bisulphite 20%	212	304 SS
Sodium bisulphate 20%	212	304 SS
Sodium carbinatate 40%	212	316 SS
Sodium chloride 30%	300	Monel
Sodium chromate	212	316 SS
Salt or brine	<i>See sodium chloride</i>	
Sodium cyanide	212	304 SS
Sodium hydroxide 30%	212	316 SS
Sodium hypochlorite 10%	75	Hastelloy C
Sodium nitrate 40%	212	304 SS
Sodium nitrite 20%	75	316 SS
Sodium phosphate 10%	212	Steel
Sodium silicate 10%	212	Steel
Sodium sulfide 30%	212	316 SS
Sodium sulfite 10%	212	316 SS
Sodium sulfate 30%	212	304 SS
Sodium thiosulfate	212	304 SS
Steam		304 SS
Stearic acid	<i>See fatty acids</i>	
Sugar solution	<i>See glucose</i>	
Sulfur	500	304 SS
Sulfur chloride, dry	75	316 SS
Sulfur dioxide, dry	500	316 SS
Sulfur trioxide, dry	500	316 SS
Sulfuric acid 10%	212	316 SS
Sulfuric acid 10-90%	212	Hastelloy B
Sulfuric acid 90-100%	212	316 SS
Sulfuric acid, fuming	175	Hastelloy C
Sulfurous acid 20%	75	316 SS
Titanium tetrachloride	75	316 SS
Tannic acid 40%	75	Hastelloy B
Toluene	75	Steel
Trichloroacetic acid	75	Hastelloy B
Trichloroethylene, dry	300	Monel
Turpentine	75	316 SS
Varnish	150	Steel
Zinc chloride	212	Hastelloy B
Zinc sulfate	212	316 SS

## Sensor Selection Guide

Sensor Type	Description	Temperature Range*	RTD Element				Thermocouple Junction				Thermistors
			Platinum	Copper	Nickel	Nickel-Iron	E	J	K	T	
Assemblies	Probes supplied complete with fittings, connection heads, thermowells, and optional transmitters	-269 to 550°C (-452 to 1022°F)	●	●	●		●	●	●	●	
Probes	Industrial probe type sensors: tip-sensitive, fast response, and high temperature models	-269 to 850°C (-452 to 1562°F)	●	●	●		●	●	●	●	
Sanitary RTDs	3-A certified for clean-in-place installations	-100 to 200°C (-148 to 392°F)	●								
Bearing Detectors & Miniature RTDs	Miniature encased sensing elements	-184 to 260°C (-300 to 500°F)	●	●	●		●	●	●	●	
Stator Winding Detectors	Flat, laminated "stick" sensors	180°C (356°F) max.	●	●	●		●	●	●	●	
HVAC Thermometers	Sensors and transmitters designed for HVAC systems	-45.5 to 135°C (-50 to 275°F)	●			●					●
Thermal-Ribbons™	Flat, flexible sensors for surface mounting	-200 to 200°C (-328 to 428°F)	●	●	●	●	●	●	●	●	●
Ceramic Elements	Wire-wound and thin-film elements	-200 to 850°C (-328 to 1582°F)	●								
Precision Laboratory Thermometers	Reference grade platinum thermometers	-260 to 660°C (-436 to 1220°F)	●								

\* Temperature range of individual models may vary.

## Miscellaneous specifications and codes

### Thread specifications

Thread	Applicable specifications
G $\frac{1}{2}$	<ul style="list-style-type: none"> <li>•ISO 228/1</li> <li>•DIN 259</li> <li>•BS 2779</li> <li>•JIS B0202</li> </ul>
R $\frac{1}{4}$ R $\frac{1}{8}$	<ul style="list-style-type: none"> <li>•ISO 7/1</li> <li>•DIN 2999</li> <li>•BS 21</li> <li>•JIS B0203</li> </ul>

### Wire gauge conversion

Wire Gauge Number AWG	Cross Sectional Area mm <sup>2</sup>		Resistance Ω/ft. at 25°C
	Stranded	Solid	
30	0.057	0.051	0.1058
28	0.089	0.080	0.0666
26	0.141	0.128	0.0418
24	0.227	0.205	0.0262
22	0.355	0.324	0.0165
20	0.563	0.519	0.0103
18	0.897	0.823	0.0065

### Ingress Protection (IP) Codes

	First Number Protection against solid bodies	Second Number Protection against liquid
0	No protection	No protection
1	Objects > 50 mm	Vertically dripping water
2	Objects > 12 mm	75° to 90° dripping water
3	Objects > 2.5 mm	Sprayed water
4	Objects > 1 mm	Splashed water
5	Dust-protected	Water jets
6	Dust-tight	Heavy seas
7		Effects of immersion
8		Indefinite immersion

### Approximate US Enclosure Type Equivalent to IPXX

Type	IP	Type	IP	Type	IP
1	10	3S	54	6 & 6P	67
2	11	4 & 4X	55	12 & 12K	52
3	54	5	52	13	54
3R	14				

## Related Literature

[www.minco.com](http://www.minco.com)

▲ Most literature is immediately downloadable at [www.minco.com/support](http://www.minco.com/support).

### Temperature sensors

#### Application Aid #16

"Use of Thermal-Ribbons for Pipe Fluid Temperature Sensing"  
Compares surface-mounted Thermal-Ribbons to traditional thermowell assemblies. 4 pages.

#### Application Aid #18

"Resistance Thermometry"  
Discusses theory and application of RTDs and thermistors. Includes information on 3 and 4-wire circuits, plus equations for calculating resistance from temperature. 16 pages.

#### Application Aid #19

"Use of Temperature Sensors In Hazardous Areas"  
Classification of hazardous atmospheres and specification of Minco sensors for explosion-proof, intrinsically safe, and non-incendive installations. 8 pages.

#### Application Aid #20

"Installation Guidelines: Resistance Thermometers and Temptran™ Thermometers for Building Automation Systems"  
Installation drawings and procedures for HVAC sensors. 8 pages.

#### Application Aid #27

"Sealing Sensor Leads Against Oil Leakage"  
Discusses the problems of oil seepage and various solutions. 2 pages.

#### Bulletin RT-13

"Sump Temperature Sensor"  
Measure overall tank temperature with a single sensor. 1 page.

#### Bulletin STD-5

"Increased Safety Stator Winding Temperature Sensors"  
CENELEC/ATEX approved stator sensors for use in hazardous areas. 2 pages.

#### SensorCalc program

"SensorCalc" is Minco's on-line program for calculating, printing and saving resistance vs. temperature or millivolt vs. temperature tables. It provides standard RTD and thermocouple choices, with the option of customizing the table to meet your specific needs. Print the table directly or convert it to an Adobe Acrobat .pdf file for storage or sending by e-mail. Go to [www.minco.com/sensorcalc](http://www.minco.com/sensorcalc).

### Temperature instruments

#### Bulletin CT124

The CT124 8-channel alarm, a programmable monitor for protection of large machinery. 4 pages.

### Thermofoil heaters

#### Bulletin HS-202

"Thermofoil™ Heaters" describes flexible, etched-foil and wire-wound precision heating elements, as well as controllers and accessories. Includes listing of standard models and specifications, plus a custom design guide. 60 pages.

#### Bulletin HR-1

"Electric Motor Anti-condensation Heaters" describes wire-wound heaters for anti-condensation. 2 pages.

#### Application Aid #21

"Estimating Power Requirements of Thermofoil™ Heaters"  
Procedure for calculating required wattage. 12 pages.

#### Application Aid #22

"Recommended Adhesives for Thermofoil Heater Installation" describes many alternatives for mounting Minco Thermofoil heaters to optimize the heat transfer, life and efficiency of the heating system. 4 pages.

#### Application Aid #25

"Prototyping Techniques for Thermofoil™ Heaters"  
Methods and tools for thermal design. 4 pages.

#### Application Aid #29

"Designing Heated Chucks for Semiconductor Processing Equipment"  
Discussion of design considerations for chucks used to process wafers. 4 pages.

#### Application Aid #30

"Comparison of Thin-film and Wire-element Heaters for Transparent Applications"  
Benefits and drawbacks of thin-film and wire-element transparent heater construction. 4 pages.

### Flex-Circuits

#### Bulletin FC-302

"Flex-Circuit Design Guide"  
Assists in the design of reliable, producible flexible circuits. 28 pages.

#### Bulletin FC-1

"Flex Coils" describes Minco's unique laminated coils for high reliability telemetry in implantable medical devices, guidance systems and other applications. 4 pages.

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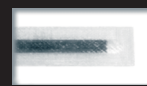
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