Technical

REFERENCE
INFORMATION

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ATHENA®
The Temperature Control Company

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THERMOCOUPLE TECHNICAL DATA

THERMOELECTRICITY IN RETROSPECT

The principles and theory associated with thermoelectric effects were not established by any one person at any one time. The discovery of the thermoelectric behavior of certain materials is generally attributed to T. J. Seebeck.

In 1821, Seebeck discovered that in a closed circuit made up of wire of two dissimilar metals, electric current will flow if the temperature of one junction is elevated above that of the other. Seebeck's original discovery used a thermocouple circuit made up of antimony and copper. Based on most common usage and recognition today, there are eight thermoelement types: S,R,B,J,K,N,T and E.

In the ensuing years following the discovery of the thermoelectric circuit, many combinations of thermoelectric elements were investigated. Serious application of the findings was accelerated by the needs brought on during the course of the Industrial Revolution.

In 1886, Le Chatelier introduced a thermocouple consisting of one wire of platinum and the other of 90 percent platinum- 10 percent rhodium. This combination, Type S, is still used for purposes of calibration and comparison. It defined the International Practical Temperature Scale of 1968 from the antimony to the gold point. This type of thermocouple was made and sold by W. C. Heraeus, GmbH of Hanau, Germany, and is sometimes called the Heraeus Couple.

Later, it was learned that a thermoelement composed of 87 percent platinum and 13 percent rhodium, Type R, would give a somewhat higher EMF output.

In 1954 a thermocouple was introduced in Germany whose positive leg was an alloy of platinum and 30 percent rhodium. Its negative leg was also an alloy of platinum and 6 percent rhodium. This combination, Type B, gives greater physical strength, greater stability, and can withstand higher temperatures than Types R and S.

The economics of industrial processes prompted a search for less costly metals for use in thermocouples. Iron and nickel were useful and inexpensive. Pure nickel, however, became very brittle upon oxidation; and it was learned that an alloy of about 60 percent copper,40 percent nickel (constantan) would eliminate this problem. This alloy combination, iron-constantan, is widely used and is designated Type J. The present calibration for Type J was established by the National Bureau of Standards, now known as the National Institute of Standards and Technology (N.I.S.T.).

The need for higher temperature measurements led to the development of a 90 percent nickel-10 percent chromium alloy as a positive wire, and a 95 percent nickel-5 percent aluminum, manganese, silicon alloy as a negative wire. This combination (originally called Chromel- Alumel) is known as Type K.

Conversely the need for sub-zero temperature measurements contributed to the selection of copper as a positive wire and constantan as a negative wire in the Type T thermoelement pair. The EMF-temperature relationship for this pair (referred to as the Adams Table) was prepared by the National Bureau of Standards in 1938. The relatively recent combination of a positive thermoelement from the Type K pair and a negative thermoelement from the type T pair is designated as a Type E thermoelement pair. This pair is useful where higher EMF output is required.

Within the past 20 years, considerable effort has been made to advance the state of the art in temperature measurement. Many new thermoelement materials have been introduced for higher temperatures.

Combinations of tungsten, rhenium and their binary alloys are widely used at higher temperatures in reducing and inert atmospheres or vacuum.

The most common thermoelement pairs are:

W-W26Re	(Tungsten Vs. Tungsten 26% Rhenium)
W3Re-W25Re	(Tungsten 3% Rhenium Vs. Tungsten 25% Rhenium)
W5Re-W26Re	(Tungsten 5% Rhenium Vs. Tungsten 26% Rhenium)

Letter designations have not yet been assigned to these combinations.

The most recent significant development in thermometry was the adoption of the International Temperature Scale of 1990 (ITS-90). The work of international representatives was adopted by the International Committee of Weights and Measures at its meeting September 1989, and is described in "The International Temperature Scale of 1990,"Metrologia 27, No. 1, 3-10 (1990); Metrologia 27,107 (1990).

LAWS OF THERMOELECTRIC CIRCUITS

Numerous investigations of thermoelectric circuits in which accurate measurements were made of the current, resistance, and electromotive force have resulted in the establishment of several basic laws.

Although stated in many different ways, these precepts can be reduced to three fundamental laws:

1. The law of the Homogeneous Circuit
2. The law of Intermediate Materials
3. The law of Successive or Intermediate Temperatures

Law of Homogeneous Circuit

A thermoelectric current cannot be sustained in a circuit of a single homogeneous material, however, varying in cross section, by the application of heat alone.

Two different materials are required for any thermocouple circuit.

Any current detected in a single wire circuit when the wire is heated in any way whatever is taken as evidence that the wire in inhomogeneous.

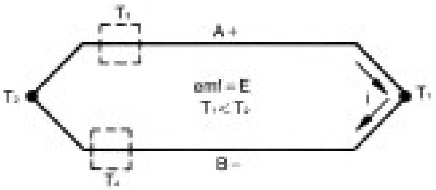

Figure 1. Law of Homogeneous Circuit.

A consequence of this law as illustrated in figure 1, is that if one junction of two dissimilar homogeneous materials is maintained at a temperature T. and the other junction at a temperature T_2, the thermal EMF developed is independent of the temperature distribution along the circuit. The EMF, E, is unaffected by temperatures T_3 and T_4.

Law of Intermediate Materials.

The algebraic sum of the thermoelectromotive forces in a circuit composed of any number of dissimilar materials is zero if all of the circuit is at a uniform temperature.

A consequence of this law is that a third homogeneous material can be added in a circuit with no effect on the net EMF of the circuit so long as its extremities are at the same temperature.

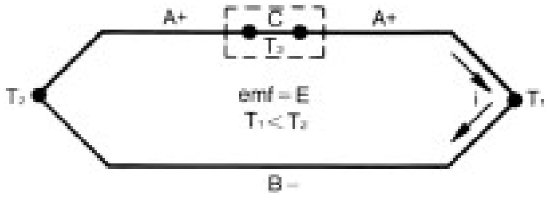

Figure 2. Law of Intermediate Materials.

In figure 2, two homogeneous metals, A and B, with their junctions at temperatures T, and T2 a third metal C, is introduced by cutting A, and forming two junctions of A and C. If the temperature of C is uniform over its whole length, the total EMF in the circuit will be unaffected.

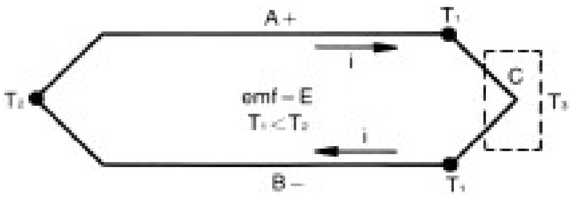

Figure 3. Combining the Law of Intermediate Materials With the Law of Homogeneous Circuit.

Combining the Law of Intermediate Materials with the Law of Homogeneous Circuit, as shown in figure 3, A and B are separated at the temperature T. junction. Two junctions AC and CB are formed at temperature T_1. While C may extend into a region of very different temperature, for example, T_3 the EMF of the circuit will be unchanged. That is, $E_{AC} + E_{CB} = E_{AB}$.

A further consequence to the combined laws of Intermediate Materials and Homogeneous Circuit is illustrated in figure 4.

When the thermal EMF of any material A or B paired with a reference material C is known, then the EMF of any combination of these materials, when paired, is the algebraic sum of their EMF's when paired with reference material C.

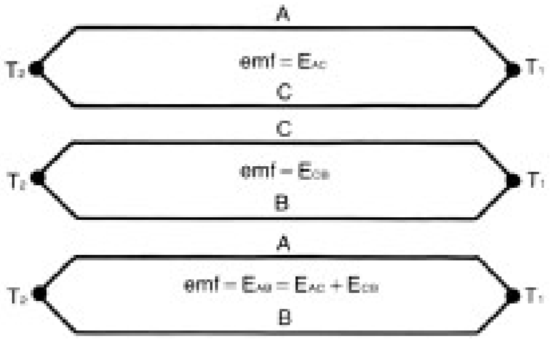

Figure 4. Thermal EMF of two materials with respect to a reference material.

Law of Successive or Intermediate Temperatures

If two dissimilar homogeneous metals produce a thermal EMF of E., when the junctions are at temperatures T_1 and T_2, and a thermal EMF of E_2, when the junctions are at T_2 and T_3, the EMF generated when the junc- tions are at T_1 and T_3, will be $E_1 + E_2$.

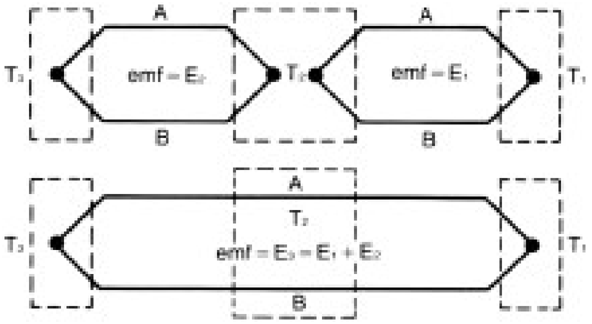

Figure 5. Law of Successive or Intermediate Temperatures.

One consequence of this law permits a thermocouple calibrated at a given reference temperature, to be used at any other reference temperature through the use of a suitable correction.

Another consequence of this law is that extension wires, having the same thermoelectric characteristics as those of the thermocouple wires, can be introduced in the ther-mocouple circuit (say from region T_2 and region T_3) without affecting the net EMF of the thermocouple.

CONCLUSION

The three fundamental laws may be combined and stated as follows: "The algebraic sum of the thermoelectric EMFs generated in any given circuit containing any number of dissimilar homogeneous materials is a function only of the temperatures of the junctions." Corollary: "If all but one of the junctions in such a circuit are maintained at some reference temperature, the EMF generated depends only on the temperature of that one junction and can be used as a measure of its temperature."

THERMOCOUPLE TECHNICAL DATA

THERMOELECTRIC EFFECTS

Seebeck Effect

The Seebeck effect, figure 6, concerns the conversion of thermal energy into electrical energy. The Seebeck voltage refers to the net thermal electromotive force established in a thermoelement pair under zero current conditions.

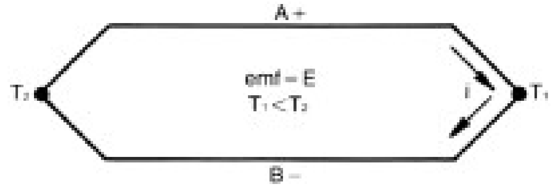

Figure 6. Seebeck Thermal EMF.

When a circuit is formed consisting of two dissimilar conductors A and B, and one junction of A and B is at temperature T_1 while the other junction is at a higher temperature T_2, a current will flow in the circuit. The electromotive force E producing this current i, is called the Seebeck thermal EMF.

Conductor A is considered thermoelectrically positive to conductor B if the current i flows from conductor A to conductor B at the cooler of the two junctions (T_1).

Peltier Thermal Effect.

The Peltier Thermal Effect, figure 7, concerns a reversible phenomenon at the junction of most thermoelement pairs.

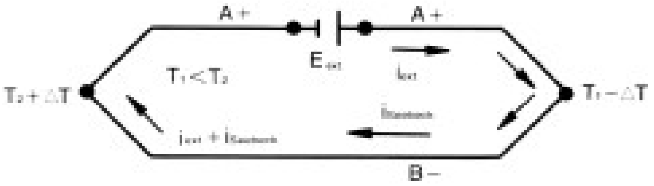

Figure 7. Peltier Thermal Effect.

When an electrical current i_{ext} flows across the junction of a thermoelement pair, heat is absorbed or liberated. The direction of current flow at a particular junction determines whether heat is absorbed or liberated.

If an external current i_{ext} flows in the same direction as the current $i_{Seebeck}$ produced by the Seebeck Effect at the hotter junction of a thermoelement pair, heat is absorbed. Heat is liberated at the other junction.

The Thomson Effect

The Thomson Effect concerns the reversible evolution, or absorption, of heat occurring whenever an electric current traverses a single homogeneous conductor, across which a temperature gradient is maintained, regardless of external introduction of the current or its induction by the thermocouple itself.

The Thomson voltage alone cannot sustain a current in a single homogeneous conductor forming a closed circuit, since equal and opposite EMFs will be set up on the two paths from heated to cooled parts of the circuit.

THERMOELECTRIC CIRCUITS

Series Circuit

A number of similar thermocouples all having thermoelements A and B may be connected in series with all of their measuring junctions at T_2 and their reference junctions at T_1. Such a series, called a thermopile, is shown in figure 8. With 3 thermocouples in series develops an EMF 3 times as great as a single thermocouple is developed.

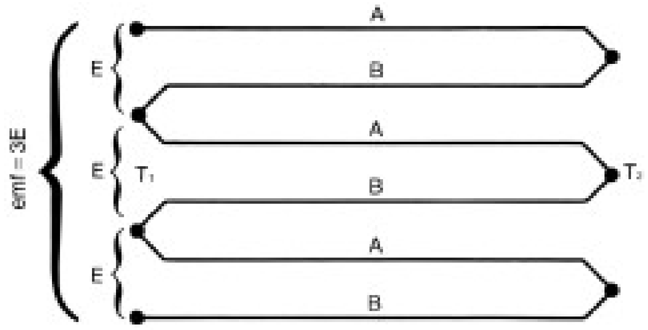

Figure 8. A thermopile of three thermocouples.

Parallel Circuit

If a quantity "N" of thermocouples of equal resistance is connected in parallel with junctions at T_1 and T_2 the EMF developed is the same as for a single thermocouple with its junctions at T_1 and T_2.

If all of the thermocouples are of equal resistance but their measuring junctions are at various temperatures T_2, T_3... T_{n+1}, see figure 9, then the EMF developed will correspond to the mean of the temperatures of the individual measuring junctions.

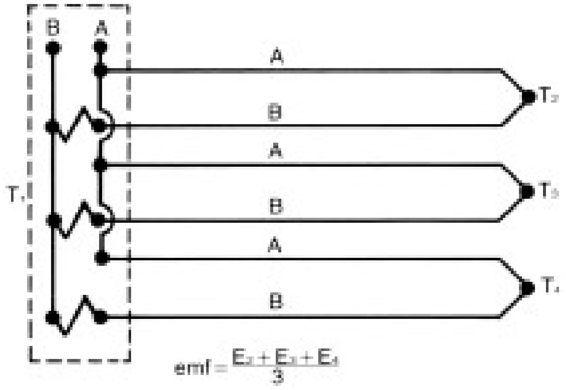

Figure 9. A parallel circuit for mean temperatures.

It is not necessary to adjust the thermocouple resistances when measuring these average temperatures. Instead, swamping resistors may be used. For example, if the thermocouples range in resistance from 5 to 10 ohms, a 500 ohm (±1%) resistor is connected in series with each, and the error in EMF introduced by the inequality in thermocouple resistance becomes an insignificant fraction of the total resistance.

Basic Thermocouple Circuit

Two continuous, dissimilar thermocouple wires extending from the measuring junction to the reference junction, when used together with copper connecting wires and a potentiometer, connected as shown in figure 10, below, make up the basic thermocouple circuit for temperature measurement.

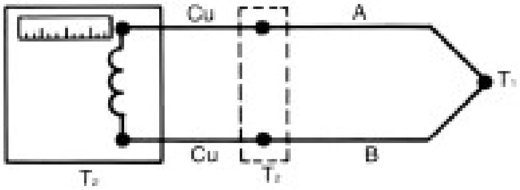

Figure 10. Basic thermocouple circuit

Differential Thermocouple Circuit

Junctions 1 and 2 are each at different temperatures. The temperature measured by the circuit shown in figure 11 is the difference between T_1 and T_2.

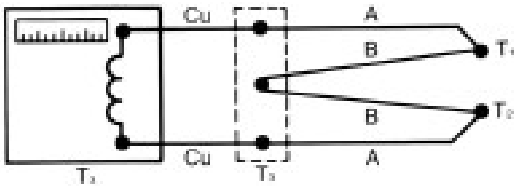

Figure 11. Differential thermocouple circuit

Typical Industrial Thermocouple Circuit

The usual thermocouple circuit includes: measuring junctions, thermocouple extension wires, reference junctions, copper connecting wires, a selector switch, and poten-tiometer. Many different circuit arrangements of the above components are acceptable, depending on given circumstances.

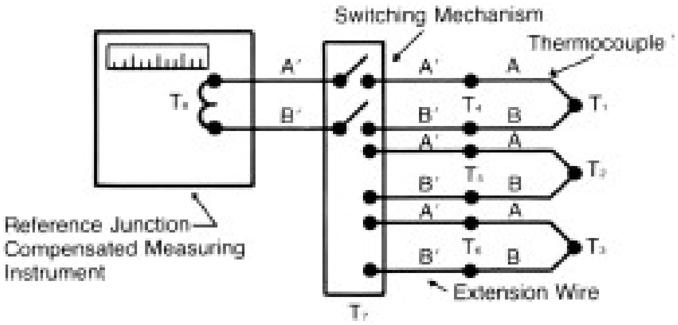

Figure 12. Typical industrial thermocouple circuit

THERMOCOUPLE ENGINEERING DATA

ENVIRONMENTAL LIMITATIONS OF THERMOELEMENTS.

JP

For use in oxidizing, reducing, or inert atmospheres or in vacuum. Oxidizes rapidly above 540˚C (1000˚F). Will rust in moist atmospheres as in subzero applications. Stable to neutron radiation transmutation. Change in composition is only 0.5 percent (increase in manganese) in 20-year period.

JN, TN, EN

Suitable for use in oxidizing, reducing, and inert atmospheres or in vacuum. Should not be used unprotected in sulfurous atmospheres above 540˚C (1000˚F).

Composition changes under neutron radiation since copper content is converted to nickel and zinc. Nickel content increases 5 percent in 20-year period.

TP

Can be used in vacuum or in oxidizing, reducing or inert atmospheres. Oxidizes rapidly above 370˚C (700˚F). Preferred to Type JP element for subzero use because of its superior corrosion resistance in moist atmospheres.

Radiation transmutation causes significant changes in composition.

Nickel and zinc grow into the material in amounts of 10 percent each in a 20-year period.

KP, EP

For use in oxidizing or inert atmospheres. Can be used in hydrogen or cracked ammonia atmospheres if dew point is below -40˚C (-40˚F). Do not use unprotected in sulfurous atmospheres above 540˚C (1000˚F).

Not recommended for service in vacuum at high temperatures except for short time periods because preferential vaporization of chromium will alter calibration. Large negative calibration shifts will occur if exposed to marginally oxidizing atmospheres in temperature range 815 to 1040˚C (1500 to 1900˚F).

Quite stable to radiation transmutation. Composition change is less than 1 percent in 20-year period.

KN

Can be used in oxidizing or inert atmospheres. Do not use unprotected in sulfurous atmospheres as intergranular corrosion will cause severe embrittlement.

Relatively stable to radiation transmutation. In 20-year period, iron content will increase approximately 2 percent. The manganese and cobalt contents will decrease slightly.

RP, SP, SN, RN, BP, BN

For use in oxidizing or inert atmospheres. Do not use unprotected in reducing atmospheres in the presence of easily reduced oxides, atmospheres containing metallic vapors such as lead or zinc, or those containing nonmetallic vapors such as arsenic, phosphorus, or sulfur. Do not insert directly into metallic protecting tubes. Not recommended for service in vacuum at high temperatures except for short time periods.

Type SN elements are relatively stable to radiation transmutation. Types BP, BN, RP and SP elements are unstable because of the rapid depletion of rhodium. Essentially, all the rhodium will be converted to palladium in a 10-year period.

NP, NN

Proprietary alloys suitable for use in applications cited for KP and KN.

Typical physical properties of thermoelement materials.

	Thermoelement Material											
Property	JP	JN, TN, EN	TP	KP, EP	KN	NP	NN	RP	SP	RN, SN	BP	BN
Melting point												
˚C	1490	1220	1083	1427	1399	1410	1340	1860	1850	1769	1927	1826
˚F	2715	2228	1981	2600	2550	2570	2444	3380	3362	3216	3501	3319
Temperature coefficient of resistance, Ω/Ω ˚C x 10^{-4} (0 to 100˚C)	65	-0.1	43	4.1	23.9	24.0	0.01	15.6	16.6	39.2	13.3	20.0
Coefficient ot thermal expansion, in./in. ˚C (0 to 100˚C)	11.7 x 10^{-6}	14.9 x 10^{-6}	16.6 x 10^{-6}	13.1 x 10^{-6}	12.0 x 10^{-6}	13.3 x 10^{-6}	12.1 x 10^{-6}	9.0 x 10^{-6}	9.0 x 10^{-6}	9.0 x 10^{-6}	—	—
Density:												
g/cm^3	7.86	8.92	8.92	8.73	8.60	8.52	8.70	19.61	19.97	21.45	17.60	20.55
lb/in.^{3}	0.284	0.322	0.322	0.315	0.311	0.308	0.314	0.708	0.721	0.775	0.636	0.743
Tensile strength (annealed):												
kgf/cm^2	3500	5600	2500	6700	6000	—	—	3200	3200	1400	4900	2800
psi	50000	80000	35000	95000	85000	90000	80000	46000	45000	20000	70000	40000
Magnetic attraction	strong	none	none	none	moderate	none	slight	none	none	none	none	none

THERMOCOUPLE ENGINEERING DATA

Nominal chemical composition of thermoelements.

Nominal Chemical Composition, %

Element	JP	JN, TN, EN	TP	KP, EN	KN	NP	NN	RP	SP	RN, SN	BP	BN
Iron	99.5	—	—	—	—	—	—	—	—	—	—	—
Carbon	**	—	—	—	—	—	—	—	—	—	—	—
Manganese	**	—	—	—	2	—	0.1	—	—	—	—	—
Sulfur	**	—	—	—	—	—	—	—	—	—	—	—
Phosphorus	**	—	—	—	—	—	—	—	—	—	—	—
Silicon	**	—	—	—	1	1.4	4.4	—	—	—	—	—
Nickel	**	45	—	90	95	84.4	95.5	—	—	—	—	—
Copper	**	55	100	—	—	—	—	—	—	—	—	—
Chromium	**	—	—	10	—	14.2	—	—	—	—	—	—
Aluminum	—	—	—	—	2	—	—	—	—	—	—	—
Platinum	—	—	—	—	—	—	—	87	90	100	70.4	93.9
Rhodium	—	—	—	—	—	—	—	13	10	—	29.6	6.1

*Types JN, TN, and EN thermoelements usually contain small amounts of various elements for control of thermal emf, with corresponding reductions in the nickel or copper content, or both.

**Thermoelectric iron (JP) contains small but varying amounts of these elements.

Upper temperature limits for various size (awg) protected thermocouples

Thermoelement	No. 8 [0.128 in.]	No. 14 [0.064 in]	No. 20 [0.032 in.]	No. 24 [0.020 in.]	No. 28 0.013 in.]
JP	760˚C (1400˚F)	593˚C (1100˚F)	482˚C (900˚F)	371˚C (700˚F)	371˚C (700˚F)
JN, TN, EN	871˚C (1600˚F)	649˚C (1200˚F)	538˚C (1000˚F)	427˚C (800˚F)	427˚C (800˚F)
TP	— —	371˚C (700˚F)	260˚C (500˚F)	204˚C (400˚F)	204˚C (400˚F)
KP, EP, KN, NP, NN	1260˚C (2300˚F)	1093˚C (2000˚F)	982˚C (1800˚F)	871˚C (1600˚F)	871˚C (1600˚F)
RP, SP, RN, SN	— —	— —	— —	1482˚C (2700˚F)	— —
BP, BN	— —	— —	— —	1705˚C (3100˚F)	— —

Nominal resistance of thermoelements

Ohms per foot at 20˚C (68˚F)

Awg. No.	Diameter, in.	KN	KP, EP	TN, JN, EN	TP	JP	NP	NN	RN, SN	SP	BP	BN
8	0.1285	0.0107	0.0257	0.0179	0.000628	0.0043	0.0354	0.0134	0.00386	0.00697	0.00700	0.00648
12	0.0808	0.0270	0.065	0.0448	0.00159	0.0109	0.0884	0.0335	0.00976	0.01761	0.01769	0.01637
14	0.0641	0.0432	0.104	0.0718	0.00253	0.0174	0.1416	0.0537	0.0155	0.0280	0.0281	0.0260
16	0.0508	0.0683	0.164	0.113	0.00402	0.0276	0.2230	0.0846	0.0247	0.0445	0.0447	0.0414
17	0.0453	0.0874	0.209	0.145	0.00506	0.0349	0.2864	0.1086	0.0311	0.0562	0.0564	0.0523
18	0.0403	0.111	0.266	0.184	0.00648	0.0446	0.3625	0.1375	0.0399	0.0719	0.0722	0.0669
20	0.0320	0.173	0.415	0.287	0.0102	0.0699	0.5664	0.2148	0.0624	0.1125	0.1130	0.1046
22	0.0253	0.276	0.663	0.456	0.0161	0.1111	0.9061	0.3437	0.0993	0.1790	0.1798	0.1664
24	0.0201	0.438	1.05	0.728	0.0257	0.1767	1.4356	0.5445	0.1578	0.2847	0.2859	0.2647
26	0.0159	0.700	1.68	1.16	0.0408	0.281	2.2942	0.8702	0.2509	0.4526	0.4546	0.4208
28	0.0126	1.11	2.48	1.85	0.0649	0.447	3.6533	1.3857	0.3989	0.7197	0.7229	0.6692
30	0.0100	1.77	4.25	2.94	0.1032	0.710	5.8000	2.2000	0.6344	1.144	1.149	1.064
36	0.0050	7.08	17.0	11.8	0.4148	2.86	23.200	8.8000	2.550	4.600	4.620	4.277
40	0.0031	18.4	44.2	30.6	1.049	7.22	60.354	22.893	6.448	11.63	11.68	10.81

THERMOCOUPLE ENGINEERING DATA

Nominal weights of thermoelements

Feet Per Pound							Feet Per Troy Ounce				
Awg. No.	Diameter, in.	KN	KP, EP	TN, JN, EN	TP	JP	RN, SN	SP	RP	BN	BP
8	.128	21	20	20	20	22	0.5	0.5	0.5	0.5	0.6
14	.064	83	82	80	80	91	2.3	2.4	2.5	2.4	2.8
16	.051	130	129	127	127	143	3.6	3.8	3.9	3.7	4.3
17	.045	167	166	163	163	184	4.6	4.9	5.0	4.8	5.6
18	.040	212	210	207	207	233	5.8	6.2	6.3	6.0	7.0
20	.032	331	328	323	322	364	9.1	9.7	9.9	9.4	11.0
22	.025	530	525	518	517	583	15.0	16.0	16.4	45.6	18.2
24	.020	838	832	820	816	924	23.4	25.1	25.6	24.4	28.5
26	0.16	1340	1331	1312	1306	1478	36.6	39.2	40.0	38.2	44.5
28	.013	2130	2119	2089	2076	2353	555	59.5	60.7	57.9	67.6
30	.010	3370	3364	3316	3296	3736	60.6	65.0	66.3	63.2	73.8
36	.005	13500	13460	13260	13180	14940	375.5	402.8	411.0	391.9	457.5
40	.003	35200	35010	34500	34292	N.A.	1042.7	1118.6	1141.4	1088.2	1270.5

Limits of Error (Ref. Junction - 0° C)

Thermocouples

			Limits of Error	
Thermo-couple Type	Temp. Range, °C	Temp. Range, °F	Standard [whichever is greater]	Special [whichever is greater]
T	0 to 350	32 to 700	±1°C or ±0.75%	±0.5°C or 0.4%
J	0 to 750	32 to 1400	±2.2°C or ±0.75%	±1.1°C or 0.4%
E	0 to 900	32 to 1600	±1.7°C or ±0.5%	±1°C or 0.4%
K	0 to 1250	32 to 2300	±2.2°C or ±0.75%	±1.1°C or 0.4%
N	0 to 1250	32 to 2300	±2.2°C or ±0.75%	±1.1°C or 0.4%
R or S	0 to 1450	32 to 2700	±1.5°C or ±0.25%	±0.6°C or 0.1%
B	800 to 1700	1600 to 3100	±0.5%	—
W3/W25	0 to 2315	32 to 4200	4.4°C or ±1%	—
W5	0 to 2200	32 to 4100	4.4°C or ±1%	—
T	-200 to 0°C	-328 to 32	±1°C to ±1.5%	±0.5°C or 0.8%
E	-200 to 0°C	-328 to 32	±1.7°C to ±1%	±1°C or 0.5%
K	-200 to 0°C	-328 to 32	±2.2°C to ±2%	—

Thermocouple Extension Wires

			Limits of Error	
Extension Wire Type	Temperature Range, °C	Temperature Range, °F	Standard	Special
KX	0 to 200°C	32° to 400°	±2.2°C	±1.1°C
JX	0 to 200°C	32° to 400°	±2.2°C	±1.1°C
EX	0 to 200°C	32° to 400°	±1.7°C	±1.0°C
TX	-60 to 100°C	-75° to 200°	±1.0°C	±0.5°C
NX	0 to 200°C	32° to 400°	±2.2°C	±1.1°C

Thermocouple Compensating Extension Wire

Thermo-couple Type	Compensating Wire Type	Temp. Range, °C	Temp. Range, °F	Limits of Error
R, S	SX*	25 to 200	32 to 400	±5°C
B	BX***	0 to 200	32 to 400	±4.2°C
B	B**	0 to 100	32 to 200	±3.7°C
W3/W25	W3X	0 to 260	32 to 500	±6.8°C
W5/W26	W5X	0 to 870	32 to 1600	±6.1°C

Thermocouples and thermocouple materials are normally supplied to meet the limits of error specified in the table for temperatures above 0°C. The same materials, however, may not fall within the sub-zero limits of error given in the second section of the table. If materials are required to meet the sub-zero limits, selection of materials usually will be required.

▶ Limits of error in this table apply to new thermocouple wire, normally in the size range (No. 30 to No. 8 Awg) and used at temperatures not exceeding the recommended range (when derated for wire size). If used at higher temperatures these limits of error may not apply.

▶ Limits of error apply to new wire as delivered to the user and do not allow for calibration drift during use. The magnitude of such changes depends on such factors as wire size, temperature, time of exposure, and environment.

▶ Other thermocouple combinations, not listed here, may be specially ordered. Limits of error needed will be determined at time of quote.

Type Wire	Measuring Junction Temperature
SX	Greater than 870°C
BX	Greater than 1000°C

*Copper(†) versus copper nickel alloy (-).

**Copper versus copper compensating extension wire, usable to 100°C with maximum errors as indicated, but with no significant error over 0 to 50°C range.

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THERMOCOUPLE ENGINEERING DATA

TEMPERATURE – E.M.F. TABLES – I.T.S. 90

Type J (Iron Constantan)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts →

-300° (-185°)	-7.519	-7.659	-7.792	-7.915	-8.030					
-200° (-129°)	-5.760	-5.962	-6.159	-6.351	-6.536	-6.716	-6.890	-7.058	-7.219	-7.373
-100° (-74°)	-3.493	-3.737	-3.978	-4.215	-4.449	-4.678	-4.903	-5.125	-5.341	-5.553
0° (-18°)	-0.886	-1.158	-1.428	-1.695	-1.961	-2.223	-2.483	-2.740	-2.994	-3.245

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.886	-0.611	-0.334	-0.056	0.225	0.507	0.791	1.076	1.364	1.652
+100° (+38°)	1.942	2.234	2.527	2.821	3.116	3.412	3.709	4.007	4.306	4.606
+200° (+94°)	4.907	5.209	5.511	5.814	6.117	6.421	6.726	7.031	7.336	7.642
+300° (+149°)	7.949	8.255	8.562	8.869	9.177	9.485	9.793	10.101	10.409	10.717
+400° (+205°)	11.025	11.334	11.642	11.951	12.260	12.568	12.877	13.185	13.494	13.802
+500° (+260°)	14.110	14.418	14.727	15.035	15.343	15.650	15.958	16.266	16.573	16.881
+600° (+316°)	17.188	17.495	17.802	18.109	18.416	18.722	19.029	19.336	19.642	19.949
+700° (+372°)	20.255	20.561	20.868	21.174	21.480	21.787	22.093	22.400	22.706	23.013
+800° (+427°)	23.320	23.627	23.934	24.241	24.549	24.856	25.164	25.473	25.781	26.090
+900° (+483°)	26.400	26.710	27.020	27.330	27.642	27.953	28.266	28.579	28.892	29.206
+1000° (+538°)	29.521	29.836	30.153	30.470	30.788	31.106	31.426	31.746	32.068	32.390
+1100° (+594°)	32.713	33.037	33.363	33.689	34.016	34.345	34.674	35.005	35.337	35.670
+1200° (+649°)	36.004	36.339	36.675	37.013	37.352	37.692	38.033	38.375	38.718	39.063
+1300° (+705°)	39.408	39.755	40.103	40.452	40.801	41.152	41.504	41.856	42.210	42.561

Type K (Chromel-Alumel)

Temperature in degrees F Reference junction at 32° F (0° C) Millivolts →

-400° (-240°)	-6.344	-6.380	-6.409	-6.431	-6.446	-6.456				
-300° (-185°)	-5.632	-5.730	-5.822	-5.908	-5.989	-6.064	-6.133	-6.195	-6.251	-6.301
-200° (-129°)	-4.381	-4.527	-4.669	-4.806	-4.939	-5.067	-5.190	-5.308	-5.421	-5.529
-100° (-74°)	-2.699	-2.884	-3.065	-3.243	-3.417	-3.587	-3.754	-3.917	-4.076	-4.231
0° (-18°)	-0.692	-0.905	-1.114	-1.322	-1.527	-1.729	-1.929	-2.126	-2.230	-2.511

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.692	-0.478	-0.262	-0.044	0.176	0.397	0.619	0.843	1.068	1.294
+100° (+38°)	1.521	1.749	1.977	2.207	2.436	2.667	2.897	3.128	3.359	3.590
+200° (+94°)	3.820	4.050	4.280	4.509	4.738	4.965	5.192	5.419	5.644	5.869
+300° (+149°)	6.094	6.317	6.540	6.763	6.985	7.207	7.429	7.650	7.872	8.094
+400° (+205°)	8.316	8.539	8.761	8.985	9.208	9.432	9.657	9.882	10.108	10.334
+500° (+260°)	10.561	10.789	11.017	11.245	11.474	11.703	11.933	12.163	12.393	12.624
+600° (+316°)	12.855	13.086	13.318	13.549	13.782	14.014	14.247	14.479	14.713	14.946
+700° (+372°)	15.179	15.413	15.647	15.881	16.116	16.350	16.585	16.820	17.055	17.290
+800° (+427°)	17.526	17.761	17.997	18.233	18.469	18.705	18.941	19.177	19.414	19.650
+900° (+483°)	19.887	20.123	20.360	20.597	20.834	21.071	21.308	21.544	21.781	22.018
+1000° (+538°)	22.255	22.492	22.729	22.966	23.206	23.439	23.676	23.913	24.149	24.386
+1100 (+594°)	24.622	24.858	25.094	25.330	25.566	25.802	26.037	26.273	26.508	26.743
+1200° (+649°)	26.978	27.213	27.477	27.681	27.915	28.149	28.383	28.616	28.849	29.082
+1300° (+705°)	29.315	29.548	29.780	30.012	30.243	30.475	30.706	30.937	31.167	31.398
+1400° (+760°)	31.628	31.857	32.087	32.316	32.545	32.744	33.002	33.230	33.458	33.685
+1500° (+816°)	33.912	34.139	34.365	34.591	34.817	35.043	35.268	35.493	35.718	35.942
+1600° (+872°)	36.166	36.390	36.613	36.836	37.059	37.281	37.504	37.725	37.947	38.168
+1700° (+927°)	38.389	38.610	38.830	39.050	39.270	39.489	39.708	39.927	40.145	40.363
+1800° (+983°)	40.581	40.798	41.015	41.232	41.449	41.665	41.881	42.096	42.311	42.526
+1900° (+1038°)	42.741	42.955	43.169	43.382	43.595	43.808	44.020	44.232	44.444	44.655
+2000° (+1094°)	44.866	45.077	45.287	45.497	45.706	45.915	46.124	46.332	46.540	46.747
+2100° (+1149°)	46.954	27.161	47.367	47.573	47.778	47.983	48.187	48.391	48.595	48.798
+2200° (+1205°)	49.000	49.202	49.404	49.605	49.806	50.006	50.206	50.405	50.604	50.802
+2300° (+1260°)	51.000	51.198	51.395	51.591	51.787	51.982	52.177	52.371	52.565	52.759
+2400° (+1316°)	52.952	53.144	53.336	53.528	53.719	53.910	54.100	54.289	54.479	54.668
+2500° (+1372°)	54.856									

THERMOCOUPLE ENGINEERING DATA

TEMPERATURE - E.M.F. TABLES - I.T.S. 90

Type E (Chromel-Constantan)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts →

-400° (-240°)	-9.604	-9.672	-9.729	-9.775	-9.809	-9.830				
-300° (-185°)	-8.404	-8.561	-8.710	-8.852	-8.986	-9.112	-9.229	-9.338	-9.436	-9.525
-200° (-129°)	-6.472	-6.692	-6.907	-7.116	-7.319	-7.516	-7.707	-7.891	-8.069	-8.240
-100° (-74°)	-3.976	-4.248	-4.515	-4.777	-5.035	-5.287	-5.535	-5.777	-6.014	-6.246
0° (-18°)	-1.026	-1.339	-1.648	-1.953	-2.255	-2.552	-2.846	-3.135	-3.420	-3.700
Deg. °F (°C)	**0°(-18°)**	**10°(-13°)**	**20°(-7°)**	**30°(-2°)**	**40°(5°)**	**50°(10°)**	**60°(16°)**	**70°(22°)**	**80°(27°)**	**90°(33°)**
0° (-18°)	-1.026	-0.709	-0.389	-0.065	0.262	0.591	0.924	1.259	1.597	1.938
+100° (+38°)	2.281	2.628	2.977	3.330	3.685	4.042	4.403	4.766	5.131	5.500
+200° (+94°)	5.871	6.244	6.620	6.998	7.379	7.762	8.147	8.535	8.924	9.316
+300° (+149°)	9.710	10.106	10.503	10.903	11.305	11.708	12.113	12.520	12.929	13.339
+400° (+205°)	13.751	14.164	14.579	14.995	15.413	15.831	16.252	16.673	17.096	17.520
+500° (+260°)	17.945	18.371	18.798	19.227	19.656	20.086	20.517	20.950	21.383	21.817
+600° (+316°)	22.252	22.687	23.124	23.561	23.999	24.437	24.876	25.316	25.757	26.198
+700° (+372°)	26.640	27.082	27.525	27.969	28.413	28.857	29.302	29.747	30.193	30.639
+800° (+427°)	31.086	31.533	31.980	32.427	32.875	33.323	33.772	34.220	34.669	35.118
+900° (+483°)	35.567	36.016	36.466	36.915	37.365	37.815	38.265	38.714	39.164	39.614
+1000° (+538°)	40.064	10.513	40.963	41.412	41.862	42.311	42.760	43.209	43.658	44.107
+1100° (+594°)	44.555	45.004	45.452	45.900	46.347	46.794	47.241	47.688	48.135	48.581
+1200° (+649°)	49.027	49.472	49.917	50.362	50.807	51.251	51.695	52.138	52.581	53.024
+1300° (+705°)	53.466	53.908	54.350	54.791	55.232	55.673	56.113	56.553	56.992	57.431
+1400° (+760°)	57.870	58.308	58.746	59.184	59.621	60.058	60.494	60.930	61.366	61.801
+1500° (+816°)	62.236	62.670	63.104	63.538	63.971	64.403	64.835	65.267	65.698	66.129
+1600° (+872°)	66.559	66.989	67.418	67.846	68.274	68.701	69.128	69.554	69.979	70.404
+1700° (+927°)	70.828	71.252	71.675	72.097	72.518	72.939	73.360	73.780	74.199	74.618
+1800° (+983°)	75.036	75.454	75.872	76.289						

Type S (Platinum 10% Rhodium-Platinum)

Temperature in degrees F (C) Reference junction at 32° F (0° C).) Millivolts →

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.092	-0.064	-0.035	-0.006	0.024	0.055	0.087	0.119	0.153	0.186
+100° (+38°)	0.221	0.256	0.292	0.328	0.365	0.402	0.440	0.479	0.518	0.557
+200° (+94°)	0.597	0.638	0.379	0.720	0.762	0.804	0.847	0.889	0.933	0.977
+300° (+149°)	1.021	1.065	1.110	1.155	1.200	1.246	1.292	1.338	1.385	1.431
+400° (+205°)	1.478	1.526	1.573	1.621	1.669	1.718	1.766	1.815	1.864	1.913
+500° (+260°)	1.962	2.012	2.062	2.111	2.162	2.212	2.262	2.313	2.364	2.415
+600° (+316°)	2.466	2.517	2.568	2.620	2.671	2.723	2.775	2.827	2.880	2.932
+700° (+372°)	2.984	3.037	3.090	3.143	3.196	3.249	3.302	3.355	3.409	3.462
+800° (+427°)	3.516	3.569	3.623	3.677	3.731	3.785	3.840	3.894	3.949	4.003
+900° (+483°)	4.058	4.112	4.167	4.222	4.277	4.332	4.388	4.443	4.498	4.554
+1000° (+538°)	4.609	4.665	4.721	4.777	4.833	4.889	4.945	5.001	5.058	5.114
+1100° (+594°)	5.171	5.227	5.284	5.341	5.398	5.455	5.512	5.569	5.626	5.684
+1200° (+649°)	5.741	5.799	5.857	5.914	5.972	6.030	3.089	6.147	6.205	6.263
+1300° (+705°)	6.322	6.381	6.439	6.498	6.557	6.616	6.675	6.734	6.794	6.853
+1400° (+760°)	6.913	6.973	7.032	7.092	7.152	7.212	7.272	7.333	7.393	7.454
+1500 °(+816°)	7.514	7.575	7.636	7.697	7.758	7.819	7.880	7.942	8.003	8.065
+1600° (+872°)	8.127	8.188	8.250	8.312	8.374	8.437	8.499	8.561	8.624	8.687
+1700° (+927°)	8.749	8.812	8.875	8.938	9.001	9.065	9.128	9.191	9.255	9.319
+1800° (+983°)	9.382	9.446	9.510	9.574	9.638	9.702	9.767	9.831	9.896	9.960
+1900° (+1038°)	10.025	10.090	10.155	10.220	10.285	10.350	10.415	10.481	10.546	10.612
+2000° (+1094°)	10.677	10.743	10.809	10.875	10.941	11.007	11.073	11.139	11.205	11.271
+2100° (+1149°)	11.338	11.404	11.470	11.537	11.603	11.670	11.737	11.803	11.870	11.937
+2200° (+1205°)	12.004	12.071	12.138	12.205	12.272	12.339	12.406	12.473	12.540	12.607
+2300° (+1260°)	12.674	12.741	12.809	12.876	12.943	13.011	13.078	13.145	13.213	13.280
+2400° (+1316°)	13.347	13.415	13.482	13.550	13.617	13.685	13.752	13.819	13.887	13.954
+2500° (+1372°)	14.022	14.089	14.157	14.224	14.291	14.359	14.426	14.494	14.561	14.628
+2600° (+1427°)	14.696	14.763	14.830	14.897	14.964	15.032	15.099	15.166	15.233	15.300
+2700° (+1483°)	15.367	15.434	15.501	15.568	15.635	15.702	15.768	15.835	15.902	15.968
+2800° (+1538°)	16.035	16.101	16.168	16.234	16.301	16.367	16.433	16.499	46.565	16.631
+2900° (+1594°)	16.697	16.763	16.829	16.895	16.961	17.026	17.092	17.157	17.222	17.288
+3000° (+1649°)	17.353	17.418	17.483	17.548	17.613	17.677	17.742	17.806	17.870	17.934
+3100° (+1705°)	17.998	18.061	18.124	18.186	18.248	18.310	18.371	18.431	18.491	18.550
+3200° (+1760°)	18.609	18.667								

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THERMOCOUPLE ENGINEERING DATA

Type T (Copper-Constantan)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts ⟶

-400° (-240°)	-6.105	-6.150	-6.187	-6.217	-6.240	-6.254				
-300° (-185°)	-5.341	-5.439	-5.532	-5.620	-5.705	-5.785	-5.860	-5.930	-5.994	-6.053
-200° (-129°)	-4.149	-4.286	-4.419	-4.548	-4.673	-4.794	-4.912	-5.025	-5.135	-5.240
-100° (-74°)	-2.581	-2.754	-2.923	-3.089	-3.251	-3.410	-3.565	-3.717	-3.865	-4.009
0° (-18°)	-0.675	-0.879	-1.081	-1.279	-1.475	-1.667	-1.857	-2.043	-2.225	-2.405

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.675	-0.467	-0.256	-0.043	0.173	0.391	0.611	0.834	1.060	1.288
+100° (+38°)	1.519	1.752	1.988	2.227	2.468	2.712	2.958	3.207	3.459	3.712
+200° (+94°)	3.968	4.227	4.487	4.750	5.015	5.282	5.551	5.823	6.096	6.371
+300° (+149°)	6.648	6.928	7.209	7.492	7.777	8.064	8.352	8.643	8.935	9.229
+400° (+205°)	9.525	9.822	10.122	10.423	41.725	11.029	11.335	11.643	11.951	12.262
+500° (+260°)	12.574	12.887	13.202	13.518	13.836	14.155	14.476	14.797	15.120	15.445
+600° (+316°)	15.771	16.098	16.426	46.755	17.086	17.418	17.752	18.086	18.422	18.759
+700° (+372°)	19.097	19.436	19.777	20.118	20.460	20.803				

Type R (Platinum 13% Rhodium-Platinum)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts ⟶

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.090	-0.063	-0.035	-0.006	0.024	0.054	0.086	0.118	0.151	0.184
+100° (+38°)	0.218	0.254	0.289	0.326	0.363	0.400	0.439	0.478	0.517	0.557
+200° (+94°)	0.598	0.639	0.681	0.723	0.766	0.809	0.853	0.897	0.941	0.986
+300° (+149°)	1.032	1.078	1.124	1.171	1.218	1.265	1.313	1.361	1.410	1.459
+400° (+205°)	1.508	1.558	1.607	1.658	1.708	1.759	1.810	1.861	1.913	1.965
+500° (+260°)	2.017	2.070	2.122	2.175	2.229	2.282	2.336	2.390	2.444	2.498
+600° (+316°)	2.553	2.608	2.663	2.718	2.773	2.829	2.885	2.941	2.997	3.054
+700° (+372°)	3.110	3.167	3.224	3.281	3.339	3.396	3.454	3.512	3.570	3.628
+800° (+427°)	3.686	3.745	3.803	3.862	3.921	3.980	4.040	4.099	4.159	4.219
+900° (+483°)	4.279	4.339	4.399	4.459	4.520	4.580	4.641	4.702	4.763	4.824
+1000° (+538°)	4.886	4.947	5.009	5.071	5.133	5.195	5.257	5.320	5.382	5.445
+1100° (+594°)	5.508	5.571	5.634	5.697	5.761	5.824	5.888	5.952	6.016	6.080
+1200° (+649°)	6.144	6.209	6.273	6.338	6.403	6.468	6.533	6.598	6.664	6.730
+1300° (+705°)	6.795	6.861	6.927	6.994	7.060	7.126	7.193	7.260	7.327	7.394
+1400° (+760°)	7.461	7.529	7.596	7.64	7.732	7.800	7.868	7.936	8.005	8.073
+1500° (+816°)	8.142	8.211	8.280	8.349	8.418	8.488	8.557	8.627	8.697	8.767
+1600° (+872°)	8.837	8.908	8.978	9.049	9.120	9.191	9.262	9.333	9.404	9.476
+1700° (+927°)	9.547	9.619	9.691	9.763	9.835	9.908	9.980	10.053	10.126	10.198
+1800° (+983°)	10.271	10.345	10.418	10.491	10.565	10.638	10.712	10.786	10.860	10.934
+1900° (+1038°)	11.009	11.083	11.158	11.233	11.307	11.382	11.457	11.533	11.608	11.683
+2000° (+1094°)	11.759	11.835	11.910	11.986	12.062	12.138	12.214	12.291	12.367	12.443
+2100° (+1149°)	12.520	12.597	12.673	12.750	12.827	12.904	12.981	13.058	13.135	13.213
+2200° (+1205°)	13.290	13.367	13.445	13.522	13.600	13.677	13.755	13.833	13.911	13.989
+2300° (+1260°)	14.066	14.144	14.222	14.300	14.379	14.457	14.535	14.613	14.691	14.770
+2400° (+1316°)	14.848	14.926	15.005	15.083	15.161	15.240	15.318	15.397	15.475	15.553
+2500° (+1372°)	15.632	15.710	15.789	15.867	15.946	16.024	16.103	16.181	16.260	16.338
+2600° (+1427°)	16.417	16.495	16.574	16.652	16.731	16.809	16.887	16.966	17.044	17.122
+2700° (+1483°)	17.200	17.279	17.357	17.435	17.513	17.591	17.669	17.747	17.825	17.903
+2800° (+1538°)	17.981	18.059	18.137	18.214	18.292	18.369	18.447	18.524	18.602	18.679
+2900° (+1594°)	18.756	18.834	18.911	18.988	19.065	19.141	19.218	19.295	19.372	19.448
+3000° (+1649°)	19.525	19.601	19.677	19.753	19.829	19.905	19.981	20.056	20.132	20.207
+3100° (+1760°)	20.281	20.356	20.430	20.503	20.576	20.649	20.721	20.792	20.863	20.933
+3200° (+1760°)	21.003	21.071								

THERMOCOUPLE ENGINEERING DATA

TEMPERATURE - E.M.F. TABLES - I.T.S. 90

Type B (Platinum 30% Rhodium-Platinum 6% Rhodium)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts →

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.001	-0.002	-0.002	-0.003	-0.002	-0.002				
+100° (+38°)	-0.001	0.000	0.002	0.004	0.006	0.009	0.012	0.015	0.019	0.023
+200° (+94°)	0.027	0.032	0.037	0.043	0.049	0.055	0.061	0.068	0.075	0.083
+300° (+149°)	0.090	0.099	0.107	0.116	0.125	0.135	0.145	0.155	0.165	0.176
+400° (+205°)	0.187	0.199	0.211	0.223	0.235	0.248	0.261	0.275	0.288	0.303
+500° (+260°)	0.317	0.332	0.347	0.362	0.378	0.394	0.411	0.427	0.444	0.462
+600° (+316°)	0.479	0.497	0.516	0.534	0.553	0.572	0.592	0.612	0.632	0.653
+700° (+372°)	0.673	0.694	0.716	0.738	0.760	0.782	0.805	0.828	0.851	0.875
+800° (+427°)	0.898	0.923	0.947	0.972	0.997	1.022	1.048	1.074	1.100	1.127
+900° (+483°)	1.154	1.181	1.208	1.236	1.264	1.293	1.321	1.350	1.379	1.409
+1000° (+538°)	1.439	1.469	1.499	1.530	1.561	1.592	1.624	1.655	1.687	1.720
+1100° (+594°)	1.752	1.785	1.818	1.852	1.886	1.920	1.954	1.988	2.023	2.058
+1200° (+649°)	2.094	2.129	2.165	2.201	2.237	2.274	2.311	2.348	2.385	2.423
+1300° (+705°)	2.461	2.499	2.538	2.576	2.615	2.654	2.694	2.734	2.774	2.814
+1400° (+760°)	2.854	5.895	2.936	2.978	3.019	3.061	3.103	3.145	3.188	3.230
+1500° (+816°)	3.273	3.317	3.360	3.404	3.448	3.492	3.537	3.581	3.626	3.672
+1600° (+872°)	3.717	3.763	3.809	3.855	3.901	3.948	3.994	4.014	4.089	4.136
+1700° (+927°)	4.184	4.232	4.280	4.328	4.377	4.426	4.475	4.524	4.574	4.623
+1800° (+983°)	4.673	4.723	4.774	4.824	4.875	4.926	4.977	5.028	5.080	5.132
+1900° (+1038°)	5.184	5.236	5.288	5.341	5.394	5.447	5.500	5.553	5.607	5.661
+2000° (+1094°)	5.715	5.769	5.823	5.878	5.932	5.987	6.042	6.098	6.153	6.209
+2100° (+1149°)	6.624	6.320	6.377	6.433	6.490	6.546	6.603	6.660	6.718	6.775
+2200° (+1205°)	6.833	6.890	6.948	7.006	7.065	7.123	7.182	7.240	7.299	7.358
+2300° (+1260°)	7.417	7.477	4.536	7.596	7.656	7.716	7.776	7.836	7.897	7.957
+2400° (+1316°)	8.018	8.079	8.140	8.201	8.262	8.323	8.385	8.446	8.508	8.570
+2500° (+1372°)	8.632	8.694	8.756	8.819	8.881	8.944	9.006	9.069	9.132	9.195
+2600° (+1427°)	9.258	9.321	9.385	9.448	9.511	9.575	9.639	9.702	9.766	9.830
+2700° (+1483°)	9.894	9.958	10.022	10.086	10.150	10.215	10.279	10.344	10.408	10.473
+2800° (+1538°)	10.537	10.602	10.666	10.731	10.796	10.861	10.925	10.990	11.055	11.120
+2900° (+1594°)	11.185	11.250	11.315	11.380	11.445	11.510	11.575	11.640	11.705	11.770
+3000° (+1649°)	11.835	11.900	11.965	12.030	12.095	12.160	12.225	12.290	12.355	12.420
+3100° (+1705°)	12.484	12.549	12.614	12.679	12.743	12.808	12.872	12.937	13.001	13.066
+3200° (+1760°)	13.130	13.194	13.259	13.323	13.387	13.451	13.515	13.579	13.642	13.706
+3300° (+1816°)	13.769									

TEMPERATURE - E.M.F. TABLES

Type W (Tungsten-Tungsten 26% Rhenium)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts →

Deg. °F (°C)	0°(-18°)	20°(-7°)	40°(5°)	60°(16°)	80°(27°)	Deg. °F (°C)	0°(-18°)	20°(-7°)	40°(5°)	60°(16°)	80°(27°)
0° (-18°)	-.016	-.007	0.006	0.026	0.050	+2200°	18.701	18.936	19.170	19.405	19.639
+100° (+38°)	0.079	0.113	0.153	0.197	0.246	+2300°	19.873	20.106	20.340	20.573	20.806
+200° (+94°)	0.299	0.357	0.420	0.487	0.559	+2400°	21.038	21.270	21.502	21.734	21.965
+300° (+149°)	0.634	0.714	0.799	0.887	0.979	+2500°	22.195	22.425	22.655	22.884	23.113
+400° (+205°)	1.075	1.175	1.279	1.387	1.498	+2600°	23.341	23.569	23.796	24.023	24.249
+500° (+260°)	1.613	1.731	1.853	1.978	2.106	+2700°	24.474	24.699	24.923	25.146	25.369
+600° (+316°)	2.238	2.373	2.511	2.652	2.796	+2800°	25.591	25.812	26.033	26.253	26.472
+700° (+372°)	2.943	3.093	3.246	3.401	3.559	+2900°	26.690	26.907	27.124	27.340	27.555
+800° (+427°)	3.720	3.884	4.049	4.218	4.389	+3000°	37.769	27.983	28.195	28.407	28.618
+900° (+483°)	4.562	4.737	4.915	5.095	5.277	+3100°	28.827	29.036	29.244	29.451	29.657
+1000° (+538°)	5.461	5.647	5.836	6.026	6.218	+3200°	29.862	30.066	30.269	30.471	30.672
+1100° (+594°)	6.412	6.607	6.805	7.004	7.205	+3300°	30.871	31.070	31.268	31.464	31.660
+1200° (+649°)	7.407	7.611	7.816	8.023	8.232	+3400°	31.854	32.047	32.240	32.430	32.620
+1300° (+705°)	8.441	8.652	8.865	9.078	9.293	+3500°	32.809	32.996	33.182	33.367	33.551
+1400° (+760°)	9.509	9.726	9.945	10.164	10.384	+3600°	33.733	33.914	34.094	34.273	34.450
+1500° (+816°)	10.606	10.828	11.051	11.275	11.500	+3700°	34.626	34.801	34.974	35.146	35.317
+1600° (+872°)	11.725	11.952	12.179	12.407	12.635	+3800°	35.486	35.654	35.821	35.986	36.150
+1700° (+927°)	12.864	13.094	13.324	13.555	13.786	+3900°	36.312	36.473	36.632	36.790	36.946
+1800° (+983°)	14.018	14.250	14.482	14.715	14.948	+4000°	37.101	37.254	37.406	37.557	37.705
+1900° (+1038°)	15.182	15.415	15.649	15.884	16.118	+4100°	37.853	37.998	38.142	38.285	38.425
+2000° (+1094°)	16.353	16.587	16.822	17.057	17.292	+4200°	38.564				
+2100° (+1149°)	17.527	17.762	17.997	18.232	18.467						

TEMPERATURE - E.M.F. TABLES

Type W3 (Tungsten 3% Rhenium-Tungsten 25% Rhenium)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts →

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-	-	-	-	0.043	0.098	0.154	0.211	0.269	0.329
+100° (+38°)	0.390	0.452	0.515	0.579	0.644	0.711	0.778	0.847	0.916	0.987
+200° (+94°)	1.058	1.130	1.204	1.278	1.354	1.430	1.507	1.585	1.664	1.743
+300° (+149°)	1.824	1.905	1.988	2.071	2.154	2.239	2.324	2.410	2.497	2.584
+400° (+205°)	2.673	2.761	2.851	2.941	3.032	3.123	3.216	3.308	3.402	3.495
+500° (+260°)	3.590	3.685	3.781	3.877	3.973	4.071	4.168	4.267	4.365	4.464
+600° (+316°)	4.564	4.664	4.765	4.866	4.967	5.069	5.171	5.274	5.377	5.480
+700° (+372°)	5.584	5.688	5.793	5.898	6.003	6.108	6.214	6.320	6.427	6.533
+800° (+427°)	6.640	6.748	6.855	6.963	7.071	7.180	7.288	7.397	7.506	7.615
+900° (+483°)	7.725	7.835	7.945	8.055	8.165	8.275	8.386	8.497	8.608	8.719
+1000° (+538°)	8.830	8.942	9.053	9.165	9.277	9.389	9.501	9.613	9.726	9.838
+1100° (+594°)	9.951	10.063	10.176	10.289	10.402	40.514	10.628	10.741	10.854	10.967
+1200° (+649°)	11.080	11.194	11.307	11.420	11.534	11.647	11.761	11.874	11.988	12.102
+1300° (+705°)	12.215	12.329	12.443	12.556	12.670	12.784	12.897	13.011	13.125	13.238
+1400° (+760°)	13.352	13.466	13.579	13.693	13.807	13.920	14.034	14.148	14.262	14.376
+1500° (+816°)	14.489	14.603	14.717	14.830	14.944	15.057	15.171	15.284	15.398	15.511
+1600° (+872°)	15.624	15.737	15.850	15.963	16.076	16.189	16.302	16.414	16.527	16.639
+1700° (+927°)	16.752	16.864	16.976	17.088	17.200	17.312	17.424	17.536	17.647	17.759
+1800° (+983°)	17.870	17.982	18.093	18.204	18.315	18.426	18.537	18.647	18.758	18.868
+1900° (+1038°)	18.979	19.089	19.199	19.309	19.419	19.528	19.638	19.747	19.857	19.966
+2000° (+1094°)	20.075	20.184	20.293	20.401	20.510	20.618	20.726	20.835	20.943	21.050
+2100° (+1149°)	21.158	21.266	21.373	21.480	21.588	21.695	21.802	21.908	22.015	22.121
+2200° (+1205°)	22.228	22.334	22.440	22.546	22.651	22.757	22.863	22.968	23.073	23.178
+2300° (+1260°)	23.283	23.388	23.492	23.596	23.701	23.805	23.909	24.013	24.116	24.220
+2400° (+1316°)	24.323	24.426	24.529	24.632	24.735	24.838	24.940	25.042	25.145	25.246
+2500° (+1372°)	25.348	25.450	25.551	25.653	25.754	25.855	25.956	26.057	26.157	26.258
+2600° (+1427°)	26.358	26.458	26.558	26.658	26.757	26.857	26.956	27.055	27.154	27.253
+2700° (+1483°)	27.352	27.450	27.548	27.647	27.745	27.842	27.940	28.038	28.135	28.232
+2800° (+1538°)	28.329	28.426	28.523	28.619	28.715	28.812	28.908	29.003	29.099	29.194
+2900° (+1594°)	29.290	29.385	29.480	29.575	29.669	29.764	29.858	29.958	30.046	30.139
+3000° (+1649°)	30.233	30.326	30.419	30.512	30.605	30.698	30.790	30.882	30.974	31.066
+3100° (+1705°)	31.158	31.249	31.340	31.432	31.522	31.613	31.703	31.794	31.884	31.974
+3200° (+1760°)	32.063	32.153	32.242	32.331	32.420	32.508	32.596	32.685	32.772	32.860
+3300° (+1816°)	32.948	33.035	33.122	33.209	33.295	33.381	33.467	33.553	33.369	33.724
+3400° (+1872°)	33.809	33.894	33.979	34.063	34.147	34.231	34.314	34.398	34.481	34.563
+3500° (+1927°)	34.646	34.728	34.810	34.892	34.973	35.054	35.135	35.215	35.295	35.375
+3600° (+1983°)	35.455	35.534	35.613	35.692	35.770	35.848	35.926	36.003	36.080	36.157
+3700° (+2038°)	36.233	36.309	36.384	36.460	36.535	36.609	36.683	36.757	36.831	36.904
+3800° (+2094°)	36.976	37.049	37.120	37.192	37.263	37.334	37.404	37.474	37.543	37.612
+3900° (+2149°)	37.681	37.749	37.816	37.884	37.950	38.017	38.082	38.148	38.213	38.277
+4000° (+2205°)	38.341	38.404	38.467	38.530	38.591	38.653	38.714	38.774	38.834	38.893
+4100° (+2260°)	38.951	39.009	39.067	39.124	39.180	39.236	39.291	39.346	39.400	39.453
+4200° (+2316°)	39.506									

THERMOCOUPLE ENGINEERING DATA

TEMPERATURE - E.M.F. TABLES

Type W5 (Tungsten 5% Rhenium-Tungsten 26% Rhenium)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts ⟶

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	–	–	–	–	0.060	0.135	0.211	0.288	0.366	0.444
+100° (+38°)	0.523	0.602	0.683	0.764	0.845	0.927	1.010	1.094	1.178	1.263
+200° (+94°)	1.348	1.434	1.520	1.607	1.695	1.783	1.872	1.961	2.051	2.141
+300° (+149°)	2.232	2.323	2.415	2.507	2.600	2.693	2.787	2.881	2.975	3.070
+400° (+205°)	3.166	3.261	3.358	3.454	3.551	3.648	3.746	3.844	3.943	4.041
+500° (+260°)	4.141	4.240	4.340	4.440	4.540	4.641	4.742	4.844	4.945	5.047
+600° (+316°)	5.149	5.252	5.354	5.457	5.560	5.664	5.768	5.871	5.976	6.080
+700° (+372°)	6.185	6.289	6.394	6.499	6.605	6.710	6.816	6.922	7.028	7.134
+800° (+427°)	7.240	7.347	7.453	7.560	7.667	7.774	7.881	7.988	8.096	8.203
+900° (+483°)	8.311	8.418	8.526	8.634	8.742	8.850	8.958	9.066	9.174	9.282
+1000° (+538°)	9.391	9.499	9.607	9.716	9.824	9.993	10.041	10.150	10.259	10.367
+1100° (+594°)	10.476	10.584	10.693	10.802	10.910	11.019	11.128	11.236	11.345	11.453
+1200° (+649°)	11.562	11.670	11.779	11.887	11.996	12.104	12.212	12.321	12.429	12.537
+1300° (+705°)	13.645	12.753	12.861	12.969	13.077	13.185	13.293	13.401	13.508	13.616
+1400° (+760°)	13.723	13.831	13.938	14.045	14.152	14.259	14.366	14.473	14.580	14.686
+1500° (+816°)	14.793	14.899	15.005	15.112	15.218	15.324	15.429	15.535	15.641	15.746
+1600° (+872°)	15.852	15.957	16.062	16.167	16.272	16.376	16.481	16.585	16.690	16.794
+1700° (+927°)	16.898	17.002	17.106	17.209	17.313	17.416	17.519	17.622	17.725	17.828
+1800° (+983°)	17.930	18.033	18.135	18.237	18.339	18.441	18.542	18.644	18.745	18.846
+1900° (+1038°)	18.947	19.048	19.149	19.249	19.349	19.449	19.549	19.649	19.749	19.848
+2000° (+1094°)	19.948	20.047	20.146	20.244	20.343	20.441	20.540	20.638	20.736	20.833
+2100° (+1149°)	20.931	21.028	21.125	21.222	21.319	21.416	21.512	21.609	21.705	21.801
+2200° (+1205°)	21.896	21.992	22.087	22.182	22.277	22.372	22.467	22.561	22.656	22.750
+2300° (+1260°)	22.844	22.937	23.031	23.124	23.217	23.310	23.403	23.496	23.588	23.680
+2400° (+1360°)	23.772	23.864	23.956	24.047	24.139	24.230	24.321	24.412	24.502	24.593
+2500° (+1372°)	24.683	24.773	24.863	24.952	25.042	25.131	25.220	25.309	25.397	25.486
+2600° (+1427°)	25.574	25.662	25.750	25.838	25.926	26.013	26.100	26.187	26.274	26.361
+2700° (+1483°)	26.447	26.553	26.620	26.705	26.791	26.877	26.962	27.047	27.132	27.217
+2800° (+1538°)	27.301	27.386	27.470	27.554	27.638	27.722	27.805	27.888	27.971	28.054
+2900° (+1594°)	28.137	28.219	28.302	28.384	28.466	28.548	28.629	28.711	28.792	28.873
+3000° (+1649°)	28.954	29.034	29.115	29.195	29.275	29.355	29.435	29.514	29.593	29.673
+3100° (+1705°)	29.752	29.830	29.909	29.987	30.065	30.143	30.221	30.299	30.376	30.453
+3200° (+1760°)	30.530	30.607	30.684	30.760	30.736	30.912	30.98	31.064	34.139	31.214
+3300° (+1816°)	31.289	31.364	31.439	31.513	31.587	31.661	31.735	31.809	31.882	31.955
+3400° (+1872°)	32.028	32.101	32.174	32.246	32.318	32.390	32.462	32.533	32.604	32.675
+3500° (+1927°)	32.746	32.817	32.887	32.958	33.027	33.097	33.167	33.236	33.305	33.374
+3600° (+1983°)	33.443	33.511	33.579	33.647	33.715	33.782	33.849	33.916	33.983	34.049
+3700° (+2038°)	34.116	34.182	34.247	34.313	34.378	34.443	34.508	34.572	34.636	34.700
+3800° (+2094°)	34.764	34.827	34.890	34.953	35.016	35.078	35.140	35.202	35.263	35.325
+3900° (+2149°)	35.386	35.446	35.506	35.567	35.626	35.686	35.745	35.804	35.862	35.920
+4000° (+2205°)	35.978	36.036	36.093	36.150	36.207	36.263	36.319	36.375	36.430	36.485
+4100° (+2260°)	36.540	36.594	36.648	36.701	36.755	36.808	36.860	36.912	36.964	37.015
+4200° (+2316°)	37.066									

TEMPERATURE - E.M.F. TABLES - I.T.S. 90

Type N (Nicrosil-Nisil)

Temperature in degrees F (C) Reference junction at 32° F (0° C) Millivolts ⟶

Deg. °F (°C)	0°(-18°)	10°(-13°)	20°(-7°)	30°(-2°)	40°(5°)	50°(10°)	60°(16°)	70°(22°)	80°(27°)	90°(33°)
0° (-18°)	-0.461	-0.318	-0.174	-0.029	0.116	0.261	0.407	0.555	0.703	0.853
+100° (+38°)	1.004	1.156	1.309	1.463	1.619	1.776	1.934	2.093	2.253	2.415
+200° (+94°)	2.577	2.741	2.906	3.072	3.240	3.408	3.578	3.748	3.920	4.093
+300° (+149°)	4.267	4.442	4.618	4.795	4.973	5.152	5.332	5.512	5.694	5.877
+400° (+205°)	6.060	6.245	6.430	6.616	6.803	6.991	7.179	7.369	7.559	7.750
+500° (+260°)	7.941	8.134	8.327	8.520	8.715	8.910	9.105	9.302	9.499	9.696
+600° (+316°)	9.895	10.093	10.293	10.493	10.693	10.894	11.096	11.298	11.501	11.704
+700° (+372°)	11.907	12.111	12.306	12.521	12.726	12.932	13.139	13.346	13.553	13.760
+800° (+427°)	13.969	14.177	14.386	14.595	14.804	15.014	15.225	15.435	16.646	15.857
+900° (+483°)	16.069	16.281	16.493	16.705	16.918	17.131	17.344	17.558	17.772	17.986
+1000° (+538°)	18.200	18.414	18.629	18.844	19.059	19.274	19.490	19.705	19.921	20.137
+1100° (+594°)	20.353	20.570	20.786	21.003	21.220	21.437	21.654	21.871	22.088	22.305
+1200° (+649°)	22.523	22.740	22.958	23.176	23.393	23.611	23.829	24.047	24.265	24.483
+1300° (+705°)	24.701	24.919	25.137	25.356	25.574	25.792	26.010	26.229	26.447	26.665
+1400° (+760°)	26.883	27.102	27.320	27.538	27.756	27.975	28.193	28.411	28.629	28.847
+1500° (+816°)	29.065	29.283	29.501	29.719	29.937	30.154	30.372	30.590	30.807	31.025
+1600° (+872°)	31.242	31.459	31.677	31.894	32.111	32.328	32.545	32.761	32.978	33.195
+1700° (+927°)	33.411	33.627	33.844	34.060	34.276	34.491	34.707	34.923	35.138	35.353
+1800° (+983°)	35.568	35.783	35.998	36.213	36.427	36.641	36.855	37.069	37.283	37.497
+1900° (+1038°)	37.710	37.923	38.136	38.349	38.562	38.774	38.986	39.198	39.410	39.622
+2000° (+1094°)	39.833	40.044	40.255	40.466	40.677	40.887	41.097	41.307	41.516	41.725
+2100° (+1149°)	41.935	42.143	42.352	42.560	42.768	42.976	43.184	43.391	43.598	43.805
+2200° (+1205°)	44.012	44.218	44.424	44.629	44.835	45.040	45.245	45.449	45.653	45.857
+2300° (+1260°)	46.060	46.263	46.466	46.668	46.870	47.071	47.272	47.473		

Seebeck coefficient of thermoelements vs. Platinum 67

Thermoelement	JP	JN,TN, EN	TP	KP, EP	KN	RP	SP	BP	BN
Temperature, °C					**Seebeck Coefficient, µV/°C**				
-190	+6.3	-20.9	-4.1	–	–	–	–	–	–
-100	14.4	27.0	+1.1	–	–	–	–	–	–
0	17.8	32.2	5.9	+25.7	-13.5	+5.5	+5.5	–	–
200	14.6	41.0	12.0	32.7	7.4	8.5	8.5	+9.2	+7.2
400	9.7	45.5	16.2	34.6	7.7	10.5	9.5	11.7	7.6
600	11.7	46.8	–	33.8	8.8	11.5	10.0	13.8	7.9
800	17.8	46.4	–	32.2	8.8	12.5	11.0	15.8	8.2
1000	–	–	–	30.8	8.3	13.0	11.5	17.7	8.5
1200	–	–	–	29.1	7.4	14.0	12.0	19.1	8.7
1400	–	–	–	–	–	14.0	12.0	19.1	8.7
1600	–	–	–	–	–	13.5	12.0	20.4	8.7
Temperature, °F					**Seebeck Coefficient, µV/°F**				
-300	+2.5	-11.9	-2.1	–	–	–	–	–	–
-200	6.7	14.0	+0.2	–	–	–	–	–	–
-100	8.8	15.8	1.5	–	–	–	–	–	–
32	9.9	17.9	3.3	+14.3	-7.5	+3.0	+3.0	–	–
200	9.6	20.5	5.0	16.7	6.5	4.1	4.0	+4.1	+3.6
400	8.0	22.9	6.7	18.3	4.0	4.9	4.7	5.1	4.0
600	6.2	24.5	8.2	19.0	4.1	5.5	5.2	5.8	4.2
800	5.3	25.3	–	19.1	4.4	5.8	5.4	6.5	4.2
1000	5.7	26.0	–	18.9	4.8	6.2	5.5	7.4	4.3
1500	9.9	25.8	–	17.8	4.9	6.8	6.1	8.8	4.6
2000	–	–	–	16.7	4.3	7.6	6.6	10.2	4.8
2500	–	–	–	14.9	4.0	7.7	6.7	11.0	4.9
3000	–	–	–	–	–	7.6	6.5	11.3	4.9

THERMOCOUPLE ENGINEERING DATA

SELECTION GUIDE FOR PROTECTION TUBES

Application	Protection Tube Material
Heal Treating:	
Annealing	
Up to 1300°F (704°C)	Wrought iron
Over 1300°F (704°C)	28% chrome iron or Inconel
Carburizing hardening	
Up to 1500°F (816°C)	Wrought iron or 28% chrome iron
1500 to 2000°F (1093°C)	28% chrome iron or Inconel
Over 2000°F (1093°C)	Ceramic
Nitriding salt baths	
Cyanide	28% chrome iron
Neutral	Nickel
High speed	Ceramic
Iron and steel:	
Basic oxygen furnace	Quartz
Blast furnaces	
Downcomer	Inconel, 28% chrome iron
Stove Dome	Silicon carbide
Hot blast main	Inconel
Stove trunk	Inconel
Stove outlet flue	Wrought iron
Open hearth	
Flues and stack	Inconel, 28% chrome iron
Checkers	Inconel, Cermet
Waste heat boiler	28% chrome iron, Inconel
Billet heating slab heating and butt welding	
Up to 2000°F (1093°C)	28% chrome iron, Inconel
Over 2000°F (1093°C)	Ceramic, silicon carbide
Bright annealing batch	
Top work temperature	Not required (use bare Type J thermocouple)
Bottom work temperature	28% Chrome iron
Continuous furnace section	Inconel, ceramic
Forging	Silicon carbide, ceramic
Soaking pits	
Up to 2000°F (1093°C)	Inconel
Over 2000°F (1093°C)	Ceramic, silicon carbide
Nonferrous metals:	
Aluminum	
Melting	Cast iron (white-washed)
Heat treating	Wrought iron
Brass of bronze	Not required (use dip-type thermocouple)
Lead	28% chrome iron, wrought iron
Magnesium	Wrought iron, cast iron
Tin	Extra heavy carbon steel
ZincExtra heavy carbon steel	
Pickling tanks	Chemical lead
Cement:	
Exit flues	Inconel, 28% chrome iron
Kilns-heating zone	Inconel
Ceramic:	
Kilns	Ceramic and silicon carbide
Dryers	Wrought iron, silicon carbide
Vitreous enameling	Inconel, 28% chrome iron

Application	Protection Tube Material
Glass:	
Fore hearths and feeders	Platinum thimble
Lehrs	Wrought iron
Tanks	
Roof and wall	Ceramic
Flues and checkers	28% chrome iron, Inconel
Paper:	
Digesters	Type 316 stainless steel, 28% chrome iron
Petroleum:	
Dewaxing	Type 304 stainless steel or carbon steel
Towers	Type 304 stainless steel or carbon steel
Transfer lines	Type 304 stainless steel or carbon steel
Fractionating column	Type 304 stainless steel or carbon steel
Bridgewall	Type 304 stainless steel or carbon steel
Power:	
Coal-air mixtures	Type 304 stainless steel
Flue gases	Wrought iron or 28% chrome iron
Preheaters	Wrought iron or 28% chrome iron
Steel lines	Type 347 or 316 stainless steel
Water lines	Carbon steel
Boiler tubes	Type 309 or 310 stainless steel
Gas producers:	
Producer gas	28% chrome iron
Water gas	
Carburetor	Inconel, 28% chrome iron
Super heater	Inconel, 28% chrome iron
Tar stills	Carbon steel
Incinerators:	
Up to 2000°F (1093°C)	28% chrome iron, Inconel
Over 2000°F (1093°C)	Ceramic (primary)
Silicon carbide (secondary)	
Food:	
Baking ovens	Wrought iron
Charretort, sugar	Wrought iron
Vegetables and fruit	Type 304 stainless steel
Sanitary	Type 316 stainless steel
Chemical:	
Acetic acid	
10 to 50%, 70°F	Type 304 stainless steel
50%, 212°	Type 316 stainless steel
99%, 70 to 212°F	Type 430 stainless steel
Alcohol, ethyl, methyl	
70 to 212°F	Type 304 stainless steel
Ammonia	
All concentration, 70°F	Type 304 stainless steel

Application	Protection Tube Material
Ammonium chloride	
All concentration, 212˚F (100°C)	Type 304 stainless steel
Ammonium nitrate	
All concentration,	
70 to 212˚F (22 to 100°C)	Type 304 stainless steel
Ammonium sulphate	
10% to saturated, 212˚F (100°C)	Type 316 stainless steel
Barium chloride	
All concentration, 70˚F (22°C)	Monel
Barium hydroxide	
All concentration, 70˚F (22°C)	Carbon steel
Barium sulfate	Nichrome*
Brines	Monel
Bromine	Tantalum
Butadiene	Type 304 stainless steel
Butane	Type 304 stainless steel
Butylacetate	Monel
Butyl alcohol	Copper
Calcium chlorate	
Dilute, 70 to 150˚F (22 to 66°C)	Type 304 stainless steel
Calcium hydroxide	
10 to 20%, 212˚F (100°C)	Type 304 stainless steel
50%, 212˚F (100°C)	Type 316 stainless steel
Carbolic acid	
All 212˚F (100°C)	Type 316 stainless steel
Carbon dioxide	
wet or dry	2017-T4 aluminum, Monel
Chlorine gas	
Dry, 70˚F (22°C)	Type 316 stainless steel
Moist, 20 to 212˚F (-7 to 100°C)	Hastelloy C
Chromic acid	
10 to 50%, 212˚F (100°C)	Type 315 stainless steel
Citric acid	
15%, 70˚F (22°C)	Type 304 stainless steel
15%, 212˚F (100°C)	Type 315 stainless steel
Concentrated, 212˚F (100°C)	Type 316 stainless steel
Copper nitrate	Type 304 stainless steel
Copper sulphate	Type 304 stainless steel
Cresols	Type 304 stainless steel
Cyanogen gas	Type 304 stainless steel
Dow therm*	Carbon steel
Ether	Type 304 stainless steel
Ethyl acetate	Monel
Ethyl chloride	
70˚F (22°C)	Type 304 stainless steel
Ethyl sulphate	
70˚F (22°C)	Monel
Ferric chloride	
5%, 70˚F (22°C) to boiling	Tantalum
Ferric sulphate	
5%, 70˚F (22°C)	Type 304 stainless steel
Ferrous sulphate	
Dilute 70˚F (22°C)	Type 304 stainless steel
Formaldehyde	Type 304 stainless steel
Formic acid	
5%, 70 to 150˚F (22 to 66°C)	Type 304 stainless steel
Freon	Monel
Gallic acid	
5%, 70 to 150˚F (22 to 66°C)	Monel
Gasoline	
70˚F (22°C)	Type 304 stainless steel
Glucose	
70˚F (22°C)	Type 304 stainless steel
Glycerine	
70˚F (22°C)	Type 304 stainless steel
Glycerol	Type 304 stainless steel
Hydrobromic acid	
98%, 212˚F (100°C)	Hastelloy B
Hydrochloric acid	
1%, 5%, 70˚F (22°C)	Hastelloy C
1%, 5%, 212˚F (100°C)	Hastelloy B
25%, 70 to 212˚F (22 to 100°)	Hastelloy B
Hydrofluoric acid	Hastelloy C
Hydrogen peroxide	
70 to 212˚F (22 to 100°)	Type 316 stainless steel
Hydrogen sulphide	
Wet and dry	Type 316 stainless steel
Iodine	
70˚F (22°C)	Tantalum
Lactic acid	
5%, 70˚F (22°C)	Type 304 stainless steel
5%, 150˚F (66°C)	Type 304 stainless steel
10%, 212˚F (100°C)	Tantalum
Magnesium chloride	
5%, 70˚F (22°C)	Monel
5%, 212˚F (100°C)	Nickel
Magnesium sulphate	
Hot and cold	Monel
Muriatic acid	
70˚F (22°C)	Tantalum
Naphtha	
70˚F (22°C)	Type 304 stainless steel
Natural gas	
70˚F (22°C)	Type 304 stainless steel
Nickel chloride	
70˚F (22°C)	Type 304 stainless steel
Nickel sulphate	
Hot and cold	Type 304 stainless steel
Nitric acid	
5%, 70˚F (22°C)	Type 304 stainless steel
20%, 70˚F (22°C)	Type 304 stainless steel
50%, 70˚F (22°C)	Type 304 stainless steel
50%, 212˚F (100°C)	Type 304 stainless steel
65%, 212˚F (100°C)	Type 316 stainless steel
Concentrated, 70˚F (22°C)	Type 304 stainless steel
Concentrated, 212˚F (100°C)	Tantalum
Nitrobenzene	
70˚F (22°C)	Type 304 stainless steel
Oleic acid	
70˚F (22°C)	Type 316 stainless steel
Oleum	
70˚F (22°C)	Type 316 stainless steel
Oxalic acid	
5%, hot and cold	Type 304 stainless steel
10%, 212˚F (100°C)	Monel
Oxygen	
70˚F (100°C)	Steel
Liquid	Stainless steel
Elevated temperatures	Stainless steel
Palmitic acid	Type 316 stainless steel
Pentane	Type 304 stainless steel
Phenol	Type 304 stainless steel

SELECTION GUIDE FOR PROTECTION TUBES

Application	Protection Tube Material
Phosphoric acid	
1%, 5%, 70°F (22°C)	Type 304 stainless steel
10%, 70°F (22°C)	Type 316 stainless steel
10%, 212°F (100°C)	Hastelloy C
30%, 70°F, 212°F (22°C,100°C)	Hastelloy B
85%, 70°F, 212°F (22°C, 100°C)	Hastelloy B
Picric acid	
70°F (22°C)	Type 304 stainless steel
Potassium bromide	
70°F (22°C)	Type 316 stainless steel
Potassium carbonate	
70°F (22°C)	Type 304 stainless steel
Potassium chlorate	
70°F (22°C)	Type 304 stainless steel
Potassium hydroxide	
5%, 70°F (22°C)	Type 304 stainless steel
25%, 212°F (100°C)	Type 304 stainless steel
60%, 212°F (100°C)	Type 316 stainless steel
Potassium nitrate	
5%, 70°F (22°C)	Type 304 stainless steel
5%, 212°F (100°C)	Type 304 stainless steel
Potassium permanganate	
5%, 70°F (22°C)	Type 304 stainless steel
Potassium sulphate	
5%, 70°F (22°C)	Type 304 stainless steel
Potassium sulphide	
70°F (22°C)	Type 304 stainless steel
Propane	Type 304 stainless steel
Pyrogalic acid	Type 304 stainless steel
Quinine bisulphate	
Dry	Type 316 stainless steel
Quinine sulphate	
Dry	Type 304 stainless steel
Sea water	Monel
Salicylic acid	Nickel
Sodium bicarbonate	
All concentration, 70°F (22°C)	Type 304 stainless steel
Saturated, 70 to 212°F (22 to 100°C)	Type 304 stainless steel
Sodium carbonate	
5%, 70 to 150°F (22 to 66°C)	Type 304 stainless steel
Sodium chloride	
5%, 70 to 150°F (22 to 66°C)	Type 316 stainless steel
Saturated, 70 to 212°F (22 to 100°C)	Type 316 stainless steel
Sodium fluoride	
5%, 70°F (22°C)	Monel
Sodium hydroxide	Type 304 stainless steel
Sodium hypochlorite	
5% still	Type 316 stainless steel
Sodium nitrate	
Fused	Type 316 stainless steel
Sodium peroxide	Type 304 stainless steel
Sodium sulphate	
70°F (22°C)	Type 304 stainless steel
Sodium sulphide	
70°F (22°C)	Type 316 stainless steel
Sodium sulphite	
150°F (66°C)	Type 304 stainless steel
Sulphur dioxide	
Moist gas, 70°F (22°C)	Type 316 stainless steel
Gas, 575°F (302°C)	Type 304 stainless steel
Sulphur	
Dry-molten	Type 304 stainless steel
Wet	Type 316 stainless steel

Application	Protection Tube Material
Sulphuric acid	
5%, 70 to 212°F (22 to 100°C)	Hastelloy B
10%, 70 to 212°F (22 to 100°C)	Hastelloy B
50%, 70 to 212°F (22 to 100°C)	Hastelloy B
90%, 70°F (22°C)	Hastelloy B
90%, 212°F (100°C)	Hastelloy D
Tannic acid	
70°F (22°C)	Type 304 stainless steel
Tartaric acid	
70°F (22°C)	Type 304 stainless steel
150°F (66°C)	Type 316 stainless steel
Toluene	2017-T4 aluminum
Turpentine	Type 304 stainless steel
Whiskey and wine	Type 304 stainless steel
Xylene	Copper
Zinc chloride	Monel
Zinc sulphate	
5%, 70°F (22°C)	Type 304 stainless steel
Saturated, 70°F (22°C)	Type 304 stainless steel
25%, 212°F (100°C)	Type 304 stainless steel

Temperature and Power Control Fundamentals

I. The Control System

The automatic control system consists of a process as shown in **Figure 1.**

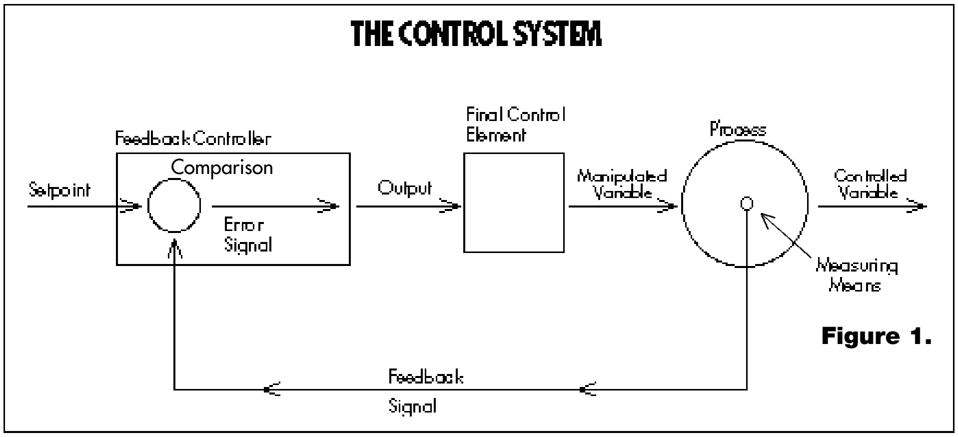


Figure 1.

II. Sensors

Sensors commonly used in temperature control are:

1. Thermistor: A non-linear device whose resistance varies with temperature. Thermistors are used at temperatures under 500°F. Fragility limits their use in industrial applications.
2. Resistance Temperature Detector (RTD): Changes in temperature vary the resistance of an element, normally a thin platinum wire. Platinum RTDs find application where high accuracy and low drift are required. 3-wire sensors are used where the distance between the process and the controller is more than several feet. The third wire is used for leadwire resistance compensation.
3. Thermocouple: A junction of two dissimilar metals produces a millivolt signal whose amplitude is dependent on (a) the junction metals; (b) the temperature under measurement. Thermocouples require cold-end compensation whereas connections between thermocouple wire and copper at the controller's terminal block produce voltages that are not related to the process temperature. Thermocouple voltage outputs are non-linear with respect to the range of temperatures being measured and, therefore, require linearization for accuracy. Thermocouple junctions are usually made by welding the dissimilar metals together to form a bead. Different thermocouple types are used for various temperature measurements as shown in **Table 1.** Thermocouples are the most commonly used industrial sensor because of low cost and durability.
4. Other temperature sensors include non-contact infrared pyrometers and thermopiles. These are used where the process is in motion or cannot be accessed with a fixed sensor.

III. Sensor Placement

Reduction of transfer lag is essential for accurate temperature control using simple temperature controllers. The sensor, heater and work load should be grouped as closely as possible. Sensors placed downstream in pipes, thermowells or loose-fitting platen holes will not yield optimum control. Gas and air flow processes must be sensed with an open element probe to minimize lag. Remember that the controller can only respond to the information it receives from its sensor.

Thermocouple Type	Wire Color	Useful Temperature Range °F
J	White	32 to1300
K	Yellow	-328 to 2200
T	Blue	-328 to 650
R/S	Black	-32 to 2642

Table 1.

IV. Process Load Characteristics

Thermal lag is the product of thermal resistance and thermal capacity. A single lag process has one resistance and one capacity. Thermal resistance is present at the heater/water interface. Capacity is the storage capacity of the water being heated.

Sometimes the sensor location is distant from the heated process and this introduces dead time. **Figure 2a.**

Introduction of additional capacities and thermal resistance changes the process to multi-lag. **Figure 2b & 2c.**

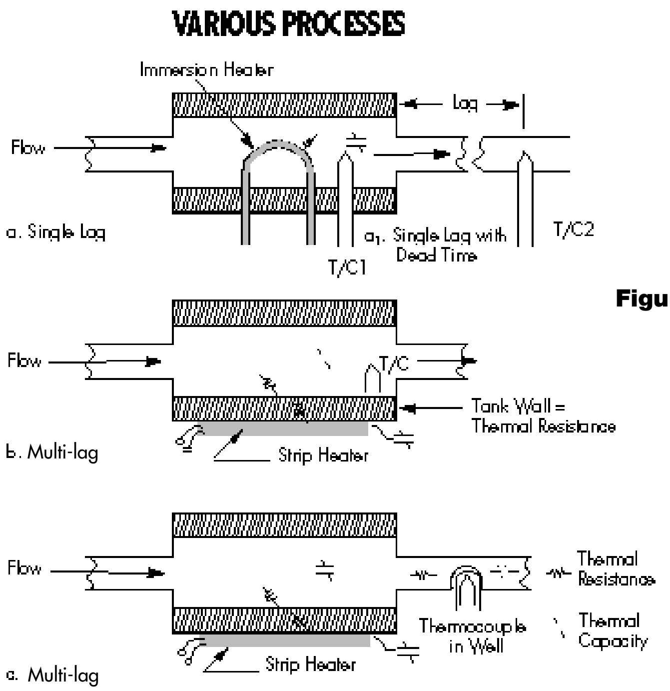


Figure 2.

V. Control Modes

1. On-Off. **Figure 3.**
   On-Off control has two states, fully off and fully on. To prevent rapid cycling, some hysteresis is added to the switching function. In operation, the controller output is on from start-up until temperature set value is achieved. After overshoot, the temperature then falls to the hysteresis limit and power is reapplied.

   On-Off control can be used where:
   (a) The process is underpowered and the heater has very little storage capacity.
   (b) Where some temperature oscillation is permissible.
   (c) On electromechanical systems (compressors) where cycling must be minimized.

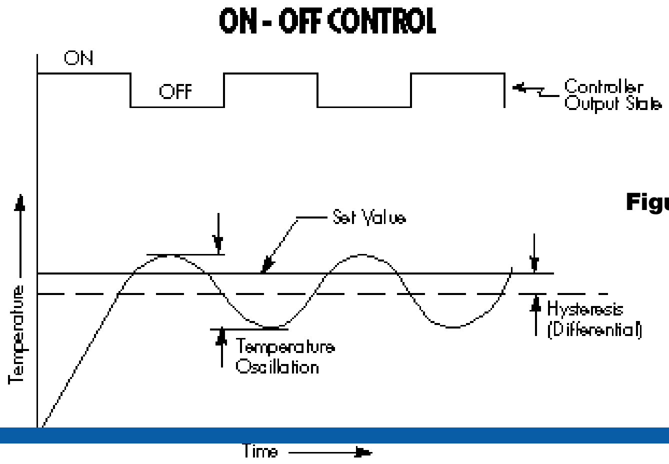


Figure 3.

2. Proportional. **Figure 4.**
   Proportional controllers modulate power to the process by adjusting their output power within a proportional band. The proportional band is expressed as a percentage of the instrument span and is centered over the setpoint. At the lower proportional band edge and below, power output is 100%. As the temperature rises through the band, power is proportionately reduced so that at the upper band edge and above, power output is 0%.

Proportional controllers can have two adjustments:

a) Manual Reset. **Figure 5.** Allows positioning the band with respect to the setpoint so that more or less power is applied at setpoint to eliminate the offset error inherent in proportional control.

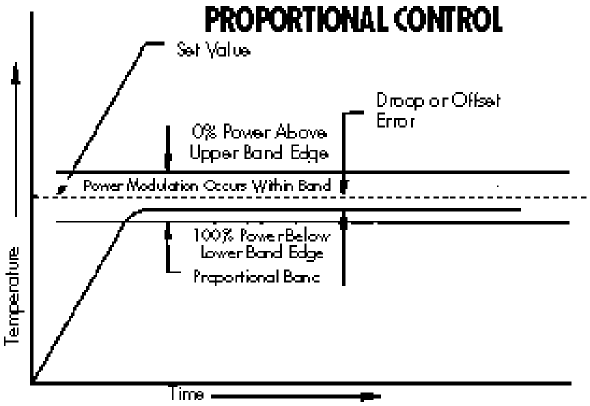


Figure 4.

b) Bandwidth (Gain). **Figure 6.** Permits changing the modulating bandwidth to accommodate various process characteristics. High-gain, fast processes require a wide band for good control without oscillation. Low-gain, slow-moving processes can be managed well with narrow band to on-off control. The relationship between gain and bandwidth is expressed inversely:

$$\textbf{Gain} = \frac{\textbf{100\%}}{\textbf{Proportional Band in \%}}$$

Proportional-only controllers may be used where the process load is fairly constant and the setpoint is not frequently changed.

3. Proportional with Integral (PI), automatic reset. **Figure 7.** Integral action moves the proportional band to increase or decrease power in response to temperature deviation from setpoint. The integrator slowly changes power output until zero deviation is achieved. Integral action cannot be faster than process response time or oscillation will occur.
4. Proportional with Derivative (PD), rate action. Derivative moves the proportional band to provide more or less output power in response to rapidly changing temperature. Its effect is to add lead during temperature change. It also reduces overshoot on start-up.
5. Proportional Integral Derivative (PID). This type of control is useful on difficult processes. Its Integral action eliminates offset error, while Derivative action rapidly changes output in response to load changes.

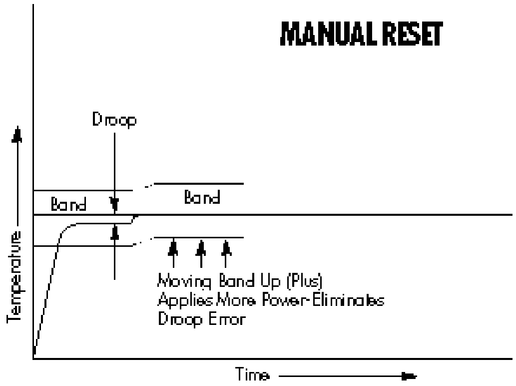


Figure 5.

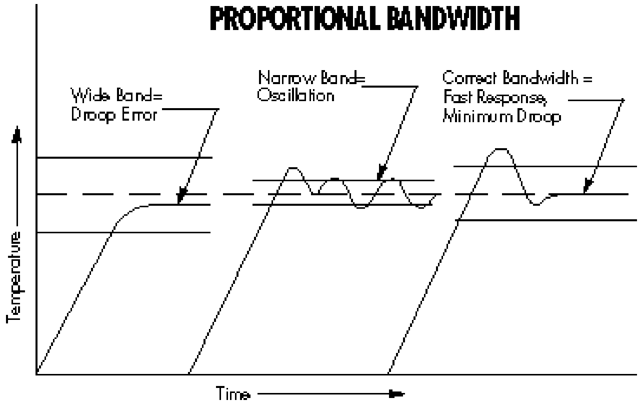


Figure 6.

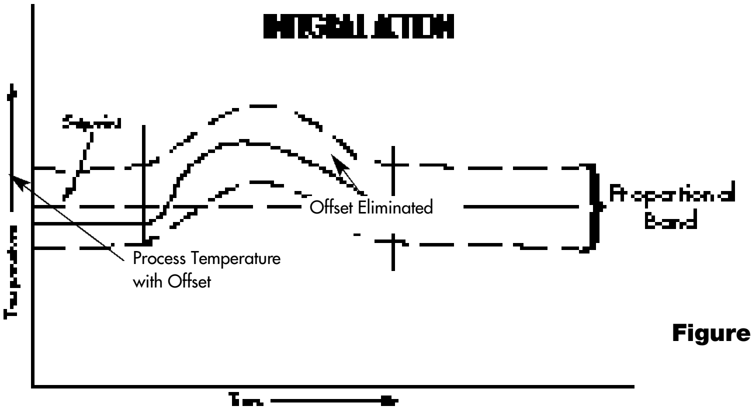


Figure 7.

VI. Proportional Outputs

Load power can be switched by three different proportioning means:

1. Current proportional: A 4-20 mA signal is generated in response to the heating % requirement. See **Figure 9.** This signal is used to drive SCR power controllers and motor-operated valve positioners.
2. Phase angle: This method of modulating permits applying a portion of an ac sine wave to the load. The effect is similar to light dimmer function.
   See **Figure 10.**
3. Time proportioning:
   A clock produces pulses with a variable duty cycle. See **Figure 11.** Outputs are either direct- or reverse-acting. Direct-acting is used for cooling; reverse-acting for heating.
4. Cycle Time:
   In time proportioning control the cycle time is normally adjustable to accommodate various load sizes. A low mass radiant or air heater requires a very fast cycle time to prevent temperature cycling. Larger heaters and heater load combinations can operate satisfactorily with longer cycle times. Use the longest cycle time consistent with ripple-free control.

Control Current vs. Power Output

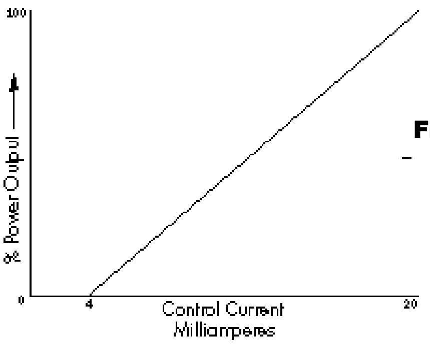
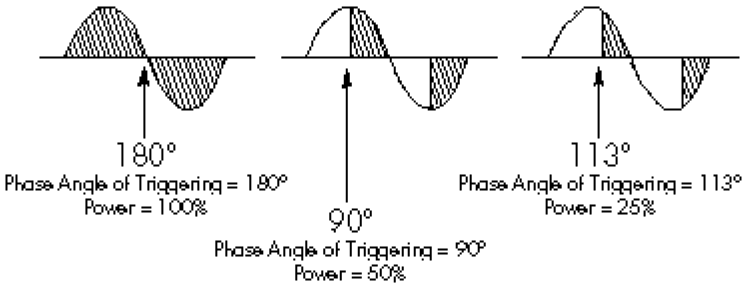


Figure 9.

PHASE ANGLE

Figure 10.



TIME PROPORTIONING

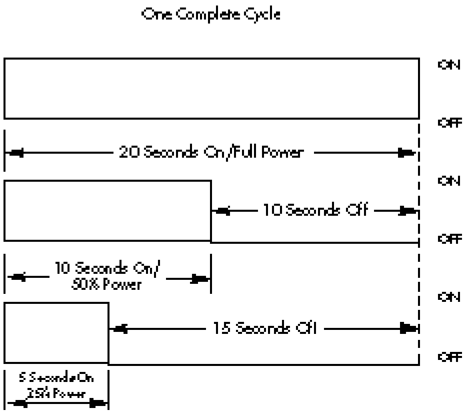


Figure 11.

VII. Power Handlers

Power is switched to an electric heating load through the final control element. Small, single-phase 120/240 V loads may be connected directly to the temperature controller. Larger, higher voltage heaters must be switched through an external power handler. Power handlers are either large relays (contactors), solid-state contactors or power controllers.

1. Mechanical contactors are probably the most widely used power handlers. They:
   - Are rugged. Fuses protect against burnout due to shorts.
   - Will wear out in time due to contact arcing.
   - Cannot be fast-cycled for low-mass loads.
   - Produce RF switching noise.
2. Solid-state contactors are often used on loads requiring fast switching times. They need heat sinking and I^2T fuse protection. 3 - 32V S.S. contactors switch power at zero crossing of the ac sine wave.
3. SCR power controllers. These devices switch ac power by means of thyristors (SCRs). These are solid-state devices that are turned on by gate pulses. They have unlimited life and require no maintenance. SCR controllers are available for switching single- or three-phase loads in zero crossing/burst firing **(Figure 12)** or phase-angle modes **(Figure 10)**

SCR power control selection by switching method can be simplified, as follows:

Use zero crossing for all standard heater applications.

Specify phase angle:

a) When soft start (ramp voltage to peak) is required on high inrush heater loads.

b) If voltage limit is needed to clamp the maximum output voltage to a level lower than the supply voltage.

VIII. HEATER AND POWER CONTROL CONNECTIONS

Power controls are connected to the control signal and load, per **Figure 12.**

The control signal to the power controller may originate from a manual potentiometer, PLC or temperature controller. This signal is normally 4-20 mA, but can be other currents or voltages. An increase in the signal level produces a corresponding increase in power controller output.

Calculation of SCR size for various voltages and heater sizes is as follows:

Loads

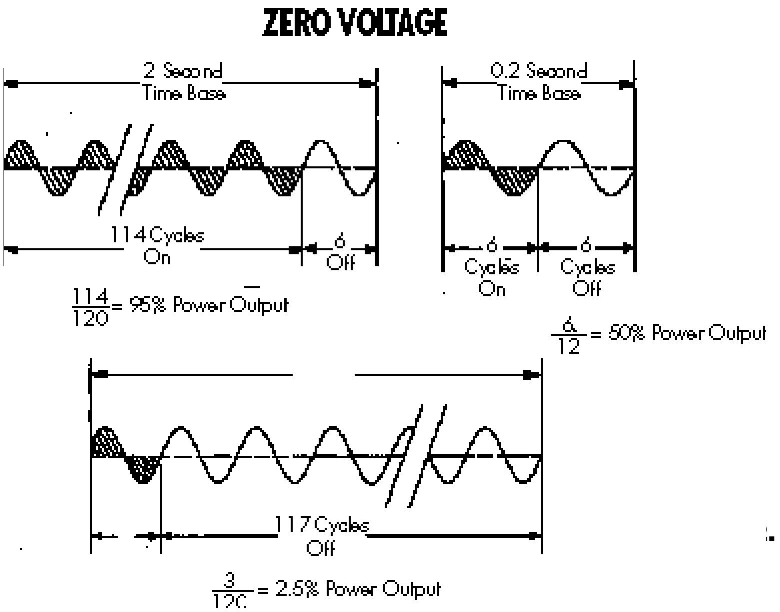
$$\text{Single-phase} \quad \frac{\text{watts}}{\text{volts}} = \text{amps}$$

$$\text{Three-phase} \quad \frac{\text{watts}}{1.73 \times \text{volts}} = \text{amps}$$

watts = total heater watts

volts = line voltage

amps = total line current



SCRs should not be sized at exactly the heater current requirement because heaters have resistance tolerances as do line supplies.

Example: A single-phase 240 volt heater is rated at 7.2 kW

7,200÷240 = 30 A

If the heater is 10% low on resistance, at 240 V, the heater will draw 33 amperes. Damage to fuses will result. Power controllers must be properly cooled and, therefore, the mounting location should be in a cool area. SCRs dissipate approximately 2 watts per ampere per phase.

Proper fusing is essential to protect the SCR devices from damage due to load short circuits. The type of fuse is marked I^2T or semiconductor.

Only SCRs designed to drive transformers should be used for that purpose.

SCR power controllers must never be used as disconnects in high-limit applications.

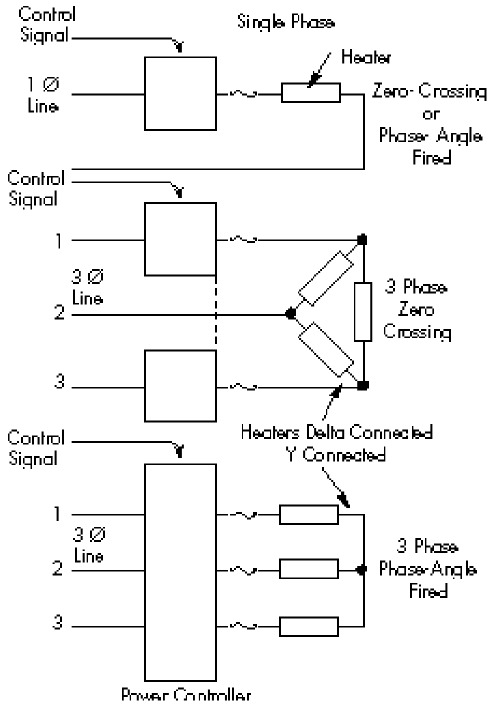


Figure 12.

GLOSSARY

ACCURACY: The difference between the reading of an instrument and the true value of what is being measured, expressed as a percent of full instrument scale.

ACTION: The function of a controller. Specifically, what is done to regulate the final control element to effect control. Types of action include ON-OFF, proportional, integral and derivative.

ACTIVE DEVICE: A device capable of producing gain; for example, transistors, and ICs.

ALARM: A condition, generated by a controller, indicating that the process has exceeded or fallen below the limit point.

AMBIENT TEMPERATURE: The temperature of the immediate surroundings in which a controller must operate.

ANALOG SETPOINT INDICATION: A dial scale to indicate setpoint as opposed to digital setpoint indication. The traditional clock face is a good example of analog indication.

AUTOMATIC TUNING: Sometimes referred to as "self-tuning." The ability of a control to select and adjust the three control parameters (Proportional, Integral, and Derivative) automatically via a complex algorithm. Generally no operator input is required.

BANDWIDTH: See "Proportional Band"

BUMPLESS TRANSFER: When transferring from auto to manual operation, the control output(s) will not change ("bumpless"- a smooth transition).

CLOSED LOOP: A signal path which includes a forward path, a feedback path and a summing point, and forms a closed circuit.

COLD JUNCTION COMPENSATION: Measurement of temperature at thermocouple connections to controller and compensation for the "cold end" junction millivoltage generated here.

COMMON MODE: The noise signal that is common to all sensor wires.

COMMON-MODE REJECTION: The ability of an instrument to reject interference from a common voltage at its input terminals with relation to ground, usually expressed in dB.

COMPENSATION: See "Cold Junction Compensation"

CONTROL POINT: See "Setpoint"

COOL GAIN: In Athena microprocessor-based temperature controllers, a reference Gain value that is expressed in terms of the controller's Span, divided by the cooling proportional band, in degrees.

CURRENT PROPORTIONING: An output from a controller which provides current proportional to the amount of power required.

CYCLE TIME: The time necessary to complete a full ON-through-OFF period in a time proportioning control system.

CURRENT ALARM: Provides an alarm signal when a current level is detected below or above a preselected level.

DV/DT: Rate of change of voltage over time. A rapidly rising voltage waveform could induce false firing of an SCR. MOV's or R-C Snubber Circuits are used to prevent this false firing.

DEAD BAND: The range through which an input can be varied without initiating observable response.

DERIVATIVE: The process by which a controller senses the rate of temperature change and alters output.

DEVIATION ALARM: An alarm referenced at a fixed number of degrees, plus or minus, from setpoint.

DIN: Deutsche Industrial Norms, a widely-recognized German standard for engineering units.

DIFFERENTIAL: The temperature difference between the points at which the controller turns the heater on and off. Typically used when discussing an on/off controller.

DIRECT ACTING: Increase in value of output as the measured value increases.

DRIFT: A deviation of the system from setpoint that typically occurs over a long period of time. Drift may be caused by such factors as changes in ambient temperature or line voltage.

DROOP: Occurs when the actual system temperature stabilizes at some value below the desired setpoint. If system droop is unacceptable, a common solution is the use of a control incorporating an automatic or manual reset feature.

DUTY CYCLE: Percentage of load "ON" time relative to total cycle time.

FEEDBACK CONTROLLER: A mechanism that measures the value of the controlled variable, compares with the desired value and as a result of this comparison, manipulates the controlled system to minimize the size of the error.

FREQUENCY RESPONSE: The response of a component, instrument, or control system to input signals at varying frequencies.

GAIN: Amount of increase in a signal as it passes through any part of a control system. If a signal gets smaller, it is attenuated. If it gets larger, it is amplified.

GUARANTEED SOAK: On a ramp and soak controller, a feature that stops the clock if the temperature drops below a preset value, then continues the timing when the temperature recovers.

HEAT GAIN: In Athena microprocessor-based temperature controllers, a reference Gain value that is expressed in terms of the controller's Span, divided by the heating proportional band, in degrees.

HYSTERESIS: Temperature sensitivity between turn on and turn off points on on-off control. Prevents chattering.

I2T: A measure of maximum one time overcurrent capability for a very short duration. Value used for fuse sizing to protect SCRs.

IMPEDANCE: The total opposition to electrical flow in an ac circuit.

INTEGRAL FUNCTION: This automatically adjusts the position of the proportional band to eliminate offset.

ISOLATION: Electrical separation of sensor from high voltage and output circuitry. Allows for application of grounded or ungrounded sensing element.

LAG: The time delay between the output of a signal and the response of the instrument to which the signal is sent.

LATCHING ALARM: Requires operator intervention to reset even though the alarm condition on the input may have disappeared.

MOV: Metal Oxide Varistor: A semiconductor device that acts as a safety valve to absorb high voltage transients harmlessly, thereby protecting the SCRs and preventing false firing.

NOISE: An unwanted electrical interference.

NORMAL-MODE REJECTION: The ability of an instrument to reject interference; usually of line frequency across the input terminals (common mode).

OFFSET: A sustained deviation of the controlled variable from setpoint (this characteristic is inherent in proportional controllers that do not incorporate reset action). Also referred to as Droop.

ON/OFF CONTROL: Control of temperature about a setpoint by turning the output full ON below setpoint and full OFF above setpoint in the heat mode.

OPEN LOOP: Control system with no sensory feedback.

OUTPUT: Action in response to difference between setpoint and process variable.

OVERSHOOT: Condition where temperature exceeds setpoint due to initial power up.

PARAMETER: A physical property whose value determines the response of an electronic control to given inputs.

PD Control: Proportioning control with rate action.

PHASE: The time-based relationship between two alternating waveforms.

PHASE-ANGLE FIRING: A form of power control where the power supplied to the process is controlled by limiting the phase angle of the line voltage as opposed to burst firing.

PI Control: Proportioning control with auto reset.

PID: Proportional, integral and derivative control action.

POSITIVE TEMPERATURE COEFFICIENT: A characteristic of sensors whose output increases with increasing temperature.

PROCESS VARIABLE: System element to be regulated, such as pressure, temperature, relative humidity, etc.

PROPORTIONAL ACTION: Continuously adjusts the manipulated variable to balance the demand.

PROPORTIONAL BAND: The amount of deviation of the controlled variable required to move through the full range (expressed in % of span or degrees of temperature). An expression of Gain of an instrument (the wider the band, the lower the gain).

PROPORTIONING CONTROL PLUS DERIVATIVE FUNCTION: A controller incorporating both proportional and derivative action senses the rate temperature change and adjusts controller output to minimize overshoot.

PROPORTIONING CONTROL PLUS INTEGRAL: A controller incorporating both proportional and integral action.

PROPORTIONAL, INTEGRAL AND DERIVATIVE CONTROL: A PID controller is a three-mode controller incorporating proportional, integral, and derivative actions.

RAMP: Automatic adjustment for the setpoint for the temperature increase or decrease from process temperature. The target value can be either above or below the current measured value. The ramp value is a combination of time and temperature.

RAMP TO SETPOINT: Allows the operator to enter a target time for the controller to reach setpoint.

RANGE: The difference between the maximum and the minimum values of output over which an instrument is designed to operate normally.

RATE (ACTION): Control function that produces a corrective signal proportional to the rate at which the controlled variable is changing. Rate action produces a faster corrective action than proportional action alone. Also referred to as Derivative Action. Useful in eliminating overshoot and undershoot.

R.C. SNUBBER CIRCUIT: Resistor - Capacitor Snubber Circuit: Controls the maximum rate of change of voltage and limits the peak voltage across the switching device. Used to prevent false firing of SCRs.

REFERENCE JUNCTION: See “Cold Junction Compensation”

REPRODUCIBILITY: The ability of an instrument to duplicate with exactness, measurements of a given value. Usually expressed as a % of span of the instrument.

RESET ACTION: Control function that produces a corrective signal proportional to the length of time and magnitude the controlled variable has been away from the setpoint. Accommodates load changes. Also called Integral Action.

REVERSE ACTING: Reduces the output as the measured value increases.

RFI: An acronym for radio frequency interference. RFI is commonly generated by devices that switch the output power at some voltage other than zero. Typically, phase-angle fired SCRs may generate RFI while zero-cross fired SCRs virtually eliminate RFI.

RTD: An acronym for a resistance temperature detector. Typically a wire wound device that displays a linear change in resistance for a corresponding temperature change. An RTD has a positive temperature coefficient.

SCR: This term has two separate and distinct meanings: 1) A solid-state semiconductor component that conducts or resists current flow depending upon whether a trigger voltage is present at the gate terminal. 2) A complete power controller that utilizes SCRs or TRIACs as the switching devices to control current flow.

SEGMENT: In a ramp and soak controller, one part of a profile.

SOAK: One segment with no setpoint change.

SSR: An acronym for solid-state relay. Semiconductor device that switches electrical current on and off in response to an electrical signal at the control terminals.

SENSITIVITY: The minimum change in input signal required to produce an output change in the controller.

SERIES MODE: A condition in which a noise signal appears in series with a sensor signal.

SETPOINT: The position to which the control point setting mechanism is set, which is the same as the desired value of the controlled variable.

SPAN: The difference between the top and bottom scale values of an instrument. On instruments starting at zero, the span is equal to the range.

STANDBY: Method of putting controller into the idle mode.

SURGE CURRENT: A high current of short duration that generally occurs when the power is first applied to inductive loads. The surge generally lasts no more than several ac cycles.

THERMISTOR: A bead-like temperature sensing device consisting of metallic oxides encapsulated in epoxy or glass. The resistance of a thermistor typically falls off sharply with increasing temperature, making it a particularly good sensing device. A thermistor has a negative temperature coefficient.

THERMOCOUPLE: The junction of two dissimilar metals. A small voltage is generated at this junction, increasing as its temperature rises.

THERMOCOUPLE BREAK PROTECTION: Fail-safe operation that ensures output shutdown upon an open thermocouple condition.

THREE-MODE CONTROL: Proportioning control with reset and rate.

THYRISTOR: Any of a group of solid-state controlling devices. These devices are referred to as TRIACs, SCRs and DIACs.

TIME PROPORTIONING CONTROL MODE: In this mode, the amount of controller “on” time depends upon the system temperature. At the beginning of each time base interval, the signal from the sensor is analyzed and the controller is kept “ON” for a percentage of the time base.

TRIAC: A device, similar to a controlled rectifier, in which both the forward and reverse characteristics can be triggered from blocking to conducting (Also see Thyristor).

ZERO SWITCHING: Action that provides output switching only at the zero voltage crossing point of the ac sine wave.

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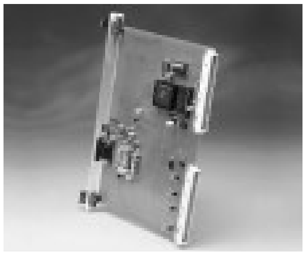

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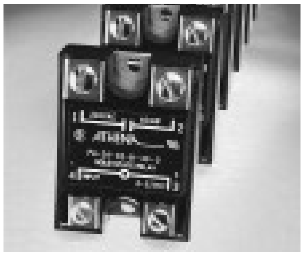

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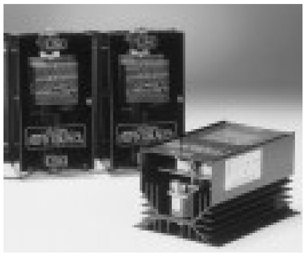

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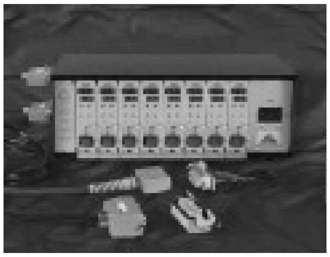

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