Technical Information

Electrical Fundamentals & Three Phase Calculations

Ohm's Law

The relationship between Wattage (heat) output and the applied Voltage of electric resistance heating elements is determined by a precise physical rule defined as Ohm's Law which states that the current in a resistance heating element is directly proportional to the applied Voltage. Ohm's Law is traditionally expressed as:

$$I = \frac{E}{R}$$

Where: I = Amperes (Current)
E = Voltage
R = Ohms (Resistance)

The same equation using the conventional abbreviation for voltage is:

$$I = \frac{V}{R}$$

Where: I = Amperes (Current)
V = Voltage
R = Ohms (Resistance)

An unknown electrical value can be derived by using any two known values in one of the variations of Ohm's Law shown at the right.

OHM'S LAW

VOLTS

VOLTS = $\sqrt{\text{WATTS X OHMS}}$

VOLTS = $\frac{\text{WATTS}}{\text{AMPERES}}$

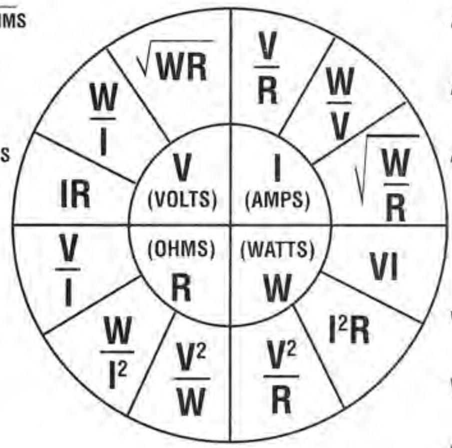
VOLTS = AMPERES X OHMS

OHMS

OHMS = $\frac{\text{VOLTS}}{\text{AMPERES}}$

OHMS = $\frac{\text{WATTS}}{\text{AMPERES}^2}$

OHMS = $\frac{\text{VOLTS}^2}{\text{WATTS}}$



AMPERES

AMPERES = $\frac{\text{VOLTS}}{\text{OHMS}}$

AMPERES = $\frac{\text{WATTS}}{\text{VOLTS}}$

AMPERES = $\sqrt{\frac{\text{WATTS}}{\text{OHMS}}}$

WATTS

WATTS = VOLTS x AMPERES

WATTS = AMPERES^2 x OHMS

WATTS = $\frac{\text{VOLTS}^2}{\text{OHMS}}$

Voltage & Wattage Relationships

An electric resistance element only produces rated Wattage at rated Voltage. It is common for electric heating elements and assemblies to be connected to a wide range of operating Voltages. Since the Wattage output varies directly with the ratio of the square of the Voltages, the actual Wattage can be calculated for any applied Voltage. The relationship is expressed by the equation below,

$$W_A = W_R \times \left(\frac{V_A^2}{V_R^2}\right)$$

Where: W_A = Actual Wattage
W_R = Rated Wattage
V_A = Applied Voltage
V_R = Rated Voltage

Percent of Rated Wattage for Various Applied Voltages

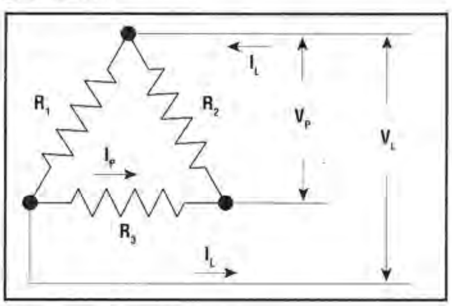
Applied Voltage	Rated Voltage													
	110	115	120	208	220	230	240	277	380	415	440	460	480	575
110	100	91	84	28	25	23	21	16	8.4	7.0	6.2	5.7	5.2	3.7
115	109	100	92	31	27	25	23	17	9.0	7.6	6.7	6.2	5.7	4.0
120	119	109	100	33	30	27	25	19	10	8.4	7.4	6.8	6.3	4.3
208	—	—	300	100	89	82	75	56	30	25	22	20	19	13
220	—	—	—	112	100	91	84	63	34	28	25	23	21	15
230	—	—	—	122	109	100	92	69	37	31	27	25	23	16
240	—	—	—	133	119	109	100	75	40	33	30	27	25	17
277	—	—	—	—	—	—	133	100	53	45	40	36	33	23
380	—	—	—	—	—	—	—	188	100	84	74	68	63	44
415	—	—	—	—	—	—	—	—	119	100	89	81	75	52
440	—	—	—	—	—	—	—	—	—	112	100	91	84	58
460	—	—	—	—	—	—	—	—	—	123	109	100	92	64
480	—	—	—	—	—	—	—	—	—	—	119	109	100	70
550	—	—	—	—	—	—	—	—	—	—	156	143	131	91
575	—	—	—	—	—	—	—	—	—	—	171	156	144	100
600	—	—	—	—	—	—	—	—	—	—	186	170	156	109

Three Phase Equations (Balanced)

Ohm's Law, as stated above, applies to electrical resistance elements operated on single phase circuits. Ohm's Law can be modifed to calculate three phase values by adding a correction factor for the phase Voltage relationships. The three phase equations shown can be applied to any balanced Delta or Wye circuit. The terms used in the equations are identified below:

V_L = Line Voltage
V_P = Phase Voltage
I_L = Line Current (Amps)
I_P = Phase Current (Amps)
W_T = Total Watts
$R_1 = R_2 = R_3$ = Element Resistance
W_C = Wattage per Circuit (Equal Circuits)
R_C = Circuit Resistance in Ohms Measured Phase to Phase

3Ø Delta

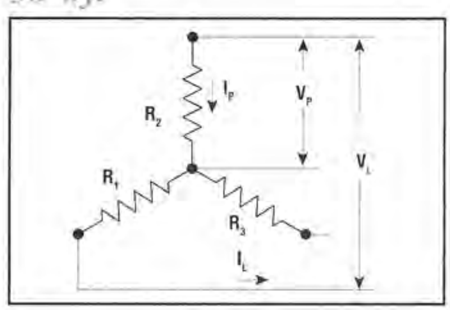


$V_P = V_L$
$W_T = 1.73\ I_L \times V_L$
$I_P = I_L \div 1.73$
$W_C = 1.73\ I_L \times V_L \div$ # Circuits
$R_C = (2 \times V_L^2) \div W_C$

$V_L = V_P$
$W_T = 3\ (V_L^2 \div R_1)$
$I_L = I_P \times 1.73$
$R_C = V_L^2 \div 0.5W_C$

Note — For Open Delta connections, see next page.

3Ø Wye



$V_P = V_L \div 1.73$
$W_T = 1.73\ I_L \times V_L$
$I_P = I_L$
$W_C = 1.73\ I_L \times V_L \div$ # Circuits
$R_C = (2 \times V_L^2) \div W_C$

$V_L = V_P \times 1.73$
$W_T = V_L^2 \div R_1$
$I_L = I_P$
$R_C = V_L^2 \div 0.5\ W_C$

Note — For Open Wye connections, see next page.

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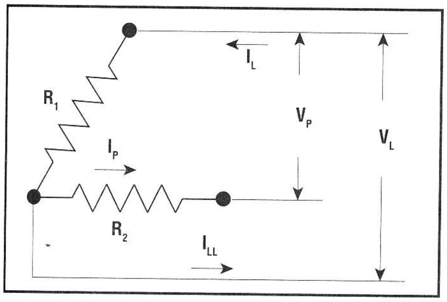
Three Phase Equations & Heater Wiring Diagrams

Open Delta & Wye

Three phase heating circuits are most efficient when operated under balanced conditions. If it is necessary to operate an unbalanced load, the equations below can be used to calculate the circuit values for open three phase Delta or Wye circuits. The terms used in the equations are identified below:

- V_L = Line Voltage
- V_P = Phase (Element) Voltage
- I_L = Line Current (Amps)
- I_{LL} = Line Current (Unbalanced Phase)
- I_P = Phase Current (Amps)
- W_T = Total Watts
- $R_1 = R_2 = R_3$ = Element Resistance
- R_C = Circuit Resistance in Ohms Measured from Phase to Phase

3Ø Open Delta

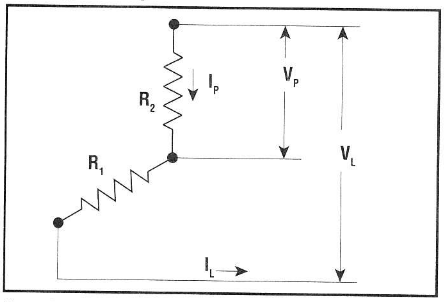


$V_P = V_L$
$W_T = 2V_L \times I_L$
$I_P = I_L$
$W_C = 2V_P \times I_P$

$V_L = V_P$
$W_T = 2\,(V_L^2 \div R_1)$
$I_L = I_P$
$I_{LL} = 1.73 \times I_P$

The loss of a phase or failure of an element in a three (3) element Delta circuit will reduce the wattage output by 33%.

3Ø Open Wye



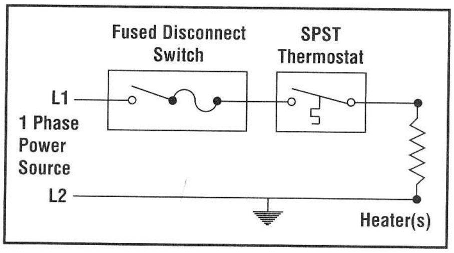
$V_P = V_L \div 2$
$W_T = I_L \times V_L$
$I_P = I_L$
$R_C = V_L^2 \div W_C$

$V_L = V_P \times 2$
$W_T = V_L^2 \div 2R_1$
$I_L = I_P$

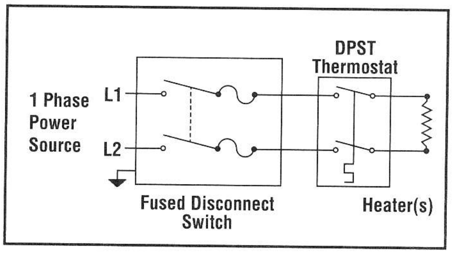
The loss of a phase or failure of an element in a three (3) element Wye circuit will reduce the wattage output by 50%. Heating elements are basically in series on single phase power.

Typical Heater Wiring Diagrams

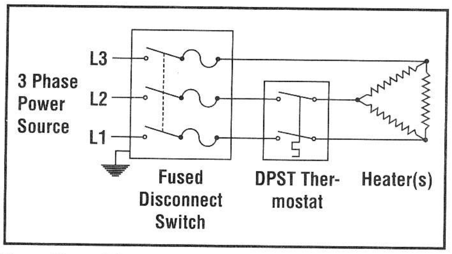
The following diagrams show typical heater wiring schematics.



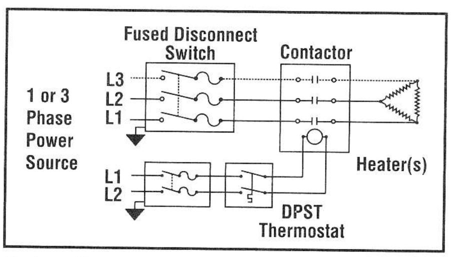
Single Phase 120 VAC heater circuit where line voltage and current do not exceed thermostat rating.



Single Phase AC circuits where line voltage and current do not exceed thermostat rating.

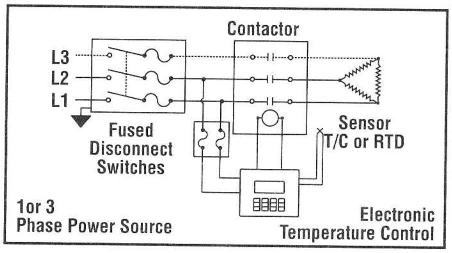


Three Phase AC heater circuit where line voltage and current do not exceed thermostat rating. Circuit does not have a "positive" off.

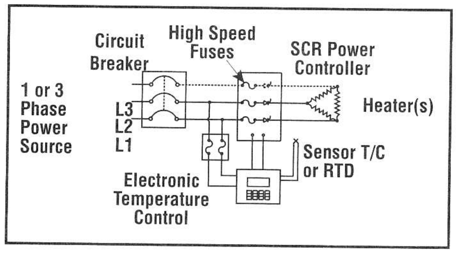


Single or Three Phase AC heater circuit where line voltage and current exceed thermostat rating. Separate control circuit can use a single pole or double pole thermostat. Control circuit requires over-current protection.

WARNING — **Hazard of Electric Shock.** Any installation involving electric heaters must be effectively grounded in accordance with the National Electrical Code to eliminate shock hazard.



Single or Three Phase AC heater circuit using electronic temperature controllers and contactors. Controller and contactor holding coil must be rated for the same voltage as the heater circuit. Control circuit requires over- current protection.



Single or Three Phase AC heater circuit using an electronic temperature controller and a SCR (solid state) power controller. Controller must be rated the same voltage as the heater circuit. Control circuit requires over-current protection. All electrical wiring to electric heaters must be installed in accordance with the National Electrical Code or local electrical codes by a qualified person.

Wiring & Ambient Temperatures

Ambient temperatures must be considered when selecting wiring materials for electric heater circuits. Heating equipment and processes may cause associated wiring to operate well above ambient temperatures. These temperatures may result from heat conducted from the heater terminals, radiation from heated surfaces or simply high ambient air temperatures. Nickel plated copper or nickel alloy conductors with high temperature insulation should always be used in high temperature areas. Outside these areas, conventional wiring materials can usually be used. 60°C building wire is usually not suitable unless otherwise indicated.

Wiring in Severe Conditions

Moist or wet locations require gasketed terminal and junction boxes to protect equipment and wiring. Rigid conduit is recommended. Hazardous Locations require the use of approved explosion-proof terminal and junction boxes. Rigid conduit or mineral insulated (MI) cable is mandatory in Division 1 areas. Some Hazardous Locations may require conduit seals (EYS) adjacent to the equipment.

Technical Information

Wiring Practices for Electric Heaters

Wire Insulation & Conductors

The selection of wiring materials to be used in a particular application depends upon the service Voltage and the anticipated operating temperatures. The table below lists some of the more common code wire constructions according to their temperature limitations. Insulated wires should be derated for elevated ambient temperatures and should never be used above their temperature rating. The operating temperature of unplated copper wire should be limited to 200°C (392°F) maximum. A complete listing of wire construction and allowable current carrying capacities is shown in the National Electric Code Article 310.

General Purpose Wiring

Max. Conductor Temperature °C	Max. Conductor Temperature °F	Wire Type (600V)	Construction (Copper Conductors)
60	140	TW	Thermoplastic
75	167	RHW THW	Rubber Thermoplastic
90	194	RHH THWN XHHN MTW	Heat Resistant Rubber Heat Resistant Thermoplastic Heat Resistant Cross-link Thermoplastic Heat Resistant Cross-link Thermoplastic
200	392	FEP	Teflon®

High Temperature Wiring Materials

Max. Conductor Temperature °C	Max. Conductor Temperature °F	Wire Type (600V)	Construction (Nickel Plated Copper or Nickel Conductors)
250	482	TGT TGGT	Teflon® - Glass - Teflon®
450	842	MGS MGT	Mica - Glass - Silicone Mica - Glass - Teflon®
594	1100	Bare	Maganese Nickel Wire or Bus Bars with Ceramic Insulators

Note — High temperature wiring materials are available for field application.

Contactor Sizing

Contactors are normally rated for inductive and resistive loads. Most electric resistance heaters have negligible inrush or inductive current. Select contactors based on resistive load ratings. Using the formulas shown in the paragraphs on wire sizing to determine the amp load per pole (phase). Select a contactor with the next highest current rating. Use a two pole contactor for single phase (two-wire) power and a three pole contactor for balanced Delta or Wye three phase loads. For heater loads with high inrush current, refer to product data information for maximum amperage.

Thermocouple Wire & Cable

Thermocouples and extension lead wires are color coded to aid in identification and to avoid inadvertent cross wiring. The following charts indicate the colors used of different alloys.

Thermocouple Color Coding

Type	Positive Color (+)	Alloys
J	White	Iron/Constantan
K	Yellow	Chromel/Alumel
T	Blue	Copper/Constantan
E	Purple	Chromel/Constantan
R	Black	Platinum/Platinum (with 13% Rhodium)
S	Black	Platinum/Platinum (with 6% Rhodium)
N	Orange	Nicrosil/Nisil

Note — Negative (-) conductor identified with red colored insulation.

Thermocouple Extension Wire Colors

Type	Positive	Negative	Color Overall	Positive Color (+)
T	TPX	TNX	Blue	Blue
J	JPX	JNX	Black	White
E	EPX	ENX	Purple	Purple
K	KPX	KNX	Yellow	Yellow
R or S	SPX	SNX	Green	Black
B	BPX	BNX	Gray	Gray

Note — Negative (-) conductor identified with red colored insulation.

Electrical Noise & Controls

Electrical "noise" refers to extraneous electrical voltages that interfere with legitimate control signals. Most electrical noise is introduced by electromagnetic coupling with fluorescent lights, contactors, power wiring, switches and other arcing devices. Shield control circuit wiring and keep thermocouple wires separate from power wiring. Trace shielded thermocouple lead wires in a separate conduit for maximum protection.

Temperature Limits for Controls

Most mechanical controls and thermostats (control bodies) can withstand a wide range of ambient temperatures ranging from below freezing to over 140°F. Electronic controls, transformers, contactors and other electrical devices are more temperature sensitive and extreme temperatures will usually shorten the life of the component. Most electrical and electronic equipment will function accurately in ambient temperatures ranging from about 30°F to about 130°F. Triacs and SCR controls frequently require special cooling for full load ratings when operated over 120°F. Refer to the installation instructions or contact the device manufacturer for recommendations.

Wiring Hints for Electric Heaters

The following are some general recommendations for wiring electric heating elements and assemblies. These recommendations are only suggestions and are not intended to conflict with the National Electric Code or local codes.

WARNING — **Hazard of Electric Shock.** Any installation involving electric heaters must be effectively grounded in accordance with the National Electrical Code to eliminate shock hazard. All electrical wiring to electric heaters must be installed in accordance with the National Electrical code or local electrical codes by a qualified person.

1. Repetitive heating and cooling can cause wiring connections to loosen over time. High amperage through a loose terminal can cause overheating and terminal failure. All heater terminal connections should be tightened to a maximum torque consistent with terminal strength. Use a second wrench or pliers to prevent twisting heater terminals.
2. Use stranded wire in applications where the power wires to heater terminal connections may be subject to movement. When using solid wire or bus bar on heater terminals, provide expansion loops between points of support to minimize damaging stresses due to expansion and contraction.
3. Solder or silver braze lead connections to heating elements that may be subject to extreme temperatures or vibration. Use a minimum of flux to complete the connection and keep flux from contaminating the heating element. Remove residual flux to prevent corrosion of the electrical joint.
4. Keep thermostat capillary tubing and thermocouple wiring clear of heater terminals to prevent accidental short circuits. Sleeving or insulated tubing is recommended.
5. Use wiring suitable for the anticipated operating temperatures. Unless the heater is specifically marked for use with low temperature copper wiring, high temperature alloy conductors are recommended for connections to the heater terminals.
6. Do not use rubber, wax impregnated or plastic covered wire inside terminal enclosures of heaters in high temperature applications. These insulations will deteriorate and give off fumes which can contaminate the heating elements and cause short circuits.

Technical Information

Wiring Practices for Electric Heaters *(cont'd.)*

Selecting Wire Size (AWG)

The size (wire gauge) of the electrical conductor for a particular application will depend upon the Amperage (current) which the heating load will draw from the power source. Current can be calculated by Ohm's Law. To calculate amperage, use the following formulas. On a single phase (two-wire) power supply, the amperage per line is calculated by:

$$1\text{ Ph Amperage} = \frac{\text{Total Circuit Wattage}}{\text{Line Voltage}}$$

On three phase power circuits with balanced Delta or Wye heating loads, line amperage is calculated by:

$$3\text{ Ph Amperage} = \frac{\text{Total Circuit Wattage}}{\text{Line Voltage x 1.73}}$$

Table II lists amperages for common kW ratings.

Allowable Ampacities

Once the load current has been determined, wire size for the calculated amperage may be selected from tables in Article 310 of the National Electrical Code (NEC). As a guide, Table III at the right lists recommended ampacities for the more common insulated wires for high temperature applications. Current ratings for 90°C wire in a 30°C ambient are included for reference.

Corrections for Elevated Ambient Temperatures

The recommended current carrying capacities of 200°C and 250°C wire are valid if conductor temperatures do not exceed 104°F (40°C). Operating temperatures in excess of 104°F (40°C) require the application of a temperature correction factor for the corresponding wire.

Example — Size 14 AWG, type TGT wire is capable of handling 39 Amperes at 104°F (40°C) but must be reduced to 0.85 (85%) or 33 Amperes when operated at 212°F (100°C).

Multiple Insulated Wires in Conduit

The wire size selected above may be used in the heating circuit with three (3) wires enclosed in rigid or flexible conduit to protect the wiring. If more than 3 conductors are installed in the same conduit, another current correction factor must be used. For 4 to 6 conductors in a single conduit use 80% of the recommended current-carrying capacity. For 7 to 24 conductors use 70%.

Table II — Amperage (Current) for Typical kW Heater Ratings

	Single Phase					Three Phase Balanced Load				
kW	120V	208V	240V	440V	480V	208V	240V	440V	480V	575V
1	8.4	4.8	4.2	2.3	2.1	2.8	2.5	1.4	1.3	1.0
2	16.7	9.7	8.4	4.6	4.2	5.6	4.9	2.7	2.5	2.0
3	25.0	14.5	12.5	6.9	6.3	8.4	7.3	4	3.7	3.0
4	33.4	19.3	16.7	9.1	8.4	11.2	9.7	5.3	4.9	4.0
5	41.7	24.1	20.9	11.4	10.5	13.9	12.1	6.6	6.1	5.0
6	50.0	28.9	25.0	13.7	12.5	16.7	14.5	7.9	7.3	6.0
7.5	62.5	36.1	31.3	17.1	15.7	20.9	18.1	9.9	9.1	7.5
10	83.4	48.1	41.7	22.8	20.9	27.8	24.1	13.2	12.1	10.0
12	100.0	57.7	50.0	27.3	25	33.4	29	15.8	14.5	12.1
15	125.0	72.2	62.5	34.1	31.2	41.7	36.2	19.7	18.1	45.1
20	167.0	96.2	83.4	45.5	41.7	55.6	48.2	26.3	24.1	20.1
25	209.0	121	105	56.9	52.1	69.5	60.3	32.9	30.1	25.1
30	—	145	125	68.2	62.5	83.4	72.3	39.4	36.2	30.2
50	—	241	209	114	105	139	121	65.7	60.3	50.3
75	—	—	313	171	157	209	181	98.6	90.4	75.4
100	—	—	417	228	209	278	241	132	121.0	100.0

Table III — Allowable Ampacities

Three Insulated Conductors in a Raceway or Conduit				Single Conductor[1,2] in Free Air (200°C Ambient)		
Conductor Type	Copper	Copper	Nickel or Nickel Coated Copper	Nickel Coated Copper	Nickel	
Insulation Type	THHN XHHW MTW	FEP PFA SRG	TGT TGGT TFE	MGT MGS	MGT MGS	
Ambient Temp.	30°C (86°F)	40°C (104°F)	40°C (104°F)	200°C (392°F)	200°C (392°F)	
Maximum Conductor Temperature (Insulation Limits)						
Size AWG	90°C (194°F)	200°C (392°F)	250°C (482°F)	450°C (842°F)	450°C (842°F)	
14	25	36	39	44	23	
12	30	45	54	58	31	
10	40	60	73	77	42	
8	55	83	93	100	53	
6	75	110	117	—	—	
Correction Factors for Elevated Ambient Temperatures						
Ambient (°C)	For ambient temperature exceeding the values in the above table, multiply the allowable ampacities by the appropriate factor below.					Ambient (°F)
36 - 40	0.91	1.00	1.00	—	—	96 - 104
41 - 45	0.87	0.97	0.98	—	—	105 - 113
46 - 50	0.82	0.96	0.97	—	—	114 - 122
51 - 55	0.76	0.95	0.95	—	—	123 - 131
56 - 60	0.71	0.94	0.94	—	—	132 - 140
61 - 70	0.58	0.9	0.93	—	—	141 - 158
71 - 80	0.41	0.87	0.9	—	—	159 - 176
81 - 90	—	0.83	0.87	—	—	177 - 194
91 - 100	—	0.79	0.85	1.22	—	195 - 212
101 - 120	—	0.71	0.79	1.19	—	213 - 248
121 - 140	—	0.61	0.72	1.16	1.16	249 - 284
141 - 160	—	0.5	0.65	1.12	1.12	285 - 320
161 - 180	—	0.35	0.58	1.06	1.06	321 - 356
181 - 200	—	—	0.49	1.00	1.00	357 - 392
201 - 225	—	—	0.35	0.92	0.92	393 - 437
226 - 250	—	—	—	0.87	0.87	438 - 542
250 - 300	—	—	—	0.70	0.70	543 - 572
300 - 350	—	—	—	0.49	0.49	573 - 662

1. Data derived or extrapolated from values and criteria set forth in NEC Article 310.
2. MGT & MGS insulated wire is intended to be used for interconnection of strip heaters and elements located in high temperature ambients and is not intended for general purpose wiring. Do not use these Amp ratings for three insulated conductors inside raceways or conduits.