FORMULAS AND DEFINITIONS

The following formulas and definitions apply to all applications:

DEFINITION: Resistivity, ρ $\Omega mm^2/m$ (Ω/cmf)

The resistance of a conductor, R_{20}, is directly proportional to its length, L and inversely proportional to its cross-sectional area, q:

$$R_{20} = \rho\frac{\ell}{q} \quad \Omega \quad [1]$$

The proportional constant, ρ is defined as the resistivity of the material and is temperature dependent. The unit of ρ is $\Omega mm^2/m$ (Ω/cmf).

DEFINITION: Temperature factor, C_t

Resistivity or change in resistance with temperature, is non-linear for most resistance heating alloys. Hence, the temperature factor, C_t, is often used instead of temperature coefficient. C_t is defined as the ratio between the resistivity or resistance at some selected temperature T °C and the resistivity or resistance at 20°C (68°F).

$$R_T = C_t R_{20} \quad \Omega \quad [2]$$

$$C_t = \frac{R_T}{R_{20}} \quad [3]$$

$$C_t = 1 + (T - 20)\alpha \quad [4]$$

DEFINITION: Surface load, p W/cm^2 (W/in^2)

The surface load of a heating conductor, p, is its power, P, divided by its surface area, A_c.

$$p = \frac{P}{A_c} \quad W/cm2\ (W/in2) \quad [5]$$

Wire

$$A_c = \pi dL \times 10 \quad \text{(metric) [6]}$$

$$A_c = \pi dL \times 12 \quad \text{(imperial) [6]}$$

Strip

$$A_c = 2(b + t)L \times 10 \quad \text{(metric) [7]}$$

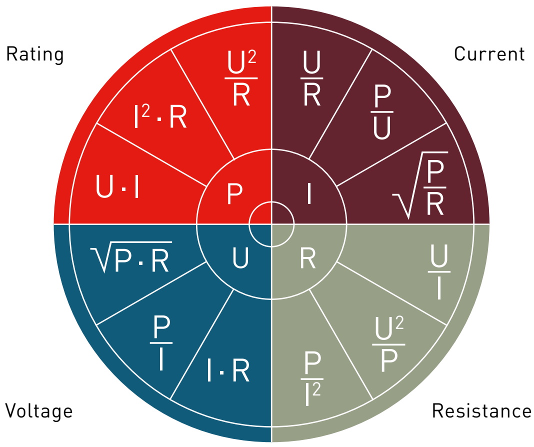
$$A_c = 2(b + t)L \times 12 \quad \text{(imperial) [7]}$$

General formulas

$$U = R_T I \quad V \quad [8]$$

$$P = UI \quad W \quad [9]$$

Combining equations [8] and [9] gives:



Combining equations [2], [5], [8] and [9] gives:

$$\eta = \frac{A_c}{R_{20}} = \frac{I^2 C_t}{p} \quad cm2/\Omega\ (in2/\Omega) \quad [10]$$

The ratio $\frac{A_c}{R_{20}}$, used for determining wire, strip or ribbon size, is tabulated for all alloys in the handbook for 'Resistance heating alloys and systems for industrial furnaces'.

DEFINITION: Cross sectional area, q mm² (in²)

Round wire

$$q = \frac{\pi}{4}d^2 \qquad \text{mm2 (in2)} \quad [11]$$

Combining equations [1], [5], [6] and [11] gives the wire diameter, d:

$$d = \sqrt[3]{\frac{4\rho P}{\pi^2 p R_{20}}} \qquad \text{mm (in)} \quad [12]$$

$$d = \sqrt[3]{\frac{4}{10\pi^2}\frac{\rho P}{pR_{20}}} \qquad \text{(metric)} \quad [12]$$

$$d = \sqrt[3]{\frac{4}{15.28 \times 10^6 \times \pi^2}\frac{\rho P}{pR_{20}}} \qquad \text{(imp.)} \quad [12]$$

Example:

ρ = 1.35 Ω mm²/m (812 Ω/cmf) for Kanthal® D (according to section 2)
P = 1,000 W
p = 8 W/cm² (51.6 W/in²)
R = 40 Ω

Strip

$$q = bt \qquad \text{mm2 (in2)} \quad [13]$$

DEFINITION: Number of turns, n

$$N = \frac{L_e}{s} \qquad [15]$$

DEFINITION: Coil pitch, s mm (in)

A round wire is often wound as a coil. For calculating coil pitch, s, the equation [16] applies:

$$\left[\frac{\pi(D-d)}{s}\right]^2 + 1 = \left(\frac{\ell}{L_e}\right)^2 \Rightarrow$$

$$s = \frac{\pi(D-d)}{\sqrt{\left(\frac{\ell}{L_e}\right)^2 - 1}} \qquad \text{mm} \quad [16]$$

$$s = \frac{\pi(D-d)}{\sqrt{\left(\frac{1{,}000 \times \ell}{L_e}\right)^2 - 1}} \qquad \text{(metric) } [16']$$

$$s = \frac{\pi(D-d)}{\sqrt{(\frac{12 \times \ell}{L_e})^2 - 1}} \qquad \text{(imperial) } [16']$$

When the pitch, s, is small relatively to coil diameter, D, and wire diameter, d.

Than $\frac{s}{\pi (D-d)} << L$, so that equation [16] can be simplified to:

$$s = \frac{\pi(D-d)L_e}{\ell} \qquad \text{mm (in)} \quad [17]$$

DEFINITION: Relative pitch, r

The ratio s/d is often used. It is called the relative pitch or the stretch factor, and may affect the heat dissipation from the coil.

$$r = \frac{s}{d} \qquad [18]$$

The ratio D/d is essential for the coiling operation, as well as the mechanical stability of the coil in a hot state.

FORMULAS FOR VALUES IN TABLES

In the chapter "Tables," the values for surface area, weight, and resistance of each material and dimension are calculated per meter. Additionally, cross-sectional area and area per ohm (Ω) are presented. The formulas below include unit corrections:

Metric units

Resistance per meter, $R_{20/m}$ Ω/m
Based on equation [1]

Wire

$$R_{20/m} = \frac{4\rho}{\pi d^2} \quad [1']$$

Strip

$$R_{20/m} = \frac{\rho}{bt} \quad [1']$$

Weight per meter, m_m g/m

$$m = \text{volume} \times \gamma = q\ell \times \gamma => m_m = q\gamma$$

Wire

$$m_m = \frac{\pi d^2 \gamma}{4} \quad [19]$$

Strip

$$m_m = bt\gamma \quad [19]$$

Surface area per meter, $A_{C/m}$ cm²/m
Based on equation [6] respectively [7]

Wire

$$A_{C/m} = 10 \times \pi d \quad [6']$$

Strip

$$A_{C/m} = 10 \times 2(b + t) \quad [7']$$

Cross sectional area, q mm²
Based on equation [11], [13] respectively [14]

Wire

$$q = \frac{\pi}{4} d^2 \quad [11']$$

Strip

$$q = bt \quad [13']$$

Surface area per Ω cm²/Ω
Combining [1'] and [6'] respectively [1'] and [7']

Wire

$$\eta = \frac{A_{C/m}}{R_{20/m}} = \frac{10 \times \pi d \times q}{\rho} = \frac{10 \times \pi^2 d^3}{4\rho}$$

Strip

$$\eta = \frac{A_{C/m}}{R_{20/m}} = \frac{10 \times 2(b + t) \times bt}{\rho} = \frac{20(b + t)bt}{\rho}$$

Other equations which could be helpful

Length per kilo, L_{kg} m/kg
Based on equation [19] → $L_{kg} = \frac{1{,}000}{m_m}$

Wire

$$L_{kg} = \frac{1{,}000 \times 4}{\pi d^2 \gamma} = \frac{4{,}000}{\pi d^2 \gamma} \quad [19']$$

Strip

$$L_{kg} = \frac{1{,}000}{bt\gamma} \quad [19']$$

Resistance per kilo, R_{kg} Ω/kg
Combining [1'] and [19]➔

$$R_{kg} = 1{,}000 \times \frac{R_{20/m}}{m_m} = 1{,}000 \times \frac{R}{q} \times \frac{1}{q\gamma} = \frac{1{,}000 \times R}{q^2 \gamma}$$

Wire

$$R_{kg} = \frac{1{,}000 \times \rho}{\left(\frac{\pi d^2}{4}\right)^2 \gamma} = \frac{16{,}000 \times \rho}{\pi^2 d^4 \gamma}$$

Strip

$$R_{kg} = \frac{1{,}000 \times \rho}{b^2 t^2 \gamma}$$

Relationship between metric and imperial units

1 Ω mm²/m (μΩm)		= 601.54 Ω/cmf
1 Ω mm²/m (μΩm)		= 472.44 Ω/smf
1 Ω/smf		= 1.2732 Ω/cmf
1 inch (in)	= 1000 mil	= 0.0254 m
1 foot (ft)	= 12 in	= 0.3048 m
1 mil	= 0.001 inch	= 0.0254 mm
1 W/cm²		= 6.45 W/in²
1 W/in²		= 0.155 W/cm²

Imperial units
ρ'_{wire} = Ω/cmf respectively
ρ''_{strip} = Ω/smf

Resistance per foot, $R_{20/ft}$ Ω/ft
Based on equation [1]

Wire

$$R_{20/ft} = \frac{\rho'}{10^6 \times d^2} \quad [1']$$

Strip

$$R_{20/ft} = \frac{\rho''}{10^6 \times bt} \quad [1']$$

Weight per foot, m_m lb/ft
m = volume · γ = q · l · γ → m_{ft} = q · γ

Wire

$$m = \text{volume} \times \gamma = q\ell \times \gamma \Rightarrow m_{ft} = q\gamma \quad [19']$$

Strip

$$m_{ft} = \frac{12 \times \pi d^2 \gamma}{4} = 3 \times \pi d^2 \gamma \quad [19']$$

Surface area per foot, $A_{C/ft}$ in²/ft
Based on equation [6] respectively [7]

Wire

$$A_{C/ft} = 12 \times \pi d \quad [6']$$

Strip

$$A_{C/ft} = 12 \times \pi d \quad [7']$$

Cross sectional area, q in²
Based on equation [11], [13] respectively [14]

Wire

$$q = \frac{\pi}{4} d^2 \quad [11']$$

Strip

$$q = bt \quad [13']$$

Surface area per Ω in²/Ω
Combining [1'] and [6'] respectively [1'] and [7']

Wire

$$\frac{A_{C/ft}}{R_{20/ft}} = \frac{12 \times 10^6 \times \pi d \times q}{\rho'} = \frac{3 \times 10^6 \times \pi^2 d^3}{\rho'}$$

Strip

$$\frac{A_{C/ft}}{R_{20/ft}} = \frac{12 \times 10^6 \times 2(b+t) \times bt}{\rho''} = \frac{24 \times 10^6 \times (b+t)bt}{\rho''}$$

Other equations which could be helpful

Length per pound, L_{lb} ft/lb
Based on equation [19] → $L_{lb} = \frac{1}{m_{ft}}$

Wire

$$L_{lb} = \frac{4}{12 \times \pi d^2 \gamma} = \frac{1}{3 \times \pi d^2 \gamma} \qquad [19']$$

Strip

$$L_{lb} = \frac{1}{12 \times bt\gamma} \qquad [19']$$

Resistance per pound, R_{lb} Ω/lb
Combining [1'] and [19]→

$$R_{lb} = \frac{R_{20/ft}}{m_{ft}} = \frac{\rho}{q \cdot q \cdot \gamma} = \frac{\rho}{q^2 \cdot \gamma}$$

Wire

$$R_{lb} = \frac{\rho'}{3 \times 10^6 \times \pi d^2 \times d^2 \gamma} = \frac{\rho'}{3 \times 10^6 \times \pi d^4 \gamma}$$

Strip

$$R_{lb} = \frac{\rho''}{12 \times 10^6 \times b^2 t^2 \gamma}$$