John Vincent
March 2012

Bus Bar Design

This document describes rule-of-thumb design laws for unconfined bus bars operating at or near dc conditions in open space. At higher frequencies the "skin effect" must be considered. In multiconductor systems (such as magnet coils) the "proximity effect" must be accounted for and the thermodynamics gets tougher. In modern power electronics based equipment switching at high frequency, all of these effects occurring simultaneously contribute to the conductor heating.

Theoretically it is possible to go into this subject in great depth and consider the surface emissivity, air properties and movement, radiation, convection, and conduction for different geometry's in differing orientations; **this is not the approach taken here**.

This note describes a practical rule-of-thumb for the conductor surface heat transfer limit and from it derives some useful design relationships. Experimentally, it is found that bus bars run near room temperature when the heat transfer is limited to 0.1 (Watts/in^2). The bus bars run hot when the heat transfer approaches 0.25 (Watts/in^2). (note: since the bus bar temperature is principally a function of the surface area, the best shape is a very thin ribbon whereas the worst shape is cylindrical as are all wires!). Using this empirical knowledge, rule-of-thumb design relationships can be established.

1. **(Power Lost)/(Unit Length) in (Watts/cm)**

$$\boldsymbol{P_l = \frac{I_o^2 \rho}{A_c}}$$

where;

$\boldsymbol{\rho}$: resistivity in (Ohms*cm), A_c: Conductor crossectional area in cm^2, I_o: Amperes

2. **(Heat Transfer)/(Unit Area) in (Watts/cm^2)**

$$Q_A = \frac{P_l}{A_s} = \frac{I_o^2 \rho}{A_c A_s}$$

where;

A_s: conductor surface area in (cm^2/unit length)

3. Rules-of-Thumb boundary conditions for heat transfer limits

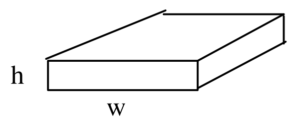
$$0.1 \le Q_A \le 0.25 \quad \text{expressed in Watts/in}^2$$

$$0.015 \le Q_A \le 0.04 \quad \text{expressed in Watts/cm}^2$$

cool → hot

$$A_c A_s = \frac{I_o^2 \rho}{Q_A} \quad \text{with } Q_A \text{ expressed in Watts/cm}^2$$

4. Rectangular Bus Bar



$$A_c A_s = 2(w+h)(wh)$$

hence:

$$w = -\frac{h}{4} + \sqrt{\left(\frac{h}{4}\right)^2 + \frac{A_c A_s}{2h}} \quad \text{with h constant}$$

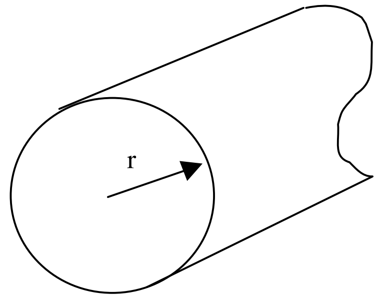
or

$$h = -\frac{w}{4} + \sqrt{\left(\frac{w}{4}\right)^2 + \frac{A_c A_s}{2h}} \quad \text{with w constant}$$

if w >>h as is typical then:

$$w = \sqrt{\frac{A_c A_s}{2h}}$$

5. Cylindrical Bus (like wire)



$$A_c A_s = \pi r^2 * 2\pi r = 2\pi^2 r^3$$

hence:

$$r = \left(\frac{A_c A_s}{2\pi^2}\right)^{\frac{1}{3}}$$

6. Test against known values

The following table illustrates the use of this formulation versus NEC data for confined and unconfined cables rated at 90 degrees Celcius.