# The heating of conductors, insulated conductors, pairs and cables and bundled cables in multiple layers due to constant current sources

**Dr.- Ing. J.- H. (Jo) Walling**
Consultant
431 Church, Beaconsfield, QC, H9W 3R9, Canada
(514) 695-8220 or (514) 695-6063
Fax: (514) 695-8220
Email : jo.walling@sympatico.ca

Program to calculate the current carrying capacity of the components listed in the title. For simplicity purposes all the pairs are assumed to be equal in their longitudinal resistance, irrespective of the twist lay of each pair and the there out resulting helix loss. This approximation is justified, as high performance data grade cables have slightly different conductor diameters, in oder to compensate for the impedance and the attenuation due to the short twist lays.

Considered are also 6 around 1; 18 around one and 36 around 1 configurations. In these cases the ambient temperature of the innermost cable is determined in a very good approximation by the jacket surface temperature of the outer surfaces of the surrounding cables, under the assumption that all pairs in all cables are energized with the same current.

Previously [2] a heating trial has been described using a cable coil, partially bundled on one side and having the cables individualized on the other side. Under these conditions it can be assume that on one side the heat dissipation is less than approximately 25 % , whereas on the other side it could be assumed to be close to 100% due to the radiated and convected heat. It should be mentioned, however, that this is a very time consuming method and is therefore not pursued here any further.

The cable for this trial was a simple Cat. 5 cable with conductors of 0.526 mm diameter and a FEP insulation of 0.182 mm wall thickness. The PVC jacket had a wall thickness of 0.356 mm and a diameter of 5.775 mm. The ambient temperature was 23 deg. C and the temperature at the surface of the innermost cable jacket, in the bundled section of the coil was 49 deg. C. In the individualized cable section of the coil the temperature increase was 40 deg. C. The cables were powered with a constant current source such that each conductor carried a current of 0.75 A. This trial clearly demonstrated that the initial power rating of 0.75 A of ISO/IEC 11801 was too high, a fact which had been recognized and as a result the maximum current has been consequently reduced to 0.175 A.

The following calculations follow a simplified program published by Steve Meyer [1] for hook-up wires. But the method used here is to all practical purposes the same as the classic method to calculate the ampacity of power cables, and it has been presented, though limited to pairs to ISO/IEC JTC1 WG3 [2]. It went from there over a liaison to IEEE.

Note: Temperature rating of cables is done according to maximum conductor surface temperature. It is frequently, but falsely assumed that the temperature rating is done according to ambient temperature. That is not the case as the maximum temperature to which the insulation is exposed to is the conductor temperature at the interface ! It is this temperature to which cables are rated

**CONSTANTS :**

| | | |
|---|---|---|
| Stefan Boltzmann constant: | $k := 5.67 \cdot 10^{-12}$ | [W/(cm^2*deg.K^4)] |
| Conversion constant: | $aa := 5.6 \cdot 10^{-4}$ | [1/(cm^-2*deg.K^-4)] |

**INPUT :** (Required inputs are in the following marked bold in blue)

| | | |
|---|---|---|
| **Relative emissivity of the insulation surface:** | $Ei := 0.82$ | [ - ] |
| **Relative emissivity of the jacket surface:** | $Ej := 0.78$ | [ - ] |

Note that the emissivity of plastic material may vary, but is generally in the range of 0.75 to 0.85 !

| | | |
|---|---|---|
| **Enter conductor diameter:** | $d := 0.051054$ | [cm] |
| **Enter insulation thickness:** | $w := 0.0172$ | [cm] |
| **Enter maximum conductor temperature:** | $tc := 75$ | [deg. C] |
| **Point to point distance of the ambient temperature:** | $\Delta P := 0.01$ | [deg. C] |
| **Maximum ambient temperature:** | $tamax := tc - 0.000001$ | [deg. C] |
| **Enter minimum ambient temperature (tamax < tc !):** | $tamin := 55$ | [deg. C] |
| **Resistivity:** | $\rho := 17.4 \cdot 10^{-7}$ | [Ω*cm] |
| **Temperature coefficient of resistance:** | $\alpha := 0.00393$ | [1/deg. C] |
| **Thermal conductivity of the insulation material:** | $\kappa ins := 0.00204$ | [W/(cm*deg. K)] |
| **Thermal conductivity of the jacket material:** | $\kappa jack := 0.001064$ | [W/(cm*deg. K)] |

Note: Select the thermal conductivity of the insulation / jacketing material from the Table 1 below :

| | | |
|---|---|---|
| **Jacket OD:** | $DD := 0.648$ | [cm] |
| **Jacket wall thickness:** | $wj := 0.0535$ | [cm] |

**Table 1**

| Material | Heat Conductivity [ W / cm*deg C (or K)] | | Material | Heat Conductivity [ W / cm*deg C (or K)] | |
|---|---|---|---|---|---|
| | Minimum | Maximum | | Minimum | Maximum |
| PVC | 0.0010490 | 0.0010782 | Nylon 4/6 | 0.0029140 | 0.0033511 |
| FEP | 0.0020398 | | Nylon 6 | 0.0027829 | 0.0043419 |
| PTFE | 0.0024769 | 0.0035259 | Nylon 6/6 | 0.0020981 | 0.0024623 |
| PVDF | 0.0010199 | 0.0012822 | Nylon 6/10 | 0.0022292 | 0.0052452 |
| PCTFE | 0.0014570 | - | Nylon 11 | 0.0034968 | 0.0043710 |
| ETFE | 0.0024769 | 0.0024769 | Nylon 6/12 | 0.0021855 | - |
| ECTFE | 0.0016027 | - | Nylon 12 | 0.0025935 | 0.0030306 |
| PP | 0.0011802 | 0.0056532 | PPO | 0.0012093 | 0.0025206 |
| PE | 0.0027829 | 0.0043419 | PET (Mylar) | 0.0014716 | 0.0020398 |
| Polyimide | 0.0012093 | - | | | |

Maximum number of points calculated: $mm := \frac{(tc - tamin)}{\Delta P}$ [ - ]

Points to be calculated: $m := 0 .. mm$ [ - ]

Ambient temperature: $ta_m := tamin + m \cdot \Delta P$ [deg. C]

Diameter of the insulated wire: $D := d + 2 \cdot w$ [cm]

Jacket wall thickness : $dd := DD - 2 \cdot wj$ [cm]

Note : The jacket ID is generally for data grade cables larger than the value calculated according to the Fig. 9 below. These would result in an inside jacket diameter z of:

$z := D \cdot \left(3 + \sqrt{2}\right)$ [cm]

$z = 0.377$ [cm]

At same jacket wall thickness this would result in substantially lower overall diameters, and hence also in an increased heating or reduced current carrying capacity as the heat dissipation would be substantially reduced.

Ambient temperature [deg. K] : $TA_m := ta_m + 273.19$ [deg. K]

Conductor temperature [deg. K] : $TC := tc + 273.19$ [deg. K]

## 0. Isulation and / or jacket surface temperature calculation:

Function for the surface temperature: $F(x,m,a,b,c,e) := \left[a\cdot\left(x - TA_m\right)^{1.25} + b\cdot x^4 + c\cdot x - e_m\right]$ [deg. K]

Differential of the function of the surface temperature : $f(x,m,a,b,c) := \left[1.25\cdot a\cdot\left(x - TA_m\right)^{0.25} + 4\cdot b\cdot x^3 + c\right]$ [ - ]

Calculation of the unknown insulation and / or jacket surface temperature [deg. K], using a Newton approximation :

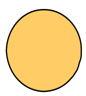
$$
FT(m, D1, d1, E1, \mu, \eta, \delta, \kappa) := \left|
\begin{array}{l}
x1 \leftarrow TA_m \\
x2 \leftarrow TC \\
a \leftarrow aa\cdot\sqrt{\eta\cdot D1}\cdot\ln\left(\delta\cdot\dfrac{D1}{d1}\right) \\
b \leftarrow \mu\cdot\eta\cdot k\cdot D1\cdot E1\cdot\ln\left(\delta\cdot\dfrac{D1}{d1}\right) \\
c \leftarrow 2\cdot\kappa\cdot\delta \\
e_m \leftarrow c\cdot TC + b\cdot\left(TA_m\right)^4 \\
xx \leftarrow \dfrac{(x1 + x2)}{1.8} \\
\text{while } \left|\dfrac{F(xx,m,a,b,c,e)}{f(xx,m,a,b,c)}\right| > .5\cdot 10^{-10} \\
\quad \left|
\begin{array}{l}
x \leftarrow xx \\
z \leftarrow x - \dfrac{F(x,m,a,b,c,e)}{f(x,m,a,b,c)} \\
x1 \leftarrow \text{if}\left[(F(x,m,a,b,c,e) < 0), x, x1\right] \\
x2 \leftarrow \text{if}\left[(F(x,m,a,b,c,e) > 0), x, x2\right] \\
xx \leftarrow \dfrac{x1 + x2}{2}
\end{array}
\right. \\
xx
\end{array}
\right.
$$

Heat transfer through the insulation / jacket: $q(m, \kappa, \delta, D1, d1, TS) := 2 \cdot \kappa \cdot \delta \cdot \pi \cdot \frac{(TC - TS_m)}{\ln\left(\delta \cdot \frac{D1}{d1}\right)}$ [W/cm]

Resistance: $R(A) := \rho \cdot \frac{(1 + \alpha \cdot tc)}{A \cdot 10^{-4}}$ [Ω / 100 m]

## 1. Individual insulated conductor:

The conditions for a straight conductor are trivial, and therefore not treated here.



The insulated conductor is in close in contact to the insulation. This interface temperature between the conductor and the insulation is the basis for any temperature rating of cables.

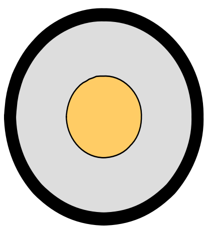


**Figure 1**

Hence the heat dissipation of the insulated conductor and with it its current carrying capacity depends on the heat conductivity of the insulating material. The heat dissipation at the surface of the insulated conductor depends on the convection and radiation. This is calculated in the following for a single insulated conductor. Please note that the conditions, defined for the conductor will be maintained throughout the entire program, i.e. for pairs, cables and bundled cables ! The heat conduction between the bundled or loomed cables is ignored, as it is under thermal equilibrium condictions very small due to the line contact, and can, therefore be neglected.

Cross-section of conductor: $Acon := \pi \cdot \left(\frac{d}{2}\right)^2$ [cm^2]

Temperature at the insulation and / or jacket surface: $TS_m := FT(m, D, d, Ei, 1, 1, 1, \kappa ins)$ [deg. K]

Heat transfer through the insulation: $QT_m := q(m, \kappa ins, 1, D, d, TS)$ [W/cm]

Current heating the conductor: $Icond_m := 100 \sqrt{\frac{QT_m}{R(Acon)}}$ [ A ]

Correction for last point: $Icond_{mm} := 0$ [ A ]

Total dissipated energy: $Lcond_m := (Icond_m)^2 \cdot R(Acon)$ [ W/100 m ]

Correction for last point: $Lcond_{mm} := 0$ [ W/100 m ]

## 2. Insulated pair:

For a pair of insulated conductors - the same as previously calculated - the following approximations are used which yield maximum current transfer. In fasct they neglect some generated heat, which will have to be taken otherwise into account. In fact they would result in an additional heating of the conductors and would require an increased heat dissipation into the environment.

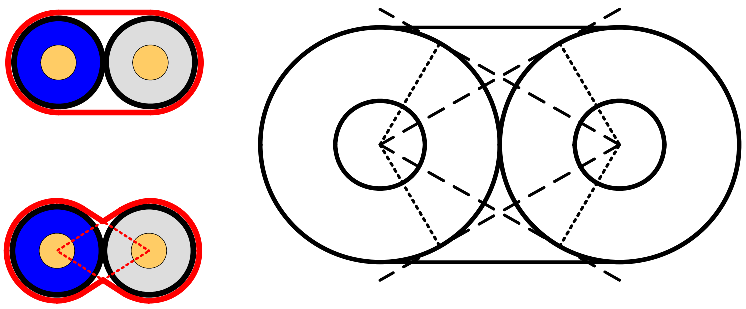


**Figure 2**

Relative circumference for radiation: $\mu := \frac{5}{3}$ [ - ]

Relative circumference: $\eta := \sqrt{\frac{\pi + 4}{\pi}}$ [ - ]

Equivalent relative circumference ratio: $\delta := \frac{\pi + 2}{\pi}$ [ - ]

Cross section of the conductors of the pair: $\text{Apair} := 2 \cdot \text{Acon}$ [cm^2]

The convection is approximated by the combined assumption of an oval and / or an equivalent logarithmic ratio of the equivalent diameters of an insulated conductor to an equivalent conductor diameter.

The radiation is calculated taking the reduction of the radiating part of the circumference into account, where the wires heat themselves mutually by radiation. However, this part, contributing the heat increase of the insulated conductor is here neglected as it is negligibly small especially under thermal equilibrium conditions. Hence we have :

Temperature at the wire insulation surface: $TS_m := FT(m, D, d, Ei, \mu, \eta, \delta, \kappa ins)$ [deg. K]

Heat transfer through the insulation: $QT_m := q(m, \kappa ins, \delta, D, d, TS)$ [W/cm]

Current heating each conductor: $\text{Ipair}_m := \frac{100}{2}\sqrt{\frac{QT_m}{R(\text{Apair})}}$ [ A ]

Correction for last point: $\text{Ipair}_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $\text{Lpair}_m := 2 \cdot \left(\text{Ipair}_m\right)^2 \cdot R(\text{Apair})$ [ W/100 m ]

Correction for last point: $\text{Lpair}_{mm} := 0$ [ W/100 m ]

## 3. Four insulated pairs contained in a jacket :

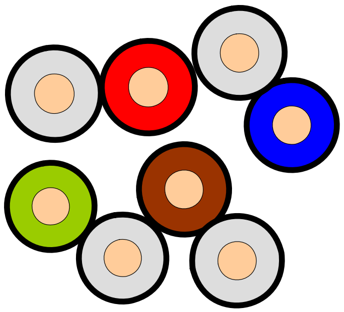


**Figure 4**

"Random" configuration of the four pairs of a cable core of a data grade cable. Such a core has a very good heat dissipation potential.

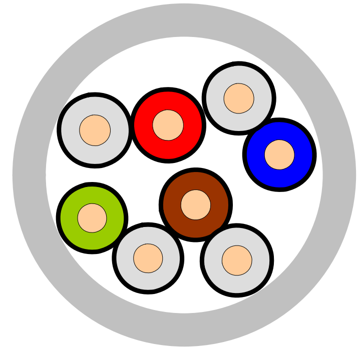


**Figure 5**

The same cable core of four pairs encapsulated in a cable jacket. At thermal equilibrium the dissipation is not so good as for the pair, hence the heat carrying capacity per conductor decreases.

Arrangement of the four pairs for calculation purposes is shown in Fig. 9. The mutual heating of the pairs in the center is neglected.

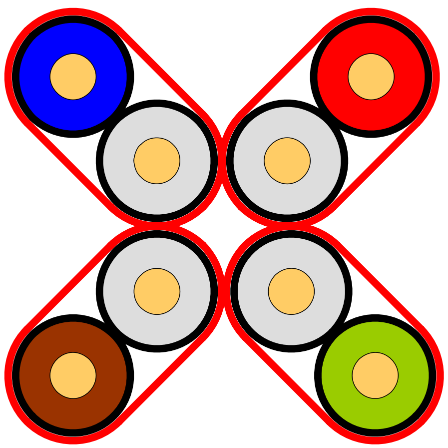


**Figure 6**

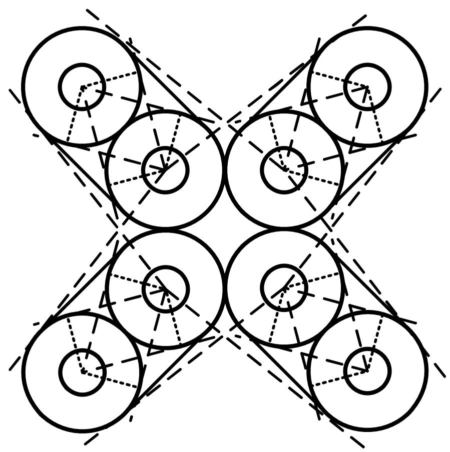


**Figure 7**

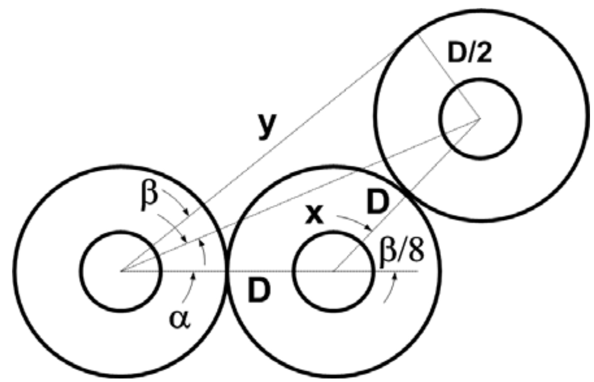



**Figure 8:** Geometry to calculate the heat transfer by radiation using the equivalent relative radiating circumference

Relative circumference for radiation:

$$\mu := \left[\frac{19}{3} - \frac{\left(8 \cdot \operatorname{atan}\left(\frac{1}{\sqrt{7 + 4 \cdot \sqrt{2}}}\right)\right)}{\pi}\right] \qquad [\ -\ ]$$

Relative circumference:

$$\eta := \sqrt{\frac{5\pi + 12}{\pi}} \qquad [\ -\ ]$$

Equivalent relative circumference ratio: $\delta := 7\cdot\frac{\pi + 2}{\pi}$ [ - ]

The temperature of the cable is calculated in two steps, first the temperature increase of the pairs, forming the cable core. With the generated heat the dissipation through a round jacket is calculated.

Cross section of all conductors in cable : $Acore := 4\cdot Apair$ [ cm^2]

Temperature at the insulation surface: $TS_m := FT(m, D, d, Ei, \mu, \eta, \delta, \kappa ins)$ [deg. K]

Heat transfer through the insulation: $QT_m := q(m, \kappa ins, \delta, D, d, TS)$ [W/cm]

Current heating each conductor: $Icore_m := \frac{100}{8}\sqrt{\frac{QT_m}{R(Acore)}}$ [ A ]

Correction for last point: $Icore_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $Lcore_m := 8\cdot(Icore_m)^2\cdot R(Acore)$ [ W/100 m ]

Correction for last point: $Lcore_{mm} := 0$ [ W/100 m ]

## 4. Four insulated pairs encapsulated in a jacket :

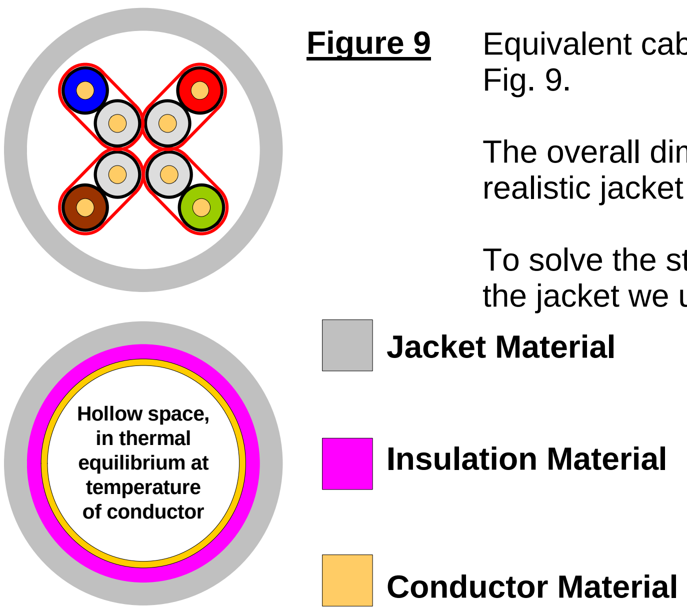



**Figure 9** Equivalent cable model: As model for the assembled cable we use the model shown in Fig. 9.

The overall dimensions of the jacket according to the sketch are much smaller than the realistic jacket dimension. Here we use the real jacket dimensions.

To solve the steady state heat transfer problem to find temperature on the surface of the jacket we use an equivalent conductor model as indicated in the lower part of Fig. 9.

Composite thermal conductivity $\kappa := \dfrac{\left[dd - \sqrt{dd^2 - 7\cdot(D^2 - d^2)}\right]\cdot\kappa ins + wj\cdot\kappa jack}{wj + dd - \sqrt{dd^2 - 7\cdot(D^2 - d^2)}}$ [ - ]

Cross-section of all conductors in configuration: $Acab := Acore$ [cm^2]

Temperature at the insulation / cable surface: $TS_m := FT(m, DD, dd, Ej, 1, 1, 1, \kappa)$ [deg. K]

Heat transfer through the insulation and the jacket: $QT_m := q(m, \kappa, 1, DD, dd, TS)$ [W/cm]

Current heating each conductor : $Icable_m := \frac{100}{8}\sqrt{\frac{QT_m}{R(Acab)}}$ [ A ]

Correction for last point : $Icable_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $Lcable_m := 8\cdot(Icable_m)^2\cdot R(Acab)$ [ W/100 m ]

Correction for last point : $Lcable_{mm} := 0$ [ W/100 m ]

Note that the dissipated heat from the entire cable is lower than the heat dissipated from the cable core. This is to be expected as a result of the core configuration, which allows a very good dissipation, and allows as a result a substantially higher current, than would occur in the comparable cable. This difference is in fact even increaseded if we take the inside diameter of the jacket equal to the outside diameter of the "optimal cable" core according to Fig. 9, while maintaining the total amount of jacketing material, as shown in the following.

## 5. Four insulated pairs encapsulated in the smallest possible size jacket :

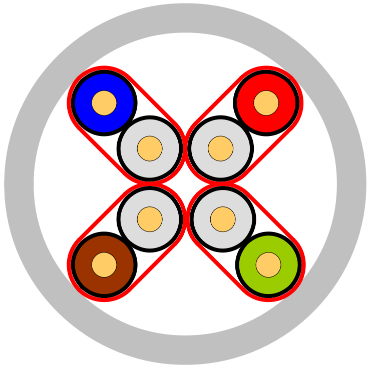


**Figure 10**

The model used to calculate the heat dissipation is the same as in Fig. 14 while only the jacket inside diameter is reduced to their minimal size while the jacket wall thickness is increased to reflect the same amount of jakcet material as before.

$dz := z$ [cm]

$Dz := \sqrt{DD^2 + z^2 - dd^2}$ [cm]

Composite thermal conductivity:

$$\kappa := \frac{\left[z - \sqrt{z^2 - 7\cdot(D^2 - d^2)}\right]\cdot\kappa ins + \left(\sqrt{DD^2 + z^2 - dd^2} - z\right)\cdot\kappa jack}{\sqrt{DD^2 + z^2 - dd^2} - \sqrt{z^2 - 7\cdot(D^2 - d^2)}}$$ [ - ]

Temperature at the cable jacket surface: $TS_m := FT(m, Dz, dz, Ej, 1, 1, 1, \kappa)$ [deg. K]

Heat transfer through the insulation and the jacket: $QT_m := q(m, \kappa, 1, Dz, dz, TS)$ [W/cm]

Current heating each conductor: $Icmin_m := \frac{100}{8}\sqrt{\frac{QT_m}{R(Acab)}}$ [ A ]

Correction for last point: $Icmin_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $Lcmin_m := 8 \cdot (Icmin_m)^2 \cdot R(Acab)$ [ W/100 m ]

Correction for last point: $Lcmin_{mm} := 0$ [ W/100 m ]

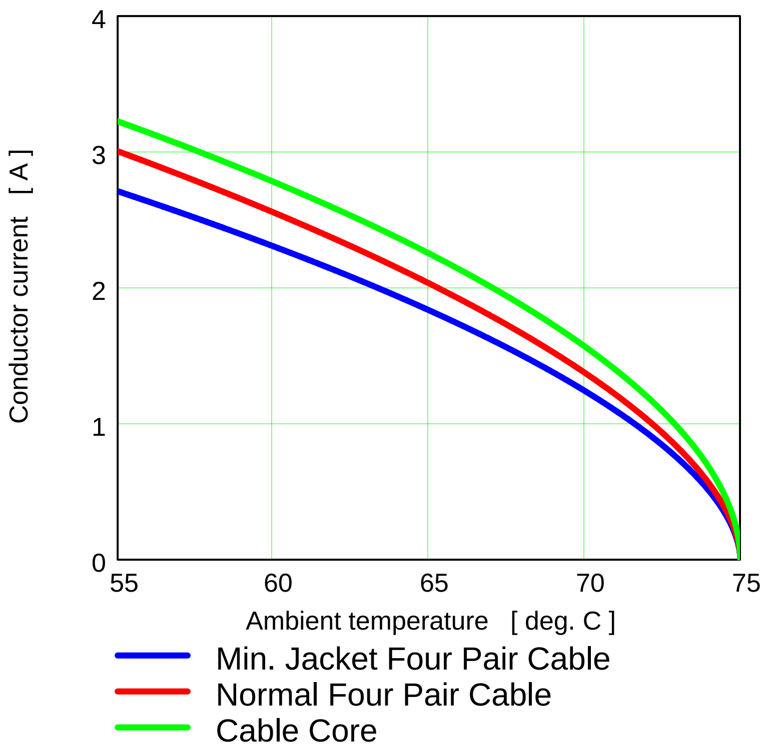



**Figure 11:** Maximum current per conductor

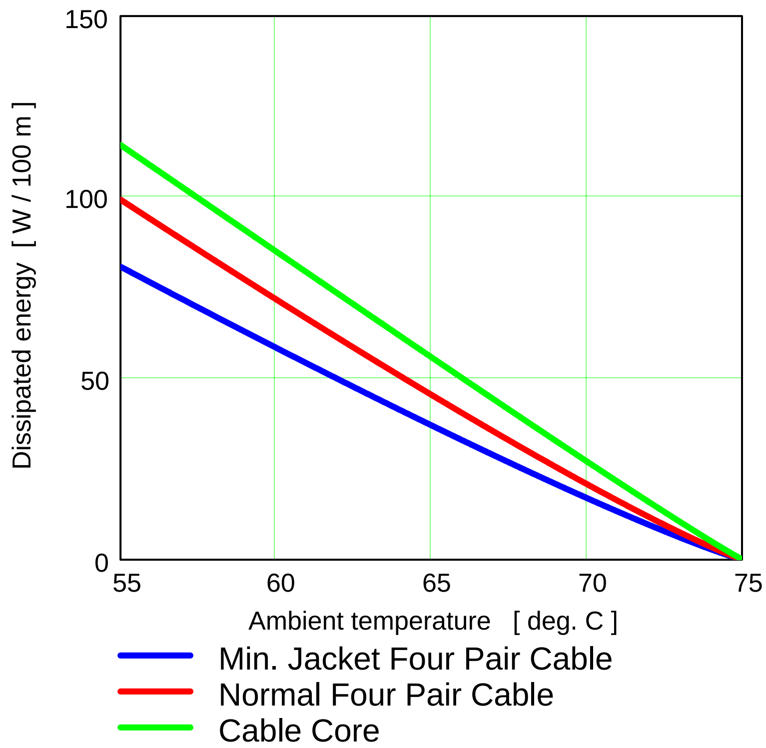



**Figure 12:** Energy to be dissipated per conductor

## 6. Bundled cable configurations:

Bundled or loomed cable configuration may be found frequently. They find their equivalent in harnessed cable bundles as may be found nearly in and in the proximity of every equipment room. There space limitations and the ambition of the installers to accomplish a nice looking job results in tightly bundled cables, which are generally ty-wrapped. This of course is counterproductive for the heat dissipation.

For the solution of any heat dissipation problem for such bundled cables one has to consider the simplest and densest structures. These are, in fact hexagonal structures as depicted in the Fig. 13. From a current carrying point of view it is also advisable to use, for simplification purposes of the calculations structures where all cables are energized. The Fig. 13 indicates structures where the cables are subject to current loading from the inside to the outside in layers. Such an approach has to be used to determine more precisely the thermodynamic behavior of the cables from a combined heat conduction, convection and radiation point of view.

Hence the approach to energize with the same current loading every cable is used here, under the additional assumption that all cables inside the bundle have the same conductor surface temperature. This assumption is definitely lenient, as it attenuates the relatively high temperature of the inner layer, especially of the center cable, while increasing only very slightly the temperature in the outer layer.

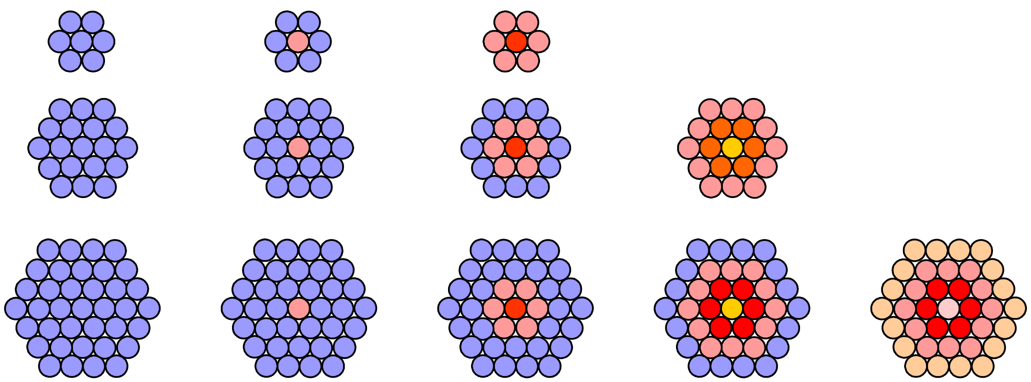


**Figure 13**

To follow through with such an approach has to be based upon a large number of trials. It is very time consuming, requires a huge amount of cables and is in fact from a cost point of view prohibitive.

That is true even for bundles of cables, where the peripheral number of cables exceeds those of the contained cables. It is estimated that this approach is valid up to an integer ratio of approximaly 1 : 1 (r=1) of contained to peripheral cables. We get:

$$N(X) := 1 + 6\cdot\sum_{l=0}^{X} l \qquad M(X) := 1 + 6\cdot\sum_{l=0}^{X-1} l \qquad i := 1..50$$

$$Y(X) := \mathrm{round}\left(\frac{M(X)}{N(X) - M(X)}\right)$$

**Ratio of contained cables to peripherally surrounding cables:** $r := 1$ $r > 0$ and integer

Note: it is left to the daring user to increase eventually this ratio

$A_i := |Y(i) - r|$

$$C := \left| \begin{array}{l} \text{for } k \in 50..1 \\ \quad \left| \begin{array}{l} x \leftarrow A_k \\ \text{break if } A_k = 0 \\ k \end{array} \right. \\ k \end{array} \right.$$

That means up to a cable bundle with $N := N(C)$

$N = 37$ Cables we may expect that the derivations presented here will hold nicely.

Note: At the end of this contribution the procedure to be followed is line out if the conductor surface of the innermost cable has to be limited to the maximum permissible conductor surface temperature, while the conductor temperatures of the surrounding cables have a lower conductor surface temperature due to better dissipation.

## 7. Six around one cable configuration :

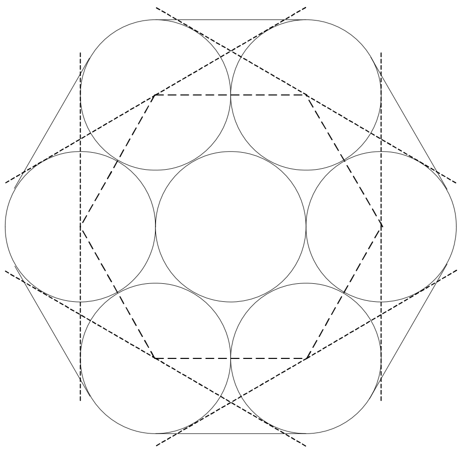


**Figure 14**

In a the six around one cable configuration all cables are subject to the same current loading. The treatment is straight forward and follows the schematics applied to the cable core. However, it has to be noted here that in this case the bundling or looming of the cables yields a very poor heat dissipation potential. Therefore, for simplicity reasons and as mentioned above, it is assumed that the cable in the center has the same "conductor surface temperature" as the surrounding cables. This would yield too optimistic results, especially with respect to the central cable. The central cable dissipates its internally generated heat exclusively through the surrounding cables, which in turn are themselves heated.
Therefore, the current is additionally downrated by a factor of 0.75 per cable layer.

Relative circumference for radiation: $\mu := 3$ [ - ]

Relative circumference: $\eta := \sqrt{\dfrac{\pi + 12 + 2\cdot\sqrt{3}}{\pi}}$ [ - ]

Equivalent relative circumference ratio: $\delta := \dfrac{\pi + 6}{\pi}$ [ - ]

Composite thermal conductivity of insulation and jacket: $\kappa := \frac{\left[dd - \sqrt{dd^2 - 7\cdot(D^2 - d^2)}\right]\cdot\kappa ins + wj\cdot\kappa jack}{wj + dd - \sqrt{dd^2 - 7\cdot(D^2 - d^2)}}$ [ - ]

Temperature at the outer cable jacket surfaces: $TS_m := FT(m, DD, dd, Ej, \mu, \eta, \delta, \kappa)$ [deg. K]

Cross section of all conductors: $Acab61 := 7\cdot Acab$ [ cm^2]

Heat transfer through the outer jackets: $QT_m := q(m, \kappa, \delta, DD, dd, TS)$ [W/cm]

Current heating each conductor: $Icab61_m := \frac{75}{56}\sqrt{\frac{QT_m}{R(Acab61)}}$ [ A ]

Correction for last point : $Icab61_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $Lcab61_m := 56\cdot(Icab61_m)^2\cdot R(Acab61)$ [ W/100 m ]

Correction for last point : $Lcab61_{mm} := 0$ [ W/100 m ]

## 7. Eighteen around one cable configuration :

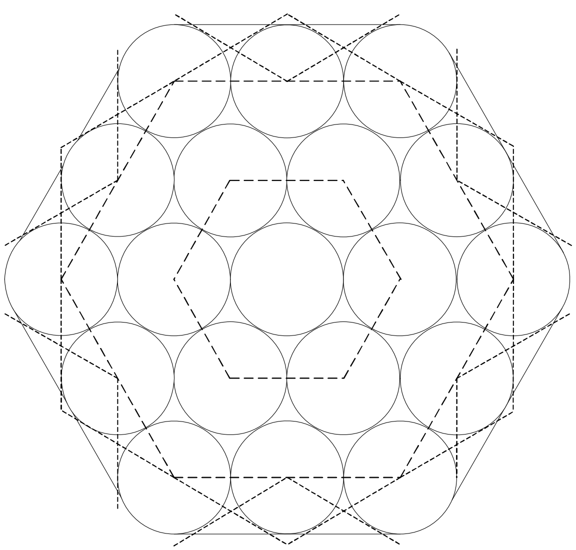


**Figure 15**

In the Fig. 15 are indicated the geometries which will have to be followed for the calculation. We get:

Relative circumference for radiation: $\mu := 5$ [ - ]

Relative circumference: $\eta := \sqrt{\frac{\pi + 24 + 12\cdot\sqrt{3}}{\pi}}$ [ - ]

Equivalent relative circumference ratio: $\delta := \frac{\pi + 12}{\pi}$ [ - ]

Cross section of all conductors: $Acab181 := 19\cdot Acab$ [ cm^2 ]

Temperature at the outer cable jacket surface: $TS_m := FT(m, DD, dd, Ej, \mu, \eta, \delta, \kappa)$ [deg. K]

Heat transfer through the outer jackets: $QT_m := q(m, \kappa, \delta, DD, dd, TS)$ [W/cm]

Current heating each conductor : $Icab181_m := \frac{56.25}{152}\sqrt{\frac{QT_m}{R(Acab181)}}$ [ A ]

Correction for last point : $Icab181_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $Lcab181_m := 152\cdot(Icab181_m)^2\cdot R(Acab181)$ [ W/100 m ]

Correction for last point : $Lcab181_{mm} := 0$ [ W/100 m ]

## 8. Thirty-six around one cable configuration :

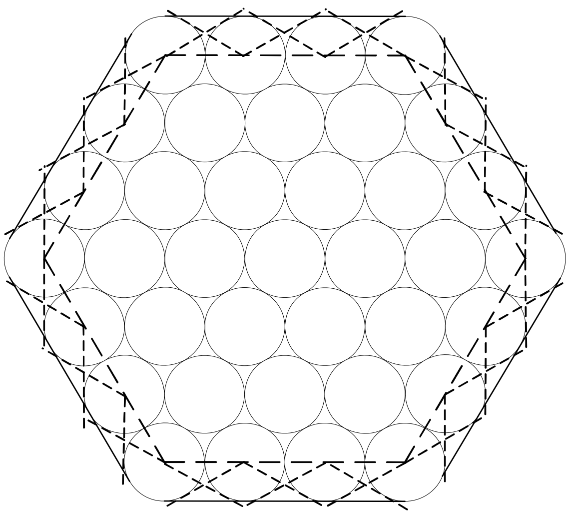


**Figure 16**

The treatment of the 36 around 1 configuration is straight forward and follows the schematics applied to the 6 around 1 configuration.

In the Fig. 16 are indicated the geometries which will have to be followed for the calculation. We get:

Relative circumference for radiation: $\mu := 7$ [ - ]

Relative circumference: $\eta := \sqrt{\frac{\pi + 36 + 27\cdot\sqrt{3}}{\pi}}$ [ - ]

Equivalent relative circumference ratio: $\delta := \frac{\pi + 18}{\pi}$ [ - ]

Temperature at the wire jacket surface : $TS_m := FT(m, DD, dd, Ej, \mu, \eta, \delta, \kappa)$ [deg. K]

Cross section of all conductors: $Acab361 := 37\cdot Acab$ [ cm^2]

Heat transfer through the outer jackets : $QT_m := q(m, \kappa, \delta, DD, dd, TS)$ [W/cm]

Current heating each conductor : $Icab361_m := \frac{42.1875}{296}\sqrt{\frac{QT_m}{R(Acab361)}}$ [ A ]

Correction for last point : $Icab361_{mm} := 0$ [ A ]

Total dissipated energy per conductor: $Lcab361_m := 296\cdot\left(Icab361_m\right)^2\cdot R(Acab361)$ [ W/100 m ]

Correction for last point : $Lcab361_{mm} := 0$ [ W/100 m ]

## 9. COMPILED RESULTS RELATIVE TO ONE CONDUCTOR :

Current limit according to ISO/IEC 11801 [ A ]: $CLimit_m := 0.175$

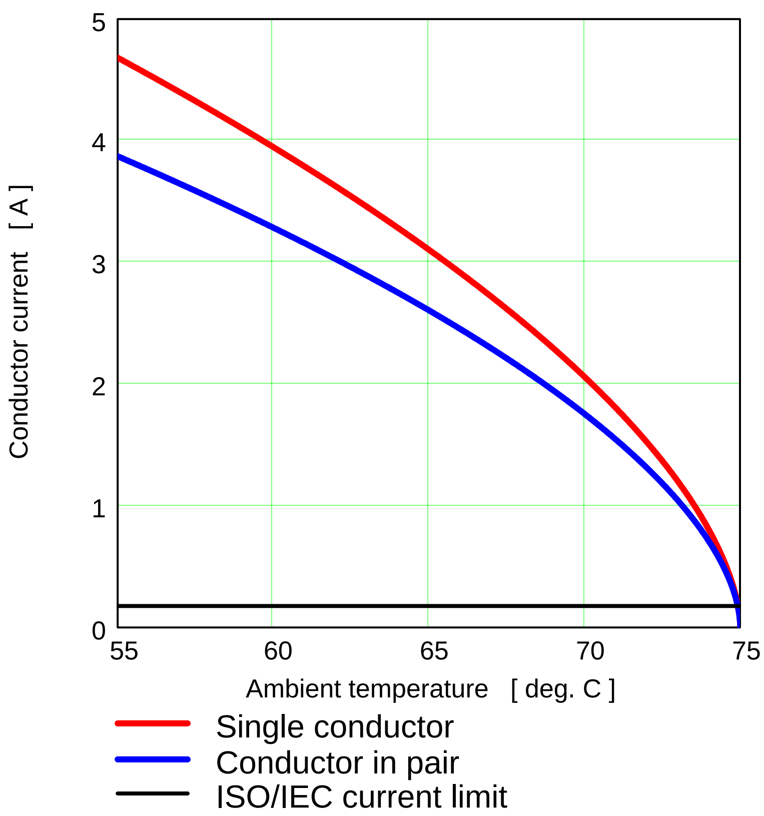



**Figure 17:** Maximum current per conductor

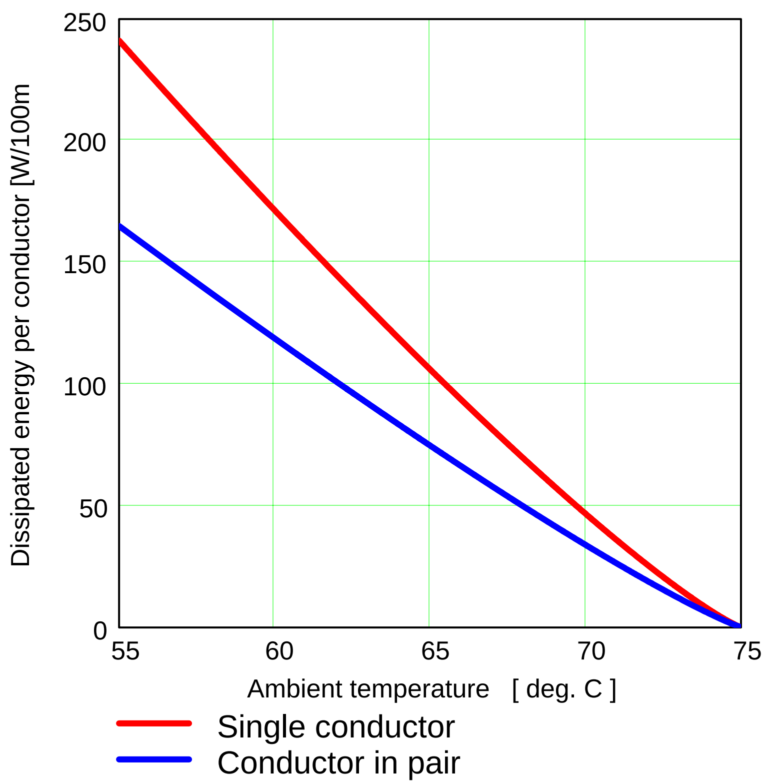



**Figure 18:** Energy to be dissipated per conductor

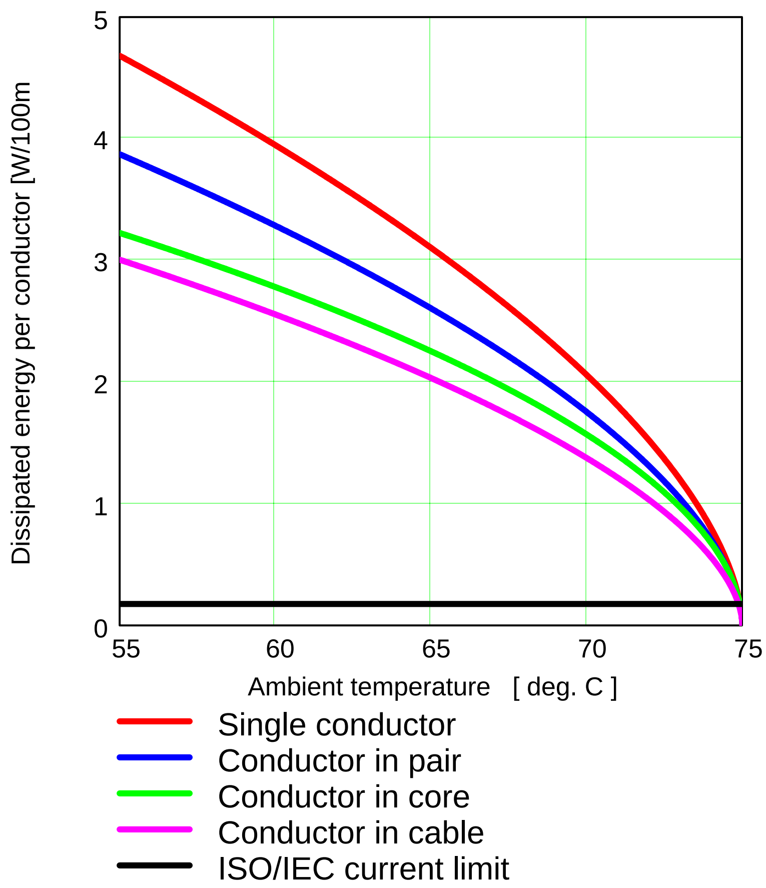



**Figure 19:** Maximum current per conductor

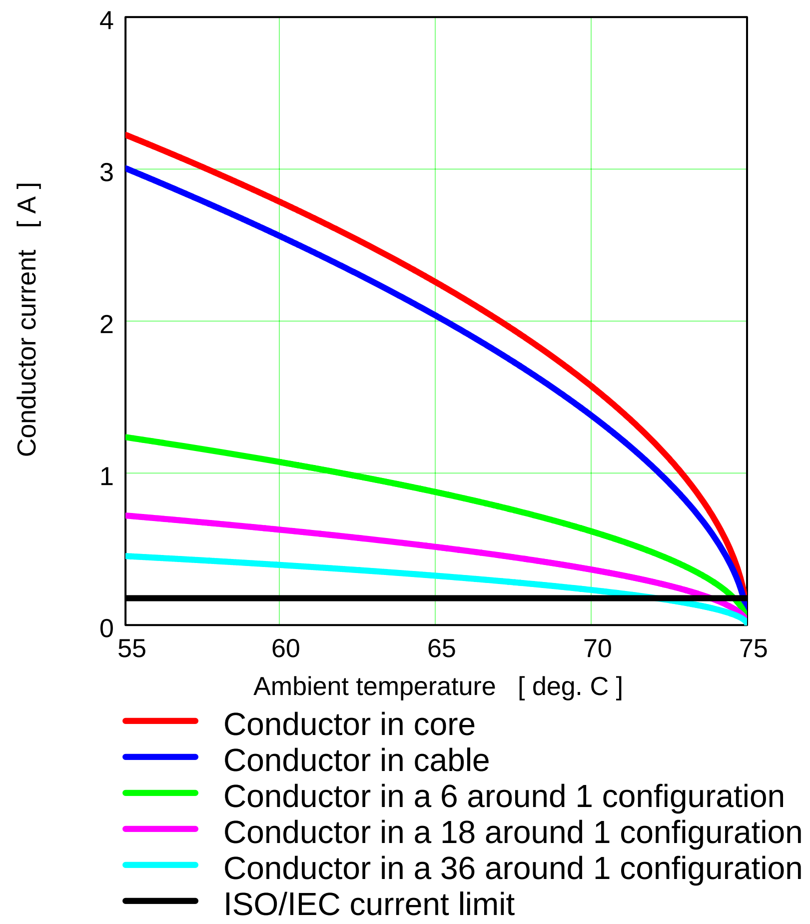



**Figure 20:** Maximum current per conductor

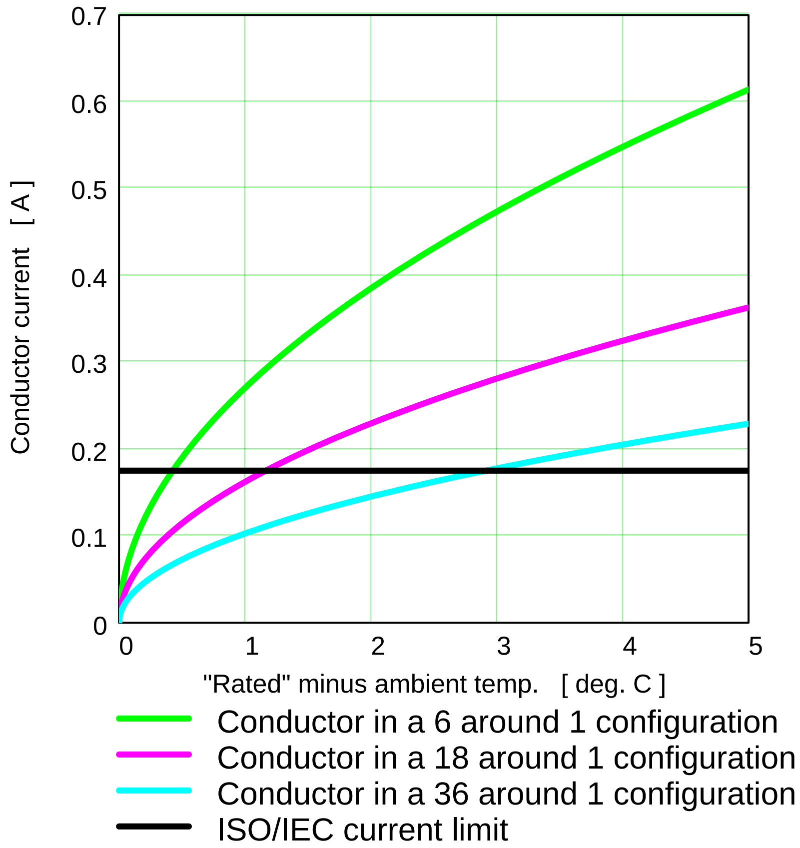



**Figure 21:** Maximum current per conductor

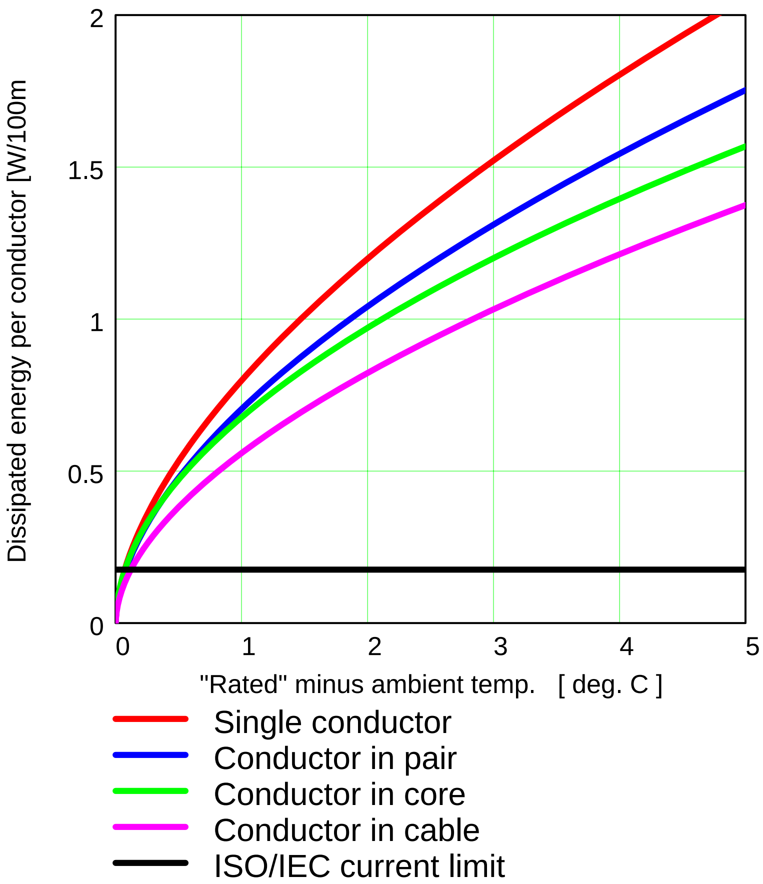
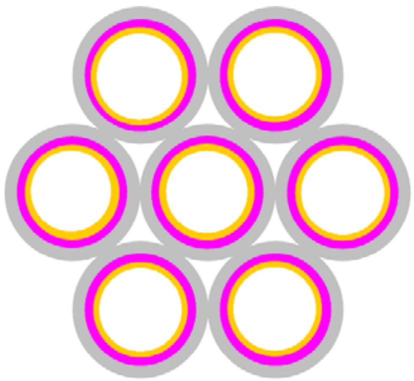



**Figure 22:** Maximum current per conductor

## 10. Indications about the comprehensive solution of the presented problem:



**Jacket Material**

**Insulation Material**

**Conductor Material**

**Center cable or layer**

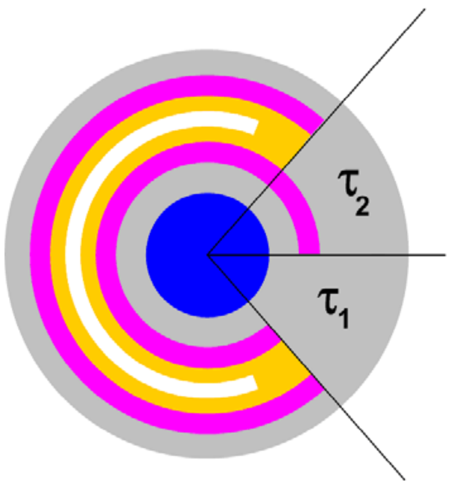



**Figure 23**

$\tau_1$ Proportion of diameter of heat transfer through the insulation of the conductors of the first layer and the jacket material to the jacket surfaces of the outer cables of the first layer

$\tau_2$ Proportion of diameter of direct heat transfer from the inner cable or bundle through the jacket material to the jacket surfaces of the outer cables of the first layer

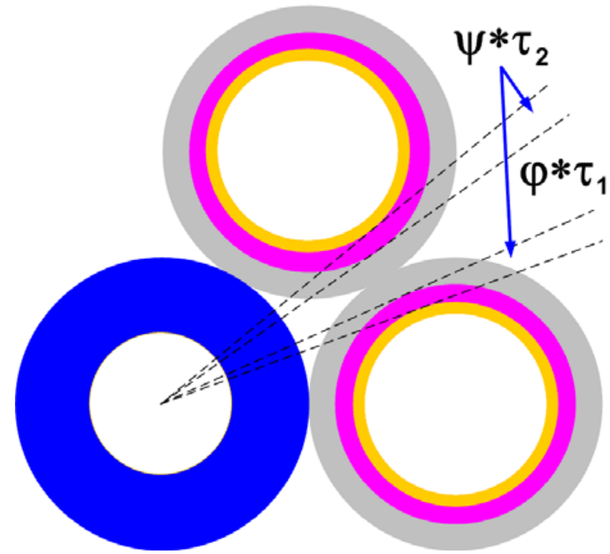



**Figure 24:** Explanation of the fractions for the calculation of the proportions of the diameters participating in the heat dissipation of the central cable or the central bundle

After determination of the angular portion of the dissipation of the heat through the part of the jacket material and consecutively through the jacket and insulation material, we can compute the heat disspation through these sections. We can assume circular configurations for the heat transfer from the inner (central) cable or layer through the jacket. We can assume as the same condicitons also for the heat dissipation through the insulation and jacket, and also for the remaining heat transfer through the insulated conductors of the outer layer all over the outer jacket into the environment. In this case the heat transfer into the outer layer increases the heat in the outer layer over the one generated by the current. As a result the surface temperature of the conductors of the central cable is the one exposed to the current limitation of the entire cable bundle.

To determine the geometries for all configurations used above is tedious, and goes definitely beyond the author's actual patience to deal with this problem.

**Saving of data to desktop:**

C:\..\data

augment(ta , Icore , Icable , Icab61 , Icab181 , Icab361 , CLimit)

## 11. References :


[1] Steve Meyer : Wire Table
Naval Air Weapons Center
Code 543400D
China Lake, CA 93555
(619)-939-6005
steve_meyer@rccgw.chinalake.navy.mil

[2] J.- H. Walling: Current carrying capacity of data grade cables
Contributuion to IEEE 802.3af : walling_1_0305