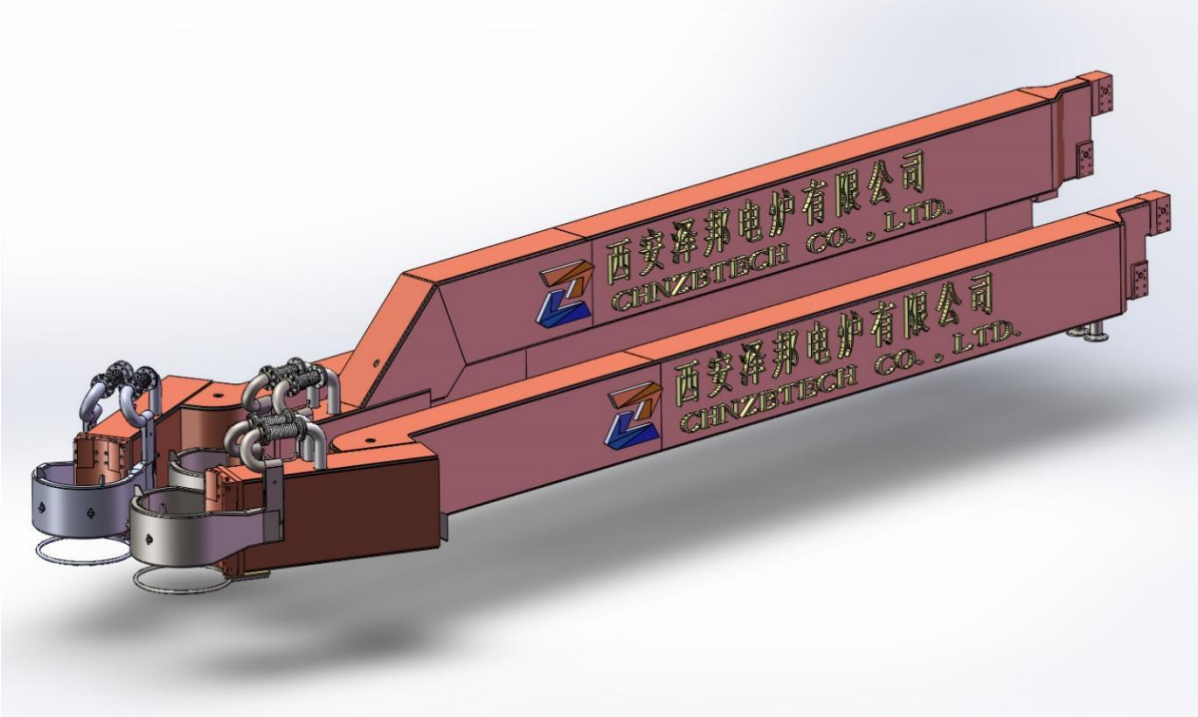
Electrode Conducting Arm
Calculation Sheet for Current Density



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The current capacity of a copper busbar follows Newton's formula:

$$I^2 \times R = K_t \times A \times \Delta t$$

Where I represents the rated current,

R is the resistance of the copper busbar,

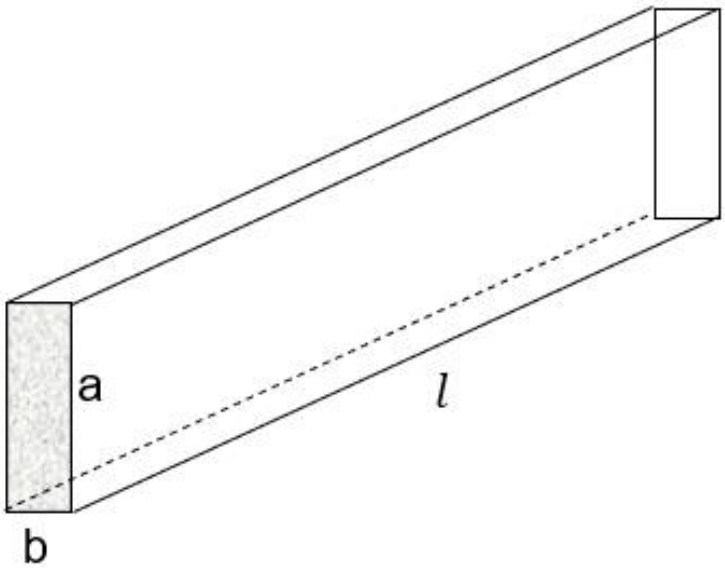
A is the heat dissipation surface area of the copper busbar (m^2),

Δt is the temperature rise, which is the difference between the surface temperature of the copper busbar and the ambient temperature,

K_t is the overall heat dissipation coefficient of the copper busbar surface ($W/m^2 \cdot K$). This coefficient reflects the heat dissipation capability of the copper busbar surface and depends on the surface condition of the copper busbar and its surrounding environment.

Taking a vertically mounted copper busbar as an example, where the cross-sectional width is bbb, the height is aaa, and the length is L, the heat dissipation surface area A is:

$$2 \times (a + b) \times L$$



The Newton's formula can be further transformed into the following expression:

$$I^2 \times R = K_t \times A \times \Delta t$$

$$I^2 \times \rho \times \frac{L}{S} = K_t \times A \times \Delta t$$

$$I^2 \times \rho \times \frac{L}{a \times b} = K_t \times l \times 2 \times (a + b) \times \Delta t$$

$$I = \sqrt{\frac{K_t \times 2ab(a + b) \times \Delta t}{\rho}}$$

From the final formula above, it can be observed that the current-carrying capacity of the copper busbar is related to factors such as resistivity, overall surface heat dissipation coefficient, busbar cross-section, and allowable temperature rise. For copper busbars of the same specifications, increasing the current-carrying capacity can be achieved by improving the efficiency of heat conduction, heat exchange, and heat radiation.

Ⅰ. Resistivity of the Conductor

The resistivity (ρ\rhoρ) of a conductor is temperature-dependent and can generally be expressed as:

$$\rho = \rho_{20}[1 + \alpha(\theta - 20)]$$

ρ_{20}: Resistivity of the conductor at 20°C (Ω·m),

α: Temperature coefficient of resistance (1/K),

θ: Temperature of the conductor (°C).

According to national standards:

For T_2 copper：

$$\rho_{20} = 0.0177 \times 10^{-6}\Omega \cdot m$$

$$\alpha = 4.33 \times 10^{-3}K^{-1}$$

Based on the DIN43671 standard, with an ambient temperature of 35°C and a maximum allowable temperature of 65°C for the copper busbar, the resistivity at 65°C is approximated as $0.0211 \times 10^{-6}\Omega \cdot m$

2. Overall Heat Dissipation Coefficient (K_t) of the Conductor

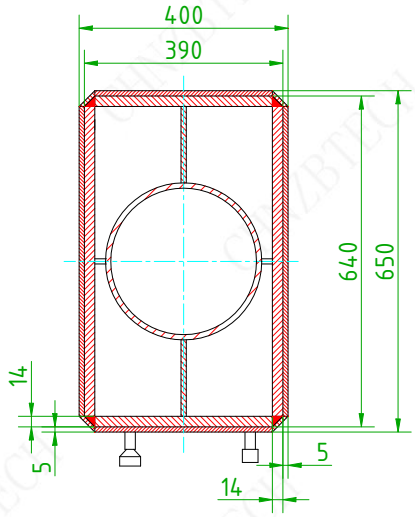
The physical significance of the overall heat dissipation coefficient (K_t) is that it represents the amount of heat dissipated per second per square meter of surface area for a temperature rise of 1K.

The value of K_t is usually determined experimentally and is considered constant within a certain temperature range.

For copper busbars in air, the typical value of the overall heat dissipation coefficient (K_t) ranges from 6~9W/m^2·K.

3. Current-Carrying Capacity Calculation for Conductive Crossarms in Air

The cross-sectional shape of the conductive crossarm is shown in the figure below:



We treat the copper cladding of the conductive crossarm as a copper busbar in air (with dimensions a=2080 mm, b=5 mm). The ambient temperature is 35°C, and the maximum allowable temperature is 65°C, meaning the allowable temperature rise for the copper busbar is 30K. The resistivity of copper at 65°C is approximated as $0.0211 \times 10^{-6} \Omega \cdot m$, and the overall heat dissipation coefficient Kt is $9W/m^2 \cdot K$. We will apply these parameters in the formula for calculation：

$$I = \sqrt{\frac{K_t \times 2ab(a+b) \times \Delta t}{\rho}} = \sqrt{\frac{9 \times 2 \times 2.08 \times 0.005 \times (2.08 + 0.005) \times 30}{0.0211 \times 10^{-6}}} = 23557.3(A)$$

Thus, it can be concluded that, under the condition where the conductive crossarm is not water-cooled, the theoretical current-carrying capacity is 23,557.3A.

4. Current-Carrying Capacity Calculation for Conductive Crossarm with Forced Cooling

We know that for the conductor's temperature to remain stable and not increase, energy conservation must be achieved, which means:

Heat generated by the current=Heat absorbed by the environment+Heat required for the conductor's temperature rise

Therefore, the increase in heat generated by the current due to the increase in the current-carrying capacity can be balanced by increasing the heat absorbed by the environment to ensure that the heat required for the conductor remains constant. **In other**

words, increasing the current-carrying capacity of the copper busbar can be achieved by enhancing heat exchange efficiency.

The following conditions are given for the calculation:

Current passing through the conductive crossarm: 45,000 A

Theoretical length of the conductive crossarm: 7 m

Cooling water flow: 10 m^3/h

Allowed temperature rise of the cooling water: 25°C

Now, the heat generated by the current over one hour is:

$$Q_1 = I^2 \times R \times t = I^2 \times \frac{\rho L}{S} \times t = 45000^2 \times \frac{0.0177 \times 10^{-6} \times 7}{10400} \times 3600 = 86.849 \times 10^3 (kJ)$$

The theoretical amount of heat carried away by the cooling water in one hour is:

$$Q_2 = C \times m \times \Delta t = 4.18 \times 10 \times 10^3 \times 25 = 1045 \times 10^3 (kJ)$$

Assuming a heat exchange efficiency of 40%, the heat carried away by the cooling water is 4.8 times the heat generated by the current. Therefore, the current-carrying capacity of the copper busbar with forced water cooling is 2.19 times higher than that in air.

Thus, under forced cooling conditions, the current-carrying capacity of the conductive crossarm is:

$$I_{cooling} = 23557.3 \times 2.19 = 51590.487 (A)$$

The current density: $J = 51590.487 \div 10400 = 4.96 (A/mm^2)$

Considering a safety margin, the current density is typically chosen as $4.5 A/mm^2$