Application Note

Derating of Connectors

WÜRTH ELEKTRONIK

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1 Introduction

We know that electrical resistance creates heat when a current goes through it. The amount of heat is directly related to these two parameters. But what is the influence of the ambient temperature on the resistance? Should we limit the current when the temperature increases and especially when it is close to the maximum operating temperature allowed on a connector?

We will try to answer these questions and give practical operating curves to be used with our connectors.

2 Temperature Rise

2.1. Temperature rise theory

Electrical connectors always specify a working current which is defined by international, national or even industry specific standards that provide a maximum temperature rise (Δt) value allowed under working current. These are measured at the hottest point of the connector by using a very precise processes (usually EIA364-70 standard is followed). Different standards might allow different values for this maximum Δt. For UL certification, Würth Elektronik chose to have a Δt maximum of 30 K (UL1059 – Terminal blocks).

Different standards can refer to different test procedures, the number of poles and especially Δt value hence it is possible to find different current values within the standards (UL and VDE for example) for the same product.

Δt can be calculated by the following Joule formula.

$$\Delta t = k \cdot R \cdot I^2 \qquad \text{Eq.(1)}$$

With:

Δt	temperature rise in Kelvin
k	constant
R	connector resistance in Ω
I	current in A

The k constant depends on environmental factors like: type of plastic material and even its color, air flow and all factors that will improve or reduce thermal dissipation. We, of course, cannot know or calculate it easily for each type of product use.

It is possible to omit this constant from the calculation when we compare values on the same system. If we measure Δt_1 of a connector with a current I_1, Δt_2 can be calculated at a different current I_2 without any measurement.

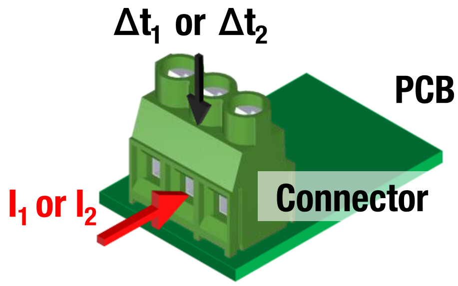

Figure 1: Temperature rise test principle

If we use Joule's formula (Equation 1), constant k and resistance R will be the same for these two lines.

$$\frac{\Delta t_1}{\Delta t_2} = \frac{I_1^2}{I_2^2} \qquad \text{Eq.(2)}$$

<u>Note:</u> *This formula is an estimation and therefore not precise because of the following reasons: injected current precision, measurement precision and environment.*

We will see in the next paragraph if this estimation is accurate compared to real measurements.

The internal temperature of the connector is

$$t = \Delta t + t_{ambient} \qquad \text{Eq.(3)}$$

2.2. Temperature rise experiment

We performed the temperature rise test to some of our products to validate the theory. The products were placed inside an enclosed space to avoid the influence of air flow. There was no temperature regulation.

In the following example a PCB terminal block is connected with its three poles in series. Then a current of 20 A is applied using a 12 AWG wire. Three thermocouples are placed on the connector, one inside of each screw clamp, an additional thermocouple is used to measure the ambient temperature.

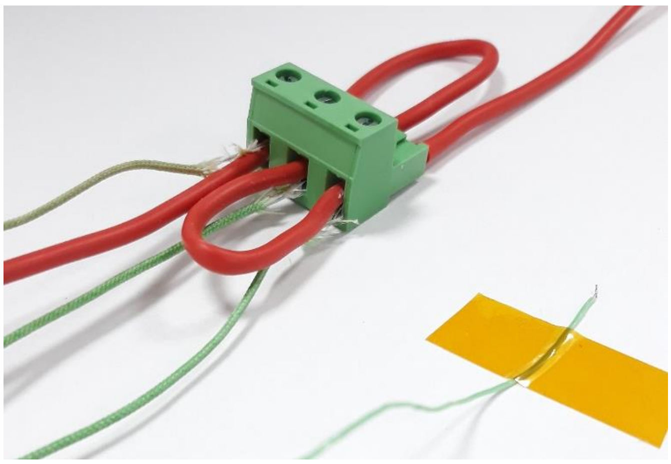

Figure 2: Test cabling

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Table 1 shows the results of the thermocouple Δt measurement (in K) and in parallel the calculated estimation using Joule's formula with the Δt at working current 20 A (green line).

As an example, the estimation of Th_1 at 10 A is calculated as follows:

$$\Delta t_{10A} = \frac{I_1^2}{I_2^2} \cdot \Delta t_{20A} = \frac{10^2\ A}{20^2\ A} \cdot 19.2\ K = 4.8\ K \qquad \text{Eq.(4)}$$

From the experimental results shown in Table 1, we notice that going from 10 A to 20 A the temperature rise of the connector multiplies by the factor of four! The prediction error (in K) is the average of each the three errors between measured and calculated value.

	Current (A)	Th_1 clamp ext	Th_2 clamp middle	Th_3 clamp ext	Prediction error (K)
Measured Δt (K)	5	1.3	1.6	0.9	0.0
Δt expected (K)		1.2	1.6	1.0	
Measured Δt (K)	10	5.4	7	4.4	0.5
Δt expected (K)		4.8	6.5	3.9	
Measured Δt (K)	15	11.5	15.4	9.5	0.7
Δt expected (K)		10.8	14.6	8.7	
Measured Δt (K)	20	19.2	25.9	15.5	na
Measured Δt (K)	25	29	38.8	22.9	-1.3
Δt expected (K)		30.0	40.5	24.2	
Measured Δt (K)	30	41.8	55.9	32	-2.1
Δt expected (K)		43.2	58.3	34.9	

Table 1: ΔT test results compared with estimation calculation

Prediction error shows that the calculation method is an valid approach to estimate the real Δt value. It means that if you know Δt of a connector at a current you can estimate Δt at another current.

Be aware that this estimation is less accurate if there is a large difference between the two currents used (2 A and 50 A for example).

3 Derating Testing

3.1. Derating Theory and Experimentation

Derating testing is a Δt test performed at the working current which is performed in climatic chamber at different temperatures, normally from 20°C up to the maximum operating temperature allowed for the product. It provides us information regarding the maximum current allowed under different thermal conditions.

Würth Elektronik products are designed so that metal parts do not lose their efficiency across the working temperature range. However we see a sensible Δt variation with temperature.

The main reason is that metal electrical resistances vary with temperature according to the following formula:

$$R_t = R_0 \cdot (1 + \alpha \cdot (t - t_0)) \qquad \text{Eq.(5)}$$

With:

- R_t — resistance of a metal conductor at a temperature t in Ω
- R_0 — resistance at a temperature t_0 in Ω
- α — temperature coefficient of resistance in K^{-1}
- t — temperature in °C (or K)

α is a material dependant constant. Two examples of materials widely used as conductors:

$\alpha_{copper} \approx 4 \cdot 10^{-3} K^{-1}$

$\alpha_{brass} \approx 1.5 \cdot 10^{-3} K^{-1}$

Note: *The symbol '≈' is used because the value varies slightly with material grade.*

Obviously, the overall contact resistance is the addition of different parameters: different material conductors, contact between wire and clamp, soldering and contact between mated terminals.

To give an idea of the resistance variation on a connector with a mix between copper and brass conductors, using as an example the temperature variation from 20 °C to 100 °C, this can be estimated using the following calculation:

$$R_{100\,°C} = R_{20°C} \cdot \left(1 + \left(\frac{1.5 + 4}{2} \cdot 10^{-3}\ K^{-1}\right) \cdot (100\ °C - 20\ °C)\right) \qquad \text{Eq.(6)}$$

$$R_{100°C} = 1.2 \cdot R_{20°C}$$

This example shows that the connector will increase its resistance by approximately 20%.

Table 2 shows some measurements at different temperatures.

Ambient temperature (°C)	Product internal temperature (°C)	Δt (K)	Δt increase vs Δt at 23°C (K)	Δt increase vs Δt at 23°C (%)
23	38.9	15.9		
34.7	51.4	16.7	0.8	5%
46.4	63.8	17.4	1.5	9%
58.1	76	17.9	2.0	13%
69.8	88.3	18.5	2.6	16%
81.5	100.7	19.2	3.3	21%
93.2	112.5	19.3	3.4	21%
104.9	124.7	19.8	3.9	25%

Table 2: Table of derating test values for a pluggable terminal block

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We must remember that the temperature rise is directly proportional to the connector resistance. When we take this into account the estimation of the resistance increase is consistent.

3.2. Derating Curves

We previously saw that working current allows a temperature rise of 30 K maximum according to the UL Standard used. We saw that the electrical resistance of a metal part would naturally increase due to the increase of the ambient temperature.

We know that all products have a working temperature range and especially a maximum operating temperature to be used under.

Now the question is "Can the product be used with the maximum working current at the maximum temperature allowed"?

The answer is we should adjust the current to avoid excessive temperature on the product as this will decrease its life time. We should follow the derating curves.

They are designed as follows:

- Working current is of course allowed from the minimum operating temperature. The curves start from 0 °C to avoid a long flat curve area.
- For UL standard, from "t_{max} - 30 K" to maximum operating temperature, current will decrease according to the square of the current.
- For VDE standard, from "t_{max} - 45 K" to maximum operating temperature

For a product with a maximum operating temperature for example of 85 °C, we could estimate the following derating curves in Figure 3 and Figure 4 (red line).

The increased resistance is taken in account because Würth Elektronik uses a safety margin of 20% against the working current obtained during the derating test.

The additional lines are the derating curves for our connectors according to the maximum operating temperature specified. These can be used for any of our eiCan products

4 Summary

If we know the temperature rise Δt_1 (in K) for a connector under a current I_1 (in A), it is possible to estimate the temperature rise Δt_2 under a different current I_2.

$$\frac{\Delta t_1}{\Delta t_2} = \frac{I_1^2}{I_2^2} \qquad \text{Eq.(7)}$$

Note: This formula is for the same connector under the same environmental conditions.

When a connector is used close to the maximum temperature allowed, it is recommended to use derating curves that are given in this application note paragraph 3.2. They are applicable for all eiCan products.

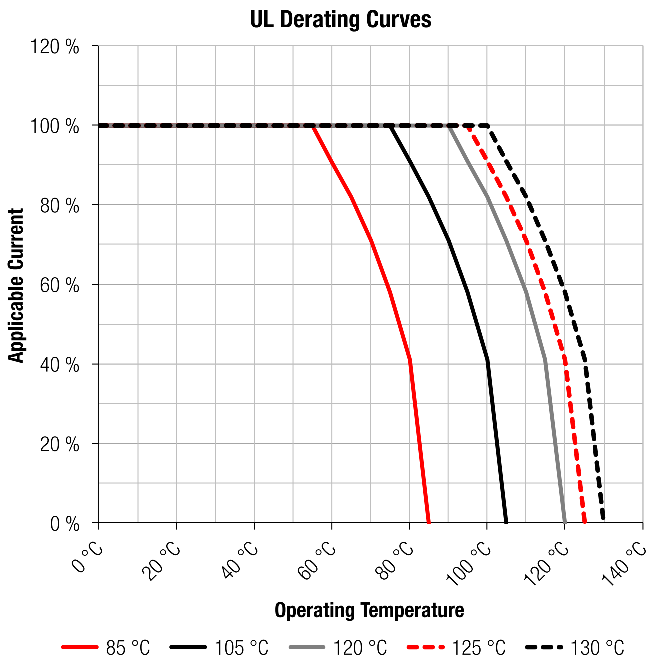

Figure 3: UL derating curves for different operating temperatures

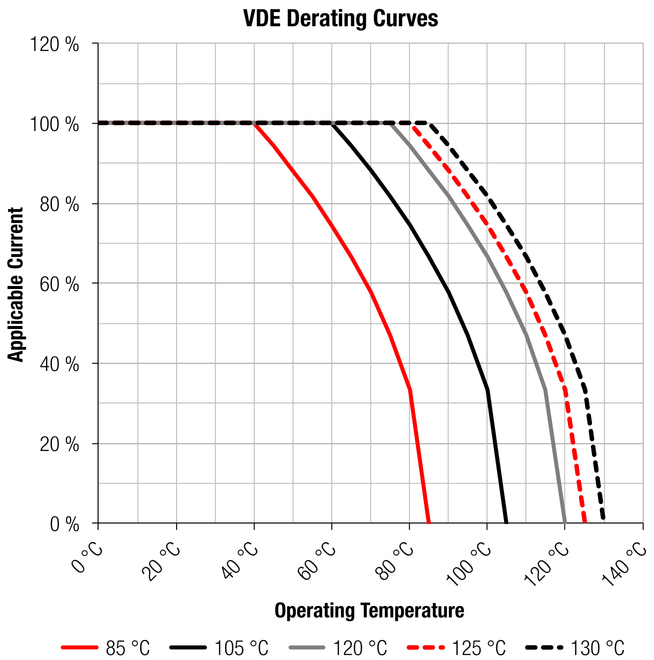

Figure 4: VDE derating curves for different operating temperatures

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