Application Note

Inrush current for connectors

ANE015 // Alexandre Chaillet, Julien Henrot

1 Introduction

This application note is related to Würth Elektronik TBL series terminal blocks only.

All resistors carrying current release heat, which is called the Joule effect. A power connector can be considered as a simple resistor from a thermal point of view. The working current of a power connector is usually defined by a standard, in our case by UL 1059. The maximum temperature rise (ΔT) in the standard is 30 K (ΔT is usually given in Kelvin and temperature in °Celsius).

$$T_{connector}\,[°C] = T_{ambient}\,[°C] + \Delta T\,[K] \qquad \text{Eq.(1)}$$

This means that at full working current, the connector's internal temperature will not exceed 30 K more than ambient temperature. The temperature rise plus the ambient temperatire (Eq.(1)) are limited by the maximum operating temperature rating.

Used with the proper derating curve, working current ensures connector durability (for more details have a look at ANE006 Derating of ceonnectors).

Some applications require a high current for a short duration, for example for a short acceleration of an electric scooter or transition phase of an electric transformer or capacitance discharge for lighting ballast.

Do we have to oversize the connector working current with this inrush current or is it possible to go above working current for a short period of time?

2 Temperature rise under current

2.1. Working current temperature rise

Temperature rise could be written as following:

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

With:

ΔT temperature rise [K]

k thermal environment constant

R connector resistance [Ω]

I current [A]

The environment (ambient plus mounting) has a big influence on the thermal behavior of a connector. It will define how quickly thermal energy will be dissipated or not. That is why k is defined as a constant.

However, it is not possible to define k for each condition and so we prefer to compare temperature rise under the same conditions. That will remove the constant as we see in Equation (3).

Thermal equilibrium is reached when the calories from the Joule effect and the calories dissipated by the connector are equal.

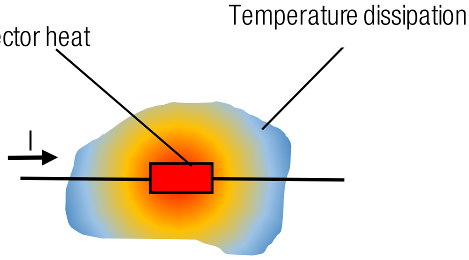

Figure 1: Connector thermal dissipation schematic

Figure 2 gives an example of a common connector temperature rise measurment over the time, of course ΔT < 30 K. As we can see, several minutes are needed for the system to stabilize the temperature increase.

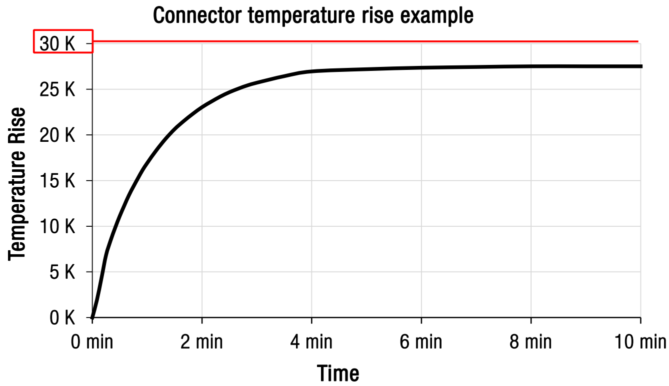

Figure 2: Connector temperature rise in minutes

Application Note

Inrush current for connectors

2.2. Temperature rise time under current

Now let's focus the first minute of the test that was described on the figure 2. Figure 3 is the same curve but just for the first 60 seconds. We see for example, at 10 s that ΔT = 5 K:

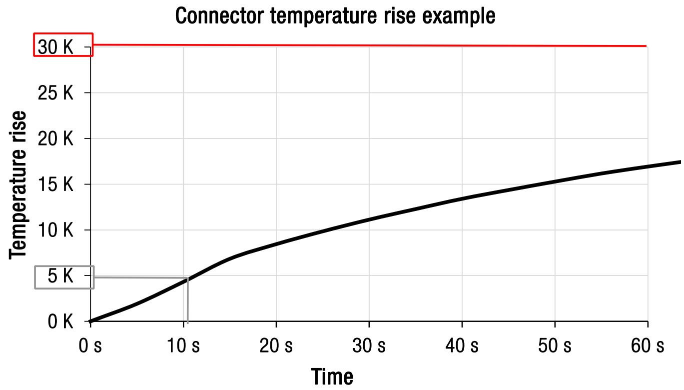

Figure 3 : Temperature rise during the first minute

We can assume, that the current could be above the working current for a short period of time without reaching ΔT = 30 K.

The question is, how to estimate the current per period of time in a connector without exceeding a temperature rise of 30 K?

3 Inrush Current

3.1. Pre-test: inrush current duration that gives a ΔT of 30 K

We will work this out by experiment by pushing the connectors over the nominal working current. Each test stops at 100°C, so as to not to exceed maximum operating temperature.

Figure 4: TBL over-current test at ambient temperature of 19.1°C

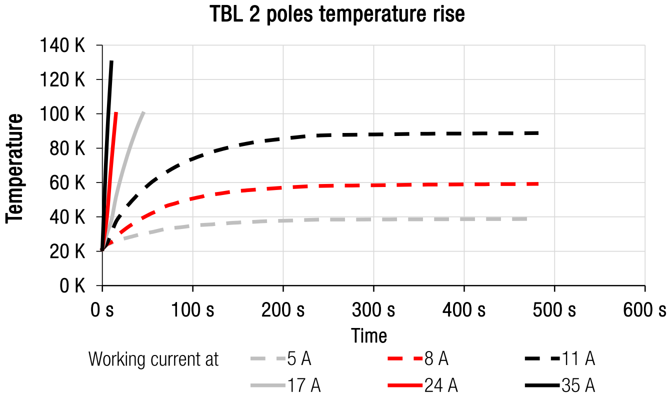

Figure 5: Temperature rise above the rated working current of 5 A

Conclusions from curves:

- Working current gives a ΔT < 30 K as requested by UL standard
- Going higher than working current obviously exceeds 30 K
- If we limit the duration, it is possible to keep the connector ΔT < 30 K. For example, with this connector, we are able to apply 11 A (2.2 times working current) for a duration of 35 s to reach 30 K.

3.2. Inrush current curve proposal:

Now we need to find out how long we could apply a current over nominal value, and to finally test it on some of our connectors to validate the inrush current and time.

We have chosen a large safety factor of greater than two between what we have measured and what we finally state in our datasheet.

3.3. Inrush current full tests

A series of connectors with a characteristic number of contacts was tested (red curve in figure 6) to check that the load from the increased current has no unacceptable effects on the connector. All values marked by the 10 red dots in figure 7 had to be tested on each connector (e.g. 1.1 times working current during 20 s). The aim was to verify that ΔT does not exceed 30 K for each point.

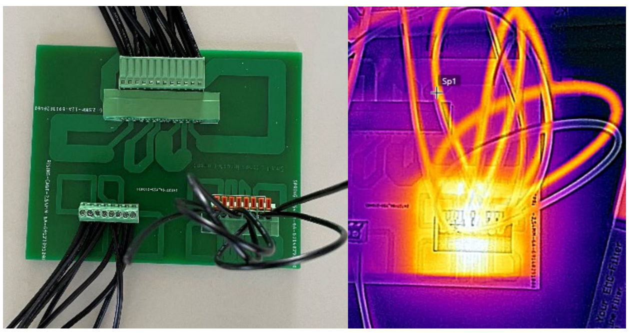

Figure 6: Set-up of the inrush current test

Application Note

Inrush current for connectors

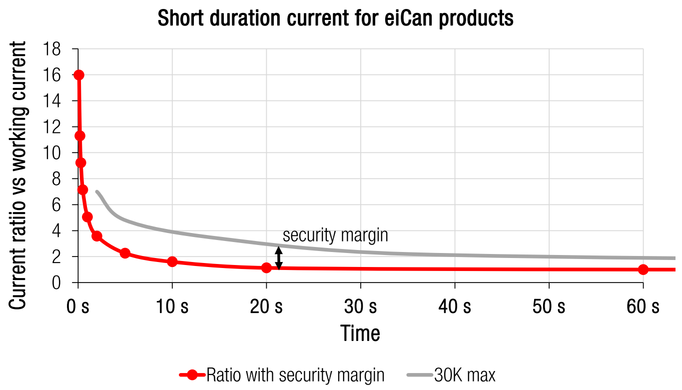

Figure 7: Typical 30 K temperature rise current and proposal with safety margin

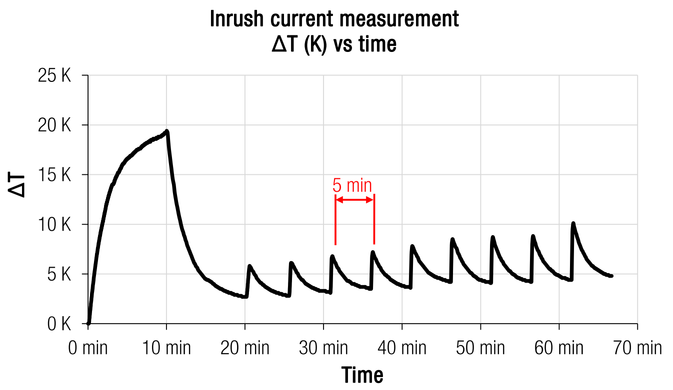

Figure 8: Inrush current test results

Ten tests were carried out with different currents, with an interval of 5 minutes to allow the temperature to slowly return to the initial value. The first ΔT-peak is the largest. It refers to the working current during a period of 10 minutes. All other "working points" have a very small effect on the ΔT, here about 5 K maximum.

3.4. Conclusions from the tests

All tests carried out with different products showed roughly similar results. Thermal energy must be dissipated to the ambient surrounding the connector. Otherwise the energy is accumulated inside the connector. In that case, the temperature would continue to increase and put in danger the electrical parts or even worse the whole appliance.

Figure 9 shows a connector at 70 % of the nominal current with 10 peaks of current with a ratio of 7:1 (peak to nominal) and an interval of 5 minutes, that is necessary to let the connector return to its initial temperature.

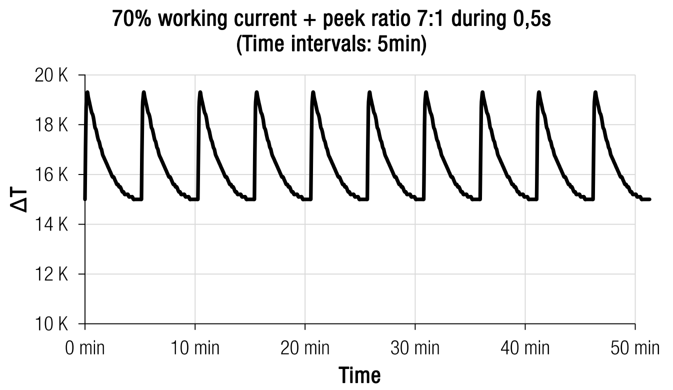

Figure 9: ΔT curve with enough time interval between peaks for energy dissipation

When the temperature rise always returns to 15 K, the system is stable.

But if the time interval is reduced, the thermal energy does not have enough time to be dissipated. Figure 10 shows, that the temperature continues to increase. The system is not stable. After a period of time, this will damage the connector so, this condition must be avoided.

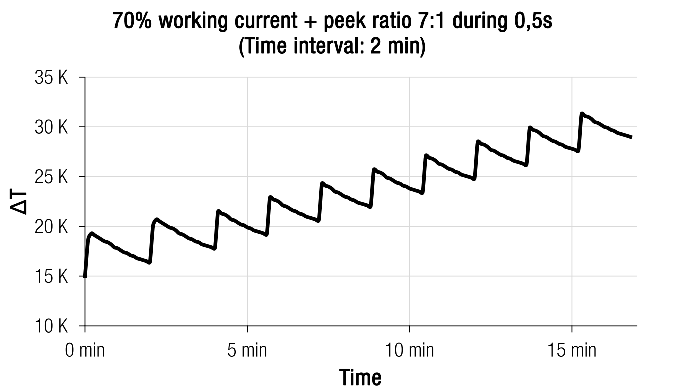

Figure 10: ΔT curve with a time interval between peaks that is too short for sufficient energy dissipation

Energy dissipation strongly depends on the connectors environment: size of PCB traces, size of wires, in a closed box or not. The amount of energy dissipation, at the 5 minute intervals given here, varies with respect to each application.

Application Note

Inrush current for connectors

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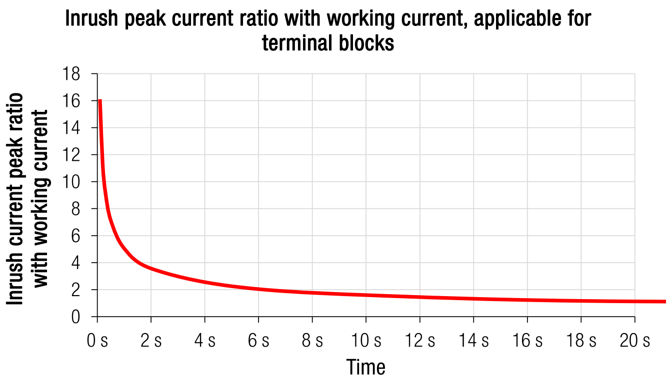
4 Final applicable curves

4.1. Inrush current curve

Finally, it is possible to have an inrush peak current every 5 minutes (minimum to be verified on real conditions) for each connector following the curves in Figures 11 and 12.



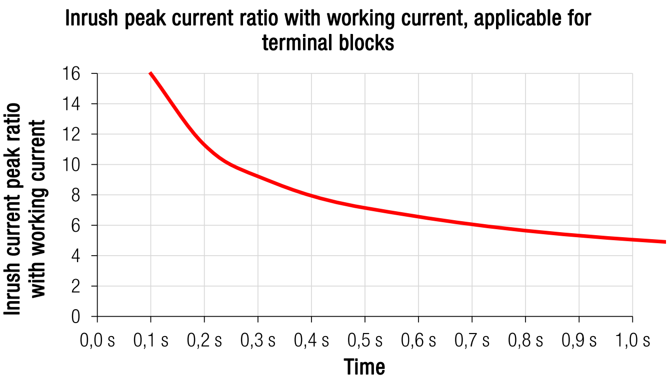


Figure 11 & 12: Close-up of applicable inrush current for WE connectors. Note different time scales

Example:

With a working current of 5 A, it is possible to use it at full current and every 5 minutes have a peak current of, e.g., two times the working current (10 A) for 6 seconds.

4.2. Derating curve – constant "inrush" current

If a WE connector is used, the following curve gives the current applicable related to the operating temperature (Figure 13).

Würth Elektronik complies with UL regulations in every situation. A maximum temperature rise of $\Delta T \leq 30$ K is set, regardless of which inrush current is applied. It is therefore not possible to operate a connector with full current and additional inrush current at the same time.

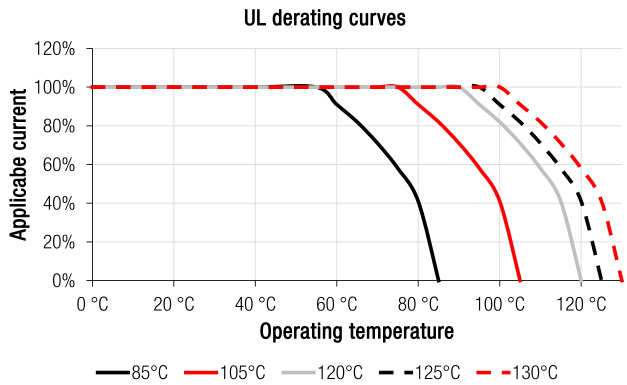


Figure 13: UL derating curves for different operating temperatures

For safety reasons, we assume that the maximum ΔT at inrush current is 15 K. This means that a maximum ΔT for the temperature rise at stable current of 30 -15 = 15 K is possible.

With Eq 2, for the same system, we know that ΔT is given by following formula:

$$\frac{\Delta T_1}{\Delta T_2} = \frac{I_1^2}{I_2^2} \qquad \text{Eq.(3)}$$

$\Delta T_1 = 30$ K and $\Delta T_2 = 15$ K, then $I_2 = \frac{I_1}{\sqrt{2}}$

With inrush current, we have to limit the working current to $\frac{100\ \%}{\sqrt{2}} \approx 70\ \%$.

So finally, if we want to use a connector with both, the continuous and the inrush current, we need to adjust the derating curves as follows:

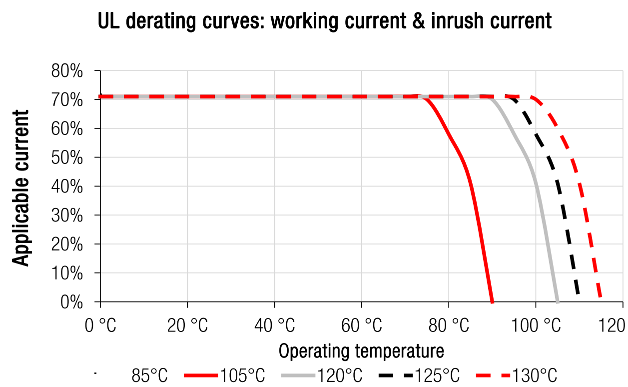


Figure 14: UL derating curves for continuous and inrush current at different operating temperatures. For WE terminal blocks only

Remember to always do a temperature rise test in real conditions to confirm that the time interval is long enough to keep system stable.

5 Summary

Basic rules:

1. Max temperature < connector operating temperature
2. Max ΔT < 30 K in all cases (UL)
3. It is recommended to let at least 5 minutes pass between two surges to allow the temperature to decrease to the initial temperature.
4. Each situation is different regarding its thermal dissipation capabilities, so each application must be validated (customer must verify that ΔT remains < 30 K in any case) by the customer in real conditions.

The curves in this application note are recommendations. However, Würth Elektronik guarantees the paramters specified in the data sheets. Furthermore, adjusting the inrush current according to the application and the ambient temparature is the responsibility of the customer.

Application Note

Inrush current for connectors

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CONTACT INFORMATION

appnotes@we-online.de
Tel. +49 7942 945 - 0

Würth Elektronik eiSos GmbH & Co. KG
Max-Eyth-Str. 1 · 74638 Waldenburg · Germany
www.we-online.com