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Exact Temperature Measurement in High Voltage Connectors

A Solvable Challenge

The design of the HV wiring harness is an essential part for the energy efficiency of modern e-vehicles. Due to its great weight, the high-voltage (HV) wiring harness offers significant savings potential for lightweight construction. With the help of system simulation, as described in the ZVEI Technical Guideline TLF0101, the conductor cross-sections in the vehicle electrical system can be optimized. This theoretical design must be validated in real operation which brings the established temperature measurement technology to its limits and shakes the principle that "the truth lies in the laboratory". The combination of simulation and real testing is a promising approach that also opens the possibility of re-evaluating the established safety factors.

In motor vehicles, the transmission of drive power from the energy source to the drive shaft has always been a major challenge. In internal combustion engines, the transmission of engine torque via clutch and transmission is of central importance for the reliability of the vehicle. In modern e-vehicles, the energy from the battery to the e-motor is connected via the HV cable harness. Here, the challenge lies in lightweight construction and ensuring electric strength. Because of its weight, the cable cross-sections must be minimized, accounting for the maximum current-carrying capacity. For this optimization measure, knowledge of the maximum local temperature is of central importance, since component reliability is inextricably linked to the local operating temperature.

The measurement of the temperature hotspot starts with the selection of the measurement method. Table 1 shows an overview of possible methods for temperature measurement. In practice, the use of thermocouples has become established for this purpose because of their price and their simple and flexible handling. The next step is to determine the location of the hotspot. This can be determined by thermography on exposed inner conductors or with the help of a system simulation.

To measure the hotspot, the sensor must be placed at the hottest point. If this is not possible due to constructional conditions, the sensor may be mounted near the hotspot according to DIN EN 60512-5-2. In addition to the measurement location, the installation orientatikon of the sensor also has an influence on the measured temperature.

Table 1 Overview of temperature measurement methods

Sensor Type	**Remarks**
Mechanical contact thermometers	Thermal expansion Inflexible, inert
Thermocouples	Seebeck effect, thermoelectric voltage, Universal, simple, cheap
Resistance thermometers	Temperature dependent ohmic resistance Universal
Semiconductor sensor	Change of electrical resistance NTCs exhibit drift
Silicon measuring resistors	Pronounced positive temperature coefficient Not very common
Oscillating quartz temperature sensor	Temperature coefficient of resonance frequency Little widespread
Noise thermometer	Temperature dependence of the average electron velocity in an unloaded resistor Expensive, complex measurement
Fiber optic temperature measuring system	Anti-Stokes part of Raman scattering
Fiber optic thermometer	Pulsed excitation of a crystal application at high magnetic fields and in hazardous areas
Infrared measurement, pyrometer	Infrared radiation For fast temperature change
Thermal imaging camera	Infrared radiation Similar to pyrometer, local temperature resolution possible
Acoustic measurement	Speed of propagation of sound For very high temperatures

Assessment of Typical Measurement Deviation

In order to quantify this influence of the sensor arrangement, a 3D FE model was set up. For this purpose, a 100 mm² copper bar was modeled with the usual arrangements for temperature measurement in the HV connector (see Table 2). The temperature-dependent electrical resistance of copper is accounted for in the model. Natural convection and radiation were stored based on the VDI heat atlas. The temperature distribution was calculated with 600 A for the steady-state load case (Figure 1) and 800 A for the transient load case (Figure 2).

Table 1 Sensor arrangements

Method	Arrangement	Deviation T_{sensor} / T_{rail}
A	Sensor in bore	Approx.0 %
B	Sensor on surface outlet vertical	-8 %
C	Sensor on surface mounting in plastic housing	-8 %
D	Sensor on surface outlet horizontal	-3 %

The temperature distribution in the sensor area (Figure 1) reveals the sensitivity of the temperature measurement in relation to the sensor arrangement. The sensor in the bore (A) measures the actual rail temperature very accurately. The measurement with arrangements B and C result in a temperature that is 10 °C too low.

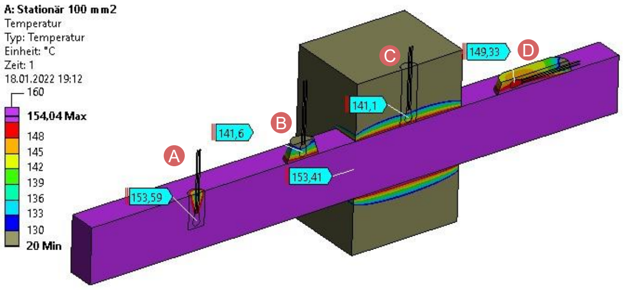

Figure 1 Influence of the sensor mounting position on the measured temperature at 600 A continuous current

The transient temperature curve in Figure 2 reveals another crucial factor in temperature measurement. The solid lines show the transient temperature curve at 800 A. The deviation of the sensor temperature from the rail temperature is shown in dotted lines. The time course of the deviation shows that the sensor arrangement has a significant influence on the response time of the sensor. For example, sensor arrangement A shows the temperature with an error of < 10% after 10 s, while arrangement C has a deviation of 15% from the actual rail temperature, even after 600 s. The deviation of the sensor arrangement C from the actual rail temperature can be significant. This delay can lead to misestimation of the current carrying capacity of a component in transient current profiles.

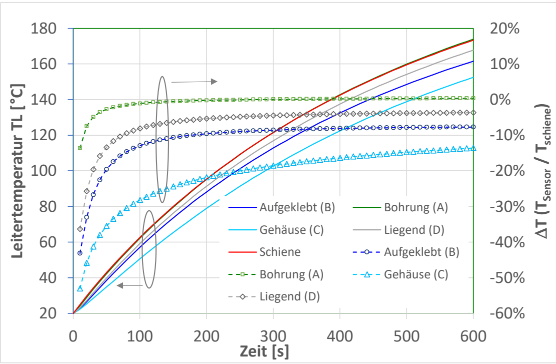

Figure 2 Transient temperature profile from switch-on at 800A.

The theoretical consideration of the sensor arrangement was verified for the described application with the aid of a laboratory experiment. For this purpose, a copper bar with a cross-section of 100 mm² was also prepared with the sensor arrangements A, B, D. A thermocouple type K was attached to one side and an NTC sensor to the opposite side to additionally compare the sensor type. The actual rail temperature is determined by a voltage tap.

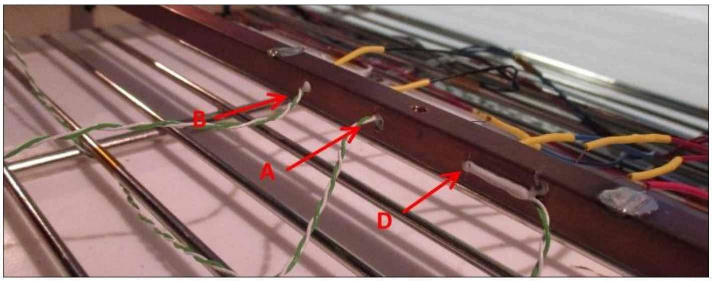

Figure 3 Copper bar with sensors, 100 mm² bar cross-section.

In [1] this experiment is described and evaluated in detail. The authors show that the deviations described in the FE simulation are actually exceeded due to further uncertainties such as the amount of adhesive used on the sensor. In the test shown in Figure 3, a deviation of up to 25% compared to the actual temperature was demonstrated.

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Effect on the Design of the On-Board Power Supply System

Measurement deviations and tolerance influences are considered during product development by means of safety factors. These safety factors lead to a planned over dimensioning to safeguard against the possible overload caused, for example, by an inaccurately determined measured variable. If the measurement deviation can be reduced or calculated back to the true value, the safety factor can be reduced.

Figure 4 shows the measurement situation on a real connector (Rosenberger HPK angle connector). The curve shown in black shows the temperature curve of the coupler inner conductor, which according to the hotspot analysis represents the best possible measurement position for the hotspot temperature measurement. This temperature is measured with method A. The violet curve shows the temperature curve if method C is to be used for measurement. This results in a difference of 6 K. The measurement deviation due to measurement method C can be determined with the help of a system simulation according to the procedure in [2]. For this purpose, the simulation parameter must be determined with 3D FE analyses and the system simulation thus created must be matched with the laboratory measurement. Once the alignment is achieved (Figure 4, simulation vs. jack IC), the real conductor temperature can be determined using the simulation. Therefore, the measurement deviation based on measurement method C can be completely back-calculated. Furthermore, this precise simulation model gives the possibility to calculate the spring temperature, which is no longer possible via the measurement technique. Figure 4 shows the spring temperature in green. This curve shows a temperature up to 8 K higher than the inner conductor and follows the underlying current profile very dynamically.

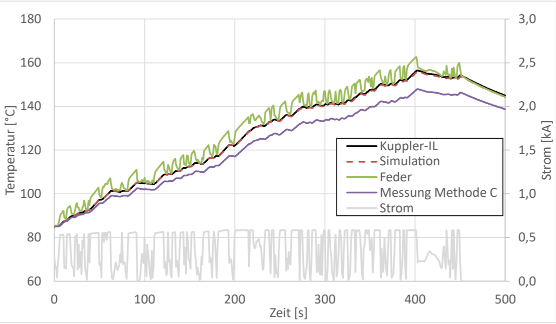

Figure 4 Transient measurement and calculation results of a balanced system simulation using the example of the HPK right-angle plug.

In order to reliably compensate for the difficulties arising from measurement technology, Rosenberger has the issue by embedding the above approach in its in-house standard. [1] describes the essential framework conditions for a reliable simulation model.

Summary and Outlook

The correct measurement of temperatures in high-voltage connectors is sometimes very challenging. This challenge can be solved by the coupled use of simulation and measurement. By consistently implementing this approach, the current HV products from Rosenberger support lightweight construction in the development of vehicle electrical systems.These products offer the required performance with optimized cross-sections and uneffected high reliability.

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SOURCES

[1] C. Dandl, S. Thies, H. Edfelder, Advantages of virtual parameter determination of connectors for electro-thermal HV on-board power system simulation, 26th Symposium Albert-Keil-Seminar 20222.

[2] ZVEI Guideline TLF0101

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