Testreport

-

Storage container for critical vehicle batteries based on LP906 and P911

DUT	**:**	**DryFire Storage**
Model	**:**	**DryFire Storage**
Test Lab	**:**	**Fraunhofer HHI / VoltaLabs GmbH**

1 General Information

Report number	VL0003/23/2610		
Test executed	Christian Redlich	Sascha Bruns	Madeleine Stahl
Report reviewed	Sascha Bruns	Antonio Nedjalkov	
Report approved	Sascha Bruns	Antonio Nedjalkov	
Pages	18		
Date of test	26. October 2023		
According to standard	Based on LP906/P911		
Published	15.11.2023		
Test lab			
Name	Fraunhofer HHI	VoltaLabs GmbH	
Address	Am Stollen 19H 38640 Goslar Germany	Schützenallee 10 38640 Goslar Germany	
Customer			
Name	Dry Fire System GmbH		
Address	Leonberger Straße 22 • 71272 Renningen		
Manufacturer			
Name	Dry Fire System GmbH		
Address	Leonberger Straße 22 • 71272 Renningen		
Description test sample	Storage container for critical vehicle batteries		
Model			
Dimensions	HxBxL: 3600x3350x2700mm		

2 Test key data

Name	DryFire Storage
Type	Storage container for critcal vehicle batteries unsafe for transport
Serial number	N/A
Details (optional)	
Test Summary	
Possible results	
Not applicable	N/A
Test sample meets criteria	PASS
Test sample does **not** meet the criteria	FAIL
Test sample received	23. October 2023
Test performed	26. October 2023

Version	Berichtsnummer	Revision	Bemerkung
V1.0	145-613-2023-0039.1		

The present container was tested by Fraunhofer HHI in cooperation with the company VoltaLabs GmbH according to the test criteria of the transport regulations LP906 and P911.

3 Results

Criteria	Test sample number	Norm/Standard	Result
Temperature on outer surface <100 °C		Based on LP906/P911	
No flames outside		Based on LP906/P911	
No fragments or projectiles		Based on LP906/P911	
Structural integrity		Based on LP906/P911	
AGEL-2 HF <9,8 mg/m³		Based on LP906/P911	

The evidence for passing the criteria is described in the following documentation and can be proven by the recorded measurement and video data.

4 Test Equipment

Name	**Art**	**Typ**
Hioki	Voltage data logger	LR8431-20
Logger Utility	Software for logger	Logger Utility Hioki
Sony	Video camera	
HF-Messgerät	HF measuring device	Dräger X-am 5100 HCl/HF Global

5 Test method and data

5.1 Objective

A storage container for critical vehicle batteries was tested on 26. October 2023. This was performed with two vehicle batteries, both of which had an energy content of just over 100 kWh. With this test, it was intended to show that if a fully charged battery in the lower part of the storage container would go into thermal propagation, the battery above would not be damaged. Furthermore, the effects of battery destruction should not significantly influence to the outside area. During use in the storage of battery systems, the container should be resistant to damage scenarios such as an internal thermal runaway or similar cases in its immediate environment. As there are no specific rules and regulations for comparable storage containers, reference was made to dangerous goods regulations.

The necessary criteria are therefore taken from the dangerous goods transport regulations LP906 and P911, which are to be implemented as strict and at least appropriate, if not excessive, for the storage case.

- temperature on the outer sides may not exceed 100 °C significantly for a longer time
- no flames on the outside of the container
- no flying parts of fragments or projectiles
- the container must be structurally intact after the test
- the permitted concentration of hydrogen fluoride [hereinafter HF] may not exceed the permissible AGEL-2 value of 9.8 mg/m³

5.2 Specification of the battery modules

5.2.1 Primary triggered battery system in the lower storage container

Designation	battery with NCM 811 12 modules/15 cells each
Manufacturer	CATL
Nominal energy	100.8 kWh
Nominal capacity	155 Ah
Nominal voltage	650 V
Installed modules	prismatic 15s 8.75 kWh
Installed cells	prismatic 155 Ah
Cell type	prismatic

5.2.2 Secondary sacrificial battery system in the upper storage container

Designation	Battery with NCM 811 pouch modules
Manufacturer	LG
Nominal energy	106 kWh
Nominal capacity	
Nominal voltage	650 V
Installed modules	30 modules pouch, 6s
Installed cells	pouch
Cell type	pouch

5.3 Setup documentation

5.3.1 Requirements

1. At least 2 video cameras to record the testing
    a. Set-up positions shall be selected for capturing any projectiles or flames
2. Sufficient thermal sensing elements [hereafter TC] on the modules to demonstrate thermal runaway [hereafter TR]
3. Sufficient TC on the outside of the container, to confirm the outside temperature
4. Gas sampling at strongest reaction to determine HF concentration for 20 up to 30 minutes

5.3.2 Preparation of battery system

The battery was charged by the customer and supplied with triggers and internal thermocouples.

The inside of the container was lined with extinguishing material (accu grain) on the walls, floor, intermediate layer, doors and ceiling. As a final test preparation, the necessary TCs (thermocouples) were implemented.

On the inside, the container was equipped with 4 TCs in order to determine the temperatures at the extinguishing agent pads and to be able to assess the temperature difference to the outer walls.

The battery systems also had several TCs to enable the TR to be assessed.

The container was equipped with 11 TCs on the outside in order to record the temperatures on the housing.

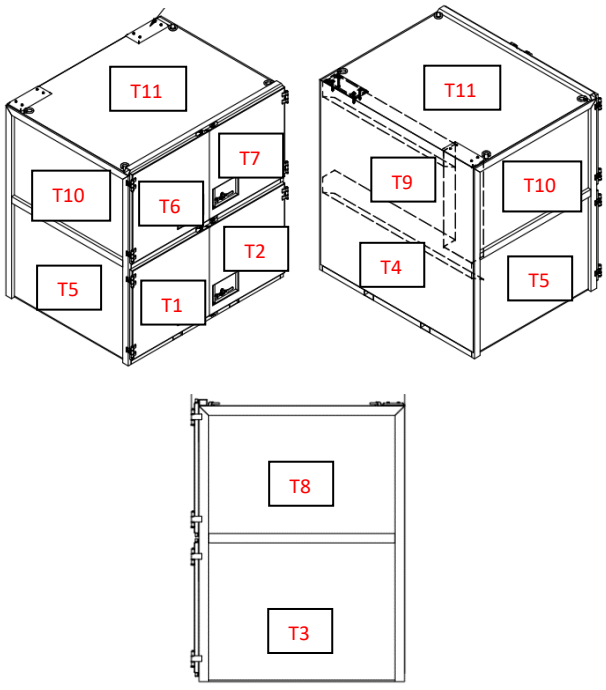


Figure 5.1 – External TC distribution

5.3.3 Measurement and camera systems

Two HD cameras were chosen for the video recording so that all sides of the container could be viewed.

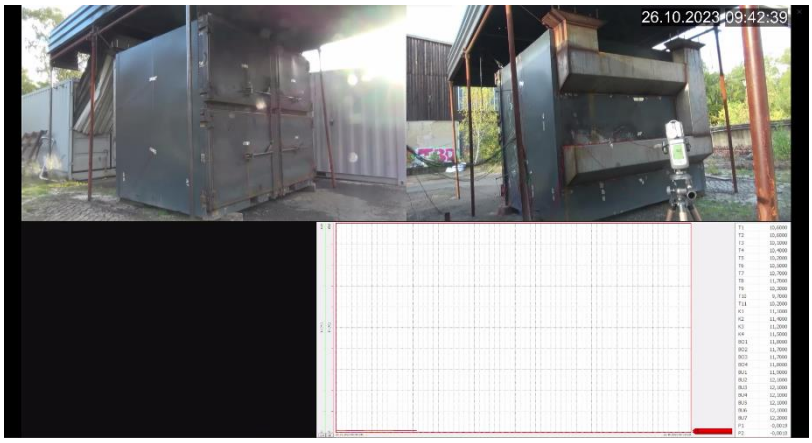


Figure 5.2 – Camera views

Three LR8431 data loggers from Hioki with the associated "Logger Utility" software were used as the measuring system for the temperature and pressure measurement data.

A gas measuring device from Dräger was used to determine the gas concentration. The measuring device was positioned at a lateral distance of approx. 4 m from the rear of the container and thus in the direction of flow of the escaping gas.

5.4 Test procedure

For the purpose of clarity, the procedure description and analysis of the test will be divided into three phases:

1. Trigger of thermal runaway – initiating TR and propagation
2. Propagation – propagation process
3. Observation – after the propagation until the end of the data recording

5.4.1 Triggering of thermal runaway

The data recording was started at 9:39.59 and a short time later, at 9:42.15, the video recording was started, marking the time of the test. At this time, the temperature of the entire setup was around 11 °C.

Heating of the battery system began at 09:45.55. Heat development in the battery system was detected via the temperature recording. An average temperature rise of 35.73 K/min could be determined.

At 09:53.23, the TR finally occurred, which was detectable by a sudden increase in TC "BU1" - "BU7".

5.5 Propagation

Propagation of the battery system continued until around 10:44 a.m.; this time can be traced by a steady drop at all TCs. The entire propagation therefore took place within 50 minutes. A periodic, sometimes strong, smoke development could be observed again and again.

5.5.1 Observation

As soon as no further reaction was recorded at 10:44 a.m., the reaction phase was completed and observation of the container began. The temperature recording was continued until 15:49.

No flame or projectile emissions were recorded during the entire test. The required temperature of 100 °C was exceeded with a small deviation (less then 5 K) on the door, which is permissible. The peak value was 104.6 °C.

5.6 Analysis

5.6.1 Heating

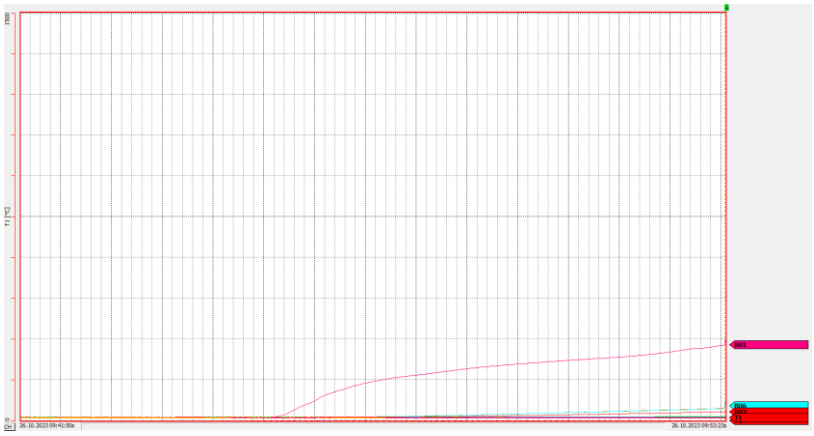


Figure 5.3 – Heating

The heating phase started at a system temperature of approx. 11 °C and the TR was reached at a temperature of 278.8 °C. The average increase in temperature was 35.73 K/min.

5.6.2 Propagation

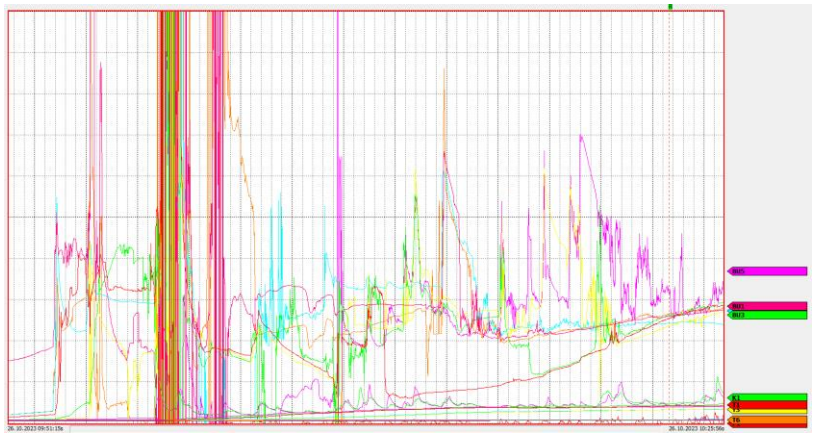


Figure 5.4 – Temperatures during propagation

At the beginning of the propagation, temperatures in the interior were in the range of the TC measurement limit.

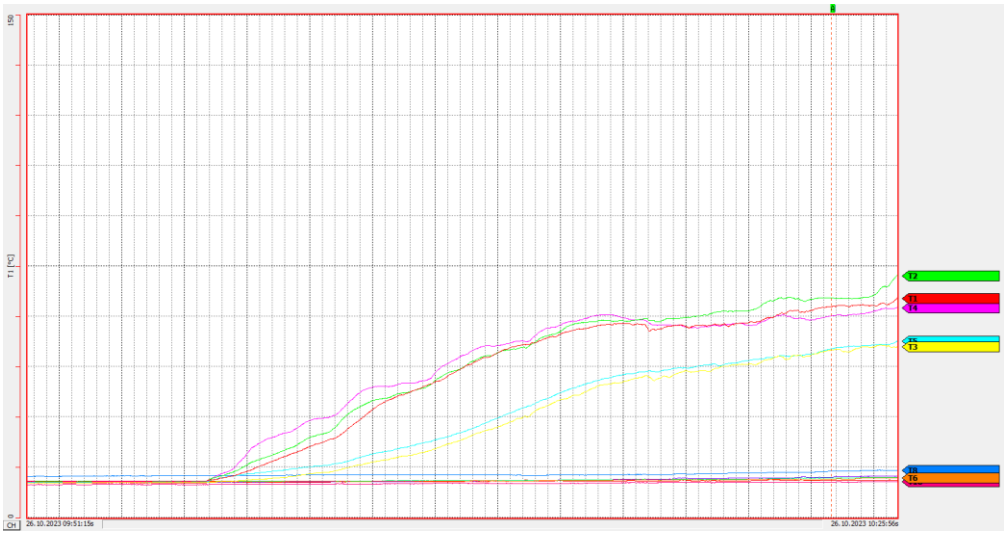


Figure 5.5 – Propagation temperatures outside

During the entire reaction phase, the temperature limit of 100 °C was exceeded for approx. 11 minutes. This resulted in a peak temperature of 104.6 °C in the lower area of the right-hand door.

5.6.3 Observation

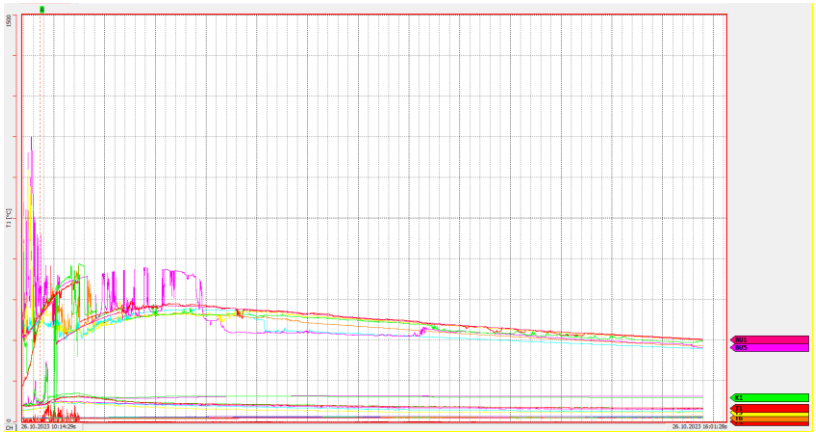


Figure 5.6 – Temperatures during observation

At the beginning of the observation phase, the temperature inside the battery system was still approx. 550 °C, but steadily decreased over the entire observation period. It was therefore possible to validate that no further reaction took place.

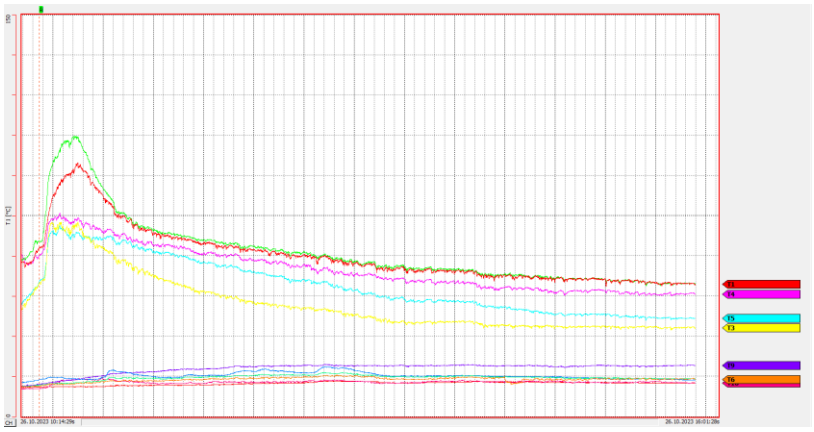


Figure 5.7 – Temperatures observation outside

During the observation phase, no significant temperature increase of the outer sides to over 100 °C could be detected.

5.7 Comparison with criterias

The following criteria had to be met during the test:

5.7.1 Temperature on the outer sides may not exceed 100 °C

a. As already mentioned in the previous chapter, the temperature at the bottom right door was exceeded by 4 °C for 11 minutes during the reaction time. This is acceptable.

5.7.2 No flames on the outside of the container

a. No flames were recorded during the entire procedure.

5.7.3 No ejection of fragments or projectiles

a. No projectiles or fragments of the container or battery modules were visible.

5.7.4 The container must be structurally intact after the test

a. After inspecting the container at the end of the test, the container was completely intact.

5.7.1 The permitted concentration of hydrogen fluoride may not exceed the permissible AGEL-2 value of 9.8 mg/m³

The concentration was measured by a Dräger X-am 5100 HCl/HF Global, which was located in the immediate vicinity of the container. There was no measurable HF concentration at any time. In addition, the device has an acoustic warning when the measured value is exceeded; the alarm was not triggered by an increased measured value at any time.

5.8 Conclusion

The DryFire Storage from DryFire serves as a safe temporary storage solution for defective e-vehicle batteries. In order to document the behavior of the storage container in an event of an e-vehicle battery being damaged, this container was tested with an e-vehicle battery with an 800 V system architecture, an 811 NCM cell chemistry and 100% SOC. In addition, another electric vehicle battery with an 800 V architecture was stored in the compartment above and thermally measured during the test to document its integrity. Taking into account the requirements of dangerous goods transport regulations, the requirements of LP906 were adopted as a guideline. The requirements from 5.7.1 to 5.7.4 are taken from LP906 and were fully met with an acceptable temperature exceedance of 4.6 °C for 11 minutes.

The pictures hereunder show the status of the battery at the end of the test.

5.8.1 Key table temperature data

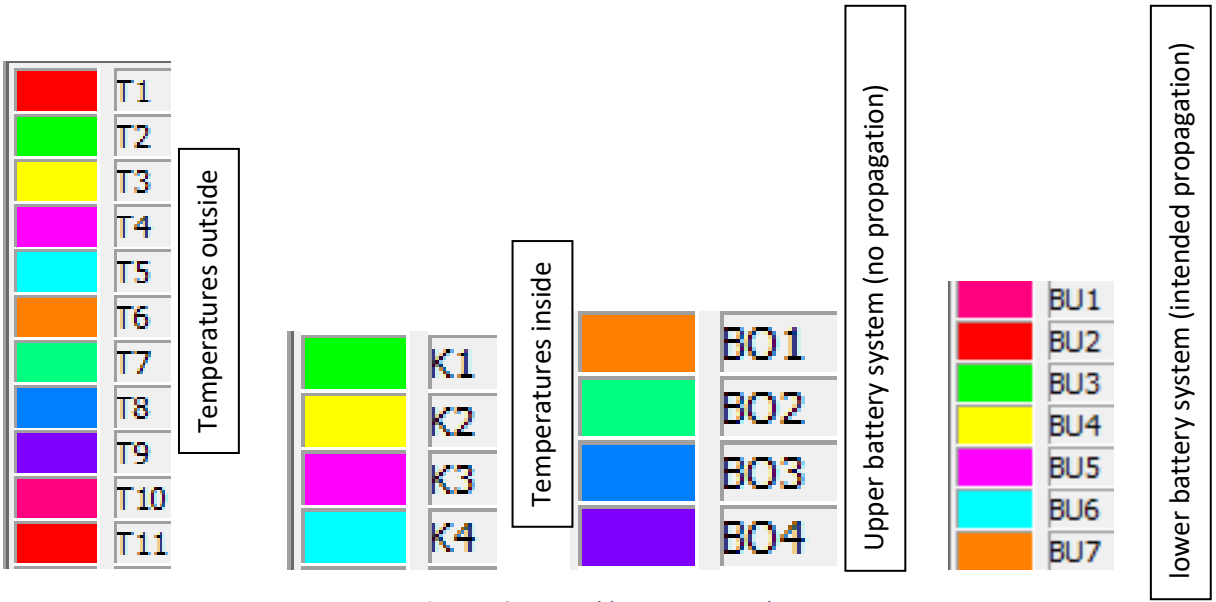
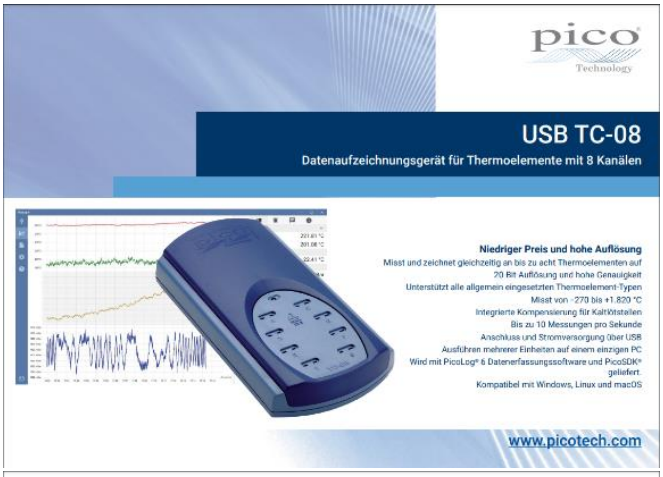
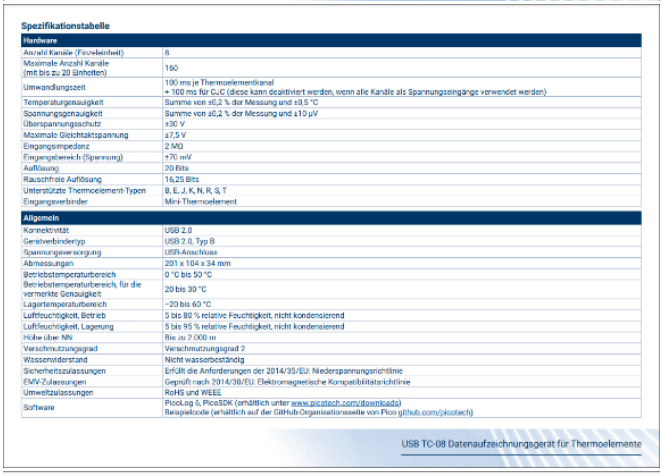


Figure 5.8 – Key table temperature data

6 Appendix

6.1 Data sheets



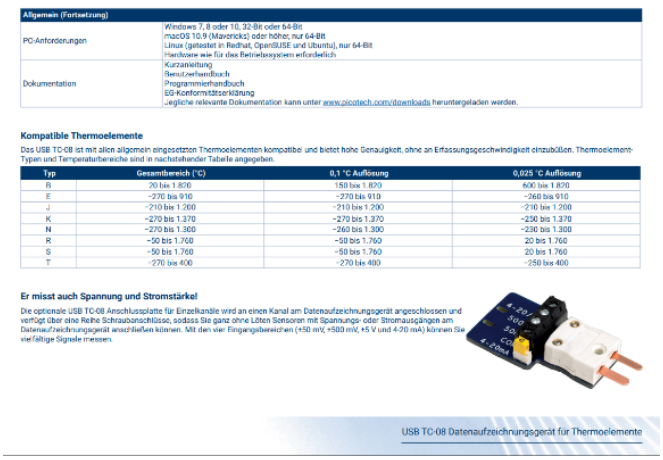


Spezifikationstabelle

Hardware	
Anzahl Kanäle (Einheiteinheit)	8
Maximale Anzahl Kanäle (mit bis zu 20 Einheiten)	160
Umwandlungszeit	100 ms je Thermoelementkanal + 100 ms für CJC (diese kann deaktiviert werden, wenn alle Kanäle als Spannungseingänge verwendet werden)
Temperaturgenauigkeit	Summe von ±0,2 % der Messung und ±0,5 °C
Spannungsgenauigkeit	Summe von ±0,2 % der Messung und ±10 µV
Überspannungsschutz	±30 V
Maximale Gleichtaktspannung	±7,5 V
Eingangsimpedanz	2 MΩ
Eingangsbereich (Spannung)	±70 mV
Auflösung	20 Bits
Rauschfreie Auflösung	16,25 Bits
Unterstützte Thermoelement-Typen	B, E, J, K, N, R, S, T
Eingangsverbinder	Mini-Thermoelement

Allgemein	
Konnektivität	USB 2.0
Geräteverbindertyp	USB 2.0, Typ B
Spannungsversorgung	USB-Anschluss
Abmessungen	201 x 104 x 34 mm
Betriebstemperaturbereich	0 °C bis 50 °C
Betriebstemperaturbereich, für die vermerkte Genauigkeit	20 bis 30 °C
Lagertemperaturbereich	-20 bis 60 °C
Luftfeuchtigkeit, Betrieb	5 bis 80 % relative Feuchtigkeit, nicht kondensierend
Luftfeuchtigkeit, Lagerung	5 bis 95 % relative Feuchtigkeit, nicht kondensierend
Höhe über NN	Bis zu 2.000 m
Verschmutzungsgrad	Verschmutzungsgrad 2
Wasserwiderstand	Nicht wasserbeständig
Sicherheitszulassungen	Erfüllt die Anforderungen der 2014/35/EU: Niederspannungsrichtlinie
EMV-Zulassungen	Geprüft nach 2014/30/EU: Elektromagnetische Kompatibilitätsrichtlinie
Umweltzulassungen	RoHS und WEEE
Software	PicoLog 6, PicoSDK (erhältlich unter www.picotech.com/downloads) Beispielcode (erhältlich auf der GitHub-Organisationsseite von Pico github.com/picotech)

USB TC-08 Datenaufzeichnungsgerät für Thermoelemente



Allgemein (Fortsetzung)	
PC-Anforderungen	Windows 7, 8 oder 10, 32-Bit oder 64-Bit macOS 10.9 (Mavericks) oder höher, nur 64-Bit Linux (getestet in Redhat, OpenSUSE und Ubuntu), nur 64-Bit Hardware wie für das Betriebssystem erforderlich
Dokumentation	Kurzanleitung Benutzerhandbuch Programmierhandbuch EG-Konformitätserklärung Jegliche relevante Dokumentation kann unter www.picotech.com/downloads heruntergeladen werden.

Kompatible Thermoelemente

Das USB TC-08 ist mit allen allgemein eingesetzten Thermoelementen kompatibel und bietet hohe Genauigkeit, ohne an Erfassungsgeschwindigkeit einzubüßen. Thermoelement-Typen und Temperaturbereiche sind in nachstehender Tabelle angegeben.

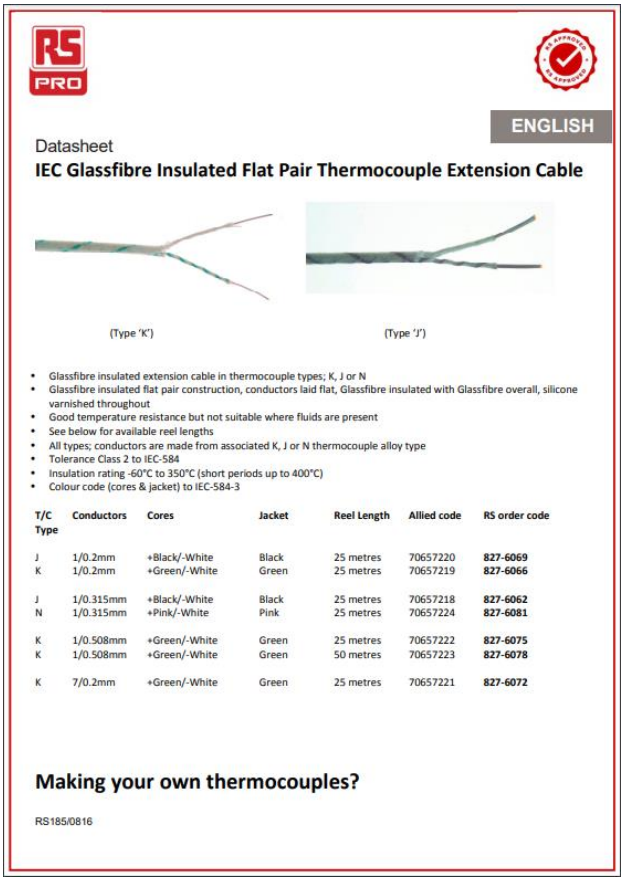
Typ	Gesamtbereich (°C)	0,1 °C Auflösung	0,025 °C Auflösung
B	20 bis 1.820	150 bis 1.820	600 bis 1.820
E	-270 bis 910	-270 bis 910	-260 bis 910
J	-210 bis 1.200	-210 bis 1.200	-210 bis 1.200
K	-270 bis 1.370	-270 bis 1.370	-230 bis 1.370
N	-270 bis 1.300	-260 bis 1.300	-230 bis 1.300
R	-50 bis 1.760	-50 bis 1.760	20 bis 1.760
S	-50 bis 1.760	-50 bis 1.760	20 bis 1.760
T	-270 bis 400	-270 bis 400	-250 bis 400

Er misst auch Spannung und Stromstärke!

Die optionale USB TC-08 Anschlussplatte für Einzelkanäle wird an einen Kanal am Datenaufzeichnungsgerät angeschlossen und verfügt über eine Reihe Schraubanschlüsse, sodass Sie ganz ohne Löten Sensoren mit Spannungs- oder Stromausgängen am Datenaufzeichnungsgerät anschließen können. Mit den vier Eingangsbereichen (±50 mV, ±500 mV, ±5 V und 4-20 mA) können Sie vielfältige Signale messen.

USB TC-08 Datenaufzeichnungsgerät für Thermoelemente

Figure 6.1 – Datasheet PicoLog TC-08



ENGLISH

Datasheet

IEC Glassfibre Insulated Flat Pair Thermocouple Extension Cable

(Type 'K') (Type 'J')

- Glassfibre insulated extension cable in thermocouple types; K, J or N
- Glassfibre insulated flat pair construction, conductors laid flat, Glassfibre insulated with Glassfibre overall, silicone varnished throughout
- Good temperature resistance but not suitable where fluids are present
- See below for available reel lengths
- All types; conductors are made from associated K, J or N thermocouple alloy type
- Tolerance Class 2 to IEC-584
- Insulation rating -60°C to 350°C (short periods up to 400°C)
- Colour code (cores & jacket) to IEC-584-3

T/C Type	Conductors	Cores	Jacket	Reel Length	Allied code	RS order code
J	1/0.2mm	+Black/-White	Black	25 metres	70657220	**827-6069**
K	1/0.2mm	+Green/-White	Green	25 metres	70657219	**827-6066**
J	1/0.315mm	+Black/-White	Black	25 metres	70657218	**827-6062**
N	1/0.315mm	+Pink/-White	Pink	25 metres	70657224	**827-6081**
K	1/0.508mm	+Green/-White	Green	25 metres	70657222	**827-6075**
K	1/0.508mm	+Green/-White	Green	50 metres	70657223	**827-6078**
K	7/0.2mm	+Green/-White	Green	25 metres	70657221	**827-6072**

Making your own thermocouples?

RS185/0816

Figure 6.2 – Datasheet TC extension cable

DEUTSCH

Datenblatt

Miniatur-Thermoelementstecker nach IEC, In-Line-Stecker

Typen K, J, T, E, N, R/S, B und Kupfer
(IEC-Farbcodierung)

- Serie von Miniatur-Thermoelementsteckverbindern mit Flachstiften, passend für Thermoelement-Typ
- Ideal für Universalanwendungen geeignet
- Alle Kontakte polarisiert, um korrekten Anschluss zu gewährleisten.
- Die Steckverbinder sind für Thermoelementkabel mit bis zu 4 mm Durchmesser geeignet
- Kabelklemme zur Befestigung des Kabels am Stecker erhältlich
- Erhältlich mit den Thermoelementtypen K, J, T, E, N, R/S, B und Kupfer
- Für die Typen K, J, T, E und N bestehen die Kontakte aus echten Thermoelement-Legierungen
- Typ R/S verfügt über kompensierende Kupfer/Kupfernickellegierungskontakte (für Thermoelemente des Typs R oder S)
- Typ B verfügt über kompensierende Kupfer/Kupferkontakte (für Thermoelemente des Typs B)
- Farbcodierung gemäß IEC-Spezifikation
- Maximale durchgehende Betriebstemperatur: 220 °C

Thermo-element-typ	Farbcode (IEC)	+Positiver Kontakt (Legierungstyp)	-Negativer Kontakt (Legierungstyp)	Allied-Code	Best.-Nr.
K	Grün	+Nickel-Chrom	-Nickellegierung	70644391	**455-9764**
J	Schwarz	+Eisen	+Kupfer-Nickel	70644387	**455-9714**
T	Braun	+Kupfer	+Kupfer-Nickel	70644402	**455-9922**
E	Violett	+Nickel-Chrom	+Kupfer-Nickel	70652488	**774-7185**
N	Rosa	+Nickel/Chrom/Silizi	-Nickel-Silizium	70644396	**455-9843**
R/S	Orange	+Kupfer	-Kupferlegierung	70644399	**455-9887**
B	Grau	+Kupfer	-Kupfer	70652487	**774-7181**
Kupfer	Weiß	+Kupfer	-Kupfer	70644384	**455-9679**

RS139/0816

Figure 6.3 – Datasheets TC Plugs

6.2 List of figures

Antonio Nedjalkov
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