Report

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Container for battery electric vehicles unsafe for transport based on LP906 and P911

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

1 General information

Report number	VL0001/23/0507		
Test executed	Christian Redlich	Sascha Bruns	Madeleine Stahl
Report reviewed	Sascha Bruns	Antonio Nedjalkov	
Report approved	Sascha Bruns	Antonio Nedjalkov	
Pages	16		
Date of test	2023-07-05		
According to standard	Based on LP906/P911		
Published	2023-09-192023-09-19		
Test lab			
Name	Fraunhofer HHI	VoltaLabs GmbH	
Address	Am Stollen 19H D-38640 Goslar Deutschland	Schützenallee 10 D-38640 Goslar Deutschland	
Customer			
Name	Dry Fire System GmbH		
Address	Leonberger Straße 22 • 71272 Renningen		
Manufacturer			
Name	Dry Fire System GmbH		
Adress	Leonberger Straße 22 • 71272 Renningen		
Description test sample	Container for battery electric vehicles unsafe for transport		
Model			
Dimensions	HxWxL:		

2 Test key data

Name	
Type	Container for battery electric vehicles 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	2023-07-03
Test performed	2023-07-05 –2023-07-06

Version	**Report number**	**Revision**	**Comment**
V1.0	145-613-2023-0028.1		

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	Sample number	Standard	Result
Temperature on outer surface < 100 °C		According to LP906/P911	
No Flames outside		According to LP906/P911	
No fragments or projectiles		According to LP906/P911	
Structural Integrity		According to LP906/P911	
AGEL-2 HF <9.8 mg/m³		According to LP906/P911	

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

4 Test Equipment

Name	Art	Typ
Picologger	Datalogger	TC-08 USB
PicoLog 6	Software for Datalogger	PicoLog6
Hioki	Voltage datalogger	LR8431-20
Logger Utility	Software for voltage datalogger	Logger Utility Hioki
Sony	Video camera	
HF-Messgerät	HF measuring device	Dräger X-am 5100 HCl/HF Global
Thermal camera	Thermal camera	
Infrared camera	Infrared camera	

5 Test method and data

5.1 Objective

A container for battery electric vehicles unsafe for transport was tested on July 5, 2023. It was performed with a battery electric vehicle with a built-in battery system. The battery system had a nominal energy of 100 kWh at 100% state of charge.

The objective of the test was to verify the resistance of the container to possible damage scenarios, such as thermal runaway or during transport and storage, and to associate consequences for the environment of the container.

The necessary criteria are specified by the transport regulations LP906 and P911:

- temperature on the outer sides may not exceed 100 °C
- no flames on the outside of the container
- no ejection 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 Battery System

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

5.3 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 vehicle was provided by the customer with a pre-prepared battery system and positioned in the test specimen by the test laboratory.

The inside of the container was prepared with an extinguishing material on the walls, floor and ceiling. As a final test preparation, the necessary TCs (thermal measuring elements) were additionally attached.

On the inside, the container was equipped with 18 TCs to determine the temperatures at the extinguishing agent pads and to be capable of assessing the temperature difference to the outer walls.

The vehicle and battery system also contained 12 TCs, which should enable an assessment of the TR.

The container is equipped with 15 TCs on the outside in order to be able to record the outside temperatures on the housing. The TC "S1" is also attached to the gas management system (6 pressure relief flaps on the top) of the container.

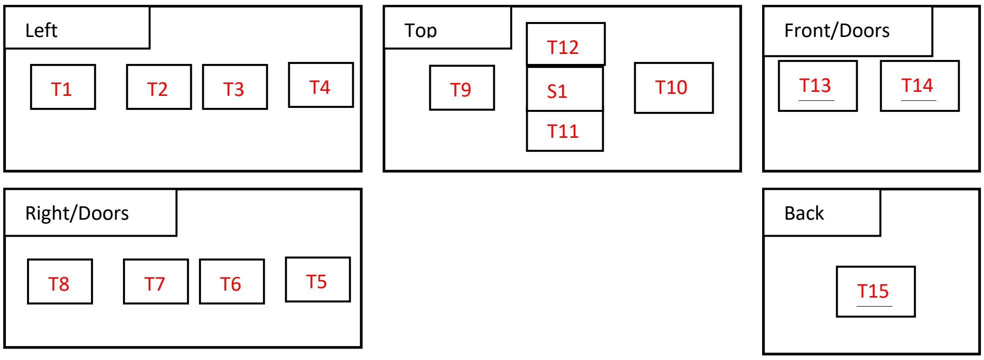

Figure 5.1 – External TC distribution

5.3.3 Measurement and camera systems

For the video recording, 3 HD cameras were chosen in order to be able to view all sides of the container. In addition, a thermal camera was used for the side doors, as well as 2 infrared cameras for the interior of the container. One infrared camera was placed inside the vehicle.

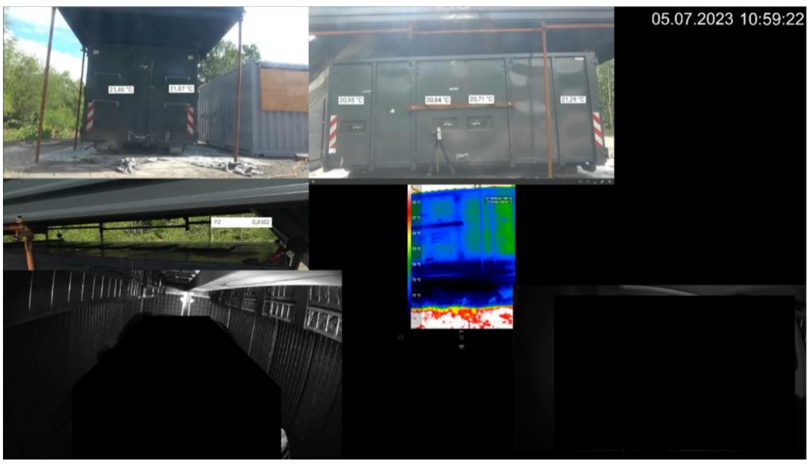

Figure 5.2 – Camera Views

6 TC-08 USB data loggers from the company PicoTech with the associated PicoLog 6 software were used as the measurement system for the temperature data. For recording the pressure data, voltage loggers from the company Hioki with the Logger Utility software were used.

A gas measuring device from Dräger was used to determine the gas concentration. The measuring device was positioned at a lateral distance of approximately 1 m from the side doors.

5.4 Test procedure

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

1. Triggering 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 video and data recording were started at 10:59.07, therefore marking the time of the testing. At this time, the temperature of the overall setup was around 20 °C.

Heating of the battery system was started at 11:04.03. Heat development in the battery system was verified via the temperature recording. An average temperature increase of 48.74 K/min has been determined.

At 11:08.11 the TR finally occurred, this was detectable by a sudden increase in TC "T16" - "T22".

2 minutes later, at 11:10.04, there was a flash or spark at the rear of the vehicle, which could be seen on the infrared camera inside the container. This time marks the start of the propagation phase at the latest.

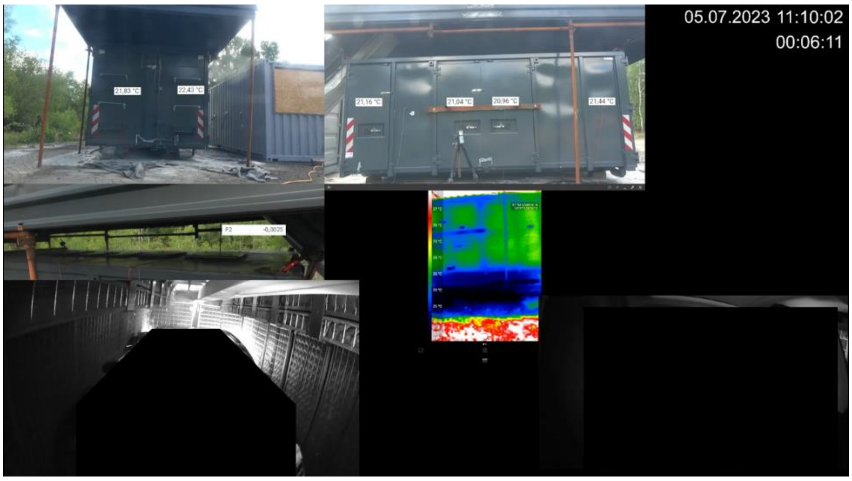

Figure 5.3 – Electrical event in rear of car

5.5 Propagation

Propagation of the battery system continued until about 11:44; this time can be reproduced by a steady drop at TC "T16". The timings could also be verified by the video and additional temperature data. Thus, the entire propagation took place within 40 minutes. A periodic, partly strong emission of smoke could be repeatedly observed.

5.5.1 Observation

When no further reaction was recorded at 11:53, the reaction phase was completed and observation of the container began. The data recording was maintained until 13:18.

No flame or projectile leaks were recorded during the entire test, nor were any temperatures above 100 °C reached on the outer sides. Although peaks of over 100 °C were recorded in the measured data at the 2 loading doors, they were <3 s long. It can therefore be assumed that these must have been measurement errors.

5.6 Analysis

5.6.1 Heating

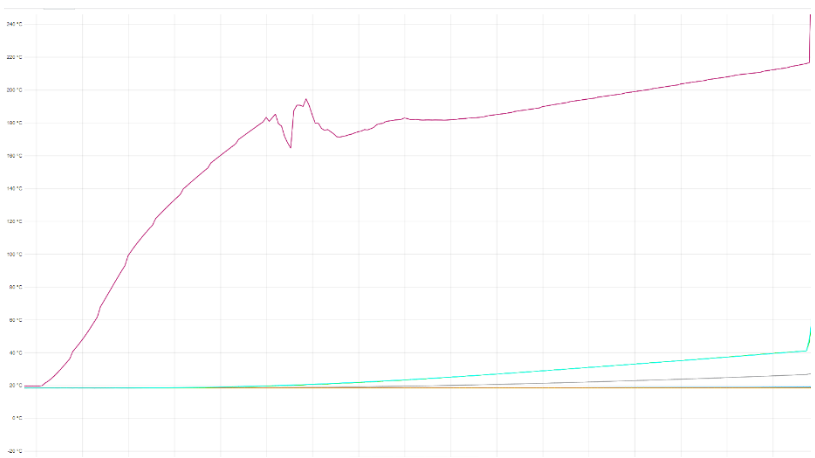

Figure 5.4 – Heating

The heating phase started at a system temperature of about 20 °C and the TR could be reached at a temperature of 216.42 °C. The average temperature gain was 48.75 K/min.

5.6.2 Propagation

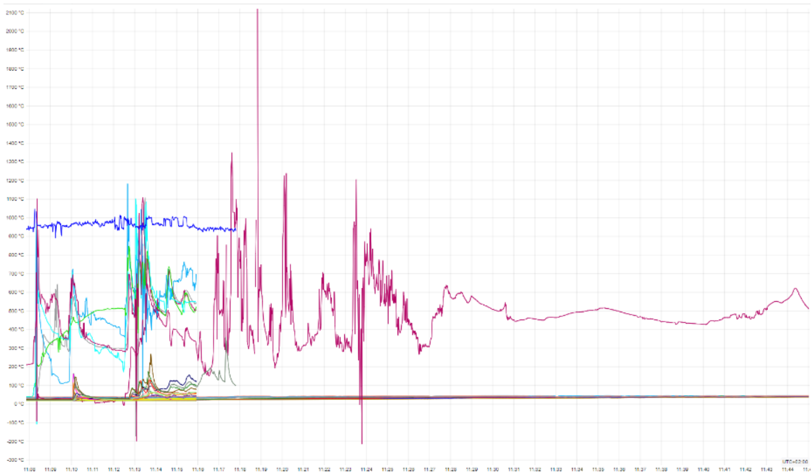

Figure 5.5 – Temperatures during Propagation

At the beginning of propagation, temperatures of up to 1,100 °C were reached in the interior, which reached the measuring range limit of the TC during propagation.

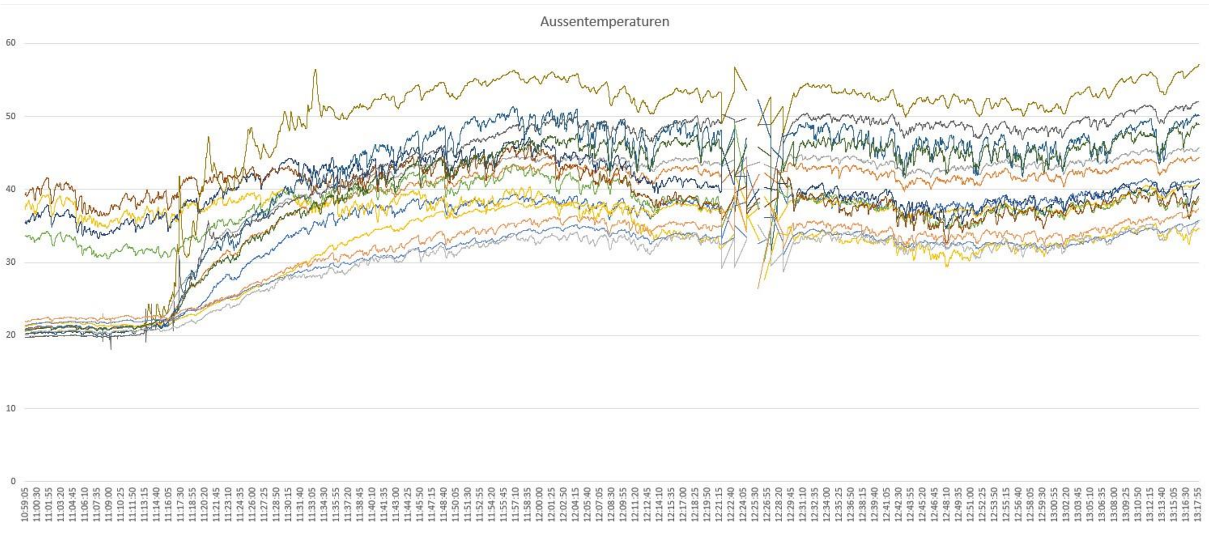

Figure 5.6 – Propagation temperatures outside

During the entire reaction phase, no temperature above 100 °C was reached on the outside of the container. The highest measured temperatures on the container's outer sides of 56.52 °C were reached in the area of the pressure relief flaps.

5.6.3 Observation

Figure 5.7 – Temperatures during observation

At the beginning of the observation phase, the temperature inside the battery system was still around 600 °C, although this decreased steadily over the entire observation period. Thus, it could be validated that no further reaction took place.

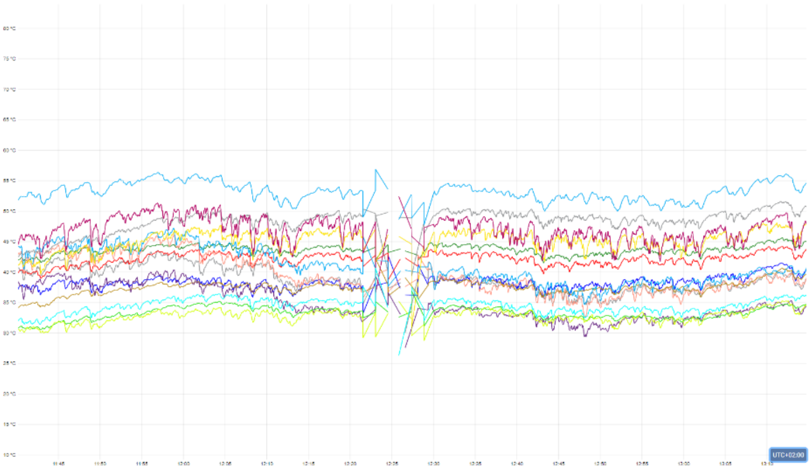

Figure 5.8 – Outside temperatures during observation

In addition, no temperature above 100 °C was reached on the outer surfaces during the observation period.

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 indicated in the previous chapter, no temperatures of 100 °C were exceeded on the outer surfaces during both the reaction and the observation phase.

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 are 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.

5.7.5 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 HCI/HF Global, which was located in the immediate vicinity of the container. There was no measurable HF concentration at any time.

5.8 Conclusion

The DryCon from the company DryFire serves as a safe interim storage solution for defective electrical vehicles. In order to document the behavior of the container in case of an accident of an electrical vehicle, this container was tested with an electrical vehicle with an 800 V system architecture, an 811 NCM cell chemistry and 100% SOC. Considering the claims of standards for hazardous materials transportation, the claims of LP906 were adopted as a guideline. The requirements from 5.7.1 to 5.7.4 originate from LP906 and were fully met.

5.8.1 Key table temperature data

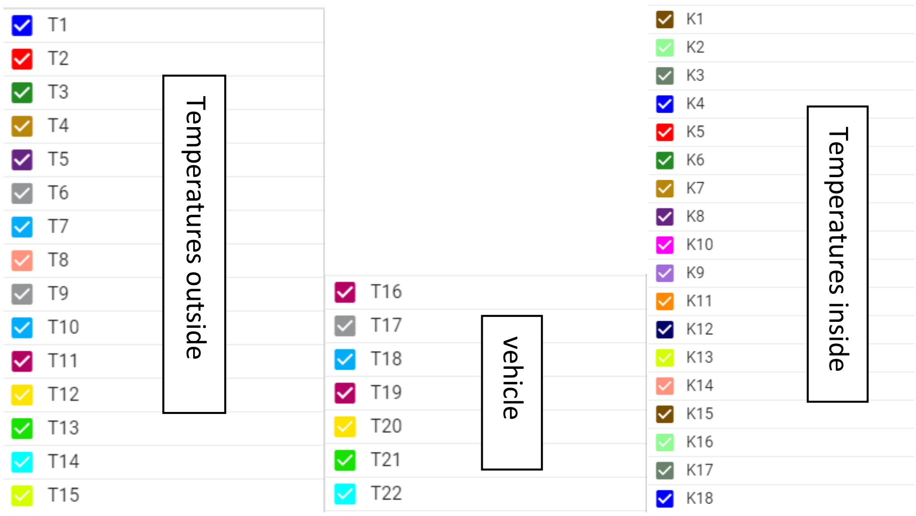

Figure 5.9 – Key table temperature data

6 Appendix

6.1 Data sheets

pico Technology

USB TC-08

Datenaufzeichnungsgerät für Thermoelemente mit 8 Kanälen

Niedriger Preis und hohe Auflösung
Misst und zeichnet gleichzeitig an bis zu acht Thermoelementen auf
20 Bit Auflösung und hohe Genauigkeit
Unterstützt alle allgemein eingesetzten Thermoelement-Typen
Misst von -270 bis +1.820 °C
Integrierte Kompensierung für Kaltlötstellen
Bis zu 10 Messungen pro Sekunde
Anschluss und Stromversorgung über USB
Ausführen mehrerer Einheiten auf einem einzigen PC
Wird mit PicoLog® 6 Datenerfassungssoftware und PicoSDK® geliefert.
Kompatibel mit Windows, Linux und macOS

www.picotech.com

Spezifikationstabelle

Hardware	
Anzahl Kanäle (Einzeleinheit)	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
Gerätverbindertyp	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	-250 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 Abbildungsverzeichnis

Antonio Nedjalkov

Digital unterschrieben von Antonio Nedjalkov
Datum: 2023.09.19 13:44:04 +02'00'