**Test Specification for Capacity, energy and energy efficiency at different discharging- C-Rates**

Project-ID: -

Sample phase: -

Supplier: -

Version:-

**Daimler Truck AG**

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Release and Version History

Table 1: Version history

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Version** | **Date** | **Change** | **Sections**  **/Test-ID** | **Author** | **Released** |
| 1.0 | 08.03.2024 | Creation of document. Document is based on former OAD-528 part 1 V2.3 (29.01.2024) | All | C. Subramanian;  T. Herdt |  |

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# Aim of the document

The aim of this test specification is to characterize Li-Ion cells according to a standardized test procedure to fulfill the customer requirements. The recorded data and calculated parameters leads to comparable, reproducible results in the various development stages during the cell qualification process between cell supplier, customer and test institutes.

# List of abbreviations

BOT Begin of Test

CNOM Nominal Cell Capacity

CRPT Cell Capacity of the latest RPT Procedure Test Cycle

Cx,y,CH Charge Capacity during RPT Procedure at Current x and Temperature y

Cx,y,DCH Discharge Capacity during RPT Procedure at Current x and Temperature y

CC Constant Current

CCCV Constant Current – Constant Voltage

CH Charge

CV Constant Voltage

DCH Discharge

Ex,y,CH Charge Energy during RPT Procedure at Current x and Temperature y

Ex,y,DCH Discharge Energy during RPT Procedure at Current x and Temperature y

EOL End of Life

EOT End of Test

ETP Cumulated Energy Throughput of whole Test

INOM Nominal Current (see section 4.2)

IRPT Current based on RPT capacity (see section 4.2)

n Number of CCCV Cycle Repetitions between RPT Procedures

OCV Open Circuit Voltage

Ri Internal Resistance as measured during RPT Procedure

RPT Reference Parameter Test, see DTC-O-5

SOC State of Charge (referenced to lates RPT capacity CRPT)

SOCstorage Defined SOC Condition for Cell Storage

SOHRPT State of Health (Current CRPT referenced to initial CRPT)

Tchamber Temperature of the Climate Chamber

Vdyn,min Minimum Allowed Voltage according to Operating Window (Under Load)

Vdyn,max Maximum Allowed Voltage according to Operating Window (Under Load)

η Efficiency

# List of references

[DTC-O-1] Testing Quality

[DTC-O-2] Measurement Data Specification

[DTC-O-3] Template for test reports

[DTC-O-4] Operating window cell

[DTC-O-5] RPTs for service life and environmental tests

[DTC-O-6] Cell jig handling manual

[DTC-O-7] Data tables for test reports

# Test Description

This test determines the capacity, energy and energy efficiency of the cell. This test is conducted under performance tests as well as a part of the RPT to evaluate the electrical parameters of the cell.

## Test equipment and setup

* Climate chamber: **25 °C**
* DC-converter: **2.2 C**

Jigs and compression forces shall be applied as specified in component requirement specification or in cell specific handling manual according to DTC-O-6.

The test setup and all equipment shall be chosen based on the requirements. Additionally, the special requirements from DTC-O-1 concerning testing quality measures and allowable testing tolerance shall be met.

## General Definitions for capacity *CRPT*, *CC/x,25°C,* -capacity, *EC/x,25°C* -energy and energy efficiency η*C/x,25°C* at different discharging C-rates

1. CNOM = xx Ah

Explanation: CNOM is the specified nominal cell capacity. It does not change throughout test duration.

1. CRPT = CRPT,X after cycle X

Explanation: CRPT is the reference CCCV discharge capacity of the latest RPT process. Therefore, CRPT is regularly updated throughout the test duration, whenever an RPT process is conducted.

1. Cx,y,DCH

Explanation: Cx,y,DCH is the discharge capacity of the CC process (without CV phase) at a current rate x and a temperature y.  
E.g. CC/3,25°C,DCH means the discharge capacity at 25 °C and a current rate of C/3.

1. SOC = *Qel* / CRPT  
   Explanation: The state-of-charge (SOC) of the battery cell is calculated based on the current electrical charge load of the cell referenced to CRPT. This is to be done even in case CRPT > CNOM (in contrast to definition 8).
2. SOHNOM = CC/3,25°C,DCH / CNOM

Explanation: The SOHNOM is calculated based on the latest CC/3,25°C,DCH capacity (from RPT process; only CC discharge capacity, without CV phase) referenced to the nominal capacity.

1. SOHRPT = CRPT / CRPT,0

Explanation: The SOHRPT is always calculated based on the latest RPT capacity referenced to the first RPT capacity.

1. INOM = CNOM / h  
   Explanation: Currents INOM are always based on the nominal cell capacity (CNOM) and do not change throughout the test duration.
2. IRPT = CRPT / h if CRPT < CNOM

IRPT = INOM if CRPT ≥ CNOM

IRPT = INOM before conduction of any RPT procedure

Explanation: Currents IRPT shall generally be based on the capacity of the latest RPT procedure (CRPT). In case the measured value of CRPT is higher than CNOM, the currents of IRPT shall be calculated based on CNOM and therefore equal the current INOM. This is to prevent high currents outside of the specified operating window.  
Additionally, in case an IRPT current is to be applied on a fresh cell that has not experienced any RPT procedure so far, IRPT shall also equal INOM.

1. Current Derating  
   Explanation: Unless otherwise specified, the applied current shall be derated in case the currents violate the operating window at any SOC for a given temperature throughout the charging or discharging process.

## Specific Description of the Test / Testplan

Table 2: Test procedure for determination of capacity *CRPT*, *CC/x,25°C*, *EC/x 25°C* and η*C/x,25°C* at different discharging C-rates*.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Step** | **Command** | **Parameter** | **Exit Condition** | **Comment** |
|  | **CYCLE-START-1** |  |  | **Pre-Cycle** |
|  | Set Temperature | *T* = 25 °C |  | Set temperature of climate chamber to 25°C |
|  | Rest |  | *t* > 30 min\* | Resting time for thermal relaxation of the cell.  \*Rest the cell for each Kelvin temperature difference (difference initial climate chamber temperature to set climate chamber temperature) 6 min, at least 30 min. |
|  | Discharge | *I* = INOM/3 | *V* < Vdyn,min | CC part of CCCV discharge |
|  | Discharge | *V* = Vdyn,min | *I* < 0.05⋅ INOM | CV part of CCCV discharge |
|  | Rest |  | *t* > 30 min |  |
|  | Charge | *I* = IRPT/3 | *V* > Vdyn,max | CC part of CCCV charge. |
|  | Charge | *V* = Vdyn,max | *I* < 0.05⋅ IRPT | CV part of CCCV charge |
|  | Set | Ah-Set = 0 |  | A fully charged cell is defined as 0 Ah. |
|  | Rest |  | *t* > 30 min |  |
|  | **CYCLE-END-1** | **COUNT = 1** |  |  |
|  | **CYCLE-START-2** |  |  | **CRPT Determination** |
|  | Discharge | *I* = INOM /3 | *V* < Vdyn,min | CC part of CCCV discharge |
|  | Discharge | *V* = Vdyn,min | *I* < 0.05⋅ INOM | CV part of CCCV discharge.  **Determination of CRPT:** Set CRPT to the combined CCCV capacity of steps 13 and 14. |
|  | Rest |  | *t* > 30 min |  |
|  | Charge | *I* = IRPT/3 | *V* > Vdyn,max | CC part of CCCV charge |
|  | Charge | *V* = Vdyn,max | *I* < 0.05⋅ IRPT | CV part of CCCV charge |
|  | Set | Ah-Set = 0 |  | A fully charged cell is defined as 0 Ah. |
|  | Rest |  | *t* > 30 min |  |
|  | **CYCLE-END-2** | **COUNT = 1** |  |  |
|  | **CYCLE-START-3** |  |  | **Cycle for determination of discharge capacity *CC/x,25°C*, energy *EC/x,25°C* and energy efficiency η*C/x,25°C*** |
|  | Discharge | *I* = xx\* | *V* < Vdyn,min | Determination of discharge capacity and energy.  Discharge with CC to lower dynamic voltage.  If I = *C/x*: Determination of *CC/x,25°C, EC/x,25°C* from step 22.  I is chosen according to the supporting points in Table 3 or DTC-O-5. |
|  | Rest |  | *t* > 30 min |  |
|  | Charge | *I* = IRPT/3 | *V* > Vdyn,max | CC part of CCCV charge |
|  | Charge | *V* = Vdyn,max | *I* < 0.05⋅ IRPT | CV part of CCCV charge. Calculate energy efficiency η*C/x,25°C* from step 22 and 25. |
|  | Rest |  | *t* > 30 min |  |
|  | **CYCLE-END-3** | **COUNT = xx** |  | **Number of cycles is equal to number of capacity cycles listed in Table 3** |
|  | Discharge | *I* = INOM / 3 | SOC = 30 % | Use this step only if no other tests are planned directly afterwards |

If there are several supporting points to be tested, repeat steps 22 to 26 for all measurements at the same temperature. The “Ah-counter” determined in steps 9 to 18 needs to be respected at all time.

In order to determine *CC/x,25°C*, *EC/x 25°C* and η*C/x,25°C­* please use the following supporting points:

* Table 3 for **Performance tests**
* DTC-O-5 for RPT during **service life tests**

Table 3: Supporting points for performance tests.

|  |  |  |
| --- | --- | --- |
| **Order of capacities to test** | **I / A** | **No. of cycles** |
|  | 2C | 1 |
|  | 1C | 1 |
|  | C/2 | 1 |
|  | C/3\* | 1 |
|  | 0.3C | 1 |
|  | C/5 | 1 |
|  | C/10 | 1 |

\*Energy efficiency shall be calculated for C/3 cycle only (cycle 4).

# Evaluation and reports

All measuring data shall be provided according to measurement data specification DTC-O-2 as per the latest version.

Please provide plots as test report according to DTC-O–3.The data tables pertaining to plots shall be provided in excel format according to DTC-O-7.