ECPE Guideline PSRRA 02

Railway Applications

HTC-CRB (Humidity Temperature Cycling – Cold Reverse Bias) test for Power Semiconductor

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Preface

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HTC-CRB test for Power Semiconductor

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1 Scope

This document describes a Humidity Temperature Cycling – Cold Reverse Bias (HTC-CRB) test for the evaluation of the behaviour of non-hermetically sealed power electronic IGBT and SiC MOSFET modules for the use in rolling stock applications.

2 Normative references

Standard	Date of Issue	Title
IEC 60749-5	2017-04	Semiconductor devices – Mechanical and climatic test methods – Part 5: Steady-state temperature humidity bias test
IEC 60068-2-67	1995	Environmental testing – Part 2-67: Tests – Test Cy: Damp heat, steady state, accelerated test primarily intended for components
IEC 60068-2-30 Db	2005 – 08	Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 + 12 h cyclic)
IEC 60747-9	2007-09	Semiconductor devices – Discrete devices – Part 9: Insulated-gate bipolar transistor (IGBTs)
IEC 60747-2	2016-04-13	Semiconductor devices - Part 2: Discrete devices - Rectifier diodes
IEC 60747-15	2010-12-16	Semiconductor devices - Discrete devices - Part 15: Isolated power semiconductor devices

3 Abbreviations

DS	Datasheet
T_a	Ambient temperature
V_{ISO}	Isolation test voltage
V_{DC}	Applied DC-voltage
V_{CES}	Collector-Emitter voltage with Gate-Emitter short-circuited
V_{DSS}	Drain-Source voltage with Gate-Source short-circuited
V_{CEsat}	Collector-Emitter saturation voltage of IGBT
$R_{DS(on)}$	Drain-Source on-resistance of MOSFETs
V_F	Forward voltage drop of Diode
V_{SD}	Forward voltage of the internal body diode (corresponds to the voltage of the Drain-Source path in reverse operation)
$V_{GE,th}$	Gate-Emitter threshold voltage of IGBT
$V_{GS,th}$	Gate-Source threshold voltage of MOSFET
I_{CES}	Collector-Emitter cut-off current, Gate-Emitter short-circuited
I_{GES}	Gate-Emitter leakage current, Collector-Emitter short-circuited

I_{DSS}	Drain-Source leakage current
I_{GSS}	Gate-Source leakage current

4 Definitions

4.1 HTC-CRB Test

The HTC-CRB test is conducted by applying a cyclic climate to induce condensation effects in power modules. The test procedure described in IEC 60068-2-30 (test Db) is adapted to the requirements of railway applications. If there is a contradiction between this document and IEC 60068-2-30, the statement of this document takes priority over IEC 60068-2-30. The overview of the test procedure is outlined in Figure 1. Details of the test conditions are described in chapter 6.

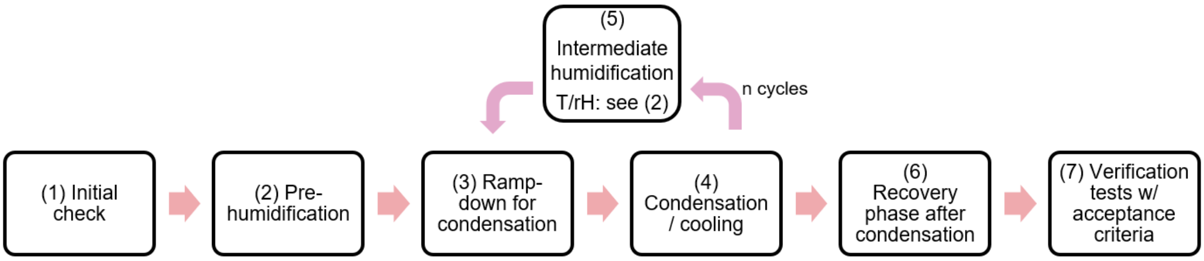

Figure 1: Overview of the HTC-CRB **test process for railway applications**

A test voltage is applied only in step (1) and step (7) of the test procedure. The details are described in chapter 6.1.1 (initial check) and chapter 6.2 (acceptance criteria).

During the climatic chamber test no voltage is applied to avoid any self-heating on device level by leakage current induced power losses. Thereby, the application use case is simulated that trains are put out of operation during night-time and restarted on the following day, which is regarded as the worst-case situation with respect to condensation conditions.

4.2 Voltage classes

The test is applicable for the standard IGBT and SiC MOSFET power module voltage classes for rolling stock applications, ranging up to 6500V.

4.3 Diffusion time for humidity τ :

The parameter τ is defined as the characteristic time constant for diffusion of humidity into a power module.

In the context of this guideline, the quasi-steady state model is assumed to approximate the time dependence of concentration of humidity c(t) in a power module, when a step like change of the ambient concentration happens [1)]. The mathematical description is given by the formula:

$$c(t) = c_a - (c_a - c_0)exp\left(\frac{-t}{\tau}\right) \qquad (1)$$

With the following abbreviations for the suffixes in equation (1): c_0: concentration at t=0, c_a: ambient moisture concentration.

In case of isothermal boundary condition, the change in concentration transforms proportionally into the change of relative humidity and the above-mentioned equation leads to the following dependency for rH

$$rH(t) = rH_a - (rH_a - rH_0)exp\left(\frac{-t}{\tau}\right) \qquad (2)$$

τ can thus be determined by measuring the step response of rH(t) in a power module and deriving τ by fitting the curve according to equation (2) to the experimental data.

5 General conditions

The general construction requirements for the test chamber are as defined in IEC 60068-2-30 and IEC 60068-2-67. The tolerances for humidity are according to IEC 60068-2-67. The details of the test severities and the test procedure for the cyclic testing are as defined in chapter 6 of this guideline.

The following definition shows typical number of test devices with new chip design and new packages. The use of generic “family data” to simplify the qualification process is accepted.

Recommended number of samples:

Criteria	Sample number
Min. number of modules	9
Min. number of modules per lot	3
Min. number of module production lots	3
Min. number of chips	72 transistors (IGBTs or MOSFETs) and diodes each
Min. number of chip production lots	3

6 Test requirements for the HTC-CRB test

6.1 Test conditions during test procedure

In the following sub chapters the relevant conditions for each step in the test procedure according to chapter 4.1 are described in detail.

6.1.1 Initial check (step 1)

During the initial check an initial characterisation must be done that includes all parameters which are applied as post-test acceptance criteria according to Table 1.

In addition, an ICES-check under DC voltage must be performed under the following conditions:

- V_{DC} = 0.8 x V_{CES}
- $Dv/dt_{10\%-90\%}$ >= 100V/ms (average voltage slope between 0.1*V_{DC} and 0.9*V_{DC} during ramp up of voltage to V_{DC})
- T_a = [room temperature]

- $t \geq 3min$
- mounting of modules on a heatsink is acceptable to avoid thermal runaway due to leakage losses (optional).

During the ICES-check, the ICES(t) must be recorded at a sampling rate that is sufficiently high to capture transient changes. The requirement is 1 sample per second (The recommendation is at least 5 samples per second).

6.1.2 Pre-humidification (step 2)

The pre-humidification humidity is defined as the relative humidity in the test chamber and shall be set to 85%. The tolerance for the humidity is ±5% according to IEC 60068-2-67.

The pre-humidification temperature is defined as the ambient temperature in the test chamber and shall be set to either 35°C (severity level I) or 45°C (severity level II). The tolerance for the temperature is ±2° according to IEC 60068-2-67.

The duration of pre-humidification depends on the use case:

- Power modules without a hard epoxy layer above the silicone gel: duration shall be set to at least 3τ, but may be limited to 35h in case $3\tau>35h$.
- Power modules with a hard epoxy layer above the silicone gel, which seals the inside of the power module from the external air: Duration shall be set to at least 3τ, but may be limited to 1000h in case $3\tau>1000h$.

  Note: The pre-humidification step may be accelerated by dividing it into 2 intervals: A first interval, where the temperature is raised above the target pre-humidification temperature and a second interval at the target pre-humidification temperature. During the first interval the diffusion of humidity is accelerated by the higher temperature. The duration of the first interval should be set, so that an absolute humidity content is reached, which is within the range of tolerance for the absolute humidity content according to severity level I or II. The second interval stabilizes the conditions.

  Note: The plastic frame and lid of the power module do not constitute the "hard epoxy layer" described in the above paragraph

The test clock for the duration of pre-humidification runs between the end of ramp-up and the beginning of ramp-down.

Note: The pre-humidification humidity can be set to higher than 85 % and the pre-humidification ambient temperature can be set to higher than 35°C (severity level I) or 45°C (severity level II), if the test conditions are documented in the relevant specification.

6.1.3 Ramp-down for condensation (step 3)

During the ramp-down for condensation the ambient temperature in the test chamber is lowered from the pre-humidification temperature down to T=10°C. The rate of change of the ambient temperature shall be in the range of $dT/dt=-1.5 \pm 0.5$ K/min.

The relative humidity does not need to be controlled during the ramp-down phase.

Note: The rate of change of the ambient temperature can be set to higher than 2.0 K/min, if the test conditions are documented in the relevant specification.

6.1.4 Condensation / Cooling (step 4)

The temperature during the condensation/cooling-phase is defined as the ambient temperature in the test chamber and shall be set to 10°C.

The humidity during the condensation/cooling-phase is defined as the relative humidity in the test chamber and shall be set to 45%. The tolerance for the humidity is ±5% according to IEC 60068-2-67, which has to be met after a phase of stabilisation of the climatic chamber.

The duration of the condensation/cooling-phase shall be in the range of t=1.5h ± 10min.

Note: The ambient temperature during the condensation/cooling-phase can be set to lower than 10°C and the duration of the condensation/cooling-phase can be set to longer than 100 min, if the test conditions are documented in the relevant specification.

6.1.5 Intermediate-humidification (step 5)

The relative humidity and the temperature in the test chamber are ramped up to reach the values as defined during the Pre-humidification. The rate of change of the ambient temperature shall be in the range of dT/dt=+1.5 ± 0.5 K/min.

Note: The rate of change of ambient temperature can be set to higher than 2.0 K/min, if the test conditions are documented in the relevant specification.

The duration of intermediate-humidification shall be in the range of t=10 ± 1 h. The test clock for the duration of intermediate-humidification runs between the end of ramp-up and the beginning of ramp-down.

After the intermediate-humidification is finished the following steps are repeated in a cyclic manner:

- Ramp-down for condensation: conditions as described in 6.1.3
- Condensation / Cooling: conditions as described in 6.1.4
- Intermediate-humidification: conditions as described in 6.1.5 (1st and 2nd paragraph)

To determine the required number of cycles, either one of the 2 criteria shall be met:

a) The number of cycles n_{cyc} is high enough to reach a stable, saturated content of humidity inside of the silicone gel,
b) If n_{cyc}, which satisfies a) is not known, n_{cyc} shall be defined based on the real-life mission profile as the number of days, which trains could be stored without operation under outdoor conditions. This value is set to n=150 based on investigations within the Pinta project.

The number of cycles n_{cyc} depends on the chosen severity level in the following manner:

- Severity level II (T=45°C during pre-humidification and intermediate humidification): n_{cyc}=10. The last cycle ends after completion of the condensation/cooling phase

  Note: Weight measurements of the content of humidity inside of silicone gel samples have shown that under conditions as specified for severity II, within 10 cycles the content of humidity saturates

- Severity level I (T=35°C during pre-humidification and intermediate humidification): n_{cyc}=150. The last cycle ends after completion of the condensation/cooling phase

  Note: At the time of compilation of this guideline, no weight measurements under severity I conditions are available, at which the saturation of the humidity content occurs, which can be used to define n_{cyc}. If those measurements are available, n_{cyc} may be reduced below 150 cycles. Due to the lower temperature level at severity I compared to severity II, diffusion phenomena for humidity intrusion are slowed down and n_{cyc} is expected to be higher compared to severity level II.

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Note: The number of cycles can be set to higher values, if the test conditions are documented in the relevant specification.

Note: The duration of intermediate-humidification per cycle can be reduced in a way that the total duration of all intermediate-humidification phases is equal or greater than the total duration of all intermediate-humidification phases according to chapter 6.1.5, which is given by $t_{total} = n_{cyc} * 10h$. The duration of intermediate-humidification per cycle shall not be set below 1h to allow for a complete heating up of the specimen during intermediate-humidification. The modified test conditions must be documented in the relevant specification.

6.1.6 Recovery phase after condensation (step 6)

The relative humidity and the temperature in the test chamber are ramped to reach values which are comparable to conditions under room temperature atmospheric storage, such as T=25°C and rH=50%. The rate of change of the ambient temperature shall be in the range of dT/dt=+1.5 ± 0.5 K/min.

Note: The rate of change of the ambient temperature can be set to higher than 2.0 K/min, if the test conditions are documented in the relevant specification.

After the target values are reached the modules are removed from the climatic chamber and stored under room temperature atmospheric conditions. It is recommended to wait at least 1h before the verification tests explained in 6.1.7 are executed to avoid impact of wet surfaces on the test result.

Another option is to leave the modules inside the climatic chamber after the target values are reached, if the first verification test (i.e ICES-check under DC voltage) is performed inside of the climatic chamber. If this option is applied, care must be taken, that drying of the outer surfaces is sufficient to ensure that the ICES-check under DC voltage is not disturbed by humidity on the outer surface.

6.1.7 Verification tests with acceptance criteria (step 7)

During the Verification tests, the following measurements are performed, and the following timing rules shall be applied:

ICES-check under DC voltage:

- Conditions: see chapter 6.1.1.
- Timing rules: The ICES-check under DC voltage shall be performed within 3h after removal of the test devices from the climatic chamber. In case the modules are not removed from the climatic chamber, the ICES-check under DC voltage shall be performed within 3h after the target values of step 6.1.6 are reached.

Room temperature post-characterisation:

- Conditions: see ‘initial characterisation’ according to chapter 6.1.1
- Timing rules: The post-characterisation shall be performed after the ICES-check. The post-characterisation shall be performed within the stabilisation phase defined in chapter 6.3.

6.2 Acceptance criteria

The acceptance criteria are split in two parts, the ICES-check and the post-test acceptance criteria.

ICES-check:

- An I_{CES} rise above the limit specified at V_{CES} and room temperature in the datasheet must be regarded as FAIL.
- An I_{CES} rise which does not stabilise within the measurement interval (min 3min) must be regarded as FAIL. Stabilisation is reached if $I_{CES}(t)$ recovers to <=10x $I_{CES}(t=0)$.
- In addition, values under 100µA are to be considered as below the measurement resolution. Initial leakage currents below 100µA should be considered as 100µA.

The post-test acceptance criteria are described in Table 1.

Prior to the HTC-CRB test an initial characterisation must be done that includes all parameters according to Table 1.

Room temperature post-characterisation tests shall be performed before any test at higher temperature. The following table summarises the acceptance criteria after the HTC-CRB test.

Table 1: Post-test acceptance criteria

Value	Test temperature	Acceptance criteria
V_F / V_{SD}	room temperature	within DS-limits AND drift <10%
V_{CEsat} / $R_{DS(on)}$	room temperature	within DS-limits AND drift <10%
$V_{GE,th}$ / $V_{GS,th}$	room temperature	within DS-limits AND drift <10%
I_{CES} / I_{DSS}^*	room temperature	within DS-limits AND drift <x10*
I_{GES} / I_{GSS}^*	room temperature	within DS-limits AND drift <x10*
V_{ISO} *minimum*	room temperature	80% of V_{ISO}

* I_{CES} / I_{DSS} values below 100 µA and I_{GES} / I_{GSS} below 100 nA are to be considered as below the measurement resolution. Initial leakage currents below 100µA or 100nA respectively should be considered as 100µA or 100nA respectively.

In case drift criteria are not met but devices are still within specified limits a risk release is possible by proving that functionality under operation conditions is still given as depicted in Figure 2 below:

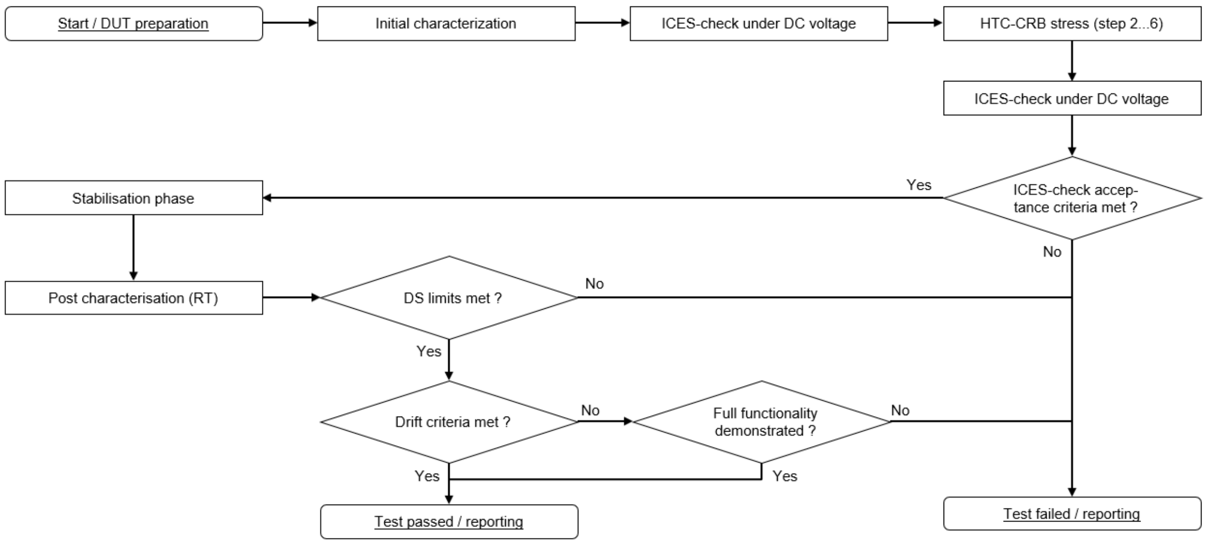

Figure 2: Test and assessment flow-chart (at all decision points pass decision is only possible if all samples pass)

6.3 Stabilisation phase after the test

The preferred procedure is defined in chapter 7 of IEC 60749-05 with modifications based on the specifics of IGBT power modules. An electrical test shall be performed not later than 48 h after the removal from the chamber, which shall include at minimum, testing of reverse blocking current and reverse blocking voltage. Within this time window drying by tempering is not allowed. A deviation of this baseline procedure shall be documented and reasoned in the procurement document.

7 Referencing rules

In case an alternative type of condensation stress test is applied in a product qualification, it is possible to reference on that alternative test, if the stress level of the alternative test is at least as high as defined in this guideline in chapter 6. By application of referencing, it is possible to reduce the test effort in a product qualification.

For relevant stress parameters the accepted modification is mentioned in the relevant subchapters of chapter 6.1. Any modification must be documented in the relevant specification.

Regarding the application of voltage to the specimen, a voltage may be applied only during intermediate-humidification phases. During the pre-humidification and condensation/cooling phases, voltage or any other electrical load must be avoided in order to simulate the use case described in chapter 4.1.

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Bibliography:

1) Use of a SPICE-based Transfer Function to Model the Absolute Humidity in a Power Semiconductor Module, O. Quittard et al., CIPS 2022