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Road vehicles — Durability test method for starter motor for stop and start system

Véhicules routiers — Méthodes de test d'endurance pour les démarreur stop and start system

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic components and general system aspects*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Stop and start systems contribute to fuel saving by stopping the engine when its operation is not needed, and to start the engine automatically when its operation is needed. The more frequent starting of the engine requires higher durability of the starter motor. Since there is no standard to evaluate the durability of starter motors for stop and start systems, individual specifications are used by engine and/or vehicle manufacturers and starter motor manufacturers. Because the stop and start systems require much more frequent starter motor operations, the testing period is much longer compared to conventional starter motors.

In addition to engine and/or vehicle manufacturers and starter motor manufacturers, testing companies also began to conduct tests. In order to carry out the time-consuming test accurately and to use the test results effectively, the test procedure in this document includes how to summarize the test results.

Road vehicles — Durability test method for starter motor for stop and start system

1 Scope

This document defines requirements and recommendations for starter motor durability testing of 12 V start systems for internal combustion engines. This includes test methods, test procedures and capabilities of test benches.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8856, *Road vehicles — Electrical performance of starter motors — Test methods and general requirements*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
stop and start system
system to stop the engine when its operation is not needed, and to start the engine automatically when its operation is needed

3.2
manual start
event when the engine is started manually by the driver

3.3
automatic start
event when the engine is started by the stop and start system automatically

3.4
dummy starter motor
starter motor used for installation purpose only

3.5
calibration starter motor
starter motor used for calibration of test condition, which is equipped for measuring temperatures of its components

3.6
engine simulator
device which simulates engine behaviour during engine start

3.7
battery simulator
electrical power supply equipment which simulates battery behaviour

3.8
engine mount
mechanical frame to support engine and gearbox

3.9
number of test start cycles
counted durability test start cycles

3.10
remaining brush length
length of brush after the test

3.11
usable brush length
length of brush that is available to be consumed

3.12
initial brush length
length of brush before starting the test

3.13
vehicle manufacturer
company which designs and produces vehicles

3.14
engine manufacturer
company which designs and produces internal combustion engines

3.15
starter motor manufacturer
company which designs and produces starter motors

3.16
cranking
condition in which the starter motor rotates the engine

3.17
overrunning
condition in which the engine rotates the starter motor pinion before starter motor OFF

3.18
engine ECU
electronic control unit for controlling internal combustion engine operation

3.19
starter solenoid
electromagnetic component of starter motor to move pinion and to switch electric motor

3.20
bi-control solenoid
starter solenoid which is able to control separately pinion movement and to switch electric motor

3.21
bench controller
device which is capable of controlling required test bench functions

3.22
nominal power
P_{nom}
power declared by the starter motor manufacturer corresponding to the maximum power output at the reference temperature when determined according to ISO 8856

3.23
battery internal and line resistance
R_{BL}
sum of power supply (battery or battery simulator) internal resistance and total resistance of external line (positive and negative sides and connections)

3.24
device under test
DUT
starter motor used for durability test

3.25
change of mind
CoM
start event before complete engine stall

3.26
starter motor voltage
U_{STR}
voltage at battery terminal of starter motor

3.27
starter motor current
I_{STR}
current drawn by starter motor

3.28
starter motor open circuit voltage
U_{0_STR}
voltage at starter motor terminals without electrical load

3.29
virtual starter motor voltage
$U_{0\_STR\_v}$
virtual starter motor voltage at I_{STR} = 0A derived from V-I curve

3.30
battery internal resistance
R_B
power supply (battery or battery simulator) resistance

3.31
line resistance
R_L
total resistance of external line (positive and negative sides and connections)

3.32
front end accessory drive
FEAD
equipment driven by belt which is connected to engine

3.33
starter motor temperature at control point
$T_{control}$
temperature measured at defined control point location

EXAMPLE At starter motor yoke surface.

3.34
temperature of starter motor brush
T_{brush}
temperature measured inside of starter motor brush

3.35
pinion to ring gear axial gap
d_{prg}
axial distance from front surface of pinion to ring gear at rest condition

3.36
starter motor input curve
V-I curve
straight line calculated from starter motor voltage vs starter motor current diagram defining starter motor input conditions

4 Planning of durability test

4.1 Determination of durability test types

The durability test is performed with an engine simulator or an engine. The following test types can be selected. See Table 1 for comparison of each test type.

1) Engine, using bench controller to control fuel/spark to specifically achieve pre-determined cranking time and overrunning time (see Table 3).

2) Engine, using its engine ECU to control the test parameters.

3) Engine simulator, using engine waveform data provided by engine and/or vehicle manufacturers as input to simulator (for cranking time, overrunning time, or torque) (see Table 3).

4) Engine simulator, using synthetic pattern or engine simulation model where starter motor manufacturer or engine and/or vehicle manufacturers define values for torque, cranking and overrunning behaviour (see Table 3).

Table 1 — Overview of test types

Test type	Starter load	Starter load characteristic	Reference
1	Engine	Engine using bench controller	Annex A
2		Engine using engine ECU	Annex B
3	Engine Simulator	Engine simulation using engine waveform data	Annex C
4		Engine simulation using synthetic pattern	Annex C

4.2 Determination of durability test conditions

The starter motor manufacturer and engine and/or vehicle manufacturers should define the test conditions according to the test planning matrix shown in Table 2.

The following items should be specifically considered:

1) In case of engine simulator, multiple starter motors can be tested simultaneously with the same ring gear. In that case, the orientation of the starter motors deviate from those of the target application. Hence, the usage of multiple starter motors shall correspond to the test purpose (e.g. verification of brush durability but not verification of pinion and ring gear durability).

2) The starter motor manufacturer and engine and/or vehicle manufacturers should agree starter motor temperature level during the durability test. Different approaches to define temperature level are established.

   For example:

   — test at maximum brush temperature defined by starter motor manufacturer;

   — test at maximum brush temperature derived from vehicle real drive cycle; and

   — test at an average brush temperature derived from brush temperature distributions of vehicle real drive cycle.

   Each approach covers different testing purposes such as focusing on thermal stress, test duration, mechanical loads or balanced field representation.

3) The starter motor manufacturer and engine and/or vehicle manufacturers should define the test pass criteria and define test stop criteria according to Table 6.

4) Additional test conditions may be defined and shall be documented in test planning matrix.

   For example:

   — always using “100 % new” battery for every test;

   — testing with maximum pinion to ring gear axial gap; and

   — number and orientation of starter motors mounted to engine simulator ring gear.

Table 2 — Test planning matrices

Test planning matrix (1/3)						**Reference**
Test type (test type #1 to #4)						4.1
Target test duration (number of test start cycles)						
Test sequence	__ x[M/S] + __ x[A/S] + __ x[CoM] + __ x[A/S] + __ x[CoM]					
	Manual start [M/S]	t_1	s	t_2	s	Table 3 including NOTE 1
		t_3	s	t_4	s	
		t_5	s	n_1	min^{-1}	
	Automatic start [A/S]	t_6	s	t_7	s	Table 3 including NOTE 2
		t_8	s	t_9	s	
		t_{10}	s	n_2	min^{-1}	
	CoM start [CoM]	n_3	min^{-1}	n_4	min^{-1}	Table 3
		t_{11}	s			

Table 2 *(continued)*

Engine information / Reference engine information for engine simulator					
	Engine manufacturer				
	Engine family or engine code				
	Engine ECU software version				
	Fuel type				
	Number of cylinders		Displacement	cm^3	
	Additional engine load		FEAD components	Exist /Not exist	
			FEAD belt tension	N	
			Alternator operation	Yes / No	
			Dual mass flywheel	Exist / Not Exist	
			Others		
	Engine coolant and oil		Coolant temperature (T_{cool})	°C < T_{cool} Maximum °C	
			Oil type		
			Oil temperature (T_{oil})	°C < T_{oil} Maximum °C	
			Others		
	Ring gear information		Number of teeth		
			Module		
			Others		
	Gearbox		Type		
	Cranking waveform data (test type 3) or synthetic pattern (test type 4) in case of engine simulator		Specify the agreed data		Table 3
Test planning matrix (2/3)					**Reference**
DUT information					
	Starter motor manufacturer				
	Starter motor family				
	Starter motor nominal power (P_{nom})			kW	ISO 8856
	Number of pinion teeth				
	Bi-control solenoid (Yes/No)				3.20
	Others				
Electric power supply (Battery or battery simulator)					
	Starter motor input V-I curve ($U_{0\_STR\_v}$, R_{BL})		Specify V-I graph or mathematical expression based on target vehicle or application measurement		7.2
	Battery manufacturer, manufactured date and size or battery simulator type				
	Battery nominal voltage			V	
	Battery internal resistance (R_B)			mΩ (_°C)	
	Line resistance (R_L)			mΩ (__°C)	
	Tolerances for R_B, R_L, R_{BL} and $U_{o\_STR\_v}$				
	Others				

Table 2 *(continued)*

Others			
	Pinion to ring gear axial gap d_{prg}	mm	Figure 6
	Temperature at control point Location of control point	± °C	7.1
	Agreed brush temperature limit Brush temperature measurement position	°C	7.1
	Brush length initial check method		7.3
	Starter motor input condition to measure starter motor output performance	Specify the agreed condition	ISO 8856
	Starter performance after the test	Agreed criteria	ISO 8856
	Test pass criteria		4.2
	Test stop criteria		5.4
	Reporting items	Specify reporting items	Annex D
	Others		

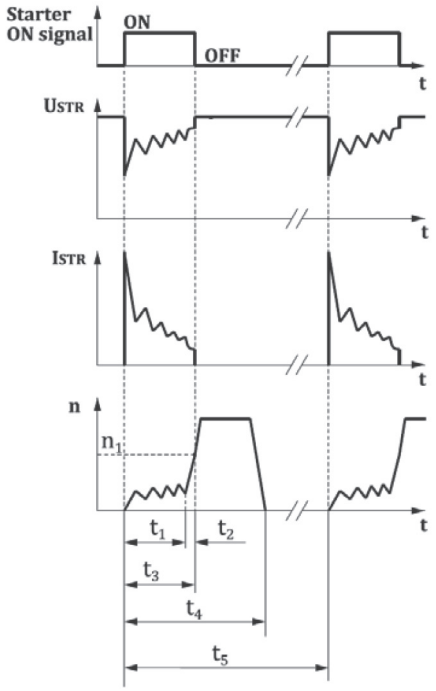
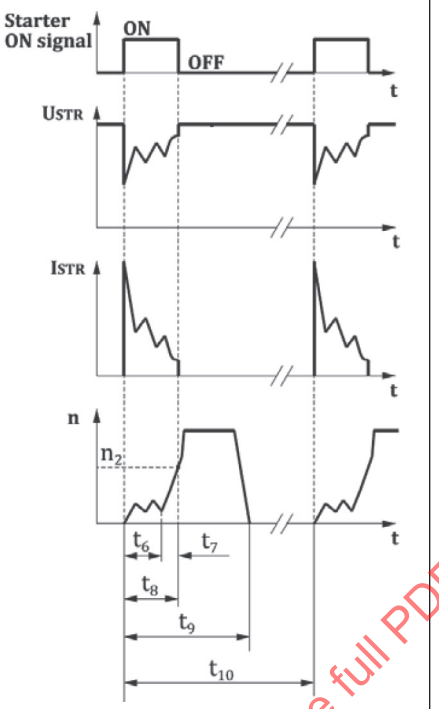
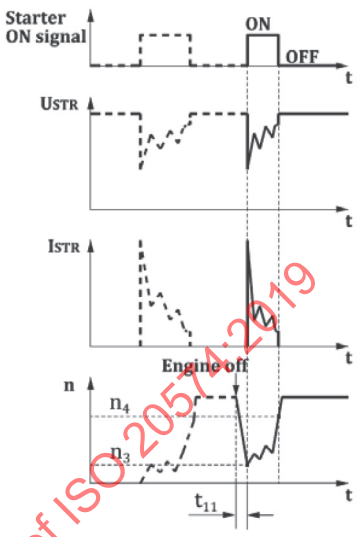
Test planning matrix (3/3)				**Reference**
Data monitoring and recording : No / Yes, if yes define the data monitoring and recording rate				
		Monitoring	Recording	
	Battery voltage (optional)			5.3
	Battery current (optional)			5.3
	Starter motor voltage			5.3
	Starter motor current			5.3
	Starter motor input V-I curve ($U_{0\_STR\_v}$, R_{BL})			5.3
	Solenoid voltage			5.3
	Solenoid current (optional)			5.3
	Engine rotational frequency			5.3
	Test start cycle count			5.3
	Temperature at control point			5.3
	Engine coolant temperature			5.3
	Engine oil temperature			5.3
	Others (specify)			5.3

4.3 Definition of cranking time, overrunning time

In the event that the engine ECU (or engine data) is not used in the setup (test types 1, 3 and 4, see Table 1), it shall be necessary to decide and setup specific values for cranking time, or overrunning time (see Table 3).

In that case, Table 2 should be used to help starter motor manufacturer and engine and/or vehicle manufacturers to reach agreement on the necessary parameters as a part of the planning phase.

Table 3 — Parameters of each engine start

Manual start	Automatic start	Change of mind (CoM) start
		

t time, in seconds

n Engine rotational frequency, in min^{-1}

t_1 Cranking time of manual start

t_2 Overrunning time of manual start

t_3 Starter motor ON time of manual start

t_4 Engine or engine simulator ON time of manual start

t_5 Start cycle time of manual start (from start to restart)

t_6 Cranking time of automatic start

t_7 Overrunning time of automatic start

t_8 Starter motor ON time of automatic start

t_9 Engine or engine simulator ON time of automatic start

t_{10} Start cycle time of automatic start (from start to restart)

t_{11} Starter motor ON time from engine OFF timing of CoM start

n_1 Engine rotational frequency at starter motor OFF timing of manual start

n_2 Engine rotational frequency at starter motor OFF timing of automatic start

n_3 Engine rotational frequency at the starter motor reengagement of CoM start

n_4 Engine rotational frequency at starter motor OFF timing of CoM start

In Table 3, the following parameters are selected as follows:

— For manual start, in addition to t_1, either t_2 or n_1 shall be specified.

— For automatic start, in addition to t_6, either t_7 or n_2 shall be specified.

— For CoM start, in addition to automatic start parameters, either t_{11} or n_3 shall be specified.

— While keeping starter motor ON time constant, t_5 and/or t_{10} are adjustable if the defined temperature at control point cannot be reached by adjusting the cooling system (see 7.1).

— In case of bi-control solenoid type starter motor, individual consultation shall be agreed between engine and/or vehicle manufacturer and starter motor manufacturer is needed as to how to operate them.

5 Test bench equipment and information

5.1 Test bench structure

Test bench structures are shown in Annex A, Annex B and Annex C, depending if testing will be done with an engine, or an engine simulator.

5.2 Minimum requirements of test bench

Each test bench shall have capability shown in Table 4.

Table 4 — Minimum requirements of test bench

Contents/function	Minimum requirements of test bench
Engine	The engine or the test bench respectively shall provide engine mount, starter motor mount, exhaust system, cooling system for engine, fuel supply, cooling system for gear box, safety function and action (e.g. fire prevention, oxygen monocarbide detection, battery gas detection, short circuit detection/protection)
Engine simulator	The engine simulator shall provide starter motor mount including adjustment capability of d_{prg} (see Figure 6), electrical motor including braking function
Bench controller	The bench controller shall be able to: — count all test start cycles for manual start/automatic start/CoM/total — provide detection of test stop criteria and shut down functions (see 5.4) — logically link multiple measurement values and times and to take appropriate action — control flexible starting patterns of program — send signals to brake and throttle for vehicle simulation (if engine ECU is used) — activate test bench relays to control starter solenoid and battery charger ON and OFF timing (additional control is required in case of bi-control solenoid type starter motor)
Battery management system (if actual battery is used)	System shall be able to use specified battery with charging system including required safety system. Battery charger shall be OFF during actual cranking event System shall be able to continuously monitor V-I curve and control charging current
Battery simulator	Battery simulator shall be able to provide agreed V-I curve and peak current
Line resistance R_L	Line resistance (positive or negative) shall be adjustable to achieve specified V-I characteristics
Data monitoring	Test bench shall have a capability to record and store measurement data for each test start cycle
Starter motor cooling system	Test bench shall have a starter motor cooling system to maintain temperature at control point during the test (Switch off cooling system or increase cooling capability when temperature is out of range)

5.3 Test bench measuring capabilities and channel list

The capability of the test equipment shall enable the parameters to be measured within the accuracy definition regarding the maximum value of the measurement range shown in Table 5 throughout the

whole test procedure. The channels to be monitored and recorded shall be documented in the test planning matrix (see Table 2, 3/3).

Table 5 — Measurement channel list and capability of equipment

Channel name		Range	Sampling rate	Accuracy	Reference
Battery voltage (optional)	U_{BAT}	0 V to 30 V	1 000 Hz	±1 % of max range	Annex A, B, C
Battery current (optional)	I_{BAT}	0 A to 1 500 A	1 000 Hz	±1,5 % of max range	Annex A, B, C
Starter motor voltage	U_{STR}	0 V to 30 V	1 000 Hz	±1 % of max range	Annex A, B, C
Starter motor current	I_{STR}	0 A to 1 500 A	1 000 Hz	±1 % of max range	Annex A, B, C
Starter solenoid voltage	U_{Sol1}	0 A to 30 V	1 000 Hz	±1 % of max range	Annex A, B, C
Starter solenoid current (optional)	I_{sol1}	0 A to 200 A	1 000 Hz	±1 % of max range	Annex A, B, C
Engine rotational frequency	n	$-1\,000\ min^{-1}$ to $4\,000\ min^{-1}$	1 000 Hz	±2 % of max range	na
Test start cycle count	N	0 to 500 000	N.A.	±1	na
Starter motor component temperature	NA	0 °C to 200 °C 0 °C to 400 °C (brush temperature measurement)	1Hz	±2,5 K	na
Engine oil temperature[a]	T_{oil}	0 °C to 200 °C	1 Hz	±2,5 K	na
Engine coolant temperature[b]	T_{cool}	0 °C to 200 °C	1 Hz	±2,5 K	na
NOTE Measuring engine rotational frequency from $-1\,000$ to 0 min^{-1} is necessary for CoM starts.					
[a,b] Engine oil temperature and/or engine coolant temperature shall be measured and monitored.					

5.4 Test stop criteria

Table 6 shows example items of test stop criteria. Criteria shall be agreed between engine and/or vehicle manufacturers and starter motor manufacturer before test. Test bench shall have capability to detect test stop criteria including shut down function in case of an error.

Table 6 — Test stop criteria

Test stop criteria			Reference
DUT monitoring parameters			
	Number of test start cycles reached	Target test duration (number of test start cycles) : _____ cycles	
	Starter motor current	Abnormal starter motor current condition: Us_{ol} = 0V and I_{STR} > 0A for _____s	
	Temperature at control point	Temperature at control point exceeds the specified value	7.1

Table 6 *(continued)*

Test stop criteria			Reference
Engine monitoring parameters			
	Engine rotational frequency [Start motor failure : No engine run-up after starter motor disengaged]	Start failure : At Δt(s) after DUT OFF timing, n < _____ min^{-1} ____ consecutive or total _____ start failures shall constitute a test failure.	Table 3
	Engine coolant temperature range	Engine manufacturer's specific value	
	Engine oil temperature range	Engine manufacturer's specific value	
	Engine oil pressure range	Engine manufacturer's specific value	
	Error detection by engine ECU		
Test bench condition and safety incidents			
	Starter motor input V-I curve	Starter motor input V-I curve deviates from the agreed range	7.2
	Battery current	I_{BAT} > _____ A for _____ s	
	Test bench controller error		
	Abnormal engine behaviour, noise, smoke, smell, heat, sparks, flame or any kind of unsafe situation		

6 Detailed test procedures

6.1 Test procedure

6.1.1 General

The structure of test benches are shown in Annex A, Annex B and Annex C, depending if testing will be done with an engine, or an engine simulator.

The test procedure for the durability test shall consist of four stages, shown below.

1) Installation and setup stage for engine or engine simulator.
2) Pre-check stage.
3) Test execution stage.
4) Post-processing and reporting stage.

The procedure shall be executed stage by stage.

6.1.2 Installation and setup stage for engine or engine simulator

In this stage, the following steps shall be conducted.

1) The engine and gearbox shall be mounted on the appropriate engine mount.
2) The engine fluids (e.g. engine oil, coolant) shall be filled and checked according to vehicle and /or engine manufacturer specifications.
3) A dummy starter motor other than the DUT shall be mounted to engine or engine simulator. d_{prg} shall be set to appropriate value and verified according to 7.4.
4) Before cranking the engine, a fluid leakage check shall be performed. In case a leakage is detected, starter motor shall not be operated.

5) The measurement equipment shall be installed.

6) All electrical connections shall be installed and checked for verifying proper coupling and no damages.

NOTE Electrical connections include digital signals, analogue signals, measurement cables and electrical power supplies.

7) To control the starter motor temperature at control point, a cooling system or cooling fan shall be installed.

8) The test bench shall be initialized. Initialization includes switch on electric equipment, boot up software and check measurement values.

9) The target parameters shall be set. Parameters include control timings and rotational frequencies, V-I parameters and temperatures. If parameters are not matching to the agreed test setup, the parameters shall be adjusted.

10) The readiness for operation and runnability of the engine shall be checked.

6.1.3 Pre-check stage

In this stage, the following steps shall be conducted.

1) The dummy starter motor shall be changed to the calibration starter motor. The calibration starter motor is used to calibrate the temperature control system for the test.

2) Starter motor input V-I curve shall be adjusted according to 7.2.

3) All test conditions shall be once again checked. If test conditions are not matching to the agreed test setup, the parameters shall be adjusted according to Table 2.

4) The starter motor cooling system (e.g. external fans) shall now be calibrated according to 7.1.

5) If all steps were taken, the durability test is ready to be executed.

6.1.4 Test execution stage

In this stage, the following steps shall be conducted.

1) Brush length of DUT should either be measured or specified nominal brush length should be used and recorded according to 7.3.

2) The performance of the DUT shall be tested with agreed starter motor input according to ISO 8856.

3) The calibration starter motor shall be changed to DUT.

4) Initial conditions shall be documented, refer to Annex D items.

5) All the channel list items and their data recording rates shall be verified.

6) The durability test shall be started.

7) During test execution stage the parameters $U_{0\_STR\_v}$ and R_{BL} shall be checked periodically by calculating the V-I curve. The data recording rates, and upper and lower limit shall be defined in the test planning matrix according Table 2, (3/3).

The test shall be stopped when one defined test stop criteria is reached (see Table 6). If criteria cannot be brought back into the defined range, the test shall be finished. Each time when the test is stopped, it shall be documented.

6.1.5 Post processing and reporting stage

At a minimum, the measurement data analysis of entire test (minimum/maximum/average analysis) shall be summarized and predefined in the test planning matrix Table 2, (2/3 reporting items).

Visual observation of starter motor from outside shall be performed and the results should be documented by photo.

The performance of the DUT shall be measured again with the same starter motor input as defined in 6.1.4 according to ISO 8856, and the results shall be recorded unless the starter motor was run to failure.

Tear down analysis shall be performed and the results should be documented by photo.

The remaining length of brushes shall be measured according to 7.3 and recorded.

Test information and analysis results on Annex D should be summarised.

Additional analysis is specific to engine and/or vehicle manufacturers and starter motor manufacturer agreement at planning stage.

7 Supplemental test methods

7.1 Brush temperature calibration

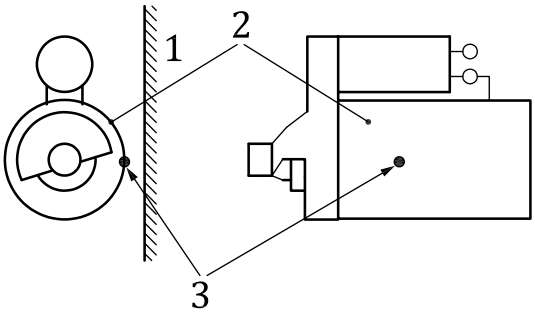
One focus of the durability test is the brush wear. Brush temperature influences strongly the brush wear. In the vehicle, brush temperature and yoke temperature are in the same range. However, during durability test, the brush temperature becomes much higher than the yoke temperature due to high number of starts per hour, and cooling of the exterior of the starter motor. Using the stabilized yoke temperature from the vehicle for the durability test will lead to brush temperatures which are significantly above the vehicle situation. Therefore, the durability test shall be performed with a brush temperature comparable to the vehicle situation or below maximum brush temperature defined by starter motor manufacturer.

Use the following method to measure and calibrate the brush temperature at the pre-check stage.

Calibration starter motor shall have thermocouples installed on one or more brushes to measure T_{brush}. In addition, at least one thermocouple shall be installed at location of control point to measure $T_{control}$. Location of temperature control point and brush temperature measurement position shall be documented (see Table 2, 2/3).

Yoke surface can be the control point location. If so, the thermocouple should be installed at the engine side, not receiving cooling effect by air flow (see Figure 1). Thermocouple shall be installed at temperature control point location of both the DUT and the calibration starter motor.

Temperature of brushes should be measured using the calibration starter motor but not the DUT. The reason is that a thermocouple influences the dynamic behaviour of the brush and therefore the brush wear.



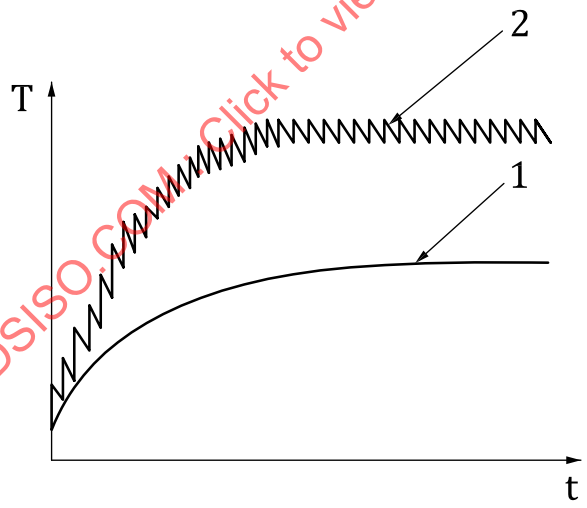
Key

1 engine
2 starter motor yoke
3 location of temperature control point

Figure 1 — Example of temperature control point

While running the agreed cranking pattern, measure the brush temperature and temperature at control point until the brush temperature level stabilizes. Maximum brush temperature shall be below starter motor manufacturer recommendation value. If the brush maximum temperature exceeds starter motor manufacturer recommended value, adjust the cooling system until acceptable brush temperature values are obtained (preferred solution). If not sufficient, additionally, the start sequences t_5 or t_{10} can be increased while keeping starter motor ON time constant (see Table 3).

The corresponding temperature at control point will be used as the guideline to monitor during the test execution stage, since the actual DUT brushes shall not be thermocoupled.



Key

t time
T temperature
1 starter motor temperature at control point $T_{control}$
2 temperature of starter motor brush T_{brush}

Figure 2 — Example brush temperature and control point temperature data

7.2 Starter motor input V-I curve and verification

The V-I curve shall be properly set up and monitored during the test. Incorrect V-I supply to the starter motor may affect the brush wear of the starter motor. Use this method to verify V-I characteristics during the setup phase.

The recording of measurement data (U_{STR}, I_{STR}) shall include one complete engine start.

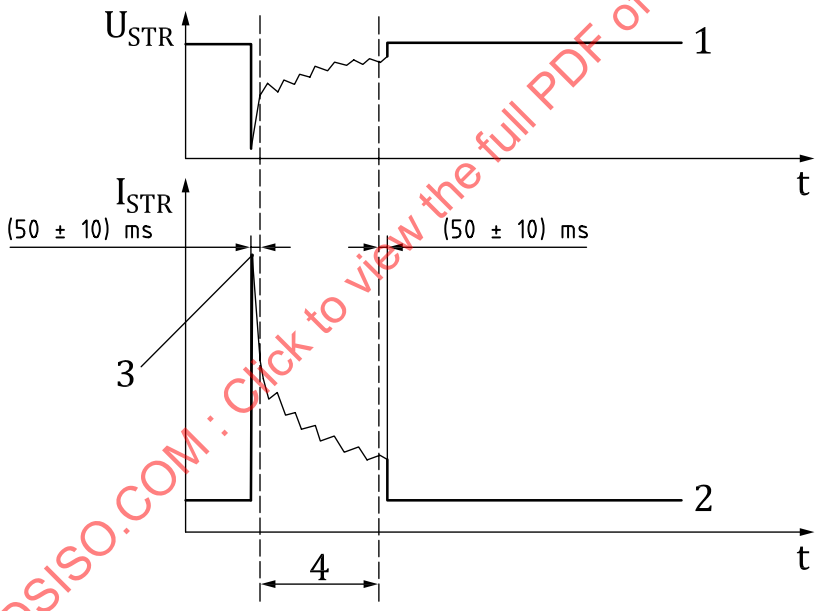
The test bench components shall be stable at the operating temperature during recording.

The starter motor voltage U_{STR} shall be measured at the measurement locations as specified in Annex A, Annex B, or Annex C.

The starter motor current I_{STR} shall be measured at the measurement locations as specified in Annex A, Annex B, or Annex C.

For the creation of the V-I curve, the following intervals for both, U_{STR} and I_{STR} shall be selected:

Select the time range (50 ± 10) ms after the absolute maximum of the starter motor current until (50 ± 10) ms before starter motor current OFF timing. This selection of the interval for an example starting wave form is depicted in Figure 3.



Key

t	time, in seconds	3	maximum point of the starter motor current
1	starter motor voltage U_{STR}	4	selected time interval
2	starter motor current I_{STR}		

Figure 3 — Example of starting wave form showing U_{STR} and I_{STR} over time

The V-I diagram shall be created by plotting I_{STR} on the horizontal axis and U_{STR} on the vertical axis.

The V-I curve shall be calculated out of the selected data by applying a linear regression.

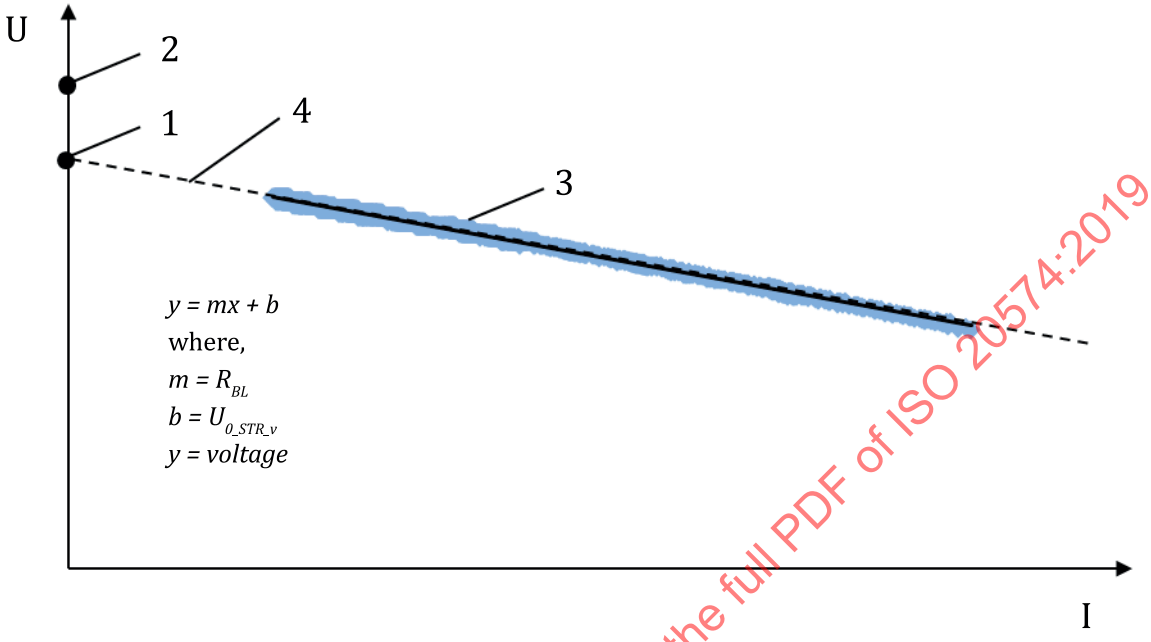
NOTE The method of ordinary least squares is suitable for this purpose.

The linear regression method creates the following function.

$$U_{STR} = -R_{BL} \times I_{STR} + U_{0\_STR\_v}$$

$$R_{BL} = R_B + R_L$$

From this function R_{BL} and $U_{0\_STR\_v}$ shall be determined as characteristic values for the test bench setup. An example plot of the V-I curve is depicted in Figure 4.



Key

I	current, in ampere	2	starter motor open circuit voltage U_{0_STR}
U	voltage, in volt	3	measurement points of U_{STR} and I_{STR}
1	virtual starter motor voltage $U_{0\_STR\_v}$	4	calculated V-I curve

Figure 4 — Example of starter motor input V-I curve

In case of battery simulator, V-I curve shall be setup with the parameters R_{BL} and virtual starter motor voltage $U_{0\_STR\_v}$ which is below the starter motor open circuit voltage U_{0_STR}.

7.3 Brush length measurement

To measure the brush length, use a calliper or equivalent measurement equipment which has accuracy of ±0,05 mm.

Maximum usable brush length of brushes shall be determined by starter motor manufacturer.

The length of all brushes shall be measured as described in Figure 5. Initial length shall be measured, or nominal brush length shall be used.

Brush life estimation shall be performed for all brushes. As final result, the minimum of all calculated brush life estimations shall be reported.

Using measurement result, brush life shall be calculated according to the following formula.

$$estimated\ brush\ life = \frac{[usable\ brush\ length] \times [number\ of\ test\ start\ cycles]}{[initial\ brush\ length] - [remaining\ brush\ length]}$$