INTERNATIONAL STANDARD

ISO 21782-6

First edition
2019-08

Electrically propelled road vehicles — Test specification for electric propulsion components —

Part 6: Operating load testing of motor and inverter

Reference number
ISO 21782-6:2019(E)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO /TC 22, *Road Vehicles*, Subcommittee SC 37, *Electrically propelled vehicles*.

A list of all parts in the ISO 21782 series can be found on the ISO website.

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Electrically propelled road vehicles — Test specification for electric propulsion components —

Part 6: Operating load testing of motor and inverter

1 Scope

This document specifies operating load tests and test criteria for motor and inverter designed as a voltage class B electric propulsion system for electrically propelled road vehicles.

2 Normative references

The following documents are referred to in the text 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 21782-1:2019, *Electrically propelled road vehicles — Test specification for components for electric propulsion — Part 1: General test conditions and definitions*

3 Terms and definitions

For the purposes of this document, the terms, definitions and abbreviated terms given in ISO 21782-1 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/

4 Tests and requirements

4.1 Operation endurance tests of motor

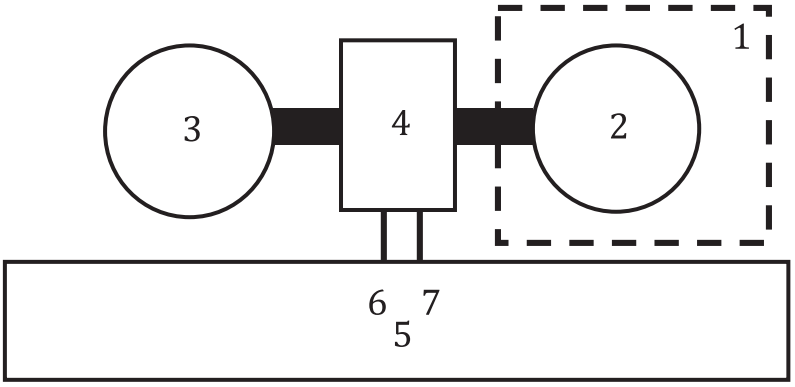
4.1.1 High acceleration/deceleration endurance test

4.1.1.1 General

The purpose of this test is to evaluate and rank the strength for the components – bearing, end ring, motor shaft key, rotor fixture, rotor, and position sensor – which are affected by mechanical fatigue by repeating the intermittent maximum speed of motor. The test is set considering repeated operations at the upper specification limits of the motor. Unless otherwise, the test method can be decided by the supplier and customer.

4.1.1.2 Test diagram

The test diagram is shown in Figure 1. The test motor is operated by opposing dynamometer on the motor test bench.



Key

1 DUT
2 motor
3 dynamometer
4 torque/speed detector
5 torque/speed meter
6 motor torque (in Nm)
7 motor speed (in min^{-1})

Figure 1 — Diagram for high acceleration/deceleration endurance test of motor

4.1.1.3 Test conditions

Test conditions are shown in Table 1.

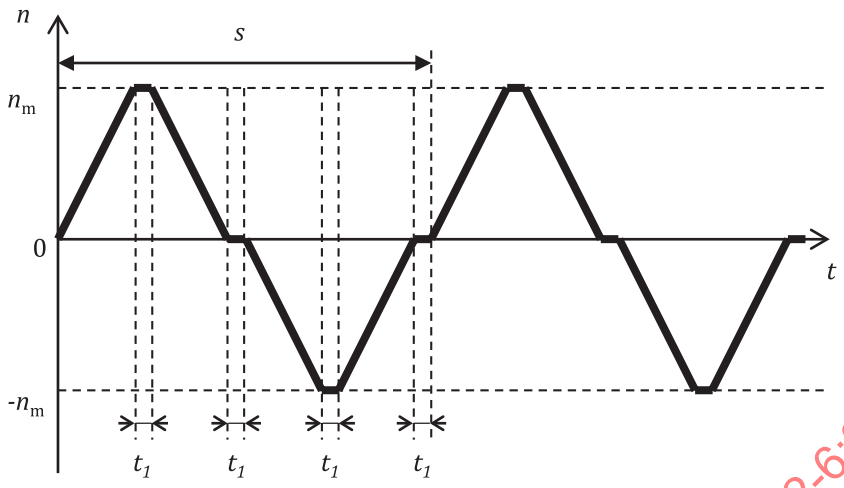
Table 1 — Conditions for high acceleration/deceleration endurance test of motor

Test conditions		Value	Remark
Ambient conditions		Room temperature (RT) and humidity as defined in ISO 21782-1:2019, 5.4.	
Coolant temperature		Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as example of coolant
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	

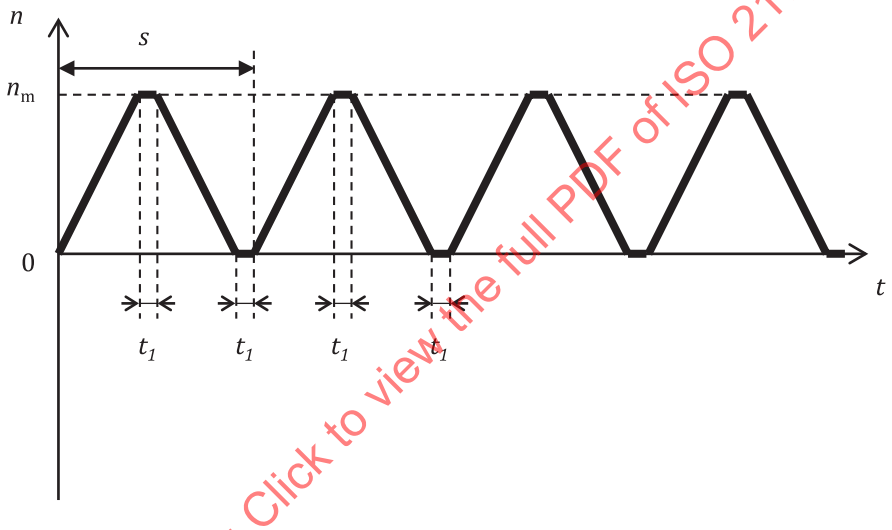
4.1.1.4 Test procedure

The test pattern is shown in Figure 2. Rotation in clockwise and counter-clockwise direction is repeated at the maximum speed of the motor specifications. The load is no load.

The number of cycles shall be decided by agreement between the supplier and customer referring to Table 2 or Table 3.



a) Test pattern for motor with bidirectional rotation



b) Test pattern for motor with single directional rotation

Key

t time (in s)
n motor speed (in min^{-1})
n_m maximum speed (in min^{-1})
s 1 cycle
t_1 holding time (in s)

Figure 2 — High acceleration/deceleration endurance test pattern for motor

The acceleration rate in Figure 2 is equivalent to that of the targeted vehicle and is decided between the supplier and customer. The time "t_1" at the maximum speed and zero speed shall be reduced to a technically possible minimum (e.g. 1 s). In case of a motor with single directional rotation, only the positive speed shall be considered as shown in Figure 2 b).

This test aims to evaluate mechanical endurance. Endurance is displayed according to the rank in Table 2 in case of a motor with bidirectional rotation, and in Table 3 in case of a motor with single directional rotation.

Table 2 — Number of cycles in high acceleration/deceleration endurance test for motor with bidirectional rotation

Ranks	Number of cycles
S	500 000
A	300 000
B	200 000
C	100 000

Table 3 — Number of cycles in high acceleration/deceleration endurance test for motor with single directional rotation

Ranks	Number of cycles
S	1 000 000
A	600 000
B	400 000
C	200 000

4.1.1.5 Test requirements

4.1.1.5.1 General

The cyclic test shall be started from C rank which is listed in Table 2 and Table 3 with the motor phases open. Confirmation by energizing and disassembling shall be conducted after the high acceleration/deceleration endurance test, in order to analyse and confirm that changes before and after energizing are within the respective criteria listed in Table 4. If it is confirmed by agreement between the supplier and customer that this motor is clearly of a higher proof than C rank, continue cyclic test to the next upper rank. If the target cycle has been achieved, disassembling shall be conducted and the criteria for disassembling are listed in Table 5. If failure has occurred during a cyclic test, the motor shall be disassembled and analysed by agreement between the supplier and customer. The rank of the motor shall be decided based on the results of energizing and post-test analysis. If changes before and after energizing are not within the criteria listed in Table 5 or any failure or anomaly occurs post-test analysis, the motor shall belong to a lower rank.

4.1.1.5.2 Energizing

Before conducting this test, the data of the test listed in Table 4 shall be obtained in order to be able to compare the data before and after this test.

— Back electromotive force (back-EMF) measurement

  The back-EMF of the motor is measured at the 10 % of maximum speed driven externally. They shall be within ±5 % difference before and after the test.

  NOTE If the type of DUT is different from a permanent magnet motor, this measurement can be omitted.

— Measurement of origin position and waveform of position sensor

  The difference in the back-EMF waveform of the reference phase and the origin position of the position sensor at the 10 % of maximum speed driven externally shall be measured. They shall be within ±5° difference in electrical angle before and after the test.

— Torque – speed characteristics

  The motor torque, motor input voltage, inverter output current, and motor speed shall be measured using the load test bench at the operating point "a" and "c" of ISO 21782-1:2019, Figure 1. The difference in torque before and after the test shall be within ±5 %.

— Measurement of vibration

The generated vibrations of the motor during acceleration by the inverter to the maximum speed shall be measured. The acceleration rate shall be adequately slow. The vibration data before and after the test shall be compared to determine if there has been no significant increase. The changes in the vibration values shall be judged by an agreement between the supplier and customer.

Criteria of energizing is shown in Table 4.

Table 4 — Criteria of energizing

Measurement items	Condition	Criteria
Back-EMF	10 % of maximum speed	Within ±5 % difference before and after the test
Origin position and waveform of position sensor	Specified speed	Within ±5° difference in electrical angle before and after the test
Torque - speed characteristics	Operating point "a" and "c"	Within ±5 % difference in the torque before and after the test
Vibration	During acceleration to the maximum speed by inverter (acceleration rate: adequately slow)	No significant increase

4.1.1.5.3 Disassembling

The motor shall be disassembled, and each part shall be investigated. The items and criteria are shown in Table 5.

Differences which adversely affect motor performance shall not occur after disassembling. Details of criteria shall be agreed by the supplier and customer.

NOTE Disassembling is optional and is agreed by the supplier and customer in case of abnormalities in the non-destructive examinations.

Table 5 — Criteria of disassembling

Parts/places	Details of investigation	Criteria
Bearing	Transferred side scratch, grease degradation, creep	Scratch not leading to noise Grease degradation < reference value No creep
End ring	Deformation, crack	No large deformation No crack
Motor shaft key	Deformation, wear	No large deformation No large wear
Rotor fixture (magnet, cage, etc.)	Peeling off of adhesive deformation	No peeling
Outer circumference of rotor	Deformation, wear	No large deformation No large wear (According to external size)
Position sensor	Deviation of position (number of poles is also indicated)	Allowable thrust displacement Allowable concentricity

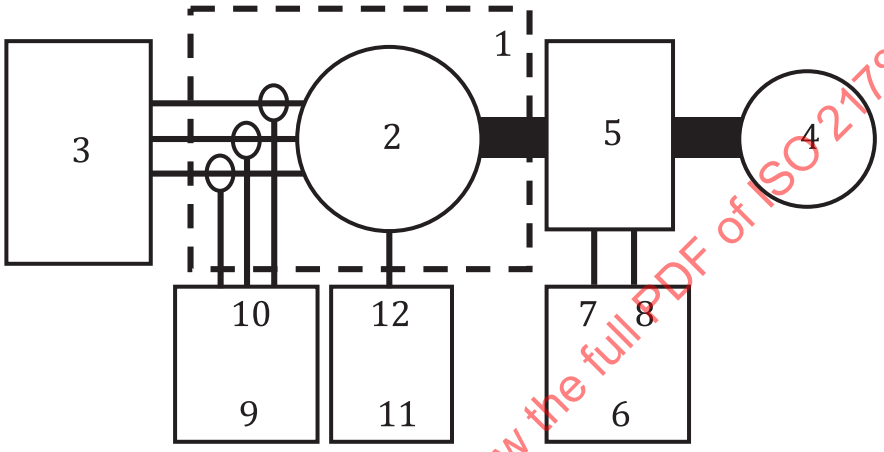
4.1.2 Maximum torque endurance test

4.1.2.1 General

The purpose of this test is to evaluate and rank the strength for the components – motor shaft key, rotor fixture, shaft tightening part, and stator fixtures – which are affected by mechanical fatigue by repeating the intermittent maximum torque of the motor. The test is set considering repeated operations at the upper specification limits of the motor. The test method can be decided by the supplier and customer.

4.1.2.2 Test diagram

The test diagram is shown in Figure 3. The test motor shall be operated at constant speed at the rated voltage outlined in ISO 21782-1 on the motor test bench.



Key

1	DUT	7	motor torque (in Nm)
2	motor	8	motor speed (in min^{-1})
3	inverter	9	power meter
4	load	10	motor input current (in A)
5	torque/speed detector	11	thermometer
6	torque/speed meter	12	motor temperature (in °C)

Figure 3 — Diagram for maximum torque endurance test of motor

4.1.2.3 Test conditions

Test conditions are shown in Table 6.

Table 6 — Conditions for maximum torque endurance test of motor

Test conditions	Value	Remark
Ambient conditions	RT and humidity as defined in ISO 21782-1:2019, 5.4.	
Coolant temperature	Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as example of coolant

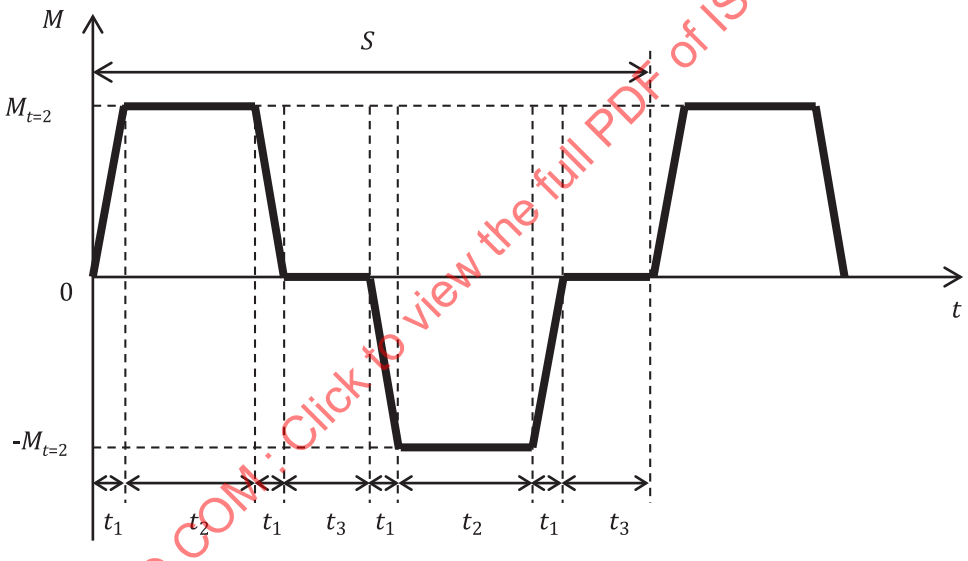
Table 6 *(continued)*

Test conditions		Value	Remark
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	

4.1.2.4 Test procedure

The test pattern is shown in Figure 4. The constant speed shall be set between operating point "d" and "a" of ISO 21782-1:2019, Figure 1. The motor torque shall be operated on $M_{t=2}$ and $-M_{t=2}$ as shown in Figure 4. Time parameter t_1, t_2 and t_3 in Figure 4 shall be as listed in Table 7. The tests shall be conducted by repeating the number of cycles according to the corresponding rank shown in Table 8. The temperature of each part of the motor shall be controlled so that they are substantially equal to the saturation temperature during operation at permissible continuous load as shown in Figure 5.

NOTE To protect the torque meter, the test can be performed without it, after setting up the maximum torque. In that case, torque meter can be replaced by power meter to measure motor input currents.



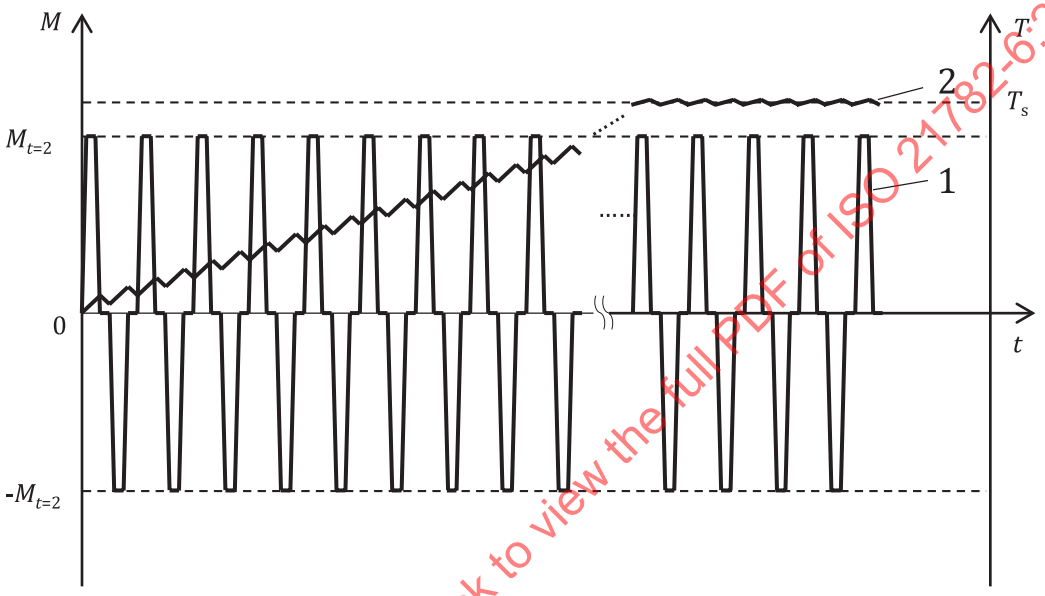
Key

t	time (in s)
M	torque (in Nm)
$M_{t=2}$	maximum motoring torque for duration of t_0 = 2 (in Nm)
$-M_{t=2}$	maximum regenerating torque for duration of t_0 = 2 (in Nm)
s	1 cycle
t_1, t_2, t_3	time parameter

Figure 4 — Maximum torque endurance pattern for motor

Table 7 — Description of time parameter in Figure 4

Time parameters	Requirements
t_1	This shall be reduced to technically possible minimum.
t_2	This should be shorter than 1 s.
t_3	This shall be controlled so that the average output power becomes the same as the permissible continuous load of the motor.



Key

t time (in s)
M torque (in Nm)
T temperature (in °C)
$M_{t=2}$ maximum motoring torque for duration of t_0 = 2 (in Nm)
$-M_{t=2}$ maximum regenerating torque for duration of t_0 = 2 (in Nm)
T_s saturation temperature during rated output power operation (in °C)
1 motor torque
2 temperature of motor

Figure 5 — Long time span view of Figure 4

Table 8 — Number of cycles in maximum torque endurance test for motor

Ranks	Number of cycles
S	2 000 000
A	1 000 000
B	500 000
C	300 000

4.1.2.5 Test requirements

4.1.2.5.1 General

The cyclic test shall be started from C rank which is listed in Table 8. Confirmation by energizing and disassembling shall be conducted after the maximum torque endurance test. Before starting the test, target rank shall be decided by the supplier and customer. After each rank, energizing should be done to confirm that changes before and after the test are within the respective criteria shown in Table 9, but the supplier and customer can agree to only conduct energizing after the target rank. After the target rank has been achieved, disassembling shall be done to confirm that the respective criteria shown in Table 10 are fulfilled.

4.1.2.5.2 Energizing

Before conducting this test, the data of the tests listed in Table 9 shall be obtained in order to compare the data before and after this test.

— Back-EMF measurement

The back-EMF of the motor is measured at the 10 % of maximum speed driven externally. They shall be within ±5 % difference before and after the test.

NOTE If the type of DUT is different from a permanent magnet motor, this measurement can be omitted.

— Position sensor origin position check and waveform check

The difference in the back-EMF waveform of the reference phase and the origin position of the position sensor at the 10 % of maximum speed driven externally shall be measured. They shall be within ±5° difference in electrical angle before and after the test.

— Torque – speed characteristics

The motor torque, motor input voltage, inverter output current, and motor speed shall be measured using the load test bench at the operating point "a" and "c" of ISO 21782-1:2019, Figure 1. The difference in torque before and after the test shall be within ±5 %.

— Measurement of vibration

The generated vibrations of the motor during acceleration by the inverter to the maximum speed shall be measured. The acceleration rate shall be adequately slow. The vibration data before and after the test shall be compared for no significant increase. The changes in the vibration values shall be agreed between the supplier and customer.

Criteria of energizing is shown in Table 9.

Table 9 — Criteria of energizing

Measurement items	Conditions	Criteria
Back-EMF	10 % of maximum speed	Within ±5 % difference before and after the test
Origin position and waveform of position sensor	Specified speed	Within ±5° difference in electrical angle before and after the test
Torque - speed characteristics	Operating point "a" and "c"	Within ±5 % difference in the torque before and after the test
Vibration	During acceleration to the maximum speed by inverter (acceleration rate: adequately slow)	No significant increase

4.1.2.5.3 Disassembling

After the energizing tests, the motor shall be disassembled, and each part shall be investigated. The investigation items are external view (deformation and damage) and dimensions. These items are shown in Table 10.

Differences which adversely affect motor performance shall not occur after disassembling. Details of criteria shall be agreed by the supplier and customer.

NOTE Disassembling is optional and is agreed by the supplier and customer in case of abnormalities in the non-destructive examinations.

Table 10 — Criteria of disassembling

Parts/places	Details of investigation	Criteria
Motor shaft key	Deformation, wear	No large deformation No large wear
Rotor magnet fixture (adhesive)	Peeling off of adhesive deformation	No peeling
Shaft tightening part (spline, etc.)	Deformation, wear	No large deformation No large wear
Stator fixtures (thermal insert, bolt)	Wear, deviation, loosening	No large wear No large deviation No loosening

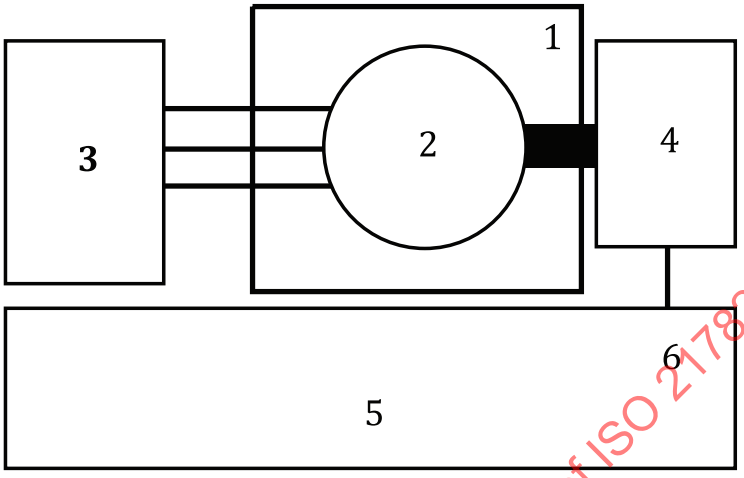
4.1.3 Over speed test

4.1.3.1 General

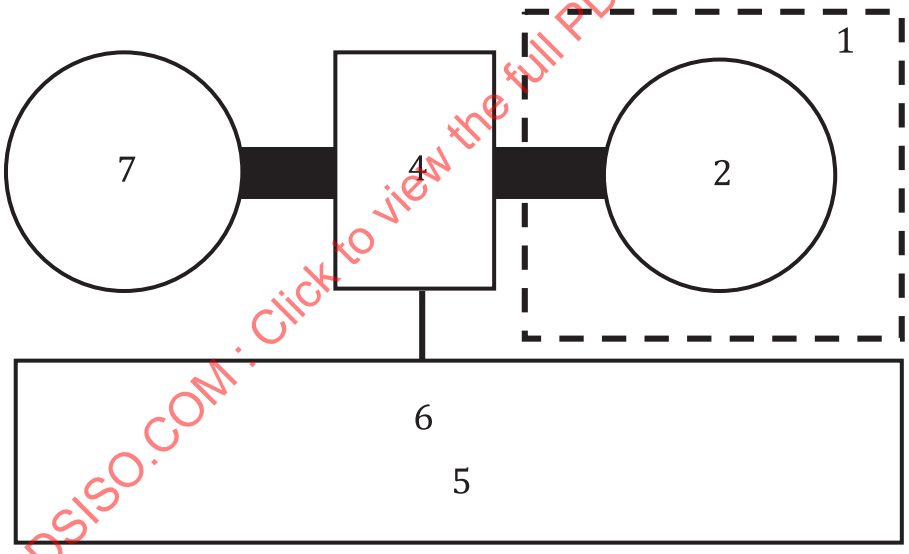
The purpose of this test is to evaluate and rank the strength for the components of the rotor – magnetic steel sheet, end plate, end ring, and balance weight – which are affected by mechanical fatigue, depending on the operating condition exceeding the maximum rotation speed of the motor.

4.1.3.2 Test diagrams

The test diagrams are shown in Figure 6.



a) In case of inverter driven



b) In case of dynamometer driven

Key

1 DUT
2 motor
3 inverter
4 speed detector
5 speed meter
6 motor speed (in min^{-1})
7 dynamometer

Figure 6 — Diagrams for over speed test of motor

4.1.3.3 Test conditions

Test conditions are shown in Table 11.

Table 11 — Conditions for over speed test

Test condition	Value	Remark
Ambient conditions	RT and humidity as defined in ISO 21782-1:2019, 5.4.	

4.1.3.4 Test procedure

For the test, the over speed value shall be selected by agreement between the supplier and customer from the listed values in Table 13. The motor shall be accelerated to the selected over speed and then continuously operated at this speed for 2 min via the dynamometer or inverter. Motor phases shall be opened when using a dynamometer. The load is no load. After the test, the performance of the motor shall be checked by the energizing and disassembling investigation.

4.1.3.5 Test requirements

4.1.3.5.1 General

Confirmation by energizing and disassembling shall be conducted after the over speed test. The criteria for energizing listed in Table 12 and for disassembling shown in 4.1.3.5.3 shall be fulfilled.

NOTE Minimum target rank is rank C.

4.1.3.5.2 Energizing

Before conducting this test, the data of the test listed in Table 12 shall be obtained in order to compare the data before and after this test.

— Back-EMF measurement

The back-EMF of the motor is measured at the 10 % of maximum speed driven externally. They shall be within ±5 % difference before and after the test.

NOTE If the type of DUT is different from a permanent magnet motor, this measurement can be omitted.

— Position sensor origin position check and waveform check

The difference in the back-EMF waveform of the reference phase and the origin position of the position sensor at the 10 % of maximum speed driven externally shall be measured. They shall be within ±5° deference in electrical angle before and after the test.

— Measurement of vibration

The generated vibrations of the motor during acceleration by the inverter to the maximum speed shall be measured. The acceleration rate shall be adequately slow. The vibration data before and after the test shall be compared for significant increase. The changes in the vibration values shall be agreed between the supplier and customer.

Table 12 — Criteria of energizing

Measurement items	Conditions	Criteria
Back-EMF	10 % of maximum speed	Within ±5 % difference before and after the test
Origin position and waveform of position sensor	Specified speed	Within ±5° difference in electrical angle before and after the test
Vibration	During acceleration to the maximum speed by inverter (acceleration rate: adequately slow)	No significant increase

4.1.3.5.3 Disassembling

After the energizing tests, the motor shall be disassembled, and each part shall be investigated. No visible damage, crack, or deformation on the rotor section (magnetic steel sheet, endplate, end ring, balance weight) shall be observed.

Differences which adversely affect motor performance shall not occur after disassembling. Details of criteria shall be agreed by the supplier and customer.

NOTE Disassembling is optional and can be agreed by the supplier and customer in case of abnormalities in the non-destructive examinations.

Test results shall be indicated with two alphabetical characters as follows:

— 1st capital letter: indicates the over speed strength according to Table 13;

— 2nd capital letter: indicates the performance of motor after the test according to Table 14.

EXAMPLE AA indicates that the motor operates normally after continuous operation for 2 min at 140 % of the maximum operating speed.

Table 13 — 1st capital letter

Ranks	Over speed
S	150 % of maximum operating speed
A	140 % of maximum operating speed
B	130 % of maximum operating speed
C	120 % of maximum operating speed
D	110 % of maximum operating speed

Table 14 — 2nd capital letter

Ranks	Motor performance after test
A	Electric performance and mechanical performance meet the manufacturer's acceptance value.
B	The vibration of motor after the test increases, however, there is no visible local damage, crack, or deformation on the rotor section (magnetic steel sheet, endplate, end ring, balance weight).
C	The signal of position sensor is defective, and the motor cannot be operated. There is visible local damage, crack, or deformation on the rotor section (magnetic steel sheet, endplate, end ring, balance weight).

4.2 Operation endurance test of inverter

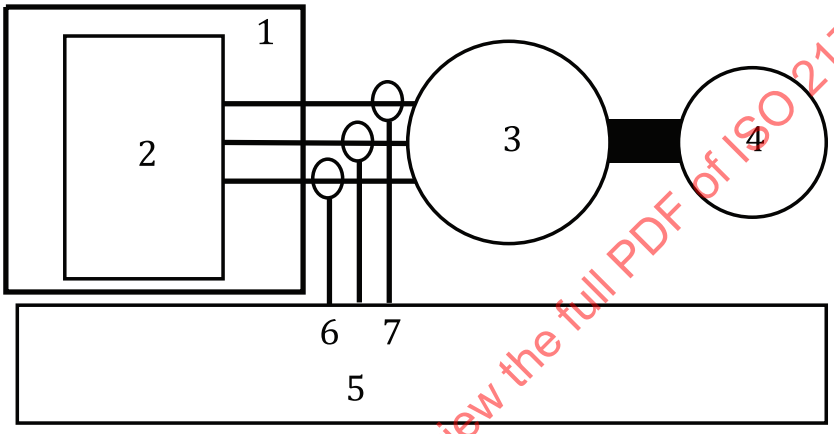
4.2.1 Cyclic test

4.2.1.1 General

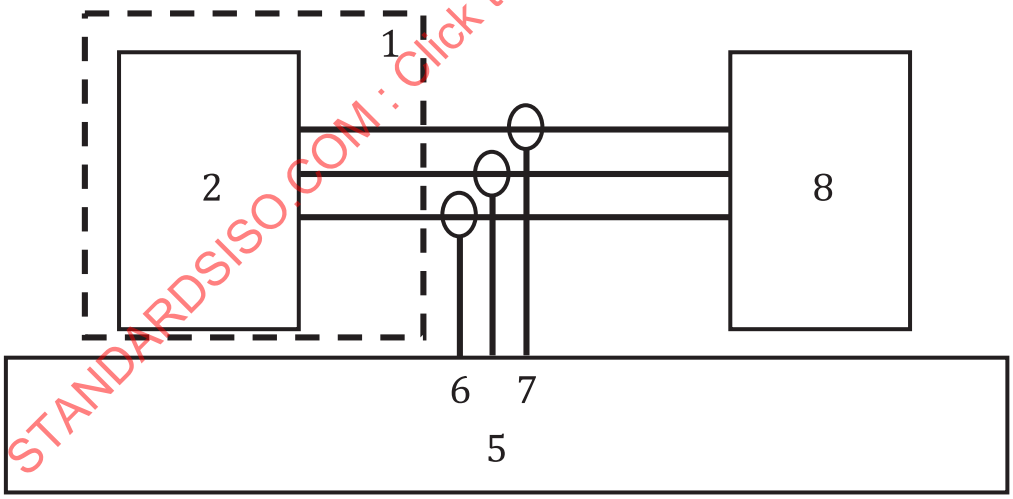
The operation endurance test method may be conducted depending on an agreement between the supplier and customer. The test methods take into account repeated operations with a representative current output pattern of the inverter. The test, including test objectives and time, aims to prevent failures in main power conversion parts.

4.2.1.2 Test diagrams

The test diagrams are shown in Figure 7.



a) With actual motor



b) With motor emulator

Key

1 DUT
2 inverter
3 actual motor
4 load
5 spectrum analyser or power meter
6 inverter output current (in A)
7 inverter output frequency (in Hz)
8 motor emulator

Figure 7 — Diagrams for operation endurance test of inverter

4.2.1.3 Test conditions

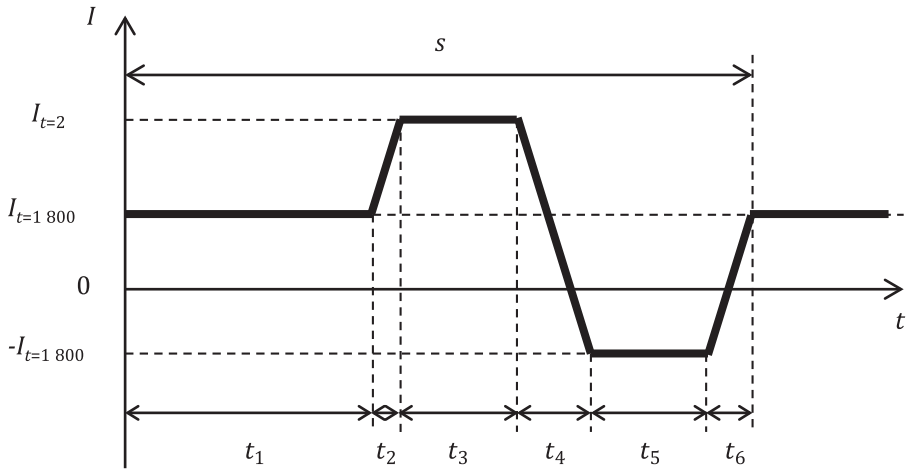
Temperature conditions of the inverter are shown in Table 15. Unless stated otherwise, the conditions shall be decided by an agreement between the supplier and customer. If conducting an accelerated test with raised temperature conditions, it shall be agreed between the supplier and customer.

Table 15 — Conditions for cyclic test of inverter

Test conditions		Value	Remark
Ambient conditions		RT and humidity as defined in ISO 21782-1:2019, 5.4.	
Coolant temperature		Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as example of coolant
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	

4.2.1.4 Test procedure

The inverter shall be tested with an equivalent load (e.g. motor emulator). The inverter shall be operated according to the load pattern shown in Figure 8 and Table 16.



Key

t	time (in s)
I	current (in A)
$I_{t=2}$	maximum motoring current for duration of t_0=2 (in A)
$I_{t=1\,800}$	maximum motoring current for duration of t_0=1 800 (in A)
$-I_{t=1\,800}$	maximum regenerating current for duration of t_0=1 800 (in A)
s	1 cycle
$t_1, t_2, t_3, t_4, t_5, t_6$	time parameters

Figure 8 — Cyclic test load pattern for endurance test of inverter

Table 16 — Test cycle parameter for endurance test of inverter

Time parameters	Inverter output current	Operating points	Operating time (in s)
t_1	$I_{t=1\,800}$	b	120
t_2	Transfer from $I_{t=1\,800}$ to $I_{t=2}$	b to a	3
t_3	$I_{t=2}$	a	2
t_4	Transfer from $I_{t=2}$ to $-I_{t=1\,800}$	a to f	4
t_5	$-I_{t=1\,800}$	f	30
t_6	Transfer from $-I_{t=1\,800}$ to $I_{t=1\,800}$	f to b	3
1 cycle cumulative time			162
Number of cycles			3 000 cycles

NOTE t_6 can be changed not to exceed the rated power of the inverter.

4.2.1.5 Test requirements

Confirmation by disassembling shall be conducted after the cyclic test. The criteria for disassembling listed in Table 17 shall be fulfilled. It shall be confirmed that no problems are found in inverter design and/or manufacture by an agreement between the supplier and customer.

4.2.1.6 Disassembling

The inverter shall be disassembled and investigated according to Table 17.

Table 17 — Criteria of disassembling of inverter

Parts/places	Criteria
Power semiconductor chip	Within ±10 % difference in electrical resistance and thermal resistance.
DC bus capacitor	Within ±10 % difference in the capacitance and impedance characteristics at the typically used frequency.

NOTE In case of insulated gate bipolar transistor (IGBT), the resistance between the collector and the emitter is measured. In case of field effect transistor (FET), the resistance between the drain and the source is measured.

4.3 Breakdown strength verification test of rotor

4.3.1 Spin test

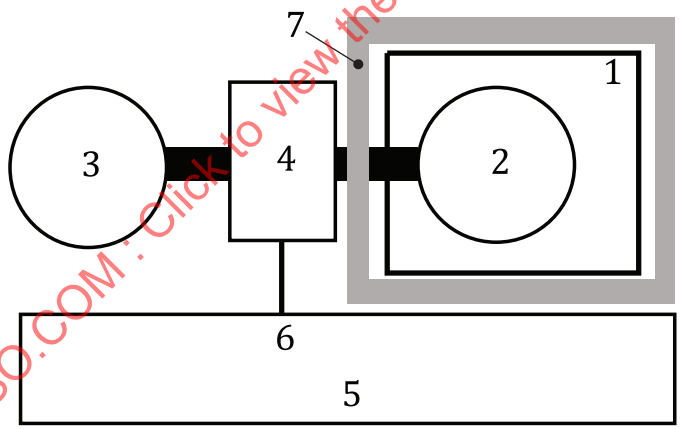
4.3.1.1 General

Spin test method may be conducted depending on an agreement between the supplier and customer. The test method aims to know the mechanical strength of the motor.

NOTE The spin test is optional and is performed by an agreement between the supplier and customer.

4.3.1.2 Test diagram

The test diagram is shown in Figure 9.



Key

1 DUT
2 rotor
3 spin tester
4 speed detector
5 speed meter
6 rotor speed (in min^{-1})
7 protection barrier for rupture

Figure 9 — Diagram for spin test of rotor

4.3.1.3 Test conditions

Test conditions are shown in Table 18.

Table 18 — Conditions for spin test of rotor

Test condition	Value	Remark
Ambient conditions	RT and humidity as defined in ISO 21782-1:2019, 5.4.	

4.3.1.4 Test procedure

This is a test conducted with the rotor and the number of DUT used is one.

The spin test shall be conducted as follows.

a) Measure the external diameter of rotor.

b) The speed shall be increased from 120 % of the maximum operating speed in a stepwise manner by 10 % of the maximum operating speed.

c) The acceleration up to the speed shall be 100 min^{-1}/s.

d) After the speed is continued for one minute, stop the revolution and measure the external diameter.

e) Repeat steps b) to d) until the rotor is broken.

Measurement points, measurement method and measurement environment shall be decided between the supplier and customer. If there is no agreement, this test shall be in accordance with following method.

1) Mark the weakest part of the centrifugal force strength of the rotor external diameter in the axial direction. The number of marks is a number that can be determined to be plastically deformed.

2) Measurements are conducted with a micrometer.

4.3.1.5 Test requirements

The rank listed in Table 19 that classifies the speed before occurrence of permanent abnormal deformation on the rotor by percentage for maximum operating speed shall be displayed.

Table 19 — Capital letter indicating breaking strength of rotor

Ranks	Speed before permanent abnormal deformation
S	Above 200 % of the maximum operating speed
A	200 % of the maximum operating speed
B	190 % of the maximum operating speed
C	180 % of the maximum operating speed
D	170 % of the maximum operating speed
E	160 % of the maximum operating speed
F	150 % of the maximum operating speed
G	140 % of the maximum operating speed
H	130 % of the maximum operating speed
I	120 % of the maximum operating speed

5 Test report

Each test shall be reported with a test report, containing sufficient information on test conditions and results.

Examples for a test report on conditions and results are given in Annex A.