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

Part 3: Performance testing of the motor and the inverter

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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 3: Performance testing of the motor and the inverter

1 Scope

This document specifies performance tests for the motor and the 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 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 21782-1, *Electrically propelled road vehicles — Test specification for electric propulsion components — Part 1: General test conditions and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions 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 Abbreviated terms

For the purposes of this document, the abbreviated terms given in ISO 21782-1 apply.

5 Tests

5.1 Motor test

5.1.1 Measurement of loss and efficiency

5.1.1.1 General

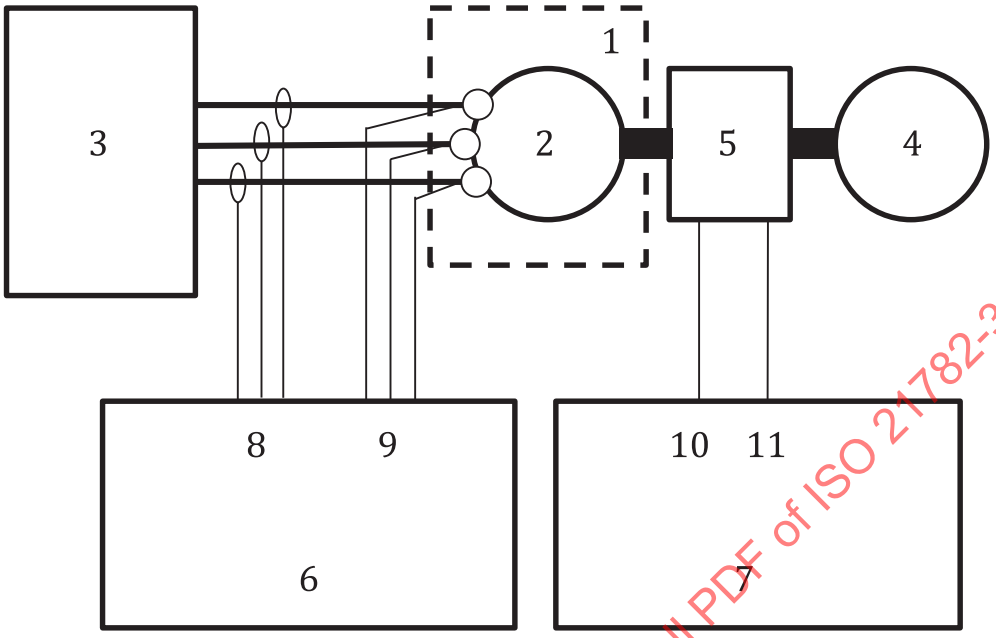
The purpose of this test is to operate the motor under the specified operating conditions and to measure the loss and efficiency of the motor in order to ensure that the performance is as designed.

5.1.1.2 Test diagram

The test diagram is shown in Figure 1.

Either the two-wattmeter method or the three-wattmeter method may be used for the three-phase power measurement.

Using the three-wattmeter method is recommended.



Key

1 DUT
2 motor
3 inverter
4 load
5 torque/speed detector
6 spectrum analyser/power meter
7 torque/speed meter
8 motor input current (in A)
9 motor input voltage (in V)
10 motor torque (in Nm)
11 motor speed (in min^{-1})

Figure 1 — Diagram for measurement of loss and efficiency of the motor

5.1.1.3 Test conditions

The test conditions are shown in Table 1.

Table 1 — Conditions for measurement of loss and efficiency of the motor

Test conditions	Value	Remark
Inverter input voltage	Rated voltage as defined in ISO 21782-1:2019, 3.22.	For the inverter input voltage tolerance, see ISO 21782-1:2019, 5.3.
Ambient conditions	Room temperature (RT) and humidity as defined in ISO 21782-1:2019, 5.4.	

Table 1 *(continued)*

Test conditions		Value	Remark
Coolant temperature		Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	
Operating point		Test points as defined in ISO 21782-1:2019, Figure 1 — "a", "a'", "b", "p_1" to "p_{10}" (optional "e", "e'", "f", "p_1'" to "p_{10}'")	
Switching frequency		The frequency shall be agreed between the supplier and customer.	
Operating time		— The operating points "a", "a'", "p_1", "p_3", "p_5", "p_7", "p_9", "p_{10}": 2 s or 10 s (optional 30 s, 60 s) — The operating point "b": 1 800 s — The operating points "p_2", "p_4", "p_6", "p_8": 1 800 s or maximum allowable time for temperature protection	For regenerative operating points, the same operating time applies as for corresponding motoring operating points.

5.1.1.4 Test procedure

1) The test motor shall be operated at specified operating points for the operating time defined in Table 1. Motor input power, output torque and speed shall be recorded. Each average of the last one second of the records shall be used. See Annex A for information about the input power measurement.

2) The loss and efficiency shall be calculated by using Formulae (1) and (2):

$$\eta_{\mathrm{m}} = \frac{P_{\mathrm{mo}}}{P_{\mathrm{mi}}} \times 100 \tag{1}$$

$$P_{\mathrm{ml}} = P_{\mathrm{mi}} - P_{\mathrm{mo}} \tag{2}$$

where

η_{m} is the efficiency of the motor (in %);

P_{mo} is the motor output power (in W);

P_{mi} is the motor input power (in W);

P_{ml} is the loss of the motor (in W).

The measurement of regenerate operation may be decided by agreement between the supplier and customer.

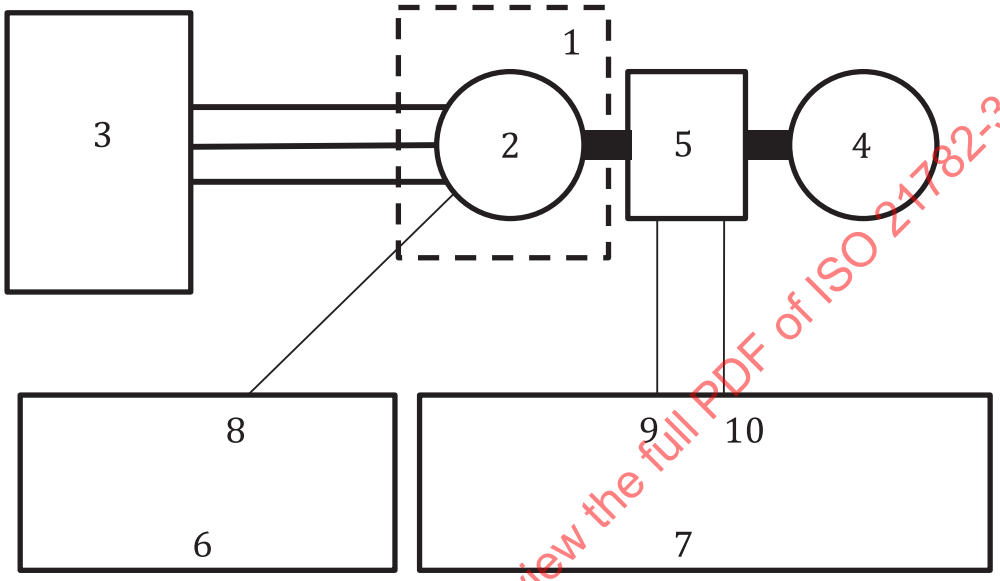
5.1.2 Temperature rise test

5.1.2.1 General

The purpose of this test is to operate the motor under the specified conditions and to measure the temperature rise in the motor in order to ensure that the motor thermal performance is as designed.

5.1.2.2 Test diagram

The test diagram is shown in Figure 2.



Key

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

Figure 2 — Diagram for temperature rise test of the motor

5.1.2.3 Test conditions

The test conditions are shown in Table 2.

Table 2 — Conditions for temperature rise test of the motor

Test conditions	Value	Remark
Inverter input voltage	Rated voltage as defined in ISO 21782-1:2019, 3.22.	For the inverter input voltage tolerance, see ISO 21782-1:2019, 5.3.
Ambient conditions	RT and humidity as defined in ISO 21782-1:2019, 5.4.	

Table 2 *(continued)*

Test conditions		Value	Remark
Coolant temperature		Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	
Operating point		The points as defined in ISO 21782-1:2019, Figure 1 — "a", "b"	May be set by agreement between the supplier and customer.
Switching frequency		The frequency shall be set by agreement between the supplier and customer.	
Operating time		— The operating point "a": 2 s or 10 s — The operating point "b": 1 800 s	

5.1.2.4 Test procedure

The test motor shall be operated at specified operating points, and the temperature at the measurement points shall be recorded.

For each torque-speed point, after the operating time as defined in Table 2 passes, the temperature shall be recorded.

An inverter that has the ability to operate continuously at the maximum torque point may be used.

The temperature of coil shall be measured at the points assumed as the highest. The measurement points in the coil and other measurement points can be added by agreement between the supplier and customer.

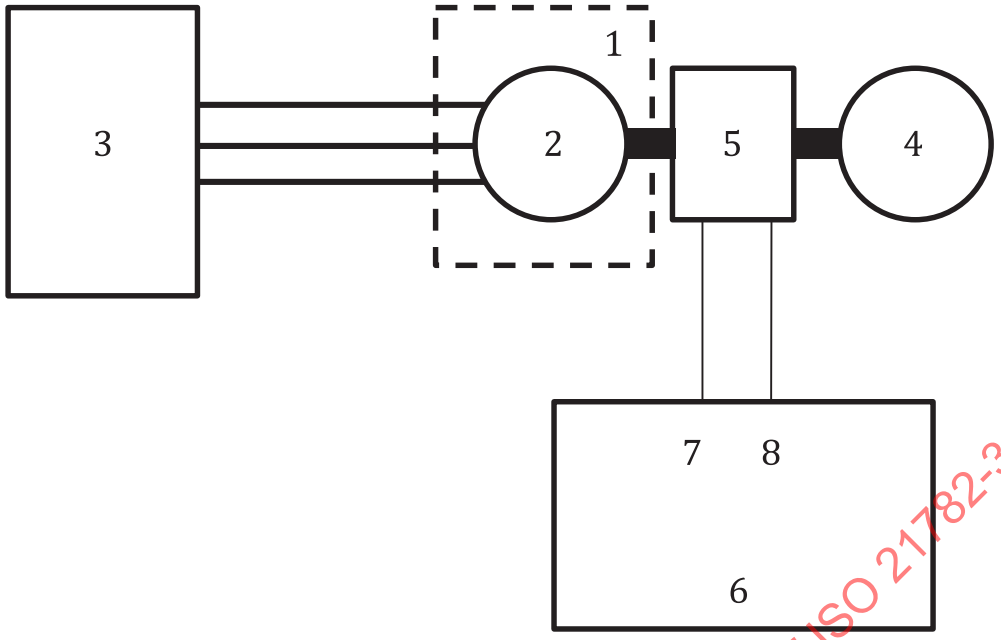
5.1.3 Torque characteristic test

5.1.3.1 General

The purpose of this test is to operate the motor under the specified operating conditions and to check the torque characteristics in order to ensure that the motor performance is as designed.

5.1.3.2 Test diagram

The test diagram is shown in Figure 3.



Key

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

Figure 3 — Diagram for torque characteristic test of the motor

5.1.3.3 Test conditions

The test conditions are shown in Table 3.

Table 3 — Conditions for torque characteristic test of the motor

Test conditions	Value	Remark
Inverter input voltage	Rated voltage as defined in ISO 21782-1:2019, 3.22.	For the inverter input voltage tolerance, see ISO 21782-1:2019, 5.3.
Ambient conditions	RT and humidity as defined in ISO 21782-1 2019, 5.4.	

Table 3 *(continued)*

Test conditions		Value	Remark
Coolant temperature		Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	
Operating point		The points as defined in ISO 21782-1:2019, Figure 1 — "a", "a'", "c", "d"	
Operating time		— The operating points "a", "a'", "c" and "d": 2 s or 10 s (optional 30 s, 60 s)	

5.1.3.4 Test procedure

The test motor shall be operated at specified operating points for the operating time as defined in Table 3. Motor input power, output torque and speed shall be recorded. Each average of the last one second of the records shall be used.

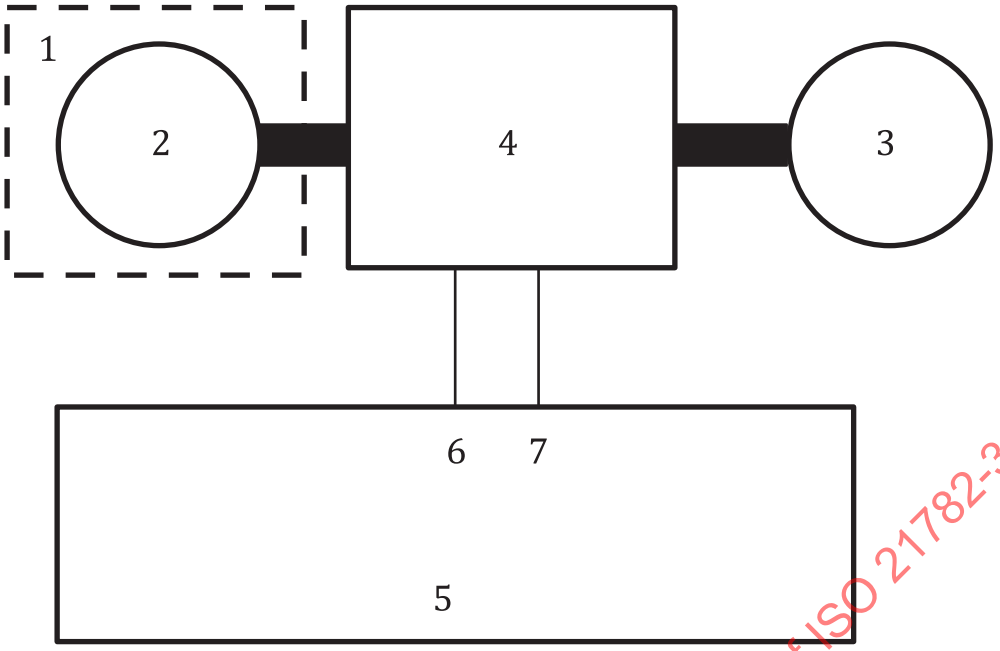
5.1.4 Cogging torque test

5.1.4.1 General

The purpose of this test is to operate the permanent-magnet motor at a low speed on the motor dynamometer and to measure the waveform of torque in order to ensure that the cogging torque is as designed.

5.1.4.2 Test diagram

The test diagram is shown in Figure 4.



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 4 — Diagram for cogging torque test of the motor

5.1.4.3 Test conditions

The test conditions are shown in Table 4.

Table 4 — Conditions for cogging torque test of the motor

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

5.1.4.4 Test procedure

1) A motor shaft shall be connected to the torque detector such as a rotary encoder or a dedicated measurement system. During the measurement at no load and at a speed as low as possible, the cogging torque waveform shall be measured.

2) The cogging torque shall be the peak to peak value of the measured waveform.

5.2 Inverter test

5.2.1 Measurement of loss, efficiency and conversion rate

5.2.1.1 General

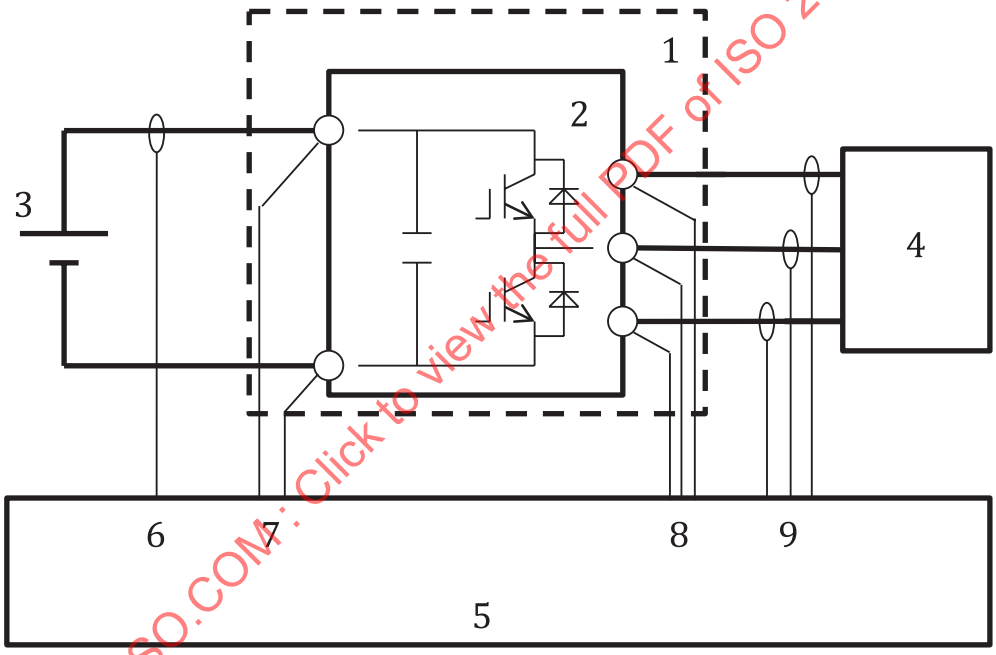
The purpose of this test is to operate the inverter under the specified conditions and to measure the loss and efficiency of the inverter in order to ensure that the inverter performance is as designed.

5.2.1.2 Test diagram

The test diagram is shown in Figure 5.

Either the two-wattmeter method or the three-wattmeter method may be used for three-phase power measurement.

Using the three-wattmeter method is recommended.



Key

1 DUT
2 inverter
3 DC power supply
4 AC load
5 spectrum analyser/power meter
6 inverter input current (in A)
7 inverter input voltage (in V)
8 inverter output voltage (in V)
9 inverter output current (in A)

Figure 5 — Diagram for measurement of loss, efficiency and conversion rate of the inverter

Examples of AC loads are shown below:

— actual motor: Motor specified by agreement between the supplier and customer;

— motor emulator: Electric load which emulates electric characteristic of actual motor;

— ACL: 3-phase inductance equivalent to the leakage inductance of the motor;

— RL load: ACL with series resistance equivalent to phase resistance of the motor.

5.2.1.3 Test conditions

The test conditions are shown in Table 5.

Table 5 — Conditions for measurement of loss, efficiency and conversion rate of the inverter

Test conditions		Value	Remark
Inverter input voltage		Rated voltage as defined in ISO 21782-1:2019, 3.22.	For the inverter input voltage tolerance, see ISO 21782-1:2019, 5.3.
Operating point		The points as defined in ISO 21782-1:2019, Figure 1 — "a", "b"	In case of no paired motor, a representative current frequency of 200 Hz shall be used. For regenerative operating points, the same operating time applies as for corresponding motoring operating points.
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 examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Value of design specification	
Output frequency		Rated frequency (f_r) as defined in ISO 21782-1:2019, 3.20.	May be changed by agreement between the supplier and customer.
Switching frequency		In accordance with the designed frequency	May be changed by agreement between the supplier and customer.
Operating time		— The operating point "a": 2 s or 10 s (optional 30 s, 60 s) — The operating point "b": 1 800 s	

5.2.1.4 Test procedure

The test shall be carried out as follows.

1) The test inverter shall be operated at specified output-current points for the operating time defined in Table 5. Inverter input power and output power shall be recorded. Each average of the last one second of the records shall be used. See Annex A for information about output power measurement.

2) The efficiency, conversion rate and loss shall be calculated by using Formulae (3) to(5):

$$\eta_i = \frac{P_{io}}{P_{ii}} \times 100 \quad (3)$$

$$\eta_{i\_conv} = \frac{P_{io\_fund}}{P_{ii\_mean}} \times 100 \quad (4)$$

$$P_{il} = P_{ii} - P_{io} \quad (5)$$

where

η_i is the efficiency of the inverter including harmonics and ripples (in %);

P_{io} is the inverter output power (in W);

P_{ii} is the inverter input power (in W);

η_{i_conv} is the conversion rate of the inverter (in %);

P_{io_fund} is the fundamental inverter output power (in W);

P_{ii_mean} is the average inverter input power (in W);

P_{il} is the loss of the inverter (in W).

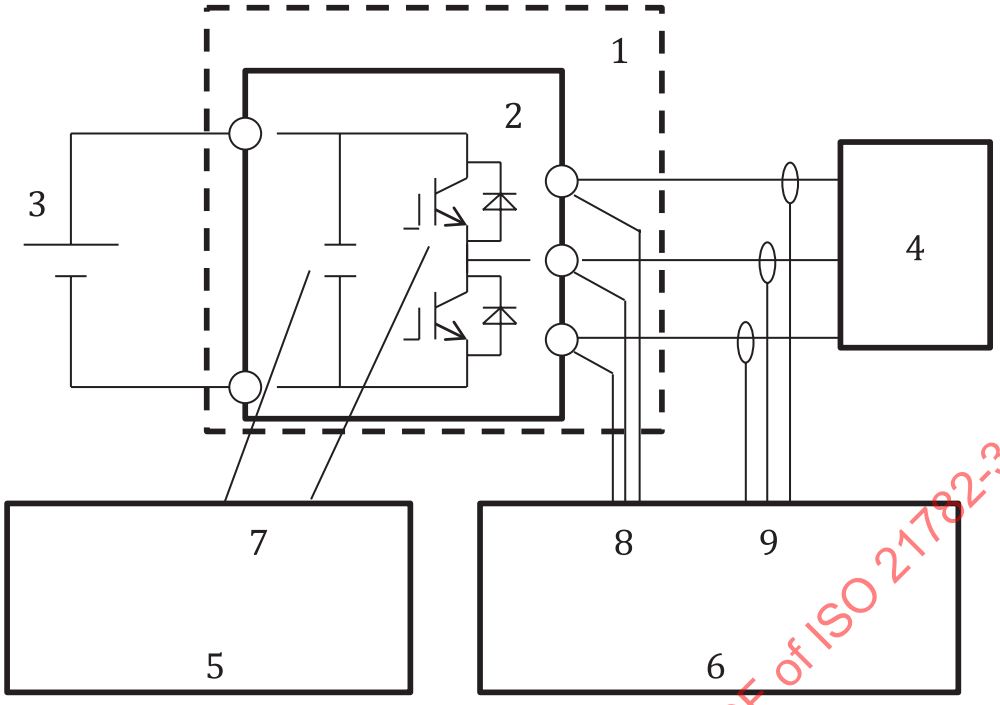
5.2.2 Temperature rise test

5.2.2.1 General

The purpose of this test is to operate the inverter under the specified conditions and to measure the temperature rise in the inverter in order to ensure that the thermal performance of the inverter is as designed.

5.2.2.2 Test diagram

The test diagram is shown in Figure 6.



Key

1 DUT
2 inverter
3 DC power supply
4 AC load
5 thermometer
6 spectrum analyser/power meter
7 measurement points temperature (in °C)
8 inverter output voltage (in V)
9 inverter output current (in A)

Figure 6 — Diagram for temperature rise test of the inverter

Examples of AC loads are shown below:

— actual motor: Motor specified by agreement between the supplier and customer;

— motor emulator: Electric load which emulates electric characteristic of actual motor;

— ACL: 3-phase inductance equivalent to the leakage inductance of the motor;

— RL load: ACL with series resistance equivalent to phase resistance of the motor.

5.2.2.3 Test conditions

The test conditions are shown in Table 6.

Table 6 — Conditions for temperature rise test of the inverter

Test conditions	Value	Remark
Inverter input voltage	Maximum voltage for unlimited operating capability as defined in ISO 21782-1:2019, 3.13.	

Table 6 *(continued)*

Test conditions		Value	Remark
Output current		The points as defined in ISO 21782-1:2019, Figure 1 — "a", "b"	
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 examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	
Output frequency		Rated frequency (f_r) as defined in ISO 21782-1:2019, 3.20.	May be changed by agreement between the supplier and customer.
Switching frequency		In accordance with the designed frequency	May be changed by agreement between the supplier and customer.
Operating time		— The operating point "a": 2 s or 10 s — The operating point "b": 1 800 s	

5.2.2.4 Test procedure

1) The inverter shall be operated by the $I_{t=t0}$, and the temperature of each part of the inverter shall be recorded after the specified time (t_0) passes.

2) The temperature of test inverter shall be measured at the measurement points as shown below:

   — electrode part of power semiconductor or specified point of the cooling components closely connected to these parts;

   — inlet and outlet of coolant.

Additional measurement points can be added by the agreement between the supplier and customer.

When the test is conducted with the paired motor, the $I_{t=1\,800}$ shall correspond to $M_{t=1\,800}$, and $I_{t=2}$ shall correspond to $M_{t=2}$ or $P_{t=2}$.

5.3 Chopper test

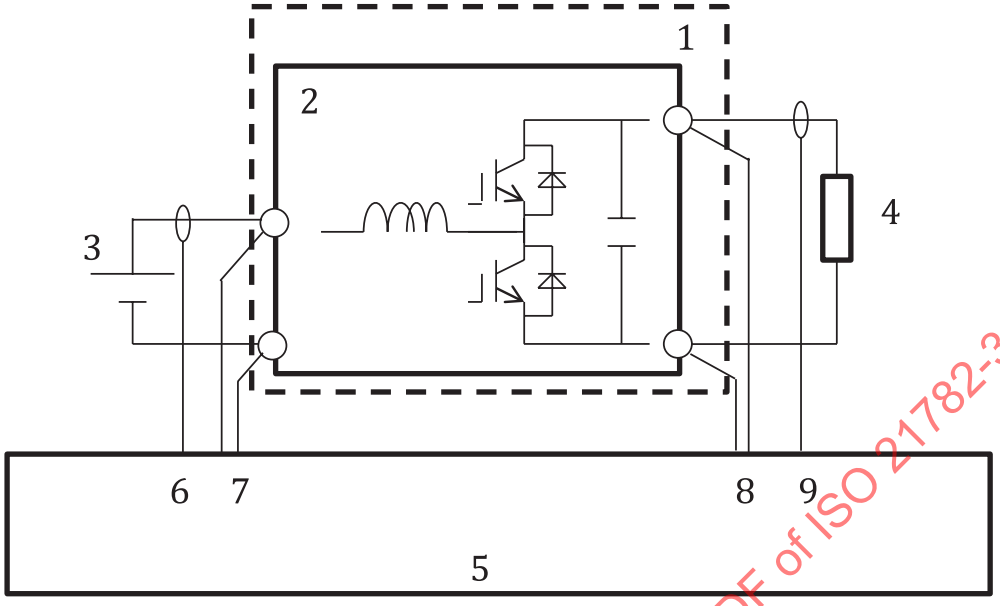
5.3.1 Measurement of loss, efficiency and conversion rate

5.3.1.1 General

The purpose of this test is to operate the chopper under the specified conditions and to measure the loss and efficiency of the chopper in order to ensure that the chopper performance is as designed.

5.3.1.2 Test diagram

The test diagram is shown in Figure 7.



Key

1 DUT
2 chopper
3 DC power supply
4 load
5 spectrum analyser/power meter
6 chopper input current (in A)
7 chopper input voltage (in V)
8 chopper output voltage (in V)
9 chopper output current (in A)

Figure 7 — Diagram for measurement of loss, efficiency and conversion rate of chopper

5.3.1.3 Test conditions

The test conditions are shown in Table 7.

Table 7 — Conditions for measurement of loss, efficiency and conversion rate of the chopper

Test conditions	Value	Remark
Chopper input voltage	Rated voltage as defined in ISO 21782-1:2019, 3.22.	For the chopper input voltage tolerance, see ISO 21782-1:2019, 5.3.
Output voltage	Maximum voltage for unlimited operating capability as defined in ISO 21782-1:2019, 3.13.	Can be changed by the agreement with the customer.
Output current	— Maximum current: $I_{t=2}$ — Rated current: $I_{t=1\,800}$	
Ambient conditions	RT and humidity as defined in ISO 21782-1:2019, 5.4.	

Table 7 *(continued)*

Test conditions		Value	Remark
Coolant temperature		Maximum temperature for unlimited operating capability	— In case of liquid cooling — Ethylene glycol and propylene glycol as examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Value of design specification	
	Air	Value of design specification	
Switching frequency		In accordance with the designed frequency	May be changed by agreement between the supplier and customer.
Operating time		— Maximum current: 2 s or 10 s (optional 30 s, 60 s) — Rated current: 1 800 s	

5.3.1.4 Test procedure

The test shall be carried out as follows.

1) The test chopper shall be operated at specified output current points for the operating time defined in Table 7. The average of the last one second of the operating time of the input power and output power of chopper shall be recorded.

2) The efficiency, conversion rate and loss shall be calculated by using Formulae (6) to (8):

$$\eta_c = \frac{P_{co}}{P_{ci}} \times 100 \tag{6}$$

$$\eta_{c\_conv} = \frac{P_{co\_mean}}{P_{ci\_mean}} \times 100 \tag{7}$$

$$P_{cl} = P_{ci} - P_{co} \tag{8}$$

where

η_c is the efficiency of the chopper including harmonics and ripples (in %);

P_{co} is the chopper output power (in W);

P_{ci} is the chopper input power (in W);

η_{c_conv} is the conversion rate of chopper (in %);

P_{co_mean} is the average chopper output power (in W);

P_{ci_mean} is the average chopper input power (in W);

P_{cl} is the loss of the chopper (in W).

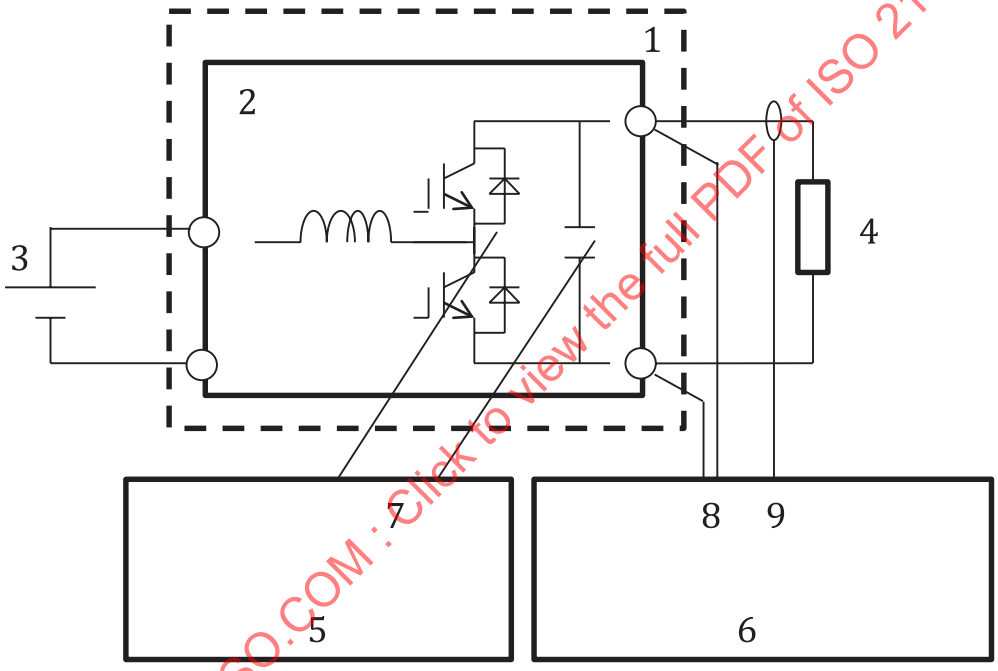
5.3.2 Temperature rise test

5.3.2.1 General

The purpose of this test is to operate the chopper under the specified conditions and to measure the temperature rise in the chopper in order to ensure that the chopper thermal performance is as designed.

5.3.2.2 Test diagram

The test diagram is shown in Figure 8.



Key

1 DUT
2 chopper
3 DC power supply
4 load
5 thermometer
6 spectrum analyser/power meter
7 measurement point temperature (in °C)
8 chopper output voltage (in V)
9 chopper output current (in A)

Figure 8 — Diagram for temperature rise test of chopper

5.3.2.3 Test conditions

The test conditions are shown in Table 8.

Table 8 — Conditions for temperature rise test of chopper

Test conditions		Value	Remark
Chopper input voltage		Minimum voltage for unlimited operating capability as defined in ISO 21782-1:2019, 3.14.	
Output voltage		Maximum voltage for unlimited operating capability as defined in ISO 21782-1:2019, 3.13.	
Output current		— Maximum current: $I_{t=2}$ — Rated current: $I_{t=1\,800}$	
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 examples of coolant — If technically feasible, the tests shall be performed at coolant temperature of 65 °C. Otherwise the deviation shall be documented in the test report.
Coolant flow rate	Liquid	Minimum flow rate for unlimited operating capability	
	Air	Minimum flow rate for unlimited operating capability	
Switching frequency		In accordance with the designed frequency	May be changed by agreement between the supplier and customer.
Operating time		— Maximum current: 2 s or 10 s — Rated current: 1 800 s	

5.3.2.4 Test procedure

1) The chopper shall be operated by $I_{t=t0}$, and the temperature of each part of the chopper shall be recorded just after the specified time (t_0) passes.

2) The temperature of test chopper shall be measured at the measurement points as shown below:

   — electrode part of power semiconductor or specified point of the cooling components closely connected to these parts;

   — inlet and outlet of coolant.

Additional measurement points can be added by the agreement between the supplier and customer.

6 Test reports

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

Examples for a test reports on conditions and results are given in Annex B.

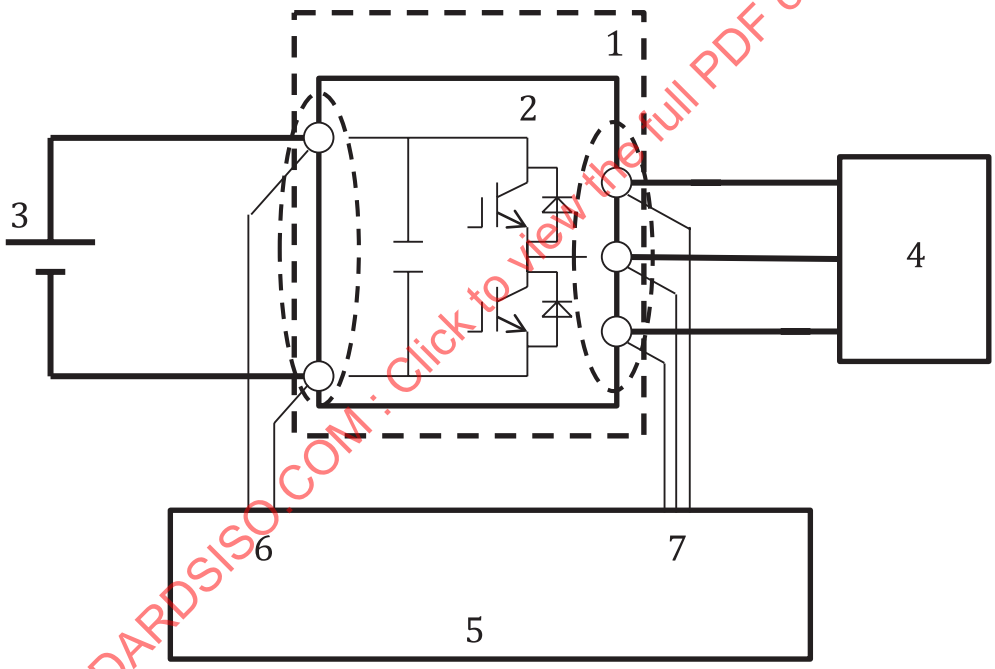
Annex A
(informative)

Precautions for measuring motor/inverter loss and efficiency

A.1 The loss measurement of the motor or the inverter is obtained by the difference between the two measured values of input power and output power. Since the loss is about one tenth of the input/output power, the measurement error has a large influence on the calculated value of loss. In consideration of these circumstances, we note the precautions of the input/output power measurement method used for loss calculation.

A.2 Handling of drop voltage in laboratory harness

The input and output voltages of the test component should be measured at the component terminal directly as shown in Figure A.1 in order to reduce the influence of the drop of the test intermediate harness.



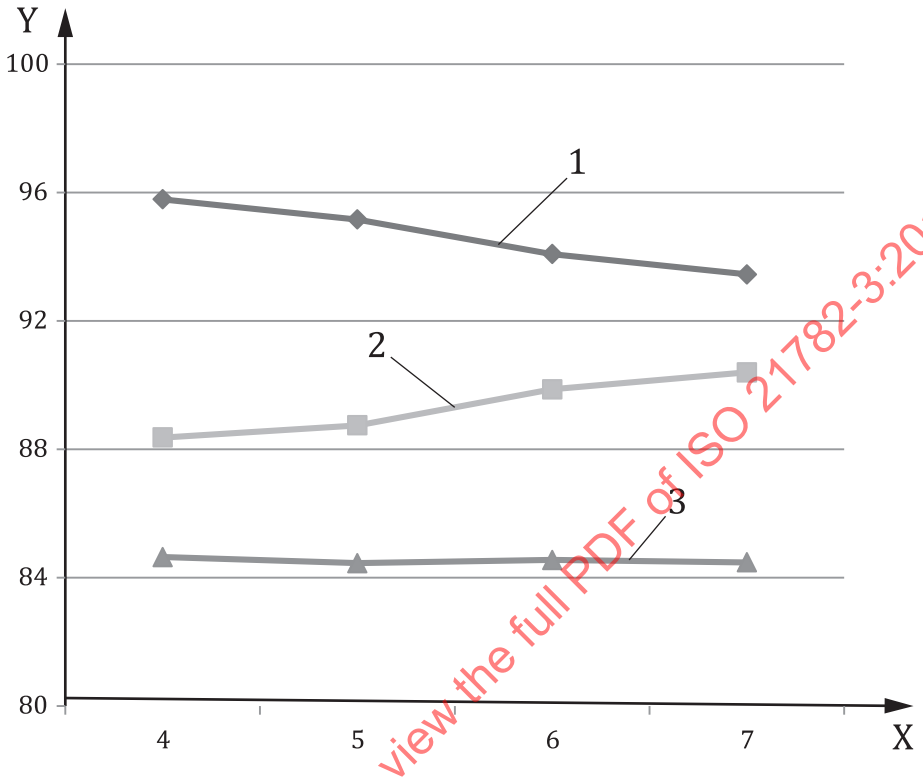
Key

1 DUT
2 inverter
3 DC power supply
4 AC load
5 spectrum analyser/power meter
6 inverter input voltage (in V)
7 inverter output voltage (in V)

Figure A.1 — Measurement points of voltage of the DUT

A.3 Filter setting for PWM voltage measurement

The use of low pass filter for PWM voltage measurement should be minimized. The setting of an inappropriate cut-off frequency deteriorates the voltage and current waveform and measures the AC power smaller than the original value.



Key

X inverter output filter condition
Y efficiency (in %)
1 inverter
2 motor
3 motor system
4 cut-off frequency of low pass filter: 500 Hz
5 cut-off frequency of low pass filter: 5,5 kHz
6 cut-off frequency of low pass filter line: 50 kHz
7 low pass filter: off

Figure A.2 — Effect of filter on efficiency

Annex B
(informative)

Test report

B.1 Motor test

B.1.1 Measurement of loss and efficiency

Table B.1 — Measurement of loss and efficiency of the motor

1 Common conditions												
	Items			**Value**								**Remark**
	Inverter input voltage (in V)											
	Ambient condition	Temperature (in °C)										
		Humidity (in %)										
	Cooling type			Liquid/Air/Others								
	Coolant temperature (in °C)											
	Coolant flow rate (in l/min)											
	Switching frequency (in kHz)											
2 Results and individual conditions												
	Items			**Value**								**Remark**
	Operating points			a	a'	b	p_1	p_2	p_3	p_4		
	Operating time (in s)											
	Input	Current (rms) (in A)										
		Voltage (rms) (in V)										
		Power (in kW)										
	Output	Torque (in Nm)	Target									
			Measured									
		Speed (in min^{-1})	Target									
			Measured									
		Power (in kW)										
	Calculated results	Loss of motor (in W)										
		Efficiency of motor (in %)										
	Operating points			p_5	p_6	p_7	p_8	p_9	p_{10}			
	Operating time (in s)											
	Input	Current (rms) (in A)										
		Voltage (rms) (in V)										
		Power (in kW)										
	Output	Torque (in Nm)	Target									
			Measured									
		Speed (in min^{-1})	Target									
			Measured									