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

**Part 1:
General test conditions and
definitions**

*Véhicules routiers à propulsion électrique — Spécification d'essai
pour les composants de propulsion électrique —*

Partie 1: Conditions générales et définitions



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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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 37, *Electrically propelled vehicles*.

This second edition cancels and replaces the first edition (ISO 21782-1:2019), which has been technically revised.

The main changes are as follows:

- addition of ISO 21782-4, ISO 21782-5 and ISO 21782-7 general specifications and requirements to this document;
- correction of the subclause numbers cited in the Terms and definitions clause.

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

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

Until now, there was no international standardized test procedure for the motor system including motors, inverters DC/DC converters and their combinations for electric propulsion systems of electrically propelled road vehicles available. There are some International Standards for industrial use which consider the steady/constant running of motors and inverters but do not consider the dynamic operation (acceleration/deceleration).

The ISO 21782 series was prepared aiming at the reproducibility of test results which will enable to compare and evaluate fairly the performance and reliability of electric propulsion system components such as the motor system (the motor, inverter, DC/DC converter and their combinations).

The overview of the ISO 21782 series is in [Tables 1](#) to [7](#) shown below.

Table 1 — Contents of this document: General test conditions and definitions

Item of this document	Description
Introduction	Background and purpose of the ISO 21782 series
Terms and definitions	Terms to use in the ISO 21782 series
Abbreviated terms	Abbreviated terms to use in the ISO 21782 series
General test conditions	Definition of general conditions: — operating point, — methods for determining the rank for operating load test, — current, voltage and power, — DC input voltage, — temperature and humidity, — measurement accuracy.

Table 2 — Contents of ISO 21782-2: Performance testing of the motor system

Item of ISO 21782-2	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Measurement of total loss and total efficiency	This test measures total loss and total efficiency between the input power of inverter and the output power of the motor.				5.1	
Temperature rise test	This test investigates the temperature rise characteristics of each part of the motor system within the specified range.				5.2	
Torque characteristic test	This test measures the torque characteristics specified in the specifications of the motor system.				5.3	
Torque ripple test	This test measures the torque ripple of the motor.				5.4	

Table 3 — Contents of ISO 21782-3: Performance testing of the motor and the inverter

Item of ISO 21782-3	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Measurement of loss and efficiency	This test measures loss and efficiency between the input power and the output power.	5.1.1	5.2.1	5.3.1		
	This test measures conversion rate between the input power and the output power.		5.2.1	5.3.1		
Temperature rise test	This test investigates the temperature rise characteristics of each part of the component within the specified range.	5.1.2	5.2.2	5.3.2		
Torque characteristic test	This test measures the torque characteristics specified in the specifications of the motor.	5.1.3				
Cogging torque test	This test measures the cogging torque of the permanent magnetic motor.	5.1.4				

Table 4 — Contents of ISO 21782-4: Performance testing of the DC/DC converter

Item of ISO 21782-4	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Measurement of loss and efficiency	This test measures loss and efficiency between the input power and the output power.					5.1
Temperature rise test	This test investigates the temperature rise characteristics of each part of the DC/DC converter within the specified range.					5.2

Table 5 — Contents of ISO 21782-5: Operating load testing of the motor system

Item of ISO 21782-5	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Endurance test	Cyclic test of output torque pattern endurance including maximum torque and maximum speed				5.1	
Surge voltage measurement test	This test measures the surge voltage applied to the input terminals of the motor.				5.2	
Over speed test	The test verifies the no control failure according to the over speed and gives the corresponding rank.				5.3	

Table 6 — Contents of ISO 21782-6: Operating load testing of the motor and the inverter

Item of ISO 21782-6	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Operation endurance tests of motor	Cyclic test of high acceleration/deceleration endurance	4.1.1				
	Cyclic test of torque pattern endurance including maximum torque	4.1.2				
	Over speed test	4.1.3				

Table 6 (continued)

Item of ISO 21782-6	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Operation endurance tests of inverter	Cyclic test of output current pattern endurance including maximum current		4.2.1			
Breakdown strength verification test	Contents of this test are mainly spin test, data acquisition of mechanical strength of the motor.	4.3.1				

Table 7 — Contents of ISO 21782-7: Operating load testing of the DC/DC converter

Item of ISO 21782-7	Description	Motor	Inverter	Chopper	Motor system	DC/DC converter
Operation endurance test	Cyclic test of output current pattern endurance including maximum current					5

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

Part 1: General test conditions and definitions

1 Scope

This document specifies the test procedures for performance and operating load for voltage class B electric propulsion components (motor, inverter, DC/DC converter) and their combinations (motor system) of electrically propelled road vehicles.

This document specifies the terms and definitions used in the ISO 21782 series and general test conditions.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

chopper

DC electronic *power converter* (3.19) without an intermediate AC link giving a variable output voltage by varying the periods of conduction and non-conduction in an adjustable ratio

[SOURCE: IEC 60050-811:2017, 811-19-11, modified — The phrase "electronic power DC convertor" was modified to "DC electronic power converter".]

3.2

conversion rate

ratio of output base wave power or output DC power to input DC power

3.3

DC/DC converter

DC electric *power converter* (3.19) with an intermediate AC link transferring electric power between a voltage class B electric circuit and a voltage class A insulated electric circuit

3.4

DC link inductor

component boosted by the *chopper* (3.1) circuit, a magnetic energy storage and released in response to actuation of the switching element

3.5
efficiency

ratio of output power to input power

3.6
induction motor

IM
AC electric motor in which the electric rotor current needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding

EXAMPLE Asynchronous motor.

3.7
inverter

electric energy converter that changes direct electric current to single-phase or polyphase alternating currents

[SOURCE: IEC 60050-151:2001, 151-13-46]

3.8
maximum current for duration of t_0

$I_{t=t_0}$
maximum current defined for the time frame t_0 which can be constantly achieved for t_0 seconds starting from the steady-state condition of room temperature (RT) and the nominal cooling conditions until the inverter (3.7) and chopper (3.1) reach the defined maximum temperature limit

3.9
maximum operating speed
upper limit revolution speed for the torque-motor speed characteristics

3.10
maximum power for duration of t_0

$P_{t=t_0}$
maximum power defined for the time frame t_0 which can be constantly achieved for t_0 seconds starting from the steady-state condition of RT and the nominal cooling conditions until the motor, inverter (3.7) and chopper (3.1) reach the defined maximum temperature limit

3.11
maximum speed

n_m
highest defined speed which can maintain maximum power

Note 1 to entry: The maximum speed can be limited by control software or supplier's definitions.

3.12
motor system

electric propulsion system for an electrically propelled road vehicle comprising a combination of components such as motor, inverter (3.7) and if necessary, DC/DC converter (3.3)

3.13
maximum torque for duration of t_0

$M_{t=t_0}$
highest torque defined for the time frame t_0 which can be constantly achieved for t_0 seconds until the power limitation at higher speed starting from the steady-state condition of RT and the nominal cooling conditions until the motor reaches the defined maximum temperature limit

3.14
maximum voltage for unlimited operating capability
highest value of OS1

Note 1 to entry: See ISO 21498-1 about OS1.

3.15**minimum voltage for unlimited operating capability**

lowest value of OS1

Note 1 to entry: See ISO 21498-1 about OS1.

3.16**no-load induced electromotive force** E_0 voltage generated in the armature when the motor is rotated at the *rated speed* (3.22) as a power generator while the terminal of the synchronous motor is opened**3.17****operating load test**

test method that takes into account the deterioration due to the operation of the device itself

3.18**output frequency**frequency of the *inverter* (3.7) output current**3.19****power converter**

device that converts electric energy from DC to AC or from AC to DC

EXAMPLE AC frequency conversion, DC power conversion, etc.

3.20**permanent magnet motor****PM**

motor using permanent magnets for the field magnetic poles

3.21**rated frequency** f_r *output frequency* (3.18) at the operating point corresponding to the *rated speed* (3.22) of the combined motor**3.22****rated speed** n_r intersection of the *maximum torque for duration of t_0* (3.13) and iso-power line**3.23****rated voltage** u_r

central value of OS1

Note 1 to entry: See ISO 21498-1 about OS1.

4 Abbreviated terms

AC alternating current

ACL 3-phase inductance equivalent to the leakage inductance of motor

DC direct current

DUT device under test

EMF electromotive force

PWM	pulse width modulation
RL	ACL with series resistance equivalent to phase resistance of motor
RT	room temperature

5 General test conditions

5.1 Operating points

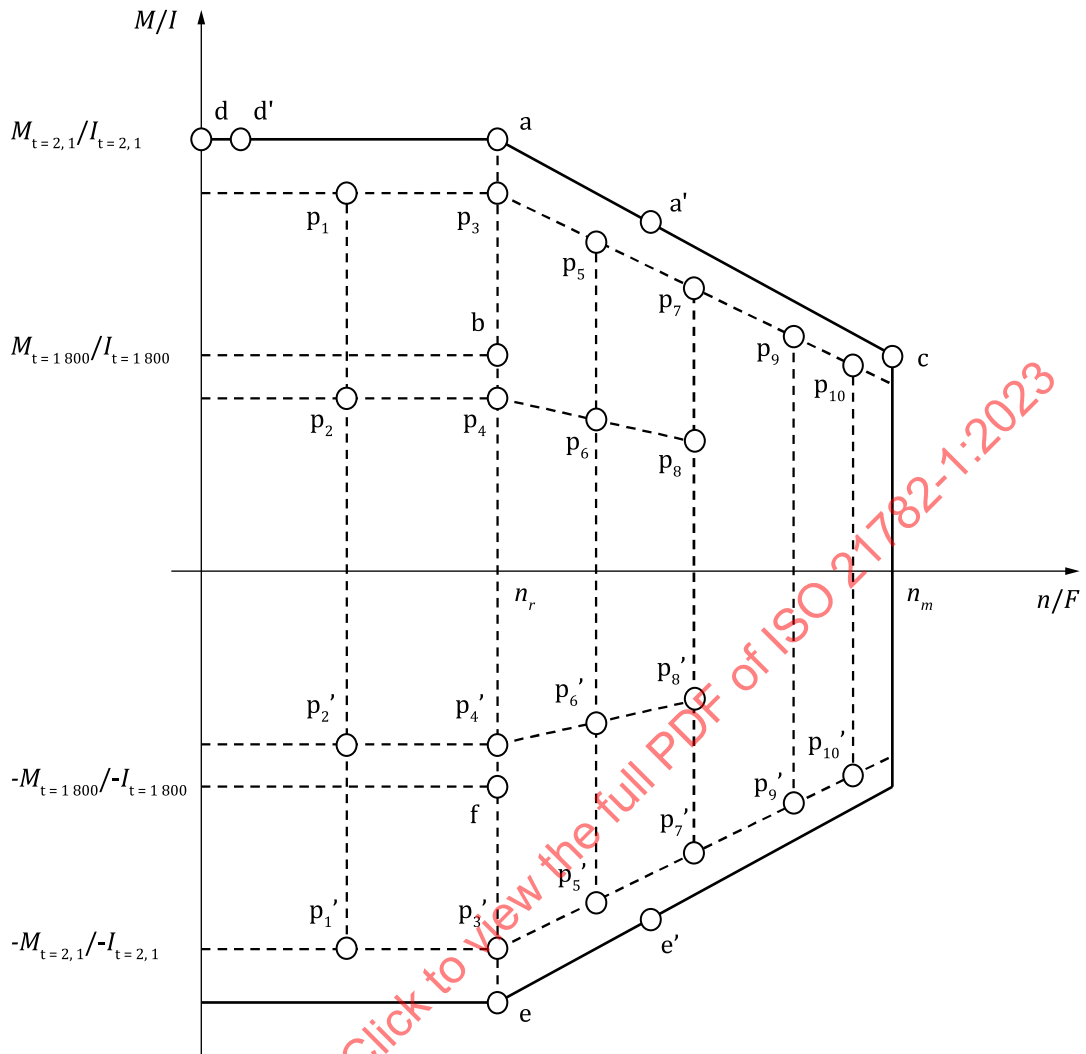
5.1.1 Operating points for motor, inverter and motor system

Operating points for motor, inverter and motor system are defined in [Figure 1](#) and [Tables 8](#) and [9](#).

t_0 shall be 2 s, 10 s or 1 800 s.

As an operation for t_0 , also 30 s or 60 s may be chosen instead of 2 s and 10 s.

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**Key**

n	motor speed [min^{-1}]
F	frequency [Hz]
M	torque [Nm]
I	current [A]
$M_{t=2,10}/I_{t=2,10}$	maximum motoring torque/current duration for $t_0=2, 10$ [Nm]/ [A]
$M_{t=1800}/I_{t=1800}$	maximum motoring torque/current duration for $t_0=1800$ [Nm]/ [A]
$-M_{t=2,10}/-I_{t=2,10}$	maximum regenerating torque/current duration for $t_0=2, 10$ [Nm]/ [A]
$-M_{t=1800}/-I_{t=1800}$	maximum regenerating torque/current duration for $t_0=1800$ [Nm]/ [A]
n_m	maximum speed/frequency [min^{-1}]/ [Hz]
n_r	rated speed/frequency [min^{-1}]/ [Hz]
$a, a', b, c, d, d', e, f, p_1-p_{10}$	operating points as defined in Table 8
$e', p'_1-p'_{10}$	optional operating points as defined in Table 9

Figure 1 — Operating points for motor, inverter and motor system

Table 8 — Definition of operating points for motor, inverter and motor system

Operating point	Motor speed [min^{-1}] /frequency [Hz]	Torque [Nm] /current [A]	Output power [W]
a	rated speed/frequency	$M_{t=2,10} / I_{t=2,10}$	$P_{t=2,10}$
a'	—	—	$P_{t=2,10}$ (if "a" is not maximum power)
b	rated speed/frequency	$M_{t=1800} / I_{t=1800}$	—
c	maximum speed/frequency	—	$P_{t=2,10}$
d	zero speed/frequency	$M_{t=2,10} / I_{t=2,10}$	—
d'	low speed/frequency	$M_{t=2,10} / I_{t=2,10}$	—
e	rated speed/frequency	$-M_{t=2,10} / -I_{t=2,10}$	—
f	rated speed/frequency	$-M_{t=1800} / -I_{t=1800}$	—
p ₁	0,5 × rated speed/frequency	$0,8 \times M_{t=2,10} / I_{t=2,10}$	—
p ₂	0,5 × rated speed/frequency	$0,4 \times M_{t=2,10} / I_{t=2,10}$	—
p ₃	rated speed/frequency	$0,8 \times M_{t=2,10} / I_{t=2,10}$	—
p ₄	rated speed/frequency	$0,4 \times M_{t=2,10} / I_{t=2,10}$	—
p ₅	0,25 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,8 \times P_{t=2,10}$
p ₆	0,25 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,4 \times P_{t=2,10}$
p ₇	0,5 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,8 \times P_{t=2,10}$
p ₈	0,5 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,4 \times P_{t=2,10}$
p ₉	0,75 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,8 \times P_{t=2,10}$
p ₁₀	0,9 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,8 \times P_{t=2,10}$

Table 9 — Definition of operating points for motor, inverter and motor system: optional

Operating point	Motor speed [min^{-1}] /frequency [Hz]	Torque [Nm] /current [A]	Output power [W]
e'	—	—	$-P_{t=2,10}$ (if "e" is not maximum power)
p ₁ '	0,5 × rated speed/frequency	$0,8 \times -M_{t=2,10} / -I_{t=2,10}$	—
p ₂ '	0,5 × rated speed/frequency	$0,4 \times -M_{t=2,10} / -I_{t=2,10}$	—
p ₃ '	rated speed/frequency	$0,8 \times -M_{t=2,10} / -I_{t=2,10}$	—
p ₄ '	rated speed/frequency	$0,4 \times -M_{t=2,10} / -I_{t=2,10}$	—
p ₅ '	0,25 × (maximum speed/frequency – rated speed/frequency) + rated speed/frequency	—	$0,8 \times -P_{t=2,10}$

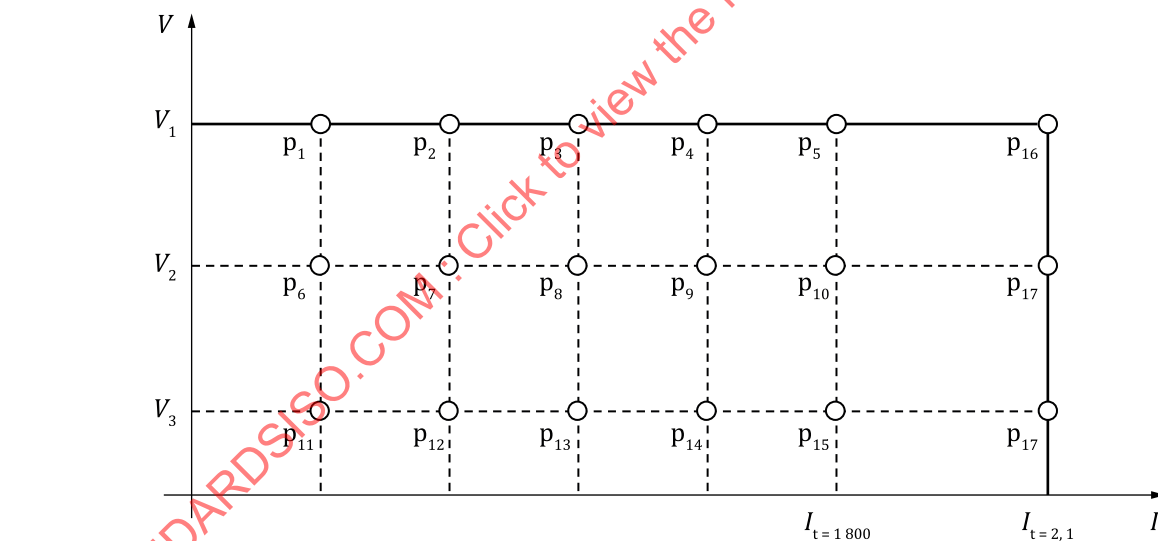
Table 9 (continued)

Operating point	Motor speed [min^{-1}] /frequency [Hz]	Torque [Nm] /current [A]	Output power [W]
p_6'	$0,25 \times (\text{maximum speed/frequency} - \text{rated speed/frequency}) + \text{rated speed/frequency}$	—	$0,4 \times -P_{t=2, 10}$
p_7'	$0,5 \times (\text{maximum speed/frequency} - \text{rated speed/frequency}) + \text{rated speed/frequency}$	—	$0,8 \times -P_{t=2, 10}$
p_8'	$0,5 \times (\text{maximum speed/frequency} - \text{rated speed/frequency}) + \text{rated speed/frequency}$	—	$0,4 \times -P_{t=2, 10}$
p_9'	$0,75 \times (\text{maximum speed/frequency} - \text{rated speed/frequency}) + \text{rated speed/frequency}$	—	$0,8 \times -P_{t=2, 10}$
p_{10}'	$0,9 \times (\text{maximum speed/frequency} - \text{rated speed/frequency}) + \text{rated speed/frequency}$	—	$0,8 \times -P_{t=2, 10}$

5.1.2 Operating points for DC/DC converter

Operating points for DC/DC converter as defined in [Figure 2](#) and [Table 10](#).

t_0 shall be 2, 10 s or 1 800 s.



Key

- I DC/DC output current [A]
- V DC/DC output voltage [V]
- V_1 maximum voltage for unlimited operating capability [V]
- V_2 rated voltage [V]
- V_3 minimum voltage for unlimited operating capability [V]
- $I_{t=1800}$ maximum current duration for $t_0=1\,800$ [A]
- $I_{t=2,10}$ maximum current duration for $t_0=2, 10$ [A]
- p_1 - p_{18} operating points as defined in [Table 10](#)

Figure 2 — Operating points for DC/DC converter

Table 10 — Definition of operating point for DC/DC converter

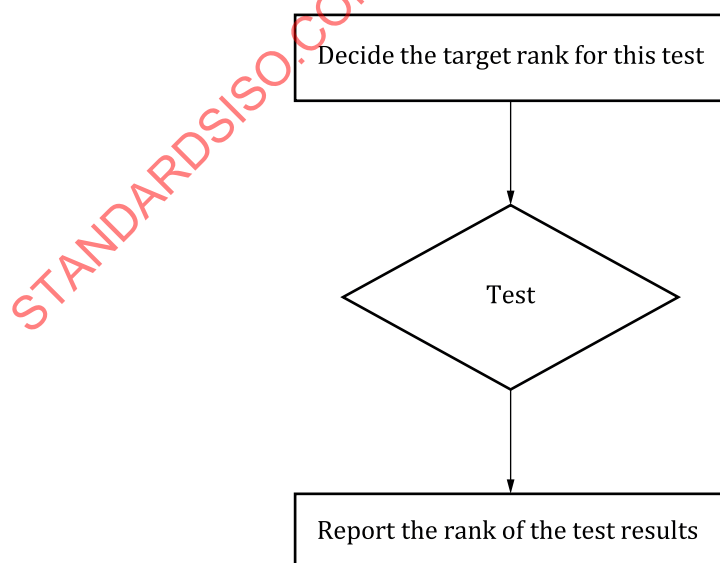
Operating point	Current [A]	Voltage [V]
p ₁	$0,2 \times I_{t=1\,800}$	Maximum voltage for unlimited operating capability
p ₂	$0,4 \times I_{t=1\,800}$	Maximum voltage for unlimited operating capability
p ₃	$0,6 \times I_{t=1\,800}$	Maximum voltage for unlimited operating capability
p ₄	$0,8 \times I_{t=1\,800}$	Maximum voltage for unlimited operating capability
p ₅	$I_{t=1\,800}$	Maximum voltage for unlimited operating capability
p ₆	$0,2 \times I_{t=1\,800}$	Rated voltage
p ₇	$0,4 \times I_{t=1\,800}$	Rated voltage
p ₈	$0,6 \times I_{t=1\,800}$	Rated voltage
p ₉	$0,8 \times I_{t=1\,800}$	Rated voltage
p ₁₀	$I_{t=1\,800}$	Rated voltage
p ₁₁	$0,2 \times I_{t=1\,800}$	Minimum voltage for unlimited operating capability
p ₁₂	$0,4 \times I_{t=1\,800}$	Minimum voltage for unlimited operating capability
p ₁₃	$0,6 \times I_{t=1\,800}$	Minimum voltage for unlimited operating capability
p ₁₄	$0,8 \times I_{t=1\,800}$	Minimum voltage for unlimited operating capability
p ₁₅	$I_{t=1\,800}$	Minimum voltage for unlimited operating capability
p ₁₆	$I_{t=2,10}$	Maximum voltage for unlimited operating capability
p ₁₇	$I_{t=2,10}$	Rated voltage
p ₁₈	$I_{t=2,10}$	Minimum voltage for unlimited operating capability

5.2 Methods for determining the rank for operating load test

5.2.1 Target rank verification method

Before starting the test, the target rank can be decided by the supplier and customer. Perform the test as shown in [Figure 3](#).

See ISO 21782-5:2021, Figure A.1 for an example of application to a specific test.

**Figure 3 — Flowchart for target rank verification method**

5.2.2 Rank search method

If no target rank has been determined, the test will start at the lowest rank. Report the highest rank that meets the criteria as shown in [Figure 4](#).

See ISO 21782-5:2021, Figure A.2 for an example of application to a specific test.

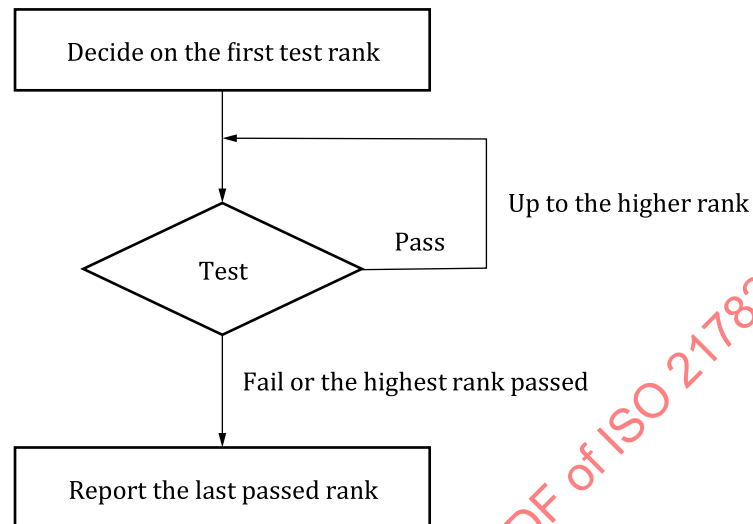


Figure 4 — Flowchart for rank search method

5.3 Provision for current, voltage and power measurement

Current, voltage and power as used in the test are defined in [Figures 5, 6, 7, 8](#) and [9](#).

See [Annex A](#) for formulae of power.

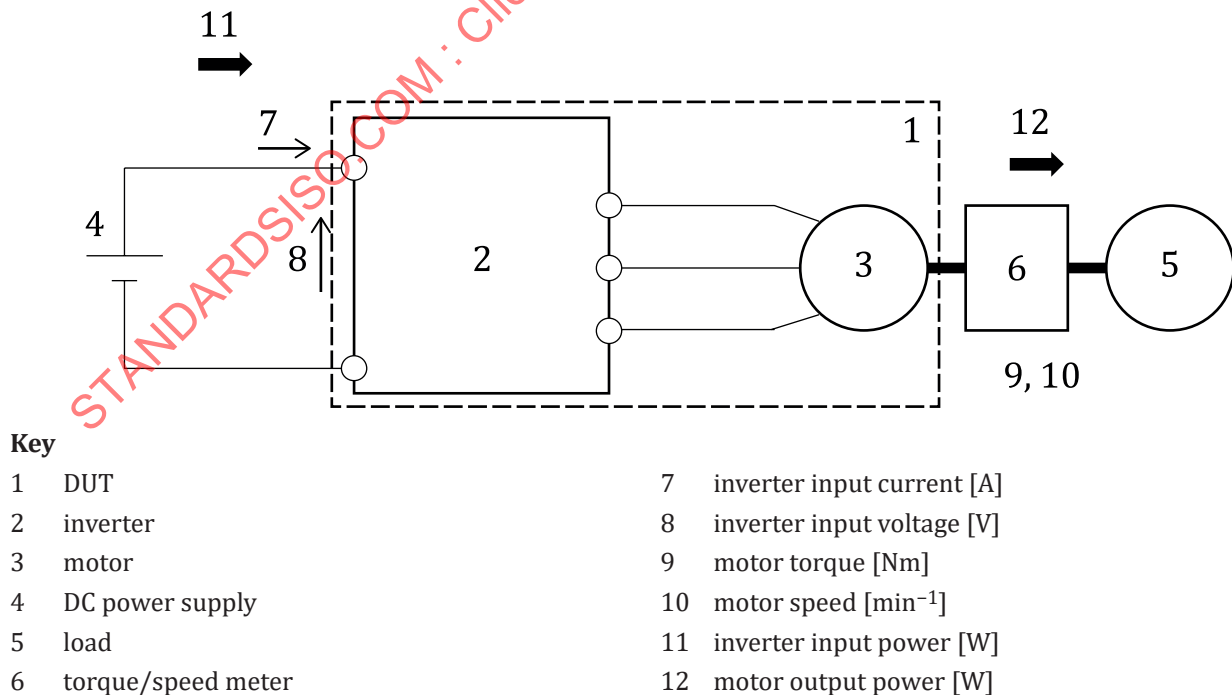
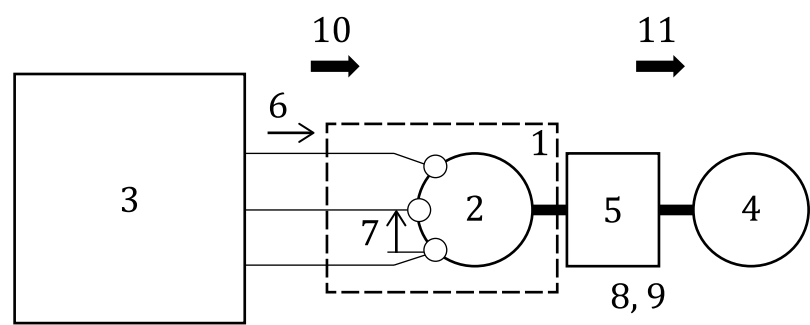


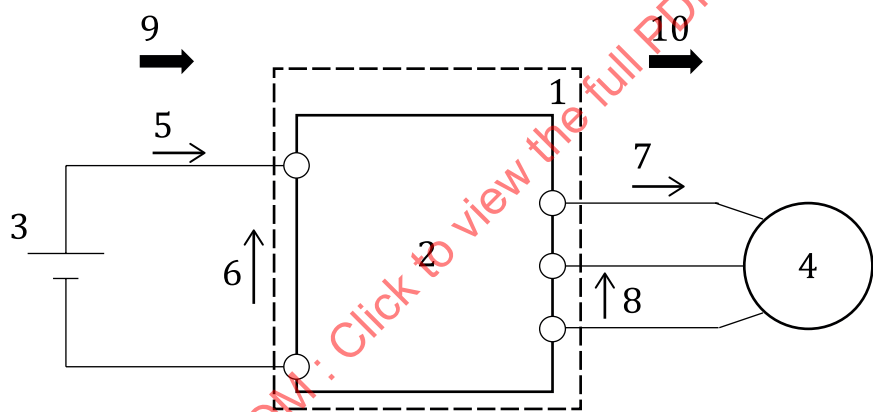
Figure 5 — Provision for current, voltage and power measurement: motor system



Key

- | | | | |
|---|-------------------------|----|----------------------------------|
| 1 | DUT | 7 | motor input voltage [V] |
| 2 | motor | 8 | motor torque [Nm] |
| 3 | inverter | 9 | motor speed [min ⁻¹] |
| 4 | load | 10 | motor input power [W] |
| 5 | torque/speed meter | 11 | motor output power [W] |
| 6 | motor input current [A] | | |

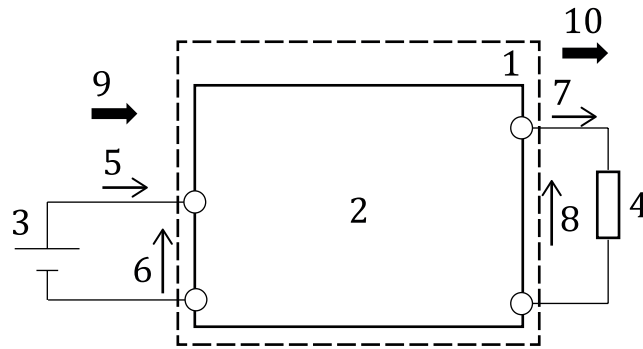
Figure 6 — Provision for current, voltage and power measurement: motor



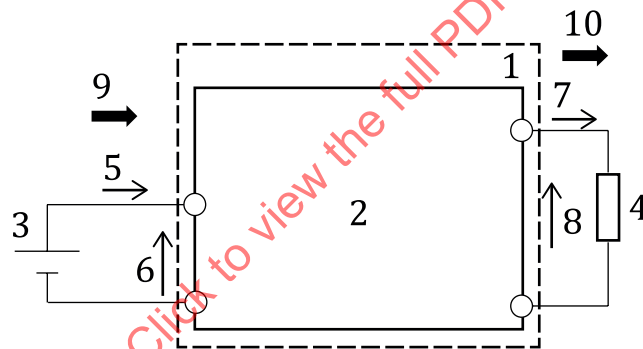
Key

- | | | | |
|---|----------------------------|----|-----------------------------|
| 1 | DUT | 6 | inverter input voltage [V] |
| 2 | inverter | 7 | inverter output current [A] |
| 3 | DC power supply | 8 | inverter output voltage [V] |
| 4 | AC load | 9 | inverter input power [W] |
| 5 | inverter input current [A] | 10 | inverter output power [W] |

Figure 7 — Provision for current, voltage and power measurement: inverter

**Key**

1	DUT	6	chopper input voltage [V]
2	chopper	7	chopper output current [A]
3	DC power supply	8	chopper output voltage [V]
4	load	9	chopper input power [W]
5	chopper input current [A]	10	chopper output power [W]

Figure 8 — Provision for current, voltage and power measurement: chopper**Key**

1	DUT	6	DC/DC converter input voltage [V]
2	DC/DC converter	7	DC/DC converter output current [A]
3	DC power supply	8	DC/DC converter output voltage [V]
4	load	9	DC/DC converter input power [W]
5	DC/DC converter input current [A]	10	DC/DC converter output power [W]

Figure 9 — Provision for current, voltage and power measurement: DC/DC converter**5.4 DC input voltage**

The DC input voltage shall be in a range of $\pm 2\%$ of the rated component or system DC input voltage, unless other values are specified in the different parts of the ISO 21782 series or are agreed upon between the supplier and customer.

5.5 Temperature and humidity

Unless otherwise specified, all tests shall be performed at RT of $(23 \pm 5)^\circ\text{C}$ and with a relative humidity between 25 % to 75 %.

5.6 Measurement accuracy

The measurement shall be conducted with an accuracy as shown below.

Current: $\pm 1,0$ %

Voltage: $\pm 0,5$ %

Torque: $\pm 0,2$ %

Motor speed: $\pm 0,5$ %

Temperature: ± 2 K

Relative humidity: ± 5 %

All measurement values, except temperature and relative humidity values, shall be measured with and recorded at a frequency of not less than 10 Hz. For temperature and relative humidity values, a measurement frequency of 1 Hz is sufficient.

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Annex A (informative)

Formula of power

A.1 Inverter input power

The inverter input power is calculated according to [Formula \(A.1\)](#):

$$P_{ii} = V_{ii} \times I_{ii} \quad (A.1)$$

where

- P_{ii} is the inverter input power, in W;
- V_{ii} is the inverter input voltage, in V;
- I_{ii} is the inverter input current, in A.

A.2 Average inverter input power

The average inverter input power is calculated according to [Formula \(A.2\)](#):

$$P_{ii_mean} = V_{ii_mean} \times I_{ii_mean} \quad (A.2)$$

where

- P_{ii_mean} is the average inverter input power, in W;
- V_{ii_mean} is the average inverter input voltage, in V;
- I_{ii_mean} is the average inverter input current, in A.

A.3 Inverter output power

The inverter output power is calculated according to [Formula \(A.3\)](#), in case of three-wattmeter method:

$$P_{io} = \frac{1}{T} \int_0^T V_{io_u}(t) \times I_{io_u}(t) dt + \frac{1}{T} \int_0^T V_{io_v}(t) \times I_{io_v}(t) dt + \frac{1}{T} \int_0^T V_{io_w}(t) \times I_{io_w}(t) dt \quad (A.3)$$

where

- P_{io} is the inverter output power, in W;
- T is the measurement time, in s;
- $V_{io_u}(t)$ is the inverter u-phase output voltage at time "t" second, in V;
- $V_{io_v}(t)$ is the inverter v-phase output voltage at time "t" second, in V;
- $V_{io_w}(t)$ is the inverter w-phase output voltage at time "t" second, in V;

$I_{io_u}(t)$ is the inverter u-phase output current at time "t" second, in A;

$I_{io_v}(t)$ is the inverter v-phase output current at time "t" second, in A;

$I_{io_w}(t)$ is the inverter w-phase output current at time "t" second, in A.

In case of two-wattmeter method, it is calculated according to [Formula \(A.4\)](#):

$$P_{io} = \frac{1}{T} \int_0^T V_{io_uv}(t) \times I_{io_u}(t) dt + \frac{1}{T} \int_0^T V_{io_wv}(t) \times I_{io_w}(t) dt \quad (A.4)$$

where

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

T is the measurement time, in s;

$V_{io_uv}(t)$ is the inverter output line voltage between u-phase and v-phase at time "t" second, in V;

$V_{io_wv}(t)$ is the inverter output line voltage between w-phase and v-phase at time "t" second, in V;

$I_{io_u}(t)$ is the inverter u-phase output current at time "t" second, in A;

$I_{io_w}(t)$ is the inverter w-phase output current at time "t" second, in A.

A.4 Fundamental inverter output power

The fundamental inverter output power is calculated according to [Formula \(A.5\)](#):

$$P_{io_fund} = \sqrt{3} \times V_{io_fund} \times I_{io_fund} \times \cos \theta \quad (A.5)$$

where

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

V_{io_fund} is the fundamental inverter output voltage, in V;

I_{io_fund} is the fundamental inverter output current, in A;

$\cos \theta$ is the power factor.

A.5 Chopper input power

The chopper input power is calculated according to [Formula \(A.6\)](#):

$$P_{ci} = \frac{1}{T} \int_0^T V_{ci}(t) \times I_{ci}(t) dt \quad (A.6)$$

where

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

T is the measurement time, in s;

$V_{ci}(t)$ is the chopper input voltage at time "t" second, in V;

$I_{ci}(t)$ is the chopper input current at time "t" second, in A.