भारतीय मानक

Indian Standard

IS 15999 (Part 20/ Sec 1) : 2023
IEC TS 60034-20-1 : 2002

विद्युत घूर्णन मशीन

भाग 20 नियंत्रण मोटर्स

अनुभाग 1 स्टेपिंग मोटर्स

(पहला पुनरीक्षण)

Rotating Electrical Machines

Part 20 Control Motors

Section 1 Stepping Motors

(First Revision)

ICS 29.160.30

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Rotating Machinery Sectional Committee, ETD 15

NATIONAL FOREWORD

This Standard (Part 20/Sec 1) (First Revision) which is identical with IEC TS 60034-20-1 : 2002 'Rotating electrical machines — Part 20-1: Control motors — Stepping motors' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Rotating Machinery Sectional Committee and approval of the Electrotechnical Division Council.

The text of the IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, theyshould be read as 'Indian Standard'.
b) Comma (,) has been used as a decimal marker, while in Indian Standards the currentpractice is to use a point (.) as the decimal marker.

This standard superseded IS 13079: 1991 'Stepping motors — Specification', which was based on BS 5000 (Part 60) : 1982.

In this adopted standard, reference appears to International Standards for which Indian Standards also exists. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60034-1 : 1996 Rotating Electrical machines — Part1: Rating and performance	IS 15999 (Part 1) : 2021 Rotating Electrical Machines Part 1 Rating and performance (*second revision*)	Identical with IEC60034-1 : 2017
IEC 60034-7 Rotating electrical machines — Part 7: Classification of types of construction, mounting arrangements and terminal box position (IM code)	IS 2253 : 1974 Designations for types of construction and mounting arrangements of rotating electrical machines (*first revision*)	Technically Equivalent with IEC 60034-7 : 1972
IEC 60072-1 : 1991 Dimensions and output series for rotating electrical machines — Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1080	IS 2223 : 1983 Dimensions of flange mounted AC induction motors	Technically Equivalent with IEC Pub 72 : 1971

The technical committee has reviewed the provisions of the following international standards referred in this adopted standard and decided that they are acceptable for use in conjunction with this standard.

(*Continued on third cover*)

CONTENTS

Indian Standard

ROTATING ELECTRICAL MACHINES
PART 20 CONTROL MOTORS
SECTION 1 STEPPING MOTORS

(First Revision)

1 Scope

This technical specification gives the requirements for rotating control motors and describes the appropriate tests. It also gives dimensions and marking information and the details to be provided by the manufacturer in associated data sheets and catalogues.

This technical specification is applicable to rotating stepping motors only.

It is not applicable to:

- induction motors;
- hydraulic and ratchet type stepping motors;
- linear motors;
- mechanically commutated motors;
- synchronous motors.

2 Normative references

The following referenced documents are indispensable for the application 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.

IEC 60034-1:1996, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-7, *Rotating electrical machines – Part 7: Classification of types of construction, mounting arrangements and terminal box position (IM code)*

IEC 60072-1:1991, *Dimensions and output series for rotating electrical machines – Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1080*

IEC 60072-3:1994, *Dimensions and output series for rotating electrical machines – Part 3: Small built-in motors – Flange numbers BF10 to BF50*

3 Definitions

For the purpose of this technical specification, the following definitions apply.

3.1
axial thrust
force applied to a shaft along its axis of rotation

3.2
bipolar drive
stepping motor drive system in which the excitation applied is such that the torque generating current reverses in the windings

3.3
canstack construction (claw pole)
permanent magnet motor having two or more coils held in position by a pair of endshields having interlaced claws or teeth

3.4
cogging torque
cyclic torque in an unenergized motor resulting from the tendency of the rotor and stator to align themselves in a position of minimum magnetic reluctance

3.5
commutation
process of sequentially exciting the windings of a motor such that the relative angle between the magnetic fields of the stator and rotor is maintained within specified limits

NOTE Commutation is accomplished either mechanically or electronically.

3.6
continuous stall torque, T_{cs}
maximum continuous output torque that the stalled motor can develop under specified conditions

3.7
counter e.m.f. (back e.m.f.), E_g
generated voltage produced by the relative movement between the magnetic field and the armature winding

NOTE 1 It is normally stated as a peak (pk) or a root mean square (r.m.s.) value.

NOTE 2 The nature of the voltage value, i.e. whether peak, or r.m.s. should be declared.

3.8
counter e.m.f. constant (back e.m.f. constant), K_E
counter e.m.f. per unit of speed at a specified motor temperature

3.9
detent position
position where the rotor of a permanent magnet motor or hybrid stepping motor comes to rest when unenergized and unloaded

3.10
detent torque
maximum steady torque that can be applied to the shaft of an unenergized permanent magnet or hybrid stepping motor without causing continuous rotation

3.11
direction of rotation
direction observed when facing the shaft extension associated with the mounting surfaces. Counter-clockwise rotation of the shaft is regarded as positive and clockwise rotation as negative.

3.12
drive circuit
combination of the translator logic and a power amplifier that switches the phases of the stepping motor in a predetermined sequence

3.13
friction torque, T_f
frictional resistance to rotation within the machine

3.14
holding torque, T_H
maximum steady torque that can be applied to the shaft of a stepping motor energized by a specific current without causing continuous rotation

3.15
hybrid (HY) stepping motor
stepping motor with permanent magnets for the polarization of rotor pole pieces of low residual magnetic material

3.16
maximum reversing rate
maximum pulse rate at which an unloaded stepping motor is able to reverse and remain in synchronism under specified drive conditions

3.17
maximum safe operating temperature
maximum temperature that a stepping motor can sustain either continuously or intermittently without damage to any of its components for a given lifetime

3.18
maximum slew rate
maximum pulse rate at which an unloaded stepping motor can remain in synchronism under specified drive conditions

3.19
mode or step sequence
particular sequence of excitation pulses produced by a drive circuit

3.20
moment of inertia of rotor (about an axis), J_r
the sum (integral) of the products of the mass elements of a body and the squares of their distances from a given axis

3.21
overshoot or transient overshoot
amount by which the shaft of the stepping motor rotates beyond the final commanded step position

3.22
peak current, I_{pk}
maximum intermittent current that under specified conditions does not cause motor damage, or irreversible degradation of motor performance

3.23
peak torque, T_{pk}
maximum torque developed by a motor under specified conditions when the maximum allowable peak current is applied

3.24
permanent magnet (PM) stepping motor
stepping motor having rotor poles of permanent magnetic material

3.25
positional error
no-load deviation from the theoretical final position after a sequence of steps, expressed as a percentage of the basic step angle

3.26
pull-out torque
maximum torque that can be applied to the rotating shaft of a stepping motor driven at a given pulse rate under specified drive conditions, without causing the motor to miss steps

3.27
pulse rate
rate at which successive steps are initiated

3.28
radial load
force applied to the motor shaft perpendicular to the axis of rotation, expressed as the equivalent value applied at the middle of the shaft extension

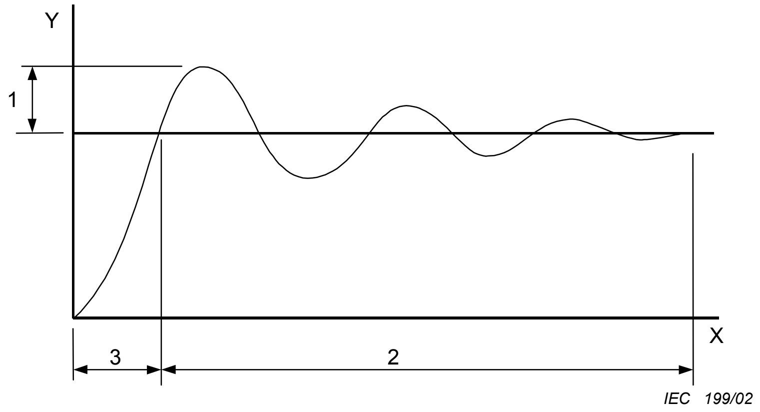
3.29
rated current
r.m.s. current developed at rated voltage and rated speed without exceeding the temperature rating

3.30
resolution
reciprocal of the number of steps per revolution of the motor shaft

3.31
settling time
total time from the first arrival at the commanded position until the amplitude of the oscillatory motion of the rotor has diminished to 1 % of the single step or as otherwise specified (see figure 1)

3.32
single step response
response to a single step command as shown in figure 1

NOTE The single step response will be controller dependent.



Key

X axis – time
Y axis – angular position
1 – overshoot
2 – settling time
3 – single step time

Figure 1 – Overshoot and settling time

3.33
stalled motor (locked rotor)
condition where the rotor is held stationary while voltage is applied to the motor terminals

3.34
step
movement of the rotor from one energized position to the next in sequence

3.35
step angle
angle through which the shaft of an unloaded stepping motor can be made to turn when two adjacent phases are energized, singly in sequence

3.36
step angle error
maximum percentage deviation from the theoretical step angle

3.37
stepping motor
motor, the rotor of which rotates in discrete angular increments when its stator windings are energized in a programmed manner

3.38
steps per revolution
number of discrete steps for one revolution

3.39
step position
angular position that the shaft of an unloaded stepping motor assumes when it is energized without causing continuous rotation

NOTE The step position is not necessarily the same as the detent position.

3.40
synchronism
state that exists when at each command pulse, the rotor rotates by only one step

3.41
thermal resistance, R_{th}
opposition to the flow of heat

3.42
thermal time constant, τ_{th}
time required for a motor winding to reach 0,632 p.u. of its continuous steady state temperature rise with constant load under specified conditions

3.43
torque ripple
variation of torque, excluding cogging torque, within one shaft revolution under specified test conditions, expressed as the ratio of half of the peak-to-peak torque amplitude to the average torque

3.44
translator logic
logic that translates the input pulse train into the selected mode pattern to be applied to a stepping motor

3.45
viscous damping factor (at infinite source impedance), D_v
measure of rotational losses in torque that are approximately proportional to speed

$$D_V \propto \frac{\Delta T}{\Delta \omega}$$

4 Symbols for quantities and their units

Table 1 – List of symbols

Quantity Symbol	Quantity	SI unit symbols
D_v	Viscous damping factor	Nms
E_g	Counter e.m.f.	V
f	Frequency	Hz
I	Current	A
I_{pk}	Peak current	A
J	Moment of inertia	kgm^2
J_r	Moment of inertia with respect to the rotational axis of the rotor	kgm^2
K_E	Back e.m.f. constant	Vs
K_T	Torque constant	NmA^{-1}
L	Inductance	H
m	Mass	kg
P_o	Output power	W
P	Power	W
R	Resistance	Ω
R_{mt}	Motor terminal resistance	Ω
R_{th}	Thermal resistance	KW^{-1}

Quantity Symbol	Quantity	SI unit symbols
T	Torque	Nm
T_{cs}	Continuous stall torque	Nm
T_f	Friction torque	Nm
T_H	Holding torque	Nm
T_{pk}	Peak torque	Nm
V	Voltage	V
V_{pk}	Peak voltage	V
V_s	Supply voltage	V
θ_t	Temperature at time *t*	C°
θ_a	Ambient temperature	C°
θ_f	Final temperature at thermal equilibrium	C°
τ_{th}	Thermal time constant	s
ω	Angular velocity $\omega = d\phi/dt$	s^{-1}

5 Dimensions

5.1 Type 1 motors (based on metric dimensions)

Motors, excluding claw pole stepping motors shall have dimensions in accordance with:

IEC 60072-3 for flange sizes up to and including BF50;

IEC 60072-1 for flange sizes above BF50.

Claw pole stepping motors shall have dimensions in accordance with table 2, see figure 2

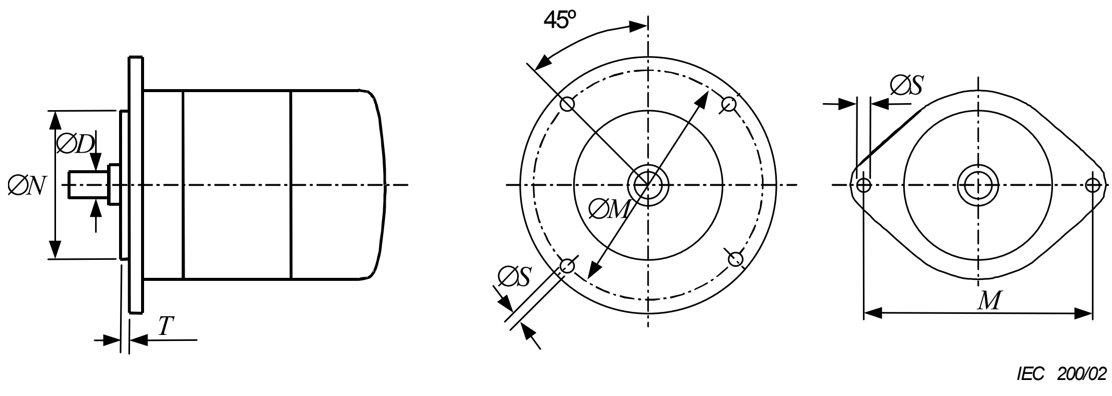


Figure 2 – Mounting dimensions of claw pole stepping motors

Table 2 – Installation dimensions for claw pole stepping motors

Dimensions in mm

Size (See note 1)	*M*	*N*	*S*	Holes	*D*	*T*
2,0	25,0	6	2,3	2	1,5	1,0
2,2	25,0	6	2,3	2	1,5	1,0
2,5	32,0	8	3,0	2	2,0	1,5
2,8	32,0	8	3,0	2		1,5
3,2	42,0	10	3,2	2	2,0	1,5
3,6	42,0	10	3,2	2	2,0	1,5
4,0	49,5	10	3,5	2	3,0	1,5
4,5	49,5	10	3,5	2	3,0	1,5
5,0	60,0	11	3,5	2	3,0	2,0
5,6	65,0	11	3,5	2	4,0	2,0
6,3; 7,1	52,0	14	4,5	4	4,0	2,0

NOTE 1 Size is equal to the motor diameter divided by 10.

NOTE 2 Although the flange may not be circular, it shall not exceed diameter P.

NOTE 3 Motors may have mounting arrangements according to IEC 60034-7 IM B5 or IM B14 classification.

5.2 Type 2 motors (based on imperial dimensions)

The mounting dimensions of type 2 motors shall be in accordance with table 3 for motors with mounting arrangement according to IEC 60034-7 IM B5 classification and table 4 for motors with mounting arrangement according to IEC 60034-7 IM B14 classification. Shaft details shall be in accordance with table 5. For dimensional sketches, see figure 3 and figure 4.

NOTE Type 2 stepping motors are based on inch dimensions and are applicable only to existing designs. New designs should conform with the requirements of type 1 motors as described in 5.1.

Table 3 – Installation dimensions for type 2 motors with IM B14 mounting

Dimensions in mm (inches)

Frame size	*N*	*T*	*AC*	*M* (Note 1)	*S*	*X* (Note 2)
23	38,151 (1,502) 38,049 (1,498)	1,956 (0,077) 1,194 (0,047)	60,20 (2,370) max max	47,269 (1,861) 47,015 (1,851)	5,461 (0,215) 4,953 (0,195)	4
34	73,076 (2,877) 72,974 (2,873)	3,302 (0,130)	86,36 (3,400) max max	69,723 (2,745) 69,469 (2,735)	5,918 (0,233) 5,410 (0,213)	4
42	55,575 (2,188) 55,474 (2,184)	1,702 (0,067) 1,448 (0,057)	109,22 (4,300) max max	89,027 (3,505) 88,773 (3,495)	6,858 (0,27) min min	4

NOTE 1 IEC 60034-7 classification IM B14 mountings have square flanges having a side dimension equal to dimension *AC*. The hole centres indicated by dimension *M* are square co-ordinates.

NOTE 2 *X* indicates the number of equi-spaced clearance holes in the flange.

Table 4 – Installation dimensions for type 2 motors with IM B5 mounting

Dimensions in mm (inches)

Frame size	*N*	*T*	*AC*	*M*	*S* (Note 1)	*X* (Note 2)
05	9,525 (0,3750) 9,512 (0,3745)	1,092 (0,043) 0,940 (0,037)	12,700 (0,500) 12,624 (0,497)			4
08	12,700 (0,5000) 11,417 (0,4495)	1,143 (0,045) 0,889 (0,035)	19,126 (0,753) 18,923 (0,745)			4
11	25,400 (1,0000) 25,387 (0,9995)	1,702 (0,067) 1,448 (0,057)	27,051 (1,065) 26,848 (1,057)	20,701 (0,815) 20,549 (0,809)		4
15	33,325 (1,3120) 33,312 (1,3115)	3,480 (0,137) 3,226 (0,127)	36,576 (1,440) 36,373 (1,432)	28,016 (1,103) 27,864 (1,097)		4
18	39,675 (1,5620) 39,662 (1,5615)	3,480 (0,137) 3,226 (0,127)	44,526 (1,753) 44,323 (1,745)			4
20	44,501 (1,7520) 44,399 (1,7480)	6,731 (0,265) 5,969 (0,235)	51,054 (2,010) 50,546 (1,990)			4
23	50,800 (2,0000) 50,775 (1,9990)	5,207 (0,205) 4,953 (0,195)	57,150 (2,250) 57,023 (2,245)			4

NOTE 1 Where no values are given for dimension *S*, the pitch circle diameter of the tapped holes should be specified by the manufacturer.

NOTE 2 *X* indicates the number of equi-spaced tapped holes in the flange, the size of the tapped holes should be specified by the manufacturer.

Table 5 – Shaft dimensions for type 2 motors

Dimensions in mm (inches)

Frame size	*E + R*		*D*		Number of teeth	Diametrical pitch
05	9,779 9,271	(0,385) (0,365)	3,1674 3,1547	(0,1247) (0,1242)	10	96
08	9,779 9,271	(0,385) (0,365)	3,1674 3,1547	(0,1247) (0,1242)	13	120
08	9,779 9,271	(0,385) (0,365)	3,1674 3,1547	(0,1247) (0,1242)	---	---
11	9,779 9,271	(0,385) (0,365)	3,1674 3,1547	(0,1247) (0,1242)	13	120
11	9,779 9,271	(0,385) (0,365)	3,1674 3,1547	(0,1247) (0,1242)	---	---
15	11,481 10,719	(0,452) (0,422)	4,4958 4,4704	(0,1770) (0,1760)	15	96
15	11,481 10,719	(0,452) (0,422)	4,4958 4,4704	(0,1770) (0,1760)	15	96
15	11,481 10,719	(0,452) (0,422)	4,7625 4,7371	(0,1875) (0,1865)	---	---
18	14,656 13,894	(0,577) (0,547)	4,4958 4,4704	(0,1770) (0,1760)	15	96
20	16,637 15,113	(0,655) (0,595)	6,3500 6,3373	(0,2500) (0,2495)	---	---
23	14,732 13,970	(0,580) (0,550)	6,3424 6,3170	(0,2497) (0,2487)	22	96
23	21,336 19,812	(0,840) (0,780)	6,3500 6,3170	(0,2500) (0,2490)	---	---
34	30,925 29,401	(1,2175) (1,1575)	9,5250 8,8265	(0,3750) (0,3475)	---	---
42	35,687 34,163	(1,405) (1,345)	12,7000 12,6873	(0,5000) (0,4995)	---	---
42	35,814 34,290	(1,410) (1,350)	14,6558 13,8938	(0,577) (0,547)	---	---
NOTE Where there are no entries in the 'number of teeth' and 'diametrical pitch' columns, a plain shaft is indicated.						

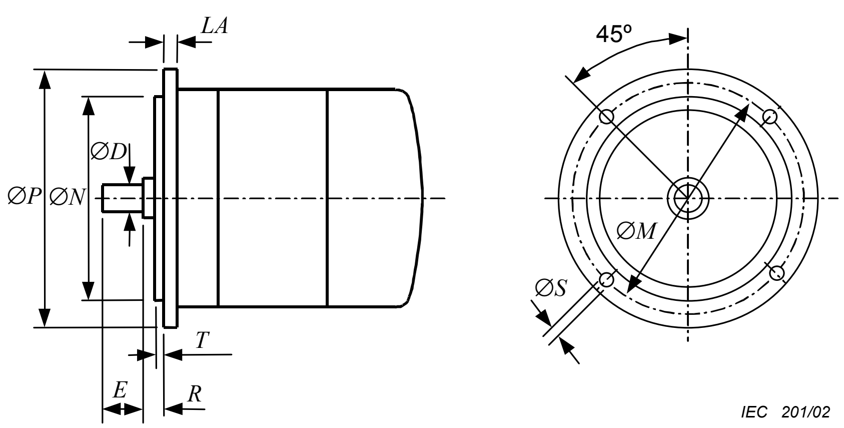


Figure 3 – Dimensions of motors with IEC 60034-7 IM B5 classification mounting arrangement

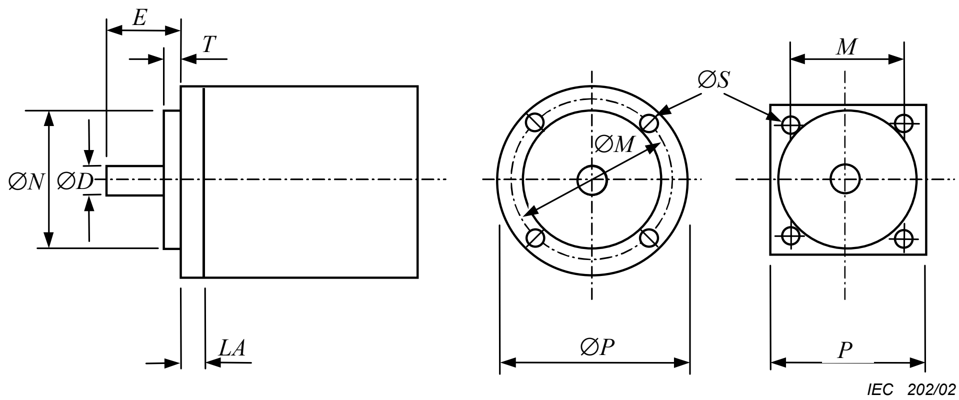


Figure 4 – Dimensions of motors with IEC 60034-7 IM B14 classification mounting arrangement

6 Test methods and acceptance criteria

6.1 Shaft extension run-out, concentricity of spigot diameter and perpendicularity of mounting face to shaft

Type 1 control motors shall comply with requirements 8.1 and 8.2 of IEC 60072-1.

Type 2 control motors shall comply with the following requirements:

The run-out of the mounting spigots with the shaft extension shall not exceed the following:

- frame sizes 05, 08, 11, 15, 18 and 20: 0,0254 mm (0,001 in) in total indicator reading;
- frame sizes 23, 34 and 42: 0,0762 mm (0,003 in) in total indicator reading.

The run-out of squareness of the flange mounting faces to the shaft extension shall not exceed the following:

- frame size 05: 0,0254 mm (0,001 in) in total indicator reading;
- frame sizes 08, 11, 15, 18 and 20: 0,508 mm (0,002 in) in total indicator reading;
- frame sizes 23, 34 and 42: 0,0762 mm (0,003in) in total indicator reading.

The maximum shaft extension run-out at a distance of 6,35 mm (0,25in) from the bearing, shall not exceed 0,02 mm (0,0008 in).

6.2 Moment of inertia of rotor

Where the moment of inertia of a rotor cannot be calculated from standard formulae, a practical method shall be used. Examples of suitable test methods are given in clauses A.2 and A.3.

The moment of inertia shall be declared by the manufacturer, see 8.5.

6.3 Voltage withstand test

For motors of imperial frame sizes up to and including frame size 42, see tables 3 and 4, the normal test voltages shall be those given in table 6.

Table 6 – Withstand voltage test for type 2 motors frame sizes up to and including 42[1]

Frame size	Test voltage $V_{r.m.s.}$
Below 11	250
11 to 42	500

For control motors below the flange size 55 as listed in IEC 60072-1, the test voltage shall be by agreement.

All other control motors shall comply with the requirements in 8.1 of IEC 60034-1

6.4 Thermal resistance R_{th} and thermal time constant τ_{th}

Examples of suitable test methods are given in clause A.4.

The thermal resistance and thermal time constant shall not exceed the values quoted by the manufacturer.

6.5 Back e.m.f. constant

An example of a suitable test method is given in clause A.5.

The back e.m.f. constant shall conform to the value quoted by the manufacturer.

6.6 Motor inductance

Examples of suitable test methods are given in clause A.6.

The inductance of the motor shall be within the tolerance band quoted by the manufacturer.

6.7 DC resistance

The d.c. resistance of each winding shall be measured and corrected if necessary to the equivalent resistance value at a temperature of 20 °C, see IEC 60034-1 clause 7.6.2.2. The value of d.c. resistance shall be declared by the manufacturer, see 8.3.

6.8 Step angle error

Examples of suitable test methods are given in clause A.7.

The step angle error shall conform to the value quoted by the manufacturer, see 8.3.

6.9 Detent torque

Energize the motor for 0,5 s to determine the step position for a particular step. Remove the energizing source and determine the detent torque using a torque watch.

---

1 Typically involving operation up to and including 28 V

The detent torque shall be within the tolerance band quoted by the manufacturer.

6.10 Holding torque

The motor shall be at room temperature unless measurement at operating temperature has been specified.

Apply the rated current or particular voltage values, see note 2, to the winding or windings and maintain this value throughout the test. Apply a torque to the motor shaft by any convenient means. Increase the torque until continuous rotation commences. Take all readings as quickly as possible as, even with a constant current supply, the torque may fall due to increasing temperature.

NOTE 1 The angle through which the shaft rotates from no torque to peak torque varies according to the design of the motor and allowance should be made for the torque loading device to make a sufficient rotation without impairing the accuracy of the reading.

NOTE 2 It is often of value to quote the peak holding torque at various terminal voltages. Generally, measurements are taken at 25 %, 50 %, 75 % and 100 % of rated supply and the results are presented as a curve.

The holding torque shall conform to the value declared by the manufacturer, see 8.3.

7 Special tests

7.1 General

The following tests are to be regarded as special tests to be performed when specified by the customer. When these tests are specified the manufacturer shall quote the appropriate parameters.

7.2 Winding temperature rise

An example of a suitable test method is given in clause B.2.

The winding temperature rise of the motor shall be within the tolerance band quoted by the manufacturer.

7.3 Torque displacement curve

An example of a suitable test method is given in clause B.3.

The torque displacement curve of the motor shall be within the tolerance band quoted by the manufacturer.

7.4 Single step response, natural frequency and settling time

An example of a suitable test method is given in clause B.4.

The single step response, natural frequency and settling time of the motor shall be within the tolerance band quoted by the manufacturer.

7.5 Maximum slew rate

An example of a suitable test method is given in clause B.5.

The maximum slew rate of the motor shall not be smaller than the value quoted by the manufacturer.

7.6 Pull-in rate

An example of a suitable test method is given in clause B.6.

The pull-in rate of the motor shall be within the tolerance band quoted by the manufacturer.

7.7 Pull-out torque

Examples of suitable test methods are given in clause B.7.

The pull-out torque of the motor shall be within the tolerance band quoted by the manufacturer.

7.8 Maximum reversing rate

An example of a suitable test method is given in clause B.8.

The maximum reversing rate of the motor shall not be less than the value quoted by the manufacturer.

7.9 Resonance

Examples of suitable test methods are given in clause B.9.

The resonance of the motor shall not be less than the value quoted by the manufacturer.

8 Rating plate and other information

8.1 Rating plate

The rating plate shall contain the following minimum information:

a) Manufacturer's name;
b) Type indication, if appropriate (e.g. PM or HY);
c) Manufacturer's serial number and/or date code;
d) Nominal voltage or peak current;
e) Number of phases;
f) Part number of this standard, or national standard number;
g) Nominal diameter;
h) Mounting type;
i) Distance from the mounting surface of the flange to the end of the motor;
j) Phase current;
k) Insulation class;
l) Phase voltage rating.

If it is possible to include additional information, it is recommended that the following should be given:

a) Resistance per phase;
b) Modification state;

c) Number of steps per revolution or step angle (basic);

d) Winding (external connection);

e) Diagram of lead colours.

8.2 Typical modes

There are four preferred sequences of excitation, mode A, mode B, mode AB and micro stepping.

Table 7 shows the three typical modes for a three-phase stepping motor and the preferred sequences of excitation, mode A, mode B and mode AB. Where a three-phase rotor is being driven, the sequence designation is prefixed by the digit 3 and, for a four-phase rotor, by the digit 4. For example, a three-phase motor driven in mode B would have the drive circuit designated mode 3B, and a four-phase motor mode 4B.

Table 7 – Typical modes for a three-phase stepping motor

Mode A			
Step	**Phase 1**	**Phase 2**	**Phase 3**
1	1	0	0
2	0	1	0
3	0	0	1
1	1	0	0
Mode B			
Step	**Phase 1**	**Phase 2**	**Phase 3**
1	1	1	0
2	0	1	1
3	1	0	1
1	1	1	0
Mode AB			
Step	**Phase 1**	**Phase 2**	**Phase 3**
1	1	0	0
2	1	1	0
3	0	1	0
4	0	1	1
5	0	0	1
6	1	0	1
1	1	0	0
NOTE Logic 1 represents the energized phase. Logic 0 represents the unenergized phase. The sequence can be extended for any number of phases.			

8.3 Values to be indicated by the manufacturer

The manufacturer shall indicate values, together with appropriate tolerances, for the parameters listed below. These shall be confirmed, where appropriate, by the tests specified in clauses 6 and 7. Where the parameters are affected by the drive circuit or load, details of that drive circuit or load shall be included in the declaration. The parameters are the following:

a) Detent torque;

b) Step angle (basic);

c) Step angle error;

d) Steps per revolution;

e) Volts or amperes per phase;

f) Inductance per phase;

g) D.C. resistance per phase at 20 °C;

h) Holding torque;

i) Volts (peak to peak) per thousand revolutions per minute as generator (where applicable);

j) Moment of inertia of rotor;

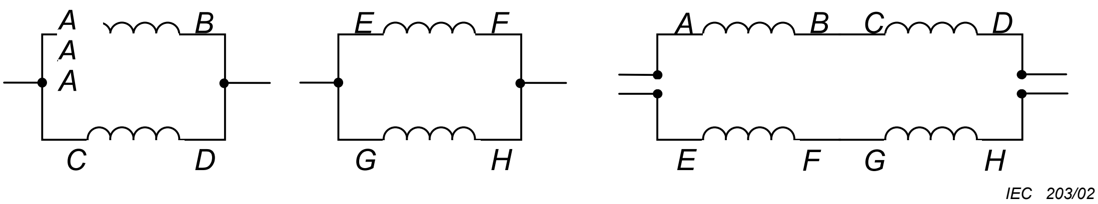
k) Insulation class;

l) Maximum safe operating temperature.

8.4 Lead identification and terminal numbering

For motors with loose leads, the colours of the leads (or marker sleeves fitted to the leads) shall be as given in table 8. Colours in parenthesis are non-preferred alternatives. Motors with terminal boards or strips shall have the terminals identified by number as given in table 8.

Where bipolar drives are used in conjunction with eight-lead motors, it is necessary to connect the windings so that the torques associated with each winding are added, not subtracted; in compliance with table 8, the winding connections will then be shown in figure 5 where the lead colouring is as follows:



Key

A – Brown	*B* – Brown-white	*C* – Orange-white	*D* – Orange
E – Red	*F* – Red-white	*G* – Yellow-white	*H* – Yellow

Figure 5 – Winding connections for bipolar drives

Table 8 – Lead identification and terminal numbering

a) No star point or common connection		
Phase	**Phase start colour**	**Phase finish colour**
1	Brown	Brown / white
2	Red	Red / white
3	Orange	Orange / white
4	Yellow	Yellow / white
5	Green	Green / white
6	Blue	Blue / white
7	Violet	Violet / white
8	Grey	Grey / white
b) With star point or common connection		
Phase	**Colour**	**Terminal number**
Three phase with star point		
1	Brown	1
2	Red	2
3	Orange	3
Star point	Black (white)	4
Four phase with star point		
1	Brown	1
2	Red	2
3	Orange	3
4	Yellow	4
Star point	Black (white)	5
Four phase with common connections		
1	Brown	1
3	Orange	3
2	Red	2
4	Yellow	4
Common connections	Brown / orange (black)	5
	Red / yellow (white)	6

8.5 Catalogue presentation

It is recommended that for uniformity of presentation and ease of comparison, the following information should be given in manufacturers' catalogues:

a) The values to be indicated by the manufacturer in accordance with 8.4;

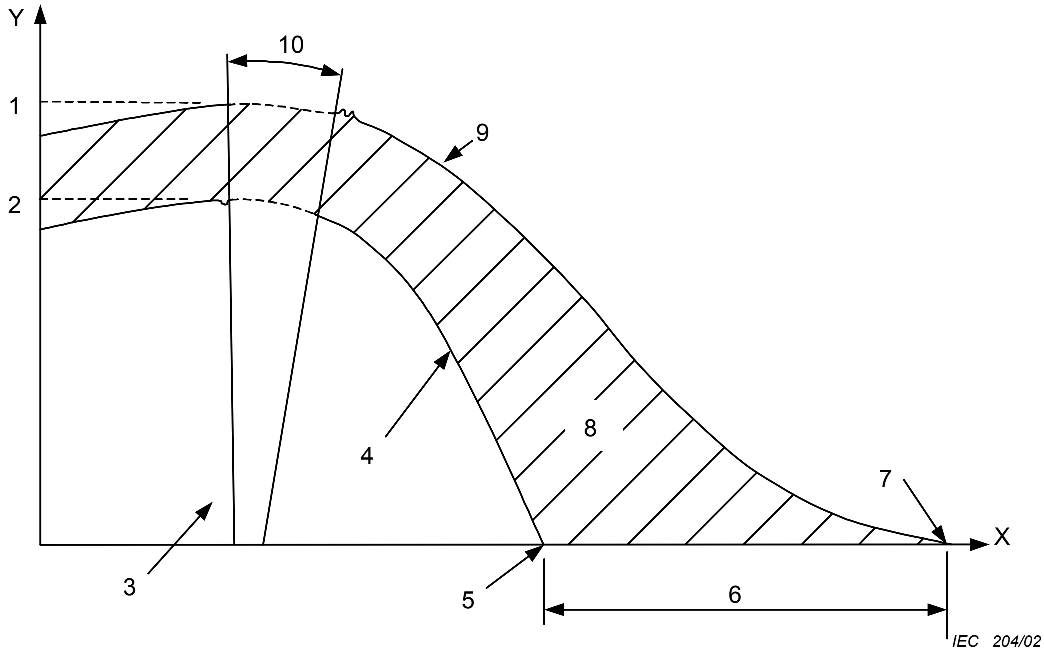
b) Maximum permissible axial thrust;

c) Maximum permissible radial load (at a specified position);

d) Mass of the motor.

8.6 Basic performance curves

The curves in figure 6 show how the basic dynamic characteristics of a given stepping motor relate to each other. The drive circuit and any inertia load, e.g. pulley, that might affect the performance, should be quoted in order that the curves are of use. The major resonant areas should be quoted but, since the curves are for guidance only, it is not anticipated that all resonant areas will be defined.



Key

1 Maximum pull-out torque
2 Maximum pull-in torque
3 Maximum reversing rate
4 Pull-in curve
5 Maximum pull-in rate
6 Slew range
7 Maximum slew rate
8 Slew rate
9 Pull-out curve
10 Resonant rates
X axis pulse rate
Y axis torque

Figure 6 – Basic performance curves

9 EMC requirements

Motors shall comply with the requirements in clause 12 of IEC 60034-1.

10 Safety requirements

Motors shall comply with the requirements in clause 13 of IEC 60034-1.

Annex A
(informative)

Test procedures

A.1 Test procedures

The following test procedures are given for information. Test requirements within this technical specification may use appropriate tests listed in this annex or suitable alternatives.

A.2 Moment of inertia of a rotor – single wire hanging method

Suspend the rotor from a 'hanging' wire and compare its period of oscillation (rotation about the axis of the shaft) to that of a known slug. The moment of inertia is then given by:

$$J_t = J_k \left(\frac{T_t}{T_k} \right)^2$$

where

J_t is the moment of inertia of rotor (Kg × m^2);

J_k is the moment of inertia of known slug (Kg × m^2);

T_t is the period of rotor (s);

T_k is the period of known slug (s).

If the difference in mass between the reference slug and the rotor is so great that different wires have to be used to obtain straightness and reasonable periods of oscillation, then an intermediate slug shall be used. Measure the period of oscillation of this intermediate slug on each wire and calculate the moment of inertia of the test rotor from the following formula:

$$J_t = J_k \left(\frac{T_t}{T_k} \right)^2 \times \left(\frac{T_{w1}}{T_{w2}} \right)^2$$

where:

T_{w1} is the period of intermediate slug on wire used for the known slug (or reference slug);

T_{w2} is the period of intermediate slug on wire used for the rotor.

NOTE 1 The moment of inertia of the intermediate slug is not required.

NOTE 2 The unidirectional displacement angle should not exceed 45º.

A.3 Moment of inertia of a rotor – double wire hanging method

Suspend the rotor with the shaft oriented vertically using two parallel wires as shown in figure A.1. The wires shall be attached diametrically, equally spaced from the centre line of the shaft with a length to separation ratio (L/d) of approximately ten.

Rotate the rotor a small amount from the equilibrium position, and after release measure the frequency of angular oscillation.

The moment of inertia shall be determined from:

$$J_t = \frac{c \times m \times d^2}{L \times f^2}$$

where

J_t is the total moment of inertia;

m is the total mass;

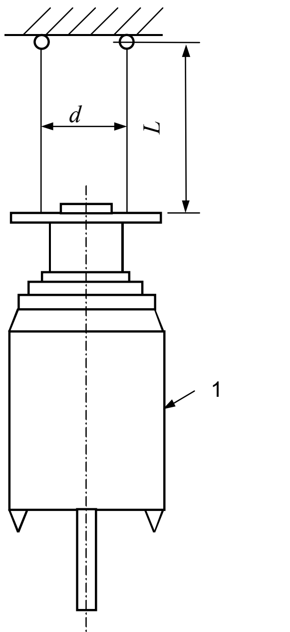
L is the length of wires;

d is the separation of wires;

f is the frequency of oscillation in Hertz;

c = $6,2 \times 10^{-2}$ for SI units for g (acceleration of free fall) = 9,8 m/s^2.

NOTE In order to determine the inertia of the rotor alone, it will often be necessary to subtract the inertia of the test fixture as well as the inertia of couplings attached to the rotor.



Key

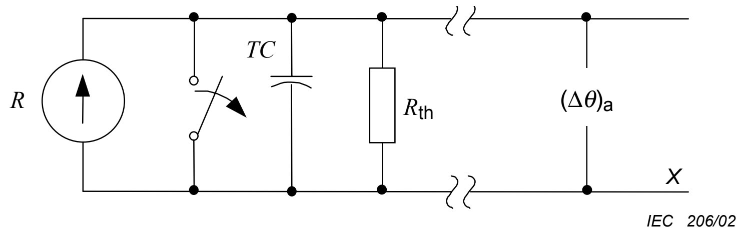
1 rotor

Figure A.1 – Double wire hanging method

A.4 Thermal resistance, R_{th} and thermal time constant, τ_{th}

A.4.1 General

The thermal model for an electrical machine may include several thermal time constants. However, for ease of analysis, a single thermal time constant is usually sufficient for most calculations, as indicated in figure A.2.



Key

P	is the power loss in watts;
TC	is the thermal capacitance in joules/kelvin;
R_{th}	is the thermal resistance in kelvins/watt;
$(\Delta\theta)_a$	is the temperature rise above the ambient temperature in kelvins;
X	is the ambient temperature.

Figure A.2 – Test circuit for determining R_{th} and τ_{th}

A.4.2 Test conditions

The motor under test shall be permitted to run at a very slow speed (less than 5 rpm) to distribute the heat generated equally, and shall be thermally isolated from the mounting structure.

Measurements shall be made in still air, or in the case of a blower cooled motor, under a specified method of cooling.

A.4.3 Test procedure

a) Apply a current equal to or less than the rated current to the motor under test and allow it to reach thermal equilibrium.

b) Determine temperature rise, $(\Delta\theta)_a$ by one of the methods specified in IEC 60034-1.

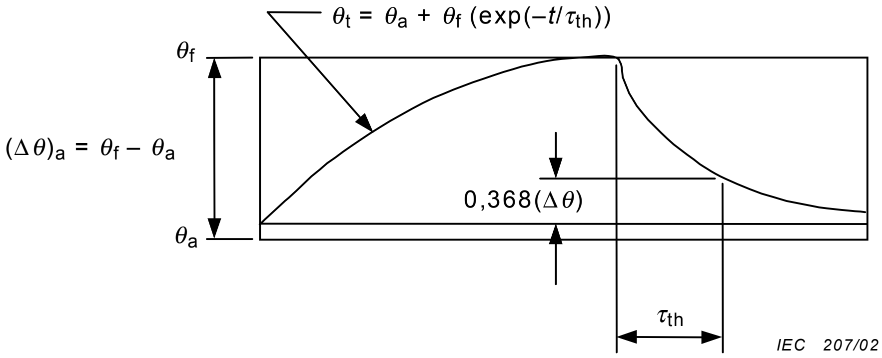
c) Multiply $(\Delta\theta)_a$ by 0,368 and add the result to the ambient temperature.

d) Remove power from the motor under test and record the time t it takes for the temperature to fall to the value calculated in step c). The blower motor should remain operational.

e) Calculate the power loss as $P = I^2R$ where I is the applied current and R is the winding resistance at θ_f (for most motors this will be true.)

Then τ_{th} is the time, t, recorded in step d) above, and $R_{th} = (\Delta\theta)_a / P$

See figure A.3 for clarification of the quantities defined in the test procedure.



Key

τ_{th} is the thermal time constant in minutes $[(TC) \times (R_{th})]$;

θ_f is the final temperature at thermal equilibrium;

θ_a is the ambient temperature in degrees Celsius;

θ_t is the temperature at time t in degrees Celsius.

Figure A.3 – Clarification of test procedure quantities

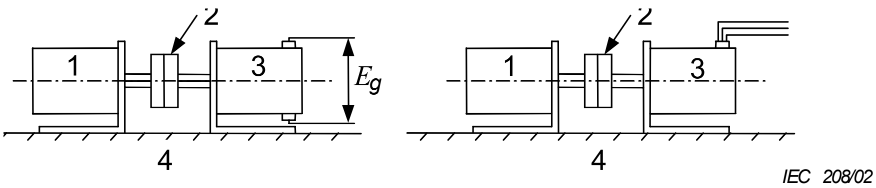
A.5 Back e.m.f. constant

Mount the motor by normal mounting means, see for example figure A.4.

Apply power to the constant speed drive motor and allow it to stabilize at the desired speed.

Measure the induced voltage in the test motor and compute the back e.m.f. constant using the formula:

$$K_E = \frac{\text{measured voltage} \times 9{,}55}{\text{r.p.m.}}$$



Key

1 drive motor

2 flexible disc coupling

3 motor under test

4 base

Figure A.4 – Test arrangements for determining back e.m.f. constant

A.6 Inductance

A.6.1 General

For motors containing a permanent magnet, before performance tests are carried out, the magnet should be stabilized in accordance with the motor manufacturer's instructions.

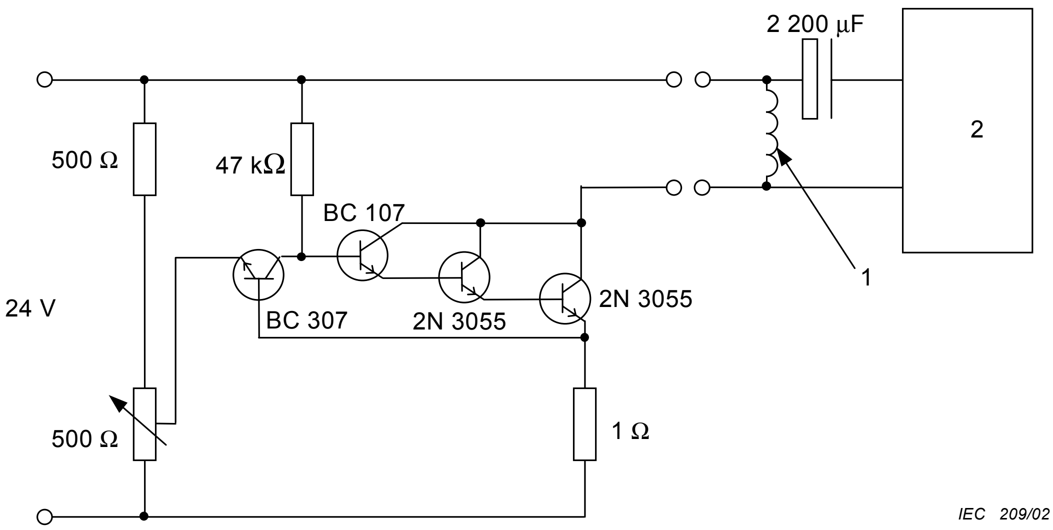
The inductance of a stepping motor winding varies both with rotor position and with excitation current. Measurements can also be affected by the rate of change of current. Thus when a figure for inductance is given, the conditions under which the measurements were taken should be quoted.

A.6.2 Inductance bridge method

Use a bridge having a test frequency of 100 Hz or another specified frequency. Align the stepping motor rotor and stator by the application of the rated current to the winding under test and then clamp the shaft relative to the motor body. De-energize the stator and measure the inductance (using a test voltage of approximately 1 V r.m.s.). Then turn the rotor through an angle equal to half its tooth or pole pitch (the point of minimum reluctance) and repeat the measurement.

NOTE These measurements give the incremental unenergized aligned and unaligned inductances of the motor. Additional useful information can be obtained by injecting current into the windings when measuring the inductance. Three levels of bias current are desirable, namely 0 %, 50 % and 100 % of the motor's rating.

This then requires six measurements, three with the rotor and stator in the aligned position and three with the rotor and stator out of line. When a bias current is applied to a winding, the inductance measuring device will be affected by the impedance of the biasing supply, and it is for this reason that a high impedance source is required. A typical circuit is shown in figure A.5.



Key

1 Motor winding

2 Inductance bridge

Figure A.5 – Typical circuit for measuring inductance by an inductance bridge

A.6.3 Current discharge method

Align the motor rotor and stator and clamp the rotor as described in A.6.2. Energize the winding for a sufficient time for the current to stabilize to a value 10 % above the motor rating. Close the switch across the winding and monitor the resulting current decay on an oscilloscope connected across a resistor placed in series with the winding, see figure A.6. Record the resulting curve. Repeat this procedure with the rotor in the unaligned position. Calculate the inductance of the winding for any part of the curve (any current area) from the formula:

$$L = \frac{R \times t}{\ln(I/i)}$$

where

L is the inductance (in H);

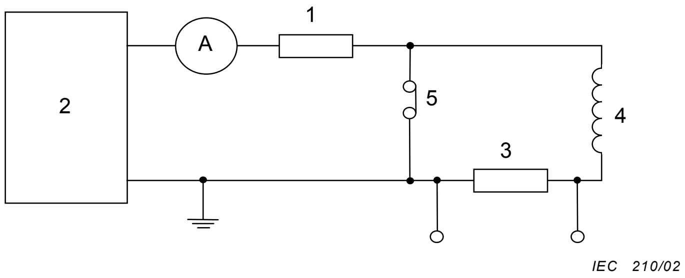
I is the initial current (in A);

i is the current after time t (in A);

R is the total circuit resistance including winding (in Ω).

The two curves (corresponding to aligned and non aligned rotors) together with the above formula, or a table of inductances at different currents, shall be presented as the result of the test.

Any values given shall be accompanied by the relevant circuit constants.



Key

1 Limiting resistor
2 Power supply unit
3 Oscilloscope
4 Motor winding
5 Switch

Figure A.6 – Circuit for measuring inductance by the current discharge method

A.7 Step angle error

A.7.1 General

The step angle error may be measured by any convenient means available, provided that the measuring device has the desired accuracy and is of sufficiently low friction for the accuracy to be unaffected.

A.7.2 Encoder method

An optical encoder can provide a very satisfactory research and production tool for step angle error measurements that are quick and unambiguous. However, it is necessary to take some care in the selection of a suitable encoder. For a large angle stepping motor, an absolute device is suitable, but for small angle (1,8°) stepping motors it will be found that an incremental encoder will provide greater resolution. When using an incremental encoder the following points should be considered. The count speed of an incremental encoder is limited, and so the angular velocity the motor shaft achieves between steps is limited. Add viscous damping or add inertia to the shaft, but take care that the inertia is sufficiently well balanced that the motor accuracy is not impaired. An encoder is generally accurate only to a half count and the read-out facility to ±1 digit. For a given encoder resolution this will therefore limit the accuracy.

A.7.3 Synchro method

An accuracy similar to that of the incremental encoder can be obtained with a synchro without the risk of losing track of position since the synchro is basically an absolute device. However, It requires special supplies and read-out facilities.

A.7.4 Dividing head method

This method is not considered suitable for production checks, but gives a more accurate result for development purposes. Carefully secure the motor body in the chuck of a dividing head, lining up the motor shaft axis with the dividing head axis. With the required phase or phases energized, focus the optics onto a scribed line on the shaft or on a drum on the shaft. With the next phase or phases energized, turn the chuck until the scribed mark again appears within the graticule and note the angular reading.

If it is desired to determine the maximum positional error, use the midpoint between the two extremes of positional error as the zero position.

Annex B
(informative)

Special tests

B.1 Special test procedures

The following procedures for special tests are given for information and should only be used when specified by the customer. These tests shall be done with an agreed-upon power supply.

B.2 Winding temperature rise

Where possible, the change of winding resistance should be used to measure the temperature rise of a stepping motor. Mount the motor away from heat conducting surfaces and draughts and attach to a heat sink where appropriate. With the motor stabilized at ambient temperature, record the motor temperature θ_1, and the winding resistance R_1. Energize the relevant windings on the appropriate duty cycle until the motor attains a stable temperature.

For voltage driven motors, energize one or more phases as required, but at zero pulse rate, that is, the phases specified are energized continuously, the others being open-circuited. Use one of the energized phases for the temperature rise measurements.

Run current driven motors at a speed such that the maximum power input is achieved (shaft unloaded). This will generally be the maximum pull-in rate. A maximum temperature is then achieved. Where it is not possible to run the motor in this condition (at its maximum pull-in rate) choose a pulse rate and quote this along with the temperature rise and the drive circuit used.

The temperature rise shall be in determined in accordance with the requirements in 7.6.2 of IEC 60034-1.

B.3 Torque displacement curve

Apply the rated current or voltage and measure the torque by adding weights to a torque arm, but when the peak holding torque is reached, use a spring balance to prevent the arm from rotating uncontrollably when obtaining figures on the negative portion of the curve. In order for measurements to be stable, it is necessary for the spring balance stiffness to be greater than that due to the motor, which may mean that a high rate balance has to be used and that accuracy of reading will be poor. Monitor the shaft angle on large angle stepping motors with a protractor and pointer. For small angle motors it will be necessary to use more sophisticated test gear. Where the motor has shaft extensions at each end, use an optical encoder to monitor the angle, and a torque transducer to monitor the torque applied. The load may then be applied by hand via a load arm and the readings from the encoder and torque transducer directly plotted on a chart using an X-Y plotter. Where the motor has one shaft only, apply the load by a combination of weights and spring balance or a load arm as described for large angle stepping motors and again monitor the angle with an encoder.

B.4 Single step response, natural frequency and settling time

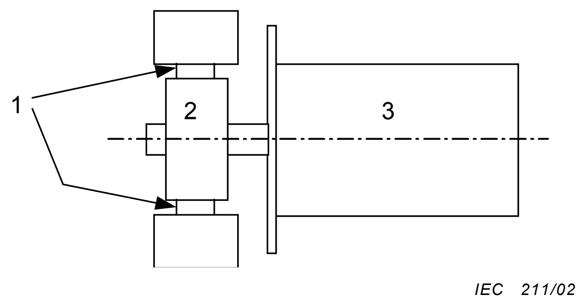
Couple a continuously rotating potentiometer to the motor output shaft and apply a voltage to the ends of the potentiometer track. Connect a recording instrument between the potentiometer wiping contact and one side of the supply. When the motor is stepped one step at a time, the resulting trace will show the 'one step response'. Take care to ensure that the inertia of the potentiometer is small compared with that of the motor rotor and that friction is very small compared with the motor torque. For large motorsl, it may be possible to monitor shaft position with an optical encoder as in the torque displacement curve measurements.

B.5 Maximum slew rate

Apply a pulse train to the motor as described in clause B.6. Slowly increase the pulse rate from a low pulse rate (before the pull-in rate) to the rate just before the rotor loses synchronism. The resulting pulse rate is the maximum slew rate. Repeat this test for the opposite direction of rotation. Take care to avoid resonances.

B.6 Pull-in rate

The drive circuit should be such that the motor can be started by application of the pulse train which will cause the drive circuit to energize the next motor winding or windings in sequence. Additionally, the pulse train should be of the correct duration and not altered by 'switch on'. Apply a load to the shaft of the motor such that the torque applied to the shaft is substantially constant with varying shaft speed. This may be achieved in several ways. For large motors, it is convenient to use a particle brake to supply the load, since the torque is approximately proportional to the supply current. Because of the high inertia, it is not possible to use a particle brake for small motors (size 34 and smaller) and other devices such as a prony brake may be used. If a cast iron drum of low inertia is mounted on the motor shaft and hardwood blocks or pads brought to bear on the surface, then provided the surfaces are clean, a fairly low stiction which is comparable to running torque can be obtained, see figure B.1.



Key

1 Hardwood blocks

2 Drum

3 Motor under test

Figure B.1 – Arrangement for determining pull-in rate

The torque will depend upon the force between the pads and the drum and should be pre-calibrated. Because of the difficulty in setting the torque, it is more convenient to alter the drive frequency and the procedure is then as follows:

- Set the prony brake to a low value of torque (10 % of holding torque);
- Set the pulse rate to a low value (e.g. 20 pps);
- Initiate the pulse train and see whether the motor pulls into speed without hesitation;
- Turn off the pulse train, increase its rate, initiate it again and observe the motor;
- Stop the pulse train.

If the motor had pulled into synchronism again without hesitation repeat the procedure until it does not. When the motor fails to respond correctly, reduce the pulse rate slightly and re-initiate. By increasing and reducing and again increasing the pulse rate, a fairly accurate figure of pull-in rate for the applied torque can be determined. It is important to check the prony brake torque after this test. Then increase the torque to a higher value and repeat the test. Finally, plot a curve of pull-in rate versus torque. It is necessary to quote the moment of inertia of the load (drum) along with the curve. When using a particle brake it may be preferable to change the brake current and therefore motor load instead of the pulse rate.

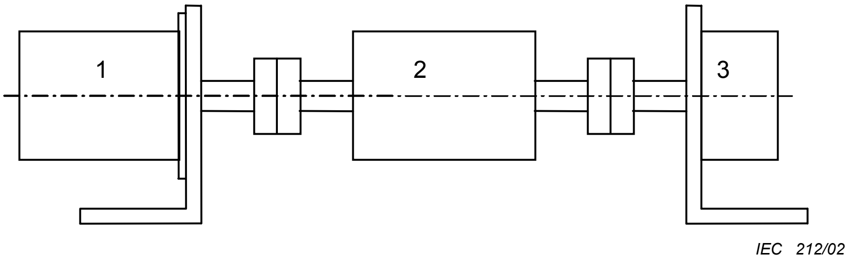
B.7 Pull-out torque

As in clause B.6, the inertia of the test apparatus affects the results and so the particle brake and dynamometer methods should be used only for the larger motors and cord/spring balance combination for the small motors (size 34 and smaller). A schematic diagram of a particle brake and torque transducer arrangement is shown in figure B.2 and of a reaction dynamometer in figure B.3. If the particle brake is removed and finger pressure applied to the torque transducer shaft, the inertia is lowered so that smaller motors may be tested depending upon the inertia of the torque transducer.

Set a low pulse train rate as in clause B.6 and start the motor. Increase the load until the motor falls out of synchronism. Make a note of the load applied just before synchronism is lost. With the load removed, restart the motor and increase the pulse rate. Then re-apply the load and increase this until the motor again loses synchronism and note the load again just before loss of synchronism. Repeat this for several values of pulse rate until the motor will run no faster. It will be necessary to start at a lower frequency and ramp up for the higher speeds when the motor is running in its slew mode.

Two methods using cord and spring balance are shown in figures B.4 and B.5, the results for each being similar. The system in figure B.5 using only one spring balance requires cord loop and a pulley mounted on a movable arm. As the arm is raised, the cord tension is increased and the torque applied is also increased; the torque is then the product of motor pulley radius and the balance reading. The system shown in figure B.5 requires the reading of both balances simultaneously; the torque is then the product of the difference in balance readings and the pulley radius. Include the diameter of the cord in the calculation only if it has not been possible to choose a cord sufficiently small to make this unnecessary.

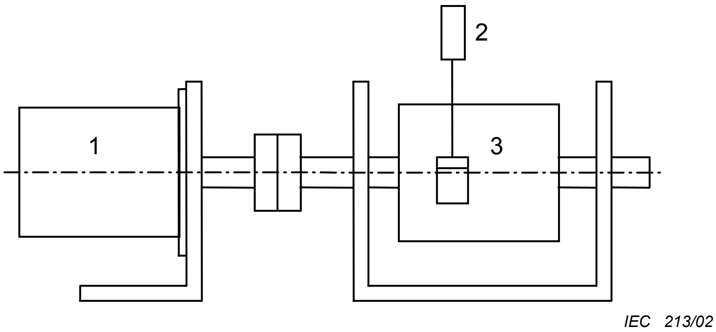
In all cases, the moment of inertia of the test load should be quoted.



Key

1 Motor under test
2 Torque transducer
3 Particle brake

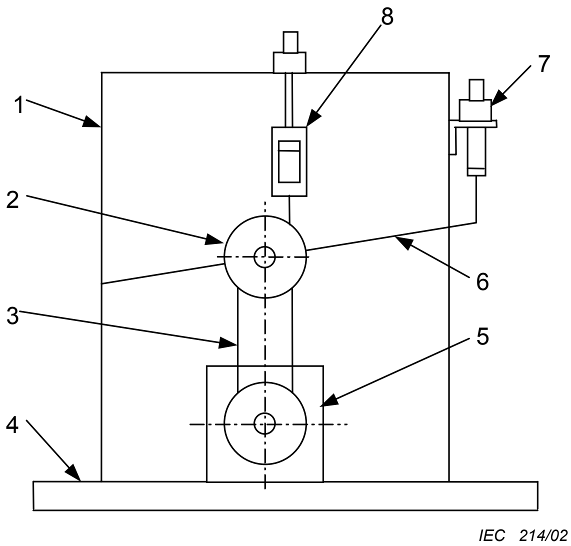
Figure B.2 – Test rig for pull-out torque measurement using torque transducer and particle brake



Key

1 Motor under test
2 Load transducer
3 Dynamometer

Figure B.3 – Test rig for pull-out torque measurement using dynamometer



Key

1 Supporting frame
2 Freely rotating pulley
3 Continuous loop of cord
4 Base board
5 Motor under test in a clamp
6 Pivoted bar attached to the pulley
7 Adjustable nut
8 Spring balance

Figure B.4 – Method of pull-out torque measurement using cord and spring balance

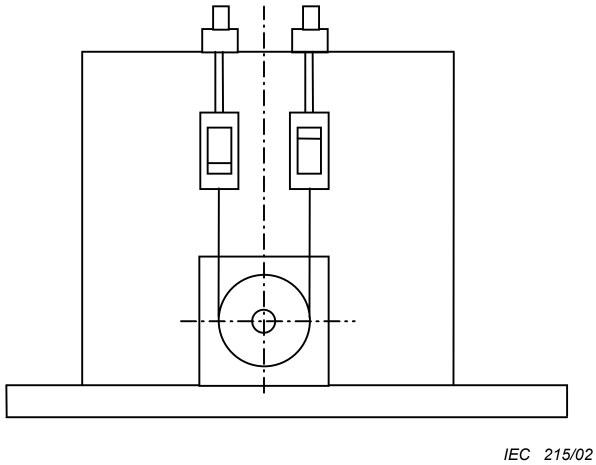


Figure B.5 – Method of pull-out torque measurement using cord and two spring balances

B.8 Maximum reversing rate

Having determined the pull-in rate as described in B.6, set the pulse rate with the motor unloaded, so that the motor is running with a pulse rate less than half the maximum pull-in rate. Reverse the motor normally by a change in logic level input to the drive circuit, taking care that the final pulse in one direction and the initial pulse in the other direction are not foreshortened. Increase the pulse rate until the motor ceases to respond correctly (loses or gains steps). Then lower again until the motor functions correctly. This value of pulse rate is the maximum reversing rate.

It is often the case that motor hesitation (incorrect response) can be observed visually, but it is recommended that a more positive indication of lost steps should be made. If the rotor is driven a certain number of steps in each direction, any lost or gained steps will result in a variation of the final position of the shaft. This can be observed much more easily than motor hesitation. If a shaft position monitoring device (for example, as discussed in B.4) is used, take care to ensure that the inertia is low enough not to affect the response unduly.

B.9 Resonance

Apply a pulse train to the motor as described in B.6 and raise the pulse rate slowly until the motor loses synchronism. Note the pulse rate. Starting from a slightly lower pulse rate (at which the motor runs satisfactorily) and, rapidly but smoothly crossing the previously noted pulse rate, again raise the pulse rate slowly until the rotor again loses synchronism. Repeat this procedure to locate all resonant rates until the motor will no longer run. Reverse the procedure (decreasing pulse rate) to find the upper thresholds of the resonant areas.

An alternative method of starting the stepping motor is to turn the shaft at a speed above the desired synchronous speed and to allow the rotor to fall into synchronism, continuing the test as before.

(*Continued from second cover*)

International Standard	*Title*
IEC 60072-3 :1994	Dimensions and output series for rotating electrical machines — Part 3: Small built-in motors — Flange numbers BF10 to BF50

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

This Indian Standard has been developed from Doc No.: ETD 13 (21170).

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