

Australian Standard[®]

**ROTATING ELECTRICAL
MACHINES OF PARTICULAR
TYPES OR FOR PARTICULAR
APPLICATIONS**

Part 60—STEPPING MOTORS

[Title allocated by Defence Cataloguing Authority:
MOTOR; STEPPING]

This Australian standard was prepared by Committee EL/9, Rotating Electrical Machinery. It was approved on behalf of the Council of the Standards Association of Australia on 7 June 1984 and published on 3 September 1984.

Review of Australian Standards. To keep abreast of progress in industry, Australian Standards are subject to periodic review and are kept up to date by the issue of amendments or new editions as necessary. It is important therefore that Standards users ensure that they are in possession of the latest edition, and any amendments thereto.

Full details of all Australian Standards and related publications will be found in the Standards Australia Catalogue of Publications; this information is supplemented each month by the magazine 'The Australian Standard', which subscribing members receive, and which gives details of new publications, new editions and amendments, and of withdrawn Standards.

Suggestions for improvements to Australian Standards, addressed to the head office of Standards Australia, are welcomed. Notification of any inaccuracy or ambiguity found in an Australian Standard should be made without delay in order that the matter may be investigated and appropriate action taken.

PREFACE

This part of the standard on rotating electrical machines was prepared by the Association's Committee on Rotating Electrical Machinery.

The text is technically identical with that of BS 5000: Part 60: 1982 of the same title. Acknowledgement is made to BSI for the use of this material.

CONTENTS

	<i>Page</i>
FOREWORD	3
SPECIFICATION	
1 Scope	4
2 Referenced Documents	4
3 Definitions	4
4 Abbreviations, Symbols and Units	5
5 Typical Modes	5
6 Values to be Indicated by the Manufacturer	5
7 Lead Identification and Terminal Numbering	5
8 Dimensions	5
9 Tests	7
10 Marking	10
APPENDICES	
A Preferred Modes for a Three-phase Stepping Motor	12
B Catalogue Presentation	13
C Basic Performance Curves	15
D Additional Test Methods	16
E Dimensions	20

First published 1984

© Copyright — STANDARDS AUSTRALIA

Users of Standards are reminded that copyright subsists in all Standards Australia publications and software. Except where the Copyright Act allows and except where provided for below no publications or software produced by Standards Australia may be reproduced, stored in a retrieval system in any form or transmitted by any means without prior permission in writing from Standards Australia. Permission may be conditional on an appropriate royalty payment. Requests for permission and information on commercial software royalties should be directed to the head office of Standards Australia.

Standards Australia will permit up to 10 percent of the technical content pages of a Standard to be copied for use exclusively in-house by purchasers of the Standard without payment of a royalty or advice to Standards Australia.

Standards Australia will also permit the inclusion of its copyright material in computer software programs for no royalty payment provided such programs are used exclusively in-house by the creators of the programs.

Care should be taken to ensure that material used is from the current edition of the Standard and that it is updated whenever the Standard is amended or revised. The number and date of the Standard should therefore be clearly identified.

The use of material in print form or in computer software programs to be used commercially, with or without payment, or in commercial contracts is subject to the payment of a royalty. This policy may be varied by Standards Australia at any time.

This standard was issued in draft form for comment as DR 83182.

ISBN 0 7262 3452 4

STANDARDS ASSOCIATION OF AUSTRALIA

Australian Standard

for

**ROTATING ELECTRICAL MACHINES OF PARTICULAR TYPES OR
FOR PARTICULAR APPLICATIONS**

PART 60—STEPPING MOTORS

FOREWORD

This Part of this standard is based upon a report by ERA Technology Ltd representing the culmination of a 2-year study carried out in collaboration with industry, universities and the UK Government. It became evident as a result of this study that there was a real need for standardization of terminology used in connection with stepping motors, for detailing the important performance parameters for which manufacturers should indicate values and for the establishment of recognized test methods for checking these values. This standard concentrates on these aspects.

The standardization of dimensions has presented a particularly difficult problem as a large proportion of stepping motors has been designed for military applications with the inch system of dimensions primarily used by NATO (and with performance parameters specified in imperial units). With the rapidly increasing use by industry and a tendency towards metric dimensions for future designs, a first step in this direction has been taken by including in Appendix E the most common existing inch dimensions and giving approximate metric equivalents of these for the guidance of future designers.

Appendices A, B, C and D give, respectively, typical modes of operation, recommended details for catalogue presentation, typical basic performance curves and additional test methods for parameters for which the indication of values is not a requirement of the standard.

SPECIFICATION

1 SCOPE. This Part of this standard specifies requirements for electromagnetic stepping motors. It defines the terminology used for this type of motor, lists the items for which values are to be indicated by the manufacturer and specifies the test methods to be adopted. Dimensions are specified for given frame sizes; however, the standard is also applicable to motors in frames having any other dimensions.

The standard does not apply to hydraulic and 'ratchet' type stepping motors.

2 REFERENCED DOCUMENTS. The following standards are referred to in this Part:

AS 1000	The International System of Units (SI) and Its Application
AS 1359	General Requirements for Rotating Electrical Machines 1359.10—Designations and Dimensions* 1359.60—Tests
AS XXXX	Electrical Insulating Materials—Evaluation and Classification Based on Thermal Endurance†

3 DEFINITIONS. For the purpose of this Part of the standard, the following definitions apply:

3.1 Stepping motor—a reversible brushless d.c. motor, the rotor of which rotates in discrete angular increments when its stator windings are energized in a programmed manner.

Rotation occurs because of the magnetic interaction between the rotor poles and the poles of the sequentially energized stator phases. The rotor has no electrical winding but rather salient or magnetized poles.

NOTE: Particular types of stepping motor are defined in Clauses 3.1.1, 3.1.2 and 3.1.3.

3.1.1 Permanent magnet (PM) stepping motor—a stepping motor utilizing a rotor that has permanently magnetized poles.

3.1.2 Variable reluctance (VR) stepping motor—a stepping motor utilizing a rotor that has salient poles of low residual magnetic material.

3.1.3 Hybrid (HY) stepping motor—a stepping motor utilizing a permanent magnet to polarize salient pole pieces of low residual magnetic material on the rotor.

3.2 Damper—a device for damping step oscillations.

3.3 Dead range or dead band—the angle between the clockwise and anti-clockwise limits under specified load conditions, within which the rotor of an energized stepping motor can stop.

3.4 Detent position—that position where the rotor of a permanent magnet or hybrid stepping motor comes to rest when unenergized and unloaded.

3.5 Detent torque—the maximum steady torque that can be applied to the shaft of an unenergized stepping motor without causing continuous rotation.

3.6 Direction of rotation—the direction of rotation of the shaft is the one observed when the observer faces the shaft end associated with the mounting surfaces. Anti-clockwise rotation of the shaft is regarded as positive and clockwise rotation as negative.

3.7 Drive circuit—a combination of the translator logic and a power amplifier that switches the phases of the stepping motor in a predetermined mode.

NOTE: The available drive circuit configurations are defined in Clauses 3.7.1 to 3.7.5.

3.7.1 Bipolar drive—a drive circuit in which the excitation applied is such that the torque-generating current reverses in the windings.

3.7.2 Chopper drive—a drive circuit in which the form of excitation is an initial voltage applied to the phase winding until the current in that winding reaches a predetermined value when the supply is switched off. When the current has decayed to a second predetermined value, the voltage is re-applied.

3.7.3 Constant current drive—a drive circuit that attempts to maintain a constant current in the windings irrespective of motor speed.

3.7.4 Multilevel drive—a drive circuit in which two or more levels of voltage are sequentially applied to a stepping motor winding.

3.7.5 Unipolar drive—a drive circuit in which the excitation is such that the torque-generating current in each winding occurs in one direction only.

3.8 Holding torque—the maximum steady torque at a specified current that can be applied to the shaft of an energized stepping motor without causing continuous rotation.

3.9 Incremental motion—the motion caused by a single pulse or a programme of steps.

3.10 Line—a terminal or wire of the motor to which a logic function from the motor driver is applied. In an electronic drive circuit, a power device will be connected to a line.

3.11 Load angle—the angle between the magnetic axis of the rotor and the stator magnetic field. In practice this is the angle between the loaded and unloaded positions of the rotor under otherwise identical conditions.

3.12 Maximum reversing rate—the maximum pulse rate at which the unloaded stepping motor is able to reverse and remain in synchronism under specified drive conditions.

3.13 Maximum safe working temperature—the maximum temperature the stepping motor, either continuously or intermittently rated, may safely be allowed to achieve (measured by the change of winding resistance method). This maximum temperature may be limited by the thermal classification of the winding (see AS XXXX), by the properties of the bearing lubricant, or by other considerations.

3.14 Maximum slew rate—the maximum pulse rate at which the unloaded stepping motor can remain in synchronism under specified drive conditions.

3.15 Mini-stepping—the subdivision of the motor's basic step angle by partial energization of a phase or phases.

3.16 Mode (step sequence)—a particular sequence of excitation defined by the drive circuit which, when applied to a stepping motor, will energize certain windings or phases.

* In course of preparation, see DR 83240.

† In course of publication, see DR 83050 (draft revision of AS C320—1958).

3.17 Overshoot or transient overshoot—the amount the shaft of the stepping motor rotates beyond the final commanded step position.

3.18 Phase—a part of the winding between a line and the centre tap or star point, or the winding between two lines if no centre tap or star point exists.

3.19 Positional error—the deviation from the theoretical final position after a sequence of steps, expressed as a percentage of basic step angle.

3.20 Pull-in rate—the (constant) maximum pulse rate at which the energized stepping motor will start driving a specified load without missing steps, under specified drive conditions.

3.21 Pull-in torque—the maximum torque at which an energized stepping motor will start driving a specified load, and run in synchronism without losing steps, on application of a fixed pulse rate.

3.22 Pull-out rate—the (constant) maximum pulse rate at which the energized stepping motor can run, driving a specified load under specified drive conditions, without missing steps.

3.23 Pull-out torque—the 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 missing steps.

3.24 Pulse rate—the rate at which the successive steps are initiated.

3.25 Resolution—the reciprocal of the number of steps per revolution of the motor shaft.

3.26 Resonant rate—a stepping rate at which the stepping motor will miss steps when operating below the pull-out torque curve, under specified load and drive conditions.

3.27 Response range—the range of pulse rates over which the motor can start, stop or reverse without missing steps under specified load and drive conditions.

3.28 Salient pole—a projecting pole on a rotor or stator.

3.29 Settling time—the total time from the application of the command signal until the motor shaft comes to rest.

3.30 Slew range—the range of pulse rates over which the motor will not miss steps unidirectionally under specified load and drive conditions, but within which the motor cannot start, stop or reverse at a fixed pulse rate.

NOTE: This is illustrated in Fig. 6.

3.31 Step—the movement of the rotor from one energized position to the next in sequence.

3.32 Step angle (basic)—the angle through which the shaft of an unloaded stepping motor can be made to turn when two adjacent phases are energized, singly in sequence.

3.33 Step angle error—the maximum percentage deviation from the theoretical step angle.

3.34 Step position—the angular position that the shaft of an unloaded stepping motor assumes when it is energized without causing continuous rotation. The step position is not necessarily the same as the detent position.

3.35 Stepping rate—the number of step angles through

which the stepping motor shaft rotates in a specified time.

3.36 Synchronism—the state that exists when the stepping rate of the rotor equals the applied pulse rate.

3.37 Torque gradient—the average slope of the torque displacement curve over a specified angle through the origin.

3.38 Translator logic—the logic that translates the input pulse train into the selected mode pattern to be applied to a stepping motor.

4 ABBREVIATIONS, SYMBOLS AND UNITS. The abbreviations, symbols and units commonly used are listed in Table 1 or are defined in AS 1000.

5 TYPICAL MODES. There are three preferred sequences of excitation, viz mode A, mode B and mode AB. Typical modes for a three-phase motor are detailed in Appendix A.

6 VALUES TO BE INDICATED BY THE MANUFACTURER. The manufacturer shall indicate values for parameters listed below. These shall be confirmed, where appropriate, by the tests specified in Clause 9. 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—

- (a) detent torque;
- (b) step angle (basic);
- (c) step angle error;
- (d) steps per revolution;
- (e) d.c. volts or amperes per phase;
- (f) inductance per phase;
- (g) d.c. resistance per phase;
- (h) holding torque;
- (j) volts (peak to peak) per thousand revolutions per minute as generator (where applicable);
- (k) rotor inertia;
- (l) insulation class; and
- (m) maximum safe working temperature.

7 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 2. Colours in parentheses are non-preferred alternatives. Motors with terminal boards or strips shall have the terminals identified by numbers as given in Table 2.

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 2, the winding connections will then be as shown in Fig. 1.

8 DIMENSIONS.

NOTES:

1. At this time, designs of stepping motors within the scope of this Part are mainly based on inch dimensions (see Foreword) and for this reason, existing outline dimensions and tolerances are given in inches in Appendix E. For frame sizes given in column 1 of Tables E1(A) and E2(A), dimensions shall be as given in those Tables. For designs having dimensions other than those given in Tables E1(A) and E2(A), dimensions are not standardized.
2. Approximate metric conversions of the inch dimensions are given in Tables E1(B) and E2(B), but these conversions are not exact, and if these metric dimensions are required or offered, this should be clearly stated. It is hoped that manufacturers producing new designs will use metric dimensions where possible.

TABLE 1
LIST OF ABBREVIATIONS, SYMBOLS AND UNITS

Term	Symbol	Unit	Unit symbol
Dead range	—	degree	°
Detent torque	T_d	newton metre*	N.m
Holding torque	T_h	newton metre*	N.m
Maximum slew range	—	steps per second	—
Mode	A, B or AB	—	—
Overshoot (transient)	—	degree	°
Phase	ϕ	—	—
Positional error	—	percent basic step angle	—
Pull-in rate	f_{pi}	steps per second	—
Pull-out rate	f_{po}	steps per second	—
Pull-in torque	T_{pi}	newton metre*	N.m
Pull-out torque	T_{po}	newton metre*	N.m
Pulse rate (p.p.s.)†	f_{pr}	hertz	Hz
Resolution	—	steps per revolution	—
Resonant rate	—	steps per second	—
Response range	—	steps per second	—
Settling time	—	second	s
Slew range	—	steps per second	—
Step angle	—	degree	°
Step angle error	—	percent basic step angle	—
Stepping rate	—	steps per second	—
Torque gradient	—	newton metre per degree‡	N.m/°

* May also be expressed in ounce inches (oz. in) (see Foreword).

† Pulses per second.

‡ May also be expressed in ounce inches per degree (oz. in/°) (see Foreword).

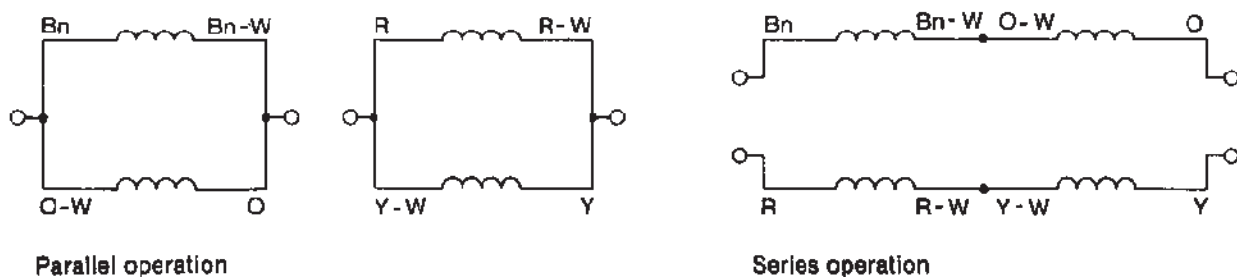


Fig. 1. WINDING CONNECTIONS FOR BIPOLAR DRIVES

TABLE 2A
LEAD IDENTIFICATION AND
TERMINAL NUMBERING
(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	Lilac	Lilac/White
8	Grey	Grey/White

TABLE 2B
LEAD IDENTIFICATION AND
TERMINAL NUMBERING
(With star point or common connection)

Phase	Colour	Terminal number
Three-phase with star point		
1	Brown	1
2	Red	2
3	Orange	3
Start 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

9 TESTS.

9.1 General.

9.1.1 Confirmation of values. The manufacturer shall carry out the tests given in this Clause to confirm the values which have been indicated in accordance with Clause 6 and also a high voltage test in accordance with Clause 9.5.

9.1.2 Type tests. Where tests are indicated as type tests these shall be made on motors as produced by a specific manufacturer before that manufacturer supplies, on a general basis, motors designed to comply with the requirements of this standard.

NOTE: These tests are not normally to be repeated except by special arrangement between the purchaser and the manufacturer.

9.1.3 Routine tests. Where tests are indicated as routine tests these shall be made on all motors in the finished state or, as appropriate, during manufacture.

NOTE: These tests may also be used as acceptance tests by arrangement between the purchaser and the manufacturer.

9.1.4 Stabilized test conditions. Before carrying out tests, the motor shall be temperature stabilized in accordance with the manufacturer's instructions.

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

9.2 Rotor inertia (type test).

9.2.1 Calculation method. Where a rotor is cylindrical, calculate the moment of inertia about its axis from the following equation:

$$I = \frac{mr^2}{2}$$

where

I = moment of inertia, in gram centimetres squared

m = mass, in grams

r = radius, in centimetres

9.2.2 Single wire hanging method. Where the rotor has salient poles, direct calculation is more complex. It is permissible to use the following formulas in conjunction with a 'hanging wire' on which the rotor is hung. Compare the period of oscillation (rotating about the axis of the shaft) with that of a known slug. The moment of inertia is then given by the following formula—

$$I_u = I_k \left(\frac{t_u}{t_k} \right)^2$$

where

I_u = moment of inertia of rotor, in gram centimetres squared

I_k = moment of inertia of known slug, in gram centimetres squared

t_u = period of rotor, in seconds

t_k = period of known slug, in seconds.

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 use an intermediate slug. 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:

$$I_u = I_k \left(\frac{t_u}{t_k} \right)^2 \times \left(\frac{t_{w1}}{t_{w2}} \right)^2$$

where

t_{w1} = period of intermediate slug on wire used for I_k

t_{w2} = period of intermediate slug on wire used for I_u .

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

9.2.3 Two-wire hanging method. Hang the rotor by two slender steel wires, as illustrated in Fig.2, and apply torsional vibration with the centreline as the axis. Measure the period T of torsional vibration and calculate the moment of inertia from the following formula:

$$I = \left(\frac{t}{2\pi} \right)^2 \frac{abmg_n}{h}$$

where

I = moment of inertia, in gram centimetres squared

t = time of one cycle of torsional vibration, in seconds

- a = one-half the distance between the steel wires on the measured object, in centimetres
 b = one-half the distance between the steel wires at fixed point, in centimetres
 h = the hanging distance of measured object, in centimetres
 m = the mass of measured object, in grams
 g_n = standard acceleration due to gravity, in centimetres per second squared
 $= 981 \text{ cm/s}^2$.

The test wire or wires shall be at least 3 m long and screened from draughts. Take care that each wire is firmly attached at its upper end and any adaptors or fastenings at its lower end are secure. Do not allow any movement at the anchorage points. The wire shall be substantially straight and free from kinks. It is important that both rotor and slug are seen to rotate concentrically. When checking magnetized rotors, take care to ensure that no magnetic materials, e.g. radiators or cabinets, are near.

9.3 Inductance (type test).

9.3.1 General. 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 shall be quoted.

9.3.2 Inductance bridge method. Use a bridge having a test frequency of 1000 Hz or less. 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. These measurements are the incremental unenergized aligned and unaligned inductances and are the minimum requirements to be indicated in accordance with Clause 6. Additional useful information can be obtained by injecting current into the windings when measuring the inductance. Three levels of bias current are desirable, viz 0 percent, 50 percent and 100 percent 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 Fig. 3.

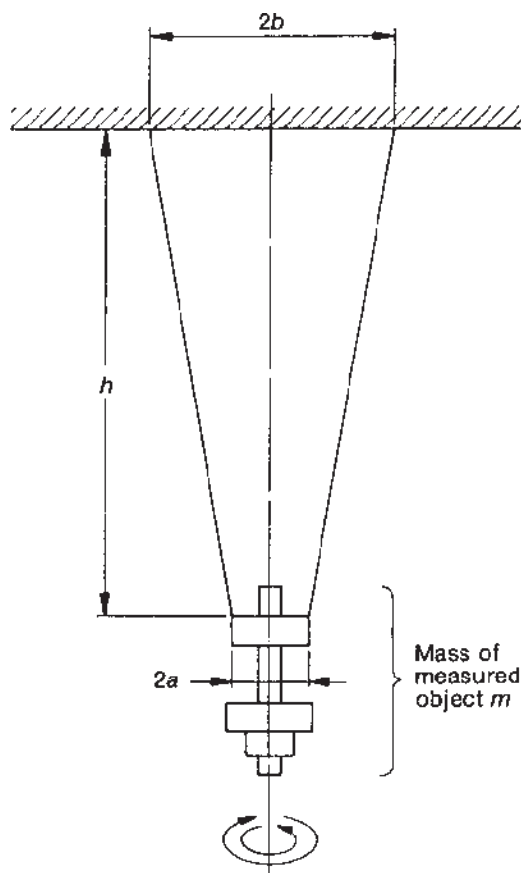


Fig. 2. TWO-WIRE HANGING METHOD TO DETERMINE ROTOR INERTIA