

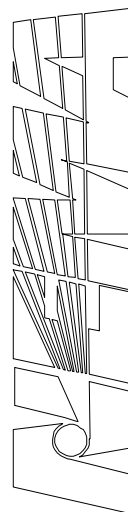
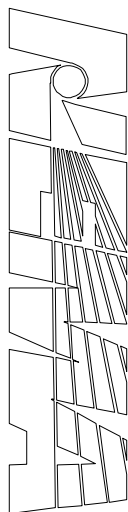
NEMA ICS 16

**INDUSTRIAL CONTROL
AND SYSTEMS**

**MOTION/POSITION
CONTROL MOTORS,
CONTROLS, AND
FEEDBACK DEVICES**

NEMA Standards Publication ICS 16

Motion/Position Control Motors, Controls, and Feedback Devices



Published by

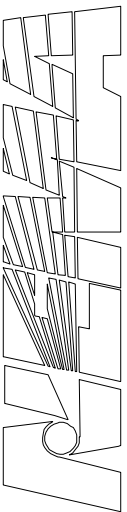
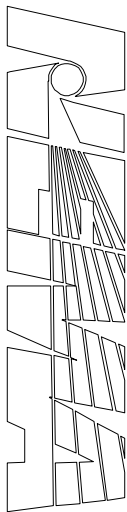
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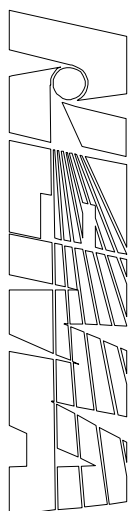
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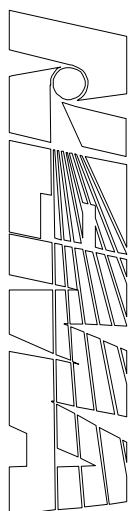


Contents

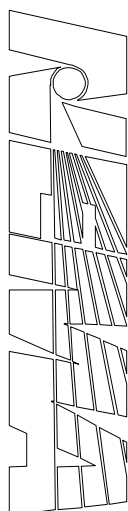
Foreword	v
1 Scope	1
2 Normative references	1
3 Definitions	3
3.1 Terms common to motion control	3
3.1.1 Acceleration definitions	3
3.1.2 Current definitions	3
3.1.3 Dielectric strength	4
3.1.4 Direction of rotation	4
3.1.5 Duty cycle	4
3.1.6 Efficiency	4
3.1.7 Electrical noise	5
3.1.8 Electrical noise immunity	5
3.1.9 Electromagnetic interference	5
3.1.10 Input impedance	5
3.1.11 Lead	5
3.1.12 Moment of inertia	5
3.1.13 Motion control system	5
3.1.14 Pitch	6
3.1.15 Power dissipation	6
3.1.16 Thermal resistance	6
3.1.17 Rotor	6
3.1.18 Temperature definitions	6
3.1.19 Time constant definitions	7
3.1.20 Torque definitions	7
3.1.21 Torsional resonance	9
3.1.22 Velocity definitions	9
3.2 Terms common to control motors	9
3.2.1 General terms	9
3.2.2 Terms specific to servo motors	13
3.2.3 Terms specific to stepping motors	17
3.3 Terms common to feedback devices	25
3.3.1 General terms	25
3.3.2 Terms specific to encoders	32
3.3.3 Terms specific to resolvers	36
3.4 Terms common to control systems	38
3.4.1 General terms	38
3.4.2 Terms specific to servo motor controls	39
3.4.3 Terms specific to stepping motor controls	41
4 Control motors	47
4.1 Requirements common to all control motors	47
4.1.1 Ratings	47

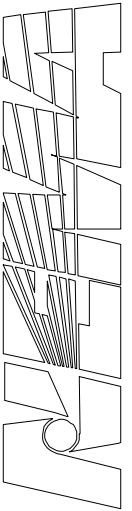
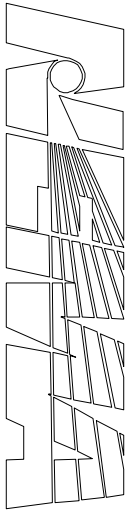


4.1.2	Dimensions, tolerances, mounting, and measurement techniques	48
4.1.3	Enclosures	59
4.1.4	Functional tests and performance.....	66
4.2	Requirements common to all servo motors	78
4.2.1	Nameplate markings.....	78
4.2.2	Maximum allowable winding temperature rating	79
4.2.3	Functional tests and performance.....	80
4.3	Requirements common to all stepping motors	84
4.3.1	Nameplate markings.....	84
4.3.2	Maximum allowable winding temperature rating	85
4.3.3	Functional tests and performance.....	86
4.3.4	Alternative test method for stepping motors.....	98
4.4	Requirements for brush type servo motors only	106
4.4.1	Functional tests and performance.....	106
4.5	Requirements for brushless servo motors only.....	109
4.5.1	Functional tests and performance.....	109
5	Controls	113
5.1	Ratings	113
5.1.1	Ambient temperature	113
5.1.2	Basis of rating.....	113
5.1.3	Input voltage and frequency rating.....	113
5.1.4	Range of operating voltage and frequency	113
5.1.5	Input current ratings	114
5.2	Enclosures	114
5.3	Spacings.....	114
5.4	Nameplate markings	114
5.5	Application information.....	114
5.5.1	Stepping motor-drive configurations	114
5.5.2	Electronically commutated (brushless) motor-drive configurations.....	117
6	Position and velocity feedback devices.....	120
6.1	Rotary encoders.....	120
6.1.1	Common requirements	120
6.1.2	Requirements specific to bearing type encoders	144
6.1.3	Requirements specific to bearingless type encoders	155
6.2	Resolvers.....	158
6.2.1	Space and mounting requirements	158
6.2.2	Connections and terminations	160
6.2.3	Markings and data sheets	160
6.2.4	Application information	161
6.2.5	Tests and performance.....	161
7	Safety requirements for construction, and guide for selection, installation, and operation of motion control systems.....	164



7.1 General considerations	164
7.2 Motion control system	164
7.3 Construction.....	164
7.3.1 Rating and identification plates	164
7.3.2 Operating and maintenance data.....	164
7.3.3 Supply circuit disconnecting devices	165
7.3.4 Protection	165
Annex A Symbols for quantities and their units	167
Annex B Index of defined terms	171





Foreword

This standards publication covers servo and stepping motors, feedback devices, and controls for use in a motion/position control system. The primary purpose of this standard is to assist users in the proper selection and application of the components of a motion/position control system, and to eliminate misunderstandings between manufacturers and users.

This standards publication provides technical information and specifications concerning performance, safety, tests, construction, and manufacture for products within the scope of this publication. The information and specifications are based on sound engineering principles, research, and records of test and field experience.

This standards publication was prepared by the Programmable Motion Control Technical Committee of the NEMA Industrial Automation Control Products and Systems Section. User needs and safety considerations were addressed during the preparation of this standard.

This standards publication will be regularly reviewed by the Programmable Motion Control Technical Committee for any revisions necessary to keep it up-to-date with technological and market changes. Comments or recommended revisions are welcome and should be submitted to:

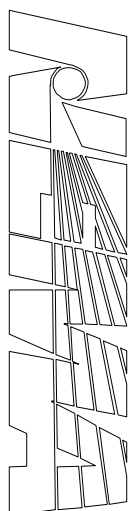
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To facilitate consideration by international standards groups, this standards publication has been developed according to the Directives of the *International Electrotechnical Commission* and the *International Organization for Standardization* for the drafting and presentation of international standards.

This standards publication was approved by the NEMA Industrial Automation Control Products and Systems Section. Section approval of this standard, however, does not necessarily imply that all section members voted for its approval or participated in its development. At the time this standard was approved, the Industrial Automation Control Products and Systems Section consisted of the following members:

ABB Control, Inc. – Wichita Falls, TX
Alstom Drives and Controls, Inc. – Pittsburgh, PA
Automatic Switch Company – Florham Park, NJ
Balluff, Inc. – Florence, KY
Carlo Gavazzi, Inc. – Buffalo Grove, IL
CMC Torque Systems – Billerica, MA
Control Concepts Corporation – Beaver, PA
Cooper Bussman – St. Louis, MO
Cummins, Inc. – Minneapolis, MN
Cyberex – Mentor, OH
Eaton Corporation – Milwaukee, WI
Echelon Corporation – Palo Alto, CA
Electro Switch Corporation – Weymouth, MA
Elliott Control Company – Hollister, CA

Entrelec, Inc. – Irving, TX
Firetrol, Inc. – Cary, NC
Fisher-Rosemount Systems, Inc. – Austin, TX
GE Fanuc Automation – Charlottesville, VA
GE Industrial Systems – Plainville, CT
Hubbell Incorporated – Madison, OH
Joslyn Clark Controls, Inc. – Lancaster, SC
Lexington Switch & Controls – Madison, OH
MagneTek Inc. – New Berlin, WI
Master Control Systems, Inc. – Lake Bluff, IL
Metron, Inc. – Denver, CO
Mitsubishi Electric Automation, Inc. – Vernon Hills, IL
Moeller Electric Corporation – Franklin, MA
Omron Electronics, LLC. – Schaumburg, IL
Peerless-Winsmith, Inc. – Warren, OH
Pepperl + Fuchs, Inc. – Twinsburg, OH
Phoenix Contact, Inc. – Harrisburg, PA
Pittman, a Div. of Penn Engineering & Manufacturing Corporation – Harleysville, PA
Post Glover Resistors, Inc. – Erlanger, KY
RENCO Encoders—Goleta, CA
Regal-Beloit Corporation – Bradenton, FL
Reliance Controls Corporation – Racine, WI
Robert Bosch Corporation – Avon, CT
Rockwell Automation – Milwaukee, WI
R Stahl, Inc. – Salem, NH
Russelectric, Inc. – Hingham, MA
Schneider Automation, Inc. – North Andover, MA
SEW-Eurodrive, Inc. – Lyman, SC
Siemens Energy & Automation – Alpharetta, GA
Square D – Lexington, KY
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Torna Tech., Inc. – St. Laurent, Quebec, Canada
Toshiba International Corporation – Houston, TX
Total Control Products Inc. – Milford, OH
Turck, Inc. – Plymouth, MN
Tyco Electronics/AMP – Harrisburg, PA
WAGO Corp. – Germantown, WI
Weidmuller, Inc. – Richmond, VA
Yaskawa Electric America – Waukegan, IL



1 Scope

This standard covers the components used in a motion/position control system providing precise positioning, speed control, torque control, or any combination thereof. Examples of these components are control motors (servo and stepping motors), feedback devices (encoders and resolvers), and controls.

Excluded from the scope of this standard are general purpose industrial controls, systems, devices, and power supplies.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Copies are available from the sources indicated.

American National Standards Institute
11 West 42nd Street
New York, NY 10036

ANSI C84.1-1989, *Electric Power Systems and Equipment — Voltage Ratings*

Electronic Industries Association
2500 Wilson Boulevard
Arlington, VA 22201

232-D-1987, *Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange*

The Institute of Electrical and Electronic Engineers, Inc.
445 Hoes Lane, P.O. Box 1331
Piscataway, NJ 08855

ANSI/IEEE 43-1974 (R1992), *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*

ANSI/IEEE 100-1988, *Dictionary of Electrical and Electronics Terms*

ANSI/IEEE 112-1992, *Test Procedures for Polyphase Induction Machines*

ANSI/IEEE 113-1985, *Test Procedures for Direct-Current Machines*

ANSI/IEEE 115-1983 (R1991), *Test Procedures for Synchronous Machines*

ANSI/IEEE 118-1978, *Test Code for Resistance Measurement*

ANSI/IEEE 488.1-1987, *Digital Interface for Programmable Instrumentation*

International Electrotechnical Commission

copies available from:

American National Standards Institute

11 West 42nd Street
New York, NY 10036

IEC 60050, *International Electrotechnical Vocabulary*

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 60529 (1989), *Degrees of protection provided by enclosures (IP Code)*

NOTE At the time of publication of this Standard, IEC 60034-20-1, *Rotating electrical machinery – Part 20-1: Control motors – Stepping motors* was an IEC Final Draft International Standard.

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250-1997, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

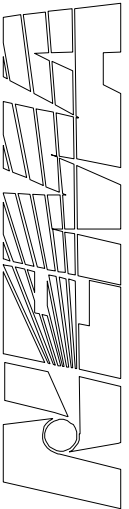
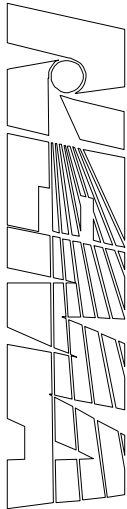
MG 1-1998, *Motors and Generators*

MG 2-1989 (R1994), *Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors and Generators*

National Fire Protection Association

Batterymarch Park
Quincy, MA 02269

ANSI/NFPA 70-1999, *National Electrical Code*



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3 Definitions

Definitions for terms not listed below can be found in ANSI/IEEE 100 or IEC 60050. Wherever a definition for a term differs between these standards, the ANSI/IEEE 100 definition is preferred.

NOTE Terms defined below are categorized by product, technology, and/or physical phenomenon. Refer to annex B for an index of terms sorted alphabetically.

3.1 Terms common to motion control

3.1.1 Acceleration definitions

The following definitions are based on acceleration/deceleration, the time rate of change of velocity.

3.1.1.1 angular acceleration

$\dot{\omega}$
time rate of change of angular velocity (ω)

NOTE Angular acceleration is expressed mathematically as $\frac{d\omega}{dt}$.

3.1.1.2 linear acceleration

a
time rate of change of linear velocity (v)

NOTE Linear acceleration is expressed mathematically as $\frac{dv}{dt}$.

3.1.2 Current definitions

3.1.2.1 form factor

FF
ratio of rms current to the absolute value of average current

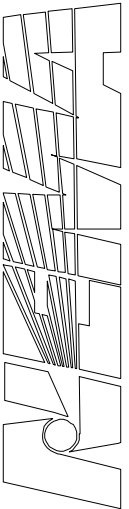
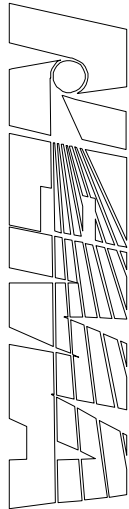
NOTE Form factor is calculated by the formula

$$FF = \frac{\sqrt{\frac{1}{t_i} \int_0^{t_i} I^2 dt}}{\left| \frac{1}{t_i} \int_0^{t_i} I dt \right|}$$

where

I is the current;

t_i is the time period i .



3.1.2.2

rms current

root mean square current

I_{rms}

current calculated by the formula

$$I_{rms} = \sqrt{\frac{\sum [(I_i)(FF)]^2 t_i}{\sum t_i}}$$

where

FF is the form factor (see 3.1.2.1);

I_i is the current at period i ;

t_i is the time period i .

3.1.3

dielectric strength

ability of insulation to withstand a voltage with a specified maximum leakage current

3.1.4

direction of rotation

direction observed when facing the shaft extension associated with the motor mounting surface

NOTE All measurements used in this standard are based on a clockwise direction of shaft rotation.

3.1.5

duty cycle

relation between the on time and the off time of a device

NOTE Duty cycle is calculated by the formula

$$\text{Duty Cycle} = \left(\frac{\text{On Time}}{\text{On Time} + \text{Off Time}} \right) 100\%$$

3.1.6

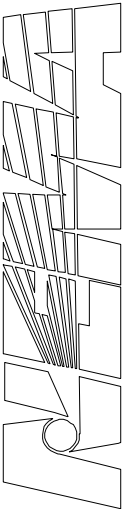
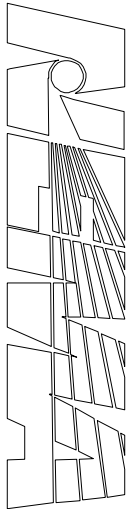
efficiency

h

ratio of power output to power input of a machine, expressed as a percentage

NOTE Efficiency is calculated by the formula

$$h = \left(\frac{P_{out}}{P_{in}} \right) 100\%$$



where

P_{in} is the input power;

P_{out} is the output power.

3.1.7 electrical noise

unwanted electrical energy that has the possibility of producing undesirable effects in the motion control system

NOTE Electrical noise includes electromagnetic interference (EMI) and radio frequency interference (RFI).

3.1.8 electrical noise immunity

extent to which the motion control system prevents an electrical noise from producing undesirable effects in the system

3.1.9 electromagnetic interference

EMI

electromagnetic energy disturbance that manifests itself in performance degradation, malfunction, or failure of electronic equipment

3.1.10 input impedance

complex quantity including the capacitive reactance and inductive reactance as well as resistance expressed in ohms measured at a specified frequency and level at the input terminals of the device

3.1.11 lead

ℓ

distance that a translating load will travel in reaction to exactly one revolution of its ballscrew or leadscrew

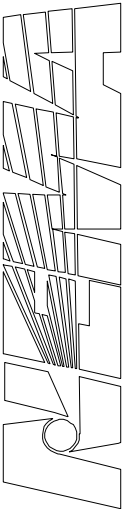
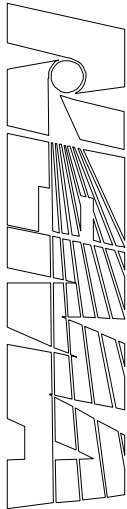
3.1.12 moment of inertia

J

property of matter that causes the mass to resist any change in its motion

3.1.13 motion control system

all rotational and linear electric servo and stepping motors and their feedback devices and controls intended for use in a system that provides precise positioning, or speed control, or torque control, or in any combination thereof



3.1.14 pitch

p

number of revolutions that a ballscrew or leadscrew must turn to move its translating load exactly one unit of distance

NOTE For single start screws, the pitch is typically the inverse of the lead (i.e. $p = 1/\ell$).

3.1.15 power dissipation

P_d

power loss in any device due to energy expended

NOTE Power dissipation is calculated by the formula

$$P_d = P_{in} - P_{out}$$

where

P_{in} is the input power;

P_{out} is the output power.

3.1.16 thermal resistance

R_{th}

opposition to the flow of heat between adjoining surfaces

3.1.17

rotor

rotating component of a device

3.1.18

Temperature definitions

3.1.18.1

ambient temperature

temperature of the cooling medium, usually air, immediately surrounding the device

3.1.18.2

case temperature

temperature of the surface of a device

3.1.18.3

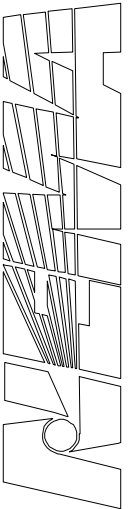
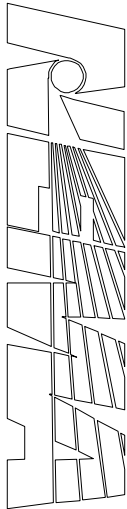
maximum allowable winding temperature

maximum temperature of the winding permitted by the temperature class of the insulation system used

3.1.18.4

temperature rise

increase in temperature (in °C) of a device above ambient temperature at designated conditions



3.1.19 Time constant definitions

3.1.19.1 electrical time constant

t_e

time required for the current to reach 63.2% of its steady state value when a step input voltage is applied

NOTE Electrical time constant is calculated by the formula

$$t_e = \frac{L}{R}$$

where

L is the winding inductance;

R is the winding resistance.

3.1.19.2 mechanical time constant

t_m

time required for a device to reach 63.2% of its steady state velocity after a zero source impedance step voltage input is applied

NOTE Mechanical time constant is calculated at a specified temperature using the following formula:

$$t_m = \frac{(J)(R_{mt})}{(K_T)(K_E)}$$

where

J is the rotor inertia;

K_E is the counter emf constant;

K_T is the torque constant;

R_{mt} is the motor terminal resistance.

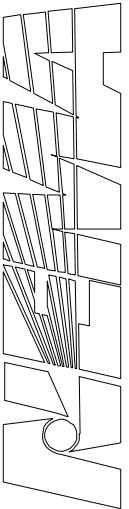
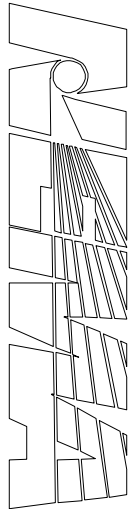
3.1.19.3 thermal time constant

t_{th}

time required for a device to reach 63.2% of steady state temperature rise with constant power dissipation

3.1.20 Torque definitions

NOTE The following definitions are derived from torque — the property which produces, or tends to produce, rotation and is equal to the product of the radius of motion and the perpendicular force.



3.1.20.1 breakaway torque

starting torque

static friction torque

<general> mechanical resistance that a device must overcome before motion can occur

NOTE Breakaway torque is usually specified at a particular temperature, e.g. 0.1 lb-in at 25° C.

3.1.20.2 coulomb friction torque

resistance to motion that is independent of velocity

NOTE See Figure 1.

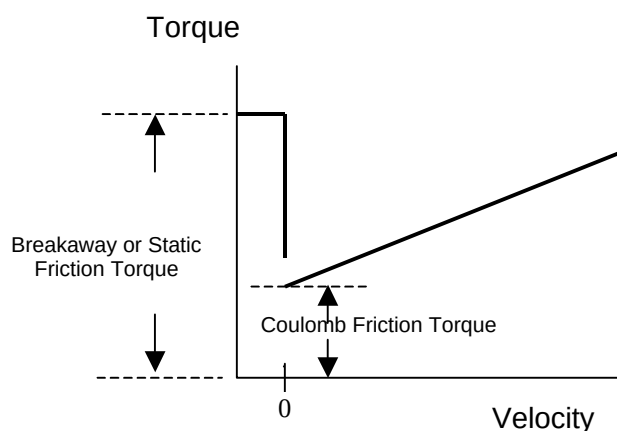


Figure 1 — Friction torque

3.1.20.3 rms torque

T_{rms}

root mean square torque

torque expressed mathematically by the formula

$$T_{rms} = \sqrt{\frac{\sum T_i^2 t_i}{\sum t_i}}$$

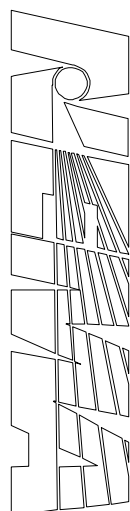
where

T_i is the torque applied at period i ;

t_i is the time period i .

3.1.20.4 stiffness

<mechanical system> ratio of applied force or torque to change in position



3.1.20.5

torque ripple

variation of torque within one shaft revolution under specified test conditions, expressed as the ratio of peak-to-peak torque amplitude to average torque (not including cogging torque)

3.1.21

torsional resonance

rotational oscillation that occurs in any rotating system when it is being excited at or near its natural frequency

3.1.22

Velocity definitions

NOTE In industry, velocity is commonly referred to as speed and is expressed in rpm.

3.1.22.1

angular velocity

ω

time rate of change of angular position (θ)

NOTE Angular velocity is expressed mathematically as $\frac{d\theta}{dt}$.

3.1.22.2

linear velocity

v

time rate of change of linear position (x)

NOTE Linear velocity is expressed mathematically as $\frac{dx}{dt}$.

3.1.22.3

maximum speed

highest speed at which the shaft can be rotated without mechanical damage

3.2 Terms common to control motors

3.2.1 General terms

3.2.1.1

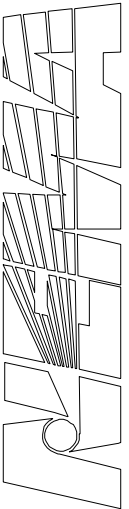
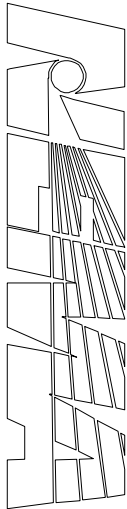
brush

conducting material which passes current from the d.c. motor terminals to the rotating commutator

3.2.1.2

commutation

mechanical or electronic 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



3.2.1.3

commutation angle

<brush type d.c. motor> angle in electrical degrees that a coil or group of coils on an armature rotate while being commutated

<brushless d.c. motor> angular difference in electrical degrees between the rotor and stator poles when the current is reversed in the windings

3.2.1.4 Current definitions

3.2.1.4.1

continuous current

current required to develop rated torque without exceeding the temperature rating

3.2.1.4.2

continuous stall current

I_{cs}
maximum rms current that can be continuously applied to a stalled motor without exceeding the temperature rating of the motor

3.2.1.4.3

peak current

acceleration current

maximum intermittent current that does not cause motor damage or irreversible degradation of motor performance

3.2.1.4.4

rated current

current developed at rated voltage and rated speed without exceeding the temperature rating

NOTE See 4.3.3.1 for the rated current test procedure for stepping motors.

3.2.1.5

damping coefficient

K_D

zero source impedance of a motor

coefficient calculated at a specified temperature that describes the braking effect in a motor

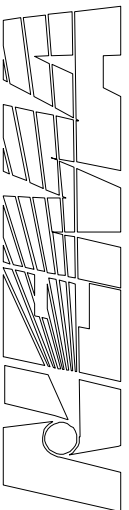
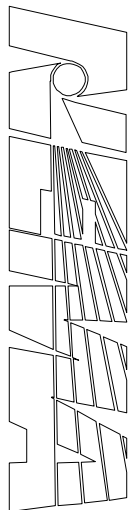
NOTE Damping coefficient can be defined by the mathematical expression

$$K_D = \frac{(K_E)(K_T)}{\text{Motor Terminal Resistance}}$$

where

K_E is the back EMF constant;

K_T is the torque constant.



3.2.1.6 EMF definitions

3.2.1.6.1

back EMF

counter EMF

E_g

internally generated voltage produced by the relative movement between the magnetic field and the armature winding when measured on an open circuit

3.2.1.6.2

voltage constant

back EMF per unit of speed at a specified temperature

3.2.1.7

End play definitions

3.2.1.7.1

axial end play

<control motor> shaft displacement along the shaft axis

3.2.1.7.2

radial end play

shaft displacement perpendicular to the shaft axis

3.2.1.8

horsepower

HP

a measure of motor output power equal to 746 watts

NOTE Horsepower is calculated by the formula

$$HP = \frac{(\tau)(s)}{1,008,000}$$

where

S is the speed, in rpm;

T is the torque, in oz-in.

3.2.1.9 Inductance definitions

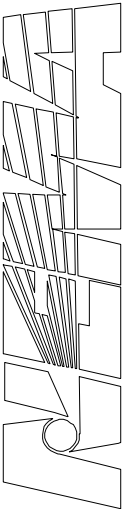
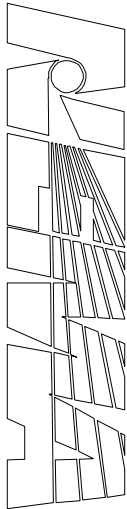
3.2.1.9.1

inductance

L

the property of a coil or other electric circuit that opposes any change in current

NOTE In a stepping motor or brushless servo motor, the inductance varies with rotor position, excitation current amplitude, and rate of change of current. Thus, when a figure for inductance is given, the conditions under which the measurements are taken shall be specified.



3.2.1.9.2 armature inductance

L_a

inductance of the armature as measured across the terminals of the device

3.2.1.10 locked rotor

stalled motor

condition where the rotor is held stationary while power is applied to the motor terminals

3.2.1.11 motor terminal resistance

R_{mt}

resistance of the armature winding and, where applicable, of the connections measured at the brush contact points

3.2.1.12 Torque definitions

3.2.1.12.1 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

3.2.1.12.2 continuous stall torque

T_{cs}

maximum continuous output torque that the motor can develop under a stall condition without the motor exceeding its rated temperature

3.2.1.12.3 peak torque

T_{pk}

maximum torque developed by a motor under specified conditions when the maximum allowable peak current is applied

3.2.1.12.4 rated torque

continuous torque

full load torque

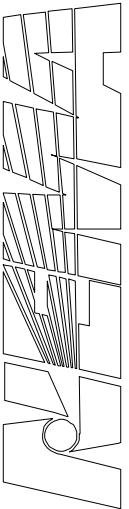
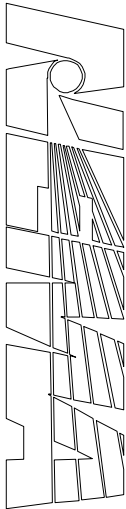
output torque

torque developed at rated voltage and rated speed without exceeding the temperature rating

3.2.1.12.5 torque constant

K_T

the ratio of change in torque to change in current developed by a motor



NOTE 1 Torque constant is expressed mathematically as $\frac{DT}{DI}$.

NOTE 2 Torque constant is temperature dependent and can be mathematically derived from the back EMF constant (K_E). For SI (metric) units, $K_T = K_E$. For English units, the following conversions apply:

- a) $K_T = K_E/11.834$ for brush commutated or trapezoidal EMF brushless motors;
- b) $K_T = K_E/13.017$ for sinusoidal EMF brushless motors with square wave current;
- c) $K_T = K_E/13.662$ for sinusoidal EMF brushless motors with sinusoidal current.

The available shaft output torque is the developed torque reduced by frictional and rotational losses.

3.2.1.13 Velocity definitions

NOTE In industry, velocity is commonly referred to as speed and is expressed in rpm.

3.2.1.13.1

cogging

non-uniform velocity

3.2.1.13.2

no load speed

actual motor speed with no external load and specified terminal voltage

3.2.1.13.3

rated speed

continuous speed

maximum motor speed that can be achieved while maintaining a specified rated torque

3.2.2 Terms specific to servo motors

NOTE The following definitions pertain to servo motors. All items relating to measured values are defined with the understanding that in most cases a test procedure will describe the specified conditions of measurement.

3.2.2.1

armature

component of an electro-magnetic machine that contains the windings that conduct the power producing component of current

3.2.2.2

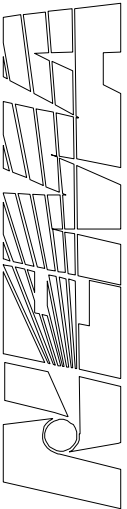
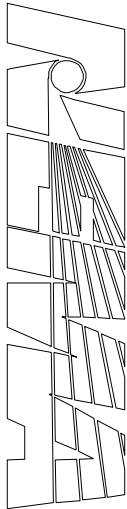
armature reaction

magnetic field produced by the current in the armature coils of an electro-magnetic machine that alters the main magnetic field

3.2.2.3

armature resistance

resistance of the armature winding and, where applicable, the connections measured at the brush contact points



3.2.2.4 brushless d.c. motor

rotating self-synchronous machine with a permanent magnet rotor and with known rotor shaft positions for electronic commutation

NOTE A motor meets this definition whether the drive electronics are integral with the motor or separate from it.

3.2.2.5 commutator

set of mechanical contacts arranged angularly or linearly, contacted by the brushes to provide the electrical path from the power source to the armature

NOTE The purpose of the commutator is to control the relative electrical phase angle between the fields of the stationary element and the moving element of a motor.

3.2.2.6 demagnetization current

the winding current that creates a magnetic flux opposing the main field flux which irreversibly decreases the field strength of the motor magnets

3.2.2.7 full load operation

continuous operation at the limits of the continuous safe operating area

3.2.2.8 maximum continuous current

the maximum root mean square (rms) current which can be continuously applied to a motor operating at low speed under specified conditions without exceeding the motor's rated temperature

NOTE Low speed is that speed which is sufficient to distribute the heat uniformly throughout the winding. It is typically less than 10 rpm.

3.2.2.9 maximum continuous torque

the maximum continuous output torque which the motor can develop when operating at low speed under specified conditions without exceeding the motor's rated temperature

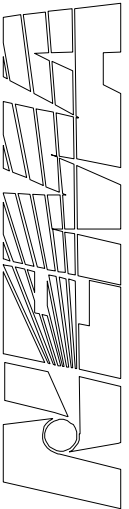
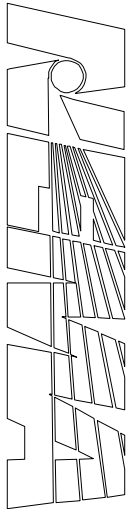
NOTE Low speed is that speed which is sufficient to distribute the heat uniformly throughout the winding. It is typically less than 10 rpm.

3.2.2.10 maximum theoretical acceleration

$\mathcal{A}$

the peak motor torque divided by the rotor inertia

NOTE Maximum theoretical acceleration is mathematically expressed as $\frac{T_{pk}}{J_r}$.



3.2.2.11 motor constant

K_M

a figure of merit used to define the ratio of torque produced to the electrical power losses of the motor

NOTE Motor constant is calculated by the formula

$$K_M = \frac{T_c}{\sqrt{\left(I_c^2\right)(R_{mt})}}$$

where

I_c is the continuous current;

R_{mt} is the motor terminal resistance;

T_c is the continuous torque.

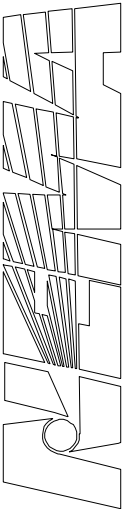
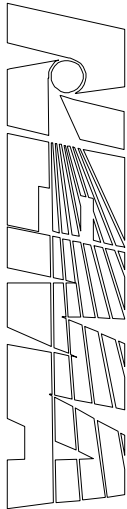
3.2.2.12 no-load current

the current drawn by an unloaded motor at the rated voltage

3.2.2.13 power amplifier duty cycle rating

the amplifier output rating when a motor is operated in intermittent duty

NOTE This rating is generally expressed as a function of both the percentage on-time to total cycle time (duty cycle) and the absolute on-time in seconds. See Figure 2 as an example.



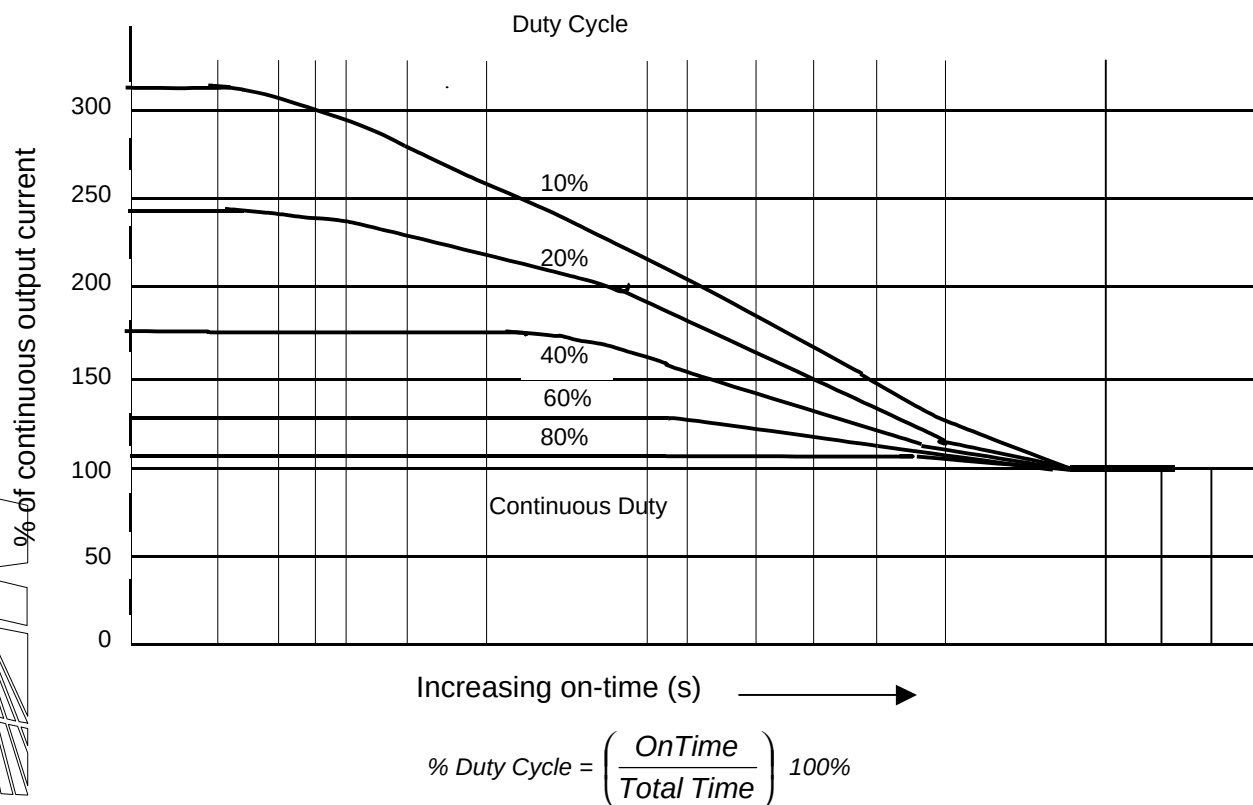


Figure 2 — Duty cycle curves

3.2.2.14

safe operating area

area defined by speed and torque conditions at which the motor will operate within its thermal limitations, centrifugal force limitations, and within its commutation capability, where applicable

3.2.2.15

servo mechanism

control system that employs feedback in order to control a desired output such as speed or position

NOTE A servo mechanism will detect and attempt to correct deviations from the desired output.

3.2.2.16

slip

<induction servo motors> the difference in speed between the applied rotating field and the rotor speed

NOTE Slip is usually expressed as a percentage of the synchronous speed.

3.2.2.17

temperature coefficient of torque

coefficient that defines the change in torque constant of the motor per unit change in motor average winding temperature

3.2.2.18

viscous damping at infinite impedance source

viscous damping factor

D_v

measure of the rotational losses in torque that are approximately directly proportional to speed

NOTE Viscous damping at infinite impedance source is expressed mathematically as $\frac{DT}{Dw}$.

3.2.2.19

viscous torque

dynamic friction torque

the resistance to motion that is velocity dependent

NOTE Viscous torque is the slope of the curve shown in Figure 1.

3.2.3 Terms specific to stepping motors

3.2.3.1

dynamic load angle

angle between the loaded and unloaded position (theoretical zero) of the rotor at a given instant under otherwise identical conditions at a specified command pulse rate, mode of winding excitation, and phase current

3.2.3.2

eddy current equivalent resistance

virtual resistor, placed in parallel with each phase winding, to represent the motor losses due to eddy currents flowing in the magnetic structure

NOTE Eddy currents flow when flux changes occur in the magnetic structure of the motor. This happens not just in the stator, but also in the rotor, and any magnets present in the structure. Their effects can be noticed when a large step voltage to a phase winding is applied: the resulting current initially makes a small jump, with the rate of change of the current not limited by the winding inductance. Eddy currents in stepping motors cause high torque losses. At high motor speeds (over 1500 rpm), they are the dominant cause of motor heating. Most effects can be modeled by assuming the presence of a virtual resistor, in parallel with each phase winding. Eddy currents occur at various levels throughout the motor structure.

3.2.3.3

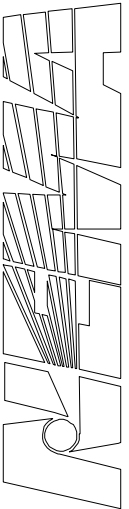
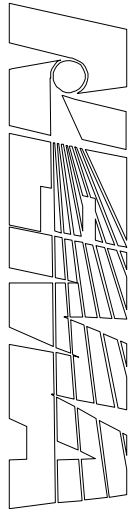
large signal inductance

L_{LS}

inductance of a phase winding, measured at rated current, averaged over one electrical cycle

NOTE Measurement of the inductance of phase A, at the approximately rated winding current I_A , results in values that closely follow the formula

$$L_{LS,A} = L - \frac{(NC)(I_A)}{(PC)|I_A|} \cos PCf$$



where

- I_A is the current for phase A;
- L is the average large signal inductance (a constant);
- $L_{LS,A}$ is the instantaneous large signal inductance of phase A;
- PC is the pole count of the motor;
- NC is the saturation term (see 3.2.3.20.3.1);
- $\ddot{\theta}$ is the position of the rotor relative to the stator.

The instantaneous inductance value $L_{LS,A}$ is a constant L , with the addition of a cyclic, position-dependent term. The value of the constant L can be measured by holding the cyclic term at zero. The current in the other phase(s) can be used to position the motor at a point where PC equals 0. Apply a high voltage to phase A. The rate of change of the current at approximately the rated current is used to calculate the large signal inductance L_{LS} . The average value of L_{LS} can also be found by back-driving the motor at high speed, measuring the EMF, and then short circuiting the winding and measuring the resulting short circuit current. There is a good correlation between the results of these two methods. They show a significant difference with the value obtained from a low voltage, high frequency measurement with an inductance bridge.

3.2.3.4 mechanical hysteresis

angle between the unloaded stable equilibrium point when approached from one direction and the unloaded stable equilibrium point (of the same step position or minimum reluctance position) when approached from the opposite direction

3.2.3.5 motor phase

set of electrically excited stator poles, consisting of one or more pairs of oppositely polarized poles

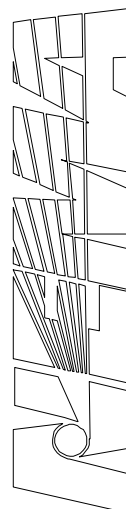
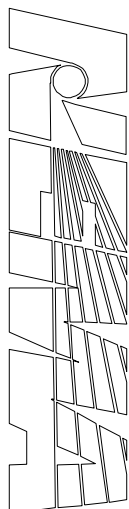
NOTE A bifilar wound set of poles constitutes one motor phase, not two, in which the windings are linked magnetically, as one set of poles.

3.2.3.6 overshoot

transient

peak angular distance the shaft of the motor rotates beyond the actual final position

NOTE See Figure 3.



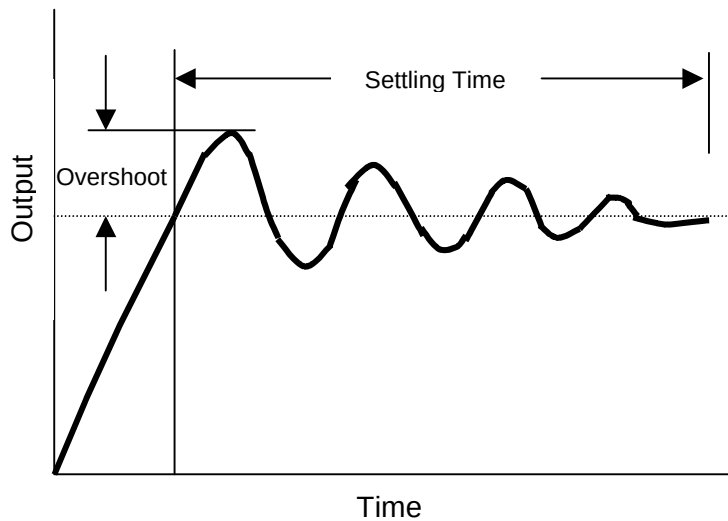


Figure 3 — Overshoot and settling time

3.2.3.7 phase resistance

internal winding resistance that is equal to the motor terminal resistance less the lead resistance

3.2.3.8 positional error

absolute accuracy
deviation from the theoretically correct angular position of any step position in a complete revolution

NOTE The zero position used in determining the theoretically correct angular position shall be the midpoint between the two extremes of position error. It is expressed as an angular measurement or a percentage of the nominal full step. It is measured under specified conditions.

3.2.3.10 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 a specified level under specified conditions

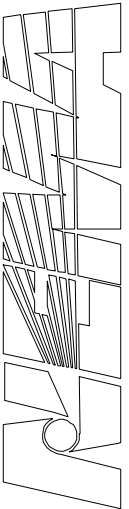
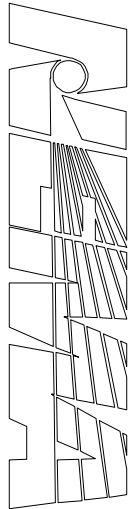
NOTE See Figure 3.

3.2.3.11 single step response

response to a single step command that includes single step time, overshoot, and settling time

NOTE 1 The single step response will be controller dependent.

NOTE 2 See Figure 4.



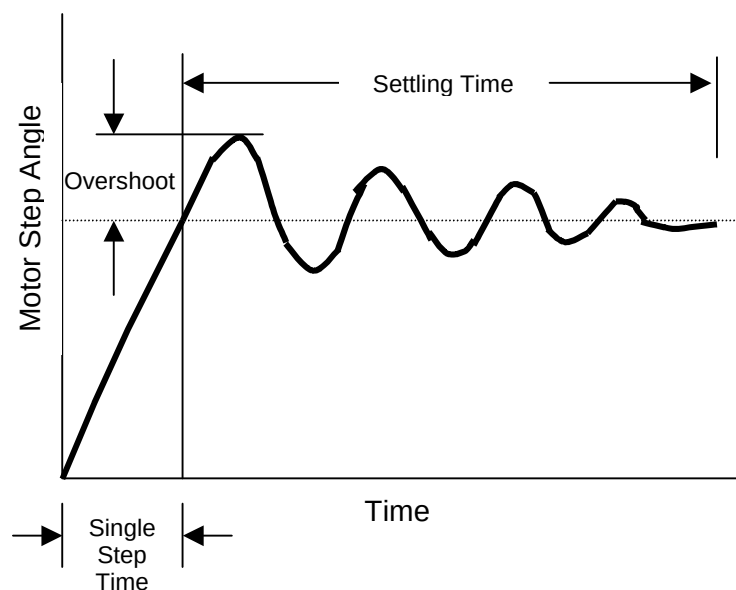


Figure 4 — Single-step response

3.2.3.12 single step time

time required for the motor shaft to initially reach its next rest position when commanded to take a single step

3.2.3.13 static load angle

angle through which the rotor is displaced from its energized stable equilibrium position by a given applied torque at a specified current

3.2.3.14 Step angle definitions

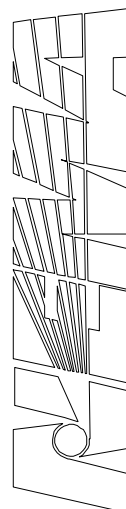
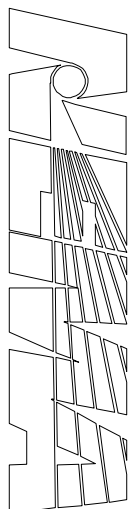
3.2.3.14.1 full-step

basic step angle

rated angular increment of rotor position, at no load, between any two adjacent stable equilibrium points when the phases are energized singly and in sequence.

NOTE A full step is always associated with the same number of phases energized for each step in the sequence. The rated angular increment of rotor position of a hybrid stepping motor is calculated by the formula

$$f = \frac{360}{(A)(B)(C)}$$



where

- A is the number of stator pole pairs per phase;
 B is the number of phases;
 C is the number of north/south pairs of rotor salients, but never less than " A ";
 f is the angular displacement.

3.2.3.14.2

half-step

same as full step except that alternate "1-on," "2-on" energization is used resulting in an angular increment of motion of one-half that of a full-step

3.2.3.14.3

micro-step

mini-step

subdivision of a full-step into some finer increment than the half-step, by profiling the phase currents in accordance with a predetermined law

3.2.3.14.4

step angle error

incremental step accuracy

maximum plus or minus deviation from the rated incremental angular motion per step for any adjacent steps in a complete revolution without reversing direction under specified conditions

NOTE Step angle error is expressed as a percent of the angle of the nominal step.

3.2.3.14.5

step position

static angular position that the shaft of an unloaded stepping motor assumes when it is energized as specified

3.2.3.14.6

step sequence

sequence of excitation defined by the translator logic that is the repeatable cyclic pattern by which the windings are energized for unidirectional motion

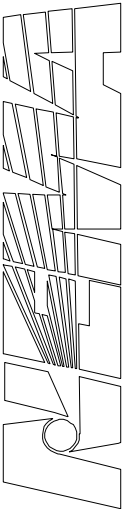
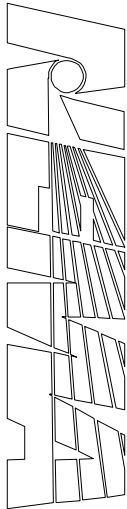
3.2.3.15 Step rate definitions

3.2.3.15.1

maximum step rate

maximum slew pulse rate

the maximum pulse rate at which the unloaded stepping motor can remain in synchronism with the command pulses under the specified drive conditions



3.2.3.15.2 pull-in step rate

error free stop/start

maximum command pulse rate (constant) under specified conditions at which the energized stepping motor can accelerate an applied load from standstill to synchronism with the command pulse rate without missing steps

3.2.3.15.3 pull-out step rate

maximum command pulse rate (constant) under specified conditions at which the energized stepping motor can run in synchronism with the command pulse rate

3.2.3.15.4 resonant step rate

step rate under specified conditions at which the motor will miss steps when operating at the primary resonance point

3.2.3.15.5 stepping rate

number of step angles through which the stepping motor rotates in a specified time

3.2.3.16 Stepping motor type definitions

3.2.3.16.1 hybrid stepping motor

HY stepping motor

motor utilizing a permanent magnet to polarize soft iron pole pieces

3.2.3.16.2 permanent magnet stepping motor

PM stepping motor

motor utilizing a rotor that has permanently magnetized poles

3.2.3.16.3 stepping motor

polyphase synchronous motor, the rotor of which rotates in discrete angular increments when the stator windings thereof are energized in a programmed manner either by appropriately timed direct current states or by a polyphase alternating current

NOTE Rotation occurs because of the magnetic interaction between the rotor poles and the poles of the sequentially energized stator phases.

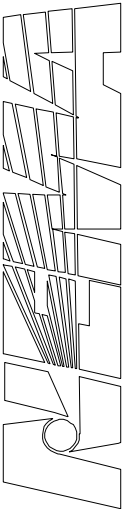
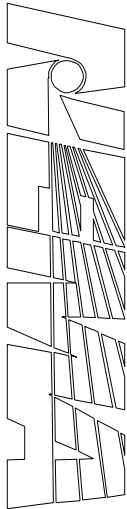
3.2.3.16.4 variable reluctance stepping motor

VR stepping motor

motor utilizing a rotor that has pole salients (soft iron) without magnetic bias in the de-energized state

3.2.3.17 steps per revolution

number of discrete steps for one motor revolution



3.2.3.18 synchronism

state that exists when the average speed of the rotor equals the command pulse rate multiplied by a constant determined by the number of full steps per revolution

3.2.3.20 Torque definitions

3.2.3.20.1 bias torque

offset torque caused by the non-orthogonal errors between phase A and phase B when the stepping motor is energized in a one phase "on" mode

3.2.3.20.2 detent torque

value of applied torque required to cause rotation between subsequent equilibrium positions over one complete revolution of an open-circuited motor

NOTE Minimum detent torque is the lowest value of torque as described above; maximum detent torque is the highest value.

3.2.3.20.3 Electromagnetic torque in a hybrid stepping motor

NOTE Experimental data has suggested that the electromagnetic torque of one phase of a hybrid stepping motor can be accurately described by the product of the these three terms:

- a) the phase current, I_{ϕ} ;
- b) the effective torque constant, expressed as $\left(K_T - \frac{N_C}{2} |I_f| \right)$;
- c) the position term, expressed as $-(\sin Nf + h_3 \sin 3Nf + h_5 \sin 5Nf + \dots)$.

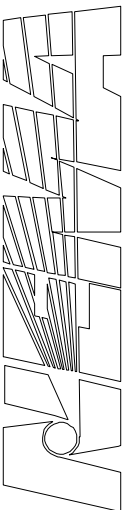
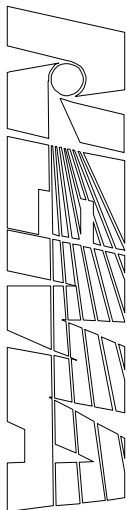
Then, the electromagnetic torque for phase A would be

$$T_A = -I_A \left(K_T - \frac{N_C}{2} |I_A| \right) (\sin Nf + h_3 \sin 3Nf + h_5 \sin 5Nf + \dots)$$

where

- h_3 is the third harmonic term (see 3.2.3.20.3.2);
- h_5 is the fifth harmonic term (see 3.2.3.20.3.2);
- I_A is the current for phase A;
- K_T is the torque constant (see 3.2.1.12.5);
- N is the pole count of the motor;
- N_C is the saturation term (see 3.2.3.20.3.1);
- ϕ is the position of the rotor relative to the stator.

Similar equations can be written for the other phase(s) of the motor. In those equations, a position offset is added to the position term.



3.2.3.20.3.1 saturation term

N_C

description of the effect of the winding current, regardless of polarity, on the effective torque constant in the electromagnetic torque of a phase

3.2.3.20.3.2 harmonic term

h

description of the harmonic component of the position term in the electromagnetic torque of any phase

NOTE The subscript with the symbol h represents the specific term, e.g. h_3 denotes the third harmonic, h_5 is the fifth harmonic, etc.

3.2.3.20.4 holding torque

peak resistance to rotation of a gradually rotated shaft of an energized motor for a specified mode of winding excitation and applied current

NOTE The torque is considered “positive” when the rotor resists rotation of the shaft by an externally applied torque, and “negative” when it requires the external torque to retard the shaft.

3.2.3.20.5 hysteresis torque

torque that generally opposes the motion of the motor and is caused by hysteresis in the magnetic structure of the motor

NOTE When a stepping motor is back-driven at a very low speed with the phase windings open circuited, a small average positive torque, in addition to the cyclic fourth harmonic detent torque and the first harmonic bias torque, is needed to drive the motor in the clockwise direction. A small negative torque is needed for rotation in the counter-clockwise direction. Upon reversal of the direction of motion, hysteresis torque reverses in approximately 90° electrical. Hysteresis torque may be accompanied by bearing friction torque that behaves more like coulomb friction, reversing virtually immediately when the motion direction is reversed.

3.2.3.20.4 pull-in torque

maximum coulomb friction torque at which the energized motor will accelerate from zero speed to the command pulse step rate and run in synchronism with the command pulse rate without losing steps under specified conditions

3.2.3.20.5 pull-out torque

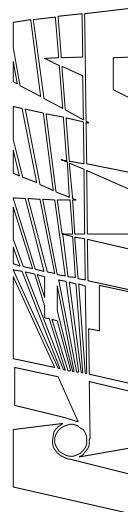
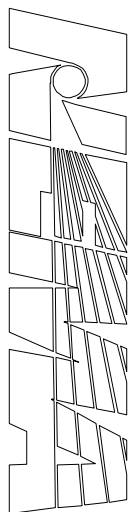
maximum coulomb friction torque that the motor will overcome while running in synchronism with a command pulse rate without losing steps

3.2.3.20.6 stiffness

torque gradient

<stepping motor> derivative (slope) of the torque versus angle curve at the stable equilibrium point

NOTE The curve is the sum of the stiffness due to holding torque and detent torque.



3.2.3.21

velocity modulation

periodic function superimposed on the average angular velocity

NOTE The peak-to-peak amplitude is expressed as a percent of the mean velocity.

3.3 Terms common to feedback devices

3.3.1 General terms

3.3.1.1

accuracy

extent to which the output electrical signals represent exact mechanical shaft position

3.3.1.2

axial end play

<feedback device> variation in shaft end surface position with reference to the feedback device mounting surface when a specified axial load is applied in each direction

3.3.1.3

axial load

force applied to a shaft end surface directed along the axis of rotation

3.3.1.4

binary-coded decimal

BCD

number-representation system in which each decimal digit is identified by a unique arrangement of binary digits

NOTE Binary-coded decimals are associated with codes of four bits used to define the Arabic numbers 0 through 9.

3.3.1.5

bit

abbreviation for binary digit; the basic unit of the binary system whose value may be either true (one) or false (zero)

3.3.1.6

channel

unique output of the feedback device

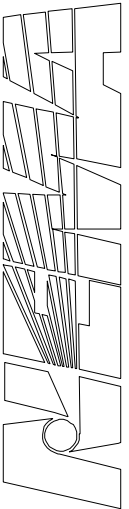
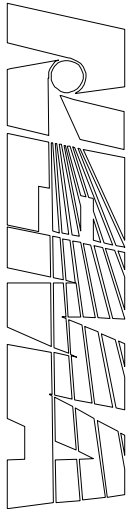
3.3.1.7

complementary

two identical periodic signals where one signal is inverted from the other

NOTE Complementary signals may be generated either through the use of multiple sensors or by inversion of the output from a single channel.

EXAMPLE See Figure 5.



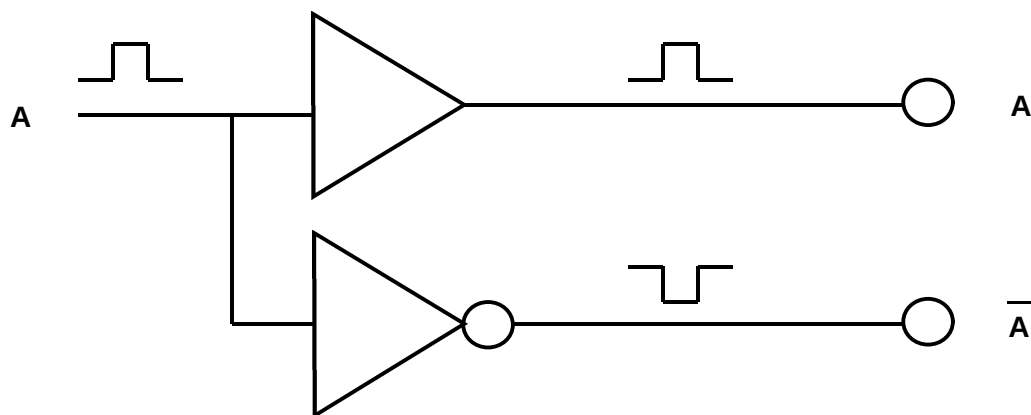


Figure 5 — Single channel complementary output

3.3.1.8

count error

missing transition or an additional transition from the intended coded output

3.3.1.9

count transition

point where the output state changes from "0" to "1" or vice versa

NOTE See Figure 6.

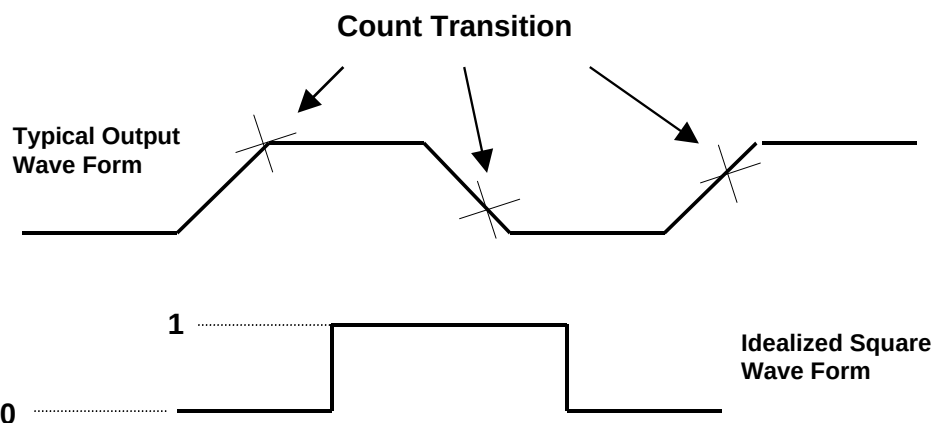


Figure 6 — Count transition

3.3.1.10

cycle error

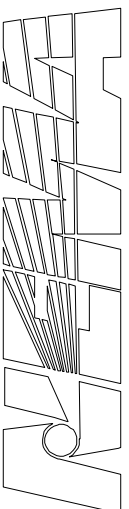
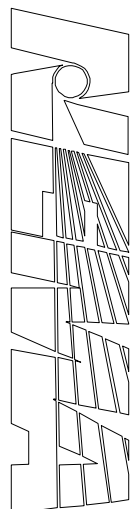
difference between the actual cycle width and the theoretically correct cycle width

3.3.1.11

cycle width

<square-wave output> the nominal distance from leading edge to next leading edge on the same output channel

<pulse output> the distance between the leading edges of two adjacent pulses



NOTE 1 See also electrical degree (3.3.2.5).

NOTE 2 With N cycles/rev of square wave output or N pulses/rev of pulse output, cycle width = $1/N$ rev.

EXAMPLE See Figure 7.

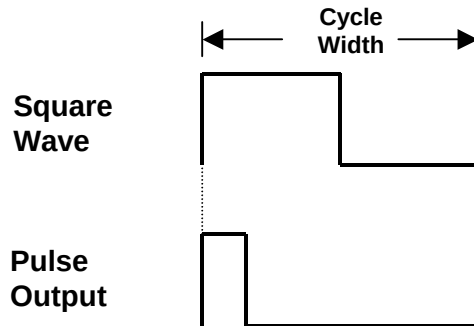


Figure 7 — Cycle width

3.3.1.12 differential output

complementary outputs from a feedback device when the signals are excited by a line driver

NOTE 1 Optimum performance is achieved when the receiver input impedance is matched to the line driver output and transmission line.

NOTE 2 See Figure 8.

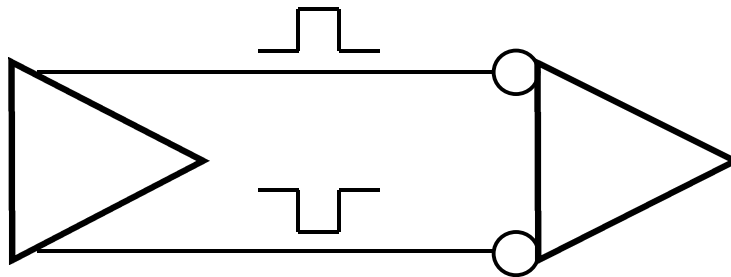


Figure 8 — Differential output

3.3.1.13 direction sensing

technique for determining the direction of motion by analyzing the relative phase relationship between the two channels of quadrature output

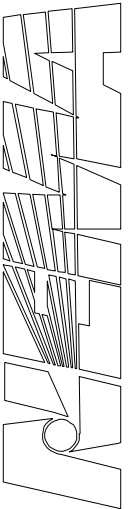
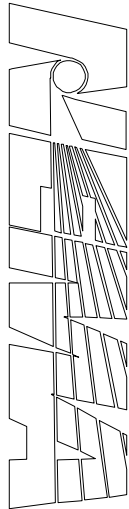
3.3.1.14 edge-to-edge separation

edge separation

separation between a transition in the output of channel A and the neighboring transition in the output of channel B

NOTE There are four states per cycle, each nominally 90° electrical for quadrature output.

EXAMPLE See Figure 9.



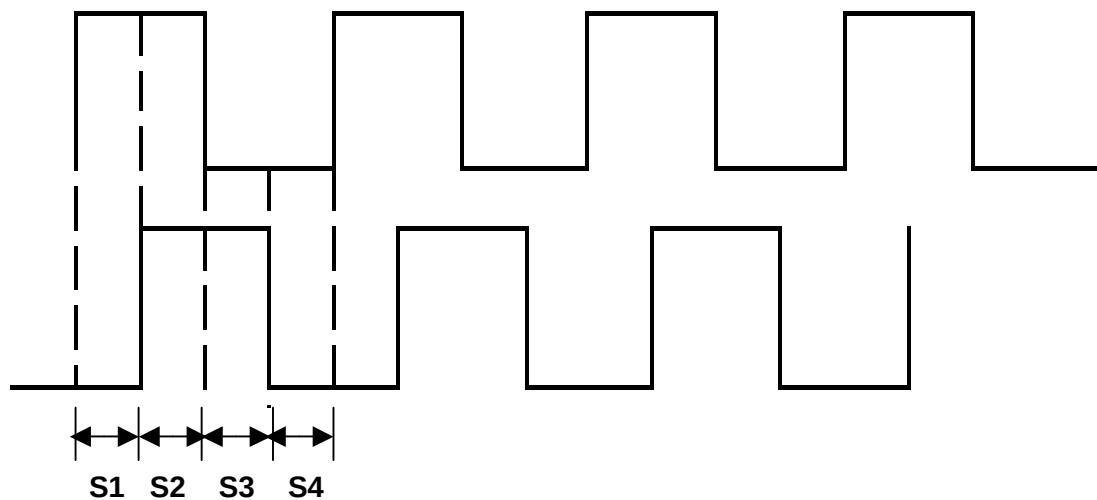


Figure 9 — Edge-to-edge separation

**3.3.1.15
excitation**

external electrical voltage or current or both applied to a transducer for its proper operation

**3.3.1.16
flutter**

variation in cycle width from cycle to adjacent cycle

**3.3.1.17
frequency response**

maximum frequency in cycles per second of the output signals

**3.3.1.18
gap tolerance**

<bearingless encoder> maximum axial movement of the disk in the air space between the disk and the scanning reticle before the encoder experiences misoperation or damage

**3.3.1.19
gray code**

cyclic binary code in which there is only one bit transition between successive counts

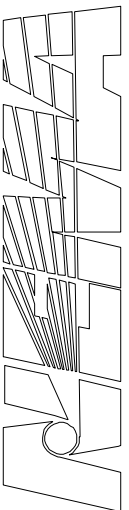
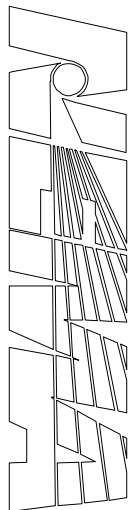
**3.3.1.20
hysteresis**

deliberately induced switching error in an electrical circuit to prevent oscillation about a transition point

**3.3.1.21
index**

separate output signal generated by a special track which produces a single pulse (or transition change) at a unique position or positions

NOTE The index is typically used to identify a center, home position, reset point, or zero reference.



3.3.1.22

maximum acceleration

<feedback device> maximum rate of speed change which will not mechanically violate the rated performance of the feedback device

NOTE Maximum acceleration is typically expressed in rad/s^2 or in/s^2 .

3.3.1.23

maximum axial load

maximum force that may be applied parallel to the shaft axis at a specified point along the shaft without reducing the rated operating life or causing deviation from the rated performance

3.3.1.24

mounting surface perpendicularity

relationship between the shaft centerline about the axis of rotation and the mounting surface of the feedback device

3.3.1.25

multiplication

technique to derive an output resolution higher than the line count

3.3.1.26

natural binary code

code in which each bit of resolution represents a value in base 2

3.3.1.27

phase error

deviation in electrical degrees from a specified phase relationship between any two channels

NOTE The phase relationship is nominally 90° electrical in a quadrature encoder as depicted in Figure 10.

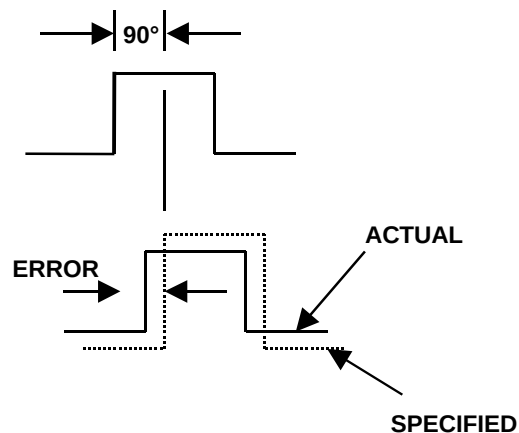
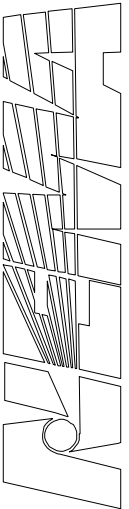
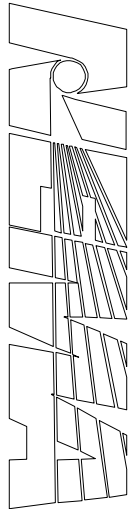


Figure 10 — Phase error



3.3.1.28

position accuracy

maximum positional difference between the feedback device's true input position and the position indicated by the feedback device's output

NOTE Accuracy is not to be confused with resolution. See the following specific errors: pulse width error, (3.3.1.30) edge-to-edge separation (3.3.1.14), state width error (3.3.1.3.8), phase error (3.3.1.2.7), position error (3.3.1.2.9), and cycle error (3.3.1.10).

3.3.1.29

position error

difference between the theoretically correct position and the actual position as indicated by the feedback device

NOTE The zero position used in determining the theoretically correct position shall be the midpoint between the two extremes of position error. It is expressed as an angular measurement for a rotary device and a linear measurement for linear devices.

3.3.1.30

pulse width error

deviation in electrical degrees of the pulse width from the ideal value of 180° electrical

NOTE See Figure 11.

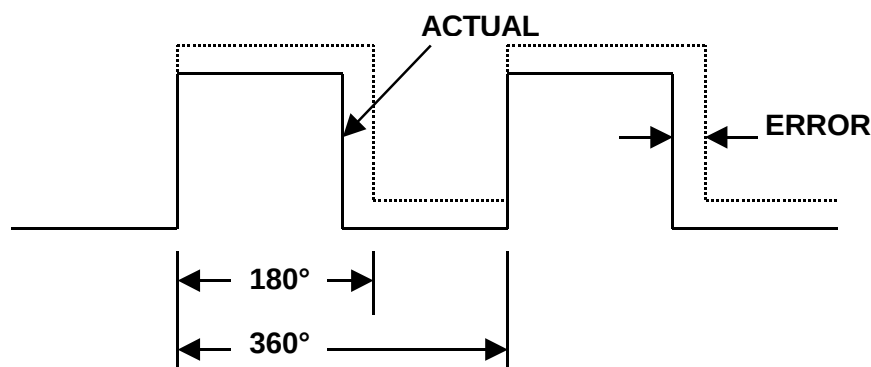
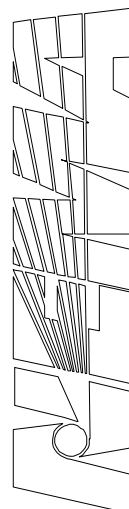
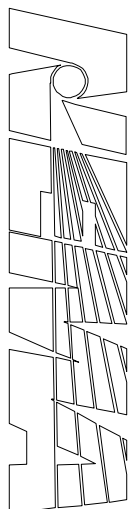


Figure 11 — Pulse width error



3.3.1.31

quadrature

two identical periodic signals when the phase displacement is nominally 90° electrical

3.3.1.32

quadrature error

deviation from 90° electrical between signals

3.3.1.33

radial load

force applied to the feedback device shaft at a specified point perpendicular to the axis of rotation

3.3.1.34

radial misalignment tolerance

allowable eccentricity caused by the rotating shaft or position of encoder sensors before errors are introduced in the encoder outputs

3.3.1.35

maximum radial load

maximum force that may be applied perpendicular to the shaft axis at a specified point along the shaft without reducing the rated operating life or causing deviation from the rated performance

3.3.1.36

repeatability

ability of a transducer to reproduce output readings when the same input is applied consecutively, under the same conditions, and in the same direction

3.3.1.37

shaft runout

TIR

difference between the maximum reading and the minimum reading of an indicator when probing the shaft surface at a specified point when the shaft is rotated 360°

NOTE 1 In the case of double ended shaft feedback device, the shaft runout for each end shall be specified separately.

NOTE 2 TIR is the acronym for Total Indicator Reading or Total Indicated Runout.

3.3.1.38

state width error

the deviation in electrical degrees of the state width from the ideal value

NOTE 1 The ideal state width is 90° electrical in a quadrature encoder.

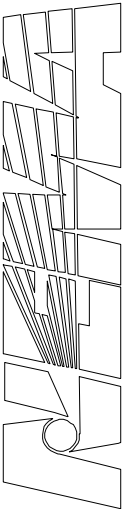
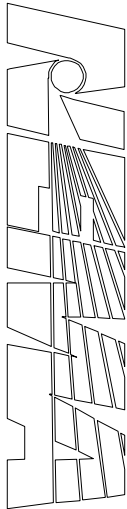
NOTE 2 State width error should be specified by the individual manufacturer.

3.3.2 Terms specific to encoders

3.3.2.1

absolute encoder

encoder providing information in the form of unique output for every resolvable position



3.3.2.2

bi-directional

encoder output code format from which direction of travel can be determined

3.3.2.3

digital tachometer

incremental encoder that is used to indicate or control speed

3.3.2.4

dual channel

encoder producing two unique incremental outputs

3.3.2.5

electrical degree

° electrical

1/360 of a cycle width and is related to mechanical degrees through line count

NOTE An electrical degree is calculated by the formula

$$360^{\circ} \text{ electrical} = \left(\frac{360}{N} \right)^{\circ} \text{ mechanical}$$

where

N is the output cycles/revolution or lines/revolution, whichever is greater.

3.3.2.6

electronic slew speed

maximum speed at which the shaft can rotate and still maintain output signal integrity of the encoder

NOTE This can be calculated in rpm by dividing the maximum output frequency of the encoder by the resolution of the encoder and multiplying by 60.

EXAMPLE 200 kHz maximum output frequency / (1000 pulses/revolution x 60 s/min) = 12000 rpm.

3.3.2.7

encoder

electro-mechanical device that translates mechanical motion (such as position, velocity, and acceleration) into electrical signals

3.3.2.8

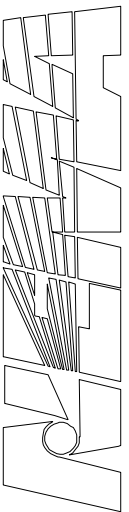
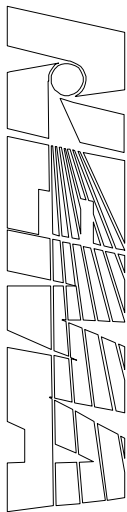
frequency

<rotary encoder> speed in revolutions per minute times the resolution (lines per turn) divided by 60

3.3.2.9

frequency modulation

the deviation from a theoretically correct output frequency when the input shaft is rotated at a constant velocity



3.3.2.10

incremental encoder

rotary pulse generator

RPG

device providing a series of periodic signals due to mechanical motion

NOTE The number of successive cycles (signals) corresponds to the resolvable mechanical increments of motion.

3.3.2.11

incremental line count

<rotary encoders> number of equally spaced radial lines per revolution

<linear encoders> number of equally spaced lines per specified length

3.3.2.12

jitter

the combined effect of cycle error, state width error, phase error, and symmetry

NOTE See Figure 12.

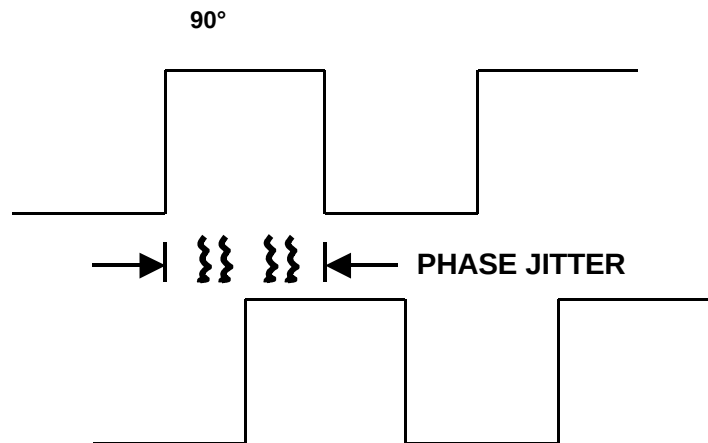


Figure 12 — Jitter

3.3.2.13

line driver

differential interface device designed for digital data transmission over balanced lines by twisted pair or parallel-wire transmission lines

3.3.2.14

mechanical slew speed

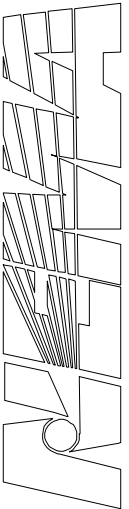
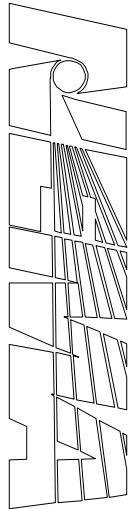
maximum speed at which the shaft can be rotated without mechanical damage to the encoder

3.3.2.15

open collector

complementary or single ended interface device or circuit which requires external resistors to produce output signals

NOTE Open collectors can be supplied with internal pull-up resistors.



3.3.2.16 phase

electrical degrees of displacement between two encoder outputs, typically 90° electrical in quadrature encoders

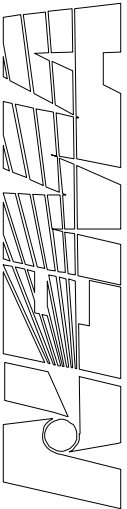
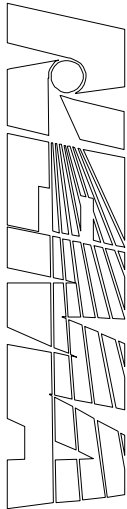
3.3.2.17 pulse

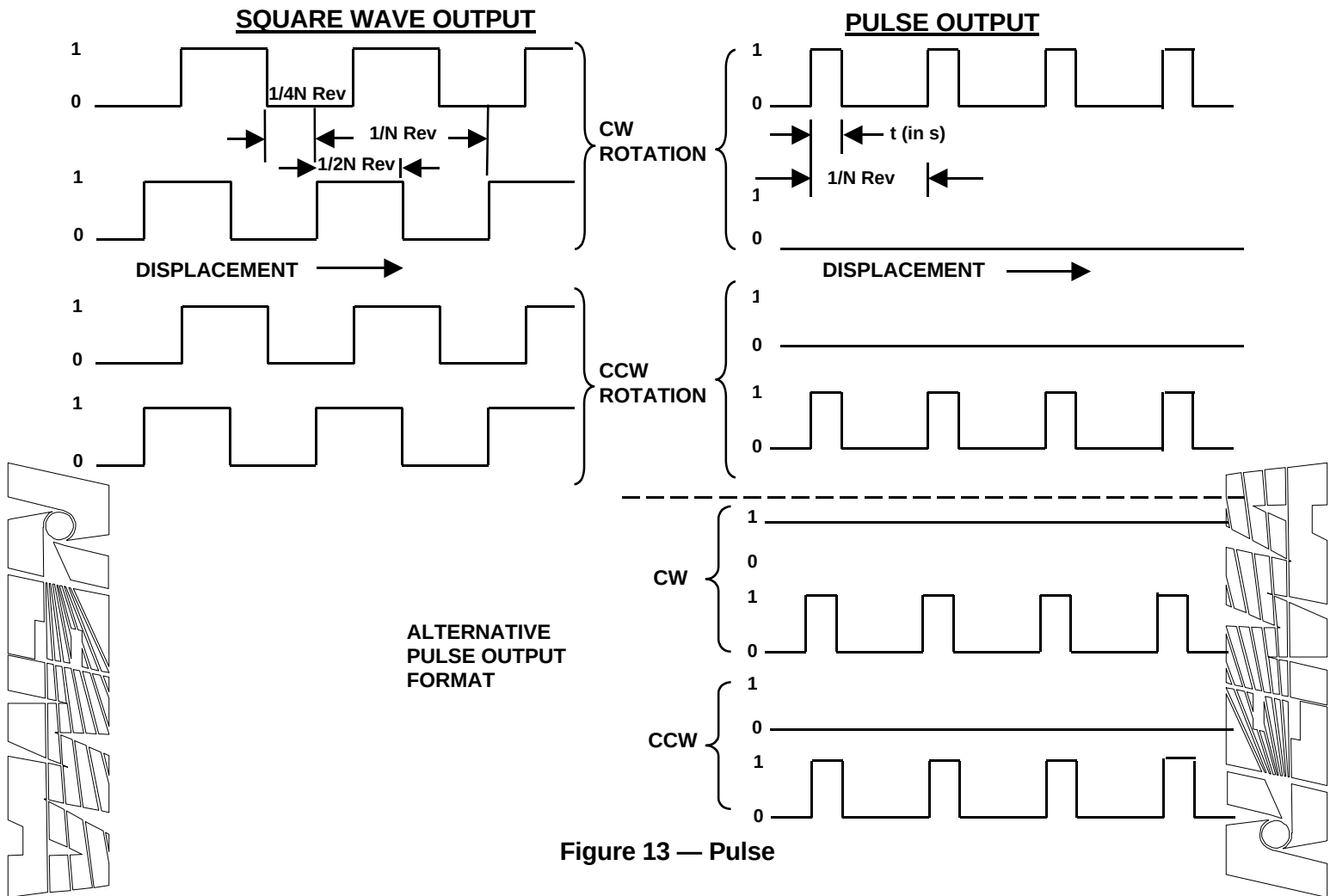
“on” portion of each output cycle in an encoder with quadrature square wave output; in an encoder with pulse output, electrical circuitry generates short-duration, direction-sensed pulses whose positions correspond to selected square wave transitions (1, 2, or 4 per output cycle), and whose duration is a fixed time, independent of speed

NOTE See Table 1 and Figure 13.

Table 1 — Pulse

	Square Wave Output	Pulse Output
Terminology	Preferred unit of resolution is “cycles/rev,” although “pulses/rev” is common. “Quadrature” refers to 90° electrical phase relationship.	Unit of resolution is “pulses/rev” “Quadrature” has no meaning with pulse output.
Duration of ON state	A function of position. If the encoder generates N cycles/rev, ON duration is nominally 1/2N rev.	A function of time. ON duration is $t_{\mu s}$ (specified by the manufacturer), regardless of speed or resolution. With N pulses/rev, interval between pulses is 1/N rev.
Output Lines	Two lines, both always active. User determines direction of travel by analyzing whether channel A leads or lags channel B.	Two lines, one for each direction. Pulses occur on only one line at a time; the other remains low. Alternatively, one line will be high or low, depending on direction, while the data pulses always appear on the other line.





3.3.2.18 resolution

available number of increments per turn for rotary encoders, or per mm or inch for linear encoders

NOTE 1 Resolution is theoretically unrelated to accuracy. Resolution is typically specified in either counts per unit motion (e.g., pulses per revolution, cycles per revolution, counts per revolution, lines per inch (millimeter), bits per turn, or bits per inch (millimeter) or motion per count (e.g., .01°, .0005 in., .001 mm, or 30 arc sec).

NOTE 2 Although "pulses per revolution" is commonly used throughout the industry to specify resolution, the preferred term is "cycles per revolution."

3.3.2.19 single channel

encoder producing one incremental output

3.3.2.20 symmetry

<incremental encoders> ratio of the "on" time to the "off" time of the output signal

NOTE This ratio is optimally 50:50, i.e., 180° electrical "on" and 180° electrical "off."

3.3.2.21 Torque definitions

3.3.2.21.1

running torque

rotary force required to keep an encoder shaft turning, typically expressed in oz-in.

3.3.2.21.2

starting torque

breakaway torque

<encoder> rotary force required to overcome static friction and cause the encoder shaft to begin rotating

3.3.2.22

TTL compatible

voltage comparator or similar circuit which provides transistor-transistor logic output levels

3.3.3 Terms specific to resolvers

NOTE The following terms and definitions apply to brushless type resolvers.

3.3.3.1

accuracy ripple

component of resolver accuracy which is caused by third or higher harmonics of the excitation frequency

3.3.3.2

digital analyzing voltmeter

DAV

a.c. measurement and analysis device that allows phase angle voltmeter component measurement as well as accurate measurement of ratio, total harmonic distortion, frequency, and harmonics

3.3.3.3

dividing head

mechanical device to precisely position the shaft of a resolver

3.3.3.4

electrical error

resolver accuracy

difference between the electrical angle, as indicated by the output voltages, and the mechanical angle or rotor position angle

3.3.3.5

frameless resolver

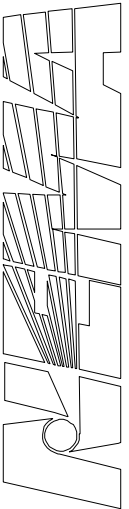
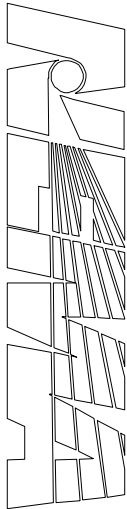
pancake resolver

separate rotor and stator assembly, which is mounted directly in the user's system

3.3.3.6

housed resolver

resolver mounted in a housing and shaft configuration that includes a set of ball bearings



3.3.3.7 Impedance definitions

3.3.3.7.1

Z_{ro}

rotor impedance, measured with stator open circuit

3.3.3.7.2

Z_{rs}

rotor impedance, measured with stator short circuit

3.3.3.7.3

Z_{so}

stator impedance, measured with rotor open circuit

3.3.3.7.4

Z_{ss}

stator impedance, measured with rotor short circuit

3.3.3.8

multi-speed resolver

resolver that produces for one mechanical revolution of the rotor “N” sine and “N” cosine waveforms at the output windings

NOTE “N” is the speed which is equivalent to the number of pole pairs.

3.3.3.9

multi-turn resolver

resolver that both determines the absolute position within one revolution and counts the number of revolutions

3.3.3.10

null voltage

residual voltage remaining when the in-phase component of the output voltage is set at zero

NOTE The total null voltage is the sum of the quadrature fundamental null voltage plus the harmonics.

3.3.3.11

phase shift

difference between the time phases of the input and the output voltages when the output is at maximum coupling

3.3.3.12

pole pair

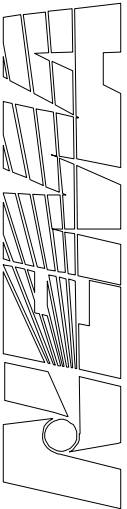
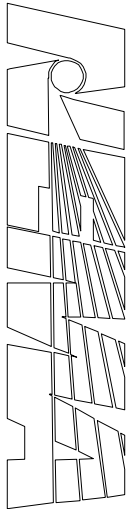
two poles of a resolver

3.3.3.13

primary windings

primary side

windings that receive excitation from a power supply



3.3.3.14 resolver

electromechanical rotary transformer that relates an angular position of the shaft to electrical voltages; device with a two phase rotor and two phase stator that creates or receives sine-cosine signals

3.3.3.15 resolver bridge

nulling type device that measures, in connection with a PAV (phase angle voltmeter) or DAV (digital analyzing voltmeter), directly and accurately the electrical angular output of a resolver

3.3.3.16 secondary windings

secondary side

output windings, configured to provide sine-cosine signals, which are inductively coupled to a primary winding

3.3.3.17 single-speed resolver

resolver that produces for one mechanical revolution of the rotor one sine and one cosine waveform at the output windings

3.3.3.18 transformation ratio

ratio of the in-phase component of the output voltage, at maximum coupling, to input voltage

3.4 Terms common to control systems

3.4.1 General terms

3.4.1.1 continuous power output

steady state power output capability of a device in watts

3.4.1.2 drift

undesired, but relatively slow, change in output over a period of time with a fixed reference input

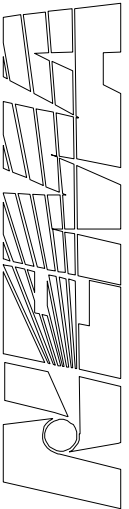
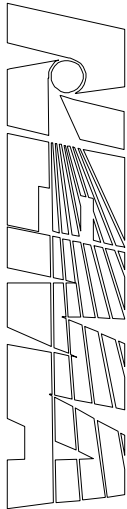
3.4.1.3 dynamic braking

technique to reduce speed, or maintain speed, in the case of an overhauling load, upon loss of power or on demand

NOTE This is done by dissipating energy within the motor or in an external resistor.

3.4.1.4 pulse width frequency modulated amplifier

amplifier that switches the supply voltage at a variable frequency or a variable pulse width or both so that an adjustable average voltage or current to the load is established



3.4.1.5 pulse width modulated amplifier

amplifier that switches the supply voltage at a constant frequency but with a variable pulse width so that an adjustable average voltage or current to the load is established

NOTE The peak voltage can be many times higher than the adjustable average voltage.

3.4.1.6 radio frequency interference RFI

term used interchangeably with EMI, which is a more recent definition that includes the entire electromagnetic spectrum, whereas RFI is more restricted to the radio-frequency band, generally considered to be between 10 KHz and 10 GHz

3.4.1.7 ripple current peak-to-peak variation in current around the average value

3.4.1.8 step response time domain response characteristic of the output of a device in response to a specified step level of input

3.4.1.9 switching frequency fundamental frequency at which a power switching device controlling the motor current is turned on and off

3.4.2 Terms specific to servo motor controls

3.4.2.1 Servo motor control system component definitions

NOTE The terms and definitions in this subclause pertain to the components of a servo motor motion/position control system as shown in Figure 14.

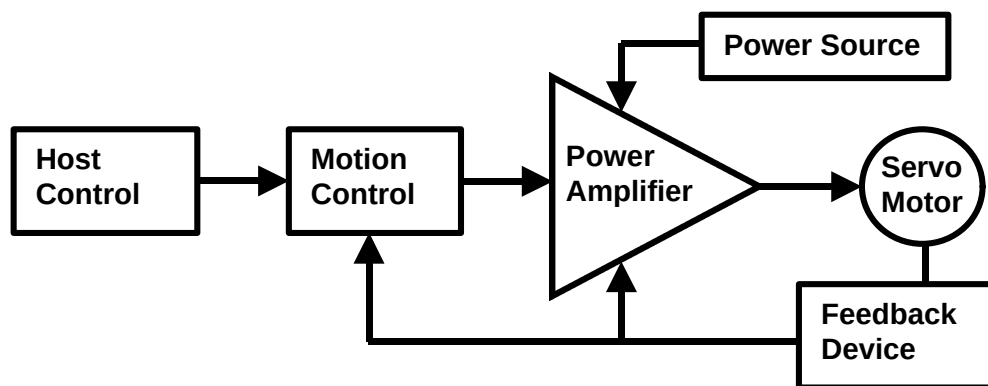


Figure 14 — Servo motor motion control system: example configuration

3.4.2.1.1 host control

device attached to a network to interface servo motor motion control systems with a machine or factory automation system

NOTE The host control could be also used to preprogram the motion system for independent operation.

3.4.2.1.2 power amplifier

device that enables an input signal to control the flow of necessary power from the power source to the servo motor for the purpose of performing desired motion

3.4.2.1.3 power source

device that provides necessary electrical energy to the power amplifier

NOTE The power source could be a battery, direct a.c. line, or rectified a.c. with or without a transformer. Any excess electrical energy could be dissipated inside the power source or could be regenerated to the prime source.

3.4.2.1.4 servo motor

electric motor that employs feedback and that has a purpose of producing mechanical power to perform the desired motion of the servo mechanism

3.4.2.1.5 servo motor motion controller

control system that provides the various inputs to the power amplifier so that the servo motor performs desired motion within an acceptable range of values

NOTE The controlled values are typically position, velocity, torque, or other servo motor parameters. Often each parameter has its own control loop with independent feedback device. In some systems feedback information is calculated inside the motion controller.

3.4.2.2 deadband

range of input signals for which there is no system response

3.4.2.3 linearity

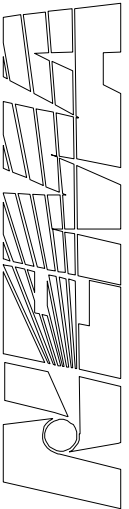
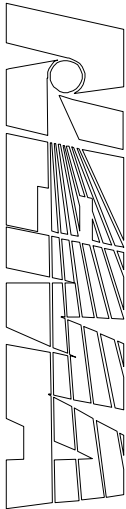
measure of the degree to which the output of a control device maintains a constant relationship to the input over a range of input values

3.4.2.4 position loop bandwidth

frequency range over which the magnitude of the closed position loop gains decreases by 3 dB or less (the position loop response time decreases as the bandwidth is increased)

3.4.2.5 regeneration

process of returning energy to the source from the load



3.4.2.6

regenerative capacity

amount of energy that the amplifier can accept during regeneration

3.4.2.7

scale factor of the amplifier

output change for a given input change

3.4.2.8

six-step brushless motor amplifier

amplifier which provides polyphase outputs consisting of six discrete switching states occurring for each 360° electrical cycle

3.4.2.9

slewing

rapid transition of the output of a control device from one value to another value without requiring that the normal output versus input relationship be maintained through the intermediate values

3.4.2.10

small signal bandwidth

bandwidth measured with the signal magnitude low enough to ensure the control system is operating in its linear range

3.4.2.11

three-phase sinusoidal brushless motor amplifier

amplifier that provides three sinusoidal current outputs, phase shifted 120° electrical

3.4.2.12

velocity loop bandwidth

frequency range over which the magnitude of the closed loop gain first decreases by no more than 3 db, the peaking is less than 3 db, and the phase shift has not exceeded -90 degrees

NOTE In closed position loop systems, phase shift is frequently specified at -45 degrees to provide additional phase margin and improve stability.

3.4.3 Terms specific to stepping motor controls

3.4.3.1 Stepping motor control system components

NOTE 1 The definitions in this subclause pertain to controls for stepping motors. All terms relating to measured values are defined with the understanding that in most cases a test procedure will describe the specified conditions of measurement.

NOTE 2 The stepping motor system includes all of the various elements necessary to create precision motion. This includes storage and limited intelligence to accommodate short or repetitive motion, or both. Access to greater intelligence for more complex motion control, status reporting, and systems interaction are provided through various interfaces as shown in Figure 15.

