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MOTION/POSITION CONTROL MOTORS, CONTROLS, AND FEEDBACK DEVICES

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STANDARDS PUBLICATION NO. MG 7

nema

Motion/Position Control Motors, Controls, and Feedback Devices

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA STANDARDS PUBLICATION NO. MG 7–1993

MOTION/POSITION CONTROL MOTORS, CONTROLS, AND FEEDBACK DEVICES

Reaffirmed with Revisions—January 26, 1993

Published by:

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Foreword

Standards Publication No. MG 7-1993 covers servo and stepper motors and their controls for use in a motion/position control system. Its primary purpose is to assist users in the proper selection and application of servo and stepper motors and to eliminate misunderstandings between manufacturers and users.

This Standards Publication provides technical information concerning performance, safety, tests, construction, and manufacture of servo and stepper motors and their control systems within the product scope defined in the Scope section of this publication. It is based upon sound engineering principles, research, and records of test and field experience. Also involved is an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, and others having specialized experience.

The standards are regularly reviewed by the Motion/Position Control Motors Group of the Motor and Generator Section of NEMA for any revisions necessary to keep it up-to-date with advancing technology and are subject to such revision as further experience or investigation may show is necessary or desirable.

Comments or recommended revisions are welcomed and should be submitted to:

Vice President, Engineering
National Electrical Manufacturers Association
2101 L Street N.W., Suite 300
Washington, DC 20037

Scope

This Standards Publication covers all rotational and linear electric servo and stepper motors and their power requirements, feedback devices, and controls intended for use in a motion/ position control system that provides precise positioning, or speed control or torque control, or in any combination.

Examples of components falling within this product scope are drives/amplifiers, and the necessary intelligence to direct the application of this power in a controlled manner.

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

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MOTION/POSITION CONTROL MOTORS, CONTROLS, AND FEEDBACK DEVICES

Section 1
REFERENCED STANDARDS, DEFINITIONS, AND SAFETY STANDARDS

1.1 REFERENCED STANDARDS

In this Standards Publication, reference is made to the following publications. Copies are available from the sources indicated.

National Electrical Manufacturers Association
2101 L Street N.W., Suite 300
Washington, DC 20037-1526

MG 1–1992 — *Motors and Generators*
MG 2–1990 — *Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors*

Electronic Industries Association
2001 Eye Street, N.W.
Washington, DC 20006

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

American National Standards Institute, Inc.
1430 Broadway
New York, NY 10018

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

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

ANSI/IEEE 43–1974 (R1992) — *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*
ANSI/IEEE 100–1988 — *Standard Dictionary of Electrical and Electronics Terms*
ANSI/IEEE 113–1985 — *Standard Test Procedures for Direct Current Machines*
ANSI/IEEE 118-1978 — *Test Code for Resistance Measurement*
ANSI/IEEE 115–1983 (R1991) — *Standard Test Procedures for Synchronous Machines*
ANSI/IEEE 488.1–1987 — *Standard Digital Interface for Programmable Instrumentation*

1.2 DEFINITIONS

1.2.1 Control Defintions

1.2.1.1 COMMON

The following definitions are common to controls for servo and stepper 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.

CONTINUOUS POWER OUTPUT

Continuous power output is the steady state power output capability of a device in watts.

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DRIFT

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

DYNAMIC BRAKING

Dynamic braking is a technique to reduce speed, or maintain speed in the case of an overhauling load, upon loss of power or on demand. This is done by dissipating energy within the motor or in an external resistor.

ELECTRICAL NOISE

Electrical noise is unwanted electrical energy that has the possibility of producing undesirable effects in the motion control system. Electrical noise includes electromagnetic interference (EMI) and radio frequency interference (RFI).

ELECTRICAL NOISE IMMUNITY

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

ELECTROMAGNETIC INTERFERENCE (EMI)

Electromagnetic interference is electromagnetic disturbance that manifests itself in performance degradation, malfunction, or failure of electronic equipment.

OPERATING AMBIENT TEMPERATURE

Operating ambient temperature is the temperature of the air immediately surrounding a device.

POWER DISSIPATION (HEAT GENERATION)

Power dissipation (heat generation) is the amount of power dissipated in the controller due to its internal power losses.

PULSE WIDTH MODULATED AMPLIFIER

A pulse width modulated amplifier is an 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.

PULSE WIDTH FREQUENCY MODULATED AMPLIFIER

A pulse width frequency modulated amplifier is an 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.

RADIO FREQUENCY INTERFERENCE (RFI)

Radio frequency interference is used interchangeably with EMI. EMI is a later definition that includes the entire electromagnetic spectrum, whereas RFI is more restricted to the radio-frequency band, generally considered to be between 10K and 10G Hz.

RIPPLE CURRENT

Ripple current is the peak-to-peak variation in current around the average value.

STEP RESPONSE

Step response is the time domain response characteristic of the output of a device in response to a specified step level of input. (See Figure 2-3.)

SWITCHING FREQUENCY

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

SYSTEM

The motion control system is defined as all rotational and linear electric servo and stepper motors and their power requirements, feedback devices, and controls intended for use in a motion/position control system that provides precise positioning, or speed control, or torque control, or in any combination.

1.2.1.2 SERVO MOTOR CONTROLS

The following definitions pertain to controls for servo 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.

COMPONENTS, SERVO MOTOR SYSTEM

The following descriptions pertain to the components of a servo motor motion/position control system as shown in Figure 1-1.

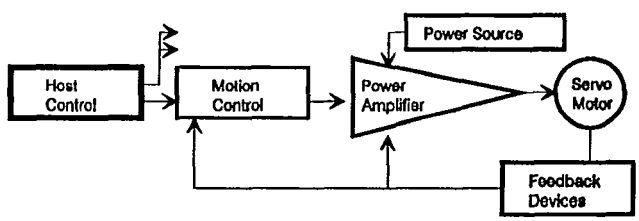


Figure 1-1
SERVO MOTOR MOTION CONTROL SYSTEM

Feedback Device

A device in the closed loop system that provides actual response information allowing comparison

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with referenced commands such as position, velocity, or torque.

Host Control
A device attached to a network to interface servo motor motion control systems with a machine or factory automation system. The host control could be also used to preprogram the motion system for independent operation.

Power Amplifier
A 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.

Power Source
A device that provides necessary electrical energy to the power amplifier. The power source could be a battery, direct ac line, or rectified ac with or without a transformer. Any excess electrical energy could be dissipated inside the power source or could be regenerated to the prime source.

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

Servo Motor Motion Controller
A 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. 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.

DEADBAND
Deadband is a range of input signals for which there is no system response.

LINEARITY
Linearity is a 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.

POSITION LOOP BANDWIDTH
Position loop bandwidth is the 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.)

REGENERATION
Regeneration is the process of returning energy to the source from the load.

REGENERATIVE CAPACITY
Regenerative capacity is the amount of energy that the amplifier can accept during regeneration.

SCALE FACTOR, AMPLIFIER
The scale factor of the amplifier is the output change for a given input change.

SIX-STEP BRUSHLESS MOTOR AMPLIFIER
A six-step brushless motor amplifier is an amplifier which provides polyphase outputs consisting of six discrete switching states occurring for each 360 degree electrical cycle.

SLEWING
Slewing is the 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.

THREE-PHASE SINUSOIDAL BRUSHLESS MOTOR AMPLIFIER
A sinusoidal brushless motor amplifier is an amplifier that provides three sinusoidal current outputs, phase shifted 120 degrees electrical.

▲ VELOCITY LOOP BANDWITH
Velocity loop bandwith is the frequency range over which the magnitude of the closed loop gain first decreases by no more than 3db, the peaking is less than 3db, 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 phased margin and improve stability.

SMALL SIGNAL BANDWIDTH
Small signal bandwidth is bandwidth measured with the signal magnitude low enough to ensure the control system is operating in its linear range.

1.2.1.3 STEPPER MOTOR CONTROLS

The following definitions pertain to controls for stepper 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.

STEPPER MOTOR SYSTEM COMPONENTS
The stepper 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 1-2.

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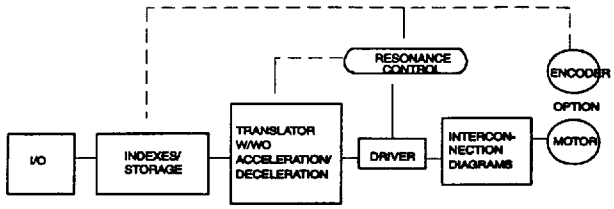


Figure 1-2
STEPPER MOTOR MOTION CONTROL SYSTEM

Generally, there are two types of stepper motor control systems:

Open Loop Control System

An open loop control system is a system that utilizes the stepper motor inherent positioning capabilities to provide precise motion.

Closed Loop Control System

A closed loop control system is a system that utilizes a feedback device (encoder, resolver, or the like) to enhance performance of the system by providing better acceleration and speed capabilities as well as better system stability. The closed loop control system also provides assurance that the programmed position is actually achieved.

There are several control devices in a stepper motor control system:

Stepper Motor Controller

The stepper motor controller is the system that provides intelligence and power to the stepper motor controlled.

Stepper Motor

The stepper motor is the device that accepts the translated electrical current and converts it to actual incremental motion.

Interconnections

Interconnections are the connecting means between the stepper motor and the driver. Various winding and/or drive configurations require different connection schemes.

Driver

The stepper motor driver is that portion of the control that provides power to the stepper motor in a controlled manner to achieve the specified motor performance characteristics.

Translator

A translator is the control section that converts the input commands to a suitable logic patterned waveform to properly drive the stepper motor.

Storage/Indexer

A storage/indexer is the part of the controller that retains the motion command data to determine the move sequence, such as a single move or a series of moves that are stored in "memory" available for continuous positioning tasks.

Interface

The interface is the link to external intelligence via an accepted interface standard such as EIA 232-D, IEEE 488, and so forth.

Resonance Controller

A resonance controller is a feedback device which may use the encoder information or internal decoded information to improve system stability. This is sometimes called "pulse placement" and is useful in other resonance applications.

Feedback Device

A feedback device is a device that is coupled to the output of the stepper motor and provides position or speed information via the feedback loop to the controller to enhance performance.

ACCELERATION/DECELERATION

Acceleration/deceleration is a change in velocity of a stepper motor by adjustment of pulse rate.

BASE SPEED

Base speed is the speed that can be achieved without ramping and with no position error with a specified load.

BI-LEVEL

A bi-level drive is a dual voltage motor drive circuit, which provides high voltage to initially build up the current in the windings, and then switches to a low voltage after the rated current or preset time is reached. This decreases the motor current build up time and improves motor performance.

CHOPPER

A chopper drive is a motor drive circuit in which the supply voltage is switched (chopped) by pulse width or frequency modulation or both to maintain an average current level to the motor windings. The chopping frequency can typically range from 1 kHz to 30 kHz. This permits the use of drive voltages several times the motor's rated value to cause the motor currents to build up rapidly for improved high-speed performance.

COMMAND PULSE RATE

Command pulse rate is the rate at which successive command pulses are applied to the motor drive logic.

CONSTANT CURRENT

Constant current drive is a motor drive circuit which maintains the average motor currents relatively constant

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independent of motor speed (e.g. chopper or linear driver with current feedback loop) in order to provide improved high speed motor performance.

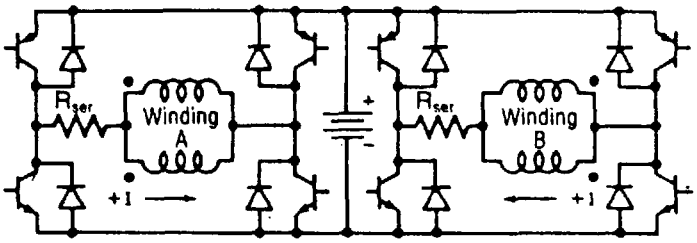
DRIVE CIRCUITS

A drive circuit is a combination of a translator and a power amplifier that energizes the phases of the stepper motor.

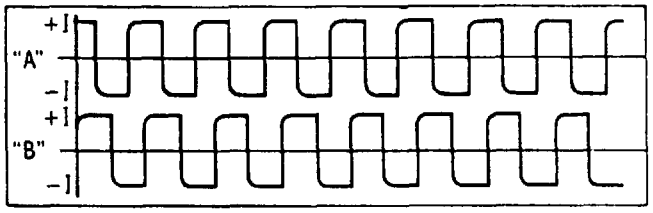
DRIVE CONFIGURATIONS

Unipolar

A unipolar drive circuit maintains the winding current flow in only one direction. An example of a unipolar drive circuit is shown in Figure 1-3.



Single Supply—Parallel Bipolar Drive Circuit



Full Step CW*

Figure 1-4
BIPOLAR DRIVE CIRCUIT

Bipolar

A bipolar drive circuit is a drive circuit in which the phase winding current is bidirectional. An example of a bipolar drive circuit is shown in Figure 1-4.

Figure 1-3
UNIPOLAR DRIVE CIRCUIT

MAXIMUM REVERSING COMMAND PULSE RATE

The maximum reversing command pulse rate is the maximum pulse rate at which the unloaded stepper motor is able to reverse and remain in synchronism under the specified drive conditions. The number of pulses must be enough to assure stability of the dynamic load angle before reversal.

MAXIMUM SLEW PULSE RATE

The maximum slew pulse rate is the maximum pulse rate at which the unloaded stepper motor can remain in synchronism with the command pulses under the specified drive conditions.

PULSE STREAM CONTROL

Clockwise/counterclockwise is a direction control method where separate pulse stream inputs are provided for clockwise or counterclockwise rotation of the stepper motor.

RAMPING

Ramping is the acceleration/deceleration of a stepper motor by means of controlled change in a pulse rate above base speed.

RESPONSE RANGE

Response range is the range of command pulse rates over which the unloaded motor can be operated in one of the following specified conditions without missing steps.

a. Start-stop without reversal
b. Reverse during acceleration, deceleration, or slew
c. Acceleration *and* deceleration
d. Acceleration *or* deceleration

ROTATION, DIRECTION CONTROL TYPES

Control input/output pulse and direction is a direction control method where a logic state (high or low) determines direction of rotation of the stepper motor, while a separate pulse stream determines rotor position.

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SERIES R, (OR L/R)

A series R drive (or L/R) is a motor drive circuit that uses extra resistors in series with the motor windings and drive transistors to reduce the current buildup time constant from L_m/R_m to $L_m/(R_m+R)$ and thus improve high speed performance,

Where:

L_m = Motor windings inductance
R_m = Motor windings resistance
R = Extra series resistance

SLEW RANGE

(See Response Range for definition.)

STEPPING

Stepping is the process of supplying a proper logic pattern of drive signals that cause the motor driver to supply required stepper motor winding currents at appropriate times to create incremental motion. (See also Stepper Motor Terminology—Step.)

Full Step

A full step is a logic pattern that will produce a unit of incremental motion that results in step increments that are determined by the basic stepper motor structure.

Half Step

A half step is the unit of incremental motion that is ½ of a basic motion increment (full step).

Micro Step

A micro step is a logic pattern that will produce regular increments smaller than a half step.

TRANSLATOR LOGIC

Translator logic converts the single channel pulse train into the multi-channel states to be applied to the power amplifier that energizes the stepper motor.

1.2.1.4 SYMBOLS FOR SERVO AND STEPPER MOTOR CONTROLS

(Under consideration.)

1.2.2 Feedback Devices Definitions

ABSOLUTE ENCODER

An absolute encoder provides information in the form of unique output for every resolvable position.

ACCELERATION (MAXIMUM)

Maximum acceleration is the maximum rate of speed change which will not mechanically violate the rated performance of the feedback device. It is typically expressed in radians per second squared (rads/sec2) or inches per second squared (in/sec2).

ACCURACY

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

AXIAL ENDPLAY

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

AXIAL LOAD

Axial load is the force applied to a shaft end surface directed along the axis of rotation.

AXIAL LOAD (MAXIMUM)

Maximum axial load is the 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.

BI-DIRECTIONAL

Bi-directional refers to an encoder output code format from which direction of travel can be determined. See also direction sensing and pulse.

BINARY

Binary is a term referring to the number 2 or to the number system with a radix of 2 (base 2).

For example, the on/off of a switch function is usually represented by "ones" and "zeros."

BINARY-CODED DECIMAL (BCD)

Binary-coded decimal refers to a number-representation system in which each decimal digit is identified by a unique arrangement of binary digits. Binary-coded decimals are associated with codes of four bits used to define the Arabic numbers 0 through 9.

BIT

The word bit is an abbreviation for binary digit. A bit is the basic unit of the binary system whose value may be either true (one) or false (zero).

CHANNEL

Each channel is a unique incremental output of the feedback device.

COMPLEMENTARY

Complementary is the term for two identical periodic signals where one signal is inverted from the other.

An example of single channel complementary output, is shown in Figure 1-5.

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

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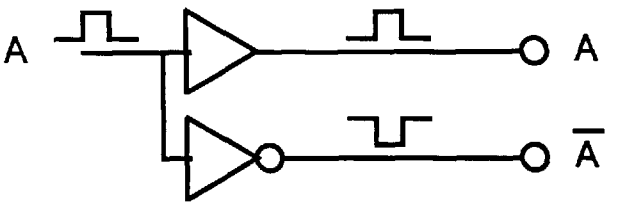


Figure 1-5
SINGLE CHANNEL COMPLEMENTARY OUTPUT

COUNT ERROR

Count error is a missing transition or an additional transition from the intended coded output.

COUNT TRANSITION

Count transition is the point where the output state changes from "0" to "1" or visa versa, as depicted in Figure 1-6.

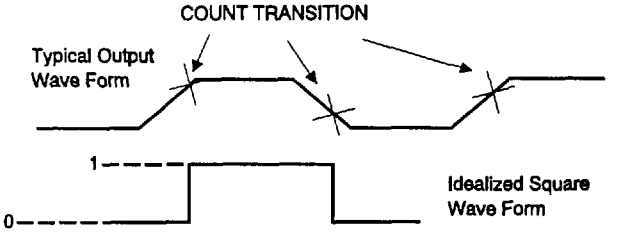


Figure 1-6
COUNT TRANSITION

CYCLE ERROR

Cycle error is the difference between the actual cycle width and the theoretically correct cycle width.

CYCLE WIDTH

See also Electrical Degree.

With square-wave output, cycle width is the nominal distance from leading edge to next leading edge on the same output channel.

With pulse output, cycle width is the distance between the leading edges of two adjacent pulses.

With N cycles/rev of square wave output or N pulses/rev of pulse output, cycle width = 1/N rev. See Figure 1-7 for an example.

DATA RATE

See also Frequency.

Data rate is the speed at which the digital code is changing. It is usually expressed in cycles per second, pulses per second or bits per second.

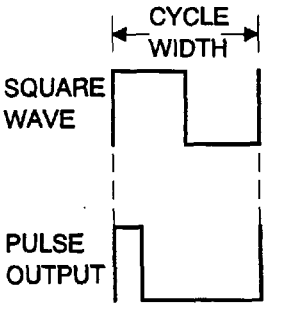


Figure 1-7
CYCLE WIDTH

Data rate of a rotary encoder is the speed in revolutions per minute times the resolution (lines/turn) divided by 60.

DIGITAL TACHOMETER

Digital tachometer is a term for an incremental encoder that is used to indicate or control speed.

DIFFERENTIAL OUTPUT

Differential output refers to the complementary outputs from a feedback device when the signals are excited by a line driver. See Figure 1-8.

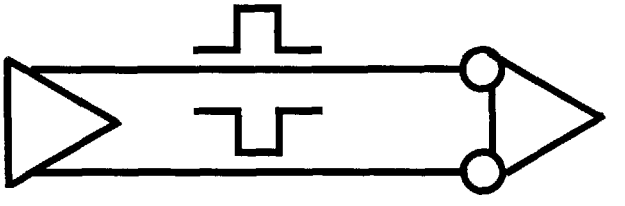


Figure 1-8
DIFFERENTIAL OUTPUT

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

DIRECTION OF ROTATION

The direction of rotation of an enclosed feedback device shall be defined as viewed toward its driven shaft, as depicted in the following line drawing.

For modular or kit feedback devices, consult the manufacturer.

DIRECTION SENSING

Direction sensing is the technique for determining the direction of motion by analyzing the relative phase relationship between the two channels of quadrature square wave output. See also Pulse.

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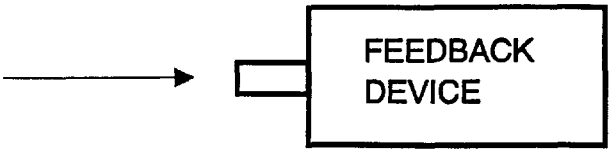


Figure 1-9
DIRECTION OF ROTATION

DUAL CHANNEL
A dual channel encoder produces two unique incremental outputs.

DUTY CYCLE ERROR
See Pulse Width Error.

EDGE-TO-EDGE VARIATION OR EDGE SEPARATION
See also State Width.

Edge-to-edge variation is the separation between a transition in the output of channel A and the neighboring transition in the output of channel B. There are four states per cycle, each nominally 90°e for quadrature output. See Figure 1-10 for an example.

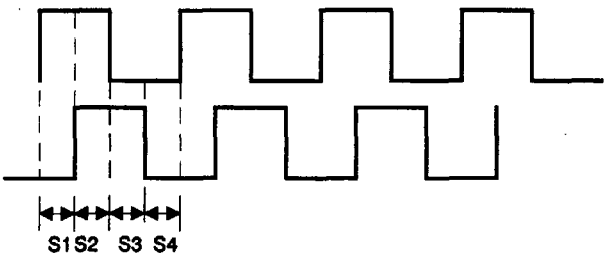


Figure 1-10
EDGE TO EDGE VARIATION

ELECTRICAL DEGREE (ENCODER)
An electrical degree (°e) is 1/360 of a cycle width and is related to mechanical degrees through line count. It is mathematically expressed as follows:

$$360°e = \left(\frac{360}{N}\right)°mech$$

Where:

N = output cycles/revolution or lines/revolution whichever is greater.

ENCODER
An encoder is an electro-mechanical device that translates mechanical motion (such as position, velocity, and acceleration) into electrical signals.

EXCITATION
Excitation is the external electrical voltage or current or both applied to a transducer for its proper operation.

FLUTTER
Flutter is variation in cycle width from cycle to adjacent cycle.

FREQUENCY (ENCODERS)
Frequency is the speed in revolutions per minute times the resolution (lines/turn) divided by 60 for rotary encoders. (See also Data Rate.)

FREQUENCY MODULATION (ENCODERS)
For encoders, frequency modulation is the deviation from a theoretically correct output frequency when the input shaft is rotated at a constant velocity.

FREQUENCY RESPONSE
Frequency response for a feedback device is the maximum frequency in cycles per second at which the error does not exceed the manufacturer's rated specification.

HYSTERESIS
Hysteresis is deliberately induced switching error in an electrical circuit to prevent oscillation about a transition point.

INCREMENTAL ENCODER
An incremental encoder is a device that provides a series of periodic signals due to mechanical motion. The number of successive cycles (signals) corresponds to the resolvable mechanical increments of motion.

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

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

JITTER
Jitter is an expression that is used to define relative phase relationships of signals. For encoders it is better defined as the combined effect of cycle error, state width error, phase error, and symmetry. See Figure 1-11.

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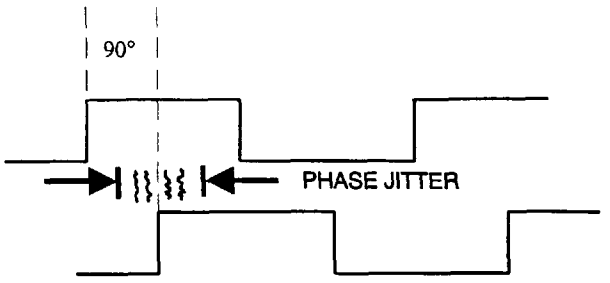


Figure 1-11
JITTER

LINE COUNT (INCREMENTAL)

For rotary encoders, line count is the number of equally spaced radial lines per revolution. For linear encoders, line count is the number of equally spaced lines per specified length.

MOUNTING SURFACE PERPENDICULARITY

Mounting surface perpendicularity is the relationship between the shaft centerline about the axis of rotation and the mounting surface of the feedback device.

MULTIPLICATION

Multiplication is a technique to derive an output resolution higher than the line count.

PHASE (ENCODER)

Phase is electrical degrees of displacement between two encoder outputs, typically 90°e in quadrature encoders.

PHASE ERROR

Phase error is the deviation in electrical degrees from a specified phase relationship between any two channels. The phase relationship is nominally 90°e in a quadrature encoder as depicted in Figure 1-12.

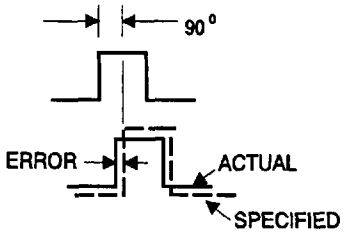


Figure 1-12
PHASE ERROR

POSITION ACCURACY

Position accuracy is the maximum positional difference between the feedback device's true input position and the position indicated by the feedback devices's output.

Accuracy is not to be confused with resolution. See the following specific errors: pulse width error; edge to edge variation (state width error); phase error; position error; and cycle error.

POSITION ERROR

Position error is the difference between the theoretically correct position and the actual position as indicated by the feedback device.

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.

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PULSE

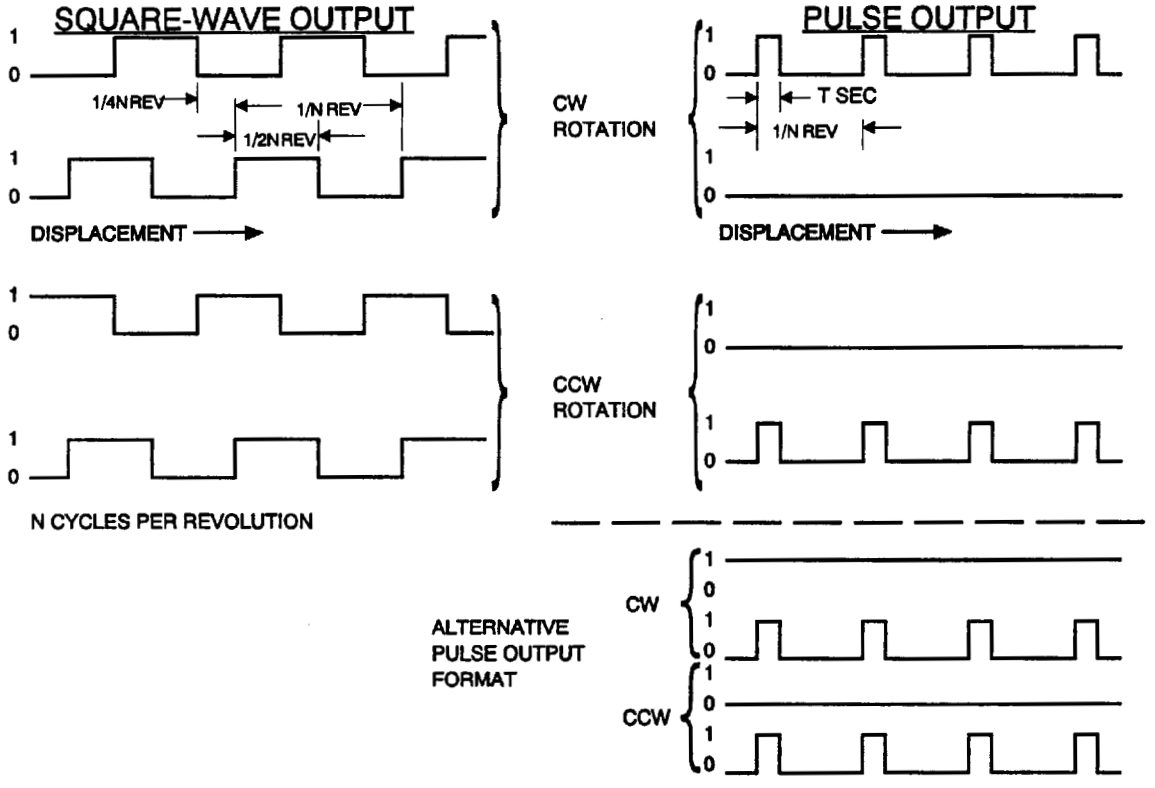
See Table 1-1.

a. In an encoder with quadrature square wave output, "pulse" is used to designate the "on" portion of each cycle. Although "pulses per revolution" is commonly used throughout the industry to specify resolution, the preferred term is "cycles per revolution."

b. In an encoder with pulse output, electrical circuitry generates short-duration pulses whose positions correspond to selected square wave transitions (1, 2, or 4 per cycle), and whose duration is a fixed time, independent of speed. The pulses are also direction-sensed.

Table 1-1
PULSE

	Square Wave Ouput	Pulse Output
Terminology	Preferred unit of resolution is "cycles per rev," although "pulses/rev" is common. "Quadrature" refers to 90°e 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 $\frac{1}{2N}$ rev.	A function of time. ON duration is Tμs (specified by manufacturer), regardless of speed or resolution. With N pulses/rev, interval between pulses is $\frac{1}{N}$ 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.



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PULSE WIDTH ERROR

Pulse width error is the deviation in electrical degrees of the pulse width from the ideal value of 180°e. See Figure 1-13.

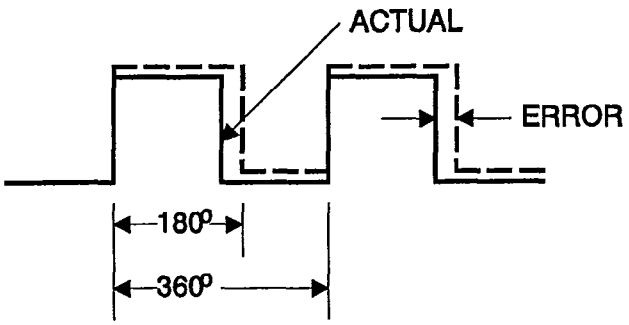


Figure 1-13
PULSE WIDTH ERROR

QUADRATURE

Quadrature is the term for two identical periodic signals when the phase displacement is nominally 90°e.

QUADRATURE ERROR

Quadrature error is the phase error when the specified phase relationship between any two channels is nominally 90°e.

RADIAL LOAD

Radial load is the force applied to the feedback device shaft at a specified point perpendicular to the axis of rotation.

RADIAL LOAD (MAXIMUM)

Maximum radial load is the 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.

REPEATABILITY

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

RESOLUTION

Resolution is a term defining the available number of increments per turn for rotary encoders or per inch (millimeter) for linear encoders.

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).

RPG (ROTARY PULSE GENERATOR)

Rotary pulse generator is another term for incremental encoder.

SHAFT RUNOUT (TIR)

Shaft runout is the 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°. In the case of double ended shaft feedback device, the shaft runout for each end shall be specified separately.

(TIR is an abbreviation for Total Indicator Reading or Total Indicated Runout.)

SINGLE CHANNEL

A single channel encoder produces one incremental output.

SLEW SPEED

The maximum speed at which the shaft can be rotated without mechanical damage to the encoder. (See also Maximum Mechanical Speed.)

STABILITY

Stability is the ability of a transducer to retain its performance characteristics over a specified period of time.

STATE WIDTH

See edge to edge variation.

STATE WIDTH ERROR

State width error is the deviation in electrical degrees of the state width from the ideal value. The ideal state width is 90°e in a quadrature encoder.

State width error should be specified by the individual manufacturer.

SYMMETRY

When used to define incremental encoders, symmetry is the ratio of the ON time to the OFF time of the output signal. This ratio is optimally 50:50, i.e., 180°e ON and 180°e OFF. (See also Pulse Width Error.)

TORQUE, RUNNING

Running torque is the rotary force required to keep an encoder shaft turning. It is typically expressed in oz × in.

TORQUE, STARTING (BREAKAWAY)

Starting (breakaway) torque is the rotary force required to overcome static friction and cause the encoder shaft to begin rotating.

1.2.3 Motor Definitions

1.2.3.1 COMMON

The following definitions are common to both servo and stepper 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.

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ACCELERATION/DECELERATION

Acceleration/deceleration is the time rate of change of velocity.

Angular acceleration is the time rate of change of angular velocity. This is expressed as:

$$\alpha = \frac{d\omega}{dt}$$

AXIAL ENDPLAY

Axial endplay is the variation in shaft end surface position with reference to the motor mounting surface when a specified axial load is applied in each direction.

AXIAL LOAD

Axial load is the force applied to a shaft end surface directed along the axis of rotation.

COMMUTATION

Commutation is the 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. Commutation is accomplished either mechanically or electronically.

COUNTER EMF (BACK EMF, E_g)

Counter electromotive force (EMF) is the generated voltage produced by the relative movement between the magnetic field and the coils of wire in an electromagnetic machine. It shall be measured in an open circuit condition and shall be stated as a peak or average or root mean square (rms) value.

COUNTER EMF CONSTANT (BACK EMF CONSTANT, K_E)

Counter electromotive force EMF constant (back EMF constant, K_E) is the voltage generated by an electro-magnetic machine per unit speed at a specific motor temperature. The voltage must be specified either as a peak or average or RMS value.

CURRENT FORM FACTOR

Current form factor is the ratio of rms current to the absolute value of average current. The rms current is the heat-producing value of the current, and the average current is the torque producing value of the current for these applications.

$$FF = \frac{\left\{\frac{1}{t_i}\int_0^{t_i} i^2\,dt\right\}^{1/2}}{\left|\frac{1}{t_i}\int_0^{t_i} i\,dt\right|}$$

DEMAGNETIZATION CURRENT

Demagnetization current is the winding current that creates a magnetic flux opposing the main field flux which irreversibly decreases the field strength of the motor magnets under specified conditions.

DUTY CYCLE

Duty cycle is the variation of torque or speed or both with time during a specified operating cycle.

DUTY CYCLE RATING

Duty cycle rating is the torque or speed or both versus time capacity of a motor during a specified time interval.

ELECTRICAL TIME CONSTANT (τ_e)

Electrical time constant is the time required for the winding current to reach 63.2 percent of its final value under specified conditions when a step voltage input is applied.

FRICTION TORQUE (T_f)

See Figure 1-14.

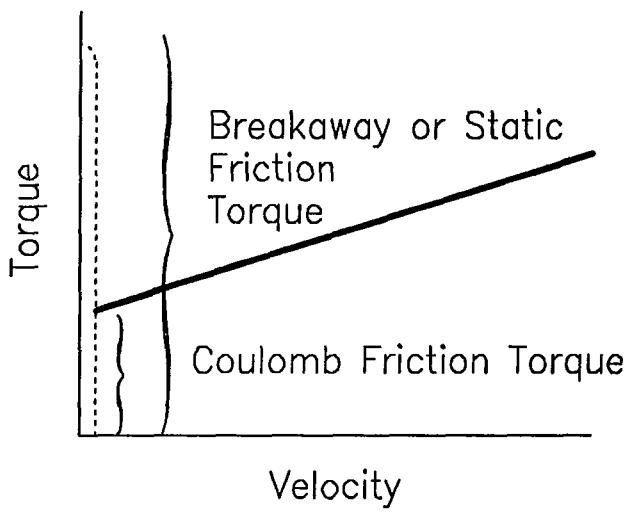


Figure 1-14
FRICTION TORQUE

Breakaway or Static Friction Torque

Breakaway or static friction torque is the mechanical resistance that the motor must overcome before motion can occur.

Coulomb Friction Torque

Coulomb friction torque is the resistance to motion that is independent of velocity.

Viscous or Dynamic Friction Torque

Viscous or dynamic friction is the resistance to motion that is velocity dependent. It is the slope of the curve.

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HIGH-POTENTIAL TEST

High-potential tests are tests that consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulation materials and spacings under normal conditions. (See MG 1, Part 3.)

INPUT IMPEDANCE

Input impedance is a 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.

INDUCTANCE (WINDING)

Inductance is that property of a coil or other electric circuit that opposes any change in current. In a stepper motor or 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.

Inductance Bridge Method

This method uses a bridge with a test frequency of 1000 Hz or less, and with current injected into the windings when inductance at a specified current level is required.

Current Change Method

With this method, the inductance is determined by measuring the time for current decay or rise to a specified level.

INTELLIGENT MOTION

Intelligent motion is the application of programmable hardware and software in conjunction with input sensory devices, actuators, and feedback devices for control of one or more linear or rotary motions.

MAGNETIC POLE

A magnetic pole is a concentrated area of magnetic flux that is the source/sink of a magnetic field. Magnetic poles are produced by permanent magnets or the current in a conductor.

MAXIMUM ALLOWABLE WINDING TEMPERATURE

The maximum allowable winding temperature is the maximum temperature of the winding permitted by the temperature class of the insulation system used.

MOUNTING SURFACE PERPENDICULARITY

Mounting surface perpendicularity is the relationship between the shaft centerline about the axis of rotation and the mounting surface of the motor.

PEAK CURRENT (I_{pk})

Peak current is the maximum intermittent current that under specified conditions does not cause motor damage, or irreversible degradation of motor performance.

RADIAL LOAD

Radial load is the force applied to the motor shaft perpendicular to the axis of rotation.

RADIAL PLAY

Radial play is the variation in position of the axis of rotation with respect to the datum axis of rotation under specified radial loading conditions.

RESISTANCE, MOTOR TERMINAL (R_{mt})

Motor terminal resistance is the total resistance measured at the motor terminals under specified conditions. For brush-type motors, it is the sum of the brush and armature resistances plus motor lead resistance. For brushless and stepper motors, the motor terminal resistance is equal to the winding resistance plus motor lead resistance.

ROTOR

The rotor is the rotating component of an electromagnetic machine.

ROTOR INERTIA (J_r)

Rotor inertia is the mass moment of inertia with respect to the rotational axis of the rotor.

SHAFT RUNOUT (TIR)

Shaft runout is the 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°. In the case of double ended shaft motors, the shaft runout for each end shall be specified separately.

STATOR

A stator is the portion of a machine that includes the stationary magnetic parts with any associated windings.

SYMMETRICAL SHORT CIRCUIT CURRENT

Symmetrical short circuit current is the periodic alternating current of which values one-half period apart are equal and have opposite signs that is drawn when the supply terminals are connected together with a near zero resistance conductor. For three phase circuits the rms current is the average of the currents in the three phases. The currents in any one phase is not to be less than ninety percent of the other currents.

THERMAL RESISTANCE (R_{th})

Thermal resistance is the opposition to the flow of heat in the materials of which the motor is constructed, ex-

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pressed as degrees Celsius per watt. All measurements shall be taken under specified conditions.

THERMAL TIME CONSTANT (τ_{th})

Thermal time constant is the time required for a motor winding to reach 63.2 percent of continuous (steady state) temperature rise with constant power dissipation under specified conditions.

TORSIONAL RESONANCE

Torsional resonance is the rotational oscillation that occurs in a rotating system when the frequency of a system rotational stimulus is equal to or close to any of the torsional natural frequencies of the system.

VELOCITY

Velocity is the time rate of change of position. Angular velocity is the time rate of change of angular displacement and is expressed mathematically as:

$$\omega = \frac{d\phi}{dt}$$

WINDING

The winding is the electrical coil structure that is used in a motor to develop electro-magnetic fields.

WINDING RESISTANCE

Winding resistance is the ohmic resistance measured with the windings at 25°C.

1.2.3.2 SERVO MOTORS

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.

ARMATURE

An armature is the component of an electro-magnetic machine that contains the windings that conduct the power producing component of current.

ARMATURE REACTION

Armature reaction is a magnetic field produced by the current in the armature coils of an electro-magnetic machine that alters the main magnetic field.

ARMATURE RESISTANCE

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

BRUSHES

Brushes are the spring-loaded elements that are in contact with the commutator bars or slip rings of the rotor. They provide the electrical path between the power source and the windings of the rotor.

BRUSHLESS DC MOTOR

A brushless dc motor is a rotating self-synchronous machine with a permanent magnet rotor and with known rotor shaft positions for electronic commutation. A motor meets this definition whether the drive electronics are integral with the motor or separate from it.

COGGING TORQUE

Cogging torque is a periodic torque in an open-circuited motor resulting from the tendency of the rotor and stator to align themselves to positions of minimum magnetic reluctance.

COMMUTATOR

A commutator is a set of mechanical contacts arranged angularly or linearly, contacted by the brushes to provide the electrical path from the power source to the armature. Its purpose is to control the relative electrical phase angle between the fields of the stationary element and the moving element of a motor.

CONTINUOUS STALL CURRENT (I_{CS})

Continuous stall current is the maximum rms current that can be continuously applied to a stalled motor under specified conditions.

CONTINUOUS STALL TORQUE (T_{CS})

Continuous stall torque is the maximum continuous output torque that the stalled motor can develop under specified conditions.

DAMPING COEFFICIENT (K_D)

A damping coefficient is a coefficient that describes the damping effect in a motor as defined by the mathematical expression:

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

It is sometimes known as zero source impedance. It is calculated at a specified temperature.

FULL LOAD OPERATION

Full load operation is continuous operation at the limits of the continuous safe operating area.

MAXIMUM CONTINUOUS CURRENT

Maximum continuous current is 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.

Low speed is defined as a speed that is sufficient to distribute the heat uniformly throughout the winding. It is typically less than 10 rpm.

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MAXIMUM CONTINUOUS TORQUE

Continuous torque is 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.

Low speed is defined as a speed that is sufficient to distribute the heat uniformly throughout the winding. It is typically less than 10 rpm.

MAXIMUM THEORETICAL ACCELERATION

Maximum theoretical acceleration is the peak motor torque divided by the rotor inertia. It is mathematically expressed as:

$$\alpha = \frac{T_{pk}}{J_r}$$

MECHANICAL TIME CONSTANT (τ_m)

Mechanical time constant is the time required for an unloaded motor to reach 63.2 percent of its final velocity after a zero source impedance step voltage input is applied. This constant is mathematically derived from the following formula at a specified temperature:

$$\tau_m = \frac{J_r \times R}{K_T \times K_E} = \frac{\text{Rotor inertia} \times \text{motor terminal resistance}}{\text{Torque constant} \times \text{counter emf constant}}$$

MOTOR CONSTANT (K_M)

Motor constant is a figure of merit used to define the ratio of torque produced to the electrical power losses of the motor. It is mathematically defined as:

$$K_M = \frac{T_c}{\sqrt{I_c^2 R_{mt}}}$$

Where:

T_C = Continuous torque
I_C = Continuous current
R_{mt} = Motor terminal resistance

PEAK TORQUE (T_{pk})

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

POWER AMPLIFIER DUTY CYCLE RATING

Power amplifier duty cycle rating is the amplifier output rating when operated in intermittent duty. 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 1-15 as an example.

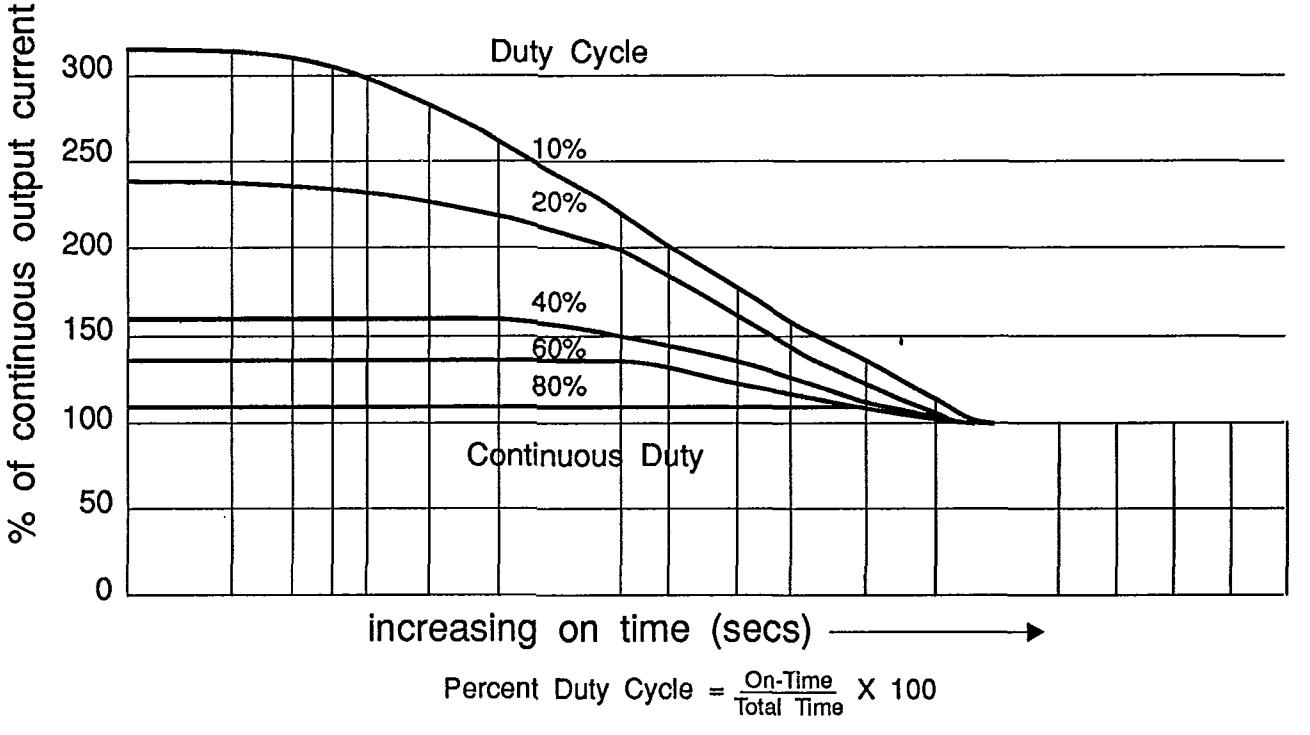


Figure 1-15
DUTY CYCLE CURVES

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ROOT MEAN SQUARE TORQUE (RMS TORQUE)

Root mean square torque is expressed mathematically by taking the square root of the summation of the products of the torque squared, multiplied by the specific time periods of torque application, divided by the summation of the time periods.

$$\text{rms Torque} = \sqrt{\frac{\Sigma T_i^2 t_i}{\Sigma t_i}}$$

SAFE OPERATING AREA

Safe operating area is the 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.

SERVO MECHANISM

A servo mechanism is a control system that employs feedback in order to control a desired output such as speed or position. A servo mechanism will detect and attempt to correct deviations from the desired output.

STALLED MOTOR (LOCKED ROTOR OR STALL)

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

TEMPERATURE COEFFICIENT OF TORQUE

Temperature coefficient of torque is a coefficient that defines the change in torque constant of the motor per unit change in motor average winding temperature.

TORQUE CONSTANT (K_T)

Torque constant is the torque developed by a motor per ampere of input current. This constant is temperature dependent and can be mathematically derived from the counter EMF constant (K_E). The available shaft output torque is the developed torque reduced by frictional and rotational losses.

TORQUE RIPPLE

Torque ripple is the variation of torque within one shaft revolution under specified test conditions. It is expressed as the ratio of peak-to-peak torque amplitude to average torque. This does not include cogging torque.

VISCOUS DAMPING (AT INFINITE IMPEDANCE SOURCE), D

Viscous damping factor is a measure of rotational losses in torque that are approximately directly proportional to speed.

$$D = \frac{\Delta T}{\Delta \omega}$$

1.2.3.3 STEPPER MOTORS

The following definitions pertain to stepper 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.

DETENT TORQUE

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

Minimum Detent Torque

The lowest value of torque, as above.

Maximum Detent Torque

The highest value of torque, as above.

DYNAMIC LOAD ANGLE

Dynamic load angle is the 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.

HOLDING TORQUE

Holding torque is the peak resistance to rotation of a gradually rotated shaft of an energized stepper motor. The mode of winding excitation and applied current shall be specified. The torque shall be 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.

MECHANICAL HYSTERESIS

Mechanical hysteresis is the 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.

OVERSHOOT (TRANSIENT)

Overshoot (transient) is the peak angular distance the shaft of the motor rotates beyond the actual final position. (See Figure 1-16.)

PHASE, MOTOR

(Motor) Phase is a set of electrically excited stator poles, consisting of one or more pairs of oppositely polarized poles.

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

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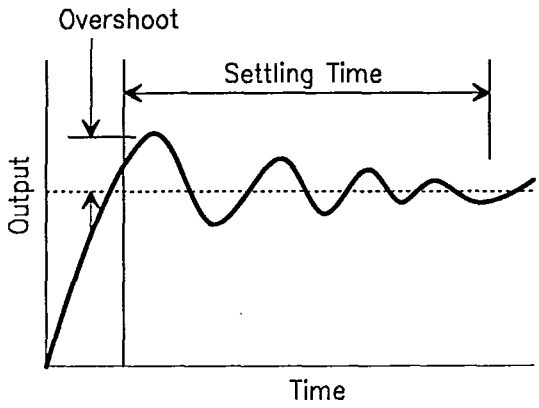


Figure 1-16
OVERSHOOT AND SETTLING TIME

PHASE RESISTANCE

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

POSITIONAL ERROR

(Sometimes designated "Absolute Accuracy")

Positional error is the deviation from the theoretically correct angular position of any step position in a complete revolution. 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.

PULL-IN STEP RATE (Error Free Stop/Start)

Pull-in step rate is the maximum command pulse rate (constant) at which the energized stepper motor can accelerate an applied load from standstill to synchronism with the command pulse step rate without missing steps. Conditions shall be specified.

PULL-IN TORQUE

Pull-in torque is the maximum coulomb friction torque at which an energized stepper motor will accelerate to command pulse step rate and run in synchronism with the command pulse rate without losing steps, under specified conditions.

PULL-OUT STEP RATE

Pull-out step rate is the maximum command pulse rate (constant) at which the energized stepper motor can run in synchronism with the command pulse rate and under specified conditions.

PULL-OUT TORQUE

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

RATED CURRENT

Rated current is the direct current, the ripple content of which has no perceptible effect on heating, that when applied to the windings of a horizontally-mounted motor at a specified ambient temperature with specified heatsinking if used (with no auxiliary cooling), will result in maximum allowable winding temperature in accordance with 2.2.1.

RESONANT STEP RATES

(Including parametric instability)

Resonant step rates are those step rates at which the motor will miss steps when operating below the curve of pull-out torque versus step rate under specified conditions.

SETTLING TIME

Settling time is the 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. See Figure 1-16.

SINGLE STEP RESPONSE

Single step response is the response to a single step command that includes single step time, overshoot, and settling time. See Figure 1-17.

The single step response will be controller dependent.

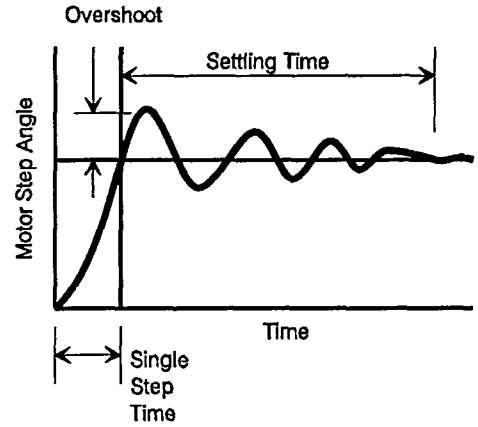


Figure 1-17
SINGLE-STEP RESPONSE

SINGLE STEP TIME

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

STATIC LOAD ANGLE

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

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STEP

Full-Step (also called "Basic Step Angle")

The 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. 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 stepper motor is given by:

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

Where:

A = Number of stator pole pairs per phase
B = Number of phases
C = Number of north/south pairs of rotor salients, but never less than "A"

Half-Step

The 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.

Micro-Step

(Sometimes called "Mini-Step")

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

STEP ANGLE ERROR

(Sometimes designated "Incremental Step Accuracy")

The step angle error is the 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. It is expressed as a percent of the angle of the nominal step.

STEP POSITION

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

STEP SEQUENCE

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

STEPPER MOTOR

A stepper motor is a 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. Rotation occurs because of the magnetic interaction between the rotor poles and the poles of the sequentially energized stator phases.

Permanent Magnet (PM)

A permanent magnet stepper motor utilizes a rotor that has permanently magnetized poles.

Variable Reluctance (VR) Stepper Motors

A variable reluctance stepper motor utilizes a rotor that has pole salients (soft iron) without magnetic bias in the de-energized state.

Hybrid (HY)

A hybrid stepper motor utilizes a permanent magnet to polarize soft iron pole pieces.

STEPPING RATE

The stepping rate is the number of step angles through which the stepper motor rotates in a specified time.

STEPS PER REVOLUTION

The steps per revolution are the number of discrete steps for one motor revolution.

STIFFNESS

(Sometimes called Torque Gradient)

Stiffness is the derivative (slope) of the torque versus angle curve at the stable equilibrium point. The curve is the sum of the stiffness due to holding torque and detent torque.

SYNCHRONISM

Synchronism is the 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.

TORQUE GRADIENT

See Stiffness for definition.

VELOCITY MODULATION

Velocity modulation is a periodic function superimposed on the average angular velocity. The peak-to-peak amplitude is expressed as a percent of the mean velocity.

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1.2.3.4 SYMBOLS FOR QUANTITIES AND THEIR UNITS

The following symbols for quantities and their units pertain to servo and stepper motors, their controls, and their systems.

Quantity Symbol	Definition	Unit Symbols	
		SI	English
cw	clockwise rotation		
ccw	counter-clockwise rotation		
D	viscous damping factor	Nm·s/rad	lb·in.·sec/rad
E_g	internally generated voltage (counter EMF)	V	V
f	frequency	H_z	H_z
I	current	A	A
I_{cs}	continous stall current	A	A
I_{pk}	peak current	A	A
J	moment of inertia	$kg·m^2$	$lb·in.·sec^2$
J_L	load moment of inertia	$kg·m^2$	$lb·in.·sec^2$
J_r	mass moment of inertia with respect to the rotational axis of the rotor	$kg·m^2$	$lb·in.·sec^2$
K_D	damping coefficient	Nm·s/rad	lb·in.·sec/rad
K_E	voltage constant	V·s/rad	V·sec/rad*
K_M	motor constant	$Nm/\sqrt{W}$	$lb·in./\sqrt{W}$
K_T	torque constant	Nm/A	lb·in./A
L	inductance	H	H
M	mass	kg	slug
n	rotational speed, shaft speed	r/min, kr/min	rpm, krpm
N	gear ration	—	—
P	lead screw pitch	rev/mm	rev/inch
P_o	output power, watts	W	W
PM	permanent magnet	—	—
r	radius	m	inch
R	resistance	Ω	Ω
R_a	armature winding resistance	Ω	Ω
R_b	brush resistance	Ω	Ω
R_{mt}	motor terminal resistance	Ω	W
R_{th}	thermal resistance	°C/W	°C/W
SI	international system of units (metric system)	—	—
t	time	s	sec
t_i	time interval	s	sec
t_f	fall time	s	sec
t_r	rise time	s	sec

* KRPM × 104.7 = rad/sec

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Quantity Symbol	Definition	Unit Symbols	
		SI	English
T	torque	Nm	lb·in.
T_i	torque per time interval, ti	Nm	lb·in.
T_a	accelerating torque	Nm	lb·in.
T_{cs}	continuous stall torque	Nm	lb·in.
T_D	damping torque Td = D·w	Nm	lb·in.
T_f	internal friction torque	Nm	lb·in.
T_L	load torque	Nm	lb·in.
T_{pk}	peak torque	Nm	lb·in.
V	voltage	V	V
Vpk	peak voltage	V	V
V_s	supply voltage	V	V
W	power (watts)	W	W
α	angular acceleration $\alpha = \frac{d\omega}{dt}$	rad/s^2	rad/sec^2
α_m	maximum theoretical acceleration from stall	rad/s^2	rad/sec2
ϕ	angular displacement	rad,°, r	rad,°, rev
τ	time constant	s	sec
τ_e	electrical time constant	s	sec
τ_m	mechanical time constant	s	sec
τ_{th}	thermal time constant	s	sec
ω	angular velocity $\omega = \frac{d\phi}{dt}$	rad/s	rad/sec
°	angular degree	—	—

CONVERSION FACTORS:

MULTIPLY:	BY:	TO OBTAIN:
lb·in.	0.113	N·m
lb·in./krpm	9.55×10^{-3}	lb·in.·sec/rad
lb·in./krpm	1.079×10^{-3}	N·m·s/rad
lb·in.·sec^2	0.113	$kg·m^2$
lb·in./krpm	113.0×10^{-3}	N·m·min/r
slug	14.6	Kg
inch	25.4	mm
krpm	104.7	rad/sec

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1.3 SAFETY STANDARD FOR CONSTRUCTION AND GUIDE FOR SELECTION, INSTALLATION AND OPERATION OF MOTION CONTROL SYSTEMS

1.3.1 General Considerations

Users and manufacturers of 1) driven equipment; 2) the motors; and 3) the electrical equipment for supplying and controlling the power should work together to assemble systems that work safely. The degree of hazard can be greatly reduced by proper design, construction, installation, maintenance, and operator training. While compliance with this publication does not assure a safe installation, cooperation of the system designers in conjunction with this publication should result in a safely operating system.

The importance of communication between manufacturer and user cannot be overemphasized. The chances for preventing hazardous incidents and limiting their consequences are greatly improved when both user and manufacturer are correctly and fully informed with respect to the intended use and all environmental and operating conditions.

1.3.2 Motion Control System

The term "motion control system" as used throughout this publication denotes the motor or motors, controls, and feedback devices as interconnected components. The motion control system may consist of a number of enclosures and other parts which may be assembled at the factory or installation site.

1.3.3 Construction

1.3.3.1 RATING AND IDENTIFICATION PLATES

A legible, durable nameplate shall be attached to each motion control system component and shall, as a minimum, include the data required by items a, b, and c.

a. Motor nameplate, Section 2.5
b. Control nameplate, Section 3.4
c. Feedback device nameplate (under consideration)

1.3.3.2 OPERATING AND MAINTENANCE DATA

Instruction documents should be furnished and should include at least the following:

a. Information necessary for calibrating components, devices and subassemblies which are intended to be adjusted by the user
b. Information to allow for the proper selection of the input circuit equipment and protection when an electronic power converter is designed for use in different applications with a range of load ratings
c. Operating instructions, including all information necessary to operate the complete drive system
d. Maintenance instructions, including information for locating and replacing faulty components or subassemblies
e. Appropriate warning notices where safety considerations exist.

Documents should be of such a size and quality as to be clearly legible.

1.3.3.3 SUPPLY CIRCUIT DISCONNECTING DEVICES

When disconnecting devices are supplied as part of the motion control system they shall meet the requirements of the National Electrical Code, Article 430, Part H., "Disconnecting Means."

1.3.3.4 PROTECTION

1.3.3.4.1 Interrupting Capacity

Devices which are intended to break short-circuit current shall have an interrupting capacity sufficient for the voltage used and for the current that must be interrupted when the control equipment or drive system is connected to a power supply having the capacity to apply maximum voltage and maximum available short-circuit current within the limits specified for the equipment.

1.3.3.4.2 Control Circuit

The motor control circuit shall meet the pertinent requirements of the National Electrical Code.

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Section 2
MOTORS

2.1 DEFINITIONS

For definitions not found in Section 1, refer to ANS/IEEE Std. 100.

2.2 RATINGS

The following performance ratings pertain to servo and stepper motors.

2.2.1 Maximum Allowable Winding Temperature for Stepper Motors

The maximum allowable winding temperature for stepper motors shall not exceed the values given in Table 2-1 when tested for rated current in accordance with 2.6.3.1.

Table 2-1
INSULATION SYSTEM CLASSIFICATION

Class	Maximum Allowable Winding Temperature
A	105°C
B	130°C
F	155°C
H	180°C

2.2.2 Maximum Allowable Winding Temperature for Servo Motors

The maximum allowable winding temperature for servo motors may be limited by the class of insulation used, or it may be limited to a lower value to protect magnets, mechanical structures, or attached feedback devices. The limiting temperatures based on class of insulation shall be determined from one of the following tables:

a. For dc servo motors (brush type) excluding moving coil motors, and for brushless dc motors with stator windings on the inner member, the temperature rise limit based on insulation class shall not exceed that shown in Table 2-2.
Temperatures shall be determined in accordance with IEEE Std 113.

b. For brushless dc motors with the windings on the outer member, moving coil dc motors, and induction servo motors, temperature limit based on insulation class shall not exceed that shown in Table 2-3 .
Temperatures shall be determined in accordance with IEEE Std 112 except for moving coil motors which shall be determined in accordance with IEEE Std 113.

Table 2-2
MOTORS WITH ALL ENCLOSURES

Class of Insulation System:	A	B	F*	H*
Time Rating:	Continuous			
Temperature, Degrees C:				
1. Armature windings, by resistance method	110	140	170	195
2. Armature windings, by alternative method	110	130	155	180
The temperatures attained by cores, commutators, and miscellaneous parts (such as brushholders, brushes, pole tips, etc.) shall not injure the insulation or the machine in any respect.				

*Where a Class F or H insulation system is used, special consideration should be given to bearing temperatures, lubrication, and such.

NOTE—The foregoing values of temperature are based upon operation at altitudes of 3300 feet (1000 meters) or less. For temperature rises for motors intended for operation at altitudes above 3300 feet (1000 meters), see 2.2.4.

Table 2-3
MOTORS WITH ALL ENCLOSURES

Class of Insulation System:	A	B	F*	H*
Time Rating:	Continuous			
Temperature, Degrees C:				
1. Windings, by resistance method	110	130	155	180
2. The temperatures attained by cores, squirrel-cage windings, commutators, collector rings, and miscellaneous parts (such as brusholders, brushes, pole tips, uninsulated shading coils, etc.) shall not injure the insulation or the machine in any respect.				

*Where a Class F or H insulation system is used, special consideration should be given to bearing temperatures, lubrication, etc.

NOTE—The foregoing values of temperature rise are based upon operation at altitudes of 3300 feet (1000 meters) or less. For temperature rises for motors intended for operation at altitudes above 3300 feet (1000 meters), see 2.2.4.

When a higher ambient temperature than 40°C is required, preferred values of ambient temperature are 50°C, 65°C, 90°C, and 115°C.

2.2.3 Ambient Temperature

Stepper and servo motors shall be rated on the basis of a specific ambient temperature. The rated value of this

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ambient temperature shall be 40°C unless otherwise specified.

2.2.4 Operation at Altitudes Above 3300 Feet (1000 Meters)

The maximum temperature ratings given for machines in 2.2.2 are based upon operation at altitudes of 3,300 feet (1,000 meters) or less. It is also recognized as good practice to use machines at altitudes greater than 3,300 feet (1,000 meters) as indicated in the following paragraphs.

2.2.4.1 Machines that are intended for operation at altitudes above 3,300 feet (1,000 meters) should be designed with maximum sea level temperature that does not exceed the value calculated in the following way:

When altitude is in feet:

$$F_D = (\text{Altitude} - 3{,}300)/33{,}000$$

When altitude is in meters:

$$F_D = (\text{Altitude} - 1{,}000)/10{,}000$$

Then:

$$T_N = (T_R - T_A) \times (1 - F_D) + T_A$$

Where:

F_D = Altitude derating factor
T_R = Normal maximum allowable winding temperature
T_A = Design ambient temperature rating
T_N = New maximum allowable temperature at sea level

2.2.4.2 Preferred values of altitude are 3,300 feet (1,000 meters), 6,600 feet (2,000 meters), 9,900 feet (3,000 meters), 13,200 feet (4,000 meters), and 16,500 feet (5,000 meters).

2.3 ENCLOSURES

2.3.1 Scope

Information in 2.3 applies to the classification of degrees of protection provided by enclosures for rotating machines.

2.3.2 Object

The object of 2.3 is to describe:

a. Definitions for standard degrees of protection provided by enclosures applicable to electrical rotating machines as regards:
   1. Protection of persons against contact with or approach to live parts and against contact with moving parts (other than smooth rotating shafts and the like) inside the enclosure and protection of the machine against ingress of solid foreign objects
   2. Protection of machines against the harmful effects due to the ingress of water.
b. Designations for these protective degrees
c. Tests to be performed to check that the machines meet the requirements of this standard.

Paragraph 2.3 defines the requirements with which protective enclosures shall comply.

Paragraph 2.3 deals only with enclosures that are in all other respects suitable for their intended use and which from the point of view of materials and workmanship ensure that the properties dealt with in 2.3 are maintained under the normal conditions of use.

Paragraph 2.3 does not specify degrees of protection against mechanical damage of the machine, or conditions such as moisture (produced for example by condensation) corrosive vapors, fungus, or vermin.

Paragraph 2.3 does not specify types of protection of machines for the use in an explosive atmosphere.

Fences external to the enclosure that have to be provided solely for the safety of personnel are not considered part of the enclosure and are not dealt with.

2.3.3 Designation

The designation used for the degree of protection consists of the letters IP followed by two characteristic numerals signifying conformity with the conditions indicated in the tables of 2.3.4 and 2.3.5 respectively.

2.3.3.1 SINGLE CHARACTERISTIC NUMERAL

When it is required to indicate a degree of protection by only one characteristic numeral, the omitted numeral shall be replaced by the letter X. For example IPX5 or IP2X.

2.3.3.2 SUPPLEMENTARY LETTERS

Additional information may be indicated by a supplementary letter.

2.3.3.2.1 Letters Following Numerals

In special applications (such as machines with open circuit cooling for ship deck installation with air inlet and outlet openings closed during standstill) numerals may be followed by a letter indicating whether the protection against harmful effects due to ingress of water was verified or tested for the machine not running (letter S) or the machine running (letter M). In this case the degree of protection in either state of the machine shall be indicated, for example IP55S/IP20M.

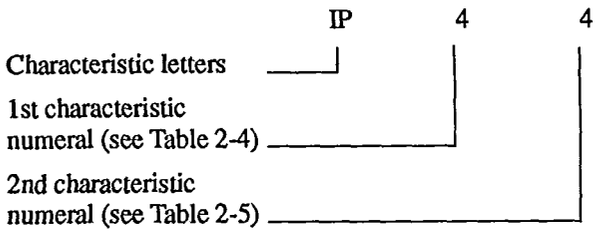
The absence of the letters S and M shall imply that the intended degree of protection will be provided under all normal conditions of use.

2.3.3.2.2 Letters Placed Immediately After the Letters IP

For machines suitable for use under specified weather conditions and provided with additional protective features or processes, the letter W (placed immediately after the letters IP) may be used.

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2.3.3.3 EXAMPLE OF DESIGNATION



2.3.4 Degrees of Protection—First Characteristic Numeral

2.3.4.1 The first characteristic numeral indicates the degree of protection provided by the enclosure with respect to persons and also to the parts of the machine inside the enclosure.

Table 2-4 gives, in column 3, brief details of objects that will be "excluded" from the enclosure for each of the degrees of protection represented by the first characteristic numeral.

The term "excluded" implies that a part of the body, or a tool or a wire held by a person, either will not enter the machine or, if it enters, that adequate clearance will be maintained between it and the live parts or dangerous moving parts (smooth rotating shafts and the like are not considered dangerous).

Column 3 of Table 2-4 also indicates the minimum size of solid foreign objects that will be excluded.

2.3.4.2 Compliance of an enclosure with an indicated degree of protection implies that the enclosure will also comply with all lower degrees of protection in Table 2-4. In consequence, the tests establishing these lower degrees of protection are not required, except in case of doubt.

Table 2-4
DEGREES OF PROTECTION INDICATED BY THE FIRST CHARACTERISTIC NUMERAL

First Characteristic Numeral	Degree of Protection		Test Conditions
	Brief Description*	Definition	
0	Non-protected machine	No special protection	No test, but see 2.3.4.3
1**	Machine protected against solid objects greater than 50 mm	Accidental or inadvertent contact with or approach to live and moving parts inside the enclosure by a large surface of the human body, such as a hand (but no protection against deliberate access). Ingress of solid objects exceeding 50 mm in diameter.	See 2.3.8
2**	Machine protected against solid objects greater than 12mm	Contact by fingers or similar objects not exceeding 80 mm in length with or approach to live or moving parts inside the enclosure. Ingress of solid objects exceeding 12 mm in diameter.	See 2.3.8
3**	Machine protected against solid objects greater than 2.5 mm	Contact with or approach to live or moving parts inside the enclosure by tools or wires exceeding 2.5 mm in diameter. Ingress of solid objects exceeding 1 mm in diameter.	See 2.3.8
4**	Machine protected against solid objects greater than 1 mm	Contact with or approach to live or moving parts inside the enclosure by wires or strips of thickness greater than 1 mm in diameter.	See 2.3.8
5=	Dust-protected machine	Contact with or approach to live or moving parts inside the enclosure. Ingress of dust is not totally prevented but dust does not enter in sufficient quantity to interfere with satisfactory operation of the machine.	See 2.3.8
6=	Dust-tight machine	Contact with or approach to live or moving parts inside the enclosure. No ingress of dust.	See 2.3.8

*The brief description given in column 2 on this table should not be used to specify the form of protection.

**Machines assigned a first characteristic numeral 1, 2, 3 or 4 will exclude both regularly or irregularly shaped solid objects provided that three normally perpendicular dimensions of the object exceed the appropriate figure in column "Definition."

=The degree of protection against dust defined by this standard is a general one. When the nature of the dust (dimensions of particles, their nature, for instance fibrous particles) is specified, test conditions should be determined by agreement between manufacturer and user.

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2.3.4.3 EXTERNAL FANS

The blades and spokes of fans external to the enclosure shall be protected against contact by means of guards complying with the following requirements:

Protection of machine	Test of fan
IP 0X	—
IP 1X	50 mm sphere test
IP 2X to IP 5X	Finger test

For the test, the rotor is slowly rotated by hand.

Smooth rotating shafts and similar parts are not considered dangerous.

NOTE—In certain applications (such as agricultural or domestic appliances) more extensive precautions against accidental or deliberate contact may be required if specified.

2.3.4.4 DRAIN HOLES

If the machine is provided with drain holes, the following shall apply:

a. Drain holes intended normally to be open on site shall be kept open during testing.

b. Drain holes intended normally to be closed on site shall be kept closed during testing.

c. If machines with protection IP 3X or IP 4X are intended to be run with open drain holes, the drain holes may comply with protection IP 2X.

d. If machines with protection IP 5X are intended to be run with open drain holes, the drain holes shall comply with protection IP 4X.

2.3.5 Degrees of Protection—Second Characteristic Numeral

2.3.5.1 GENERAL

The second characteristic numeral indicates the degree of protection provided by the enclosure with respect to harmful effects due to ingress of water.

Table 2-5 gives, in column 3, details of the type of protection provided by the enclosure for each of the degrees of protection represented by the second characteristic numeral.

A machine is *weather-protected* when its design reduces the ingress of rain, snow, and airborne particles, under

Table 2-5
DEGREES OF PROTECTION INDICATED BY THE SECOND CHARACTERISTIC NUMERAL

Second Characteristic Numeral	Degree of Protection		Test Conditions
	Brief Description	Definition	
0	Non-protected machine	No special protection	No test
1	Machine protected against dripping water	Dripping water (vertically falling drops) shall have no harmful effect.	See 2.3.8
2	Machine protected against dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the machine is tilted at any angle up to 15° from its normal position.	See 2.3.8
3	Machine protected against spraying water	Water falling as a spray at an angle up to 60° from the vertaical shall have no harmful effect.	See 2.3.8
4	Machine protected against splashing water	Water splashing against the machine from any direction shall have no harmful effect.	See 2.3.8
5	Machine protected against water jets	Water projected by a nozzle against the machine from any direction shall have no harmul effect.	See 2.3.8
6	Machine protected against heavy seas	Water from heavy seas or water projected in powerful jets shall not enter the machine in harmful quantities.	See 2.3.8
7	Machine protected against the effects of immersion	Ingress of water in the machine in a harmful quantity shall not be possible when the machine is immersed in water under stated conditions of pressure and time.	See 2.3.8
8	Machine protected against continuous submersion	The machine is suitable for continuous submersion in water under conditions which shall be specified by the manufacturer. Note—Normally, this will mean that the machine is hermetically sealed. However with certain types of machines it can mean that water can enter but only in such a manner that it produces no harmful effect.	See 2.3.8

NOTE—The brief description given in column 2 of this table should not be used to specify the form of protection.

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specified conditions, to an amount consistent with correct operation.

This degree of protection is designated by the letter "W" placed immediately after the two letters IP.

2.3.5.2 LOWER DEGREES OF PROTECTION

Compliance of an enclosure with an indicated degree of protection implies that the enclosure will also comply with all lower degrees of protection in Table 2-5.

In consequence, the tests establishing these lower degrees of protection are not required, except in case of doubt.

2.3.6 Additional Degrees of Protection

The letter "V" placed between IP and the numerals designates a machine that has been tested for hazardous rotating parts and enameled insulated wire by substituting the probes shown in Figure 2-1 and Figure 2-2 for the probe shown in Figure 2-3, respectively. The letter "V" is intended for use only with small machines.

2.3.7 Commonly Used Degrees of Protection

The most frequently used degrees of protection for electrical machines are given in Table 2-6.

2.3.8 Marking

It is recommended that the characteristic letters and numerals be marked on the machine preferably on the rating plate, or, if this is not practicable, on the enclosure.

When all parts of a machine don't have the same degree of protection, the designation of the lowest degree shall be shown first, followed if applicable by the other designation with reference to the part to which it applies.

Where the mounting of the machine has an influence on the degree of protection, the intended mounting arrangement shall be indicated by the manufacturer on the rating plate or in his instructions for mounting or the like.

Table 2-6
DESIGNATION FOR COMMONLY USED DEGREES OF PROTECTION FOR STEPPER AND SERVO MOTORS

1st Characteristic Numeral	2nd Characteristic Numeral						
	0	2	4	5	6	7	8
0							
1		IP12					
2		IP22	IP24				
3			IP34	IP35			
4			IP44	IP45			
5			IP54	IP55	IP56	IP57	
6				IP65		IP67	

2.3.9 General Requirements for Tests

Test and acceptance conditions shall be in accordance with NEMA Standards Publication MG 1.

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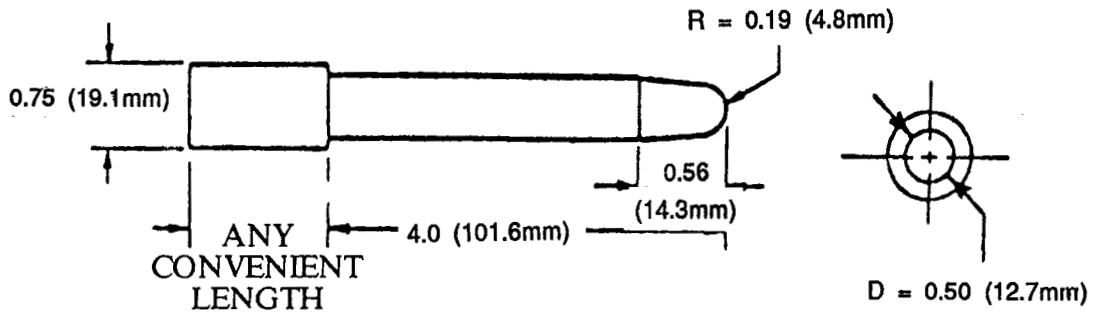


Figure 2-1
PROBE FOR HAZARDOUS ROTATING PARTS

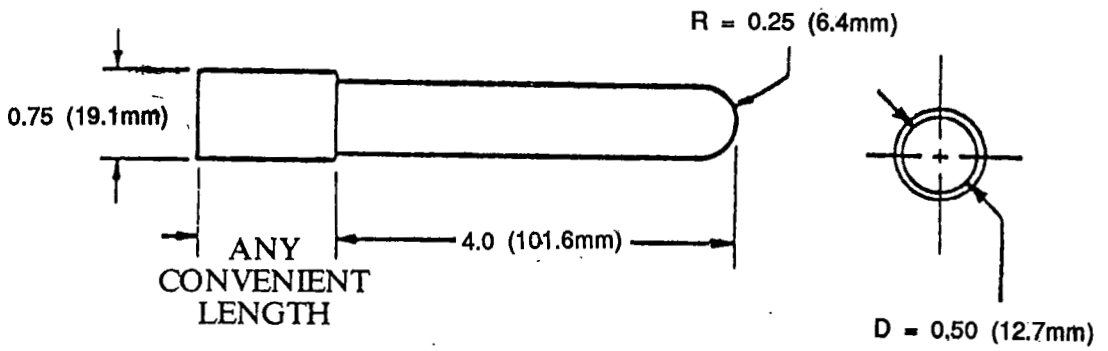


Figure 2-2
PROBE FOR FILM-COATED WIRE

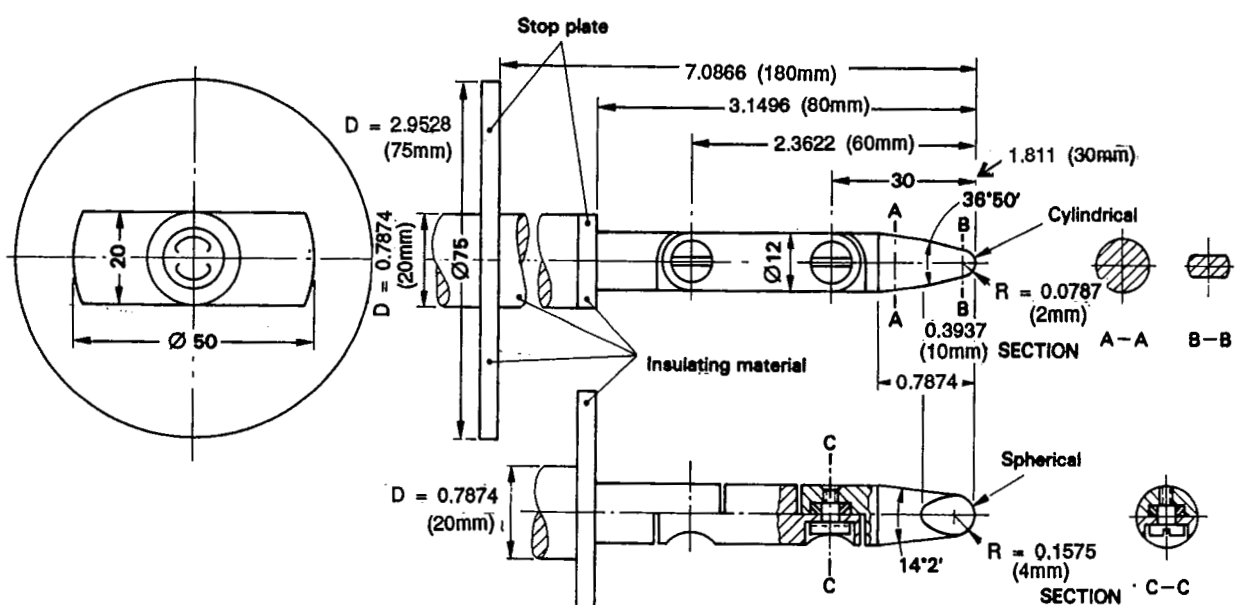


Figure 2-3
ARTICULATED PROBE
(Courtesy of IEC)

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2.4 DIMENSIONS, TOLERANCES, AND MOUNTING

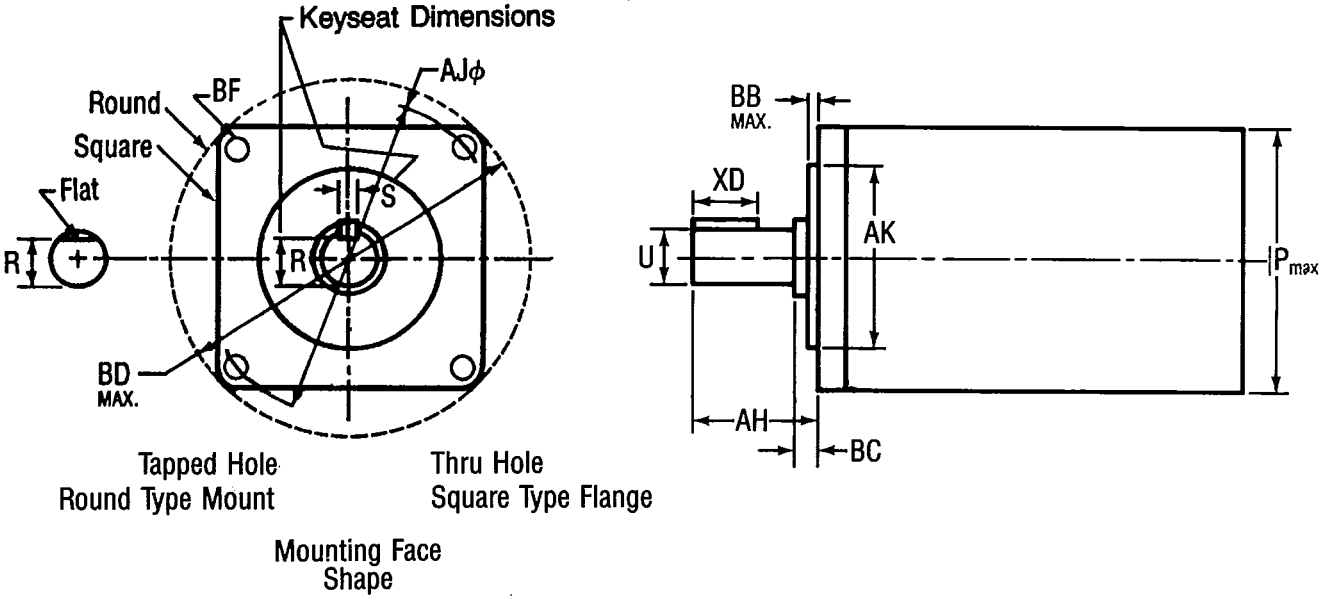
2.4.1 Dimensions for Servo Motors

2.4.1.1 ENGLISH DIMENSIONS

(Under consideration.)

2.4.1.2 METRIC MOUNTING DIMENSIONS

Dimension sheets shall be lettered in accordance with Figure 2-4.



AJ	Diameter of mounting bolt circle in face, flange or base of machine.	BB_{max}	Maximum depth of male or female pilot of mounting face, flange or base of machine.
AK	Diameter of male or female pilot on face, flange or base of machine.	BF	Threaded or clearance hole in mounting face, flange or base of machine.
AH	Mounting surface of face, flange or base of machine to end of shaft.	XD	Usable length of keyseat.
U	Diameter of shaft extension.	S	Width of keyseat.
P_{max}	Maximum width of machine (end view) including pole bolts, fins, and such, but excluding terminal housing, lifting devices, feet and outside diameter of face or flange.	R	Bottom of keyseat or flat to opposite side of shaft or bore.
BD_{max}	Maximum outside diameter of mounting face, flange, or base of machine.	BC	Distance between mounting surface of face, flange or base of machine to shoulder on shaft.

Figure 2-4
LETTERING OF DIMENSION SHEETS FOR SERVO MOTORS

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2.4.1.3 METRIC MOUNTING DIMENSIONS FOR SERVO MOTORS

Flange	Number	AJ mm	AK mm	AK Tol mm	AH mm Pri	AH mm Sec	U mm Pri	U mm Sec	U Tol mm Pri	U Tol mm Sec	BC mm	Pmax/BDmax mm	BBmax mm	BF mm	BF Tol mm	Thread	XD mm Pri	XD mm Sec	S mm Pri	S mm Sec
55CM	55DM	55	40	+0.011 - 0.005	20	30	9	14	+0.007 - 0.002	+0.008 - 0.003	0	70	2.5	5.8	+.300 - 0	M5×0.8	15	20	3×3	5×5
65CM	65DM	65	50	+0.011 - 0.005	20	30	9	14	+0.007 - 0.002	+0.008 - 0.003	0	80	2.5	5.8	+.300 - 0	M5×0.8	15	20	3×3	5×5
75CM	75DM	75	60	+0.012 - 0.007	23	40	11	16	+0.008 - 0.003	+0.008 - 0.003	0	90	2.5	5.8	+.300 - 0	M5×0.8	18	30	4×4	5×5
85CM	85DM	85	70	+0.012 - 0.007	30	40	14	19	+0.008 - 0.003	+0.009 - 0.004	0	105	2.5	7	+.360 - 0	M6×1.0	20	30	5×5	6×6
100CM	100DM	100	80	+0.012 - 0.007	30	40	14	19	+0.008 - 0.003	+0.009 - 0.004	0	120	3	7	+.360 - 0	M6×1.0	20	30	5×5	6×6
115CM	115DM	115	95	+0.013 - 0.009	40	50	19	24	+0.009 - 0.004	+0.009 - 0.004	0	140	3	10	+.360 - 0	M8×1.25	30	40	6×6	8×7
130CM	130DM	130	110	+0.013 - 0.009	40	50	19	24	+0.009 - 0.004	+0.009 - 0.004	0	160	3.5	10	+.360 - 0	M8×1.2	30	40	6×6	8×7
145CM	145DM	145	110	+0.013 - 0.009	40	50	19	28	+0.009 - 0.004	+0.009 - 0.004	0	165	3.5	10	+.360 - 0	M8×1.2	30	40	6×6	8×7
165CM	165DM	165	130	+0.014 - 0.011	50	50	24	28	+0.009 - 0.004	+0.009 - 0.004	0	200	3.5	12	+.430 - 0	M10×1.5	40	40	8×7	8×7
200CM	200DM	200	114.3	+0.0 - 0.025	79	—	35	—	+0.01 - 0.00	—	0	235	4	13.5	+.430 - 0	M12×1.75	70	—	10×8	—
215CM	215DM	215	180	+0.014 - 0.011	60	—	32	—	+0.018 +0.002	—	0	250	4	15	+.430 - 0	M12×1.75	50	—	10×8	—
265CM	265DM	265	230	+0.016 - 0.013	85	—	48	—	+0.018 +0.002	—	0	300	4	15	+.430 - 0	M12×1.75	60	—	14×9	—
300CM	300DM	300	250	+0.016 - 0.013	85	—	48	—	+0.018 +0.002	—	0	350	5	19	+.520 - 0	M16×2.0	60	—	14×9	—
350CM	350DM	350	300	+0.016 - 0.016	110	—	55	—	+0.030 +0.011	—	0	400	5	19	+.520 - 0	M16×2.0	90	—	16×10	—

NOTES

1—The suffix CM denotes C face-mounting motors with tapped mounting holes. The suffix DM denotes D flange-mounting motors with free-mounting holes.

2—The reference for the tolerances is ISO Recommendation 286, S.I. Metric System of Limits and Fits. If a stepper motor is designed to be a direct substitute for servo motors in servo motor applications, the stepper motor dimensions should comply with the dimensions specified for servo motors.

2.4.2 Dimensions for Stepper Motors

2.4.2.1 English dimensions shall be lettered in accordance with Figure 2-5.

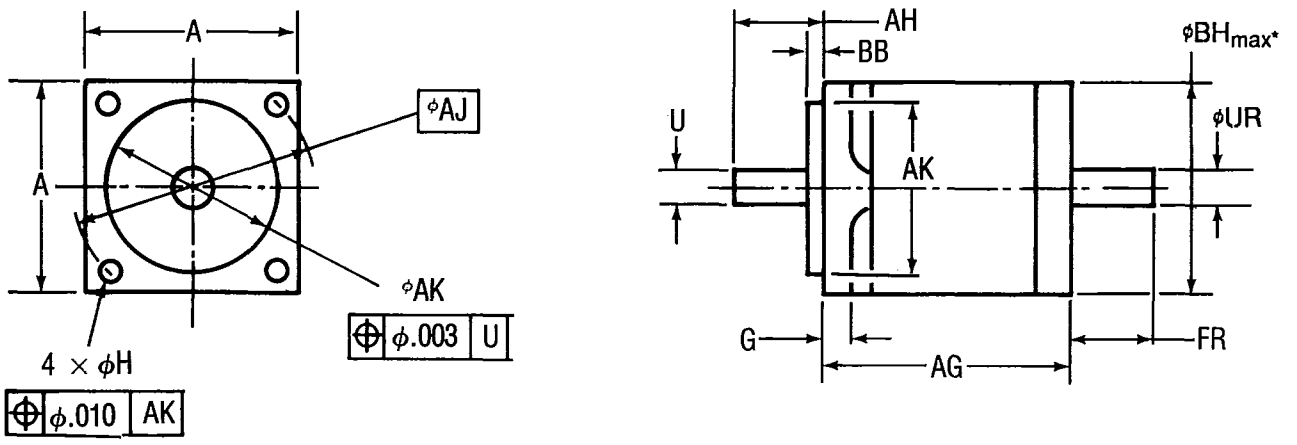


Figure 2-5
LETTERING OF DIMENSION SHEETS FOR HYBRID STEPPER MOTORS

*BHmax—Basic body diameter not including connection means.

*These dimensions apply to hybrid stepper motors. Other stepper motors may have similar dimensions.

NEMA Letter	IEC Letter	
A	P	Outside diameter of mounting face, flange, or base of machine
G	LA	Thickness of mounting flange or base of machine
U	D	Diameter to shaft extension, drive end
AG	LB	Mounting surface of face, flange, or base of machine to opposite end of housing (side view)
AH	...	Mounting surface of face, flange, or vase of manine to end of shaft
AJ	M	Diameter of mounting bolt circle in face, flange, or base of machine
AK	N	Diameter of male or female pilot on face, flange, or base of machine
BB	T	Depth of male or female pilot of mounting face, flange, or base of machine
BH	...	Outside diameter of core or shell (side view)
FR	...	Length of shaft from end of housing to end of shaft, end opposite the drive
UR	...	Diameter of shaft extension, end opposite the drive

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2.4.2.2 ENGLISH MOUNTING DIMENSIONS FOR HYBRID STEPPER MOTORS

NEMA DIA. and Length Code*	23C016 23D016	23C021 23D021	23C025 23D025	23C031 23D031	23C035 23D035	23C041 23D041	23C045 23D045
Industry Frame Size (Ref)	23	23	23	23	23	23	23
Dimension Symbol			Dimension (Inches)				
A	<-	-	-	- 2.27 -	-	-	->
AG	1.6	2.1	2.5	3.1	3.5	4.1	4.5
AH	<-	-	-	- 0.85/0.78 -	-	-	->
AJ	<-	-	-	- 2.625 -	-	-	->
AK	<-	-	-	- 1.502/1.498 -	-	-	->
BB	<-	-	-	- 0.140/0.030 -	-	-	->
BH	<-	-	-	- 2.3 -	-	-	->
FR	<-	-	-	- 0.80/0.55 -	-	-	->
G	<-	-	-	- 0.232/0.156 -	-	-	->
H	<-	-	-	- 0.215/0.195 -	-	-	->
U	<-	-	-	0.2500/0.2495	-	-	->
UR	<-	-	-	0.2500/0.2494	-	-	->

*Length code is optional and may be deleted or used as deemed necessary by the manufacturers.

NEMA DIA. and Length Code*	34C025 34D025	34C032 34D032	34C038 34D038	34C046 34D046	34C051 34D051	34C059 34D059	
Industry Frame Size (Ref)	34	34	34	34	34	34	
Dimension Symbol			Dimension (Inches)				
A	<-	-	-	- 3.42 -	-	->	
AG	2.5	3.2	3.8	4.6	5.1	5.9	
AH	<-	-	-	- 1.31/1.16 -	-	->	
AJ	<-	-	-	- 3.875 -	-	->	
AK	<-	-	-	- 2.877/2.873 -	-	->	
BB	<-	-	-	- 0.140/0.030 -	-	->	
BH	<-	-	-	- 3.42 -	-	->	
FR	<-	-	-	- 1.23/1.13 -	-	->	
G	<-	-	-	- 0.25/0.18 -	-	->	
H	<-	-	-	- 0.228/0.213 -	-	->	
U	<-	-	-	- 0.3750/0.3745 -	-	->	
UR	<-	-	-	- 0.3750/0.3745 -	-	->	

*Length code is optional and may be deleted or used as deemed necessary by the manufacturers.

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NEMA DIA. and Length Code*	42C048 42D048	42C055 42D055	42C070 42D070	42C077 42D077	42C089 42D089	42C105 42D105	
Industry Frame Size (Ref)	42	42	42	42	42	42	
Dimension Symbol			Dimension (Inches)				
A	<----------	----------	------4.38------		----------	--------->	
AG	4.8	5.5	7.0	7.7	8.9	10.5	
AH	<----------	----------	-----1.42/1.22-----		----------	--------->	
AJ	<----------	----------	-------4.950------		----------	--------->	
AK	<----------	----------	-----2.188/2.184----		----------	--------->	
BB	<----------	----------	-----0.140/0.050----		----------	--------->	
BH	<----------	----------	-------4.27-------		----------	--------->	
FR	<----------	----------	------1.35/1.15----		----------	--------->	
G	<----------	----------	------0.57/0.28----		----------	--------->	
H	<----------	----------	-----0.330/0.210----		----------	--------->	
U	<---- 0.3750/0.3745 ---->		<------0.6250/0.6245 (Note 1)----		----------	--------->	
UR	<----------	----------	0.5000/0.4995 (Note 2)		----------	--------->	

NOTES

1—0.5000/0.4995 inch diameter shafts are supplied by some manufacturers.

2—0.3750/0.3745 inch diameter shafts are supplied by some manufacturers.

*Length code is optional and may be deleted or used as deemed necessary by the manufacturers.

NEMA DIA. and Length Code*	66C110 66D110	66C122 66D122	66CX 66DX	66C 66D	66C 66D	66C 66D	
Industry Frame Size (Ref)	66	66	66	66	66	66	
Dimension Symbol			Dimension (Inches)				
A	<----------	----------	-------6.39-------		----------	--------->	
AG	11.0	12.2	Not Specified				
AH	<----------	----------	------1.77/1.73----		----------	--------->	
AJ	<----------	----------	-------7.512------		----------	--------->	
AK	<----------	----------	-----2.752/2.748----		----------	--------->	
BB	<----------	----------	-----0.150/0.120----		----------	--------->	
BH	<----------	----------	--------6.6-------		----------	--------->	
FR	<----------	----------	------1.66/1.58----		----------	--------->	
G	<----------	----------	-----0.52/0.46-----		----------	--------->	
H	<----------	----------	-----0.423/0.404----		----------	--------->	
U	<----------	----------	----0.6250/0.6245---		----------	--------->	
UR	<----------	----------	----0.6250/0.6245---		----------	--------->	

*Length code is optional and may be deleted or used as deemed necessary by the manufacturers.

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2.4.2.3 METRIC STEPPER MOTOR MOUNTING DIMENSIONS

Refer to Figures 2-4 and 2-5 in conjunction with the following:

	Mounting Dimensions							Shaft Extensions					
Frame	AJ mm	AK mm	Tol. (AK) μm	P max, BD max mm	BB max. mm	BF mm	Tol. (BF) μm	AH mm	U mm	Tol. (U) μm	XD mm	S mm	R mm
D70	70	36	+11	82	3.5	5.8	+300	20	6	+6,-2	15	—	—*
			-5				-0	20	9	+7,-2	15	3	7.2**
D100	100	68	+12	120	3.5	5.8	+300	30	10	+7,-2	20	3	6.2*
			-7				-0	30	14	+8,-3	20	5	11**
D125	125	52	+12	155	3.5	7.0	+360	35	16	+8,-3	25	5	13*
			-7				-0	40	19	+9,-4	30	6	15.5**
D190	190	68	+12	233	4.0	10	+360	45	19	+9,-4	35	6	15.5*
			-7				-0	50	24	+9,-4	40	8	20**
D215	215	180	+14	250	4.0	15	+430	50	24	+9,-4	40	8	20*
			-11				-0	60	32	+18,+2	50	10	27**

If a servo motor is designed to be a direct substitute for stepper motors in stepper motor applications, the servo motor dimensions should comply with the dimensions specified for stepper motors.

Shaft Extensions:
*Preferred Series
**Secondary Series

2.4.3 Measurement and Tolerances

2.4.3.1 METHOD OF MEASUREMENT OF SHAFT RUNOUT AND OF ECCENTRICITY (CONCENTRICITY) AND FACE RUNOUT (PERPENDICULARITY) OF MOUNTING SURFACES

1. Shaft Runout
   The shaft runout shall be measured with the indicator stationary with respect to the motor and with its point at the end of the finished surface of the shaft. (See Figures 2-6 and 2-7 for typical fixtures.)
2. Pilot Eccentricity and Face Runout of Mounting Surfaces
   Pilot eccentricity and face runout of the mounting surfaces shall be measured with indicators mounted on the shaft extension. The point of the eccentricity indicator shall be at approximately the middle of the rabbet surface, and the point of the face runout indicator shall be at approximately the outer diameter of the mounting face. (See Figure 2-8 for typical fixture for "C" face or Figure 2-9 for "D" flange, approximately at the included diameter.)

   Read the maximum and minimum values on the indicators as the shaft is rotated slowly through 360 degrees. The difference between the readings shall not exceed the specified value.

   On ball-bearing motors, it is recommended that the test be made with the shaft vertical to minimize the effect of bearing clearances.

   Pilot eccentricity is sometimes called concentricity and face runout is sometimes called perpendicularity, although not strictly correct.

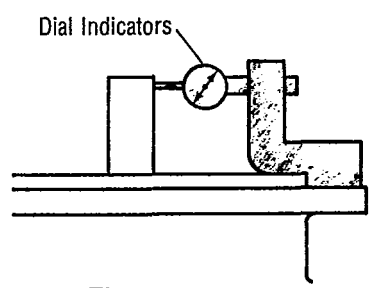


Figure 2-6

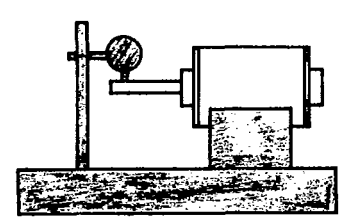


Figure 2-7

SHAFT RUNOUT TYPICAL MEASUREMENT TECHNIQUES

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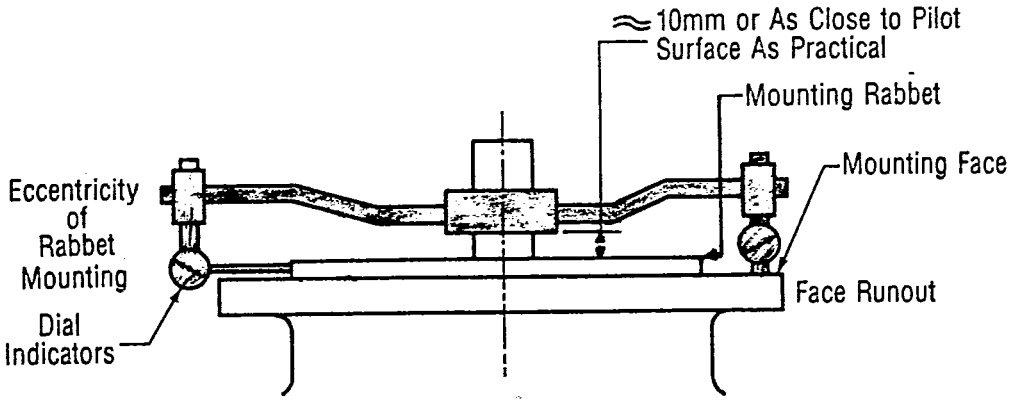


Figure 2-8
FACE RUNOUT MEASUREMENT FIXTURE FOR "C" FACE MOUNTING MOTORS

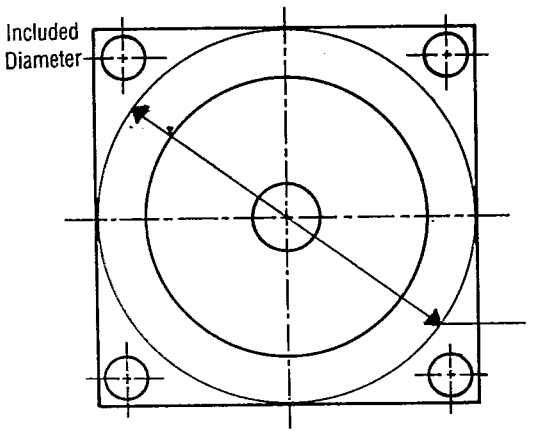


Figure 2-9
INCLUDED DIAMETER MEASUREMENT FOR "D" FLANGE MOUNTING MOTORS

2.4.3.2 TOLERANCES FOR SHAFT RUNOUT, PILOT ECCENTRICITY AND FACE RUNOUT (SERVO AND STEPPER)

NEMA Metric Frame		Runout at Shaft End			
		Normal		Precision	
Servo	Stepper	Metric	English (ref.)	Metric	English (ref.)
55–100	D70–D100	0.035mm*	0.0015 in*	0.025 mm	0.001 in
115–215	D70–D100 D125–D215	0.050 mm	0.002 in	0.035 mm*	0.0015 in*
265–350	—	0.075 mm	0.003 in	0.050 mm	0.002 in

*Not applicable to stepper motors.

NEMA Metric Frame		Pilot Eccentricity and Face Runout			
		Normal		Precision	
Servo	Stepper	Metric	English (ref.)	Metric	English (ref.)
55–100	D70–D100 D125=	0.080 mm	0.003 in	0.025 mm	0.001 in
130–265	—	0.100 mm	0.004 in	0.050 mm	0.002 in
300–350	D215=	0.125 mm	0.005 in	0.063 mm	0.0025 in

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2.4.3.3 TEST PROCEDURE FOR AXIAL END PLAY

Place a hub on the motor shaft and lock the motor in a test fixture, with a dial indicator touching the hub. See Figure 2-10.

Apply a force, F1, to the end of the shaft first in one direction and then in the other and note the maximum and minimum readings of the indicator. The axial end play is the difference between the maximum and minimum readings. Force F_1 is the maximum axial load rating of the motor.

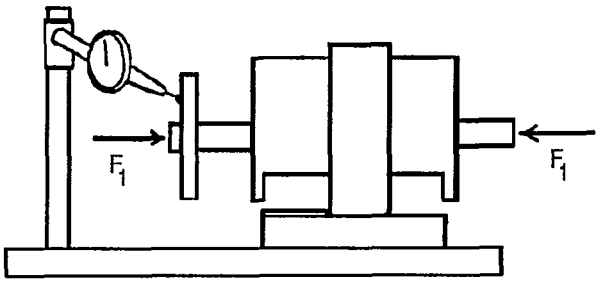


Figure 2-10
AXIAL END PLAY TEST SETUP

The support structure must be rigid so that it does not affect the indicator readings under the forces applied. Alternatively, mount the indicator to the motor face to make the indicator readings independent of the support structure.

2.4.3.4 TEST PROCEDURE FOR RADIAL PLAY

Place an indicator on the motor shaft or hub as close to the motor face as practicable and lock the motor in a test fixture with a dial indicator touching the periphery of the shaft or hub. See Figure 2-11.

Apply a force, F_2, at a distance "B" from the mounting surface, first in one vertical direction and then the other. Radial play is the total displacement measured. Force F_2 is the maximum radial load rating of the motor at distance "B" as specified by the manufacturer.

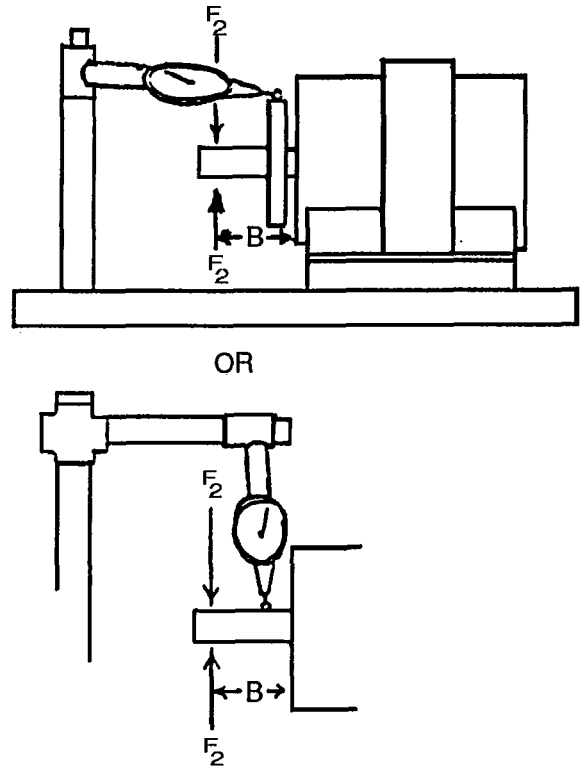


Figure 2-11
RADIAL PLAY TEST SETUP

2.5 NAMEPLATE MARKINGS

2.5.1 Servo Motors

The minimum standard nameplate information for brush or brushless servo motors three inches in diameter or greater shall be as follows:

a. Manufacturer's name
b. Manufacturer's model number (includes motor type identification such as ac, dc, and so forth)
c. Manufacturer's serial number or date code
d. Maximum continuous stall torque at __°C ambient
e. Maximum continuous rms amperes at __°C ambient
f. Maximum continuous output power (kW) at __°C ambient
g. Maximum allowable intermittent volts (brush type only)
h. Maximum allowable speed
i. Resistance, terminal at 25°C

2.5.1.1 MOTOR DATA SHEET

A data sheet shall be provided with the following data. Nominal values and tolerances or maximum values shall be specified.

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a. Manufacturer's model number
b. Drawings showing motor dimensions, mounting, outline, and endplay
c. Weight
d. Thermal time constant
e. Torque constant at 25°C
f. Counter EMF constant at 25°C
g. Line-to-line armature resistance at 25°C
h. Rotor inertia
i. R_{th} in °C/W
j. Insulation class
k. Maximum winding temperature
l. Inductance
m. Motor connections
n. Operating ambient temperature range
o. Peak current
p. IP number (degree of protection)

[Optional]

a. Static friction torque (breakaway) maximum
b. Coulomb friction torque, maximum
c. Viscous damping torque, maximum
d. Cogging torque, maximum
e. Radial load capability versus distance from mounting face, and axial load capability
f. Thermal protection device and its rating
g. Electrical time constant
h. Mechanical time constant
i. On motors with integral brakes, the release voltage and tolerance, torque rating, current requirement and response time with a specified control circuit

Any accessory enclosed in the motor housing shall be considered integral.

j. Peripheral connections such as Hall effect devices, tachometers, encoders, resolvers, or brakes

2.5.2 Stepper Motors

The manufacturer's name and manufacturer's type number shall be marked on stepper motor nameplates. In addition, the following data shall be marked on stepper motor nameplates.

NEMA Code	Description	Example
To be coded:		
DD	Diameter, inches* ×10 (nominal)	34 = 3.4 in
MM	Mounting Code	D-flange; C-face; and such
LLL (optional)	Length in inches* ×10 (AG dimension)	016 = 1.6
To be coded or individually marked:		
CCC	Phase current in amps** ×10, rated, for 2 phase-on operation.	016 = 1.6
I	Insulation class (NEMA definition)	B
VVV	Phase voltage rating*×10	053 = 5.3
SSS	Steps per revolution	200
W (optional)	Winding code	See 2.6.3

*Quantities expressed with one place after the decimal point.

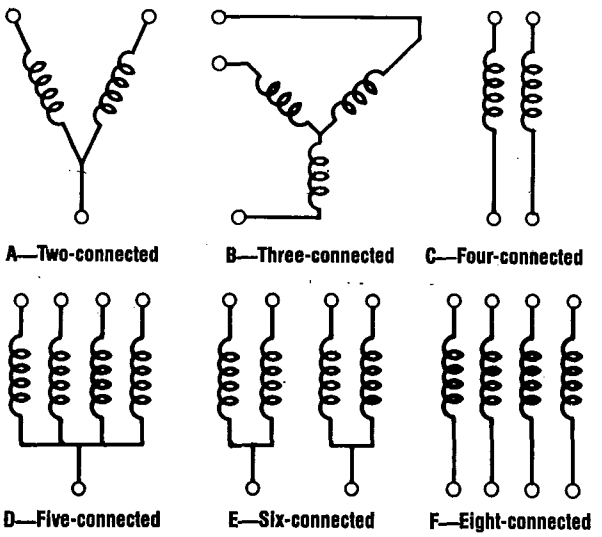
**A dash (—) is used to separate mounting characteristics from other data.

Examples:	
1. 3.4" dia., D-flange	34D
2. 4.2" dia., D-flange w/C face tapped holes	42CD
3. 2.3" dia., D-flange, 1.6" long	23D016
4. 2.3" dia., D-flange, 1.6" long 1.6A, Class B, 5.3V, 200 steps per revolution, winding connection A	23D016-016B053200A
5. 2.3" dia., D-flange, 1.6A, Class B, 5.3V, 200 steps per revolution, winding connection A	23D-016B053200A

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2.5.3 Winding Codes for Stepper Motors

When stepper motors use a winding code on the nameplate marking to identify external connections, the letter symbol assignment shall be determined from the diagrammatic arrangement in Figure 2-12.



NOTE—o indicates external connections.

Figure 2-12
WINDING CODES

2.6 TESTS AND PERFORMANCE

2.6.1 Common

2.6.1.1 MOMENT OF INERTIA

Suspend the rotor with the shaft oriented vertically using two parallel wires as shown in Figure 2-13. The wires shall be attached diametrically, equally spaced from the centerline of the shaft with the length to separation ratio (L/d) approximately ten.

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

The moment of inertia shall be determined from the following equation:

$$J_r = \frac{c \times m \times d^2}{l \times f^2}$$

Where:

J_r = moment of inertia
m = armature weight
l = length of wires
d = separation of wires
f = frequency of oscillation in Hertz
c = constant related to units used:

J	m	l,d	c
$kg \cdot m^2$	kg	m	$6.2 \cdot 10^{-2}$
$*lb \cdot ft^2$	lb	ft	$2.04 \cdot 10^{-1}$
$lb \cdot in \cdot sec^2$	lb	in	$7.61 \cdot 10^{-2}$

*Numerically equal to wk^2 ($lb \cdot ft^2$)

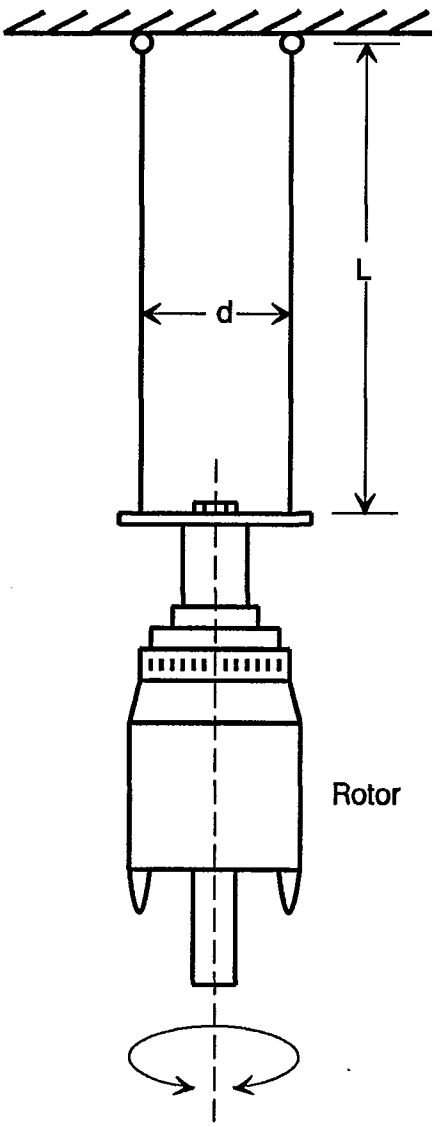


Figure 2-13
MOMENT OF INERTIA wK^2 TEST

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

2.6.1.2 HIGH POTENTIAL TESTS (DIELECTRIC WITHSTAND) FOR STEPPER AND SERVO MOTORS

2.6.1.2.1 Safety

WARNING—Because of the high voltages used, high-potential tests should be conducted only by trained personnel, and adequate safety precautions should be taken to avoid injury to personnel and damage to property. Tested windings should be discharged carefully to avoid injury to personnel on contact. See NEMA Standards Publication MG 2.

2.6.1.2.2 Definition

High-potential tests consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.

2.6.1.2.3 Dielectric Tester

The dielectric tester shall indicate by visual and/or audible means when the resistive leakage current exceeds the following limits: 2 milliamps for test potentials up to and including 1920 volts, and 3 milliamps for test potentials from 1921 volts to and including 2640 volts. The dielectric tester shall be designed to limit the leakage current to a nondestructive value at the high-potential voltage.

2.6.1.2.4 Test Voltage

The high-potential test shall be made by applying a test voltage having the magnitude specified in Table 2-7.

The frequency of the test circuit shall be 50 to 60 Hertz, and the effective value of the test voltage shall be the crest value of the specified test voltage divided by the square root of two. The wave shape shall have a deviation factor not exceeding 0.1.

The dielectric test shall be made with a dielectric tester which will maintain the specified voltage at the terminals during the test.

When leakage current is measured, the total leakage current from the motor windings to ground or frame is made up of capacitive current and resistive current. Resistive leakage current is a measurement of the level of insulation resistance and is an effective evaluation of the insulation system. Any capacitive current should be determined and excluded when evaluating resistive leakage current.

2.6.1.2.5 Test Procedure

The high-potential test voltage shall be successively applied between each electric circuit and the frame, with the windings not under test and the other metal parts connected to the frame. Interconnected polyphase windings are considered as one circuit.

No leads shall be left unconnected during the test as this may cause an extremely severe strain at some point of the winding. In making the test, the voltage shall be increased to full value as rapidly as possible while still maintaining an accurate meter reading, and the full voltage should be maintained for 1 minute. (See 2.6.1.2.6.) It shall then be reduced at a rate that will bring it to one-quarter value or less in not more than 15 seconds.

2.6.1.2.6 Duration of Application of Test Voltage

The specified high-potential test voltage shall be applied continuously for 1 minute. See Table 2-7 (Condition A). Machines for which the specified test voltage is 2500 volts or less may be tested for 1 second at a voltage that is 1.2 times the specified 1-minute test voltage as an alternative to the 1-minute test, if desired. See Table 2-7 (Condition B).

To avoid excessive stressing of the insulation, repeated application of the high-potential test voltage is not recommended.

2.6.1.2.7 Additional Tests Made After Installation

When a high-potential test is made after installation on a new machine which has previously passed its high-potential test at the factory and whose windings have not since been disturbed, the test voltage shall be 75 percent of the test voltage specified in Table 2-7.

2.6.1.2.8 Evaluation of Dielectric Failure

Dielectric failure in high-potential testing of motion/position control motors shall be a resistive leakage current exceeding the limits described in 2.6.1.2.3 when tested in accordance with 2.6.1.2.5.

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Table 2-7
VOLTAGE TESTS

Condition A		
Motor Rating	**Potential, Volts, RMS**	**Time, Seconds**
250 volts or less	1000	60
More than 250 volts	1000 + 2V*	60
Condition B		
Motor Rating	**Potential, Volts, RMS**	**Time, Seconds**
250 volts or less	1200	1
More than 250 volts	1200 + 2.4V*	1

*Maximum Rated Voltage

2.6.1.3 INSULATION RESISTANCE

For insulation resistance test procedures refer to ANSI/IEEE Std. 43, Section 7.

2.6.1.4 THERMAL RESISTANCE AND TIME CONSTANT

The thermal model for an electrical machine may consist of several thermal time constants, however, for ease of analysis a single thermal time constant is usually sufficient for most calculations. See Figure 2-14.

Where:

Q = Power loss (watts)
TC = Thermal capacitance (watt-sec/degrees C)
R_{th} = Thermal resistance (degrees C/watt)

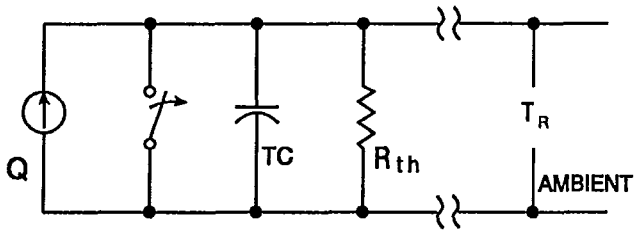


Figure 2-14
THERMAL MODEL FOR THERMAL RESISTANCE AND TIME CONSTANT

T_R = Temperature rise above ambient (degrees C)
τ_{th} = Thermal time constant (min.) = (TC)(R_{th})
T_F = Final temperature at thermal equilibrium
T_A = Ambient temperature
T_t = Temperature at time t

2.6.1.4.1 Test Conditions

The motor under test shall be permitted to run at very slow speed (less than 5 rpm) to equally distribute the heat generated.

The motor under test shall be thermally isolated from the mounting structure.

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

2.6.1.4.2 Test Procedure

a. Apply a current equal to or less than rated current to the motor under test and allow it to reach thermal equilibrium.
b. Determine temperature rise (T_R) by the method specified in 2.6.3.2.
c. Multiply $T_R \times .368$ and add the result to the ambient temperature.
d. Remove power from the motor under test and record the time (t) it takes for the temperature to fall to the value calculated in Step c. The blower motor shall remain operational.
e.

$$Q = I^2R$$

Where:

I = Applied current
R = Winding resistance at T_F (For most motors this will be true.)
τ_{th} = Time, t, recorded in Step d. above
$R_{th} = T_R/Q$

See Figure 2-15 for clarification of the quantities defined in the test procedure.

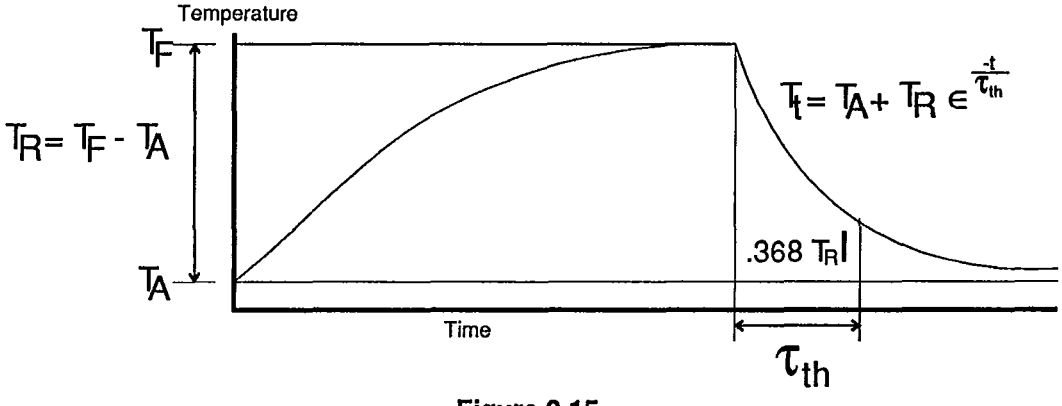


Figure 2-15
CLARIFICATION OF TEST PROCEDURE QUANTITIES

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2.6.1.5 BRUSHLESS SERVO MOTOR TERMINAL RESISTANCE

The terminal resistance of brushless servo motors shall be measured as follows with motor temperature stabilized at ambient to ensure the frame and winding are at the same temperature.

a. Measure resistance between each pair of leads or terminals using a four-terminal Kelvin Bridge (for resistance values of 1 ohm or less), or a Wheatstone Bridge (for resistance values greater than 1 ohm), having an accuracy of ±1% or better. Average the values to determine the nominal terminal resistance. Measurement techniques described in IEEE Std. 118 shall apply. Measure motor frame temperature at the end of the test.

b. Calculate the resistance at 25°C using the following formula:

$$R_{25} = \left(\frac{K + 25}{K + T}\right) R_T$$

Where:

R_{25} = Motor terminal resistance at 25° (ohms)
R_T = Resistance at temperature, T, (ohms)
K = 234.5 (copper)
T = Motor temperature, (°C)

Measurement techniques described in IEEE Std 115.

2.6.1.6 MOUNTING CONFIGURATIONS FOR SERVO MOTOR OUTPUT TESTS

Motors shall be mounted in their normal mounting configuration. Foot-mounting motors are mounted by the feet. Face- or flange-mounting motors are mounted by the mounting face or flange.

Foot-mounting motors are mounted to any type or size of mounting base.

For face- or flange-mounting motors, the motor shall be mounted to a standard mounting plate that shall be thermally separated from the motor support bracket. (See Figures 2-16 and 2-17 for typical mounting configurations.)

Motor mounting plates for thermal testing may be either square or round and shall have a width or diameter that is not greater than 1.5 times the primary motor body diameter. Mounting plate thickness shall be appropriate to adequately support the weight of the motor, but it shall not exceed 1.5 times the thickness of the motor mounting flange or 1.5 times the mounting thread engagement.

For motors weighing less than 40 pounds (18 kg), mounting plates may be made of aluminum.

2.6.1.7 TEST PROCEDURES FOR CONTINUOUS OPERATING AREA/MAXIMUM CONTINUOUS OUTPUT POWER

2.6.1.7.1 Preparation for Test

Mount motor as in Figure 2-18. The coupling shall be of a flexible disc type to minimize heat transfer from the motor shaft to the dynamometer. Use standardized mounting configuration.

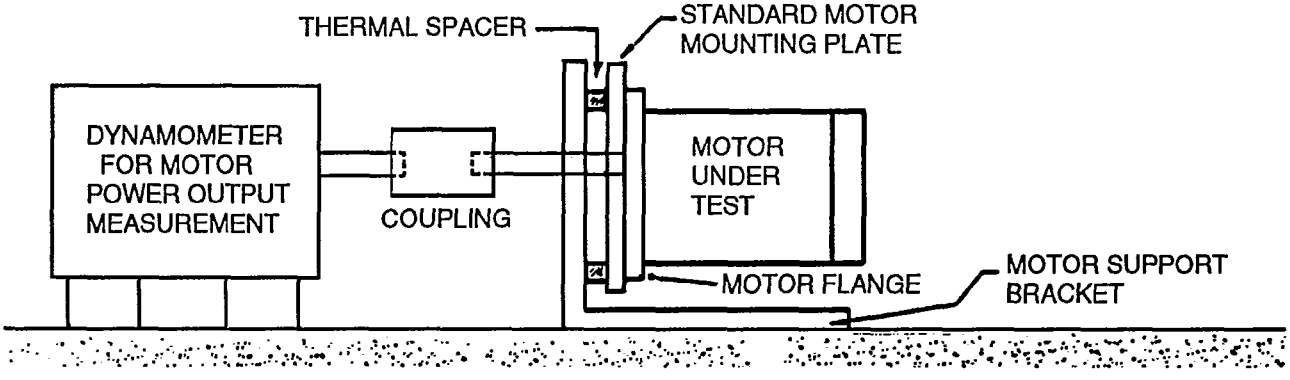


Figure 2-16
FLANGE MOUNTED MOTOR TEST CONFIGURATION

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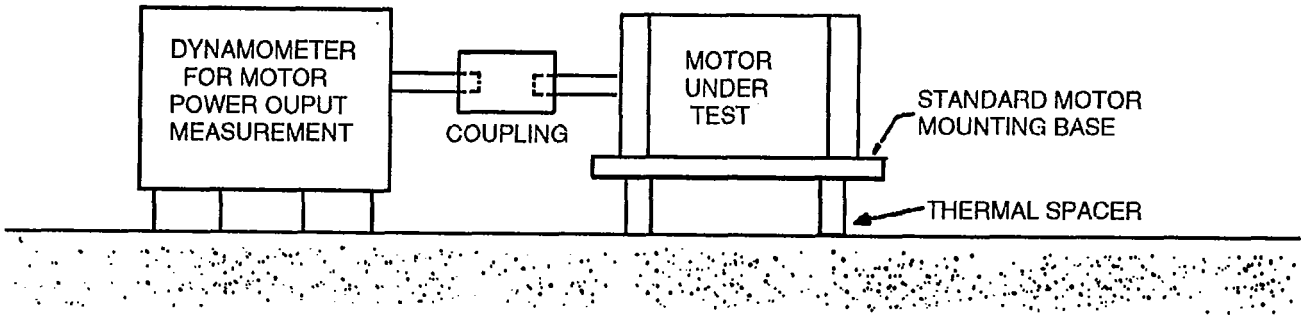


Figure 2-17
FOOT MOUNTED MOTOR TEST CONFIGURATION

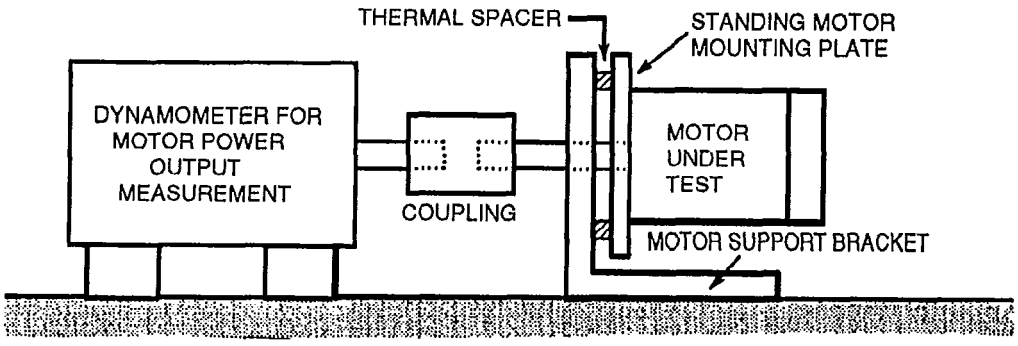


Figure 2-18
MOTOR MOUNT FOR TEST

2.6.1.7.2 Test Procedure

a. Measure the winding resistance. With the motor running at 1 to 5 rpm, gradually increase the armature current until the motor temperature stabilizes at the maximum continuous operating temperature. Record the measured load torque and armature current and winding resistance. Record ambient temperature after each test cycle.

b. Repeat step a. at a minimum of five additional speeds: up to a point where the measured load torque for temperature stability at rated motor temperature decreases to a value of about 20 percent of the torque measured in Step a.

NOTE—In no case during the test procedure should the combination of torque and speed exceed either the commutation limits or mechanical constraints of the motor.

c. Plot torque versus speed adjusted for rated ambient temperature. See 2.6.1.9.3. This curve defines the continuous operating area.

d. Calculate power output at the test speeds using one of the following formulae:

1. Power (watts) = Speed (rpm) × Torque (lb.in.)/84.5
2. Power (watts) = Speed (rpm) × Torque (Nm)/9.55

e. Plot a curve of power versus speed for the results in d. above.

f. The maximum continuous power output is defined as the peak value of power from the curve in e. above.

2.6.1.7.3 Calculation of the Continuous Operating Area for a Different Ambient or Operating Temperature or Both

a. The continuous operating area for a different ambient operating temperature or both may be calculated using the following values from prior tests:

T_F = final test temperature (hot)
T_A = ambient test temperature
R_f = hot terminal resistance
I_f = amperes at hot test point
R_{th} = thermal resistance (degree C/watt at low speed test point)
K_T = torque constant at final temperature (T_F)

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b. The new peak continuous torque at any speed is calculated as follows (nomenclature same as above except new values indicated by (') i.e., new final temperature = T_F':

Old watts loss: $Q_f = (T_F - T_A / R_{th}$

New watts loss: $Q_f' = T_F' - T_A') / R_{th}$

New hot winding resistance:

$R_f' = R_f * (K + T_F') / (K + T_F)$

where K = 234.5 for copper

Find new hot K_t' from the procedure in 2.6.2.9.3

At a given speed, the rotational losses can be assumed to be constant over a considerable temperature range. Therefore, all of the change in watts loss should be accounted for by a change in winding losses:

$$Qf' - Qf = [(I_f')^2 * R_f' - (I_f)^2 * R_f] * K_1$$

where K_1 = 1.0 for brush type and trapezoidal-driven brushless motors, and 1.5 for three phase sinusoidally driven motors.

Therefore: $I_f' = [(Q_f' - Q_f)/K_1 + I_f^2 * R_f]R_f'^{\frac{1}{2}}$

and the new torque is:

$T' = K_t' * I_f'$

Performing this calculation for each test point defines the new continuous operating area.

2.6.2 Servo Motors

2.6.2.1 MOTOR TERMINAL RESISTANCE FOR BRUSH COMMUTATED MOTORS

The terminal resistance of brush commutated motors shall be measured as follows:

a. Lock the rotor shaft and apply a dc voltage sufficient to drive a current equal to 10 percent of rated current through the motor.
b. Measure voltage and current for at least five different equally spaced shaft angular positions. Take readings quickly to avoid heating effects
c. Measure motor frame temperature, T, at the end of the test
d. Average the values of resistance (R=V/I) to obtain R_T.
e. Calculate the resistance at 25°C using the following formula:

$$R_{25} = \left(\frac{K+25}{K+T}\right) R_T$$

Where:

R_{25}= Motor terminal resistance at 25°C (ohms)

R_T = Average resistance at temperature, T (ohms)

K = 234.5 (for copper windings)

T = Motor frame temperature at time of test (°C)

The resistance of brush commutated motors cannot be accurately measured with a conventional ohmmeter because the low voltage and current output of such devices will not break down the normal film which is present on the commutator surface. Where it is not in conflict, the ANSI/IEEE Std. 113 should be used.

2.6.2.2 MOTOR TERMINAL RESISTANCE FOR BRUSHLESS MOTORS

The terminal resistance of brushless servo motors shall be measured as follows:

a. Measure resistance of each pair of leads or terminals using a four-terminal Kelvin Bridge (for resistance values of 1 ohm or less), or a Wheatstone Bridge (for resistance values greater than 1 ohm), having an accuracy of ±1 percent or better. Measure motor frame temperature at the end of the test.
b. Calculate the resistance at 25°C using the following formula:

$$R_{25} = \left(\frac{K+25}{K+T}\right) R_T$$

Where:

R_{25}= Motor terminal resistance at 25°C (ohms).

R_T = Resistance at temperature, T, (ohms).

K (copper) = 234.5

T = Motor frame temperature at time of test (°C).

Measurement techniques described in IEEE Std. 115 apply.

2.6.2.3 COGGING TORQUE

Cogging torque shall either be measured by the torque wrench or torque transducer method described below. The torque wrench method is typically used on motors whose cogging torque is much greater than the static friction. All measurements are made with no power applied to the motor under test, the motor leads open, and the motor at 25°C±5°C.

Torque Wrench Method—Rotate the motor shaft through one complete revolution with a torque wrench. Record the peak-to-peak value measured with the torque wrench. This is the cogging torque.

Torque Transducer Method—Rotate the motor shaft at 3 or less rpm with a torque transducer connected between the motor under the test and the driver. Record the peak-to-peak value measured with the torque transducer. The cogging torque is the measured peak-to-peak value.

2.6.2.4 FRICTION TORQUE AND VISCOUS DAMPING—SERVO MOTORS

Friction torque (T_f) and viscous damping factor (D) shall be determined by measuring the torque required to drive the motor under test at 30 rpm, half maximum continuous speed, and maximum continuous speed. The torque versus speed shall be plotted as a best fit straight line on a graph.

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The Y intercept is the friction torque and the slope is the viscous damping factor. (See Figure 2-19).

A preferred method is to drive the motor under test with an external motor and use a torque transducer to measure the required torque. (See Figure 2-20)

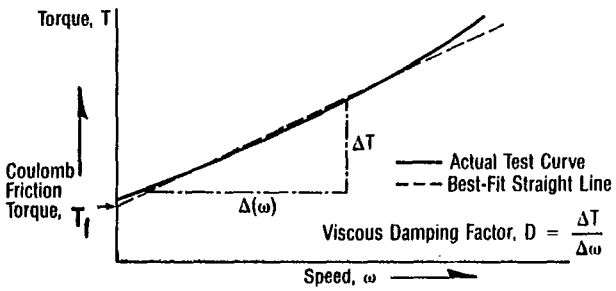


Figure 2-19
FRICTION TORQUE AND VISCOUS DAMPING

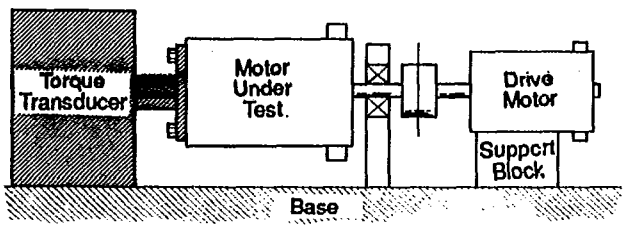


Figure 2-20
VISCOUS DAMPING TEST LAYOUT

2.6.2.5 WINDING INDUCTANCE—BRUSHLESS SERVO MOTORS

Two methods are used to determine winding inductance:

Method A—The Inductance Bridge Method

This method, which uses a bridge with a test frequency of 1000 Hz or less and with current injected into the windings, is used when inductance at a specified current level is required.

Method B—The Current Change Method

Test Method A: The Inductance Bridge Method—Rated Value

a. Lock the rotor in place and with a suitable dc supply, pass rated current through the winding under test.
b. Measure the inductance of the winding used in Step a with a suitable bridge with 1 kHz at 1 V rms applied to the winding under test. See Figure 2-21.
c. Reduce the current in Step a to zero and unlock the rotor. Reposition the rotor by 45°. Repeat steps a. and b.
d. Repeat Step c until one revolution is complete (8 measurements).
e. The average of the readings taken is the value of rated winding inductance.

NOTE—When the inductance value with the winding energized is required, the dc source should remain connected and the winding current adjusted to the desired level. When the inductance bridge is connected to the same winding a suitable blocking capacitor should be used to protect the inductance bridge from the dc current source.

Test Method B: Current Change Design Values

a. Lock the rotor in place.
b. Connect the winding to be measured to a suitable dc power source as shown in Figure 2-22 and adjust the output of the power source to provide 110 percent rated current to the winding.
c. Actuate Switch 1 and with the oscilloscope read the current decay on the oscilloscope across r_2 and record the time, t, when the current reaches the value, i.
d. Calculate the incremental inductance of the winding for any part of the curve according to the following formula:

$$L = \frac{-R \times t}{\ln\left(\frac{i}{I}\right)}$$

Where:

L = Incremental inductance (henries)
R = Circuit resistance rw + r_2 (ohms)
I = Initial current (amps) (Time=Zero)
t = Time when current = i (seconds)
ln = Natural logarithm
i = Current at time t

At time when i = 0.37 I (63% of total change)

$$L = R \times t$$

e. Unlock the rotor and re-position by 45°.
f. Repeat steps a. to e. until one completed revolution is made (8 measurements).
g. The average of the ratings is the inductance used for design.

Switch 1 is a make before break switch. Therefore, SW1A is normally open and SW1B is normally closed.

NOTE—The value of R Limit in Figure 2-22 will provide the current limit when Switch 1A is actuated prior to Switch 1B opening. Current is monitored across the resistor, r_2.

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2.6.2.6 TORQUE RIPPLE

Torque ripple is a system characteristic. It is measured with the servo motor under test energized by a specified controller to the maximum continuous stall torque level. This minimizes measurement errors due to cogging torque.

2.6.2.6.1 Procedure

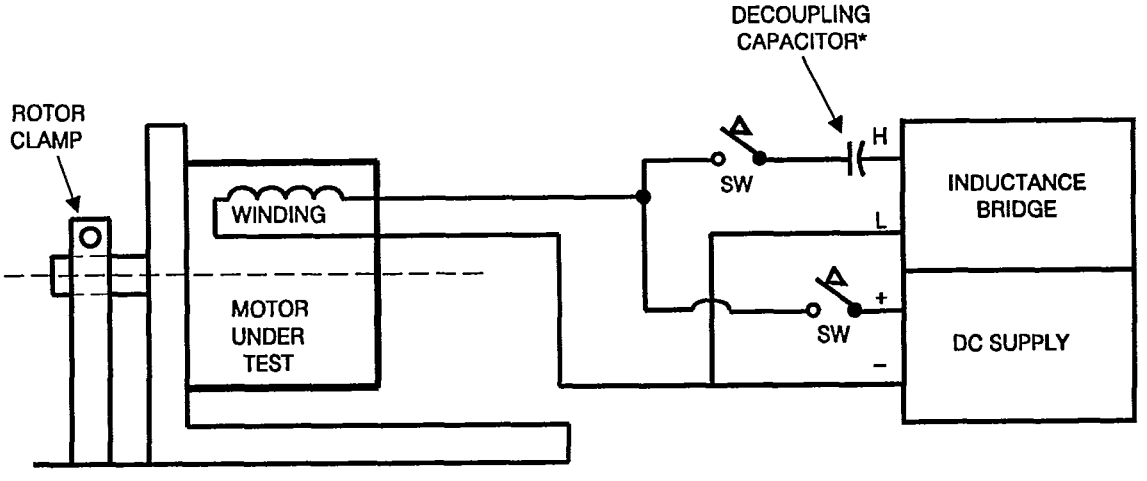
Apply a constant current sufficient to develop maximum continuous stall torque to the motor using a specified controller. Drive the shaft of the servo motor under test through a torque transducer at 3 rpm or less in a direction that opposes the developed torque of the motor under test (See Figure 2-23).

The torque ripple is:

$$\frac{\text{Peak-to-peak torque amplitude}}{\text{Average torque}}$$

Care should be taken to differentiate between true torque ripple and possible commutation spikes. This procedure defines a measurement technique for torque ripple. In some cases it will be necessary to also specify the peak-to-peak value of commutation spikes and the bandwidth of the measuring apparatus.

Measurement techniques described in IEEE Std. 115 apply.



*USED IF DC SUPPLY IS LEFT CONNECTED DURING MEASUREMENT.
VALUE OF C>> 39.44/L μF. (for f = 1 KHz) (L in henries)

Figure 2-21
TEST CIRCUIT FOR INDUCTANCE BRIDGE METHOD

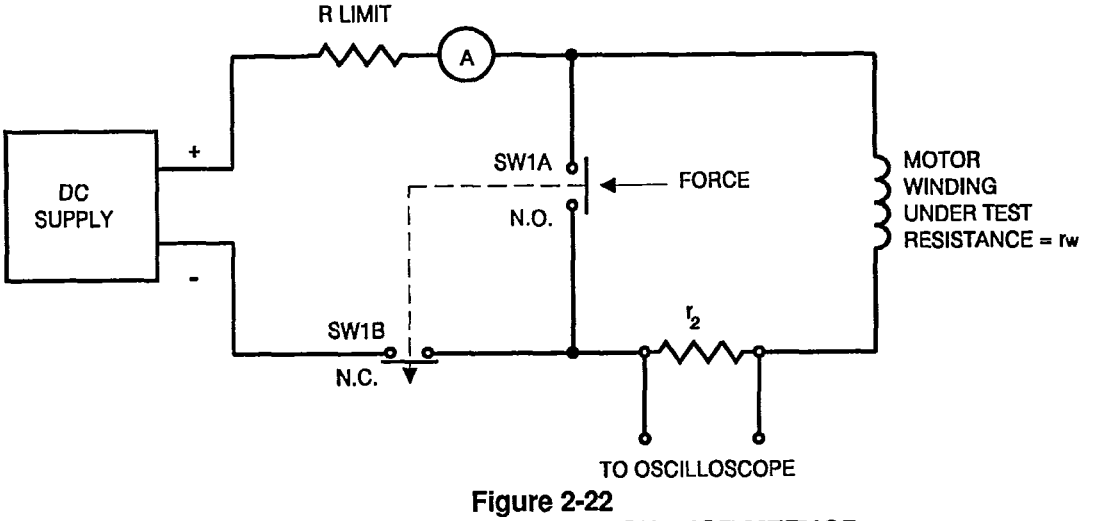


Figure 2-22
TEST CIRCUIT FOR CURRENT CHANGE METHOD

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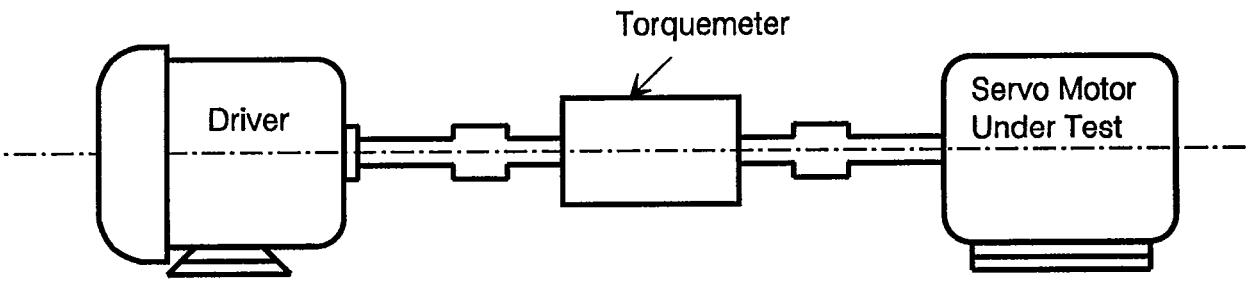


Figure 2-23
TORQUE RIPPLE TEST SET-UP

2.6.2.7 BACK EMF CONSTANT

a. Motor to be mounted by normal mounting means. See Figure 2-24.
b. Power is applied to constant speed drive motor and motor is allowed to stabilize at desired speed.
c. Measure induced voltage in test motor.
   1. For brush commutated motor measure dc average voltage.
   2. For brushless motors measure the peak voltage
d. Compute back EMF per the formula:

$$K_E = \frac{\text{measured volts}}{0.1047\ \text{rpm}} = V \times \text{sec/rad}$$

or

$$K_E = \frac{\text{measured volts} \times 1000}{\text{rpm}} = \text{volts/krpm}$$

NOTE—Peak voltage is used for brushless motors because the wave shape is not always pure sinusoidal.

2.6.2.8 ELECTRICAL TIME CONSTANT—BRUSHLESS SERVO MOTORS

The following are procedures for determining electrical time constant for brushless servo motors:

a. Lock the rotor in place.
b. Connect the winding to be measured to a suitable dc power source and adjust the output of the power source to provide 10% of rated current to the winding.
c. Actuate Switch 1 and use an oscilloscope with a high speed current probe to read the decay of the current through the motor winding.
d. The electrical time constant is defined as the time it takes the current to decay to 37% of the original value.
   Or: At t_o, $i_o = I$
   Find time, t, at which $i_t = 0.37\ I$
   Then t = electrical time constant
   Where:
   I = steady state current before switchclosure
   t_o = time when switch is closed
   i_o = current at instant the switch is closed
   i_t = measured current at any time, t
e. Unlock the rotor and reposition by 90° electrical.
f. Repeat Steps a. through e. until one completed revolution is made.
g. The average of the readings is the motor electrical time constant.

NOTE—A storage or digital scope of chart recorder will simplify this measurement procedure.

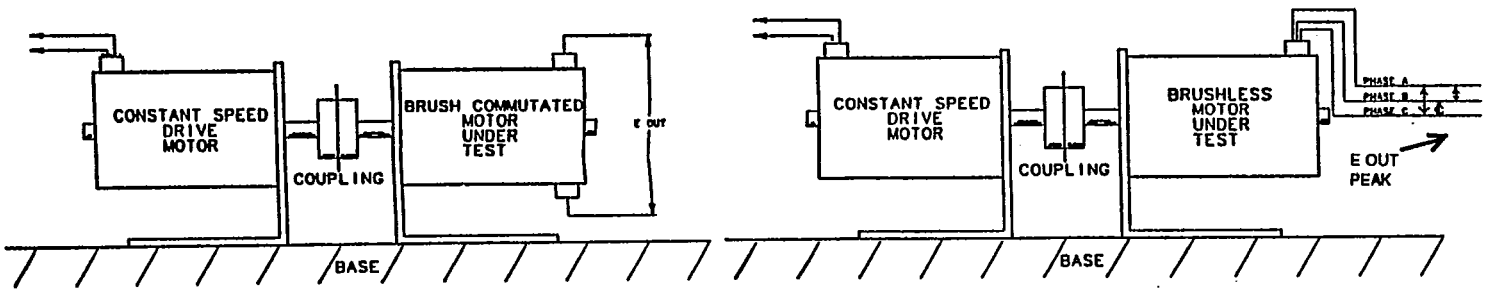


Figure 2-24
BACK EMF CONSTANT MOTOR RUNNING

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Switch 1A is a make before break switch. Therefore, SW1A is normally open and SW1B is normally closed.

NOTE—The value of R limit in Figure 2-12 will provide the current limit when Switch 1A is actuated prior to Switch 1B opening.

2.6.2.9 TEST PROCEDURES FOR TORQUE CONSTANT OF BRUSH COMMUTATED MOTORS

2.6.2.9.1 Preparation for Test

Mount the motor as in Figure 2-25. The coupling shall be of a flexible disk type.

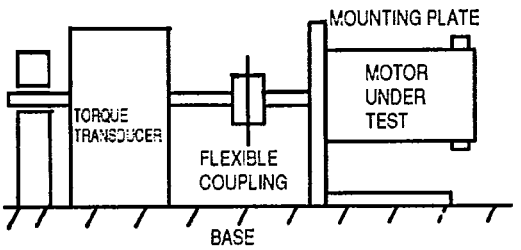


Figure 2-25
TORQUE CONSTANT TEST LAYOUT

2.6.2.9.2 Test Procedure

a. Motor Torque Constant (Cold)
   1. With the motor temperature stabilized at ambient temperature, measure and record the winding resistance (per test procedure 2.6.2.1) and ambient temperature.
   2. If the motor is a wound field design, energize the motor field with the rated field current. Maintain this rated current through the rest of the test.
   3. Successively energize the armature circuit with approximately 0.25, 0.50, 0.75, 1.00, 1.25, and 1.50 times the rated armature current. Record armature current and locked rotor output torque at each test current value.
      IMPORTANT: Take readings as rapidly as possible to prevent appreciable change in motor temperature.

b. Motor Torque Constant (Hot)
   1. Apply sufficient current to the motor to cause the windings to heat to approximately 100°C and maintain this condition until thermal stability has been reached (at least three thermal time constants).
   2. Repeat the test procedure outlined in a.3 above.
   3. Immediately after the above test is completed and before the motor temperature can change appreciably, measure and record the motor winding resistance and the ambient temperature.

2.6.2.9.3 Calculation of Torque Constant

a. For both hot and cold test data, plot output torque versus armature amperes as shown in Figure 2-26.

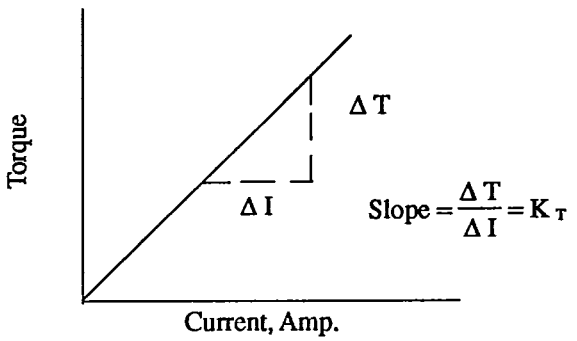


Figure 2-26
TORQUE VS ARMATURE AMPS

b. Due to magnetic saturation, the torque per ampere may decrease at higher test current values.

c. The torque constant shall be determined using the linear portion of the plotted line obtained from the lower test current values. The slope of the plotted line is the torque constant, K_T, at the test temperature.

Various units are : $\frac{\text{lb. ft.}}{\text{amps}}$ $\frac{\text{N.m.}}{\text{amps}}$ $\frac{\text{lb. in., etc.}}{\text{amps}}$

d. The motor winding temperature for the hot test should be determined according to 2.2.2.

e. The temperature coefficient of the torque constant can be determined as follows:

$$C_1 = \frac{[K_T\,(\text{cold}) - K_T\,(\text{hot})]}{K_T\,(\text{cold})} \times \frac{100}{T_W\,(\text{hot}) - T_W\,(\text{cold})}$$

Where:

C_1 = Torque Constant Temperature Coefficient, %/degrees C
K_T (cold) = Torque Constant, Cold
K_T (hot) = Torque Constant, Hot
T_W (cold) = Winding Temperature, Cold
T_W (hot) = Winding Temperature, Hot

f. The torque constant at any winding temperature can now be calculated from the following formula:

$$K'_T = K_T\,(\text{cold}) \times \left[1 - \frac{C_1}{100}\,(T'_W - T_W\,[\text{cold}])\right]$$

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Where:

K'_T = Torque Constant at Winding Temperature, T'_W

T'_W = Any winding temperature, degrees C

2.6.2.10 Maximum Volts and Maximum Speed

The purpose of this test is to ensure that the servo motor can operate with the maximum applied voltage and achieve its maximum speed safely.

Procedure: Apply the maximum voltage to the motor from a current-limited power supply so that current does not exceed the peak current. Accelerate the motor to maximum speed in one direction and while operating at that speed reverse the polarity of the applied voltage and allow the motor to reach maximum speed in the opposite direction.

2.6.3 Stepper Motors

2.6.3.1 RATED CURRENT

Rated current for stepper motors shall be determined by applying direct current from a suitable constant current supply, the ripple content of which has no perceptible effect on heating, that will maintain the output current within ±1 percent to the specified winding and will result in a maximum winding temperature at thermal equilibrium in accordance with Table 2-1 (see 2.2.1). If multiple windings are specified, they shall be connected in series for this test. The motor shall be suspended horizontally in a 25°C ambient without external heatsinking and no auxiliary cooling for this test.

2.6.3.2 TEST PROCEDURES FOR STEPPER MOTOR TERMINAL RESISTANCE

The terminal resistance of brushless stepper motors shall be measured as follows:

a. Measure resistance between each pair of leads or terminals using a four-terminal Kelvin Bridge (for resistance values of 1 ohm or less), or a Wheatstone Bridge (for resistance values greater than 1 ohm), having an accuracy of ±1% or better. Measure motor frame temperature at the end of the test.

b. Calculate the resistance at 25°C using the following formula:

$$R_{25} = \left(\frac{K+25}{K+T}\right) R_T$$

Where:

R_{25} = Resistance at temperature, T, (ohms).

K = 234.5 (copper)

T = Motor frame temperature at end of test (°C).

Measurement techniques described in IEEE Std. 115 apply.

2.6.3.3 WINDING TEMPERATURE

The winding temperature of stepper motors shall be determined by measurement of the winding resistance change under the specified test current and mounting conditions* according to the formula:

$$T_h = \frac{R_h}{R_c}(K+t_{ac}) - K$$

Where:

T_h = Temperature of energized winding (final)

R_h = Resistance at final temperature T_h (ohms)

t_{ah} = Ambient temperature at the end of the heat run in the vicinity of the motor

t_{ac} = Initial ambient temperature in the vicinity of the motor

R_c = Cold resistance at temperature t_{ac} (ohms). The temperature of the motor shall be allowed to stabilize at ambient (t_{ac}) prior to measurement of R_c

K = Constant for copper, 234.5

$$\text{Also, Temperature Rise (TR)} = \frac{R_h}{R_c}(K+t_{ac}) - (K+t_{ah})$$

Where TR = Winding temperature rise above ambient temperature, (t_{ah})

All temperatures are in degrees Celsius. The measurement shall be made in accordance with the 2.6.3.2 test procedure. Rapid transfer from the power source to the resistance measuring device shall be made to avoid error due to motor cooling.

Errors due to rapid cooling may be avoided by plotting a cooling curve of resistance versus time and extrapolating to zero time. (Zero time is the time when power was removed from the motor.)

*This test procedure is consistent with ANSI/IEEE Std. 113.

2.6.3.4 HOLDING TORQUE

Holding torque for stepper motors shall be measured with rated current applied through two phases in series. The peak resistance to rotation is measured by slowly rotating a torque wrench or other suitable torque transducer applied to the motor shaft. The holding torque is the minimum value observed through the full rotation of the shaft in either direction.

For rating purposes, the motor should be allowed to reach thermal equilibrium at the test current prior to measurement.

2.6.3.5 DETENT TORQUE

Detent torque for stepper motors shall be measured in the same manner as holding torque except the phases are open-circuited. For rating purposes, the motor temperature should be stabilized at 25°C prior to measurement.

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2.6.3.6 WINDING INDUCTANCE STEPPER MOTORS

Two methods are used to determine:

Method A—The Inductance Bridge Method is used to determine the value of inductance for catalog rating purposes.

Method B—The current change method is used to provide inductance values for design related purposes.

Test Method A—Inductance Bridge—Rated Value

a. Pre-position the rotor to establish tooth alignment by passing rated current from a suitable dc source through the winding to be measured and lock the rotor in place. Disconnect the current source.
b. Measure the inductance of the winding used in Step 1 with a suitable bridge with 1 kHz at 1 Vrms applied to the winding under test. See Figure 2-21.
c. Other windings shall be measured by repeating Steps 1 and 2.

NOTE—When the inductance value with the winding energized is required, the dc source should remain connected and the winding current adjusted to the desired level. When the inductance bridge is connected to the same winding, a suitable blocking capacitor should be used to protect the inductance bridge from the dc current source.

Test Method B—Current Change Design Values

a. Pre-position the rotor to establish tooth alignment by rated current from a suitable dc source through the winding to be measured and lock the rotor in place.
b. Connect the winding to be measured to a suitable dc power source as shown in Figure 2-22 and adjust the output of the power source to provide 10 percent rated current to the winding.
c. Actuate Switch 1 and read the current decay on the oscilloscope across r_2.
d. Calculate the incremental inductance of the winding for any part of the curve according to the following formula:

$$L = \frac{-R \times t}{\ln\left(\frac{i}{I}\right)}$$

Where:

L = Incremental inductance (henries)
R = Circuit resistance (rw + r_2)(ohms)
I = Initial current (amps) (Time = Zero)
t = Time when current = i (seconds)
ln = Natural logarithm
i = Current at time t

At time when i = 0.37 I (63 percent of total change)

$L = R \times t$

Switch 1 is a make before break switch. Therefore, SW1A is normally open and SW1B is normally closed.

NOTE—The value of R Limit in Figure 2-22 will provide the current limit when Switch 1A is actuated prior to Switch 1B opening. Current is monitored across the resistor, r_2.

2.6.3.7 SINGLE STEP RESPONSE

a. Couple a continuous rotation-film potentiometer whose inertia is less than 1/10 the rotor inertia to the motor shaft.
b. The coupling to the potentiometer shall be torsionally rigid but radially and axially flexible.
c. Connect the terminals of the fixed potentiometer element to a filtered dc power supply. Connect the wiper arm of the potentiometer and one terminal of the fixed element to the vertical displacement terminals of the oscilloscope. Set the horizontal displacement for displaying "time."
d. Energize the motor with rated current from an appropriate controller and command it to take one step. The resultant display will be the single step response of the motor. See Figure 1-17.
e. The settling time is determined by the point at which the peak of the oscillation of the rotor has diminished to within 10 percent of the step angle displacement.

The single step response will be controller dependent.

2.6.3.8 PULL-OUT TORQUE

a. Couple the output shaft to the torque measurement system.* See Figure 2-27. The couplings shall have an inertia that is ≤10 percent of the rotor inertia.
b. Connect the input terminals of the motor under test to the drive for which motor torque is to be determined. Adjust the motor current at standstill to its rated value or the value specified by the manufacturer.
c. Adjust the motor to the synchronous speed in steps per second for which torque is to be measured.
d. Increase the load to the motor using the brake current adjustment or equivalent control, until the motor pulls out of synchronism with the drive.**
e. Record the pull-out torque, speed, type drive, drive bus voltage, measurement system inertia, and motor current set in Step b.

*Couplings should be rigid for rotational forces, but allow flexibility for alignment and shaft runout, for example, bellows type or the equivalent.

**This may be determined for speeds above base speed by the motor stalling and not restarting. Below base speed the motor will turn discontinuously when the pull-out torque value is reached.

2.6.3.9 MEASUREMENT SYSTEMS FOR STEPPER MOTOR PULL-OUT TORQUE

The pull-out torque for stepper motors may be measured in three ways: the cord and spring scale method; the hysteresis dynamometer method; or the magnetic particle brake dynamometer method. Each has advantages and disadvantages that are compared in Figure 2-28.

Pertinent information to be recorded during these tests is as follows:

a. Drive type

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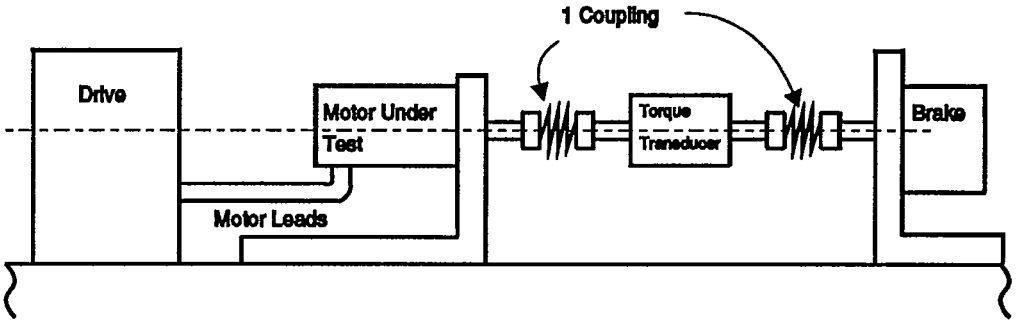


Figure 2-27
TYPICAL PULL-OUT TORQUE TEST SET-UP
(MAGNETIC PARTICLE BRAKE DYNAMOMETER SHOWN)

b. Drive bus voltage
c. Current delivered to the motor at standstill
d. Speed in steps per second
e. Couplings from the motor to the transducer or brake or both
f. Inertia of system coupled to the shaft
g. Torque measurement system, such as transducer and brake type

The theoretically ideal torque measurement system would have zero inertia and be entirely passive, that is, not affect the rate of response and not interact with the motor and drive system. However, it is understood that the torque measurement system will influence the indicated torque and should therefore be documented.

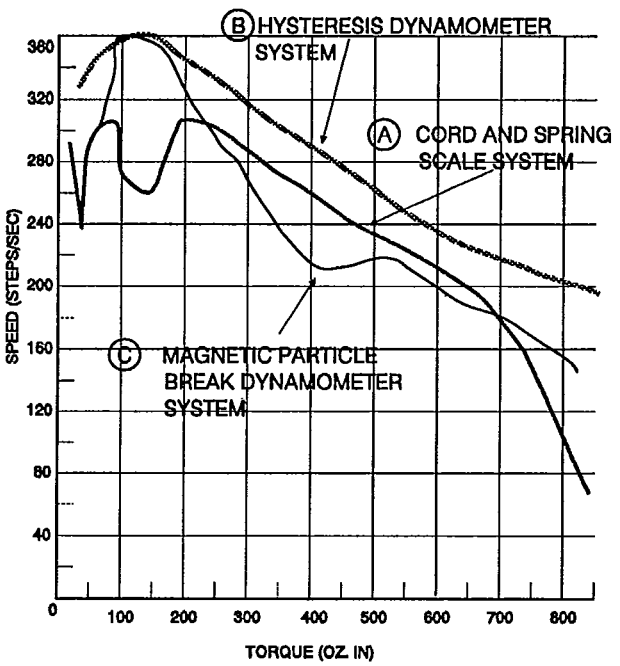


Figure 2-28
COMPARISONS OF STEPPER MOTOR PULLOUT TORQUE MEASUREMENT SYSTEMS

2.6.3.10 CORD AND SPRING SCALE METHOD

The cord and spring scale method utilizes a cord wrapped on a pulley to apply frictional load and a spring scale for measurement of steady state conditions. See Figure 2-29.

The cord and spring scale method has the following advantages:

a. It is easy to use and to calibrate. The accuracy of the system is based upon pulley diameter and scale calibration.

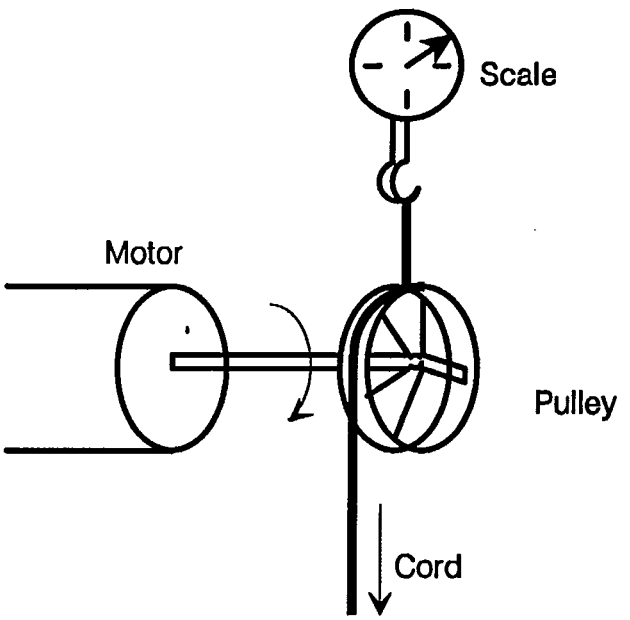


Figure 2-29
CORD AND SPRING SCALE

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b. Power is dissipated as heat in the pulley. Dissipation capacity may be increased by external cooling or increasing pulley size.
c. System inertia may be controlled by the size of the pulley. The larger the pulley the greater the inertia.

However, it also has the following disadvantage: it may accentuate resonant points on the torque speed characteristic, as well as create additional resonant points.

2.6.3.11 HYSTERESIS DYNAMOMETER METHOD

The hysteresis dynamometer method utilizes a hysteresis brake to apply frictional load and a gravity balance for measurement of torque. See Figure 2-30.

The hysteresis dynamometer method has the following advantages: it is easy to use and control accurately because torque is varied by changing the current to the brake.

However, it also has the following disadvantages:

a. Power is dissipated in the brake and care must be taken to maintain operation within ratings.
b. Low speed torque may have substantial ripple due to discrete poles on rotor and stator. This may interfere with low speed data since the motor itself has an oscillatory behavior at lower step rates.
c. The rotor of the dynamometer may add considerable inertia to the system. This may shift or even hide midrange resonance effects.

2.6.3.12 MAGNETIC PARTICLE BRAKE DYNAMOMETER METHOD

The magnetic particle brake dynamometer method utilizes a rotor surrounded by fine magnetic particles that is enclosed in a non-rotating housing. A coil is energized to create a magnetic field which tends to solidify the particles, thus loading the rotor. The load torque is then controlled by current in the coil.

An optical torque-bar transducer (Figure 2-31) provides an efficient torque measuring device for use with the magnetic particle brake. It measures transmitted torque by modulating a beam of light in proportion to the applied torque. Lamps are mounted at one end of the transducer housing and photocells at the other. Two identical discs are mounted on a pair of sleeves that are attached to opposite ends of the rotatable torsion shaft. The light from the lamp

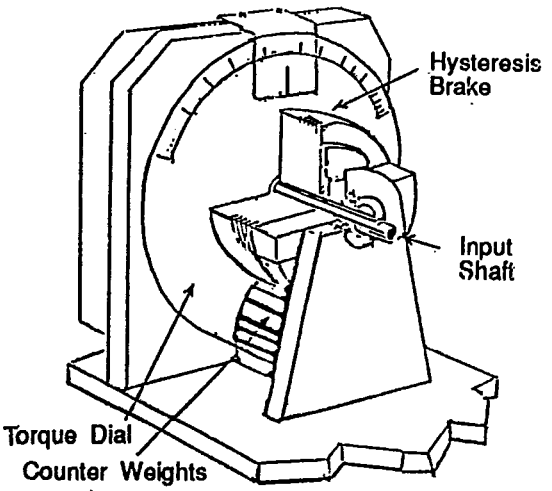


Figure 2-30
HYSTERESIS DYNOMOMETER

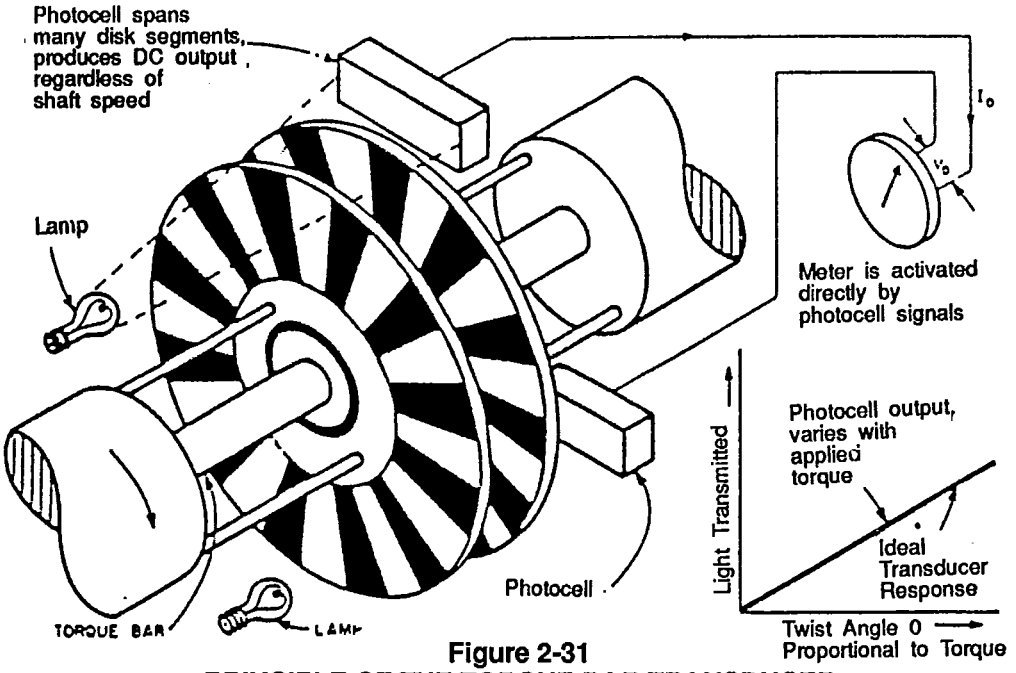


Figure 2-31
PRINCIPLE OF THE TORQUE BAR TRANSDUCER

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shines through the slots in the discs and impinges on the photocells, thus generating a dc voltage. When the shaft is twisted, the alignment of the discs changes, and the photocell output changes with it. Hence, dc output is directly proportional to the torque applied to the shaft.

The magnetic particle brake dynamometer has the following advantages:

a. It is easy to use.
b. It provides a uniform, low inertia load that is adjustable with input current. It is capable of approaching a theoretically no-load condition.
c. It has steady state and transient capability.

The magnetic particle brake dynamometer using the torque transducer has the following disadvantages:

a. It is limited by power dissipation in the brake and may be less effective for testing large size motors.
b. Friction seals on the brake produce drag, which limits low-torque data on high-torque units.

2.6.3.13 STEP ACCURACY

a. Test Conditions (See Figure 2-32)
   1. Motor and ambient temperature shall be 25°C±5°C.
   2. The flexible couplings shall be torsionally rigid but radially and axially flexible.
   3. Motor phase currents shall be equal to rated current and balanced to within 1 percent of each other.
   4. Tests shall be made with zero shaft load on the motor.
   5. The encoder resolution shall be 10 percent of the maximum angular error expected, or finer. For example, for a 200 step/revolution stepper motor having 3 percent accuracy, the angular measurement system shall be able to resolve the following angle:

$$= 0.1\left(\frac{360^\circ/\text{rev}}{200\ \text{steps/rev}}\right)(0.03)^\circ = 0.0054^\circ$$

   Therefore, the minimum number of pulses/revolution from the encoder is 360/0.0054 = 66,667 pulses.*
   6. The viscous damper, if required, is chosen to allow enough time between steps to ensure that motor shaft oscillations are damped before the next step is taken.

*The next higher standard pulse rate for typically available encoders is 72,000 pulses/revolution.

b. Procedure

Step the motor through one complete shaft revolution, measuring the maximum positive or negative deviation from the rated step angle for any adjacent step. The incremental step angle error is expressed as a percentage of the rated step angle.

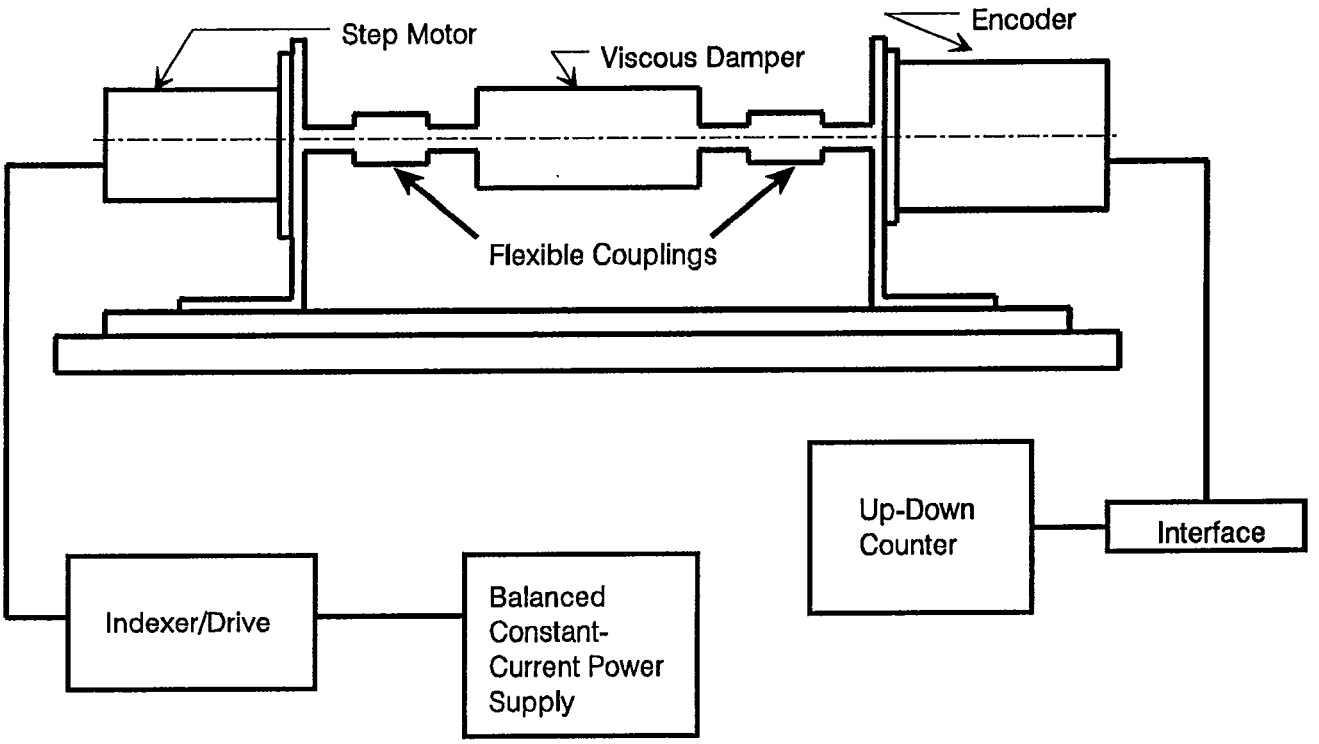


Figure 2-32
TEST CONDITIONS FOR STEP ACCURACY

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2.6.3.14 ELECTRICAL TIME CONSTANT—STEPPER MOTORS

The following are test procedures for determining electrical time constant for stepper motors (See Figure 2-33):

a. Pre-position the rotor to establish tooth alignment by passing rated current from a suitable dc source through the winding to be measured and lock the rotor in place.
b. Connect the winding to be measured to a suitable dc power source as shown in Figure 2-12 and adjust the output of the power source to provide 10% rated current to the winding.
c. Actuate Switch 1 and use an oscilloscope with a high speed current probe to read the decay of the current through the motor winding.
d. The electrical time constant is defined as the time it takes the current to decay to 37% of the original value.

Or: At T_o, $i_o = I$

Find time, t, at which $i_t = 0.37\ I$

Then t - electrical time constant

Where:

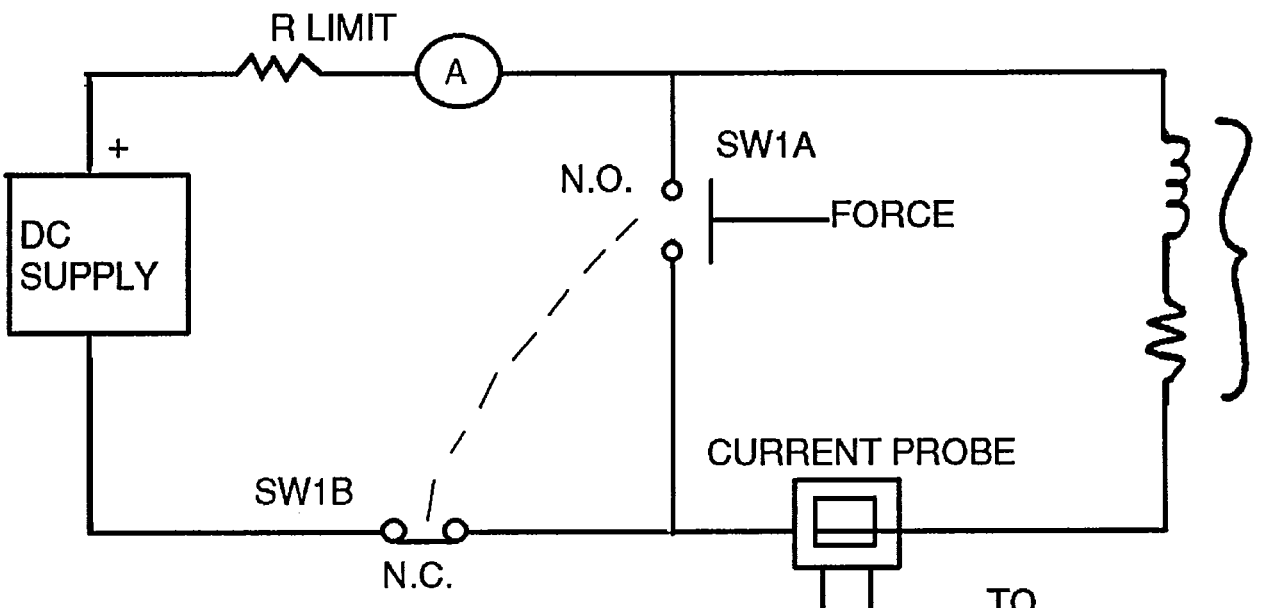
I = steady state current before switchclosure
t_o = time when switch is closed
i_o = current at instant the switch is closed
i_t = measured current at any time, t

Switch 1A is a make before break switch. Therefore SW1A is normally open and SW1B is normally closed.

NOTE—The value of R limit in Figure 2-12 will provide the current limit when Switch 1A is actuated prior to Switch 1B opening.

2.7 APPLICATION DATA

(Under consideration.)



N.C. = normally closed
N.O. = normally open
NOTE—A storage or digital scope of chart recorder will simplify this measurement procedure.

Figure 2-33
ELECTRICAL TIME CONSTANT TEST CIRCUIT

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Section 3
CONTROLS

3.1 RATINGS

3.1.1 Ambient Temperature

Care should be taken not to exceed the ambient temperature range specified by the manufacturer.

3.1.2 Basis of Rating

The ratings of motion/position control apparatus are based on an operating ambient temperature (immediately surrounding the control) of either 40°C for enclosed units that are intended to stand alone, or 55°C for units intended for mounting within another enclosure.

At the option of the manufacturer, a lower ambient temperature can be used as the basis of rating. If a lower ambient temperature is used, the manufacturer shall provide an output derating factor, stated in % output/°C, to allow adjustment of the control output power to an equivalent rating based on the ambient temperatures specified above.

For unusual conditions where other operating ambient temperatures are required, the manufacturer should be consulted.

3.1.3 Input Voltage and Frequency Ratings

Preferred input power voltage and frequency ratings for motion/position controls shall be as follows:

Alternate current, 60 Hertz—115, 200, 230, 460, and 575 volts.

Alternating current, 50 Hertz—100, 200, 220, 380, 415, and 500 volts.

Other ac and dc input voltages shall be permitted to be used by agreement between the manufacturer and user.

AC voltages are based on ANSI C84.1 where applicable and reflect the fact that motion/position control is normally applied at the point of power utilization. Individual manufacturers may choose to make their controls at the utilization voltage (listed above) or at the corresponding nominal system voltage (e.g., 120, 208, 240, 480, or 600 volts, 60 Hertz.)

3.1.4 Range of Operating Voltage and Frequency

The motion/position control shall operate at rated output with a variation of the applied voltage or frequency up to the following:

a. The rms input voltage shall not deviate more than plus or minus 10 percent from the rated nameplate value.
b. The input frequency shall not deviate more than plus or minus 2 percent from the rated nameplate value.

3.1.5 Input Current Ratings

Maximum continuous input current ratings shall be determined by the manufacturer of the controller.

▲3.2 ENCLOSURES

For motion/position control systems that are designed to be used without installation in another enclosure, the system enclosure shall comply with classifications defined in ANSI/NEMA Standards Publication No. 250. Systems designed for installation within another enclosure shall be defined in accordance with the degrees of protection (IP codes) given in Tables 2-4 and 2-5 of this publication and shall comply with paragraph MG 7-1.3, "Safety Standard for Construction and Guide for Selection, Installation and Operation of Motion/Position Control Systems."

3.3 MANUFACTURING

3.3.1 Dimensions

3.3.2 Spacings

Refer to NEMA Standards Publication ICS 1 for spacing requirements.

3.4 NAMEPLATE MARKINGS

Motion/position controls that are intended for mounting within another enclosure shall be permanently marked with the following minimum information:

a. Manufacturer's name
b. Equipment identification

In addition to the manufacturer's name and equipment identification, motion/position controls that are intended for use without installation inside of another enclosure or to be directly connected to the main incoming power source shall be permanently marked with the following input rating minimum information:

c. Input rating
   1. Voltage
   2. Maximum continuous current
   3. Frequency (if ac)
   4. Number of phases (if ac)
   5. Maximum allowable system short circuit current
d. Output full load current or power

3.5 TESTS AND PERFORMANCE

(Under consideration.)

3.6 APPLICATION DATA

(Under consideration.)

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Section 4
FEEDBACK DEVICES

The standards in this section apply to encoders providing quadrature output or square wave output.

4.1 OPERATING CONDITIONS AND MINIMUM/MAXIMUM RATINGS

4.1.1 Encoder Temperature Ranges

4.1.1.1 Encoders shall perform within their rated specifications within one or more of the following standard temperature ranges.

Ambient Temperature Ranges, °C

0 to +60	Normal operating temperature range
-20 to +85	Extended operating temperature

For unusual service conditions and other extreme operating temperature ranges, the manufacturer should be consulted.

Caution should be exercised when attaching the encoder to a heat generating device, such as a motor, to prevent damage to the encoder. The maximum temperature of the heat generating surface or the free air ambient, whichever is greater, should be selected as ambient.

4.1.2 Encoder Operating Supply Voltage Ranges

Normal operating supply voltage ranges shall be as follows:

5 Vdc	±5%
5 Vdc	±10%
12 Vdc	±5%
15 Vdc	±5%
12–15 Vdc	....
24 Vdc	±5%

Other operating supply voltages are available.

WARNING: Damage to the encoder may occur if the specified operating supply voltage tolerances are exceeded. For momentary and long term tolerance considerations, the manufacturer should be consulted.

4.1.3 High/Low Output Voltage

The manufacturer shall provide high and low level output voltage and output current information according to the following format. See Figure 4-1.

V_{OH} and I_{OH} are the electrical characteristics points of logic level one.

V_{OL} and I_{OL} are the electrical characteristics points of logic level zero.

High Level Output Voltage (V_{OH}) shall be specified in volts.

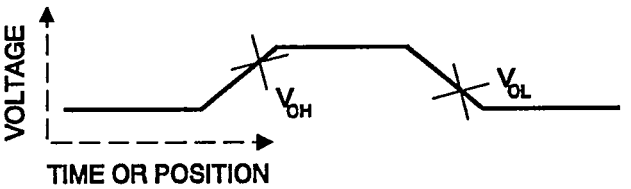


Figure 4-1
HIGH/LOW OUTPUT VOLTAGE

High Level Output Current (I_{OH}) shall be specified in milliamperes.

Low Level Output Voltage (V_{OL}) shall be specified in volts.

Low Level Output Current (I_{OL}) shall be specified in milliamperes.

For specific values the manufacturer should be consulted. As an alternative the manufacturer may specify the output device.

4.1.4 Encoding Characteristics

(Under consideration.)

4.1.4.1 INDEX PULSE CHARACTERISTICS

Encoder manufacturers identify the index pulse in different ways and users should consult the manufacturer for index pulse characteristics. The encoder manufacturer should therefore clearly show the user the relationship of the index pulse to the data channels through the use of a waveform diagram.

4.1.5 Output Protection

Encoders shall be operated within the manufacturer's recommended operating conditions for supply and output voltage. Improper interconnection will result in component damage.

Electrostatic discharge precautions shall be observed at all times, to include final inspection, packaging, shipping, receiving, storage, and final installation.

When proper electrical connections have been made, output protection from reverse biasing during removal and replacement may be accomplished by use of a polarized connector and polarized receptacle.

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4.2 ENCLOSURES FOR FEEDBACK DEVICES

See 2.3, Enclosures.

4.3 DIMENSIONS

The mounting dimensions for a NEMA size 25 encoder shall be as shown in Figure 4-2.

4.4 MARKING

Encoders shall bear the following minimum amount of information:

a. Manufacturer's name or identifier
b. Model number or part number

4.4.1 Encoder Data Sheet

A data sheet shall be provided with the following information. Nominal values and tolerances or maximum values shall be specified.

a. Electrical
   1. Resolution (line count)
   2. Supply voltage
   3. Current requirements
   4. Integrated circuits or output voltage levels
   5. Frequency response
   6. Accuracy (applies only to absolute encoders)
   7. Output signal waveform including index and diagram
   8. Cycle error
   9. Symmetry
   10. Phase
   11. Quadrature
   12. Direction of rotation
   13. Shaft runout for modular encoders
   14. Shaft loading (radial and axial)

b. Mechanical
   1. Size (dimensions and tolerances) with drawing
   2. Torque (starting and running)
   3. Maximum mechanical speed
   4. Terminations
   5. Moment of inertia

c. Environmental
   1. Operating temperature
   2. Storage temperature
   3. Shock
   4. Vibration
   5. Humidity
   6. IP rating

4.5 APPLICATION INFORMATION

The following are some of the important factors which should be considered by the user in the application of digital position encoders:

a. The method of coupling the encoder to the machine whose motion is being detected is a vital consideration because of possible errors or stresses which can be introduced.
   1. Care should be taken that the rated shaft loading, both radial and axial, not be exceeded. Common causes of difficulty are end thrust, misalignment, and belt or gear thrust.
   2. Backlash or modulation in the coupling can cause serious errors of position indication.

b. The moment of inertia of the encoder, including the coupling, as well as starting and running torque, may affect the dynamics of the system to which the encoder is coupled.

c. Exceeding the maximum mechanical speed, taking into account shaft loading (see a.), may cause permanent damage to the encoder. Exceeding the maximum electrical speed may result in incorrect data.

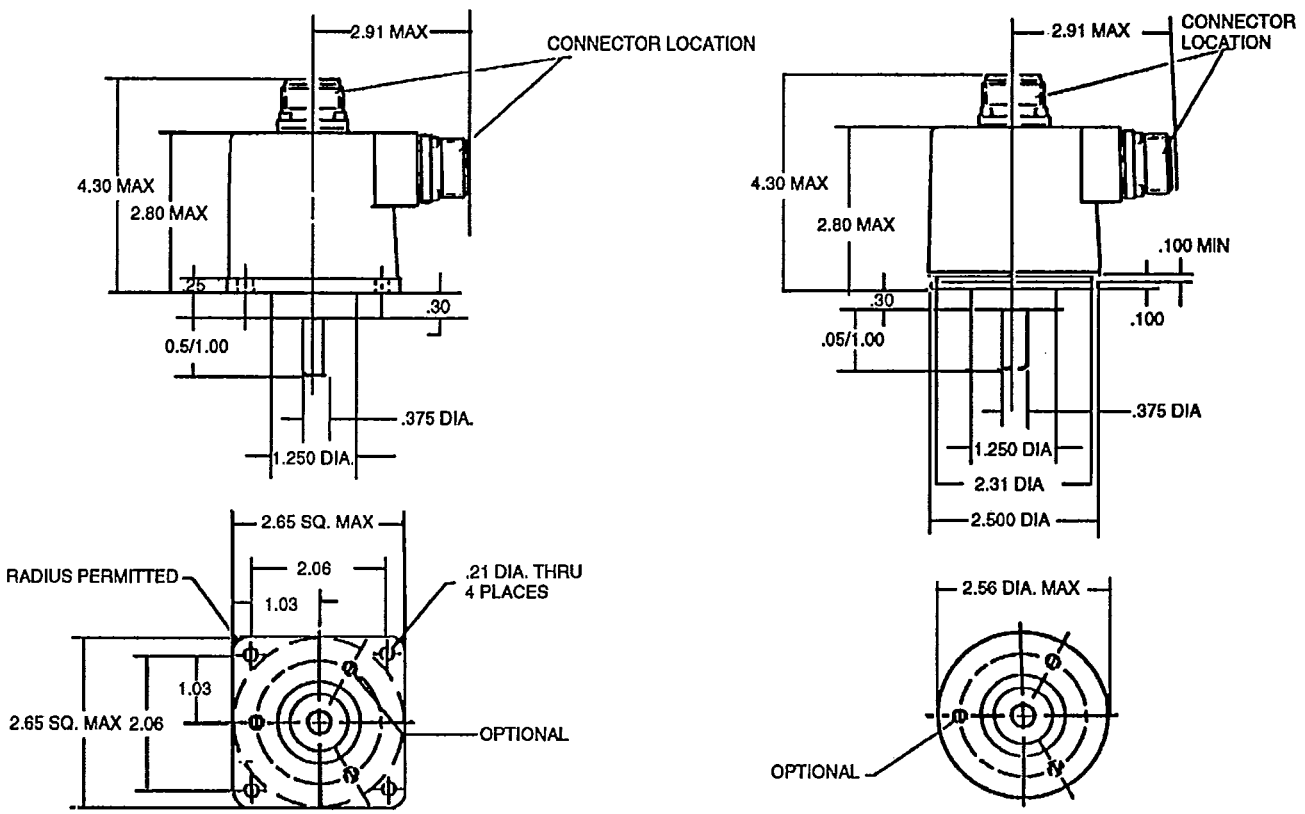
d. Noise in the input power supply or output of an encoder may cause application problems. Some of the common means of minimizing such noise are grounding, twisted pairs, shielding, and isolation of leads.

e. Consideration should be given to the ability of the output to handle resistive and capacitive loads. Long leads on the output have an associated capacitance which can degenerate high-frequency signals.

f.
   1. Encoders should be operated within the manufacturer's recommended operating conditions for supply and output voltage. Electrostatic discharge precautions should be observed at all times.
   2. Damage to the encoder may occur if the operating supply voltage tolerances are exceeded. For momentary and long term tolerance conditions the manufacturer should be consulted.
   3. Care should be exercised when attaching the encoder to a heat generating device, such as a motor, to prevent damage to the encoder. The maximum temperature of the heat generating surface or the free air ambient, whichever is greater, should be selected as ambient.

g. Other factors to be considered are:
   1. Type, location, and accessibility of terminations
   2. Mounting dimensions and type of mounting, such as face, servo-type, foot, flange
   3. Suitability of the enclosure

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NOTE—It is understood that encoders will typically have an end-mounting connector or a radially-mounting connector, not both. For the purpose of this standard, however, both connector location options are depicted.

Figure 4-2
NEMA SIZE 25 ENCODER DIMENSIONS

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA Standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

A Standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 8)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 7 & 16)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to authorized engineering information and not to procedures required for compliance with the standard.

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