ALLEN-BRADLEY

1326AD High Performance Rare-Earth AC Servomotors

Product Data

Introduction

This publication provides detailed information about the Bulletin 1326AD AC Servomotor. The topics covered in this publication include:

Basic Servomotor Description

The 1326AD is a family of brushless rare-earth AC servomotors designed to provide high performance, dependability and exceptional life. The motors offer up to 25 lb.-in. of RMS continuous torque and 75 lb.-in. of peak torque from a 3 inch (76.2 mm) diameter motor frame. The use of Samarium-Cobalt (SmCo) permanent magnets provide high torque to inertia ratios and high torque across the entire speed range. 1326AD motors have been selected to operate with Allen-Bradley 1389/1391 Servo Controllers and are suitable for applications that require quick response, high peak torque and smooth running characteristics.

Features

The following features are standard on all 1326AD Servomotors:

- Brushless construction improves reliability and eliminates brush maintenance.
- Samarium-Cobalt permanent magnets provide high torque to inertia ratios for rapid acceleration.
- 3 inch (76.2 mm) diameter frame minimizes space requirements.
- TENV IP65 type construction provides superior performance in harsh environments.
- Sinusoidal commutation and a special magnet configuration helps provide smooth low speed operation.
- High torque over a wide speed range minimizes oversizing.
- Thermal switch in winding for protection against overtemperature.
- Motor includes 6 foot (1.8 m) integral cables for power, commutation and optional position feedback (when ordered).

Options/Accessories

The options available for the 1326AD include (option code designation or catalog number in parenthesis):

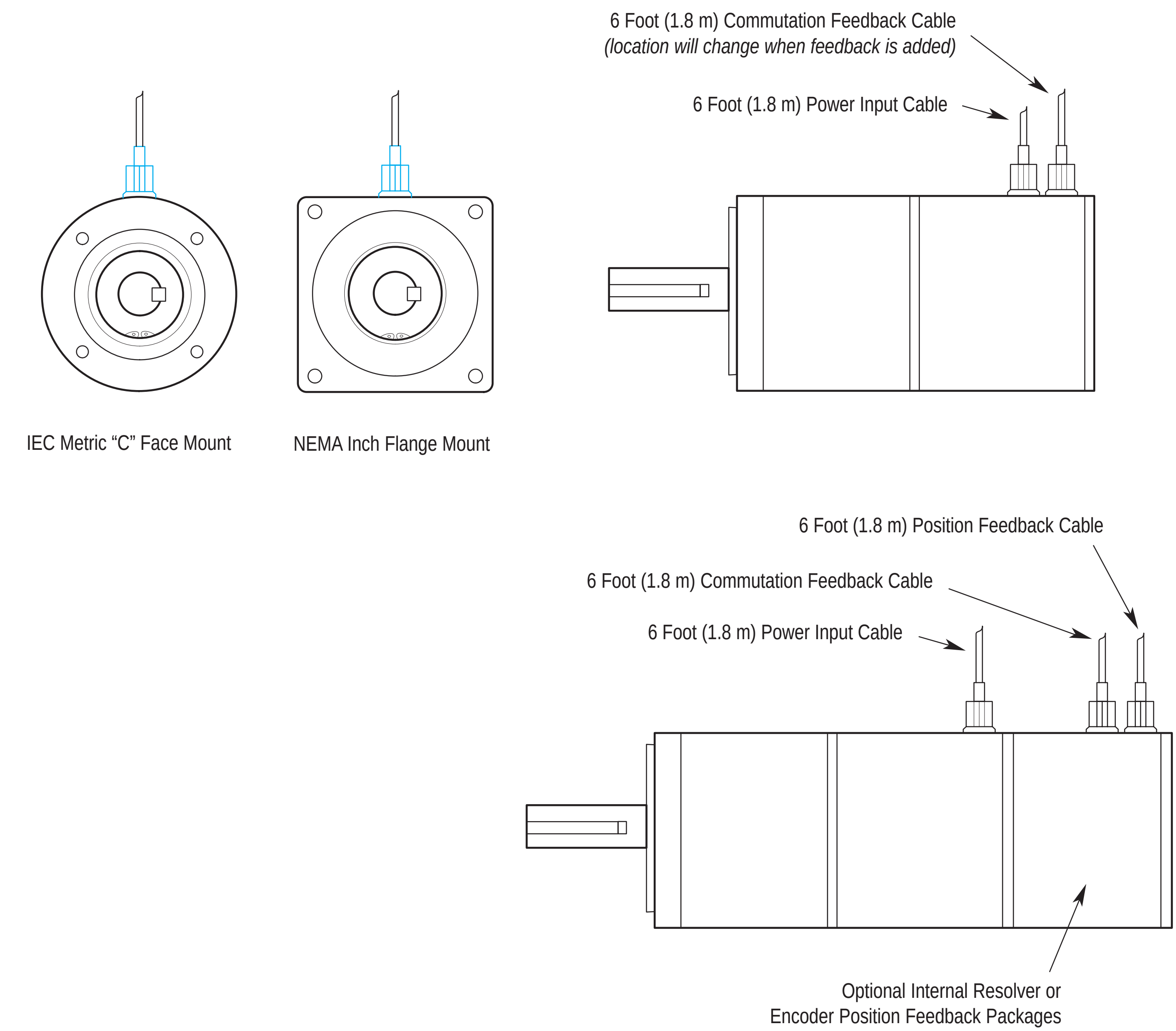
- NEMA inch flange mount (-11) or metric “C” face (-31).
- Encoder feedback (-E1) which provides 1000 pulses per revolution with 4 channel output for use with 8200, 8400, 8600 CNC, Creonics and IMC family controls. This encoder is connected directly to the rear of the motor (1:1 ratio) and requires a +5V DC (±10%,100mA maximum) voltage input.
- Two pole resolver feedback which provides a single brushless resolver feedback for use with Allen-Bradley 8600 CNC/GP (-RD) and IMC 120, 121, 123, 8200 (-RC) controls. This resolver is connected directly to the rear of the motor (1:1 ratio).

Please note that integral holding brakes are not available.

Motor Configuration & Options

Figure 1 shows the 1326AD motor configuration and available mounting options.

Figure 1
AC Servomotor Configuration and Options



Catalog Number Explanation

An explanation of the catalog numbering system for the 1326AD AC Servomotor is provided below.

1326 A D – K 2 G – 11 – E1

First Position	Second Position	Third Position	Fourth Position	Fifth Position	Sixth Position	Seventh Position	Eighth Position
Bulletin Number	**Type**	**Design**	**Series**[1]	**Motor Length**[1]	**Max. Op. Speed**[1]	**Mounting & Shaft Description**	**Standard Options**
	Letter / Description	Letter / Description	Description	Description	Letter / rpm	Code / Description	
	A — AC Servomotor PM Type	D — Rare-Earth Series D	Sequentially lettered to designate frame diameters. Code / Description K — 3.0” (76.2mm)	Sequentially numbered to indicate stack length within a given frame size.	E — 3000 F — 3500 G — 5000	11 — Inch Combination Face/Flange with Keyway 31 — Metric “C” Face	

Code	Description
E1	1000 Line Encoder, Factory Installed for 8200, 8400, 8600, Creonics & IMC Family
RC	Size 11 Resolver, Factory Installed for IMC 120, 121, 123 & 8200 CNC Harowe 11BRW-300-F-58A or equivalent (Receiver Type)
RD	Size 11 Resolver, Factory Installed for 8600 CNC and Creonics Harowe 11BRCX-300-C10/6 or equivalent (Transmitter Type)

[1] IMPORTANT: These designators are factory set and are only for descriptive purposes. Only the motors shown below are available.

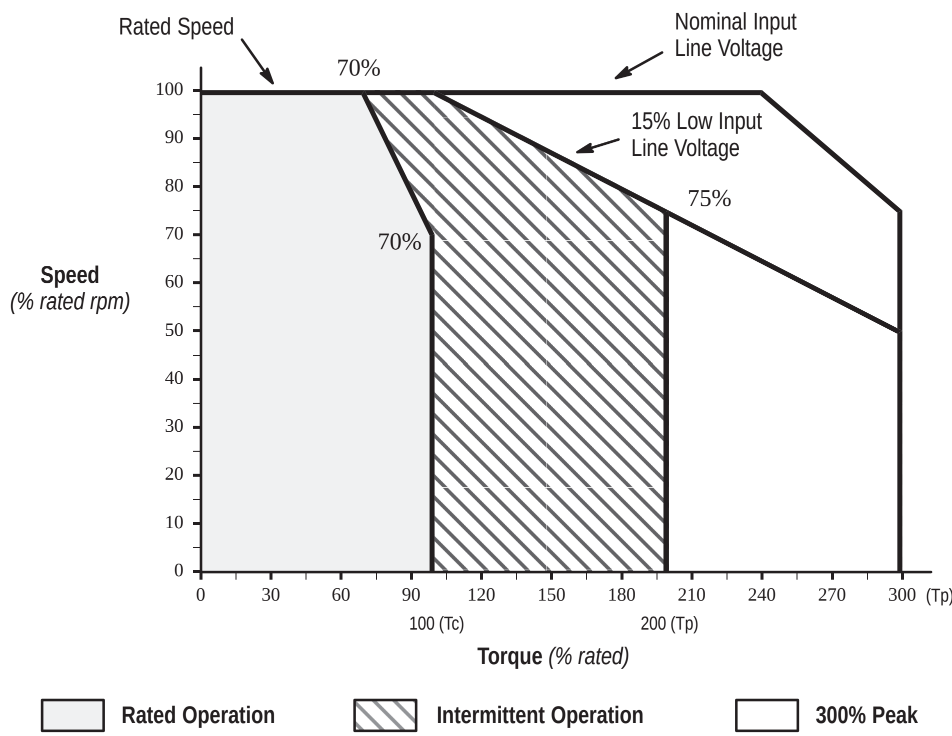
1326AD Performance Data

The following section contains the 1326AD performance data. Included in Table A is a Selection List detailing the performance parameters of selected amplifier/motor combinations. Following the Selection List are typical speed-torque curves for the standard motors.

Table A
1326AD / 1389 AC Servo System Selection List

Motor Rated Stall Torque (lb.-in./N-m)	Peak Stall Torque (lb.-in./N-m)	Operational Speed (rpm)	Motor Catalog Number	Amplifier Catalog Number for 300% Peak Torque	Rotor Inertia x 10^{-4} (lb.-in.-s^2/kg-m^2)	Motor kW
11.0/1.24	33.0/3.73	5000	1326AD-K2G-xx	1389-AA09-A01	4.5/0.51	0.52
15.0/1.69	45.5/5.14	5000	1326AD-K3G-xx	1389-AA09-A01	6.2/0.70	0.53
21.0/2.37	63.0/7.12	3500	1326AD-K4F-xx	1389-AA09-A01	8.0/0.90	0.67
25.0/2.82	75.0/8.47	3000	1326AD-K5E-xx	1389-AA09-A01	9.9/1.12	0.60

Figure 2
Typical 1326AD Speed-Torque Curve



Tc – rated torque of motor with windings at rated temperature and an ambient of 40°C. The controller is operating in a rated ambient of 60°C.

Tp – the peak torque that can be produced by the motor/controller combination with both at rated temperature and the motor in a 40°C ambient and the controller in a 60°C ambient. Since 200% current torque peaks are common in many applications for optimal controller usage, the following curves show typical system performance. Also shown is 300% peak torque which is available for acceleration/deceleration only (300% is available only with 1389-AA09-A01 amplifiers).

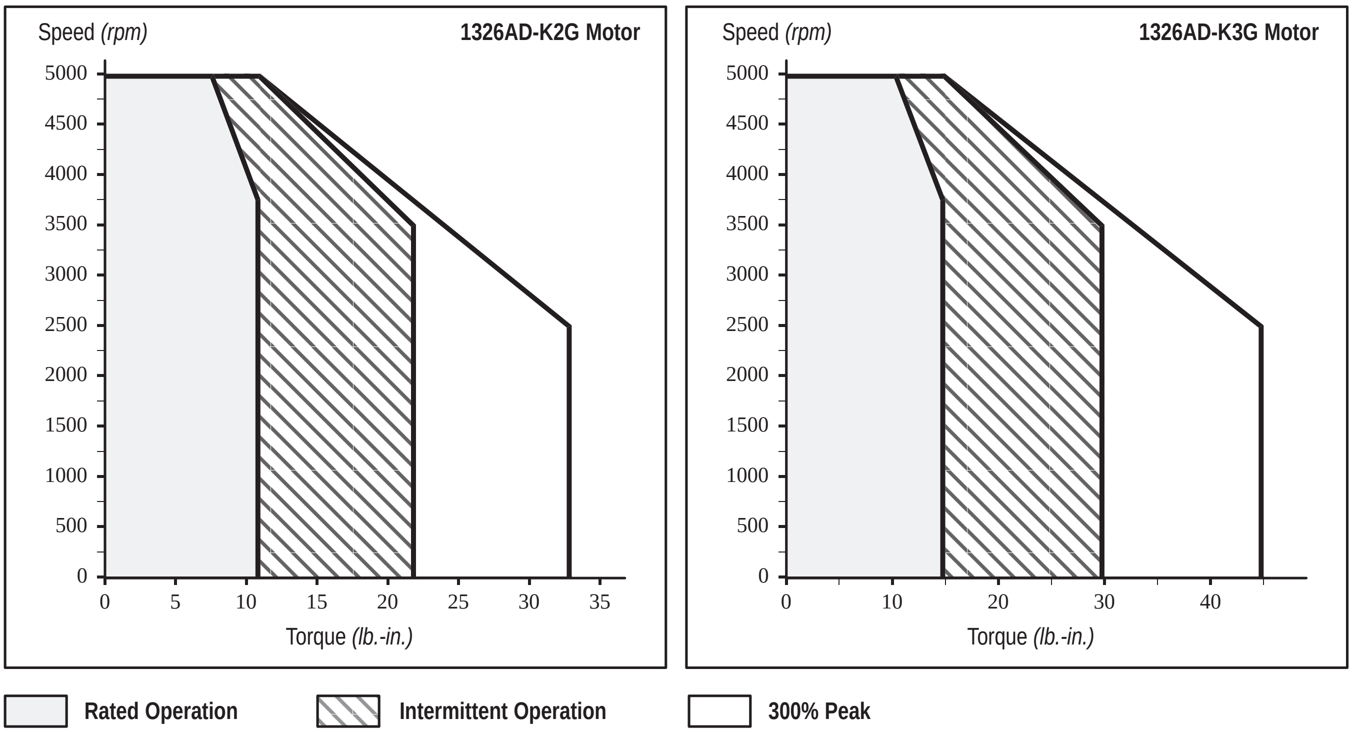
Rated Speed – the operating speed of the controller and motor combination at which a minimum of 70% of continuous rated torque (Tc) can be developed. This point is defined with the motor at 25°C and controller operating in a 60°C ambient.

Rated Operation Area – boundary of speed-torque curve where the motor and controller combination may operate on a servo basis without exceeding the RMS rating of either. See page 13 for formula details.

$$\text{RMS Torque} = \sqrt{\frac{Tpa^2 \times t_1 + Tss^2 \times t_2 + Tpd^2 \times t_3 + Tr^2 \times t_4}{t_1 + t_2 + t_3 + t_4}}$$

Intermittent Operation Area – boundary of speed-torque curve where the motor and controller combination may operate in acceleration-deceleration mode without exceeding peak rating of either, provided that the duty cycle RMS continuous torque limit is not exceeded.

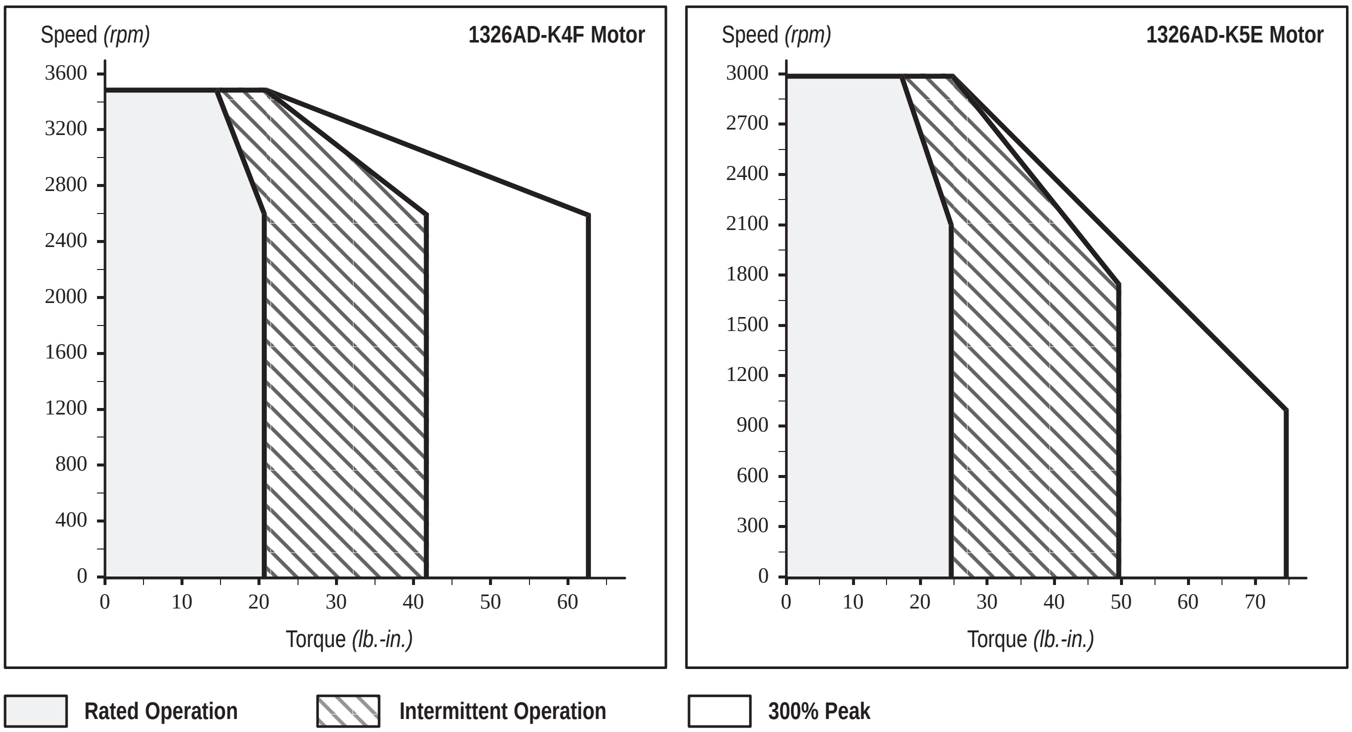
Figure 3
1326AD-K2G and K3G Motor Performance Curves



Category	Parameter	Symbol	Units	1326AD-K2G-xx	1326AD-K3G-xx
General	RMS Continuous Torque [1]	T_{CS}	lb.-in. (N-m)	11.0 (1.24)	15.0 (1.69)
	Peak Torque [1, 6]	T_{PK}	lb.-in. (N-m)	33.0 (3.73)	45.5 (5.14)
	Maximum Continuous Rated Current (RMS) [1]	I_{CS}	amperes	4.8	4.9
	Maximum Current at Peak Torque [1, 6]	I_{PK}	amperes	14.4	14.7
	Inertia	J_M	lb.-in.-s^2 (kg-m^2)	4.5 (0.51) x 10^{-4}	6.2 (0.70) x 10^{-4}
	Damping Coefficient [2]	KD_V	lb.-in. (N-m)/krpm	0.04 (0.0045)	0.06 (0.0068)
	Static Friction (Maximum)	T_f	lb.-in. (N-m)	0.23 (0.03)	0.31 (0.035)
	Operational Speed		rpm	5000	5000
	Maximum Continuous Output Power [1]		kW	0.52	0.53
	Terminal Resistance [2]		ohms	1.8	1.7
Thermal	Thermal Resistance [2]	R_{TH}	degrees C/watt	0.93	0.84
	Thermal Time Constant [2]	T_{TH}	minutes	20.0	23.0
Winding	Torque Constant, ±10% [3]	K_T	lb.-in. (N-m)/A	2.3 (0.26)	3.3 (0.37)
	Voltage Constant, ±10% [3]	K_e	volts/1000 rpm	19.4	26.0
	Phase to Phase Inductance, ±10% [2]	La	millihenry	5.8	7.0
	Phase to Phase Resistance, ±10% [2]	R	ohms	1.8	1.7
Mechanical	Motor Weight	W	lbs. (kg)	5.5 (2.5)	7.1 (3.2)

1 100° C case, 75° C rise
2 at 25° C ambient
3 L-L RMS value of sinusoidal waveform
4 nominal line
5 for all 1326AD-Kxx motors, use only 1389-AA045-A01 (200% peak torque), 1389-AA09-A01 (300% peak torque) or 1391B-AA15-A12 (300% peak torque)
6 200% operation = 2 x continuous, 300% operation = 3 x continuous

Figure 4
1326AD-K4F and K5E Motor Performance Curves



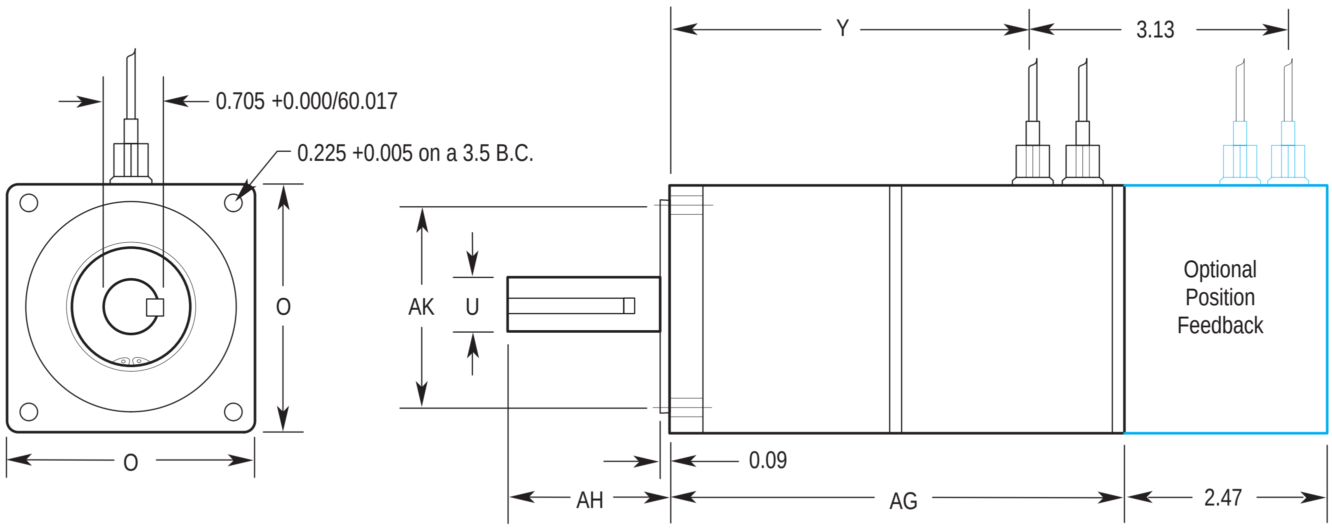
Category	Parameter	Symbol	Units	1326AD-K4F-xx	1326AD-K5E-xx
General	RMS Continuous Torque [1]	T_{CS}	lb.-in. (N-m)	21.0 (2.37)	25.0 (2.82)
	Peak Torque [1, 6]	T_{PK}	lb.-in. (N-m)	63.0 (7.12)	75.0 (8.47)
	Maximum Continuous Rated Current (RMS) [1]	I_{CS}	amperes	4.9	4.8
	Maximum Current at Peak Torque [1, 6]	I_{PK}	amperes	14.7	14.4
	Inertia	J_M	lb.-in.-s^2 (kg-m^2)	8.0 (0.90) x 10^{-4}	9.9 (1.12) x 10^{-4}
	Damping Coefficient [2]	KD_V	lb.-in. (N-m)/krpm	0.09 (0.01)	0.11 (0.010)
	Static Friction (Maximum)	T_f	lb.-in. (N-m)	0.39 (0.04)	0.47 (0.05)
	Operational Speed		rpm	3500	3000
	Maximum Continuous Output Power [1]		kW	0.67	0.60
	Terminal Resistance [2]		ohms	2.0	2.3
Thermal	Thermal Resistance [2]	R_{TH}	degrees C/watt	0.76	0.70
	Thermal Time Constant [2]	T_{TH}	minutes	26.0	29.0
Winding	Torque Constant, ±10% [3]	K_T	lb.-in. (N-m)/A	4.3 (0.46)	5.0 (0.56)
	Voltage Constant, ±10% [3]	K_e	volts/1000 rpm	35.0	43.0
	Phase to Phase Inductance, ±10% [2]	La	millihenry	9.0	11.0
	Phase to Phase Resistance, ±10% [2]	R	ohms	2.0	2.3
Mechanical	Motor Weight	W	lbs. (kg)	8.7 (3.9)	10.2 (4.6)

1 100° C case, 75° C rise
2 at 25° C ambient
3 L-L RMS value of sinusoidal waveform
4 nominal line
5 for all 1326AD-Kxx motors, use only 1389-AA045-A01 (200% peak torque), 1389-AA09-A01 (300% peak torque) or 1391B-AA15-A12 (300% peak torque)
6 200% operation = 2 x continuous, 300% operation = 3 x continuous

Motor Dimensions

Figure 5 and Figure 6 provide approximate dimensions for the 1326AD flange and face mount motors, respectively.

Figure 5
Motor Dimensions – NEMA Inch Flange Mount



Dimensions are in inches

Catalog Number	AG	AH[1]	AK[2]	O	U[3]	Y	Key[4]
1326AD-K2x-11	7.94	1.125	2.500	3.00	0.625	6.5	0.1875 Sq. x 0.750
1326AD-K3x-11	8.94	1.125	2.500	3.00	0.625	7.5	0.1875 Sq. x 0.750
1326AD-K4x-11	9.94	1.125	2.500	3.00	0.625	8.5	0.1875 Sq. x 0.750
1326AD-K5x-11	10.94	1.125	2.500	3.00	0.625	9.5	0.1875 Sq. x 0.750

Pilot Eccentricity	0.002 T.I.R.
Shaft Runout	0.002 T.I.R.
Shaft Endplay	0.005 T.I.R.
Maximum Face Runout	0.002 T.I.R.

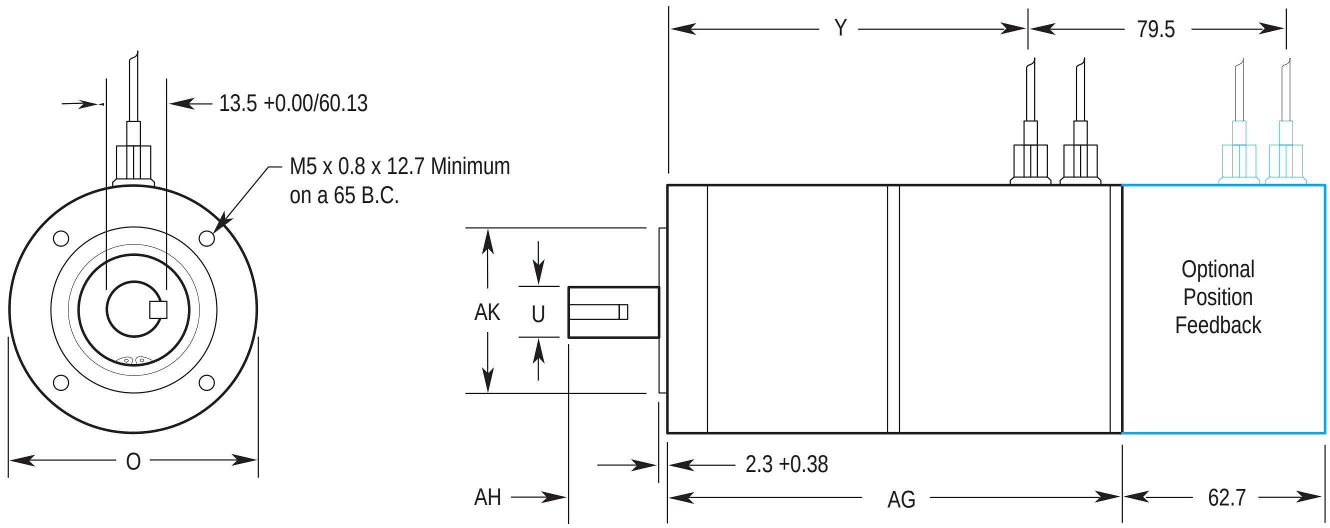
1 ±0.03

2 +0.000, –0.002

3 +0.0000/–0.0005

4 +0.000, –0.020 x ± 0.010

Figure 6
Motor Dimensions – Metric "C" Face Mount



Dimensions are in millimeters

Catalog Number	AG	AH[1]	AK[2]	O	U[3]	Y	Key[4]
1326AD-K2x-31	202	30	50	76.2	12	165	0.4 Sq. x 20.0
1326AD-K3x-31	227	30	50	76.2	12	191	0.4 Sq. x 20.0
1326AD-K4x-31	253	30	50	76.2	12	216	0.4 Sq. x 20.0
1326AD-K5x-31	278	30	50	76.2	12	241	0.4 Sq. x 20.0

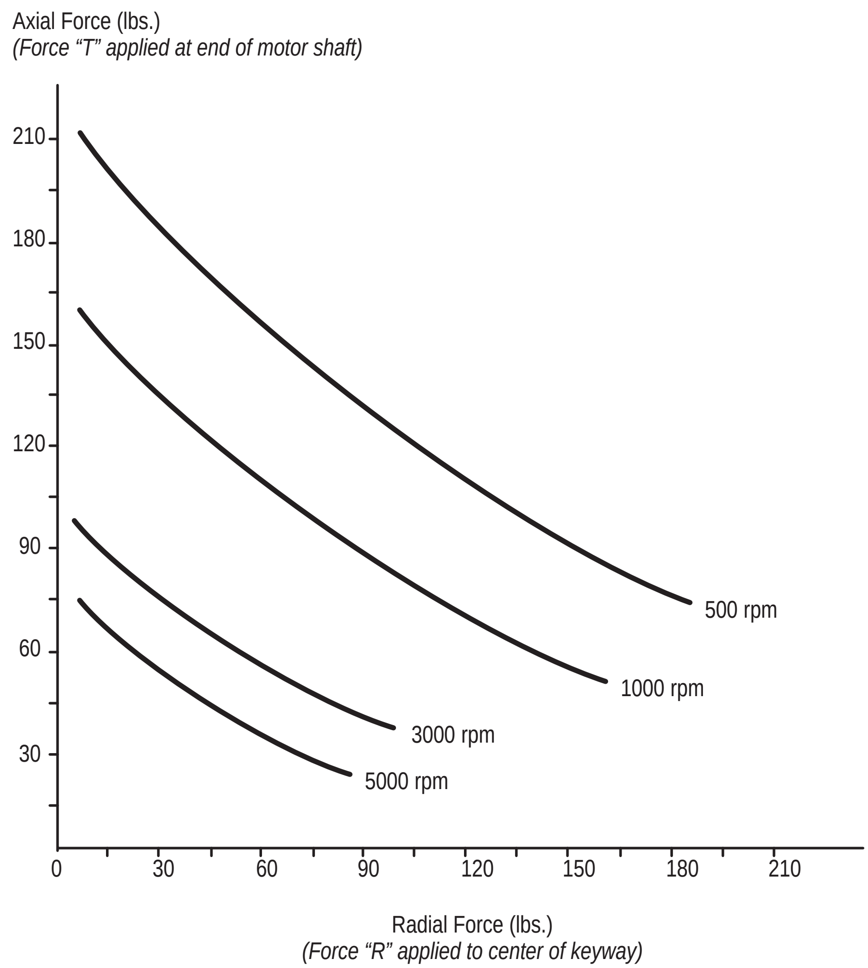
Pilot Eccentricity	0.050 T.I.R.
Shaft Runout	0.050 T.I.R.
Shaft Endplay	0.127 T.I.R.
Maximum Face Runout	0.050 T.I.R.

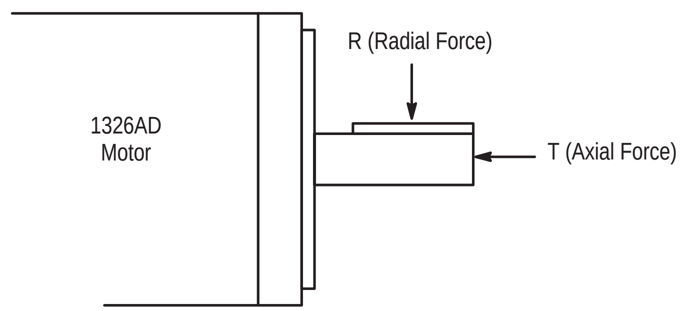
1 ±0.75
2 +0.00, –0.05
3 +0.000, –0.013
4 +0.00, –0.05 x ± 0.025

Bearing Life Curves

Figure 7 shows the 20,000 hour B10 bearing life curves for the 1326AD motor. The curves shown are applicable for either vertical or horizontal mounting.

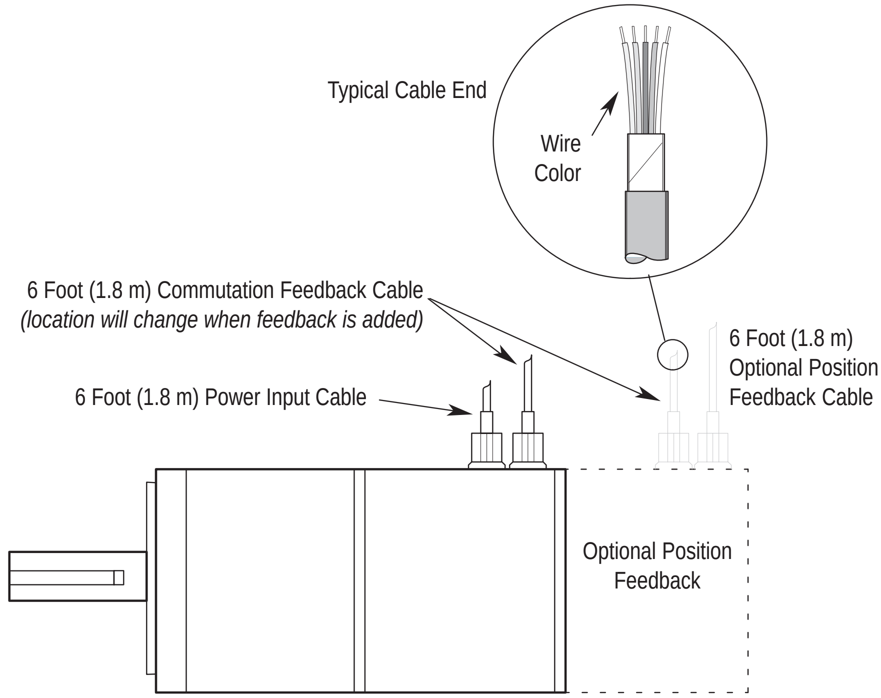
Figure 7
20,000 Hour B10 Bearing Life





Cable Wiring Information

Figure 8
1326AD Cabling



Commutation Cable

Wire Color	Gauge	Description	Servo Control Connection 1389-AAxx Terminal #	1391-AAxx Terminal #
Red/White	#22	Rotor 1	TB2-1	TB1-10
Black/White	#22	Rotor 2	TB2-2	TB1-9
Shield - Drain	#22	Shield	TB2-3	TB1-8
Red	#22	Stator 1 (Sine)	TB2-4	TB1-7
Black	#22	Stator 3 (Sine)	TB2-5	TB1-6
Shield - Drain	#22	Shield	TB2-6	TB1-5
Yellow	#22	Stator 4 (Cosine)	TB2-7	TB1-4
Blue	#22	Stator 2 (Cosine)	TB2-8	TB1-3
Shield - Drain	#22	Shield	TB2-9	TB1-2
Brown	#22	Not Used	–	–
Green	#22	Not Used	–	–
Yellow	#22	Not Used	–	–
Shield - Drain	#22	Shield	TB2-10	TB1-1 to Ground Stud

Motor Power Cable

Wire Color	Gauge	Description	Servo Control Connection 1389-AAxx Terminal #	1391-AAxx Terminal #
Blue	#18	Phase A	TB3-1	TB5-1
Brown	#18	Phase B	TB3-2	TB5-2
Violet	#18	Phase C	TB3-3	TB5-3
Green	#18	Ground	Ground Stud	Ground Stud
White	#24	Thermal Switch	N/A	N/A
White	#24	Thermal Switch	N/A	N/A
Shield - Drain	–	Drain	Ground Stud	Ground Stud

Secondary Resolver Position Feedback Cable – Optional

Wire Color	Description	Gauge
Red/White	Rotor 1	#22
Black/White	Rotor 2	#22
Shield - Drain	Shield	
Red	Stator 1 (Sine)	#22
Black	Stator 3 (Sine)	#22
Shield - Drain	Shield	
Brown	Stator 2 (Cosine)	#22
Green	Stator 4 (Cosine)	#22
Yellow	Not Used	#22
Shield - Drain	Shield	
Yellow	Not Used	#22
Blue	Not Used	#22
Shield - Drain	Shield	

Encoder Position Feedback Cable – Optional

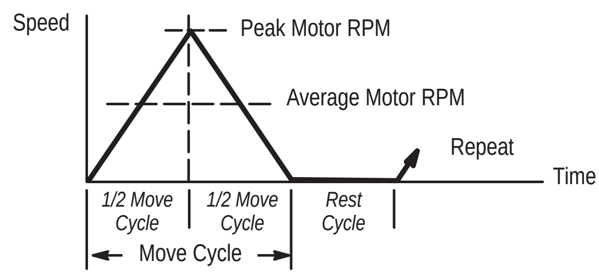
Wire Color	Description	Gauge
Red/White	Channel A	#22
Black/White	Channel A (NOT)	#22
Shield - Drain	Shield	
Yellow	Channel B	#22
Blue	Channel B (NOT)	#22
Shield - Drain	Shield	
Green	Channel Z	#22
Brown	Channel Z (NOT)	#22
Yellow	Not Used	#22
Shield - Drain	Shield	
Red	+5V DC	#22
Black	+5V DC Return	#22
Shield - Drain	Shield	

Servomotor Application Guide

The following steps are a general guide designed to assist in servomotor selection. Formulas provided on the following pages should be used in conjunction with the steps below to determine correct motor sizing. For further assistance, complete the appropriate Application Data Sheet (pages 21-24) and contact your local Allen-Bradley Sales Office.

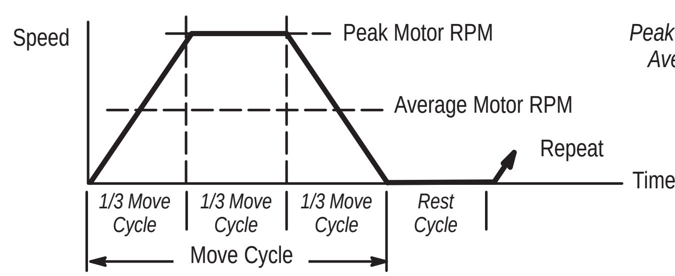
1. Determine the motor speed requirements.
   Based on the power train configuration of your application (leadscrew, rack and pinion, conveyor) determine the average and peak rpm of the servomotor. Choose the velocity profile that provides the closest approximation of your cycle.

   a) Triangular Velocity Profile.



Peak RPM = 1.2 x Average RPM

   b) Trapezoidal Velocity Profile.



Peak RPM = 1.5 x Average RPM

2. Determine the minimum continuous motor torque required.
   Calculate motor torque (Tm) using the formulas on page 15, 17 or 19.

3. Determine the peak motor torque required to accelerate the load.
   If the motor must accelerate within a specified time, determine the system inertia using the formula sheets for your specific power train configuration, otherwise go to step 5. Use the time (Time) to achieve peak rpm, change in rpm (Δrpm), power train inertia (System Inertia) and load torque (Tl) in one of the two formulas that follow:

   <u>System Inertia in lb.-ft.^{2}</u>

$$\text{Peak Torque} = \frac{\text{System Inertia x } \Delta\text{rpm}}{\text{308 x Time (to accelerate)}} + \text{Tl}$$

where:
Peak Torque = motor torque required to accelerate the load in lb.-ft.
System Inertia = total system inertia (including motor) in lb.-ft.^{2}
Time = seconds
Tl = load torque present at the motor shaft during accel in lb.-ft.

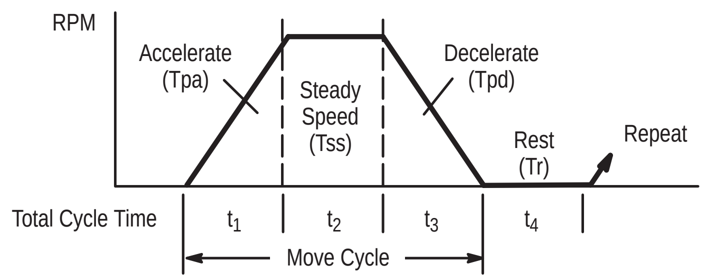
System Inertia in lb.-in.-s^2

$$\text{Peak Torque} = \frac{\text{System Inertia} \times \Delta\text{rpm}}{9.6 \times \text{Time (to accelerate)}} + \text{Tl}$$

where:
Peak Torque = motor torque required to accelerate the load in lb.-in.
System Inertia = total system inertia in lb.-in.-s^2 (listed as Jtjm on formula sheets)
Time = seconds
Tl = load torque present at the motor shaft during accel in lb.-in.

4. If the motors total time to accelerate/decelerate ($t_1 + t_3$)exceeds 20% of the total cycle time ($t_1+t_2+t_3+t_4$), determine the motors average torque with the formula shown.

Duty Cycle Profile



$$\text{Trms} = \sqrt{\frac{\text{Tpa}^2 \times t_1 + \text{Tss}^2 \times t_2 + \text{Tpd}^2 \times t_3 + \text{Tr}^2 \times t_4}{t_1 + t_2 + t_3 + t_4}}$$

where:

Trms	The motors RMS or average torque over the duty cycle. (Expressed in lb.-in. or lb.-ft. The same units must be used throughout the formula.)
Tpa	Motor peak torque to accelerate to maximum speed. (Expressed in lb.-in. or lb.-ft. The same units must be used throughout the formula.)
Tss	Motor torque present at the motor shaft during constant speed segment. (Expressed in lb.-in. or lb.-ft. The same units must be used throughout the formula.)
Tpd	Motor peak torque to decelerate to zero speed. (Expressed in lb.-in. or lb.-ft. The same units must be used throughout the formula.)
Tr	Torque when motor is at zero speed (typically is Tss).
t_1, t_2, t_3, t_4	Time for each portion of the duty cycle in seconds.

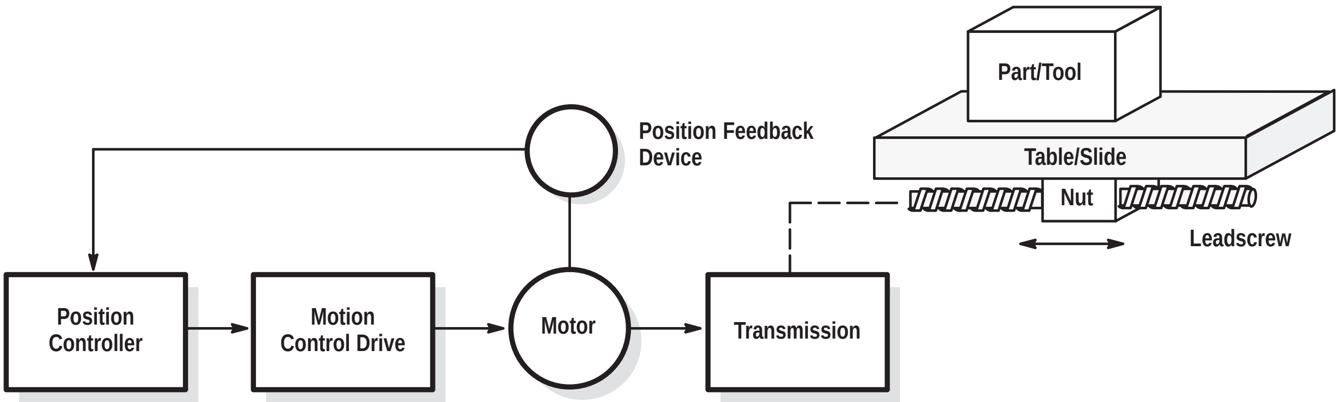
5. To select a servomotor:

a) Select a motor with maximum speed capability of at least the peak rpm calculated in step 1.

b) Select a motor with continuous torque capability equal to or greater than the value determined in step 2 or 4, whichever is greater.

c) Select a motor with the capability to supply peak torque as determined in step 3, up to the maximum speed determined in step 1.

Servomotor Driven Leadscrew Formulas



Motor Speed

$$Nm = \frac{V1}{Lead} \times G.R.$$

Continuous Torque at the Leadscrew

$$Tb = \underset{(1)}{\frac{W1 \times u \times Lead}{6.28 \times e_1}} + \underset{(2)}{\frac{Thrust \times Lead}{6.28 \times e_1}} + \underset{(3)}{\frac{Thrust \times Lead \times u}{6.28 \times e_1}}$$

Continuous Motor Torque

$$Tm = \frac{Tb}{G.R. \times e_2} \times \underset{(4)}{1.1}$$

Total System Inertia

$$Jtjm = \left[\frac{W1}{386} \left(\frac{Lead}{6.28} \right)^2 + Jb \right] \times \frac{1}{G.R.^2} + Jgb + Jm$$

Accelerating Torque

See step 3 of the *Servomotor Application Guide* on page 13.

Where:

- e = Efficiency of leadscrew, e_1 (90% typical) or gearbox, e_2 (95% typical).
- G.R. = Ratio of motor speed to leadscrew speed.
- Jb = Leadscrew inertia (lb.-in.-s^2).
- Jgb = Gearbox inertia at the motor shaft (lb.-in.-s^2).
- Jm = Motor inertia (lb.-in.-s^2).
- Jtjm = Total system inertia at the motor shaft (lb.-in.-s^2).
- Lead = Movement of slide in inches per revolution of leadscrew.
- Nm = Motor velocity (rpm).
- Tb = Torque at leadscrew (lb.-in.).
- Thrust = Cutting force applied by slide/load on a workpiece (lbs).
- Tl = Load torque present at the motor shaft during accel (lb.-in.).
- Tm = Load torque required at the motor (lb.-in.).
- u = Table/slide sliding coefficient of friction (typically 0.03 to 0.2).
- V1 = Linear velocity of slide/load (IPM).
- W1 = Weight of slide and load (lbs.).

Notes:

(1) Friction torque generated by the weight of the table/slide and part/tool.

(2) Torque required for thrust (cutting force) load.

(3) Friction torque generated by the thrust (cutting force) load (approximation).

(4) Safety factor to account for torque required to overcome seals, gib adjustments, etc. (10% of Tm, minimum).

Typical Leadscrew Data

(Using Formulas from Previous Page)

Torque at Lead to Produce 1000 lbs. Thrust Force

1. Divide the lb.-in. value shown by efficiency of screw to obtain corrected value.

Lead *(in./rev)*	**Torque** *(lb.-in.)*	**Lead** *(in./rev)*	**Torque** *(lb.-in.)*
0.200	31.84	0.333	53.02
0.250	39.80	0.500	79.61
0.300	47.77	1.000	159.23

2. For thrust other than 1000 lbs.

$$\text{Torque} = \frac{\text{Required Thrust}}{1000} \times \text{Torque at 1000 lbs.}$$

Inertia of the Leadscrew

1. To determine total leadscrew inertia.

$$\text{Leadscrew Inertia} = \frac{\text{Total Leadscrew Length } (in.)}{10} \times \text{Inertia } (per\ 10\text{" } length)$$

Diameter *(inches)*	**Inertia (10" length)** *(lb.-in.-s^2)*	**Diameter** *(inches)*	**Inertia (10" length)** *(lb.-in.-s^2)*
0.50	0.000048	2.00	0.0115
0.75	0.00023	2.25	0.0184
1.00	0.00072	2.50	0.0281
1.25	0.0018	2.75	0.0412
1.50	0.0038	3.00	0.0583
1.75	0.0068	3.50	0.1080

2. Formula to determine leadscrew inertia.

$Jb = 0.000073^{(1)} \times D^4 \times L$

where:
D = Screw diameter in inches.
L = Screw length in inches.

(1) Leadscrew is assumed to be made of steel. If it is made of aluminum, the 0.000073 constant becomes 0.000024.

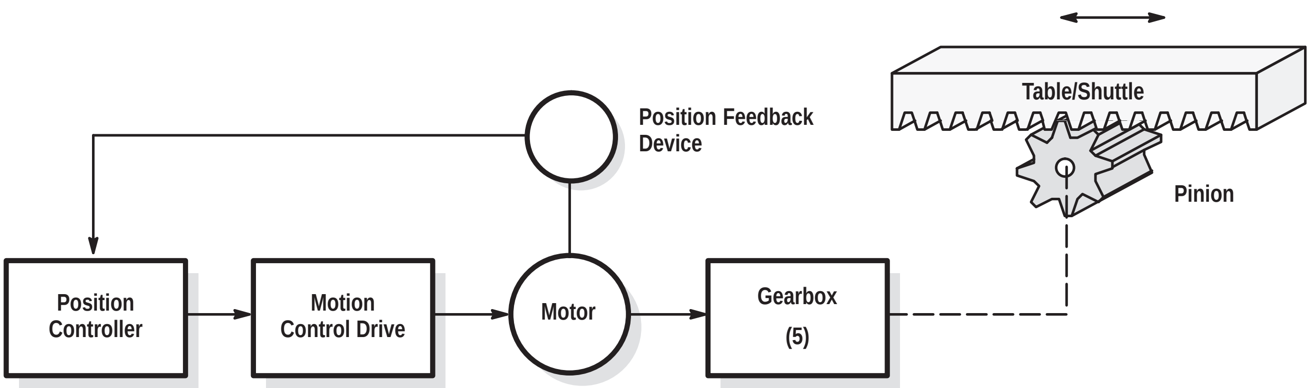
Inertia of the Slide/Table Reflected to the Motor per 1000 lbs. Weight

1. For slide/table weight other than 1000 lbs.

$$\text{Slide/Table Inertia at Leadscrew} = \frac{\text{Actual Weight}}{1000} \times \text{Reflected Inertia } (1000\ lbs.)$$

Lead *(in./rev)*	**Reflected Inertia (per 1000 lbs.)** *(lb.-in.-s^2)*	**Lead** *(in./rev)*	**Reflected Inertia (per 1000 lbs.)** *(lb.-in.-s^2)*
0.200	0.0026	0.333	0.0074
0.250	0.0042	0.500	0.0167
0.300	0.0060	1.000	0.0666

Servomotor Driven Rack and Pinion Formulas



Motor Speed

$$Nm = \frac{V1}{6.28 \times R} \times G.R.$$

Continuous Torque at the Pinion

$$Tpin = \underset{(1)}{\frac{R \times W1 \times u}{e_1}} + \underset{(2)}{\frac{R \times Thrust}{e_1}} + \underset{(3)}{\frac{R \times Thrust \times u}{e_1}}$$

Continuous Motor Torque

$$Tm = \frac{Tpin}{G.R. \times e_2} \times \underset{(4)}{1.1}$$

Total System Inertia

$$Jtjm = \left[\frac{W1}{386} \times R^2 + Jpin \right] \times \frac{1}{G.R.^2} + Jgb + Jm$$

Accelerating Torque

See step 3 of the *Servomotor Application Guide* on page 13.

Where:

e	= Efficiency of pinion to rack mesh (95%) e_1 or gearbox (95%/mesh) e_2.
G.R.	= Ratio of motor speed to pinion speed.
Jgb	= Gearbox inertia at the motor shaft (lb.-in.-s^2).
Jm	= Motor inertia (lb.-in.-s^2).
Jpin	= Pinion inertia (lb.-in.-s^2).
Jtjm	= Total system inertia at the motor shaft (lb.-in.-s^2).
Nm	= Motor velocity (rpm).
R	= Pinion radius (in.).
Thrust	= Force applied by table against workpiece, stop, etc. (lbs).
Tl	= Load torque present at the motor shaft during accel (lb.-in.).
Tm	= Continuous torque required at the motor (lb.-in.).
Tpin	= Continuous torque required at the pinion (lb.-in.).
u	= Sliding coefficient of friction of table or shuttle support bearings (typically 0.03 to 0.2).
V1	= Linear velocity of slide/load (IPM).
W1	= Weight of table/shuttle and load (lbs.).

Notes:

(1) Friction torque required to move table/load.

(2) Motor torque required for thrust load.

(3) Friction torque generated by the thrust load.

(4) Safety factor to account for torque required to overcome misalignment, mechanical adjustments, etc. (10% of Tm minimum).

(5) Gearbox/reducer typically required between motor and pinion.

Typical Rack & Pinion System Data

(Using Rack and Pinion Formulas from Previous Page)

Torque at Pinion to Produce 1000 lbs. Thrust Force

1. Divide lb.-in. value shown at pinion by gearbox ratio and efficiency to obtain required motor torque (Tm)
2. To determine pinion torque for other thrust values, divide the thrust by 1000 and multiply by the pinion torque shown for the proper radius.

Pinion Radius[1] *(inches)*	Pinion Torque *(lb.-in.)*	Pinion Radius[1] *(inches)*	Pinion Torque *(lb.-in.)*
0.5	526.3	2.0	2105.3
1.0	1052.6	3.0	3157.9
1.5	1578.9	4.0	4210.5

[1] Pinion efficiency of 95% assumed.

Torque at Pinion to Move 1000 lbs. Total Table/Slide Weight

1. Divide the lb.-in. value shown at pinion by gearbox ratio and efficiency to obtain required motor torque (Tm)
2. To determine pinion torque for other weight values, divide the weight by 1000 and multiply by the pinion torque shown for the proper radius.

Pinion Radius[1]	Pinion Torque[2] (lb.-in.)				
(inches)	u=0.03	u=0.05	u=0.1	u=0.15	u=0.2
0.5	15.8	26.3	52.6	78.9	105.3
1.0	31.6	52.6	105.2	157.9	210.5
1.5	47.4	78.9	157.8	236.7	315.9
2.0	63.2	105.2	210.4	315.6	421.2
3.0	94.7	157.9	315.6	473.4	631.8
4.0	126.3	210.4	420.8	631.2	842.4

[1] Pinion efficiency of 95% assumed.
[2] u = Coefficient of friction.

Inertia of Table Plus Load Reflected to Pinion per 1000 lbs. Weight

1. Divide the inertia value by the square of the gearbox ratio to obtain system inertia at the motor.
2. To determine reflected inertia for other weights, divide the weight by 1000 and multiply by the inertia shown for the appropriate radius.

Pinion Radius *(inches)*	Reflected Load Inertia *(lb.-in.-s²)*	Pinion Radius *(inches)*	Reflected Load Inertia *(lb.-in.-s²)*
0.5	0.648	2.0	10.360
1.0	2.590	3.0	23.300
1.5	5.830	4.0	41.450

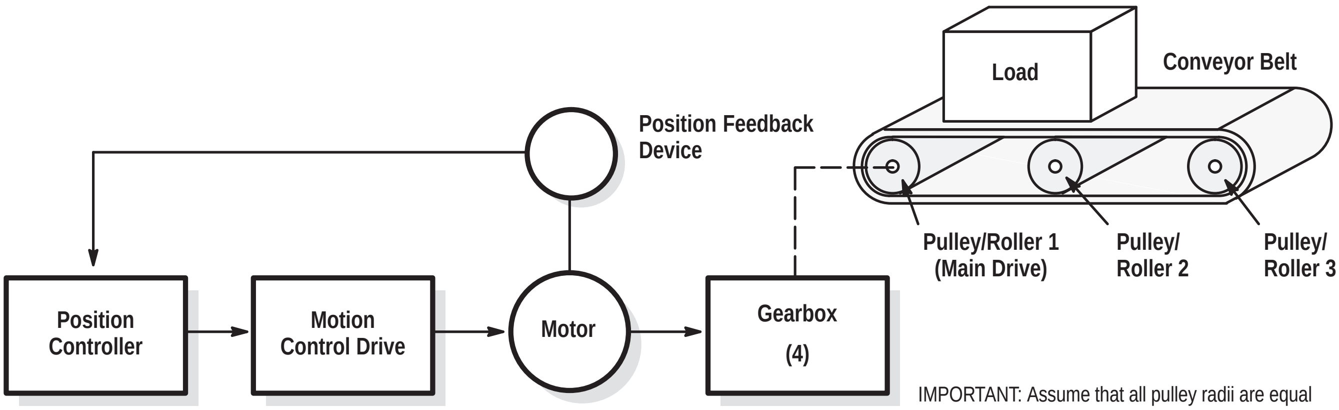
3. Formula to determine pinion inertia.

$Jpin = 0.000073^{(1)} \times D^4 \times WH$

where:
D = Pinion diameter in inches.
Jpin = Inertia in $lb.\text{-}in\text{-}s^2$
WH = Pinion width in inches.

(1) Pinion is assumed to be made of steel. If it is made of aluminum, the 0.000073 constant becomes 0.000024.

Servomotor Driven Conveyor Formulas



IMPORTANT: Assume that all pulley radii are equal

Motor Speed

$$Nm = \frac{V1}{6.28 \times R} \times G.R.$$

Continuous Torque at Pulley/Roller 1

$$Tp/r = \underbrace{\frac{R \times W1 \times u}{e_1}}_{(1)} + \underbrace{\frac{R \times Wb \times u}{e_1}}_{(2)}$$

Continuous Motor Torque

$$Tm = \frac{Tp/r}{G.R. \times e_2} \times \underbrace{1.25}_{(3)}$$

Total System Inertia

$$Jtjm = \frac{W1}{386} \times R^2 \times \frac{1}{G.R.^2} + \frac{Jpull_{1+2+3}}{G.R.^2} + Jgb + Jm$$

Accelerating Torque

See step 3 of the *Servomotor Application Guide* on page 13.

Where:

- e = Efficiency of drive roller to gearbox (95% typical) e_1 and gearbox (95%/mesh typical) e_2.
- G.R. = Ratio of motor speed to pinion speed.
- Jgb = Gearbox inertia at the motor shaft (lb.-in.-s^2).
- Jm = Motor inertia (lb.-in.-s^2).
- Jpull = Pulley + roller inertia, 1, 2, 3 (lb.-in.-s^2).
- Jtjm = Total system inertia at the motor shaft (lb.-in.-s^2).
- Nm = Motor velocity (rpm).
- R = Pulley/roller radius (in.).
- Tl = Load torque present at the motor shaft during accel (lb.-in.).
- Tm = Continuous torque required at the motor (lb.-in.).
- Tp/r = Continuous torque required at the main drive pulley/roller (lb.-in.).
- u = Rolling coefficient of friction. Typically 0.03 to 0.05 for ball bearing rollers.
- V1 = Linear velocity of load (IPM).
- Wb = Weight of conveyor belt (lbs.).
- W1 = Weight of load and belt (lbs.).

Notes:

(1) Torque required to move the load at pulley/roller 1 (lb.-in.).

(2) Torque required to move the belt at pulley/roller 1 (lb.-in.).

(3) Safety factor to account for torque required to overcome miscellaneous tensions, etc.

(4) Gearbox/reducer typically required between motor and pulley/drive roller.

Typical Conveyor System Data

(Using Conveyor Formulas from Previous Page)

Torque at Drive Pulley/Roller 1 w/1000 lbs. Load

1. Divide lb.-in. value shown at the roller by the gearbox ratio, roller/ belt (e_1) and gearbox (e_2) efficiency to obtain required motor torque (Tm)
2. To determine pulley/roller torque for other load values, divide the load weight by 1000 and multiply by the pulley/roller torque shown for the appropriate radius.

Roller Radius[1] *(inches)*	**Torque at Pulley 1**[2] *(lb.-in.)* *u=0.03*	*u=0.05*	*u=0.1*	*u=0.15*	*u=0.2*
0.5	15.8	26.3	52.6	78.9	105.3
1.0	31.6	52.6	105.2	157.9	210.5
1.5	47.4	78.9	157.8	236.7	315.9
2.0	63.2	105.2	210.4	315.6	421.2
3.0	94.7	157.9	315.6	473.4	631.8
4.0	126.3	210.4	420.8	631.2	842.4

[1] Pinion efficiency of 95% assumed. [2] u = Coefficient of friction.

3. Formula used to determine torque at pulley/roller.

$$\text{Torque} = \frac{R \times W1 \times u}{e}$$

where:
W1 = 1000 lbs.

Inertia of the Load Reflected to the Drive Pulley/Roller per 1000 lbs. Load *(does not include roller, pulley or belt inertia)*

1. Divide the inertia value shown by the square of the gearbox ratio to obtain system inertia at the motor.
2. To determine reflected inertia for other weights, divide the weight by 1000 and multiply by the inertia shown for the appropriate radius.

Roller Radius *(inches)*	**Reflected Load Inertia** *(lb.-in.)*
0.5	0.648
1.0	2.590
1.5	5.830
2.0	10.360
3.0	23.300
4.0	41.450

3. Formula to determine inertia of each roller or pulley.

$$Jr = 0.0012^{(1)} \times [(D_1^4 \div 16) - (D_2^4 \div 16)] \times L$$

where:
D_l = Pulley/roller outer diameter in inches.
D_2 = Pulley/roller inner diameter in inches.
L = Pulley/roller width in inches.

(1) Pulley/roller is assumed to be made of steel. If it is madeof aluminum, the 0.0012 constant becomes 0.00004.

Leadscrew Application Data for Point to Point Positioning

A. CUSTOMER ______________________

B. AXIS DESCRIPTION ______________________

C. ❏ NEW SYSTEM

D. ❏ EXISTING EQUIPMENT

1. SERVOMOTOR — MANUFACTURER ______________________
   - ❏ AC — MODEL NO. / RATED CURRENT / RATED RPM / KW= / CONTINUOUS TORQUE / PEAK TORQUE / SHAFT INERTIA
   - ❏ DC — ______________________
   - WINDING NO. ______________________
2. SERVO AMPLIFIER — MANUFACTURER ______________________
   - ❏ PWM — MODEL NO. ______________________
   - ❏ SCR — OUTPUT VOLTAGE ______________________

E. MACHINE DATA

1. AXIS (HORIZONTAL / VERTICAL) ______________________ H / V
2. SLIDE / WAY MATERIAL (STEEL ON STEEL, TURCITE, ETC.) ______________________
3. SLIDING COEFFICIENT OF FRICTION (SLIDE / WAY – TYPICAL = 0.03, OTHERWISE RANGE = 0.03 TO 0.2) ______________________ .XX
4. TOTAL WEIGHT OF SLIDE / LOAD ______________________ LBS.
5. MAXIMUM WEIGHT OF LOAD ______________________ LBS.
6. MAXIMUM SPEED ______________________ IN. / MIN
7. ACCELERATION / DECELERATION TIME TO MAXIMUM SPEED ______________________ SEC.
8. MOTOR / SCREW REDUCER EFFICIENCY (TYPICAL = 0.95) ______________________ .XX
9. MOTOR / SCREW GEAR RATIO (___ TO 1) ______________________ MOTOR RPM / SCREW RPM
10. SCREW TYPE ______________________
11. SCREW EFFICIENCY (TYPICAL = 0.90) ______________________ .XX
12. SCREW LENGTH ______________________ IN.
13. SCREW DIAMETER ______________________ IN.
14. SCREW LEAD ______________________ IN. / REV
15. APPLIED FORCE OR THRUST ______________________ LBS.
16. FOR DIRECT DRIVE SYSTEMS - MOTOR TO SCREW COUPLING DIAMETER ____________ IN. LENGTH ________ IN.
17. FOR PULLEY DRIVE SYSTEM - MOTOR MOUNTED GEAR DIAMETER ____________ IN. LENGTH ________ IN.
18. FOR PULLEY DRIVE SYSTEM - SCREW MOUNTED GEAR DIAMETER ____________ IN. LENGTH ________ IN.
19. MOTOR MODIFICATIONS (SEAL, SPECIAL SHAFT, ETC.) ______________________
    ____
20. SYSTEM POSITION LOOP GAIN AT CUTTING SPEED ______________________ IN. / MIN / MIL

20A. IF GAIN NOT SPECIFIED, SPECIFY TIME TO ACHIEVE CUTTING SPEED ______________________ SECONDS

21. SYSTEM POSITION LOOP GAIN ABOVE CUTTING SPEED (0.5 X #6 TYPICAL) ______________________ IN. / MIN / MIL
22. RAPID TRAVERSE SPEED ______________________ IN. / MIN
23. SYSTEM INERTIA REFLECTED TO MOTOR SHAFT ______________________ LB.-IN.-S^2

F. POSITION FEEDBACK

1. TYPE OF FEEDBACK DEVICE ❏ RESOLVER ❏ ENCODER
2. FEEDBACK DEVICE MOUNTING ❏ MOTOR ❏ SCREW
3. RESOLUTION AT FEEDBACK DEVICE ______________________

Leadscrew Application Data for Point to Point Positioning *(Continued)*

G. DUTY CYCLE & TOTAL CYCLE TIME (TRIANGULAR OR TRAPEZOIDAL) ______

______

______

______

______

H. ENVIRONMENT (NOTE IF OILY, CORROSIVE, HIGH TEMPERATURE, ETC.) ______

______

______

______

Rack and Pinion Application Data for Point to Point Positioning

A. CUSTOMER ______________________________

B. AXIS DESCRIPTION ______________________________

C. ❑ NEW SYSTEM

D. ❑ EXISTING EQUIPMENT

1. SERVOMOTOR — MANUFACTURER ______________________________
   - ❑ AC — MODEL NO. / RATED CURRENT / RATED RPM / KW= / CONTINUOUS TORQUE / PEAK TORQUE / SHAFT INERTIA
   - ❑ DC ______________________________
   - WINDING NO. ______________________________
2. SERVO AMPLIFIER — MANUFACTURER ______________________________
   - ❑ PWM — MODEL NO. ______________________________
   - ❑ SCR — OUTPUT VOLTAGE ______________________________

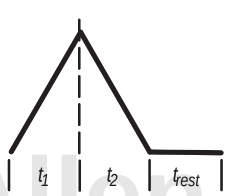
E. MACHINE DATA

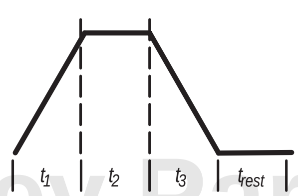
1. AXIS (HORIZONTAL / VERTICAL) ______________________________ H / V
2. TABLE / SLIDE SUPPORT TYPE (ROLLERS, ROLLER BEARINGS, ETC.) ______________________________
3. SLIDING COEFFICIENT OF FRICTION (SLIDE / WAY – TYPICAL = 0.03, OTHERWISE RANGE = 0.03 TO 0.2) ______________ .XX
4. TOTAL WEIGHT OF TABLE / LOAD ______________________________ LBS.
5. MAXIMUM TABLE SPEED ______________________________ IN. / MIN
6. ACCELERATION / DECELERATION TIME TO MAXIMUM SPEED ______________________________ SEC.
7. RAPID TRAVERSE SPEED ______________________________ IN. / MIN
8. MOTOR PINION REDUCER EFFICIENCY (TYPICAL = 0.95) ______________________________ .XX
9. MOTOR TO GEARBOX SPEED RATIO (___ TO 1) ______________________________ MOTOR RPM / REDUCER RPM
10. APPLIED FORCE (THRUST) ______________________________ LBS.
11. PINION RADIUS ______________________________ IN.
12. PINION LENGTH ______________________________ IN.
13. PINION TO RACK EFFICIENCY (TYPICAL = 0.95) ______________________________ .XX
14. MOTOR TO GEARBOX COUPLING DIAMETER ______________ IN. LENGTH ________ IN.
15. OTHER GEAR / PULLEY DIAMETERS ______________ IN. LENGTH ________ IN.
    ____
16. PINION MOUNTED SHEAVE / GEAR DIAMETER ______________ IN. LENGTH ________ IN.
17. MOTOR MODIFICATIONS (SEAL, SPECIAL SHAFT, ETC.) ______________________________
    ____
18. SYSTEM INERTIA REFLECTED TO MOTOR SHAFT ______________________________ LB.-IN.-S^2

F. POSITION FEEDBACK

1. TYPE OF FEEDBACK DEVICE ❑ RESOLVER ❑ ENCODER
2. FEEDBACK DEVICE MOUNTING ❑ MOTOR ❑ OTHER
3. RESOLUTION AT FEEDBACK DEVICE ______________________________

G. DUTY CYCLE & TOTAL CYCLE TIME ______________________________





H. ENVIRONMENT (NOTE IF OILY, CORROSIVE, HIGH TEMPERATURE, ETC.) ______________________________

Conveyor Application Data

A. CUSTOMER ____________________

B. AXIS DESCRIPTION ____________________

C. ☐ NEW SYSTEM

D. ☐ EXISTING EQUIPMENT

1. SERVOMOTOR — MANUFACTURER ____________________
   - ☐ AC — MODEL NO. / RATED CURRENT / RATED RPM / KW= / CONTINUOUS TORQUE / PEAK TORQUE / SHAFT INERTIA
   - ☐ DC ____________________
   - WINDING NO. ____________________
2. SERVO AMPLIFIER — MANUFACTURER ____________________
   - ☐ PWM — MODEL NO. ____________________
   - ☐ SCR — OUTPUT VOLTAGE ____________________

E. MACHINE DATA

1. CONVEYOR LOAD SUPPORT TYPE (BEARING SUPPORTED, ROLLERS, ETC.) ____________________
2. SLIDING COEFFICIENT OF FRICTION OF SUPPORT (TYPICAL = 0.03) ____________________ .XX
3. TOTAL WEIGHT OF LOAD / BELT ____________________ LBS.
4. MAXIMUM SPEED ____________________ IN. / MIN
5. ACCELERATION TIME TO MAXIMUM SPEED ____________________ SECONDS
6. MOTOR TO DRIVE ROLL REDUCER EFFICIENCY (TYPICAL = 0.95) ____________________ .XX
7. GEARBOX RATIO (___ TO 1) ____________________ MOTOR RPM / GEARBOX RPM
8. NUMBER OF SUPPORT ROLLS ____________________
9. COUPLING BETWEEN ROLLS (CHAIN, BELT, ETC.) ____________________
10. ROLL O.D. ____________________ IN.
11. ROLL I.D. ____________________ IN.
12. ROLL LENGTH ____________________ IN.
13. ROLL MATERIAL ____________________ STEEL / ALUMINUM
14. MOTOR TO GEARBOX COUPLING DIAMETER ____________________ IN. LENGTH __________ IN.
15. OTHER GEAR / PULLEY DIAMETERS ____________________ IN. LENGTH __________ IN.
    ____
16. MOTOR MODIFICATIONS (SEAL, SPECIAL SHAFT, ETC.) ____________________
    ____
17. SYSTEM INERTIA REFLECTED TO MOTOR SHAFT ____________________ $LB.\text{-}IN.\text{-}S^2$

F. POSITION FEEDBACK

1. TYPE OF FEEDBACK DEVICE ☐ RESOLVER ☐ ENCODER
2. FEEDBACK DEVICE MOUNTING ☐ MOTOR ☐ OTHER
3. RESOLUTION AT FEEDBACK DEVICE ____________________

G. DUTY CYCLE & TOTAL CYCLE TIME ____________________

H. ENVIRONMENT (NOTE IF OILY, CORROSIVE, HIGH TEMPERATURE, ETC.) ____________________
____

Conversion Factors

Abbreviations used in this publication are in ( ).

Torque

To Convert	*To*	*Multiply By*
lb.-in.	Newton-meters (N-m)	0.113
lb.-ft.	Newton-meters (N-m)	1.3558
Newton-meters (N-m)	lb.-in.	8.85
Newton-meters (N-m)	lb.-ft.	0.7376
lb.-in.	kg-cm	1.155
lb.-in.	lb.-ft.	0.0833
lb.-ft.	lb.-in.	12
oz.-in.	lb.-in.	0.0625
Joules (J)	lb.-in.	8.85

Temperature

To Convert	*To*	*Use the Formula*
degrees F (°F)	degrees C (°C)	(degrees F – 32) ÷ 1.8
degrees C (°C)	degrees F (°F)	(degrees C x 1.8) + 32

Rotation / Rate

To Convert	*To*	*Multiply By*
rpm	degrees / second (d / s)	6.00
rpm	radians / second (rad / s)	0.1047
degrees / second (d / s)	rpm	0.1667
radians / second (rad / s)	rpm	9.549
feet / minute (fpm)	meters / second (m / s)	0.00508
feet / second (fps)	meters / second (m / s)	0.3048
inches / second (in. / s)	meters / second (m / s)	0.0254
kmph	meters / second (m / s)	0.2778
rpm	radians / second (rad / s)	0.1047
revolutions	radians (rad)	6.283
radians (rad)	degrees	57.3
degrees	seconds (s)	3600
degrees	minutes (min)	60

Moment Of Inertia

To Convert	*To*	*Multiply By*
N-m^2	lb.-ft.^{2}	2.42
oz.-in.^{2}	lb.-ft.^{2}	0.000434
lb.-in.^{2}	lb.-ft.^{2}	0.00694
lb.-in.^{2}	lb.-in.-s^2	0.00259
Slug-ft^2	lb.-ft.^{2}	32.17
oz.-in.-s^2	lb.-ft.^{2}	0.1675
lb.-in.-s^2	lb.-ft.^{2}	2.68
lb.-in.-s^2	kg-cm-s^2	1.155
lb.-in.-s^2	kg-m^2	0.113
lb.-ft.^{2}	lb.-in.-s^2	0.373
kg-m^2	kg-cm-s^2	10.20
kg-m^2	lb.-ft.^{2}	23.73
kg-m^2	lb.-in.-s^2	8.85
kg-cm^2	lb.-in.-s^2	0.000885

Mass / Weight

To Convert	*To*	*Multiply By*
ounces (oz.)	grams	31.1
pounds (lbs.)	kilograms (kg)	0.4536
pounds (lbs.)	ounces (oz.)	16
kilograms (kg)	pounds (lbs.)	2.205
Newtons	pounds (lbs.)	0.2248

Length

To Convert	*To*	*Multiply By*
meters (m)	inches (in.)	39.37
meters (m)	feet (ft.)	3.281
meters (m)	yards (yd)	1.094
meters (m)	millimeters (mm)	1000
meters (m)	centimeters (cm)	100
millimeters (mm)	inches (in.)	0.0394
millimeters (mm)	centimeters (cm)	0.10
micrometers (μm)	inches (in.)	0.00003937
inches (in.)	meters (m)	0.0254
inches (in.)	millimeters (mm)	25.4
inches (in.)	centimeters (cm)	2.54
feet (ft.)	meters (m)	0.3048
yards (yd)	meters (m)	0.914

Power

To Convert	*To*	*Multiply By*
watts (W)	horsepower (hp)	0.00134
lb.-ft. / min	horsepower (hp)	0.0000303
horsepower (hp)	watts (W)	746

Acceleration

To Convert	*To*	*Multiply By*
in. / s^2	m / s^2	0.0254
in. / s^2	g	386.4
ft / s^2	m / s^2	0.3048
ft / s^2	in. / s^2	12
ft / s^2	g	32.2
rad / s^2	Degrees / s^2	57.3

Area

To Convert	*To*	*Multiply By*
$in.^2$	ft^2	0.00694
ft^2	m^2	0.0929
$in.^2$	m^2	0.000645
$in.^3$	ft^3	0000579

Rockwell Automation

Allen-Bradley

Allen-Bradley, a Rockwell Automation Business, has been helping its customers improve productivity and quality for more than 90 years. We design, manufacture and support a broad range of automation products worldwide. They include logic processors, power and motion control devices, operator interfaces, sensors and a variety of software. Rockwell is one of the world's leading technology companies.

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