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Small Motors Gearmotors Motion Controls

MOTOR & GEARMOTOR SELECTION GUIDE.

IT'S AS EASY AS

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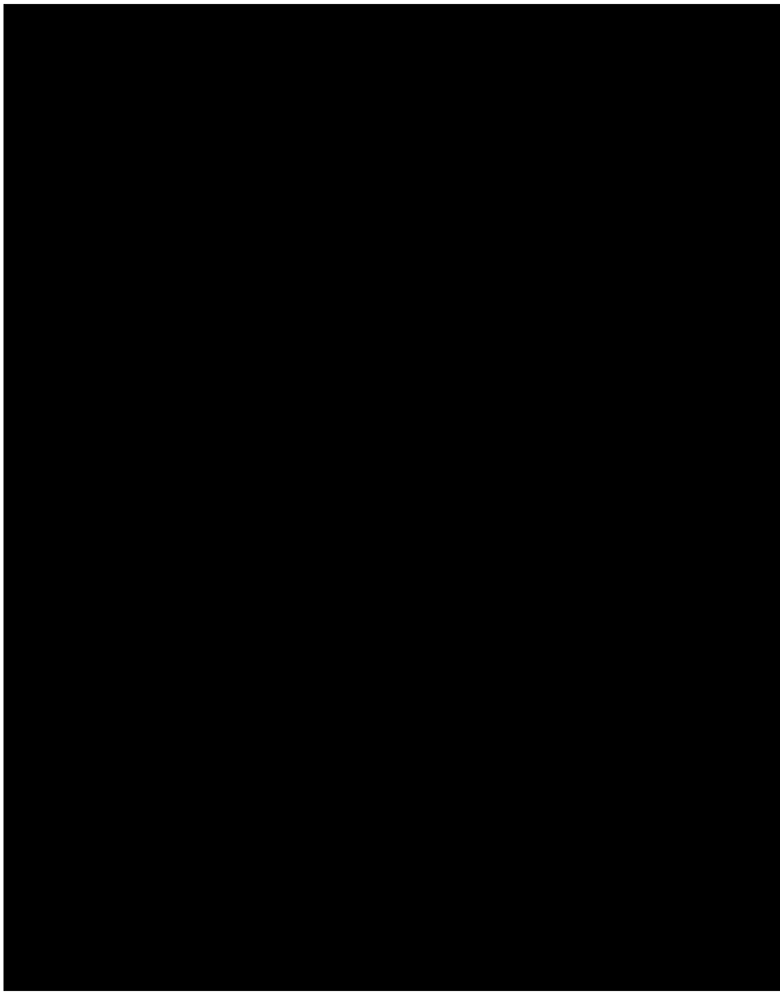

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Created by the Bodine Electric Company, this Motor and Gearmotor Selection Guide is designed to help you specify the best motor or gearmotor for your application.

By considering three key design criteria, you can quickly select a drive system that allows for productive follow-up with the motor manufacturer's sales engineers, saving you considerable time and expense.

The three design criteria are:

1. Determine speed and torque.
2. Select the appropriate motor type.
3. Select gear reducer, if needed.

Enclosed is an easy-to-complete worksheet that serves as the companion to this guide. When you are ready, just fill in the blanks and return it to Bodine Electric Company.

There's no easier way to determine the best motor for your application.

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1 Determine speed and torque

For assistance with calculations in Step 1, see DEFINITION OF TERMS on facing page.

The desired output speed of the motor or gearmotor is usually known. The load torque might be measured, calculated, estimated, or arrived at using a combination of methods, depending on the type of mechanical system. Four common systems are:

- **Direct drive** ■ **Lead screw** ■ **Belt drive or rack & pinion**
- **Gear drive, chain & sprocket, belt & pulley**

Identify which type of mechanical system is similar to yours and proceed to one of the following sections to determine what torque and speed are required for your application. Note that many applications involve a combination of the basic mechanical systems.

DIRECT DRIVE

For a Direct Drive application, acceleration torque, (T_{ACCEL}), and friction torque, ($T_{FRICTION}$), must be determined. The following equations assume that the driven load is a hollow cylinder. For a solid cylinder, $r_1 = 0$.

$$T_{ACCEL}\text{ (oz-in)} = \left[\frac{\rho L(r_2^4 - r_1^4)}{246} + J_{MOTOR}R^2E\right]\frac{N}{9.55t_a}$$

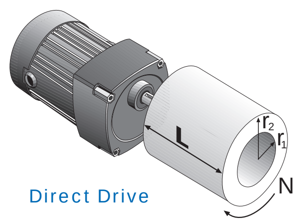
Assume that $J_{MOTOR} = 0$, solve the equation, choose a motor based on your result, and then come back and recalculate T_{ACCEL} using J_{MOTOR} of the motor you selected. $T_{FRICTION}$ (oz-in) can either be estimated or measured using one of the methods described in Figure 1 (See inside). After solving for T_{ACCEL} and $T_{FRICTION}$, select a motor or gearmotor that meets the following criteria:

$$HP_{CONT} = \frac{T_{FRICTION}N}{1{,}008{,}400} \quad \text{at a speed of } N$$

or

$$T_{CONT}\text{ (oz-in)} = T_{FRICTION} \quad \text{at a speed of } N$$

Make sure the motor or gearmotor has a starting torque capability equal to $T_{ACCEL} + T_{FRICTION}$. Then proceed to Step 2 (See inside).



Direct Drive

LEAD SCREW

For a Lead Screw application, acceleration torque, (T_{ACCEL}), friction torque, ($T_{FRICTION}$), breakaway torque, ($T_{BREAKAWAY}$), and gravity torque, ($T_{GRAVITY}$), must be determined. T_{ACCEL} may be ignored unless acceleration time is critical.

$$T_{ACCEL}\text{ (oz-in)} = \left[\frac{d^2W_{L\&C}}{15239e} + \frac{\rho Lr^4}{246} + J_{MOTOR}R^2E\right]\frac{60V_{LOAD}}{9.55\,d\,t_a}$$

Assume that $J_{MOTOR} = 0$, solve the equation, choose a motor based on your result, and then come back and recalculate T_{ACCEL} using J_{MOTOR} of the motor you selected.

$T_{FRICTION}$ can either be measured, using one of the methods in Figure 1 (See inside), or calculated using the equation:

$$T_{FRICTION}\text{ (oz-in)} = \frac{dW_{L\&C}\mu}{6.28e}$$

$T_{BREAKAWAY}$ is only a factor during starting and can either be estimated or measured using one of the methods in Figure 1 (See inside).

$T_{GRAVITY}$ only needs to be considered when the lead screw is not mounted horizontally. It is a positive number when the load is moved upward, and a negative number when the load is moved downward. It can be calculated using the equation:

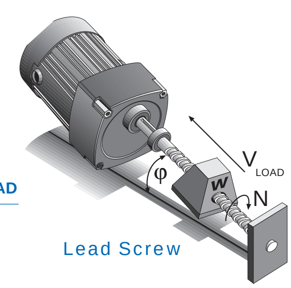
$$T_{GRAVITY}\text{ (oz-in)} = \frac{dW_{L\&C}\sin\varphi}{6.28e}$$

After solving for T_{ACCEL}, $T_{FRICTION}$, $T_{BREAKAWAY}$, and $T_{GRAVITY}$, select a motor or gearmotor that meets the following criteria:

$$HP_{CONT} = \frac{(T_{FRICTION} + T_{GRAVITY})60V_{LOAD}}{1{,}008{,}400d} \quad \text{at a speed of } \frac{60V_{LOAD}}{d}$$

or

$$T_{CONT}\text{ (oz-in)} = T_{FRICTION} + T_{GRAVITY} \quad \text{at a speed of } \frac{60V_{LOAD}}{d}$$



Lead Screw

Make sure the motor or gearmotor has a starting torque capability equal to $T_{ACCEL} + T_{FRICTION} + T_{BREAKAWAY} + T_{GRAVITY}$. Then proceed to Step 2 (See inside).

BELT DRIVE or RACK & PINION

For a Belt Drive or Rack & Pinion application, acceleration torque, (T_{ACCEL}), friction torque,($T_{FRICTION}$), breakaway torque,($T_{BREAKAWAY}$), and gravity torque,($T_{GRAVITY}$) must be determined. T_{ACCEL} may be ignored unless acceleration time is critical. The following equations assume a belt drive system. For a rack & pinion system, substitute the word "pinion" in place of "roller", and "rack" in place of "belt."

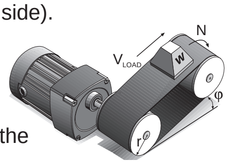
$$T_{ACCEL}\ \text{(oz-in)} = \left[\frac{W_{LOAD}r^2}{386} + \frac{nW_{ROLLER}r^2}{772} + \frac{W_{BELT}r^2}{386} + J_{MOTOR}R^2E\right]\frac{V_{LOAD}}{rt_a}$$

Assume that $J_{MOTOR} = 0$, solve the equation, choose a motor based on your result, and then come back and recalculate T_{ACCEL} using J_{MOTOR} of the motor you selected.

$T_{FRICTION}$ can be estimated or measured using one of the methods in Figure 1 (See inside).

$T_{BREAKAWAY}$ is only a factor during starting and can either be estimated or measured using one of the methods in Figure 1 (See inside).

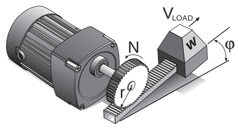
$T_{GRAVITY}$ only needs to be considered when the belt is not mounted horizontally. It is a positive number when the load is moved upward, and a negative number when the load is moved downward. It can be calculated using the equation:



Belt Drive

$$T_{GRAVITY}\ \text{(oz-in)} = rW_{LOAD}\sin\varphi$$

After solving for T_{ACCEL}, $T_{FRICTION}$, $T_{BREAKAWAY}$, and $T_{GRAVITY}$, select a motor or gearmotor that meets the following criteria:



Rack & Pinion

$$HP_{CONT} = \frac{(T_{FRICTION} + T_{GRAVITY})V_{LOAD}}{105{,}592r}\ \text{at a speed of}\ \frac{9.55V_{LOAD}}{r}$$

or

$$T_{CONT}\ \text{(oz-in)} = T_{FRICTION} + T_{GRAVITY}\ \text{at a speed of}\ \frac{9.55V_{LOAD}}{r}$$

Make sure the motor or gearmotor has a starting torque capability equal to $T_{ACCEL} + T_{FRICTION} + T_{BREAKAWAY} + T_{GRAVITY}$. Then proceed to Step 2 (See inside).

GEAR DRIVE, CHAIN & SPROCKET, BELT & PULLEY

For a Gear Drive application, acceleration torque, (T_{ACCEL}), breakaway torque, ($T_{BREAKAWAY}$), and reflected load torque, ($T_{REFLECTED}$), must be determined. T_{ACCEL} may be ignored unless acceleration time is critical. The same equations can be used for chain & sprocket or belt & pulley systems. Just replace the word "gear" with "sprocket" or "pulley."

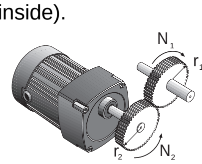
$$T_{ACCEL}\ \text{(oz-in)} = \left[\frac{J_{LOAD}}{eG^2} + \frac{W_{GEAR1}r_1^2}{772G^2} + \frac{W_{GEAR2}r_2^2}{772} + J_{MOTOR}R^2E\right]\frac{N_1G}{9.55t_a}$$

The value for J_{LOAD} depends on what is connected to the output of GEAR 1. Refer to the equations for the other types of mechanical systems to solve for J_{LOAD}.

$T_{FRICTION}$ can be estimated or measured using one of the methods in Figure 1 (See inside).

$T_{BREAKAWAY}$ is only a factor during starting and can either be estimated or measured using one of the methods in Figure 1 (See inside).

$$T_{REFLECTED}\ \text{(oz-in)} = \frac{T_{LOAD}}{e(G)}$$



Gear Drive

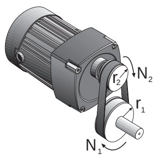
T_{LOAD} depends on what is connected to the output gear. Refer to the equations for the other mechanical systems to solve for T_{LOAD}.

After solving for T_{ACCEL}, $T_{BREAKAWAY}$, and $T_{REFLECTED}$, select a motor or gearmotor that meets the following criteria:

$$HP_{CONT} = \frac{T_{REFLECTED}\,N_1G}{1{,}008{,}400}\ \text{at a speed of}\ N_1G$$

or

$$T_{CONT}\ \text{(oz-in)} = T_{REFLECTED}\ \text{at a speed of}\ N_1G$$



Belt & Pulley

Make sure the motor or gearmotor has a starting torque capability equal to $T_{ACCEL} + T_{BREAKAWAY} + T_{LOAD}$. Then proceed to Step 2 (See inside).

The equations used in this selection guide have been derived from fundamental motion control formulas. For more application-specific information, please contact the Bodine Electric Company.

Definition of terms

d = lead of screw (inch/rev)

E = gearmotor gearing efficiency (see Table 3)

e = mechanism efficiency (see Table 3)

G = ratio of input speed to output speed

J_{LOAD} = inertia of driven load (oz-in-sec^2)

J_{MOTOR} = motor inertia (oz-in-sec^2)

L = length of cylinder or lead screw (inches)

N = angular velocity of load (RPM)

n = number of rollers

φ = angle of screw or belt from horizontal (degrees)

ρ = density of cylinder or lead screw (oz/in^3) (see Table 1)

R = gearmotor gear ratio

r = radius of roller, screw, gear, or pulley (inches)

t_a = time to accelerate (seconds)

T_{LOAD} = load torque (oz-in)

μ = coefficient of friction (see Table 2)

V_{LOAD} = linear velocity of load (inch/sec)

W_{BELT} = weight of belt or roller (ounces)

$W_{GEAR\ 1}$ = weight of gear 1 (ounces)

$W_{GEAR\ 2}$ = weight of gear 2 (ounces)

$W_{L\&C}$ = weight of load & carriage (ounces)

W_{LOAD} = weight of load (ounces)

W_{ROLLER} = weight of roller (ounces)

FIGURE 1

METHODS FOR MEASURING THE BREAKAWAY AND FRICTION TORQUE OF A MACHINE.

The String and Pulley Method

Affix a pulley to the shaft of the machine to be driven (see Figure A). Secure one end of a cord to the outer surface of the pulley and wrap the cord around it. Tie the other end of the cord to a spring scale. Pull on the scale until the shaft turns. The force, in pounds indicated on the scale, multiplied by the radius of the pulley (in inches) gives the breakaway torque in pound-inches.

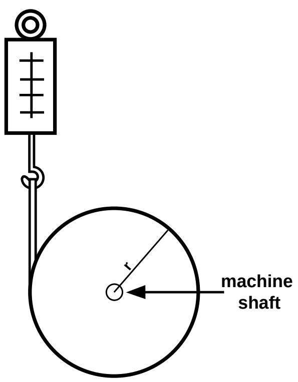


Figure A—Simple "string and pulley" method of torque measurement (Torque = Force reading on spring scale x radius of the pulley)

Torque Wrench Method

A simple torque wrench can be applied to the shaft of the machine to be driven. Turn the wrench as you would an ordinary pipe wrench, and when the shaft begins to rotate, read the value for $T_{BREAKAWAY}$ (in ounce-inches or pound-inches) on the torque wrench gauge.

"Test" Motor method

Both AC and DC test motors or gearmotors can be used to measure breakaway torque, ($T_{BREAKAWAY}$), and friction torque, ($T_{FRICTION}$). This method requires more time and instrumentation, but can be well worth the expense in the long run. It is the best way to optimally match machine and drive unit, and is popularly used for all high volume OEM (original equipment manufacturer) applications. After using these methods, contact the motor manufacturers' sales engineer for help in interpreting the data.

"Test" With An AC Drive

Use a torque wrench or "string and pulley" to find the approximate size of the test motor or gearmotor needed. An AC motor or gearmotor whose rated output speed is close to the desired "final" speed of the machine should be obtained. Next, hook up the AC drive, along with a variable autotransformer to the load (See Figure B). With a voltmeter connected to the line, increase the voltage supplied by the autotransformer until it starts and accelerates the load up to speed (to check speed use a tachometer or stroboscope). Record the starting voltage at all possible starting locations of the device. This is proportional to the $T_{BREAKAWAY}$. Next, back off slowly until the motor stalls. Read the voltage. This is proportional to the $T_{FRICTION}$.

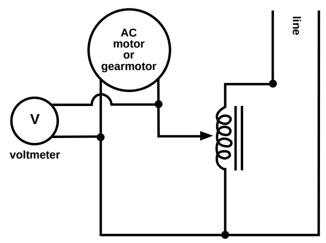


Figure B—AC motor or gearmotor with adjustable autotransformer, and voltmeter connected for load measurement.

"Test" With A DC Drive

The DC method requires that both voltage and amperage readings be taken from the armature circuit (See Figure C). Speed of the DC motor is proportional to the voltage while $T_{FRICTION}$ is proportional to the armature amperage.

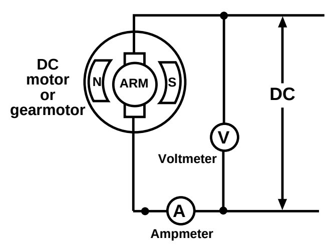


Figure C—PM DC motor or gearmotor with voltmeter and ampmeter connected for load measurement.

For maximum accuracy, the actual test motor should be sent to the manufacturer with the voltage, amperage and speed information for bench (or dynamometer) testing. The minimum starting torque should also be supplied.

conversion tables

table 1

MATERIAL DENSITIES	oz/in^3	lb/in^3	gm/cm^3
Aluminum	1.57	.098	2.72
Brass	4.96	.31	8.6
Copper	5.15	.322	8.91
Plastic	.64	.04	1.11
Steel	4.48	.28	7.75

table 2

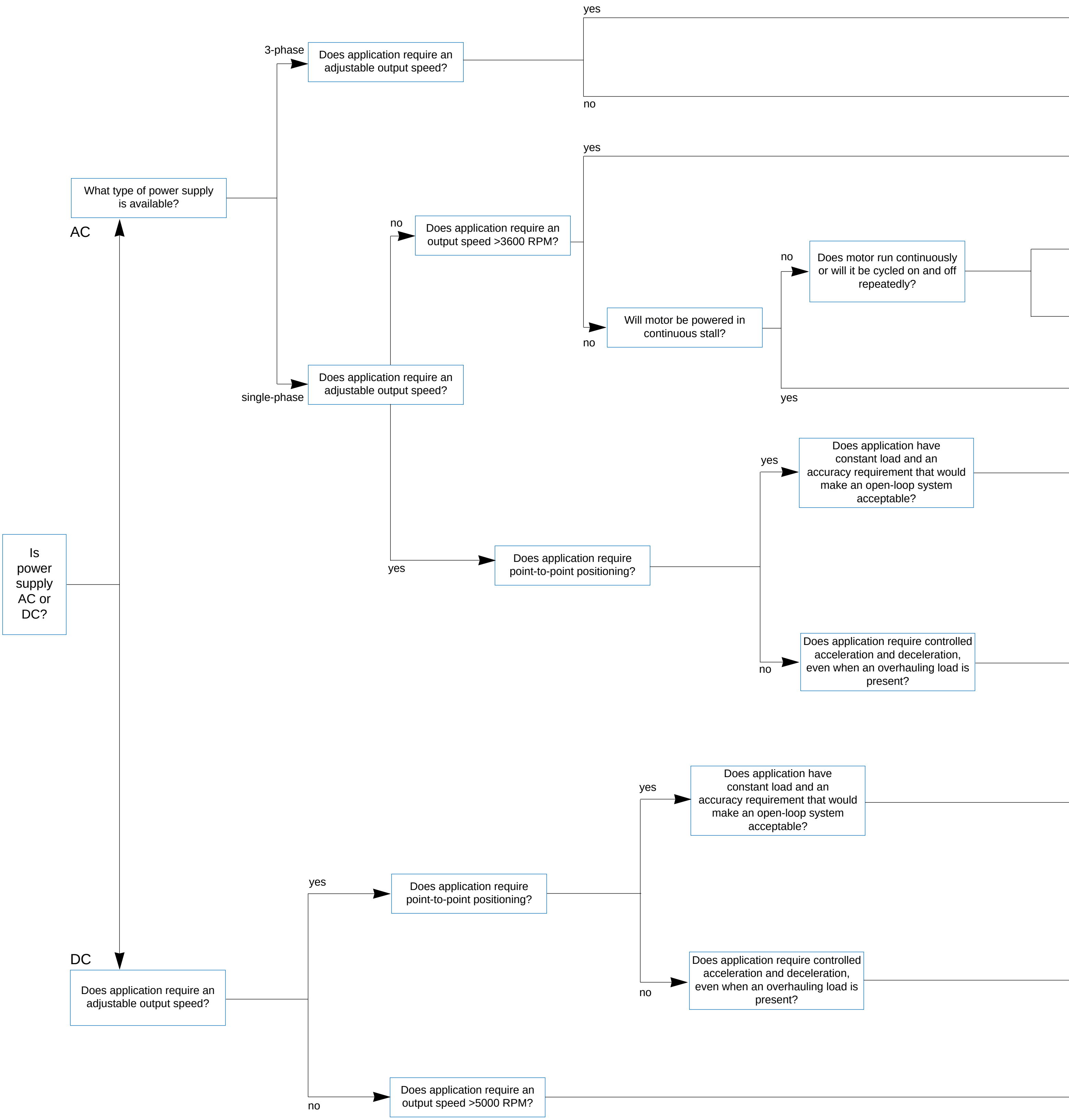
FRICTION COEFFICIENTS (SLIDING)	μ
Steel on Steel	.58
Steel on Steel(Greased)	.15
Aluminum on Steel	.45
Copper on Steel	.36
Brass on Steel	.44
Plastic on Steel	.2
Liner Bearings	.001

table 3

MECHANISM EFFICIENCIES	%
Acme Screw (Brass Nut)	35 - 65
Acme Screw (Plastic Nut)	5 - 85
Ball-Screw	85 - 95
Preloaded Ball-Screw	75 - 85
Spur or Bevel Gears	92 per stage
Timing Belt	96 - 98
Chain and Sprocket	95 - 98
Worm Gears (G=gear ratio)	80 - .6G

2. Select a motor type appropriate for the application

By answering a few key questions, you can select a suitable motor type as a sample in your application. You can then discuss the application in detail with the motor manufacturer's sales engineers. Actual testing of the sample will confirm your selection.



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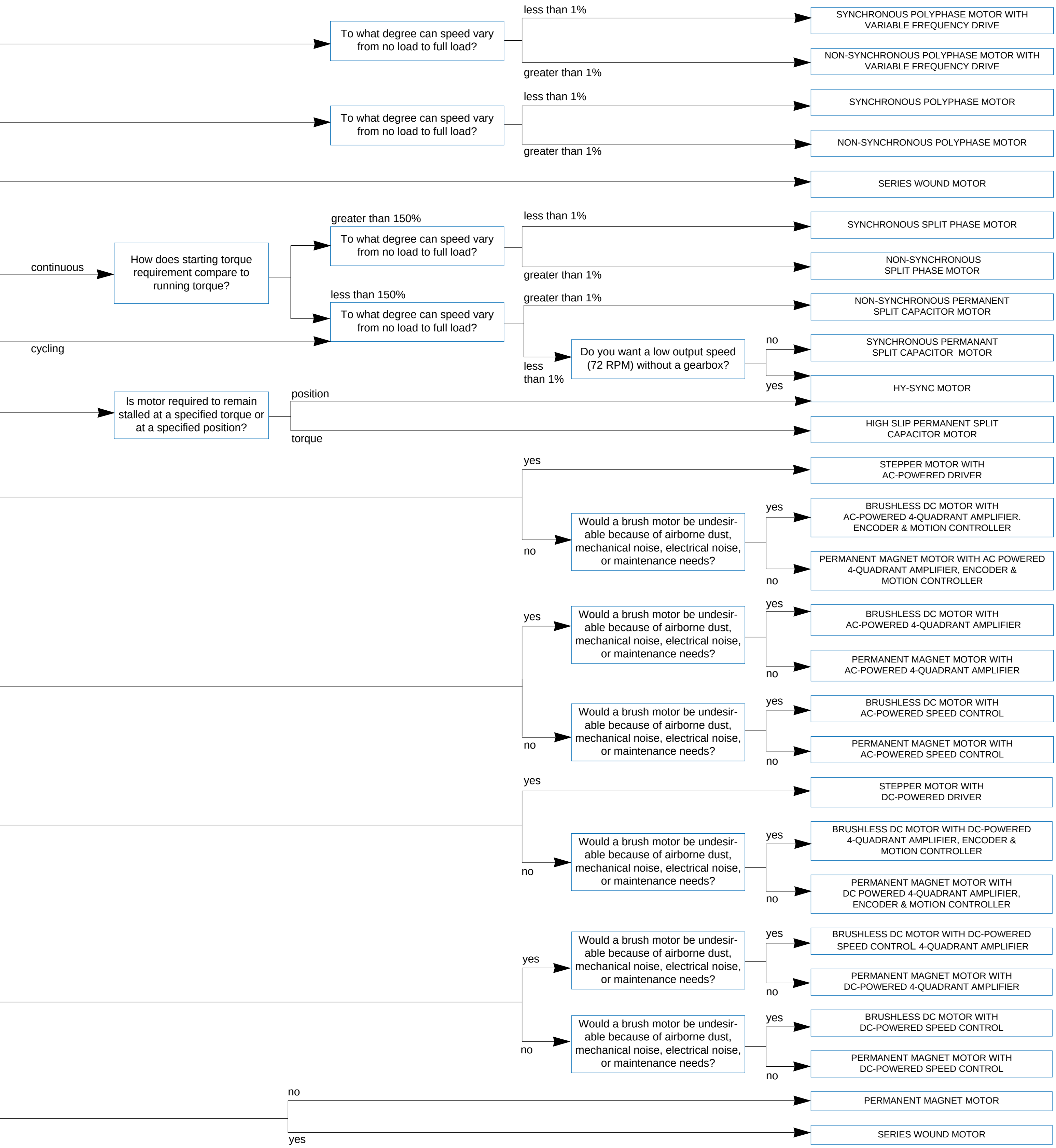


3. select gear reducer, if needed

After the speed and torque are determined in Step 1 and the motor type is selected in Step 2, the next step is to determine if a gear reducer is needed and, if so, select the best type and ratio.

How to select the best gear ratio

Some reasons for using a gear reducer are speed reduction, torque multiplication, and inertia matching. The amount of speed reduction needed depends on the motor type that was selected in Step 2. Some motors can operate at low speeds (i.e. less than 1000 RPM) without a gear reducer; others can't. If speed reduction is the only concern, then the gear ratio can be calculated as:

$$G = \frac{N_{MOTOR}}{N_{LOAD}}$$

Gear reducers multiply the output torque of a motor. This might be desired because a small motor with a gear reducer could be less expensive and smaller in overall size than a large motor without a gear reducer. If torque multiplication is the only concern, then the gear ratio can be calculated as:

$$G = \frac{T_{LOAD}}{T_{MOTOR}e_{GEARS}}$$

Gear reducers reduce the load inertia reflected to the motor by a factor of the square of the gear ratio. In high performance motion control applications, it is ideal for the reflected load inertia to equal the motor inertia. If inertia matching is the only concern, then the gear ratio can be calculated as:

$$G = \sqrt{\frac{J_{LOAD}}{J_{MOTOR}}}$$

How to select the best type of gear reducer

There are two basic classes of gear reducers with several different types within each class. The two classes are the right angle and the parallel shaft gear reducers. Different types of right angle gear reducers include worm, bevel (straight and spiral), and hypoid. Different types of parallel shaft gear reducers include spur (internal and external), helical, planetary, and harmonic. A single gear reducer package may be made up of multiple stages that combine more than one type of gear reducer.

Space restrictions usually determine whether to use a right angle or a parallel shaft gear reducer.

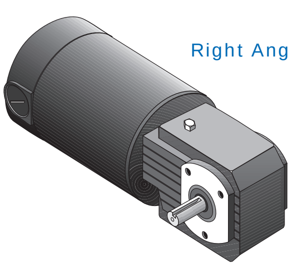
However, there are other characteristics to consider. Worm gears with ratios 20:1 or higher are typically self-locking. This might be desirable in applications that require the load to stay in place after the motor is turned off. Unfortunately, worm gears are much less efficient than other gear types and so require a larger motor to get the same continuous output torque. The effect of gear efficiency on motor horsepower can be seen in the equation:

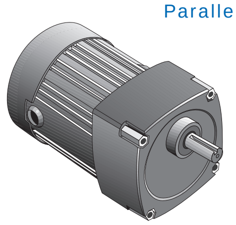
$$HP_{MOTOR} = \frac{T_{LOAD}N_{MOTOR}}{1{,}008{,}400Ge}$$

For example, a 50% efficient worm gear reducer would require a motor with a horsepower rating 1.6 times that of an 80% efficient spur gear reducer with the same gear ratio.

Spur, helical, and bevel gears are much more efficient, but they tend to produce more noise than worm gears, which may or may not be objectionable.

High precision positioning applications may not tolerate the inherent backlash of spur, helical, worm, and bevel gears. Those applications often require low-backlash planetary or harmonic gear reducers.


Right Angle


Parallel Shaft

The 3-step procedure that we've just presented should help you to select an acceptable motor or gearmotor for your application. If you want the optimum motor or gearmotor, then there are many other details that should be discussed with the motor manufacturer's sales engineer. Some of these are:

AMBIENT TEMPERATURE

Motor ratings are based on a certain ambient temperature, usually 40°C. Continuous duty applications with a higher ambient temperature may require a motor with a higher torque rating than calculated with this selection guide.

DUTY CYCLE

Duty cycle influences the temperature rise of motors and the wear rate of gears. Intermittent duty applications might be able to use a motor with a lower torque rating than calculated with this guide. On the other hand, frequent starts and stops would reduce the expected life of gears. This is related to the service factors that many gear manufacturers publish in their catalogs.

FORM FACTOR

When using DC motor speed controls, the form factor of the output DC voltage from the control can influence the motor size and the gear ratio, if a reducer is needed. Unfiltered controls result in a higher temperature rise in the motor, so a larger motor might be needed than calculated with this guide, especially if the duty cycle is continuous. Unfiltered controls also have a lower output voltage than filtered controls, so the motor speed would be slower. Be sure to use the correct motor speed when calculating the gear ratio.

RADIAL & AXIAL LOADS

Different types and different sizes of motor bearings have different radial and axial loading capacities. Applications that have a high radial load, such as pinch rollers and belt drives, or that have a high axial load, such as lead screws, may require a larger motor than calculated with this guide. In this case, a motor or gearmotor is needed that is stronger in terms of physical robustness, rather than in terms of output power.

CONVERSION OF MOMENT OF INERTIA

A \ B	kg-m^2	kg-cm-s^2	oz-in-s^2	lb-in-s^2	oz-in^2	lb-in^2	lb-ft^2
kg-m^2	1	10.2	141.6	8.85	5.27×10^4	3.42×10^3	23.73
kg-cm-s^2	.098	1	13.88	.868	5.36×10^3	3.35×10^2	2.32
oz-ins^2	7.06×10^3	7.19×10^2	1	6.25×10^{-2}	386.09	24.13	.1676
lb-in-s^2	.113	1.152	16	1	6.18×10^3	386.09	2.681
oz-in^2	1.83×10^{-5}	1.87×10^{-4}	2.59×10^{-3}	1.62×10^{-4}	1	.0625	4.34×10^{-4}
lb-in^2	2.93×10^{-4}	2.985×10^{-3}	4.14×10^{-2}	2.59×10^{-3}	16	1	6.94×10^{-3}
lb-ft^2	4.21×10^{-2}	.429	5.968	.373	2304	144	1

To convert from A to B, multiply A by entry in table.

Gravity constant = g = 386 $\frac{in}{s^2}$ = 32.2 $\frac{ft}{s^2}$ = 9.8 $\frac{m}{s^2}$

BODINE® ELECTRIC COMPANY
2500 W. Bradley Place
Chicago, Illinois 60618 U.S.A.
Phone: (312) 478-3515
Fax: (312) 478-3232
Printed in U.S.A.

For location and contact information of nearest District Representative or Authorized Distributor, phone 1-800-7BODINE

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