1. MOTOR & GEARMOTOR SELECTION GUIDE.

It's as easy as:

2.

3.
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:

1. **Direct Drive**
2. **Lead Screw**
3. **Belt Drive or Rack & Pinion**
4. **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, \( T_{FRICITION} \), must be determined. The following equations assume that the driven load is a hollow cylinder. For a solid cylinder, \( r_1 = 0 \).

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. \( T_{FRICITION} \) (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 \( T_{FRICITION} \), select a motor or gearmotor that meets the following criteria:

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

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

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. \( T_{FRICITION} \) (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 \( T_{FRICITION} \), select a motor or gearmotor that meets the following criteria:

\[
HPCONT = \frac{T_{FRICITION} N}{1,008,400} \quad \text{at a speed of } N
\]

or

\[
T_{CONT} (\text{oz-in}) = T_{FRICITION} \text{ at a speed of } N
\]

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

### LEAD SCREW

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

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. \( T_{FRICITION} \) (oz-in) can either be measured, using one of the methods in Figure 1 (See inside), or calculated using the equation:

\[
T_{FRICITION} (\text{oz-in}) = \frac{dW_{L&C} \tan \psi}{6.28 \epsilon}
\]

\( T_{BREAKAWAY} \) 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:

\[
T_{GRAVITY} (\text{oz-in}) = \frac{d W_{L&C} \sin \phi}{6.28 \epsilon}
\]

After solving for \( T_{ACCEL} \), \( T_{FRICITION} \), \( T_{BREAKAWAY} \), and \( T_{GRAVITY} \), select a motor or gearmotor that meets the following criteria:

\[
HPCONT = \frac{(T_{FRICITION} + T_{GRAVITY}) 60VLOAD}{1,008,400} \quad \text{at a speed of } \frac{60VLOAD}{d}
\]

or

\[
T_{CONT} (\text{oz-in}) = T_{FRICITION} + T_{GRAVITY} \quad \text{at a speed of } \frac{60VLOAD}{d}
\]

Make sure the motor or gearmotor has a starting torque capability equal to \( T_{ACCEL} + T_{FRICITION} + T_{BREAKAWAY} + T_{GRAVITY} \). Then proceed to Step 2 (See inside).
BELT DRIVE or RACK & PINION

For a Belt Drive or Rack & Pinion application, acceleration torque, \( T_{\text{ACCEL}} \), friction torque, \( T_{\text{FRICION}} \), breakaway torque, \( T_{\text{BREAKAWAY}} \), and gravity torque, \( T_{\text{GRAVITY}} \) must be determined. \( T_{\text{ACCEL}} \) 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.”

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

\[ T_{\text{ACCEL}} \text{ (oz-in)} = \frac{W_{\text{LOAD}}r^2 + nW_{\text{ROLLER}}r^2 + W_{\text{BELT}}r^2 + JMOTORR^2E}{n_a} \]

\( V_{\text{LOAD}} \)

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

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

\( T_{\text{GRAVITY}} \) 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:

\[ T_{\text{GRAVITY}} \text{ (oz-in)} = rW_{\text{LOAD}} \sin \phi \]

After solving for \( T_{\text{ACCEL}} \), \( T_{\text{FRICION}} \), \( T_{\text{BREAKAWAY}} \), and \( T_{\text{GRAVITY}} \), select a motor or gearmotor that meets the following criteria:

\[ \text{Make sure the motor or gearmotor has a starting torque capability equal to} \ T_{\text{ACCEL}} + T_{\text{FRICION}} + T_{\text{BREAKAWAY}} + T_{\text{GRAVITY}}. \]

Then proceed to Step 2 (See inside).

GEAR DRIVE, CHAIN & SPROCKET, BELT & PULLEY

For a Gear Drive application, acceleration torque, \( T_{\text{ACCEL}} \), breakaway torque, \( T_{\text{BREAKAWAY}} \), and reflected load torque, \( T_{\text{REFLECTED}} \), must be determined. \( T_{\text{ACCEL}} \) 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.”

\[ T_{\text{ACCEL}} \text{ (oz-in)} = \frac{J_{\text{LOAD}}}{\epsilon G^2} + \frac{W_{\text{GEAR1}}r_1^2}{772G^2} + \frac{W_{\text{GEAR2}}r_2^2}{772} + JMOTORR^2E \]

\( N_1 \) \( G \)

The value for \( J_{\text{LOAD}} \) 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 \( J_{\text{LOAD}} \).

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

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

\[ T_{\text{REFLECTED}} \text{ (oz-in)} = \frac{T_{\text{LOAD}}}{\epsilon(G)} \]

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

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

\[ \text{Make sure the motor or gearmotor has a starting torque capability equal to} \ T_{\text{ACCEL}} + T_{\text{BREAKAWAY}} + T_{\text{LOAD}}. \]

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.
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.

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 $T_{\text{BREAKAWAY}}$ (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, $(T_{\text{BREAKAWAY}})$, and friction torque, $(T_{\text{FRICION}})$. 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.

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.
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.

**Is power supply AC or DC?**

- **AC**
  - **What type of power supply is available?**
    - 3-phase
      - **Does application require an adjustable output speed?**
        - no
        - yes
      - no
    - single-phase
      - **Does application require an adjustable output speed?**
        - no
        - yes
  - no

- **DC**
  - **Does application require an adjustable output speed?**
    - no
    - yes
  - yes

**Does application require an output speed >3600 RPM?**

- yes
  - **Will motor be powered in continuous stall?**
    - no
    - yes

**Does application require controlled acceleration and deceleration, even when an overhauling load is present?**

- yes
  - **Does application have constant load and an accuracy requirement that would make an open-loop system acceptable?**
    - no
    - yes

- no

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- yes
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    - no
    - yes

- no

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- yes
  - **Does application have constant load and an accuracy requirement that would make an open-loop system acceptable?**
    - no
    - yes

- no
How does starting torque requirement compare to running torque?

To what degree can speed vary from no load to full load?
- less than 1%
  - SYNCHRONOUS POLYPHASE MOTOR WITH VARIABLE FREQUENCY DRIVE
  - NON-SYNCHRONOUS POLYPHASE MOTOR WITH VARIABLE FREQUENCY DRIVE
  - SYNCHRONOUS POLYPHASE MOTOR
  - NON-SYNCHRONOUS POLYPHASE MOTOR
  - SERIES WOUND MOTOR
- greater than 1%
  - SYNCHRONOUS SPLIT PHASE MOTOR
  - NON-SYNCHRONOUS SPLIT PHASE MOTOR
- less than 150%
  - SYNCHRONOUS PERMANENT SPLIT CAPACITOR MOTOR
  - NON-SYNCHRONOUS PERMANENT SPLIT CAPACITOR MOTOR
- greater than 150%
  - HY-SYNC MOTOR

Is motor required to remain stalled at a specified torque or at a specified position?

To what degree can speed vary from no load to full load?
- less than 1%
  - SYNCHRONOUS SPLIT PHASE MOTOR
  - NON-SYNCHRONOUS SPLIT PHASE MOTOR
  - SYNCHRONOUS PERMANENT SPLIT CAPACITOR MOTOR
- greater than 1%
  - HY-SYNC MOTOR

Do you want a low output speed (72 RPM) without a gearbox?
- no
  - PERMANENT MAGNET MOTOR WITH AC POWERED 4-QUADRANT AMPLIFIER, ENCODER & MOTION CONTROLLER
  - STEPPER MOTOR WITH DC-POWERED DRIVER
- yes
  - STEPPER MOTOR WITH AC-POWERED DRIVER
  - BRUSHLESS DC MOTOR WITH AC-POWERED 4-QUADRANT AMPLIFIER, ENCODER & MOTION CONTROLLER
  - PERMANENT MAGNET MOTOR WITH AC-POWERED 4-QUADRANT AMPLIFIER
  - BRUSHLESS DC MOTOR WITH AC-POWERED SPEED CONTROL
  - PERMANENT MAGNET MOTOR WITH AC-POWERED SPEED CONTROL
  - STEPPER MOTOR WITH DC-POWERED DRIVER
  - BRUSHLESS DC MOTOR WITH DC-POWERED 4-QUADRANT AMPLIFIER
  - PERMANENT MAGNET MOTOR WITH DC-POWERED 4-QUADRANT AMPLIFIER
  - BRUSHLESS DC MOTOR WITH DC-POWERED SPEED CONTROL
  - PERMANENT MAGNET MOTOR WITH DC-POWERED SPEED CONTROL
  - SERIES WOUND MOTOR
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:

$$G = \frac{N_{\text{Motor}}}{N_{\text{Load}}}$$

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:

$$G = \frac{T_{\text{Load}}}{T_{\text{Motor}}^{\text{Gears}}}$$

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:

$$G = \sqrt{\frac{J_{\text{Load}}}{J_{\text{Motor}}}}$$

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:

$$\text{HP}_{\text{Motor}} = \frac{T_{\text{Load}}N_{\text{Motor}}}{1,088,400G_e}$$

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.
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**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>kg-m²</th>
<th>kg-cm-s²</th>
<th>oz-in-s²</th>
<th>lb-in-s²</th>
<th>oz-in²</th>
<th>lb-in²</th>
<th>lb-ft²</th>
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<td>kg-m²</td>
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<td>13.88</td>
<td>.868</td>
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<td>3.35x10³</td>
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<td>7.19x10²</td>
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To convert from A to B, multiply A by entry in table. Gravity constant = \( g = 386 \text{ in} \text{s}^2 = 32.2 \text{ ft} \text{s}^2 = 9.8 \text{ m} \text{s}^2 \)