Superior Electric

DESIGN ENGINEER'S GUIDE TO AC SYNCHRONOUS MOTORS

CONTENTS
AC SYNCHRONOUS MOTORS

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1.0 CONSTRUCTION AND PRINCIPLES OF OPERATION

The SLO-SYN motor is unique in that it has the capability of being operated as an AC synchronous, constant speed motor or as a phase switched DC stepper motor. In either case, it is classified as a permanent magnet inductor motor.

Figure 1 shows the simplicity of the basic motor construction. Note that the motor has no brushes, commutators, belts or slip rings. Essentially, the motor consists of a rotor and a stator which make no physical contact at any time, due to a carefully maintained air gap. As a result of the simple construction, the motor provides long life and high reliability. A continuous running life of five years can be expected.

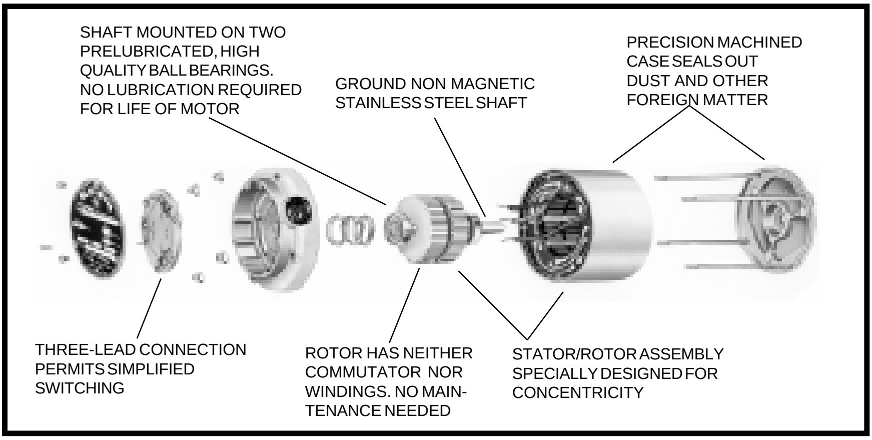


FIGURE 1

In a typical 72 rpm motor, the stator has eight salient poles with a two-phase, four-pole winding (see Figure 2). Poles designated N1, S3, N5 and S7 are energized by one phase, while Poles N2, S4, N6 and S8 are controlled by the opposite phase.

The stator teeth are set at a pitch of 48 teeth for a full circle, although there are actually only 40 teeth, as one tooth per pole has been eliminated to allow space for the windings. The windings of each four alternate poles are connected in series.

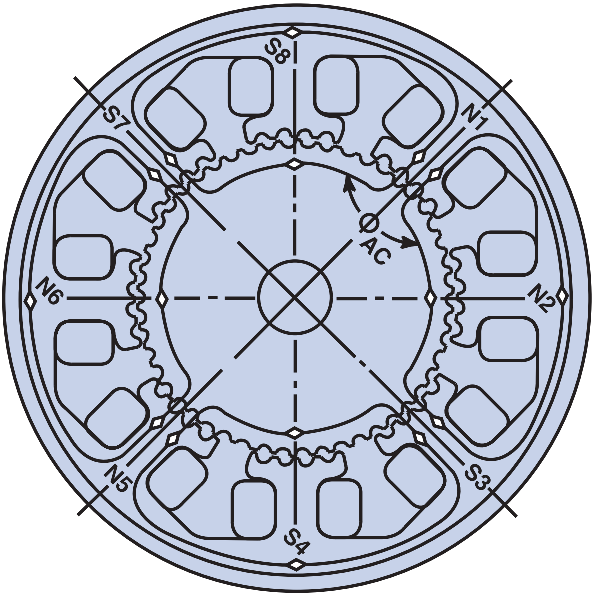


FIGURE 2

The rotor shown in Figure 3 consists of a nonmagnetic drive shaft, and an axially magnetized permanent magnet. The splines, or teeth, of the pole pieces are offset by one-half a tooth pitch to permit the use of a common stator magnetic structure and windings.One pole piece is a south pole and the other, a north pole.

FIGURE 3

Unlike the stator teeth, rotor teeth of a typical motor are at a pitch of 50 teeth for a full circle, two more than in the stator. Because of this difference, only two rotor teeth and two stator teeth can be perfectly aligned simultaneously. The magnetic arrangement of the rotor creates a south pole over the entire periphery of one-half of the rotor and a north pole over the other half. An amount of residual, or unenergized, torque is provided in the rotor, which results in the motor having the ability to stop instantaneously.

2.0 INTRODUCTION

A SLO-SYN motor operating from AC power is an extremely effective method of obtaining precise motion control. Operation simply involves connecting the SLO-SYN motor to the AC power line, incorporating a phase shifting network consisting of a resistor/capacitor or just a capacitor, and using a three-position switch “forward”, “off” and “reverse” control. The phase shifting network provides the capacitive reactance necessary to produce a 90° phase shift between the two windings.

2.1 PRINCIPAL ADVANTAGES OF THIS TYPE OF MOTOR ARE AS FOLLOWS:

1. **Simple circuitry**
2. **Bidirectional control**
3. **Instantaneous start, stop and reverse**
4. **Starting and running current are identical**
5. **Stalling causes no damage**
6. **Torque can be increased by increasing voltage**
7. **Residual (Power Off) torque is always present**
8. **Holding torque can be increased by applying DC voltage**
9. **Long life and exceptional reliability**

We will now discuss these features along with other aspects of the the SLO-SYN AC Synchronous Motor in more detail.

2.2 AC IDENTIFICATION SYSTEM

The type number identification system for SLO-SYN Synchronous Motors is straightforward and easily understood. For example, in type number SS25, the “SS” indicates “Standard SLO-SYN”, which has a synchronous shaft speed of 72 rpm at 120 volts, 60 hertz. The “25” in the type number designates the torque rating of the motor in ounce-inches. Figure 4 shows the letter designations which are offered and Figure 5 shows how the two elements of the type number identify the characteristics of the motor.

Understanding the motor identification system makes it easy to select the correct type number. For example, if an application requires a synchronous motor with a speed of 72 rpm and a torque output of 200 ounce-inches at 120 volts, 60 hertz, the SS221 motor, which produces 220 ounce-inches of torque at 72 rpm, could be specified. Consult the SLO-SYN motor catalog for a complete description of the motor identification system and a list of the motors available.

AC IDENTIFICATION SYSTEM

Type	Speed (rpm @ 60 Hertz)
KS/SS	72
TS	200

FIGURE 4

IDENTIFICATION SYSTEM EXAMPLE

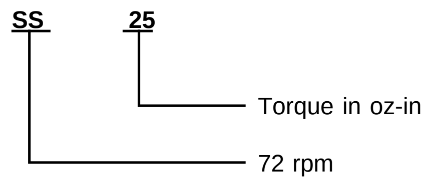


FIGURE 5

2.3 SINGLE-PHASE OPERATION

Figure 6 contains a diagram showing the connections for operating a SLO-SYN motor as a three-lead, reversible motor from a single-phase source. Since a SLO-SYN motor is inherently a two-phase or a three-phase device, depending on model, a phase shifting network is required to convert the single-phase excitation into the two- or three-phase excitation required. Two-phase motors require a resistor and a capacitor for the phase-shifting network, while three-phase motors need only a capacitor. The connections in Figure 6 are for a two-phase motor.

Specific phase shifting component values are required for each motor and these values are from published Ratings and Specifications charts in our catalog. Unless otherwise specified, the component values listed in the catalog will provide satisfactory operation at any frequency between 50 and 60 hertz. Different values may be necessary at other frequencies to give the required 90° phase shift. It may also be necessary to adjust the applied voltage level.

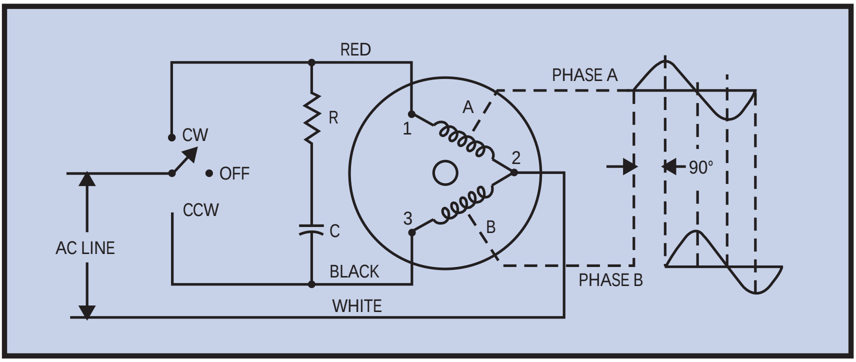


FIGURE 6

"Tuning" the phase-shifting by adjusting the component values can help achieve maximum torque, minimum vibration, or any combination thereof. The correct phase-shifting component values are necessary for proper operation of the motor. Without the proper values, motor direction will be completely random. There will also be a tendency to reverse in response to even slight load changes and, at times, the motor may fail to start. Incorrect phase-shifting component values will also cause erratic, unstable operation.

The Phase-shifting network components are normally mounted externally. Certain motor models are available with the components mounted in a housing on the rear of the motor. Consult the catalog for availability of these models.

2.4 STARTING AND STOPPING CHARACTERISTICS

Virtually instant starting and stopping characteristics are among the principal advantages of a SLO-SYN motor. Generally, the motor will start within 1-1/2 cycles of the applied frequency and will stop within 5 mechanical degrees. Figure 7 shows a typical starting curve for a 72 rpm SLO-SYN motor. The motor will start and reach its full synchronous speed within 5 to 25 milliseconds. The unusually short stopping distance of a SLO-SYN motor is obtained by simply deenergizing the motor. No mechanical or electrical braking is necessary. The quick stopping is the result of the slow rotor speed and the presence of a no-load reluctance torque produced by the permanent magnet and the tooth construction of the stator and rotor.

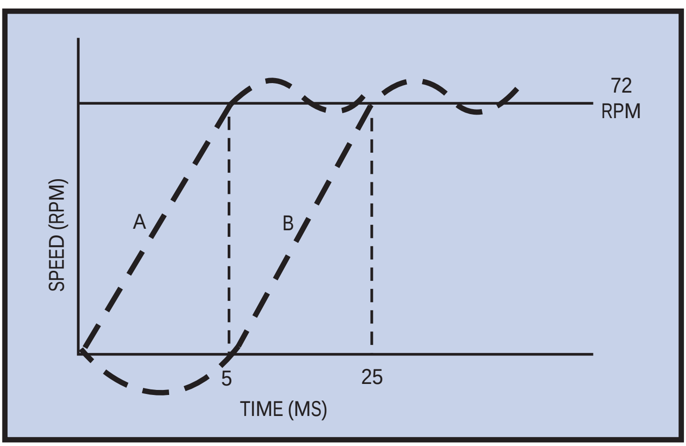


FIGURE 7

2.5 STARTING IN THE DESIRED DIRECTION

The two conditions which determine the instantaneous starting direction of a SLO-SYN motor are the position of the rotor prior to start and what portion of the AC sine wave is apparent when it is first applied to the motor windings. Curve A in Figure 7 shows the motor starting in the correct direction. The motor may also momentarily start in the wrong direction, then quickly reverse and rotate in the correct direction (Curve B in Figure 7). In most instances, this action is negligible and is of no consequence. The motor will still start within the 25 milliseconds stated earlier. In applications where no motion in the opposite direction can be tolerated, external control circuits employing "Zero Crossover" techniques must be used.

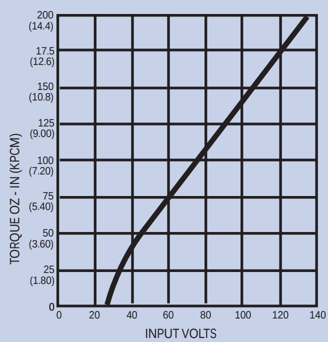
2.6 STARTING AND RUNNING CURRENT

Because of the nature of the permanent magnet inductor motor, there is no high inrush current when power is applied. The windings are excited by the alternating current, with no current being conducted through the rotor or through brushes. Because energization of the SLO-SYN motor merely involves energizing the windings, the starting, running and stall currents are, for all practical purposes, identical. Therefore the engineer designing a system need not be concerned about high inrush currents with the SLO-SYN motor. Consult the motor catalog for current requirements of the various SLO-SYN motor models

2.7 STALLING CAUSES NO DAMAGE

Because of the characteristics described in Section 2.6, a SLO-SYN motor does not draw excessive current when the motor is stalled. Since the windings are merely being energized by the alternating current, it doesn't matter whether the rotor is in motion or at a standstill. Also, no detrimental overheating will take place. Therefore, if this motor were used in an application in which it was operating a remotely controlled valve, and the motor stalled, there would be no possibility of system damage due to overheating of the motor, etc. One precaution must be noted: in this stalled condition, the motor will oscillate severely, eventually causing bearing failure.

2.8 TORQUE VERSUS VOLTAGE



TYPICAL TORQUE VS. VOLTAGE CURVE FOR AC OPERATION OF A SLO-SYN MOTOR

As shown in Figure 8, the torque output of a SLO-SYN motor is linearly proportional to the applied voltage.Primarily for intermittent operation, this capability can be used to increase the torque output by increasing the voltage. For example, assume the steady-state torque requirement for a given application is 110 ounce-inches. Normally a standard 130 ounce-inch motor would be adequate for the application. If, however, the application is subject to wide variations in line voltage, the 20 ounce-inch safety margin may be inadequate. A simple solution is to increase line voltage by approximately 10 volts with a step-up transformer or a POWERSTAT® Variable Transformer. Because operation at higher than rated voltage will cause an increase in motor temperature rise, the motor shell temperature must be monitored and must not be permitted to go above 100° C. Obviously, where more torque is needed, the next larger motor size should be used. The torque/voltage relationship should only be used to increase torque when a larger motor will not fit into the space available.

2.9 SPEED VERSUS FREQUENCY

The speed of a SLO-SYN motor is directly proportional to the applied frequency. Because the winding impedance is also a function of frequency, a constant-torque output will only be obtained at different excitation frequencies by varying line voltage, as shown in Figure 9. Only when the motor is operating from a two-phase or three-phase supply (depending on motor model) can different synchronous speeds be easily achieved by varying the line frequency.

When varying the frequency of a single-phase system, the phase shifting component values must be changed to provide the necessary 90° phase shift at each new operating frequency. Figure 10 shows the speeds at different frequencies for the two standard SLO-SYN motor series.

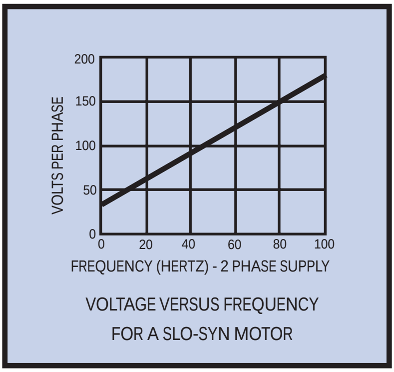


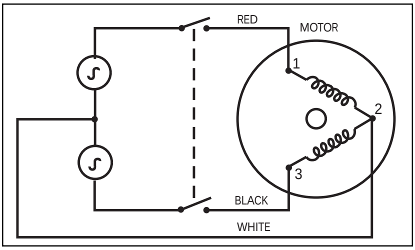
FIGURE 9

FREQUENCY (HERTZ)	KS/SS SERIES	TS SERIES
10	12	33.4
20	24	66.8
30	36	100.2
40	48	133.6
50	60	167.0
60	72	200.0
70	84	233.8
80	96	267.2
90	108	300.6
100	120	334.0

FIGURE 10

3.0 TWO-PHASE OR THREE-PHASE OPERATION

In some applications, SLO-SYN AC Synchronous Motors are operated directly from a two-phase or a three-phase source. Connections for two-phase motor operated from a two-phase supply are shown, no phase-shifting network is needed as long as the supply provides the necessary phase shift between the windings (90° for two-phase motors; 120° for three-phase motors). From 0 hertz to approximately 100 hertz, motor speed can be varied by simply changing the supply frequency. The chart in Figure 10 shows the speeds obtainable at different frequencies for the SS and TS series of motors. Depending on the motor used and the torque and inertia requirements, a motor may fail to start at frequencies above 100 hertz. Note that, as shown in Figure 9, voltage must be adjusted as frequency is changed.



Typical Wiring for Operation
From a Two-Phase Source

FIGURE 11

3.1 STARTING HIGH INERTIAL LOADS

Because of the rapid starting characteristics of a SLO-SYN motor, a maximum moment of inertia value is listed for each motor model. These values represent the maximum inertial load which specific motor models can start when driving the load through a rigid coupling. Inertial loads five to ten times these values can be started by using a flexible coupling between the motor shaft and the load. The flexible coupling should allow approximately 5° of flex before the full inertial load is “seen” by the motor shaft. The coupling can be as simple as a rubber coupling between the motor and the load, or it could be a chain with sufficient slack. Timing belts are also used as load coupling devices and, in many cases, will provide sufficient flex as well as serve as a smooth and quiet power transmission device. Figure 12 shows two typical flexible couplings.

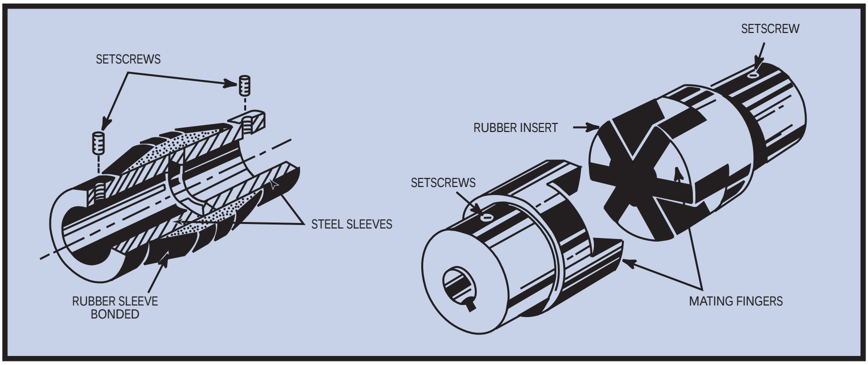


FIGURE 12

3.2 PARALLEL MOTOR OPERATION

Any number of SLO-SYN motors may be operated in parallel if their total current requirement does not exceed that of the power supply. It is important to realize, however, that due to the starting characteristics of this type of motor, mechanical synchronization of parallel operated motors is not practical. As mentioned earlier, the two conditions that determine the direction of rotation are the position of the rotor prior to start and the portion of the sine waveform apparent when the voltage is applied. Because of these variables, one motor may start within a 5 millisecond period, while another motor operated in parallel with the first may take up to 25 milliseconds to start. This will occur because the rotor of the second motor was in a slightly different position at the start of the cycle. This situation was previously illustrated in Figure 7.

3.3 HOLDING TORQUE

Some applications require more holding torque than the small residual torque provided by the permanent magnet rotor. To increase the holding torque, DC voltage can be applied to one or both motor windings when the motor is in the off condition. Connections which can be used to accomplish this are shown in Figure 13.

With DC voltage applied to one winding, the holding torque will be increased approximately 20% over the rated torque of the motor. When DC voltage is applied to both motor windings, holding torque will be approximately 1-1/2 times the rated torque.

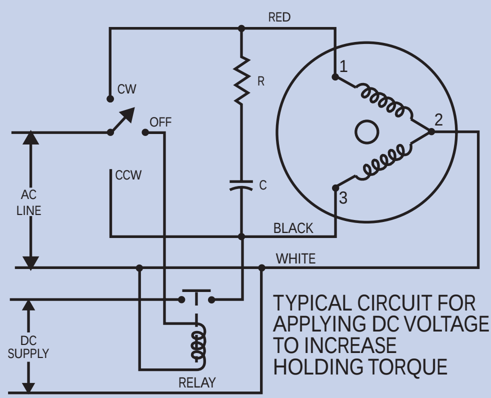


FIGURE 13

When DC voltage is applied to the windings, the motor may jump into a position of maximum magnetic attraction. The degree of movement depends on the position of the rotor relative to the stator when the DC voltage is applied and can be up to ±3.6° for an SS series motor. Figure 14 shows the holding torque available for various motor models when DC voltage is applied.

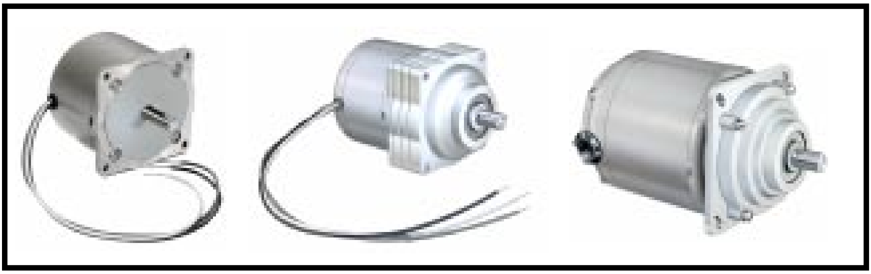
FIGURE 14

3.4 EFFECT OF GEARING

The use of gearing with a SLO-SYN motor allows a reduction in speed and an increase in output torque when gearing down. Under “gearing down” conditions, torque is increased and output speed decreased by the factor of the gear ratio. For example, an SS91 motor produces 90 ounce-inches of torque at 72 rpm. If 4:1 step-down gearing is used between the motor and the load, the motor output torque would be approximately 360 ounce-inches at a speed of 18 rpm.

The mechanical advantage of gearing is most apparent in dealing with inertia as the inertia moving capability is affected by the square of the gear ratio. Again, assume 4:1 step-down gearing is being used with an SS91 motor. The SS91 has a maximum moment of inertia capability of 1.6 lb-in^2. With 4:1 gearing, however, the maximum moment of inertia is increased 16 times and would become approximately 25.6 lb-in^2 (42 = 16 x 1.6 lb-in^2).

Timing belts and pulleys are also widely used and provide a “softer” coupling with the same overall effect as steel gearing. Some SLO-SYN motors are available with “in-line” planetary type gearheads. A complete listing of these “SLO-SYN AC Gearmotors” can be found in the motor catalog.



3.5 THE SELECTION PROCESS

Selecting the correct AC synchronous motor for a particular application is a relatively simple task. The most important parameters are:

1. **Speed (rpm)**
2. **Torque (ounce-inches)**
3. **Inertia (lb-in^2)**

Since the standard available speeds of SLO-SYN motors are 72 and 200 rpm, the two key variables become torque and inertia. Of the two, inertia has always been the least understood parameter and one that often serves as a “trap” if overlooked. For example, assume an application requires 35 ounce-inches torque and the inertia is 2 lb-in^2. A typical initial reaction is to select an SS91 motor, rated at 90 ounce-inches, simply because the application requires only 35 ounce-inches torque. However, the SS91 motor is only capable of moving 1.6 lb-in^2. Therefore, the SS91 motor would be unable to start the load. For this application as described, the best choice would be the SS221 motor, which provides 220 ounce-inches of torque and is rated for a maximum moment of inertia of 2.5 lb-in^2.

As can be seen from this example, it is important to know the *maximum moment of inertia* which will be reflected to the motor. Only when all the parameters are known can an intelligent decision be made in selecting the correct motor for the application. Formulas for calculating torque and inertia are follow.

a. TORQUE (oz-in) = Fr

where F = Force (in ounces) required to drive the load
r = Radius (in inches)

Force can be measured using a pull type spring scale. The scale may be attached to a string that is wrapped around a pulley or handwheel attached to the load. If the scale reading is in pounds, it must be converted into ounces to obtain a torque value in ounce-inches.

For example, a 4" diameter pulley requires a 2 pound pull on the scale to rotate it.

F = 2 pounds x 16 = 32 ounces

$$\mathbf{r} = \frac{4''}{2} = 2''$$

TORQUE = 32 x 2 = 64 ounce-inches

b. MOMENT OF INERTIA

$$(\text{lb-in}^2) = \frac{Wr^2}{2} \text{ for a disc}$$

$$\text{or} \quad (\text{lb-in}^2) = \frac{W}{2}(r_1^2 + r_2^2) \text{ for a cylinder}$$

where W = Weight (in pounds)
r = Radius (in inches)

For example, a load is a 8" diameter gear weighing 8 ounces

$$W = \frac{8}{16} = 0.5 \text{ pound}$$

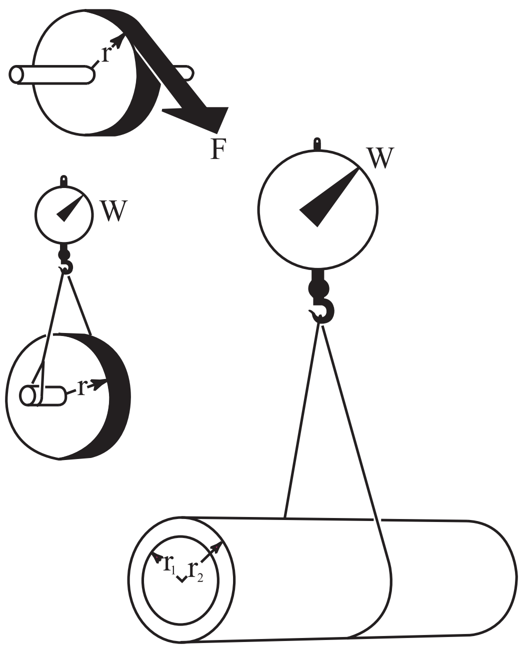
$$r = \frac{8''}{2} = 4''$$

$$\textbf{MOMENT OF INERTIA} = \frac{0.5 \times (4)^2}{2} = 4 \ (\text{lb-in}^2)$$

GEARS AND PULLEYS

When the load is to be driven through gears or pulleys, the torque should be decreased or increased by the overall ratio. For example, if the load is 90 ounce-inches and it is to be driven through a step-down ratio of 3:1, the required torque is 30 ounce-inches.

Load inertia should be decreased or increased by the square of the ratio. For example, with a load inertia of 4 pound-inches^2 and a 2:1 step-down ratio, the effective inertia would be 1 pound-inch^2 plus the inertia of the first gear or pulley.



INERTIA CONVERSION FACTORS

slug-ft^2 x 4600	=	lb-in^2
lb-ft^2 x 144	=	lb-in^2
oz-in^2 x 0.0625	=	lb-in^2
lb-ft-sec^2 x 4600	=	lb-in^2
lb-in-sec^2 x 384	=	lb-in^2
oz-in-sec^2 x 24	=	lb-in^2
gm-cm^2 x 0.000342	=	lb-in^2
kp-m-sec^2 x 33,500	=	lb-in^2

METRIC-DECIMAL EQUIVALENTS

1 inch	=	2.54 cm
1 cm	=	0.3937 inch
1 pond (gm)	=	0.03527 oz
1 oz	=	28.35 pond (gm)
1 kp (kg)	=	2.205 pound
1 gm-cm	=	0.0139 oz-in
1 kg-cm	=	1 kp-cm = 13.9 oz-in
1 hp	=	746 watts

3.6 CAPABILITIES

SLO-SYN AC Synchronous Motors produce torque outputs ranging from 25 ounce-inches to 1800 ounce-inches in various frame sizes. In addition to the wide variety of torque ratings and frame sizes, special capability motors such as double-ended shaft, militarized, limited vacuum, high temperature, radiation resistant, dust-ignition proof and explosion-proof types are available.

Gearmotors and motors with phase-shifting components are also offered on some models.

3.7 AC APPLICATIONS

SLO-SYN AC Synchronous Motors provide low, constant-speed positioning control with minimum control circuitry and maximum life. The following is a partial list of possible applications.

a. Valve controls
b. Timing belt drives
c. Conveyor systems
d. Card positioning
e. X-Ray scanning
f. Antenna rotators
g. Film handling
h. Microfilm scanners
i. Paper feed
j. Furnace damper controls
k. Tape dispensers
l. Remote control of switches, rheostats, etc.
m. X-Y positioning
n. Textile edge guide controls
o. Printing press ink pump control
p. Generators
q. Automated welding equipment
r. Paper handling
s. Medical pumps
t. Fluid metering