SELECTING THE SURESERVO® SYSTEM

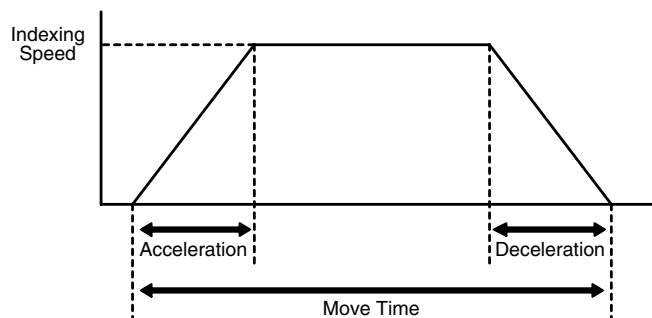## CONTENTS OF THIS CHAPTER...

SELECTING THE SURESERVO® SERVO SYSTEM

The selection of your SureServo® servo system follows a defined process. Let's go through the process and define some useful relationships and equations. We will use this information to work some typical examples along the way.

THE SELECTION PROCEDURE

The motor provides for the required motion of the load through the actuator (mechanics that are between the motor shaft and the load or workpiece). Key information to accomplish the required motion is:

- *total number of pulses from the PLC*
- *positioning resolution of the load*
- *indexing speed (or PLC pulse frequency) to achieve the move time*
- *required motor torque (including the 25% safety factor)*
- *load to motor inertia ratio*

In the final analysis, we need to achieve the required motion with acceptable positioning accuracy.

HOW MANY PULSES FROM THE **PLC** TO MAKE THE MOVE?

The total number of pulses to make the entire move is expressed with the equation:

Equation 1: P_{total} = total pulses = $(D_{total} \div (d_{load} \div i)) \times \theta_{count}$

- D_{total} = *total move distance*
- d_{load} =
  lead or distance the load moves per revolution of the actuator's drive shaft (P = pitch = $1/d_{load}$)
- θ_{count} = *servo resolution (counts/rev_{motor}) (default = 10,000)*
- i = *gear reduction ratio ($rev_{motor}/rev_{gearshaft}$)*

Example 1: The motor is directly attached to a disk and we need to move the disk 5.5 revolutions. How many pulses does the PLC need to send to the driver?

- P_{total} = (5.5 $rev_{disk} \div$ (1 $rev_{disk}/rev_{driveshaft} \div$ 1 $rev_{motor}/rev_{driveshaft}$))
      5.5 ÷ (1.0 ÷ 10) x 10,000 = 550,000
      x 10,000 counts/rev_{motor}
      = 55,000 pulses

Example 2: The motor is directly attached to a ballscrew where one turn of the ballscrew results in 20 mm of linear motion and we need to move 45 mm. How many pulses do we need to send the driver?

- P_{total} = (45 mm ÷ (20 mm/$rev_{screw} \div$ 1 rev_{motor}/rev_{screw})) x 10,000 counts/rev_{motor}
      = 22,500 pulses

45 mm	1 rev$_{screw}$	1 rev$_{motor}$	10,000 pulses
move	20 mm	1 rev$_{screw}$	1 rev$_{motor}$

Example 3: Let's add a 2:1 belt reduction between the motor and ballscrew in example 2. Now how many pulses do we need to make the 45 mm move?

- P_{total} = (45 mm ÷ (20mm/$rev_{screw} \div$ 2 rev_{motor}/rev_{screw})) x 10,000 counts/rev_{motor}
      = 45,000 pulses

WHAT IS THE POSITIONING RESOLUTION OF THE LOAD?

We want to know how far the load will move for one command pulse. The equation to determine the positioning resolution is:

Equation 2: L_θ = load positioning resolution = $(d_{load} \div i) \div \theta_{count}$

Example 4: What is the positioning resolution for the system in example 3?

- $L_\theta = (d_{load} \div i) \div \theta_{count}$
  $= (20 \text{ mm/rev}_{screw} \div 2 \text{ rev}_{motor}/\text{rev}_{screw}) \div 10,000 \text{ counts/rev}_{motor}$
  $= 0.001\text{mm/count}$
  $\approx 0.00004 \text{ in/count}$

WHAT IS THE INDEXING SPEED TO ACCOMPLISH THE MOVE TIME?

The most basic type of motion profile is a "start-stop" profile where there is no acceleration or deceleration period. This type of motion profile is only used for low speed applications because the load is "jerked" from one speed to another and the servo system may experience a position deviation error if excessive speed changes are attempted. The equation to find indexing speed for "start-stop" motion is:
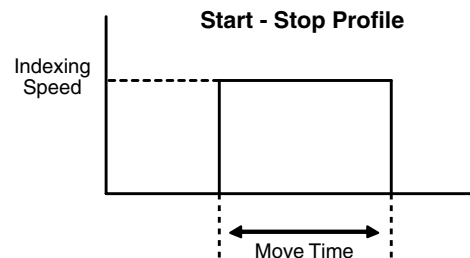
Equation 3: f_{SS} = indexing speed for Start/Stop profiles = $P_{total} \div t_{total}$
- t_{total} = move time

Example 5: What is the indexing speed to make a "start-stop" move with 10,000 pulses in 800 ms?
- f_{SS} = indexing speed = $P_{total} \div t_{total}$ = 10,000 pulses ÷ 0.8 seconds
  = 12,500 Hz.

For higher speed operation, the "trapezoidal" motion profile includes controlled acceleration & deceleration and, in some cases, an initial non-zero starting speed. With the acceleration and deceleration periods equally set, the indexing speed can be found using the equation:
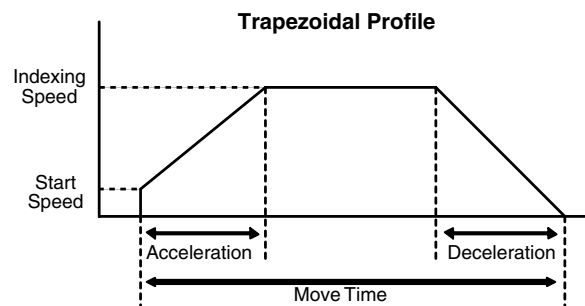
Equation 4: $f_{TRAP} = (P_{total} - (f_{start} \times t_{ramp})) \div (t_{total} - t_{ramp})$
for trapezoidal motion profiles
- f_{start} = starting speed
- t_{ramp} = acceleration or deceleration time

Example 6: What is the required indexing speed to make a "trapezoidal" move in 1.8s, accel/decel time of 200 ms each, 100,000 total pulses, and a starting speed of 40 Hz?
- f_{TRAP} = (100,000 pulses - (40 pulses/sec x 0.2 sec)) ÷ (1.8 sec - 0.2 sec)
  $\approx$ 62,375 Hz

CALCULATING THE REQUIRED TORQUE

The required torque is the sum of acceleration (or deceleration) torque and the running torque. The equation for required motor torque is:

Equation 5: $T_{motor} = T_{accel \, (or \, decel)} + T_{run}$

- T_{accel} = motor torque required to accelerate the total system inertia (including motor inertia).
- T_{decel} = motor torque required to decelerate; not always the same as acceleration.
- T_{run} = constant motor torque requirement to run the mechanism due to friction, external load forces, etc.
- <u>Continuous Duty Zone</u> means the system can provide the torque under the curve 100% of the time.
- <u>Intermittent Duty Zone</u> means the system can provide the torque under the curve LESS THAN 100% of the time.

400W Low Inertia
SVL-204
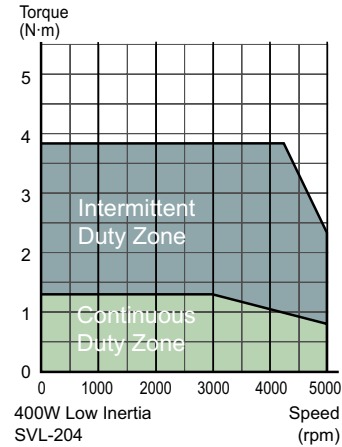
The amount of time the system can operate in this region depends on the amount of torque. In general, the higher the torque, the shorter period of time is allowed. See overload curves information in Chapter 1. If a system requires more than rated torque occasionally, but only for a short time, the system can do it. Running in this zone continuously will result in an overload fault.

In **Table 1** we show how to calculate torque required to accelerate or decelerate an inertia from one speed to another and the calculation of running torque for common mechanical actuators.

Table 1 – Calculate the Torque for "Acceleration" and "Running"

The torque required to accelerate or decelerate a constant inertia with a linear change in velocity is:

Equation 6:
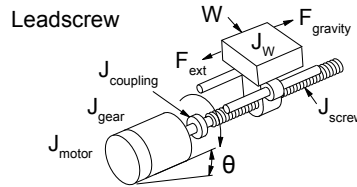
$T_{accel} = J_{total}$ x (Δspeed ÷ Δtime) x (2π ÷ 60)

- J_{total} *is the motor inertia plus load inertia ("reflected" to the motor shaft).*
- *The (2π ÷ 60) is a factor used to convert "change in speed" expressed in rpm into angular speed (radians/second).*
- *Refer to information in this table to calculate "reflected" load inertia for several common shapes and mechanical mechanisms.*
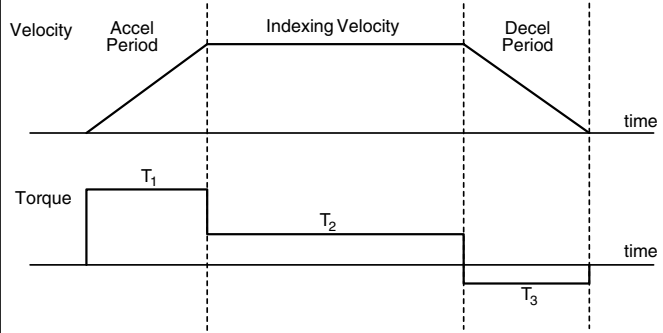
Example 7: What is the required torque to accelerate an inertia of 0.002 lb·in·sec² (motor inertia is 0.0004 lb·in·sec² and "reflected" load inertia is 0.0016 lb·in·sec²) from zero to 600 rpm in 50 ms?

- *T_{accel} = 0.002 lb·in·sec² x (600 rpm ÷ 0.05 seconds) x (2π ÷ 60)*
  ≈ 2.5 lb·in

Leadscrew Equations

Description:	Equations:	
Definitions	coefficient of friction = μ efficiency = e gear ratio = i incline angle = θ pitch = P	μ = coefficient of friction e = efficiency i = gear ratio θ = incline angle P = pitch
Motor rpm	n_{motor} = (v_{load} x P) x i; n_{motor} (rpm); v_{load} (in/min)	
Torque required to accelerate and decelerate the load	$T_{accel} = J_{total}$ x (Δspeed ÷ Δtime) x 0.1	
Motor total inertia	$J_{total} = J_{motor} + J_{gear} + ((J_{coupling} + J_{screw} + J_W) ÷ i^2)$	
Inertia of the load	$J_W = (W ÷ (g x e)) x (1 ÷ 2 π P)^2$	
Pitch	P = revs/inch of travel	
Running torque	$T_{run} = ((F_{total} ÷ (2 π P)) + T_{preload}) ÷ i$	
Torque due to preload on the ballscrew	$T_{preload}$ = ballscrew nut preload to minimize backlash	
Force total	$F_{total} = F_{ext} + F_{friction} + F_{gravity}$	
Force of friction	$F_{friction} = μWcosθ$	
Force of gravity	$F_{gravity} = Wsinθ$	

Typical Leadscrew Data			
Material:	**e = efficiency**	**Material:**	**μ = coef. of friction**
ball nut	0.90	**steel on steel**	0.580
acme with plastic nut	0.65	**steel on steel (lubricated)**	0.150
acme with metal nut	0.40	**teflon on steel**	0.040
		ball bushing	0.003

(table continued next page)

Table 1 – Calculate the Torque for "Acceleration" and "Running"   (continued from previous page)

## Belt Drive (or Rack & Pinion) Equations

Conveyor

Rack & Pinion
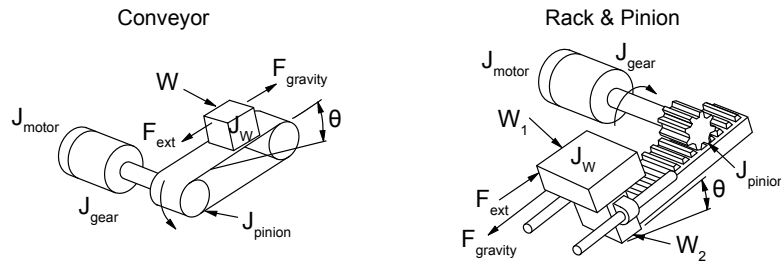
Description:	Equations: [i = gear ratio]
Motor rpm	$n_{motor} = (v_{load} \times 2 \pi r) \times i$
Torque required to accelerate and decelerate the load	T_{accel} $J_{total} \times (\Delta speed \div \Delta time) \times 0.1$
Inertia of the load	$J_{total} = J_{motor} + J_{gear} + ((J_{pinion} + J_W) \div i^2)$
Inertia of the load	$J_W = (W \div (g \times e)) \times r^2$; $J_W = ((W_1 + W_2) \div (g \times e)) \times r^2$
Radius of pulleys	r = radius of pinion or pulleys (inch)
Running torque	$T_{run} = (F_{total} \times r) \div i$
Force total	$F_{total} = F_{ext} + F_{friction} + F_{gravity}$
Force of gravity and Force of friction	$F_{gravity} = Wsin\theta$; $F_{friction} = \mu Wcos\theta$
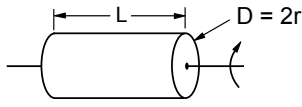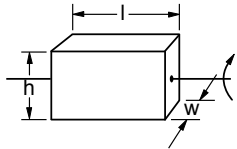
Belt (or Gear) Reducer Equations

Timing Belt

Gearing
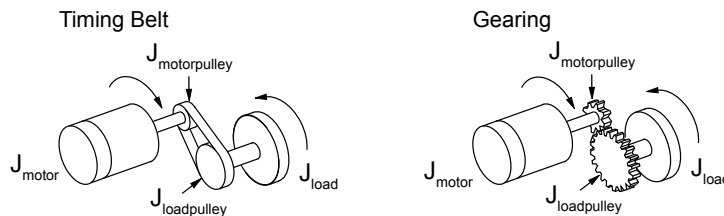
Description:	Equations: [i = gear ratio]
Motor rpm	$n_{motor} = n_{load} \times i$
Torque required to accelerate and decelerate the load	$T_{accel} = J_{total} \times (\Delta speed \div \Delta time) \times 0.1$
Inertia of the load	$J_{total} = J_{motor} + J_{motorpulley} + ((J_{loadpulley} + J_{load}) \div i^2)$
Motor torque	$T_{motor} \times i = T_{load}$

Inertia of Hollow Cylinder Equations

Hollow Cylinder
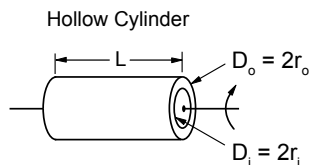
Description:	Equations:
Inertia (known weight)	$J = (W \times (r_o^2 + r_i^2)) \div (2g)$
Inertia (known density)	$J = (\pi \times L \times \rho \times (r_o^4 - r_i^4)) \div (2g)$
Volume	volume $= \pi/4 \times (D_o^2 - D_i^2) \times L$

(table continued next page)

Table 1 – Calculate the Torque for "Acceleration" and "Running"   (continued from previous page)

Inertia of Solid Cylinder Equations

Solid Cylinder

Description:	Equations:
Inertia (known weight)	$J = (W \times r^2) \div (2g)$
Inertia (known density)	$J = (\pi \times L \times \rho \times r^4) \div (2g)$
Volume	volume $= \pi \times r^2 \times L$

Inertia of Rectangular Block Equations

Rectangular Block

Description:	Equations:
Inertia (known weight)	$J = (W \div 12g) \times (h^2 + w^2)$
Volume	volume $= l \times h \times w$

Symbol Definitions

J = inertia, lb·in·s² (kg·m·s²)	**ρ = density**
L = Length, inches (m)	**ρ = 0.098 lb/in³ (aluminum)**
h = height, inches (m)	**ρ = 0.28 lb/in³ (steel)**
w = width, inches (m)	**ρ = 0.04 lb/in³ (plastic)**
W = weight, lb (kg)	**ρ = 0.31 lb/in³ (brass)**
D = diameter, inches (m)	**ρ = 0.322 lb/in³ (copper)**
r = radius, inches (m)	
g = gravity = 386 in/sec² (9.8 m/s²)	**π ≈ 3.14**

LEADSCREW – EXAMPLE CALCULATIONS

STEP 1 – DEFINE THE ACTUATOR AND MOTION REQUIREMENTS

Leadscrew
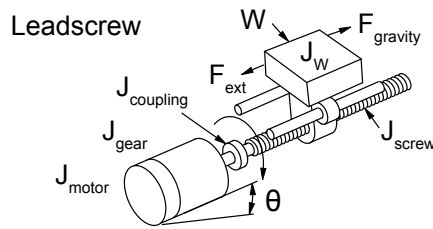
- *Weight of table and workpiece = 150 lb*
- *Angle of inclination = 0°*
- *Friction coefficient of sliding surfaces = 0.05*
- *External load force = 0*
- *Ball screw shaft diameter = 0.8 inch*
- *Ball screw length = 96 inch*
- *Ball screw material = steel*
- *Ball screw lead = 8.0 inch/rev (P ≈ 0.125 rev/in)*
- *Desired Resolution = 0.0005 inches/count*
- *Gear reducer = 2:1*
- *Stroke = 78 inches*
- *Move time = 12 seconds*

Definitions
d_{load} = lead or distance the load moves per revolution of the actuator's drive shaft (P = pitch = $1/d_{load}$)
D_{total} = total move distance
θ_{count} = servo resolution (counts/rev_{motor})
i = gear reduction ratio ($rev_{motor}/rev_{gearshaft}$)
T_{accel} = motor torque required to accelerate and decelerate the total system inertia (including motor inertia)
T_{run} = constant motor torque requirement to run the mechanism due to friction, external load forces, etc.
t_{total} = move time

STEP 2 – DETERMINE THE POSITIONING RESOLUTION OF THE LOAD

The resolution of the load can be determined using ***Equation 2***. If the servo motor is connected directly to the ballscrew, then the best resolution possible would be:

- $L_\theta = (d_{load} \div i) \div \theta_{count}$
  $= (8 \div 1) \quad \div 10,000$
  $= 0.0008$

This does not meet the system requirements; however, if we add a 2:1 transmission with no lost motion (backlash, etc.) to the output of the motor, the resolution gets better by a factor of 2, so the minimum requirements would be met.

- $L_\theta = (8 \div 2) \div 10,000$
  $= 0.0004$

STEP 3 – DETERMINE THE MOTION PROFILE

From **Equation 1**, the total pulses to make the required move is:

- $P_{total} = (D_{total} \div (d_{load} \div i)) \times \theta_{count}$
  $= (78 \div (8 \div 2)) \times 10{,}000 = 195{,}000$ pulses

From **Equation 4**, the indexing frequency for a trapezoidal move is:

- $f_{TRAP} = (P_{total} - (f_{start} \times t_{ramp})) \div (t_{total} - t_{ramp})$
  $= (195{,}000 - (100 \times 0.6)) \div (12 - 0.6) \approx 17.1$ kHz
  where accel time is 5% of total move time and starting speed is 100Hz.
  $= 17.1$ kHz $\times$ (60 sec/1 min) $\div$ 10,000 counts/rev
  ≈ 103 rpm

STEP 4 – DETERMINE THE REQUIRED MOTOR TORQUE

Using the equations in **Table 1**:

- $J_{total} = J_{motor} + J_{gear} + ((J_{coupling} + J_{screw} + JW) \div i^2)$

For this example, let's assume the gearbox and coupling inertia are zero.

- $J_W = (W \div (g \times e)) \times (1 \div 2\pi P)^2$
  $= (150 \div (386 \times 0.9)) \times (1 \div 2 \times 3.14 \times 0.125)^2$
  ≈ 0.700 lb·in·sec^2
- $J_{screw} \approx (\pi \times L \times \rho \times r^4) \div (2g)$
  $\approx (3.14 \times 96 \times 0.28 \times 0.0256) \div (2 \times 386)$
  ≈ 0.0028 lb·in·sec^2

The inertia of the load and screw reflected to the motor is:

- $J_{(screw + load)}$ to motor $= ((J_{screw} + J_W) \div i^2)$
  $\approx ((0.0028 + 0.700) \div 2^2) = 0.176$ lb·in·sec^2

The torque required to accelerate the inertia is:

- $T_{accel} \approx J_{total} \times (\Delta_{speed} \div \Delta_{time}) \times 0.1$
  $= 0.176 \times (103 \div 0.6) \times 0.1 \approx 1.08$ lb·in

Next, we need to determine running torque. If the machine already exists then it is sometimes possible to actually measure running torque by turning the actuator driveshaft with a torque wrench.

- $T_{run} = ((F_{total} \div (2\pi P)) + T_{preload}) \div i$
- $F_{total} = F_{ext} + F_{friction} + F_{gravity}$
  $= 0 + \mu W \cos\theta + 0 = 0.05 \times 150 = 7.5$ lb
- $T_{run} = (7.5 \div (2 \times 3.14 \times 0.125)) \div 2$
  ≈ 4.77 lb·in
  where we have assumed preload torque to be zero.

From **Equation 5**, the required motor torque is:

- $T_{motor} = T_{accel} + T_{run} = 1.08 + 4.77 \approx 5.85$ lb·in ≈ 0.66 N·m

However, this is the required motor torque before we have picked a motor and included the motor inertia.

STEP 5 – SELECT AND CONFIRM THE SERVO MOTOR AND DRIVER SYSTEM

It looks like a reasonable choice for a motor would be the SVL-207. This motor has an inertia of:

- J_{motor} = 0.00096 lb·in·sec²

The actual motor torque would be modified:

- $T_{accel} = J_{total}$ x (Δspeed ÷ Δtime) x 0.1
        = (0.176 + 0.00096) x (103 ÷ 0.6) x 0.1
        ≈ 1.09 lb·in

So that:

- $T_{motor} = T_{accel} + T_{run}$
        = 1.09 + 4.77 ≈ 5.86 lb·in ≈ 0.66 N·m

Torque (N·m) vs Speed (rpm) — 750W Low Inertia SVL-207, showing Intermittent Duty Zone and Continuous Duty Zone
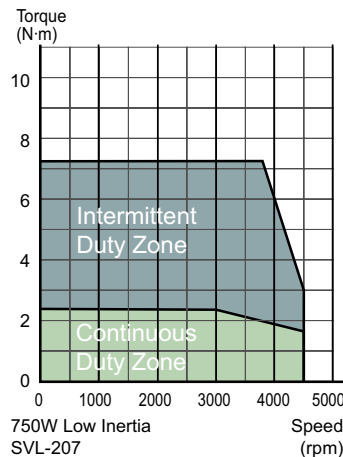
It looks like the 750W system will work. However, we still need to check the load to motor inertia ratio:

- Ratio = $J_{(screw + load)\ to\ motor}$ ÷ J_{motor}
        = 0.176 ÷ 0.00096 = 183.3

It is best to keep the load to motor inertia ratio below 10, so 183 is well outside this guideline. Although the servo has enough power to control the system, the large mismatch ratio may prevent proper tuning and faster acceleration settings in the future. Since the motor speed required to move the system is well within the motor specs, we can change the gear ratio to use a 750W motor or select a much larger motor such as the SVM-220. Because the reflected inertia is decreased by the square of the ratio, we will change the gear ratio to 10:1. By doing this, the mismatch ratio is now 7.3 (before we consider any added inertia due to the reducer).

- Reflected J = ($J_{screw}+J_{load}$) ÷ 2^2 = 0.176, so:
- New Reflected J = ($J_{screw}+J_{load}$) ÷ 10^2 = 0.00704
- New J Ratios = 0.00704 ÷ 0.00096 = 7.33

BELT DRIVE – EXAMPLE CALCULATIONS

STEP 1 – DEFINE THE ACTUATOR AND MOTION REQUIREMENTS

Conveyor
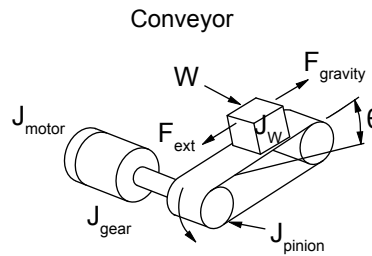
- *Weight of table and workpiece = 90 lb*
- *External force = 0 lb*
- *Friction coefficient of sliding surfaces = 0.05*
- *Angle of table = 0°*
- *Belt and pulley efficiency = 0.8*
- *Pulley diameter = 2.0 inch*
- *Pulley thickness = 0.75 inch*
- *Pulley material = aluminum*
- *Desired Resolution = 0.0005 inch/step*
- *Gear Reducer = 10:1*
- *Stroke = 50 inch*
- *Move time = 4.0 seconds*
- *Accel and decel time = 1.0 seconds*

Definitions
d_{load} = lead or distance the load moves per revolution of the actuator's drive shaft (P = pitch = $1/d_{load}$)
D_{total} = total move distance
θ_{count} = servo resolution (counts/rev$_{motor}$)
i = gear reduction ratio (rev$_{motor}$/rev$_{gearshaft}$)
T_{accel} = motor torque required to accelerate and decelerate the total system inertia (including motor inertia)
T_{run} = constant motor torque requirement to run the mechanism due to friction, external load forces, etc.
t_{total} = move time

STEP 2 – DETERMINE THE POSITIONING RESOLUTION OF THE LOAD

The resolution of the load can be determined using **_Equation 2_**. If the servo motor is connected directly to the pulley, then the best resolution possible would be:

- $L_\theta = (d_{load} \div i) \div \theta_{count}$
  $= ((\pi \times 2.0) \div 1) \div 10{,}000$
  $= 0.00063$
  where $d_{load} = \pi \times$ Pulley Diameter.

This does not meet the system requirements. However, if we add a 10:1 transmission to the output of the motor, the resolution improves by a factor of 10, meeting the minimum system requirements.

- $L_\theta = ((\pi \times 2.0) \div 10) \div 10{,}000$
  $= 0.000063$

STEP 3 – DETERMINE THE MOTION PROFILE

From **_Equation 1_**, the total pulses to make the required move is:

- $P_{total} = (D_{total} \div (d_{load} \div i)) \times \theta_{count}$
  $= 50 \div ((3.14 \times 2.0) \div 10 \times 10{,}000$
  $\approx 795{,}775$ pulses

From **_Equation 4_**, the running frequency for a trapezoidal move is:

- $f_{TRAP} = (P_{total} - (f_{start} \times t_{ramp})) \div (t_{total} - t_{ramp})$
  $= 795{,}775 \div (4 - 1)$
  $\approx 265{,}258$ Hz or 265.3 kHz
  [where accel time is 25% of total move time and starting speed is zero]
  $=\ 265.3$ kHz $\times$ (60 sec/1 min) $\div$ 10,000 counts/rev
  $\approx 1{,}592$ rpm motor speed

STEP 4 – DETERMINE THE REQUIRED MOTOR TORQUE

Using the equations in **_Table 1_**:

- $J_{total} = J_{motor} + J_{gear} + ((J_{pulleys} + J_W) \div i^2)$

For this example, let's assume the gearbox inertia is zero.

- $J_W =\ (W \div (g \times e)) \times r^2$
  $= (90 \div (386 \times 0.8)) \times 1$
  ≈ 0.291 lb·in·sec^2

Pulley inertia (remember, there are two pulleys) can be calculated as:

- $J_{pulleys} \approx ((\pi \times L \times \rho \times r^4) \div (2g)) \times 2$
  $\approx ((3.14 \times 0.75 \times 0.098 \times 1) \div (2 \times 386)) \times 2$
  ≈ 0.0006 lb·in·sec^2

The inertia of the load and pulleys reflected to the motor is:

- $J_{(pulleys + load)\ to\ motor} = ((J_{pulleys} + J_W) \div i^2)$
  $\approx ((0.291 + 0.0006) \div 100) \approx 0.0029$ lb·in·sec^2

The torque required to accelerate the inertia is:

- $T_{acc} \approx J_{total} \times (\Delta_{speed} \div \Delta time) \times 0.1$
  $\approx 0.0029 \times (1592 \div 1) \times 0.1$
  ≈ 0.46 lb·in

- $T_{run} = (F_{total} \times r) \div i$
- $F_{total} = F_{ext} + F_{friction} + F_{gravity}$
  $= 0 + \mu Wcos\theta + 0 = 0.05 \times 100 = 5.0$ lb
- $T_{run} = (5.0 \times 1) \div 10$
  ≈ 0.50 lb·in

From **_Equation 5_**, the required motor torque is:

- $T_{motor} = T_{accel} + T_{run} = 0.46 + 0.50 \approx 0.96$ lb·in ≈ 0.11 N·m

However, this is the required motor torque before we have picked a motor and included the motor inertia.

STEP 5 – SELECT AND CONFIRM THE SERVO MOTOR AND DRIVER SYSTEM

It looks like a reasonable choice for a motor would be the SVL-2040. This motor has an inertia of:

- J_{motor} = 0.0003 lb·in·sec^2

The actual motor torque would be modified:

- $T_{accel} = J_{total}$ x $(\Delta_{speed} \div \Delta_{time})$ x 0.1
  = (0.0029 + 0.0003) x (1592 ÷ 1) x 0.1 ≈ 0.51 lb·in

So that:

- $T_{motor} = T_{accel} + T_{run}$
  = 0.51 + 0.5 ≈ 1.01 lb·in ≈ 0.12 N·m
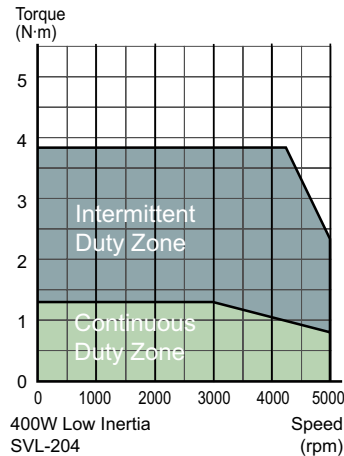
It looks like the 400W system will work. However, we still need to check the load to motor inertia ratio:

- $Ratio = J_{(pulleys + load)\ to\ motor} \div J_{motor}$
  = 0.0029 ÷ 0.0003 = 9.6

It is best to keep the load to motor inertia ratio at or below 10, so 9.6 is within an acceptable range.

INDEX TABLE – EXAMPLE CALCULATIONS

STEP 1 – DEFINE THE ACTUATOR AND MOTION REQUIREMENTS

Index Table

- *Diameter of index table = 12 inch*
- *Thickness of index table = 3.25 inch*
- *Table material = steel*
- *Number of workpieces = 8*
- *Desired Resolution = 0.006°*
- *Gear Reducer = 6:1*
- *Index angle = 45°*
- *Index time = 0.5 seconds*

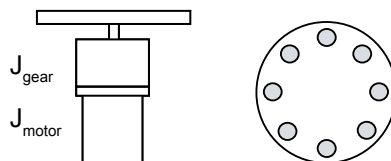| Definitions |
|---|
| d_{load} = lead or distance the load moves per revolution of the actuator's drive shaft (P = pitch = $1/d_{load}$) |
| D_{total} = total move distance |
| θ_{count} = servo resolution (counts/rev_{motor}) |
| i = gear reduction ratio ($rev_{motor}/rev_{gearshaft}$) |
| T_{accel} = motor torque required to accelerate and decelerate the total system inertia (including motor inertia) |
| T_{run} = constant motor torque requirement to run the mechanism due to friction, external load forces, etc. |
| t_{total} = move time |

STEP 2 – DETERMINE THE POSITIONING RESOLUTION OF THE LOAD

The resolution of the load can be determined using **_Equation 4_**. If the servo motor is connected directly to the table, then the best resolution possible would be:

- $L_\theta = (d_{load} \div i) \div \theta_{count}$
    $= (360° \div 1) \div 10,000$
    $= 0.036°$

This does not meet the system requirements. However, if we add a 6:1 transmission to the output of the motor, the resolution gets better by a factor of 6, meeting the minimum system requirements.

- $L_\theta = (360° \div 6) \div 10,000$
    $= 0.006°$

STEP 3 – DETERMINE THE MOTION PROFILE

From **_Equation 1_**, the total pulses to make the required move is:

- $P_{total} = (D_{total} \div (d_{load} \div i)) \times \theta_{count}$
    $= (45° \div (360° \div 6) \times 10,000$
    $= 7,500$ pulses

From **_Equation 4_**, the running frequency for a trapezoidal move is:

- $f_{TRAP} = (P_{total} - (f_{start} \times t_{ramp})) \div (t_{total} - t_{ramp})$
    $= 7,500 \div (0.5 - 0.13) \approx 20.27$ kHz
    [where accel time is 25% of total move time and starting speed is zero]
    $= 20.27$ kHz $\times$ (60 sec/1 min) $\div$ 10,000 counts/rev
    ≈ 121 rpm

STEP 4 – DETERMINE THE REQUIRED MOTOR TORQUE

Using the equations in **_Table 1_**:

- $J_{total} = J_{motor} + J_{gear} + (J_{table} \div i^2)$

For this example, let's assume the gearbox inertia is zero.

- $J_{table} \approx (\pi \times L \times \rho \times r^4) \div (2g)$
  $\approx (3.14 \times 3.25 \times 0.28 \times 1296) \div (2 \times 386)$
  $\approx 4.80 \ lb{\cdot}in{\cdot}sec^2$

The inertia of the indexing table reflected to the motor is:

- $J_{table\ to\ motor} = J_{table} \div i^2$
  $\approx 0.133 \ lb{\cdot}in{\cdot}sec^2$

The torque required to accelerate the inertia is:

- $T_{accel} \approx J_{total} \times (\Delta_{speed} \div \Delta_{time}) \times 0.1$
  $= 0.133 \times (121 \div 0.13) \times 0.1$
  $\approx 12.38 \ lb{\cdot}in$

From **_Equation 5_**, the required motor torque is:

- $T_{motor} = T_{accel} + T_{run}$
  $= 12.38 + 0 = 12.38 \ lb{\cdot}in \approx 1.40 \ N{\cdot}m$

However, this is the required motor torque before we have picked a motor and included the motor inertia.

STEP 5 – SELECT AND CONFIRM THE SERVO MOTOR AND DRIVER SYSTEM

It looks like a reasonable choice for a motor would be the SVM-220. This motor has an inertia of:

- $J_{motor} = 0.014 \ lb{\cdot}in{\cdot}sec^2$

The actual motor torque would be modified:

$T_{accel} = J_{total} \times (\Delta_{speed} \div \Delta_{time}) \times 0.1$
   $= (0.133 + 0.014) \times (121 \div 0.13) \times 0.1$
   $\approx 13.68 \ lb{\cdot}in$

So that:

- $T_{motor} = T_{accel} + T_{run}$
  $= 13.68 + 0$
  $= 13.68 \ lb{\cdot}in \approx 1.55 \ N{\cdot}m$

2kW Medium Inertia
SVL-220
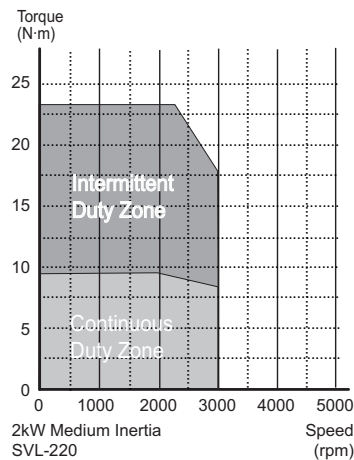
It looks like the 2 kW medium inertia system will work. However, we still need to check the load to motor inertia ratio:

- $Ratio = J_{table\ to\ motor} \div J_{motor}$
  $= 0.133 \div 0.014 = 9.5$

It is best to keep the load to motor inertia ratio at or below 10, so 9.5 is within an acceptable range.

Engineering Unit Conversion Tables, Formulas, & Definitions

Conversion of Length

*		B					
		µm	**mm**	**m**	**mil**	**in**	**ft**
A	**µm**	1	1.000E–03	1.000E–06	3.937E–02	3.937E–05	3.281E–06
	mm	1.000E+03	1	1.000E–03	3.937E+01	3.937E–02	3.281E–03
	m	1.000E+06	1.000E+03	1	3.937E+04	3.937E+01	3.281E+00
	mil	2.540E+01	2.540E–02	2.540E–05	1	1.000E–03	8.330E–05
	in	2.540E+04	2.540E+01	2.540E–02	1.000E+03	1	8.330E–02
	ft	3.048E+05	3.048E+02	3.048E–01	1.200E+04	1.200E+01	1

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

Conversion of Torque

*		B					
		N·m	**kpm(kg·m)**	**kg·cm**	**oz·in**	**lb·in**	**lb·ft**
A	**N·m**	1	1.020E–01	1.020E+01	1.416E+02	8.850E+00	7.380E–01
	kg·m (kpm)	9.810E+00	1	1.000E+02	1.390E+03	8.680E+01	7.230E+00
	kg·cm	9.810E–02	1.000E–02	1	1.390E+01	8.680E–01	7.230E–02
	oz·in	7.060E–03	7.200E–04	7.200E–02	1	6.250E–02	5.200E–03
	lb·in	1.130E–01	1.150E–02	1.150E+00	1.600E+01	1	8.330E–02
	lb·ft	1.356E+00	1.380E–01	1.383E+01	1.920E+02	1.200E+01	1

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

Conversion of Moment of Inertia

*		B						
		kg·m²	**kg·cm·s²**	**oz·in·s²**	**lb·in·s²**	**oz·in²**	**lb·in²**	**lb·ft²**
A	**kg·m²**	1	1.020E+01	1.416E+02	8.850E+00	5.470E+04	3.420E+03	2.373E+01
	kg·cm·s²	9.800E–02	1	1.388E+01	8.680E–01	5.360E+03	3.350+02	2.320E+00
	oz·in·s²	7.060E–03	7.190E–02	1	6.250E–02	3.861E+02	2.413E+01	1.676E–01
	lb·in·s²	1.130E–01	1.152E+00	1.600E+01	1	6.180E+03	3.861E+02	2.681E+00
	oz·in²	1.830E–05	1.870E–04	2.590E–03	1.620E–04	1	6.250E–02	4.340E–04
	lb·in²	2.930E–04	2.985E–03	4.140E–02	2.590E–03	1.600E+01	1	6.940E–03
	lb·ft²	4.210E–02	4.290E–01	5.968E+00	3.730E–01	2.304E+03	1.440E+02	1

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

General Formulae & Definitions

Description:	Equations:
Gravity	gravity = 9.8 m/s² = 386 in/s²
Torque	$T = J\alpha$, $\alpha = rad/s^2$
Power (Watts)	$P(W) = T(N·m) \cdot \omega(rad/s)$
Power (Horsepower)	$P(hp) = T(lb·in) \cdot v(rpm) / 63{,}024$
Horsepower	1 hp = 746 W
Revolutions	1 rev = 1,296,000 arc·sec = 21,600 arc·min = 360 degrees

Equations for Straight-Line Velocity & Constant Acceleration

Description:	Equations:
Final velocity	$v_f = v_i + at$ final velocity = initial velocity + (acceleration · time)
Final position	$x_f = x_i + \frac{1}{2}(v_i + v_f)t$ final position = initial position + [½ · (initial velocity + final velocity) · time]
Final position	$x_f = x_i + v_i t + \frac{1}{2}at^2$ final position = initial position + (initial velocity · time) + (½ · acceleration · time squared)
Final velocity squared	$v_f^2 = v_i^2 + 2a(x_f - x_i)$ final velocity squared = initial velocity squared + [2·acceleration·(final position – initial position)]