MCA Workshop #4 – Group Activity – Selecting Motion Hardware

The aim of this exercise is to think about the process one should go through when selecting components for a motion system. Additionally, it is also useful to become familiar with the components that ESS MCAG encourages engineers to use. The questions consists of scenarios that one might encounter when designing a neutron instrument. In your groups, complete the exercise to the best of your ability. It is more about the process and the considerations that should to be taken into account rather finding exact values. A summary session will be held after the exercise to compare answers so it is suggested to document your work. Please take note of issues that arise during the discussions which should be considered when designing such systems. The work notes are given as a guide due to time constrains, if you disagree with anything then feel free to do things your own way.

Useful Equations:

Torque to overcome the load due to friction:	
$\tau_{load} = \frac{F_A \times P}{2 \times \pi \times \eta}$	$P =$ pitch of screw in m $F_A =$ axial force to slide load N $\eta =$ efficiency of ball screw
Torque required to accelerate a rotational mass:	
$\tau_{accel} = J \times \omega$	$J =$ Moment of inertia in $kg \cdot m^2$ $\omega =$ rotational acceleration in rad/s^2
Inertia of a solid cylinder (i.e. ball screw):	
$J_{cylinder} = \frac{m \times r^2}{2}$	$m =$ mass of cylinder in kg $r =$ radius of cylinder in m
Inertia of a load driven by a screw:	
$J_{load} = m \times \left(\frac{P}{2\pi}\right)^2$	$m =$ mass of cylinder in kg $P =$ pitch of screw in m
System Inertia:	
$J_{Total} = J_{motor} + J_{gearbox} + (J_{coupling} + J_{lead-screw} + J_{load})/GR^2$	$GR =$ Gear ratio

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Question 1

A linear translation stage (horizontal) with a ball screw needs to be driven by a stepper motor to carry a load of 200kg. The stage is on linear guides/bearings that have a coefficient of friction $\mu_{linear-bearing}$ = 0.025. The ball screw has pitch P of 2mm/revolution, weight of 3kg and efficiency η of 85%. The stage has a travel of 300mm and needs to cover this distance in 20 seconds. Assume the inertia of any couplings are negligible.

A) *The whole system should have an accuracy of 100 microns. Calculate the step increment using the stepper motor full step size, comment on whether the system is can achieve this and if not what changes you would make to the system design.*

B) *Select an encoder for the application, specify where to place it and calculate the measurement resolution of the system.*

C) *Calculate the total torque required for the application and select a stepper motor from the ESS Components Standard. The motor will be run with the Beckhoff EL7041-0052 stepper drive.*

Part A)

Determine the smallest full step increment that the load can theoretically make

$$Resolution_{full-step} = \frac{P_{screw}}{MotorSteps}$$

$$Resolution_{full-step} =$$

Part B)

From the ESS Standard the first choice for encoder is the ______________________ encoder which has ______ bit single turn.

$$Resolution = \frac{P}{2^{Bits}}$$

$$Resolution =$$

Part C)

Total torque

To move the load from stationary

$$\tau_{total} = \tau_{load} + \tau_{accel}$$

$$\tau_{run} = \tau_{friction} + \tau_{gravity} \quad \& \quad \tau_{accel} = J_{toral} \times \omega$$

Load torque

Calculate axial force of load on the stage

$$F_{axial} = m \times g \times \mu_{linear-bearing}$$

$$F_{axial} =$$

Calculate torque required to move axial load on the rails

$$\tau_{load} = \frac{F_A \times P_{screw}}{2 \times \pi \times \eta}$$

$$\tau_{load} =$$

Select motor/gearbox for first iteration

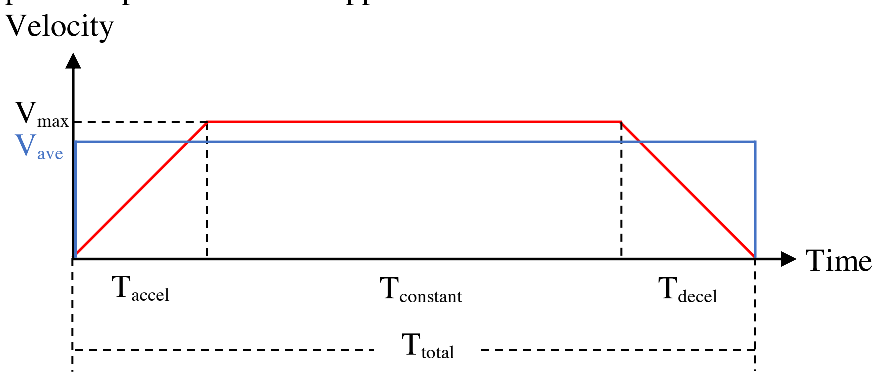
Using a margin factor of ______________ the estimate torque required would be:

$$\tau =$$

Motor/gearbox choice:

Create a motion profile

Assume a trapezoidal profile as a first approach



Choose an acceleration of 1.5 seconds to start with.

$$T_{constant} = T_{total} - 2 \times T_{accel} = 20 - 1.5 \times 2 = 17$$

The total distance traveled is the sum of the areas of the three segments.

$$Distance_{total} = D_{accel} + D_{constant} + D_{decel}$$

Insert formulas for triangle, rectangle and triangle.

$$D_{total} = \left(\frac{b \times h}{2}\right) + (b \times h) + \left(\frac{b \times h}{2}\right)$$

$$D_{total} = \left(\frac{T_{accel} \times V_{max}}{2}\right) + (T_{const} \times V_{max}) + \left(\frac{T_{decel} \times V_{max}}{2}\right)$$

Rearrange to find max velocity

$$V_{max} = \frac{D_{total}}{\left(\frac{T_{accel} + T_{decel}}{2}\right) + T_{const}}$$

$$V_{max} =$$

Convert to motor rpm to later to look at torque speed curve

$$V_{max} =$$

Using the velocity and acceleration time calculate maximum acceleration of the stage

$$A_{max} = \qquad\qquad mm/s^2$$

Convert to motor acceleration

$$\omega_{max} = \qquad\qquad rad/s^2$$

System inertia

$$J_{total} = J_{motor} + J_{gearbox} + (J_{coupling} + J_{lead-screw} + J_{load})/GR^2$$

Using the proposed motor. Note: the moment of inertia of the motor is chosen as estimation and can be changed on a second iteration.

$$J_{motor} =$$

Inertia of screw (solid cylinder)

$$J_{lead-screw} = \frac{m \cdot r^2}{2} =$$

Inertia of screw-driven load (screw's lead must be taken into account)

$$J_{load} = m \cdot \left(\frac{P_{screw}}{2\pi}\right)^2 =$$

Total system inertia

$$J_{total} =$$

Accelerating Torque

Calculate the torque required to accelerate the system:

$$\tau_{accel} = J_{Toral} \times \omega_{Max}$$

$$\tau_{accel} =$$

Total Torque

Calculate the torque by adding load torque and acceleration torque

$$\tau_{total} = \tau_{load} + \tau_{accel}$$

$$\tau_{total} =$$

Multiplying by a margin factor of ______

$$\therefore \tau_{required} =$$

Is the motor from the first iteration adequate? If not what do you change?

Question 2

Use the same parameters from the previous question, this time perform the design for vertical stage carrying a detector in a vacuum tank. However for this application the time needed to travel the distance has been relaxed to 4 minutes and the weight is increased to 250kg..

A) The whole system should have an accuracy of 25 microns. Calculate the step increment using the stepper motor full step size, comment on whether the system is can achieve this and if not what changes you would implement.

B) Select an encoder for the application, specify where to place it and calculate the measurement resolution of the system.

C) Calculate the total torque required to accelerate the load vertically and select a stepper motor/gearbox from the ESS Components Standard. The motor will be run with the Beckhoff EL7041-0052 stepper drive.

D) Is anything required to prevent the system back driving?

Part A)

Determine the smallest full step increment that the load can make

$$Resolution_{full-step} = \frac{P_{screw}}{MotorSteps}$$

$$Resolution_{full-step} =$$

The smallest full-step that the driving system should be able to make is ___________.
Therefore add a gearbox with ________ ratio.

$$New\_Resolution_{full-step} =$$

Part B)

Looking at the ESS Standard the first choice for encoder is the ____________________ encoder which has _____ bit single turn.

$$Resolution = \cdot$$

Part C)

Total torque

To move the load from stationary

$$\tau_{total} = \tau_{load} + \tau_{accel}$$

$$\tau_{load} = \tau_{friction} + \tau_{gravity} \quad \& \quad \tau_{accel} = J_{toral} \times \omega$$

Load torque

Calculate axial force of load using a gearbox with ratio ___________ for first iteration

$$F_{axial} = m \times g$$

$$F_{axial} =$$

Calculate torque required to move axial load on the rails

$$\tau_{load} = \frac{F_A \times P_{screw}}{2 \times \pi \times \eta \times GR}$$

$$\tau_{load} =$$

Select motor/gearbox for first iteration

Using a margin factor of ______________ the estimate torque required would be:

$$\tau =$$

Motor/gearbox choice:

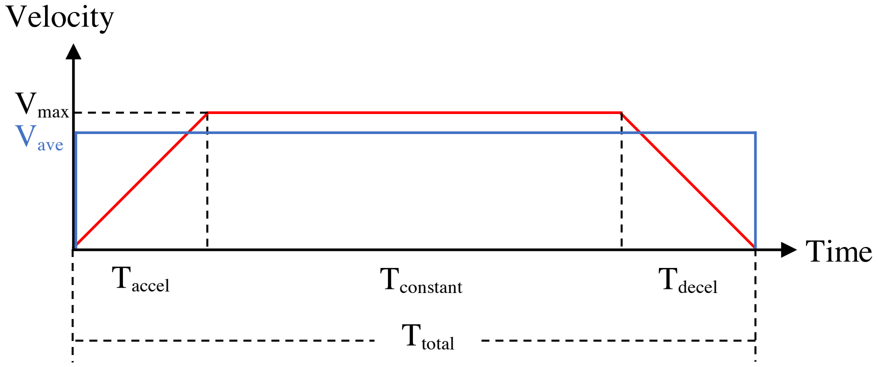
Recalculate torque required using selected gearbox

$$\tau_{load} = \frac{F_A \times P_{screw}}{2 \times \pi \times \eta \times GR}$$

$$\tau_{load} =$$

Create a motion profile

Assume a trapezoidal profile as a first approach



Choose an acceleration of 1.5 seconds to start with.

$$T_{constant} = T_{total} - 2 \times T_{accel} = 240 - 1.5 \times 2 = 237$$

The total distance traveled is the sum of the areas of the three segments.

$$Distance_{total} = D_{accel} + D_{constant} + D_{decel}$$

Insert formulas for triangle, rectangle and triangle.

$$D_{total} = \left(\frac{b \times h}{2}\right) + (b \times h) + \left(\frac{b \times h}{2}\right)$$

$$D_{total} = \left(\frac{T_{accel} \times V_{max}}{2}\right) + (T_{const} \times V_{max}) + \left(\frac{T_{decel} \times V_{max}}{2}\right)$$

Rearrange to find max velocity

$$V_{max} = \frac{D_{total}}{\left(\frac{T_{accel} + T_{decel}}{2}\right) + T_{const}}$$

$$V_{max} =$$

Convert to motor rpm to look at torque speed curve (required later)

$$V_{max} =$$

Use the velocity and acceleration time calculate the max acceleration of the stage (mm/s^2)

$$A_{max} =$$

Convert to motor acceleration (rad/s^2)

$$\omega_{max} =$$

System inertia

$$J_{total} = J_{motor} + J_{gearbox} + \left(J_{coupling} + J_{lead-screw} + J_{load}\right)/GR^2$$

Using the proposed motor. Note: the moment of inertia of the motor is chosen as estimation and can be changed on a second iteration.

$$J_{motor} =$$

Using the proposed gearbox

$$J_{gearbox} =$$

Inertia of screw (solid cylinder)

$$J_{lead-screw} = \frac{m \cdot r^2}{2} =$$

Inertia of screw-driven load (screw's lead must be taken into account)

$$J_{load} = m \cdot \left(\frac{P_{screw}}{2\pi}\right)^2 =$$

Total system inertia

$J_{total} =$

Accelerating Torque

Calculate the torque required to accelerate the system:

$$\tau_{accel} = J_{Toral} \times \omega_{Max}$$

$$\tau_{accel} =$$

Total Torque

Calculate the required torque by adding load torque and acceleration torque

$$\tau_{total} = \tau_{load} + \tau_{accel}$$

$$\tau_{total} =$$

Multiplying by a margin factor of _____

$$\therefore \tau_{required} =$$

Earlier the ______________ was chosen as a first iteration with a _________ Nm at_________ rpm so this should be sufficient.

Part D)

Back driving

$$\tau_{backdrive} = \frac{F_A \times P_{screw} \times \eta_{screw} \times \eta_{gearbox}}{2 \times \pi \times GR}$$

$$\tau_{backdrive} =$$

The _______________ motor has a detent torque of ___________Nm. Is this adequate to prevent back driving?