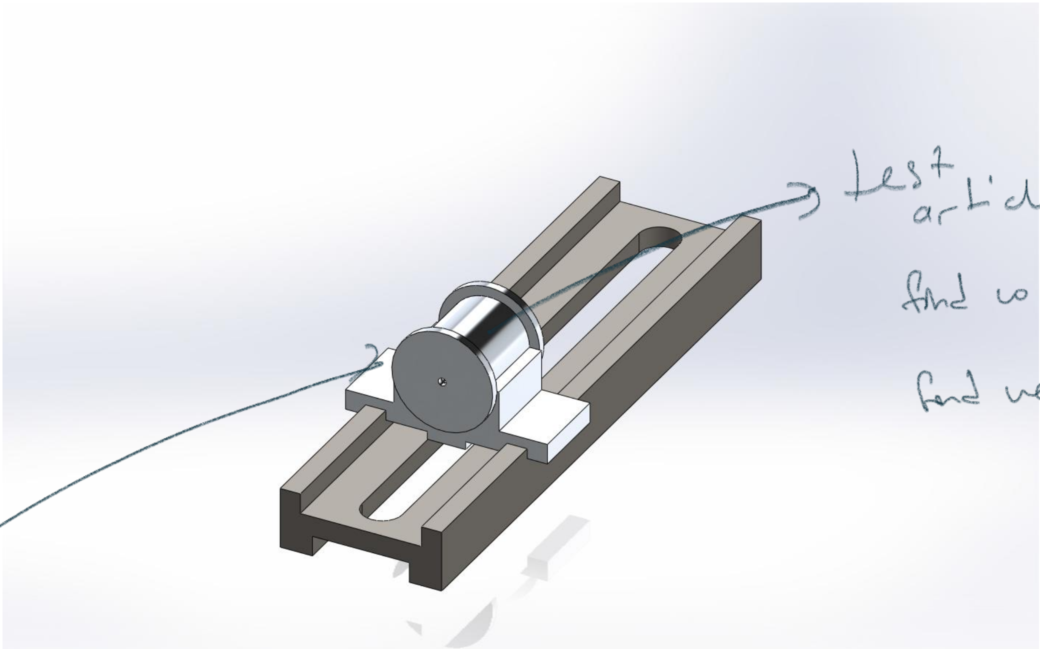
mhbylg21

Faculty of Physical and Applied Sciences

Electronics and Computer Science

Power Electronics and Drives 2022/23: Assignment

You have received an inquiry from one of your major customers to supply the drive system for an aerospace test system, shown in Figure 1, the purpose of which is to subject the test article to rapid continual motion including acceleration and decelerations. The dimension for the test rig and test article are provided on separate engineering drawing provided. The purpose of this request is to size the system and select suitable components for a ballscrew based drive system for the application. ?
Due to the application domain a linear motor or belt drive cannot be used.



Test article.
find volume!
find weight!

Figure 1: The proposed test system, excluding the motor drive system and associated sensors.

NOTE:
(i) A number of application specific requirements are individually defined and provided on a separate sheet.
(ii) All dimensions on the drawings are in millimetres.

lightest

- The test article is filled with one of three liquids, methyl alcohol ((ρ =785 kgm^{-3}), pure water (ρ = 1000 kgm^{-3}) , or 1,2,4-Trichlorobenzene (ρ = 1454kgm^{-3}).

- The system's maximum speed is such that the load can move a predefined distance in a predefined time, the motion profile being a cubic polynomial, as defined on the spreadsheet.

distance = 800mm = 80cm = 0.8m
x^3

- After completion of a move, the drive reverses. The motion profiles being identical - this motion continues for a considerable period of time.

time = 4s.

- No gear box is to be used. ?

- The carriage structure is manufactured from aluminium (ρ = 2700 kgm^{-3}) and the test article from nylon, (ρ = 1140 kgm^{-3}).

- The friction coefficient (μ) between the carriage and the slideway will not exceed 0.1, due to the provision of a lubrication system.

- A linear positional measurement is required. The required resolution is 10^{-5}m. 0.00001 m

- While the system will be used in a laboratory environment, you are not required to consider any environmental requirements.

The ball screw is manufactured from steel (ρ = 7850 kgm^{-3}) and has a radius of 15mm, length of 1.6m and efficiency of 85%. You can assume that the nut and the associated hardware to connect the nut to the carriage has a total mass of 0.5kg.

The motor to be used is to be selected from the following:

(5)

Type	Continuous torque (Nm)	Peak torque (Nm)	Maximum Speed (rpm)	Inertia (kgm^2)
AKM11B	0.18 3	0.61 3	4000 2	0.0000017
AKM11C	0.19 2	0.62 2	6000 1	0.0000017
AKM21C	0.48 1	1.48 1	2500 3	0.00001078

no. 1 lightest, need speed as I need to cover 80 cm in 4s

You are required to provide the following:

- The completed design summary sheet.

- Detailed design calculations for your selected approach, in your calculations clearly identify any assumptions, and omissions that have been made in your analysis.

- Select suitable components from the supplied list.

- A high quality sketch of the final system. On your drawing identify the key electrical and mechanical components and a suitable location of the limit and datum switches. The drawing can be either drawn by hand or using a drawing/CAD/sketching package. The majority of the marks will come from clarity and annotation. There are no space limitations, below the sideway, in addition no part of the drive system can extend beyond the face marked on the diagram.

You should submit your material on Blackboard in the assignment tab in the usual manner, with a **deadline of 17:00, 27 April 2022**.

Marking Scheme:

Your attention is drawn to the University's Academic Integrity Regulations, and the penalties that can be imposed. The assignment is worth 15% of the module and will be assessed as follows:

- Sizing the application. 70 Marks
- Indicative detailed diagram and components, including provision of limit and datum switches. 30 Marks

University of Southampton
School of Electronics and Computer Science
Application of Modern Drive Systems - 2022/23

Assignment Summary Sheet

You are required to complete this summary sheet and include it as part of your submission, **the answers are required in the units shown**.

Name: MUHAMMAD HAZIMI BIN YUSRI

Student ID: 32548419

① MOTION PROFILE ✓

Distance moved by load (given): 800 mm

Time per move (given): 4 s

Peak load speed (calculated): 0.225 ms^{-1}

Peak load acceleration (calculated.): ± 0.3 ms^{-2}

② LOAD

Total load mass: carriage, nut and filled test article ✓ ①

34.163 kg

③ FRICTION FORCES

Friction (at most): 3.3514 N

③ ~~$F_R = \mu F_w = \mu mg = (0.1)(34.163)(9.81)$~~ ✓ =

~~assume frictionless in ballscrew.~~

④ BALL SCREW

Ball screw inertia excluding nut: 9.9879×10^{-4} kgm^2

Peak rotational speed: 1350 Rpm

Peak rotational acceleration: 60π rad s^{-2}

Reflected inertia of the load: 8.6536×10^{-5} kgm^2

Total system inertia: 1.0853×10^{-3} kgm^2

Peak acceleration torque required into ball screw

6.2752×10^{-3} Nm

✓

Motor Selection

this motor is chosen as I don't need high torque (low weight liquid) but need high speed (800mm in 4s) thus high RPM.

Motor part number

AKM11C

Motor peak torque

0.62 Nm

Continuous torque rating

0.19 Nm

Motor inertia

0.0000017 kgm^2

Peak Motor Speed

6000 Rpm

5

Verification

Total SYSTEM Inertia

1.087×10^{-3} kgm^2

Required Peak Torque

2.1023×10^{-1} Nm

✓ passed as 0.62 >> 0.21023.

R.M.S Torque Required

0.1051 Nm

✓ passed as 0.19 > 0.1051

Is motor Usable

Yes/No

Yes.

Student Name		ID/email	T (sec)	Distance (mm)	Liquid	Lead(mm)
Sandaru	Algoda Gamaethiralalage	sdag1n21@soton.ac.uk	6	800	Water	25
Don	Amarasekara	ddha1c20@soton.ac.uk	8	750	Methyl alcohol	10
Aimilios	Angelopoulos	aa3u21@soton.ac.uk	6	500	Trichlorobenzene	15
Laura-Jane	Apthorp	lja2g21@soton.ac.uk	8	600	Water	20
Robert	Aries	raa1g21@soton.ac.uk	9	450	Water	25
Samarth	Basavapatna	ssb1g21@soton.ac.uk	9	800	Methyl alcohol	25
Lisa	Bidgood	lb11g21@soton.ac.uk	5	750	Trichlorobenzene	10
Luca	Bowe	lwrb1g21@soton.ac.uk	4	500	Water	15
Kaya	Boyacioglu	mkb1g21@soton.ac.uk	4	600	Water	20
Cecil-Maurice	Browne	cmb1g20@soton.ac.uk	5	450	Methyl alcohol	25
Huw	Burgin	hb3g21@soton.ac.uk	8	800	Trichlorobenzene	25
Hongjun	Cai	hc1g21@soton.ac.uk	6	750	Water	10
Chun	Cho	cc10g21@soton.ac.uk	8	500	Water	15
Ching	Chu	chic1g21@soton.ac.uk	9	600	Methyl alcohol	20
Patrick	Clout	pc1g21@soton.ac.uk	4	450	Trichlorobenzene	25
Maxwell	Cox	mjc1g21@soton.ac.uk	5	800	Water	25
Oliver	Enrico	ojme1n21@soton.ac.uk	4	750	Trichlorobenzene	10
Rekem	Ereku	rtge1g21@soton.ac.uk	4	500	Water	15
Emile	Farman	ef6g21@soton.ac.uk	5	600	Methyl alcohol	20
Callum	Fereday	cf3n20@soton.ac.uk	8	450	Trichlorobenzene	25
Klevis	Filaj	kf6g21@soton.ac.uk	6	800	Water	10
Oliver	Freeman	of3g21@soton.ac.uk	8	800	Trichlorobenzene	10
Athena	Geremia	alg1g20@soton.ac.uk	9	750	Water	15
Giulio	Girelli	gg6n21@soton.ac.uk	4	500	Methyl alcohol	20
Sameen	Goonatilake	skg1g21@soton.ac.uk	5	600	Trichlorobenzene	25
John	Harrold	jh10g21@soton.ac.uk	4	450	Water	25
Zhaoyan	He	zh2a21@soton.ac.uk	8	800	Trichlorobenzene	10
Sippaphas	Hirunyanitiwatna	sh2g21@soton.ac.uk	5	450	Water	15
Osman	Hoshgor	oyh1g21@soton.ac.uk	8	750	Methyl alcohol	20
Yiyang	Hu	yh10u21@soton.ac.uk	6	500	Trichlorobenzene	25
Sicheng	Hua	sh2y21@soton.ac.uk	8	600	Water	25
Kharrum	Hudson	kh5g21@soton.ac.uk	9	450	Trichlorobenzene	10
William	Jameson	wj3g21@soton.ac.uk	8	800	Water	15
Samuel	Jasper	sj3g21@soton.ac.uk	5	800	Methyl alcohol	20
Abi	Johnson-Brett	aljb1g21@soton.ac.uk	4	750	Trichlorobenzene	25
Islombek	Karamatov	ik5g21@soton.ac.uk	8	800	Water	25
Isa	Khalil	mik1u21@soton.ac.uk	9	750	Methyl alcohol	10
Ibrahim	Khan	ik4g21@soton.ac.uk	9	500	Trichlorobenzene	15
Jawadur	Khan	jrk1e21@soton.ac.uk	5	600	Water	25
Henry	Knox-Johnston	hkj1g21@soton.ac.uk	4	450	Water	25
Stepan	Kononko	sk3g21@soton.ac.uk	4	800	Methyl alcohol	25
Mohamed	Lafi	mal1g21@soton.ac.uk	5	750	Trichlorobenzene	10
Reuben	Leanage	rl2g21@soton.ac.uk	8	500	Water	15
Aoyang	Leng	al7g20@soton.ac.uk	6	600	Water	20

Riley	Lewis	ol1u20@soton.ac.uk	8	450	Methyl alcohol	25
Cameron	Light	cl5g21@soton.ac.uk	9	800	Trichlorobenzene	25
Yihao	Liu	yl14m20@soton.ac.uk	4	750	Water	10
Chang-Yu	Liu	cyl1g21@soton.ac.uk	5	500	Water	15
Tsz	Lo	tykl1g21@soton.ac.uk	4	600	Methyl alcohol	20
William	Ly	wl3g21@soton.ac.uk	4	450	Trichlorobenzene	25
Achala	Makalanda	aum1g20@soton.ac.uk	5	800	Water	25
Jakub	Markiewicz	jm18g20@soton.ac.uk	8	750	Trichlorobenzene	10
Mathyus	Marshall-Panayiotou	mmp1u19@soton.ac.uk	6	500	Water	15
Isabella	Martin	im1n21@soton.ac.uk	8	600	Methyl alcohol	20
Chandler	Mauger	cmm2g21@soton.ac.uk	9	450	Trichlorobenzene	25
Umit	Mida	udm1g21@soton.ac.uk	4	800	Water	25
Luca	Milazzo	lm11g20@soton.ac.uk	5	800	Trichlorobenzene	10
Afiah	Mohd Sukeri	nams1g21@soton.ac.uk	4	750	Water	15
Al	Omair	ado1g20@soton.ac.uk	8	500	Methyl alcohol	20
Meng	Ong	mljo1d22@soton.ac.uk	5	600	Trichlorobenzene	25
Sittadon	Panpayom	sp4g21@soton.ac.uk	5	800	Water	25
Dilan	Parjiea	dp1g21@soton.ac.uk	4	750	Methyl alcohol	25
Nyal	Patel	nrp1g21@soton.ac.uk	8	500	Trichlorobenzene	10
Joseph	Pater	jp7g21@soton.ac.uk	9	600	Water	15
Cameron	Philip	cmp2g20@soton.ac.uk	9	450	Methyl alcohol	20
Xiuping	Qi	xq3g21@soton.ac.uk	5	800	Trichlorobenzene	25
Humzah	Rathur	hr7g21@soton.ac.uk	4	750	Water	25
Quinn	Rice	qr1g21@soton.ac.uk	4	500	Water	10
Peter	Richards	prr1g21@soton.ac.uk	5	600	Methyl alcohol	15
Seb	Rigg	sr10g21@soton.ac.uk	8	450	Trichlorobenzene	20
Nikita	Rolls	nr3g21@soton.ac.uk	6	500	Water	25
Zhangqian	Rui	zr1g21@soton.ac.uk	8	600	Water	25
Yai	Sagolsem	ys6g21@soton.ac.uk	9	450	Methyl alcohol	10
Bartosz	Sarwa	bs7g21@soton.ac.uk	5	600	Trichlorobenzene	25
Shakeerthan	Sayanthan	ss21g21@soton.ac.uk	9	450	Water	25
Thomas	Short	tsas1g21@soton.ac.uk	4	800	Methyl alcohol	10
Andrei	Sontea	as1g21@soton.ac.uk	5	750	Trichlorobenzene	15
Tobey	Spriggs	ts6g20@soton.ac.uk	4	500	Water	20
Shantam	Sridev	ss28g21@soton.ac.uk	4	600	Water	25
Efstratios	Stamatopoulos	es5g21@soton.ac.uk	5	450	Methyl alcohol	25
Lily	Stollery	lks1g21@soton.ac.uk	8	800	Trichlorobenzene	10
Joen	Suero Thomas	jast1g20@soton.ac.uk	6	800	Water	15
Eszter	Szabo	ers1u21@soton.ac.uk	8	750	Water	20
Jun	Tan	jt10g21@soton.ac.uk	9	500	Methyl alcohol	25
Wai	Tang	wwt1u21@soton.ac.uk	4	600	Trichlorobenzene	25
Shehroz	Tariq	st1e20@soton.ac.uk	5	800	Water	10
Ahpiraam	Thussanthan	at18g21@soton.ac.uk	4	750	Water	15
Jade	Vaux	jv1g21@soton.ac.uk	8	500	Trichlorobenzene	20
Denel	Virendrakumar	dv2g21@soton.ac.uk	5	600	Water	25
Gagan	Vithanala	gv4g21@soton.ac.uk	8	450	Methyl alcohol	25
Gia	Vu	gnv1g21@soton.ac.uk	6	800	Trichlorobenzene	10
Xucheng	Wang	xw6n20@soton.ac.uk	8	750	Water	15

Pei	Wang	pfw1g21@soton.ac.uk	9	500	Water	20
Jerry	Wang	zw14g21@soton.ac.uk	8	450	Methyl alcohol	25
Yat	Wong	yw15g21@soton.ac.uk	5	800	Trichlorobenzene	10
Yufei	Xi	yx3g21@soton.ac.uk	4	750	Water	10
Siqi	Xu	sx5n21@soton.ac.uk	8	500	Water	15
Sasank	Yadavalli	hsy1g21@soton.ac.uk	9	600	Methyl alcohol	20
Jiakun	Yang	jy2u20@soton.ac.uk	9	450	Trichlorobenzene	25
Xiaoqing	Yang	xy5g21@soton.ac.uk	5	800	Water	25
Muhammad	Yusri	mhby1g21@soton.ac.uk	4	800	Methyl alcohol	10
Syazwan	Zulkepli	ssdz1g21@soton.ac.uk	4	750	Trichlorobenzene	15

(1) MOTION PROFILE . Check slides for clues:
↳ Chapter 1 summary.pdf.

(pg 10, 11)

From 1.4.4, contour path of cubic polynomial:

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

$\theta(0) = \theta_1$ and $\dot{\theta}(0) = 0$

$\theta(t_f) = \theta_2$ $\dot{\theta}(t_f) = 0$

where t_f is time required to complete path from θ_1 to θ_2.

∴ differentiate: $\dot{\theta}(t) = a_1 + 2a_2 t + 3a_3 t^2$

$\ddot{\theta}(t) = 2a_2 + 6a_3 t$

∴ solve 4 simultaneous eq:

$a_0 = \theta_1$, $a_2 = \frac{3}{t_f^2}(\theta_2 - \theta_1)$

$a_1 = 0$, $a_3 = \frac{2}{t_f^3}(\theta_2 - \theta_1)$

∴ position: $\theta(t) = \theta_1 + \frac{3}{t_f^2}(\theta_2 - \theta_1)t^2 - \frac{2}{t_f^3}(\theta_2 - \theta_1)t^2$

∴ speed: $\dot{\theta}(t) = \frac{6}{t_f^2}(\theta_2 - \theta_1)t - \frac{6}{t_f^3}(\theta_2 - \theta_1)t^2$

∴ acceleration: $\ddot{\theta}(t) = \frac{6}{t_f^2}(\theta_2 - \theta_1) - \frac{12}{t_f^3}(\theta_2 - \theta_1)t$

Assuming $\theta_2 - \theta_1$ is relative, $\theta_2 = 800mm = 0.8m$, $\theta_1 = 0$.

and $t_f = 4s$ as given.

$\therefore$ to find max speed: $\frac{dv}{dt} = 0$, $\ddot{\theta}(t) = \frac{6}{(4)^2}(0.8) - \frac{12}{(4)^3}(0.8)t$

$\therefore \ddot{\theta}(t) = \frac{3}{10} - \frac{3}{20}t = 0$. $\therefore \frac{3}{20}t = \frac{3}{10}$, $t = 2s$.

$\therefore V_{max} = \dot{\theta}(2)$, $\therefore \dot{\theta}(t) = \frac{6}{(4)^2}(0.8)t - \frac{6}{(4)^3}(0.8)t^2$

$$\dot{\theta}(t) = \frac{3t}{10} - \frac{3t^2}{40}$$

$$\therefore \dot{\theta}(3) = \frac{3(3)}{10} - \frac{3(3)^2}{40} = \frac{9}{40} = 0.225 \ ms^{-1}$$

$a_{max} = \ddot{\theta}(0) = -\ddot{\theta}(t_f)$ $\therefore$ $\ddot{\theta}(0) = \frac{3}{10} - \frac{3}{20}(0) = \frac{3}{10} = 0.3 ms^{-2}$

$$\ddot{\theta}(4) = \frac{3}{10} - \frac{3}{20}(4) = -\frac{3}{10} = -0.3 ms^{-2}$$

load

(2) Total Load = Carriage + Article + Nut system + Liquid

assumed 0.5 kg

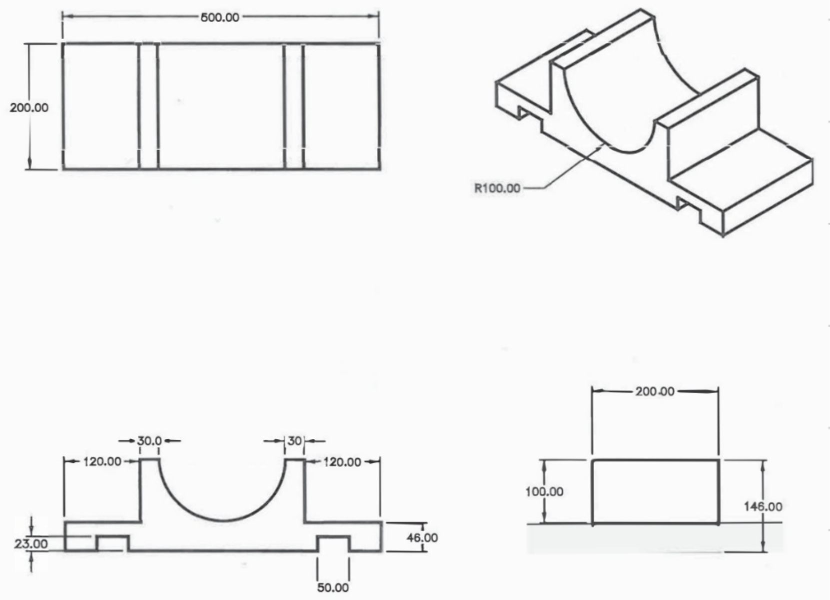
$\rho_{carriage} = 2700 \ kgm^{-3}$ (steel)

$\rho_{article} = 1140 \ kgm^{-3}$ (nylon)

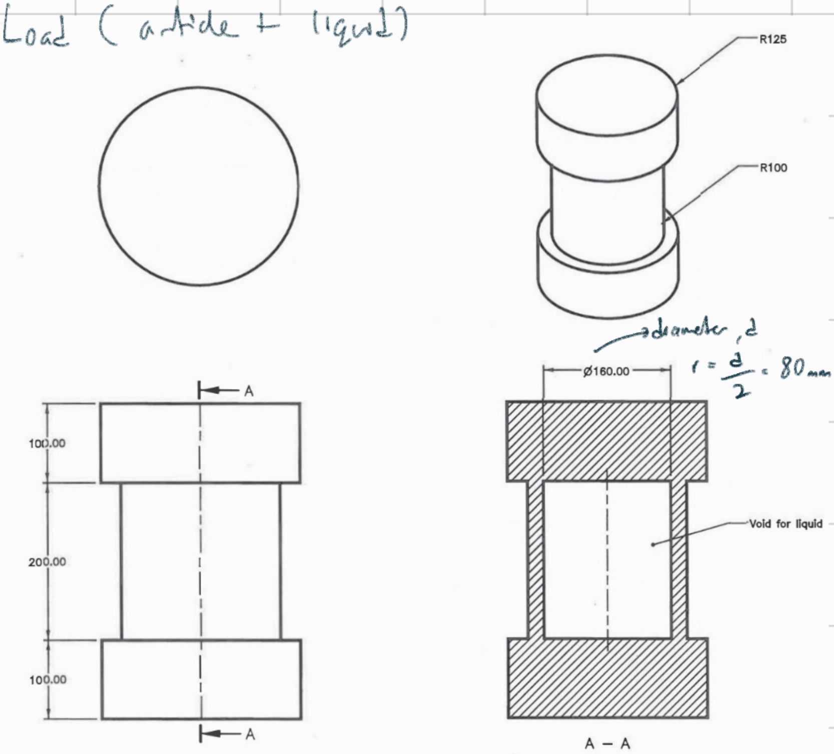
$\rho_{liquid} = 785 \ kgm^{-3}$ (methyl alcohol)

$\rho = \frac{m}{V}$, $m = \rho V$

Carriage



Load (article + liquid)



diameter, d

$r = \frac{d}{2} = 80\,mm$

$V_{carriage} = V_{cuboid} - V_{displacement}$

$V_{displacement} = 2V_{cuboid\ large} + 2V_{cuboid\ small} + \frac{1}{2}V_{cylinder}$

$= 2(200 \times 120 \times 100) + 2(200 \times 50 \times 23) + \frac{1}{2}(\pi \times 100^2 \times 200)$

$= 8.4016 \times 10^6\ mm^3$

$V_{cuboid} = 200 \times 500 \times 146$

$= 1.46 \times 10^7\ mm^3$

$V_{carriage} = 1.46 \times 10^7 - 8.4016 \times 10^6$

$= 6.1984 \times 10^6\ mm^3$

$= 6.1984 \times 10^{-3}\ m^3$

$M_{carriage} = \rho_{carriage} V_{carriage}$

$= (2700)(6.1984 \times 10^{-3}) = 16.7357\,kg$

$V_{liquid} = \pi(80^2)(200) = 4.0212 \times 10^6\ mm^3$

$= 4.0212 \times 10^{-3}\ m^3$

$M_{liquid} = \rho_{liquid} V_{liquid}$

$= (785)(4.0212 \times 10^{-3})$

$= 3.1567\ kg$

$V_{article} = 2V_{cylinder\ top\ bot} + V_{cylinder\ middle} - V_{liquid} = 2[\pi(125^2)(100)] + \pi(100^2)(200) - V_{liquid}$

$= 9.8175 \times 10^6 + 6.2832 \times 10^6 - 4.0212 \times 10^6$

$= 1.2079 \times 10^7\ mm^3 = 1.2079 \times 10^{-2}\ m^3$

$\therefore M_{particle} = \rho_{particle} V_{particle}$

$= (1140)(1.2079 \times 10^{-2}) = 13.7706$ kg

$\therefore$ Total load $= 16.7357 + 13.7706 + 0.5 + 3.1567 = 34.163$ kg

(3) Friction force

lead = 10mm

also it may were been accounted in efficiency of ball screw.

W

no need to consider friction as most weight is rested on slideway. (assumed and friction of ball bearing is not given.

$\therefore W = mg\cancel{\cos\theta} = 34.163 \times 9.81 = 33.5139$ N   (1 as $\theta = 0°$)

$F_{friction\ max.} = \mu W = (0.1)(33.5139) = 3.3514$ N at most (max)

(4) Ball Screw.

Ball screw inertia excluding nut, $J_{screw} = \dfrac{m_{screw} r^2}{2}$ ← from pg16 and also because it is cylinder about zz axis.

$m_{screw} = \rho_{screw} V_{screw}$ ~~+0.5kg~~ (~~associated hardwares~~), $\rho_{screw} = 7850$ kgm^{-3} (steel)

$r = 15$mm $= 0.015$m, $l = 1.6$m, $e = 85\% = 0.85$

assume screw is cylinder shape, $V_{screw} = \pi r^2 h$

$= \pi(0.015^2)(1.6)$

$= 1.1310 \times 10^{-3}$ m^3

$m_{screw} = (7850)(1.1310 \times 10^{-3})$ ~~+0.5~~

$= 8.8781$ ~~+0.5 = 9.3781 kg~~

$= 8.8781$ kg (excluding nut)

1. $J_{screw} = \frac{(8.8781)(0.015^2)}{2} = 9.9879 \times 10^{-4}$ kgm^2

max linear speed $= 0.225 ms^{-1}$

Peak rotational speed, $N = \frac{V_{linear}}{L} = \frac{0.225}{0.010} = \frac{45}{2} = 22.5$ rps

$60_s \times N = 1350$ RPM.

max $= 0.3 ms^{-2}$

peak rotational acceleration, $\dot{N} = \frac{a_{linear}}{L} = \frac{0.3}{0.01} = 30$ rps^2

convert to rad s^{-2}, $\dot{N} \times 2\pi = 60\pi$ rad $s^{-2} = 188.4956$ rad s^{-2}

reflected inertia of load, $J_{load} = M_{load}\left(\frac{L}{2\pi}\right)^2 = (34.163)\left(\frac{0.01}{2\pi}\right)^2$

$= 8.6536 \times 10^{-5}$ $kg\,m^2$

Total System inertia, $J_{TOTAL} = J_{screw} + J_{load}$

$= 9.9879 \times 10^{-4} + 8.6536 \times 10^{-5}$

$= 1.08533 \times 10^{-3}$ $kg\,m^2$

Torque required into ball screw, $T_{load} = \frac{L F_{load}}{2\pi} = \frac{(0.01)(3.3514)}{2\pi}$

$F_{load} = F_{friction}$

$= 5.3339 \times 10^{-3}$ Nm

$T_{eff} = \frac{T_{load}}{e} = \frac{5.3339 \times 10^{-3}}{0.85}$

$T_{effective} = 6.2752 \times 10^{-3}$ Nm

#

(5) Verification

Total system inertia, $J_{TOTAL} = J_{screw} + J_{load} + J_{motor}$

$$= 9.9879 \times 10^{-4} + 8.6536 \times 10^{-5} + 1.7 \times 10^{-6}$$

$$= 1.087 \times 10^{-3} \ kgm^{-2}$$

Peak torque required, T_m :

$$T_m - T_L = J \frac{dw}{dt}$$, theres no damping constant, β

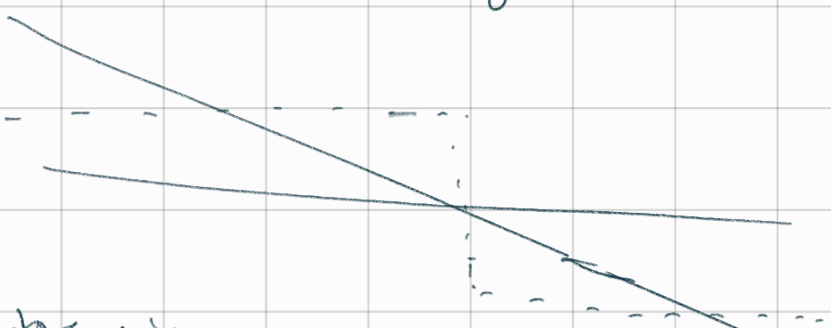
$\therefore T_m = J \frac{dw}{dt} + T_L$, $J = 1.087 \times 10^{-3} \ kgm^2$, $\frac{dW}{dt} = 188.4956 \ rad \, s^{-2}$

$T_L = 5.33339 \times 10^{-3}$

$T_m = 2.1023 \times 10^{-1}$ Nm.

R.M.S. Torque Required:

as the acceleration graph is:



RMS torque is $\frac{1}{2}$ peak torque. $= \frac{1}{2}(0.21023) = 0.1051$

PPR needed for optical encoder, $PPR = \frac{L}{S_{resolution}} = \frac{0.001}{0.00001} = 100$ ppr

(i chose)

encoder itself is capable of 1000 ppr (E6B2-CW26C 1000P/R 2M)

So more than enough