Motor Design

Documentation

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Contents

Part I.
General

Overview of to parameters to take into account

- Moving mass
- Maximum rotational speed
  - of motor
  - regarding electrical frequency of output stage
  - of spindle or belt if present
- Maximum acceleration
- Mechanical losses
  - Static friction
  - Viscous friction
  - Efficiency (Spindel, Belt, ...)
- Required Accuracy

General method

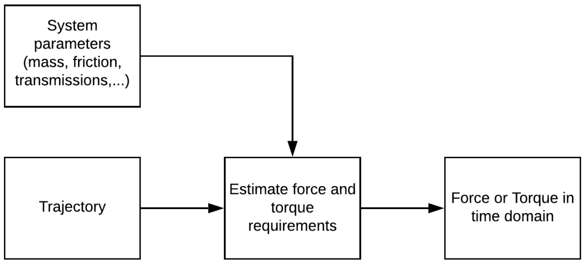
1. Estimate system parameters from section I
2. Calculate required torque for desired trajectory
3. Compare required torque over speed against the manufacturers reference curve

List of occured issues

Efficiency of indirect linear spindel axis	For fully assembled indirect-linear-spindle-drives from Nanotec a force over speed curve is provided. The spindle efficiency is already taken into account in the force-speed curve.
Max rotational Speed of Stepper Motors	Stepper motors are usually not built for high speed applications. Therefore it is understandable that the torque-reference-curve is only correct for rotational speeds up to 700rpm. Above that speed, the from Nanotec given torques are usullay not achieved.

Part II.
Estimate Force and Torque Requirements

Goal of this chapter is to estimate a sufficient enough force/torque requirement due to a given trajectory of the axis.



1. d'Alembert's principle (taking masses into account)

$$F = ma$$
$$M = J\alpha$$

2. Static and viscous friction

Friction source can be focussed onto the linear guidance. Friction resulting from rotational bearing can be neglected due to very low impact of rough estimation calculation. Thus, only friction of linear guidance with ball guiding is considered and estimated. The amount of static friction is proportinal to the size and number of guide carriages. A distinction into two different sizes of guide carriages is made.

Figure 1: Linear guidance with ball guiding

Friction estimation values

Guidance width	**Static friction estimation per guide carriage**	**Viscous friction estimation per guide carriage**
< 12mm	5 N	15 $\frac{N}{m/s}$
> 12mm	10 N	30 $\frac{N}{m/s}$

Important: This estimated friction force is only for ONE guide carriage. Multiply it with the number of carriages you have on your axis.

2.1. Examples and measurments of designed axis

2.1.1. Overview

Axis name	drive type	Number and width of linear guides	Number of guide carriages	Static linear friction in N	Viscous linear friction in N
Tape Feeder Camera X	indirect spindle and belt axis	2x12mm	4	35	120
Component Shuttle X	ironless linear motor	1x15mm	2	7.5	15.8

Tape Feeder Camera X (TC-Next)

The spindle efficiency is 99% and can therefore be neglected for this ball screw (lead angle is 24.3°). Otherwise the measured force would not all be caused by friction of the linear guides but also from the spindle efficiency itself.

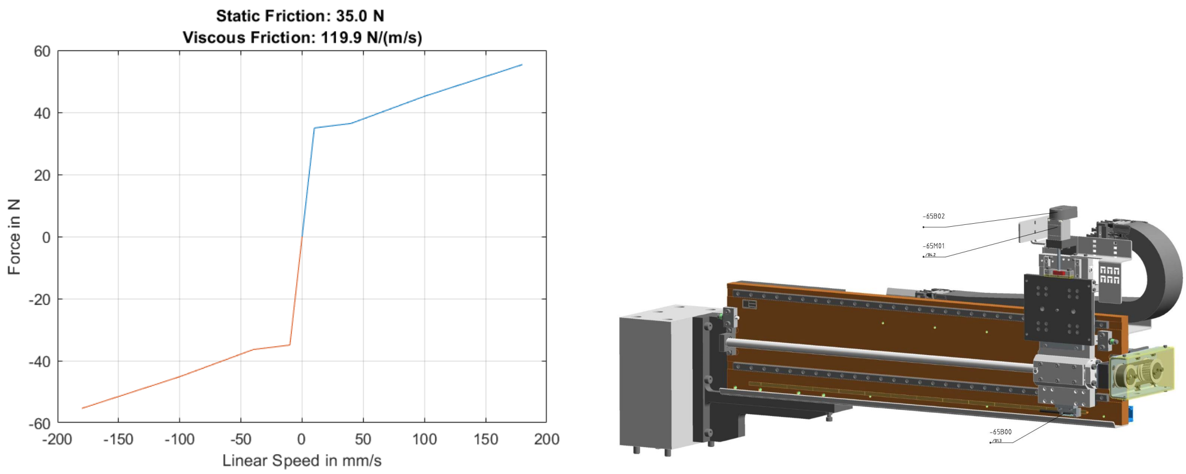


Figure 2: Friction plot and image of tape feeder camera axis X

Component Shuttle X (TC-Next)

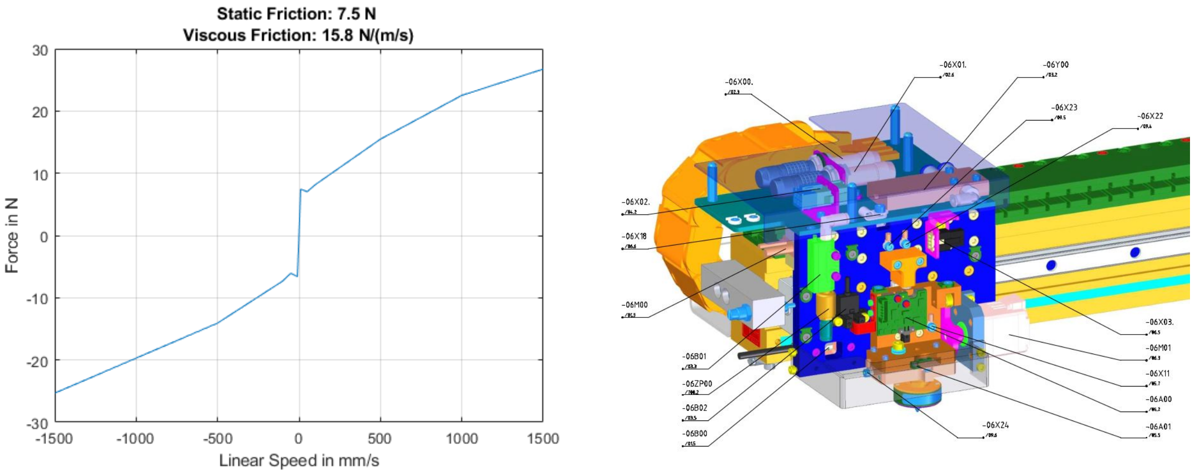
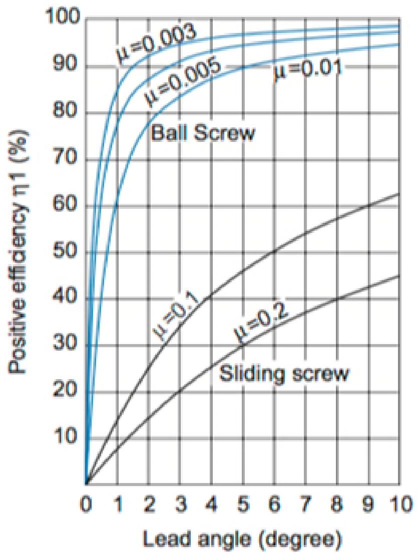


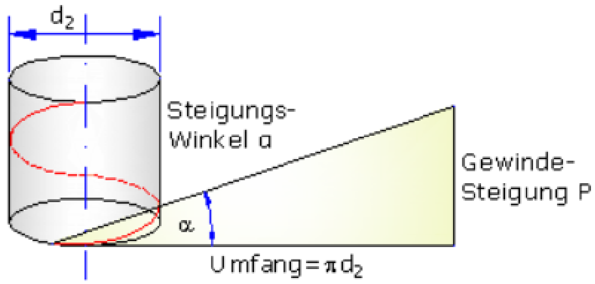
Figure 3: Friction plot and image of tape component shuttle axis X

3. Spindle

3.1. Efficiency

Basically we differentiate between Ball Screw (ger.: Kugelumlaufspindel) and Sliding-screw (ger.: Gleitspindel). The efficiency is determinded by the lead angle of the spindle.





Calculation of spindle lead angle

Lead angle is calculate by the spindle pitch and the circumference

$$\beta = \arctan\left(\frac{S}{D\pi}\right)$$

β ... Lead Angle
S ... Spindle pitch
D ... Spindle diameter

3.2. Pitch accuracy

Basically grinded (ger.: geschliffene) spindles are more accuarte than rolled spindles.

Spindle type	**Rough pitch error**
Grinded screw (ger.:Geschliffene Spindel)	$\pm 60 \frac{\mu m}{m}$
Rolled screw (ger.:Gerollte Spindel)	$\pm 167 \frac{\mu m}{m}$

Tab. 1 Wegabweichung und Wegschwankung (Maximalwerte) Einheit: μm

Genauigkeits-klassen		Präzisions-Kugelgewindetriebe										Gerollte Kugelgewindetriebe		
		C0		C1		C2		C3		C5		C7	C8	C10
Nutzweg über	Nutzweg bis	Mittlere Wegab-weichung	Variation	Mittlere Wegab-weichung	Variation	Mittlere Wegab-weichung	Variation	Mittlere Wegab-weichung	Variation	Mittlere Wegab-weichung	Variation	Wegab-weichung	Wegab-weichung	Wegab-weichung
—	100	3	3	3,5	5	5	7	8	8	18	18	± 50/ 300 mm	± 100/ 300 mm	± 210/ 300 mm
100	200	3,5	3	4,5	5	7	7	10	8	20	18			
200	315	4	3,5	6	5	8	7	12	8	23	18			
315	400	5	3,5	7	5	9	7	13	10	25	20			
400	500	6	4	8	5	10	7	15	10	27	20			
500	630	6	4	9	6	11	8	16	12	30	23			
630	800	7	5	10	7	13	9	18	13	35	25			
800	1000	8	6	11	8	15	10	21	15	40	27			
1000	1250	9	6	13	9	18	11	24	16	46	30			
1250	1600	11	7	15	10	21	13	29	18	54	35			
1600	2000	—	—	18	11	25	15	35	21	65	40			
2000	2500	—	—	22	13	30	18	41	24	77	46			
2500	3150	—	—	26	15	36	21	50	29	93	54			
3150	4000	—	—	30	18	44	25	60	35	115	65			
4000	5000	—	—	—	—	52	30	72	41	140	77			
5000	6300	—	—	—	—	65	36	90	50	170	93			
6300	8000	—	—	—	—	—	—	110	60	210	115			
8000	10000	—	—	—	—	—	—	—	—	260	140			

Hinweis: Der Nutzweg wird angegeben in: mm

Figure 4: HIWIN accuary classes for grinded and rolled spindles

4. Summary

Force/Torque

Linear force:

$$F_{lin} = m_{lin} \cdot a + F_r + b_v \cdot v$$

b_v ... viscous friction coefficient in $\frac{N}{m/s}$
F_r ... static friction force
m_{lin} ... linear mass to be moved

Torque:

$$M_{rot} = M_r + J \cdot \alpha$$

M_r ... friction torque in N
J ... moment of inertia in $kg \cdot m^2$
α ... angular acceleration in $\frac{rad}{s^2}$

Force/Torque Transmissions

Linear Force to Torque:

$$M_{rot} = \frac{F_{lin} \cdot S}{2\pi \cdot \eta}$$

S ... spindle pitch in $\frac{m}{turn}$
η ... spindle efficiency

Torque to linear force:

$$F_{lin} = \frac{2\pi \cdot M_{rot} \cdot \eta}{S}$$

Position/Speed/Acceleration

Transmission Linear to rotational

$$\phi = 2\pi \cdot \frac{s}{S}$$

$$\omega = 2\pi \cdot \frac{v}{S}$$

$$\alpha = 2\pi \cdot \frac{a}{S}$$

ϕ ... Rotional position in rad
ω ... Rotational speed in $\frac{rad}{s}$
α ... Rotational acceleration in $\frac{rad}{s^2}$
S ... spindle pitch in $\frac{m}{turn}$

Transmission Rotational to linear

$$s = \frac{\phi \cdot S}{2\pi}$$

$$v = \frac{\omega \cdot S}{2\pi}$$

$$a = \frac{\alpha \cdot S}{2\pi}$$

s ... Linear position in m
v ... Linear speed in $\frac{m}{s}$
a ... Linear acceleration in $\frac{m}{s^2}$

Number of revolutions

$$n = \frac{\omega \cdot 60}{2 \cdot \pi}$$

n ... number of revolutions in rpm

Motor related

Force constant

$$k_t = \frac{M_{stall}}{I_{max}}$$

k_t ... force constant in $\frac{Nm}{Arms}$
I_{max} ... maximum current in $Arms$

Continuous current

$$I_{cont} = \frac{M_{mean}}{k_t}$$

I_{cont} ... contiuous current in $Arms$
M_{mean} ... mean torque of trajectory in Nm

Part III.
Stepper-Motor-Design

Part IV.
Linear-Motor-Design