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System Simulation of Linear Actuator System

Peter Gravesen, LINAK A/S

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Line Out

- Introduction
  - Examples of LINAK linear Actuators
- Challenges
  - Mechatronics with many moving parts (FEA on system too complex)
  - Difficult to predict thermal behavior under various mission profiles
  - Extensive testing of sub-systems and full systems impacts time-to-market
- Solution
  - SimScape multi-physics Actuator model based on standard building blocks
  - Adding more advanced DC-motor building block
  - "Tricks" used to fix problem of changing heat conduction between moving parts
- Results
  - Simulation results
  - New learnings based on simulation results
  - Democratisation of SimScape models
  - Further work towards a digital twin

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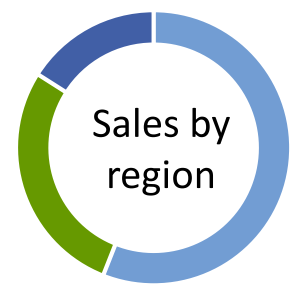
LINAK – a global company with HQ on island of Als

30
Subsidiaries

4
Factories

15
Distributors

2,220
employees
(January 2017)



56% EMEA

28% Americas

16% Asia/Pacific

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Example of LINAK actuator system for healthcare Hospital beds, Patient lifts, Couches, Wheel chairs etc.

A typical actuator system consists of one or more actuators/columns, a control box and a control unit. Below are just a few examples of the vast product programme.

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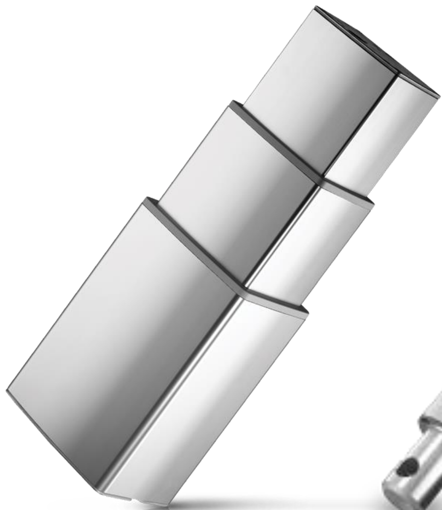

Column

Actuator

Control box

Control

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Other examples of LINAK actuator systems

DESKLINE®

HOMELINE®

TECHLINE®

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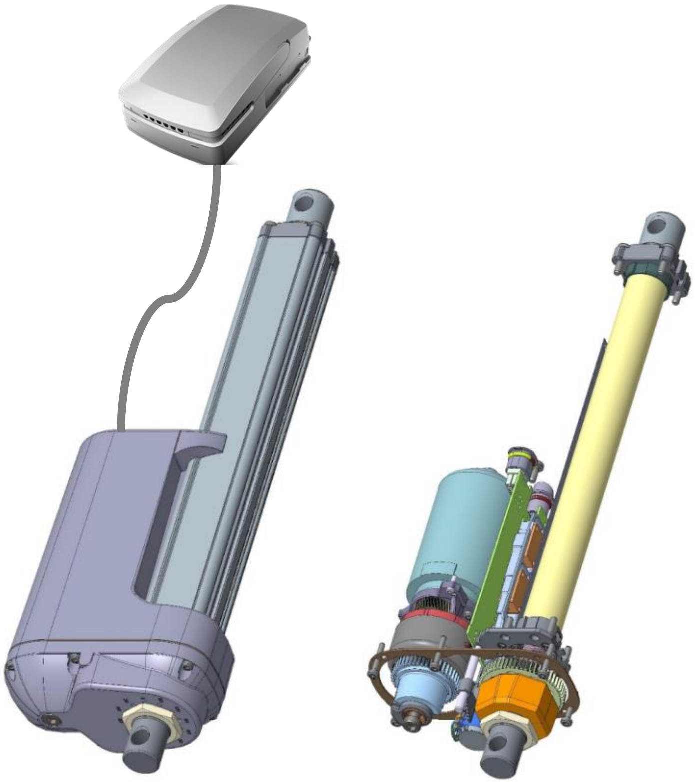
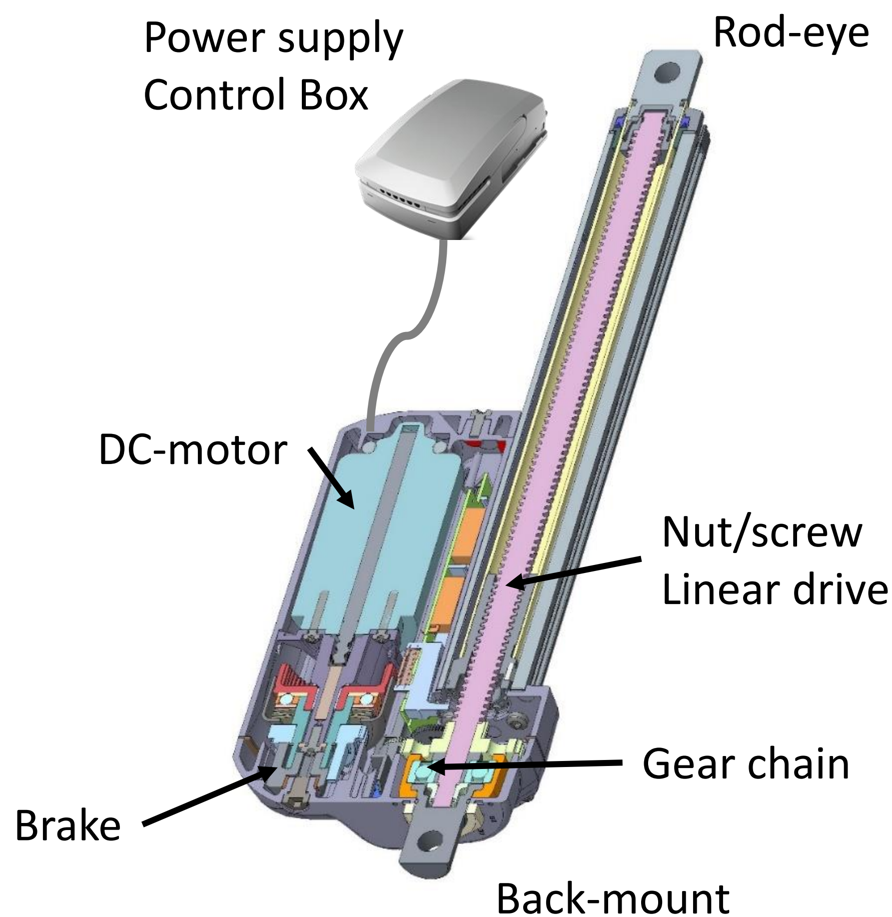
Challenge - How to model a LINAK actuator system





Technical characteristics of most applications

- Mission profiles have low duty cycle.
  - Most products are specified with max 10% duty-cycle (2min/18min)
  - Motor working point is often beyond max efficiency point
  - Gear wheels are made of plastic to reduce noise (and reduce cost).
  - Nut is made of plastic to reduce noise (and reduce cost).
- Critical components for Product lifetime depends on application
  - Wear of motor bushing
  - Wear of Gear wheel(s) (impacted by temporary high temperature)
  - Wear of Nut (impacted by temporary high temperature)
  - Wear of Brake (impacted by temporary high temperature)
  - Wear of other components due to environmental factors
- Estimation of dynamic temperature of single parts is key to lifetime prediction

Challenge – What do we want to predict

- Simple questions to be answered
  - Dimensioning drive-line with motor working point
  - Predict torque on all elements
  - Predict brake torque required to obtain self-locking
  - Predict system efficiency and surface temperature
- More demanding questions to be answered
  - What is the maximum temperature of key components as a function of mission profile. (Gear wheels, Nut, Brake, Motor-winding etc.).
  - What is the dynamic surface temperature of Nut working against screw
  - What would we gain in terms of static and dynamic temperature inside device if replacing brush DC-motor with brushless DC-motor.

- Historically latter questions have been answered by testing only

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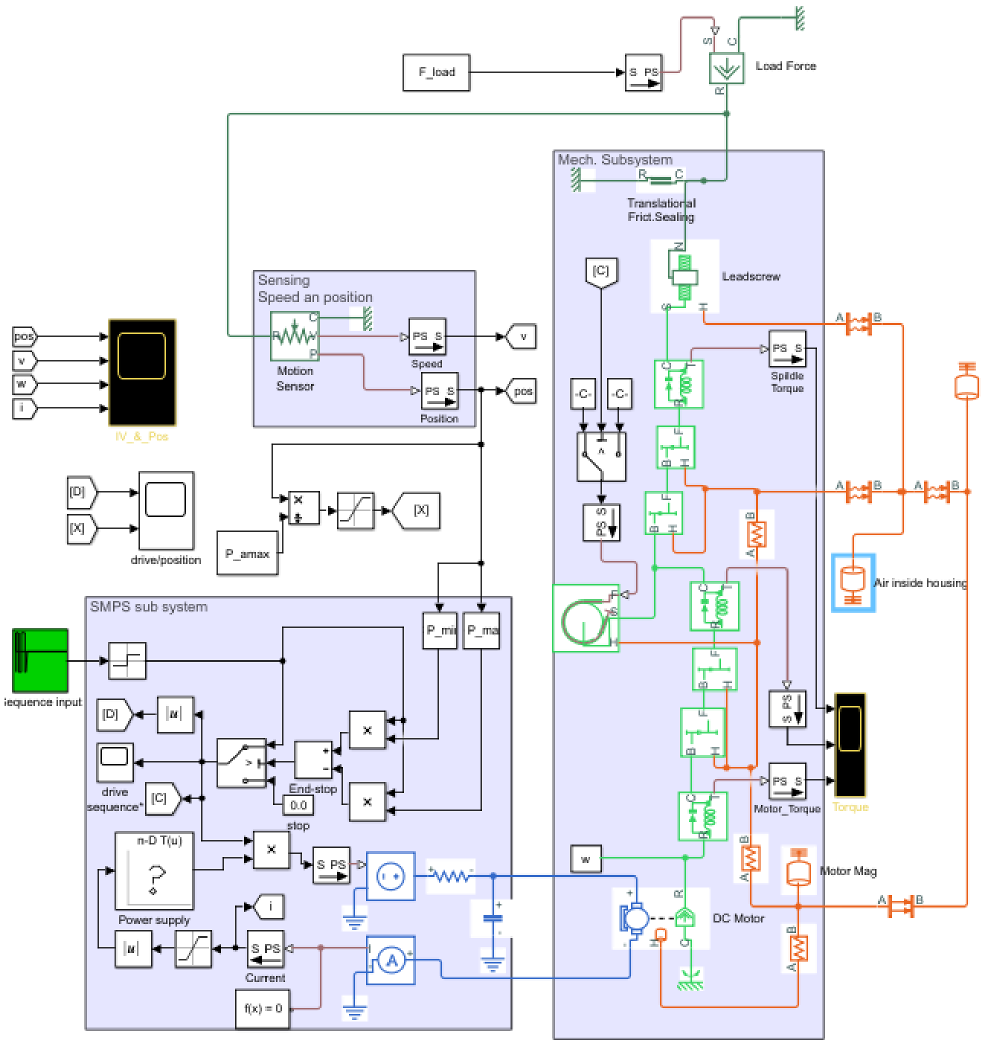
Solution – Simscape Simple stage 1 model



- Easy to built.
  - ”Drive-line” standard modules
  - Set-up model in < 1 hour
- Answer ”simple” questions
  - Drive-line lay-out
  - Dimensioning gear stage(s)
  - Dimensioning Brake
  - Determine system efficiency
  - Predict surface temperature
- Same questions have historically been answered by Excel-based calculation sheet.

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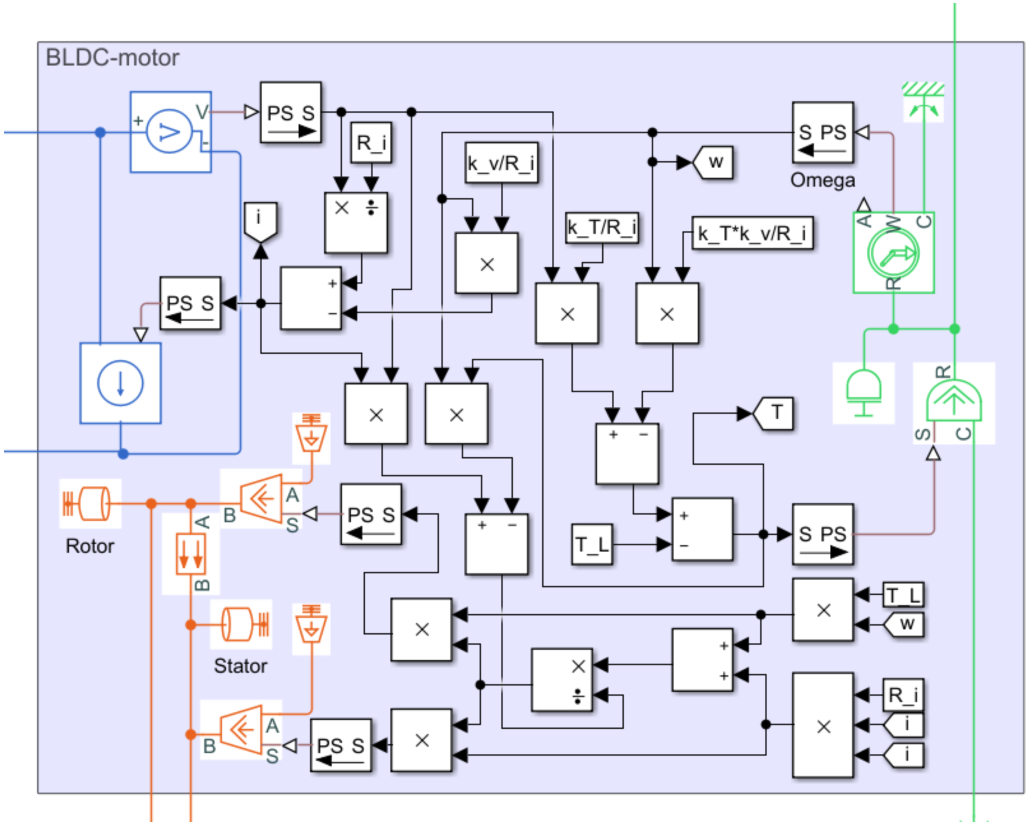
Solution – Shortcoming of simple stage1 model

- Motor model assumes no electromagnetic losses
  - All LINAK motors are characterized by a 4-parameter linear model within its primary working range (k_T, k_v, R_i, T_{loss}).
  - Simscape model only supports a 3-parameter model (k , Ri , ω(T=0))
  - Simscape offers one heat port (one heat capacitance) for entire motor
  - Differentiating between rotor and stator heat capacitance and heat capacities allows for more accurate prediction of heat transfer. In particular when comparing brush DC-motor to BLDC-motor.
- Calculating dynamic temperature of single parts requires modeling of all parts as one of more heat capacitance(s) and calculation of all heat conduction pathways between parts.
  - Relatively easy to calculate heat capacitance and heat transfer between stationary parts.
  - An extra challenge to model heat transfer between moving parts such as Nut moving along screw.

Improved motor-models DC and BLDC



Linear Motor model
With 4 parameters

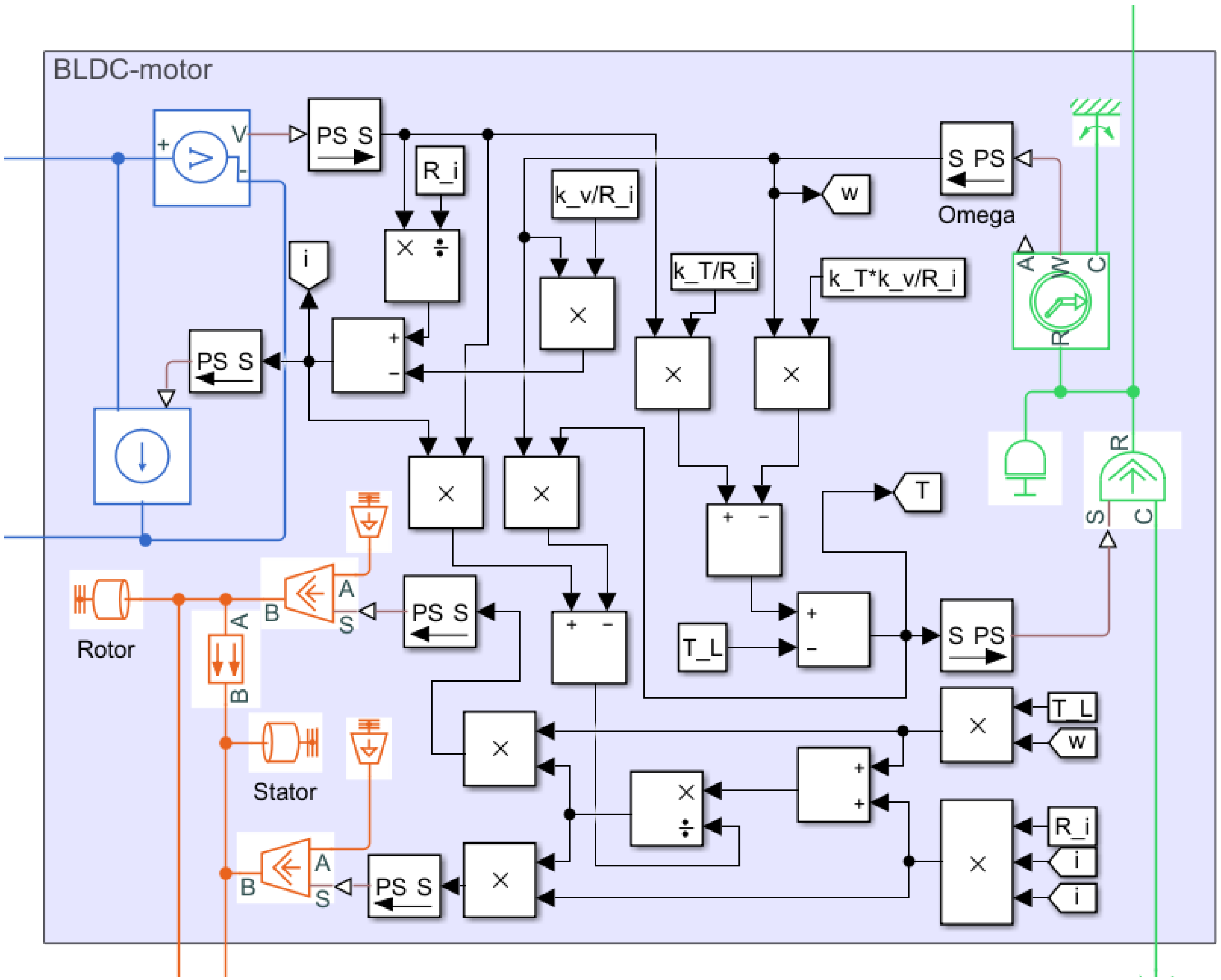
Additional 4 parameters for
Inertia and heat ransfer

k_v [V*s/rad]	(speed motor constant)
k_T [N*m/A]	(Torque motor constant)
R_i [Ohm]	(Winding resistance)
T_L [N*m]	(Torque friction)
J_motor [g*cm^2]	(Motor Inertia)
HC_rotor [J/K]	(Rotor heat capacitance)
HC_stator [J/K]	(Stator heat capacitance)
HR_gap [K/W]	(Heat Resistance of motor air-gap)

Improvements compared to built-in DC-motor module

- Allows to use measured motor characteristics where $k_T \neq k_v$
- Includes two thermal ports. One for Rotor and one for Stator

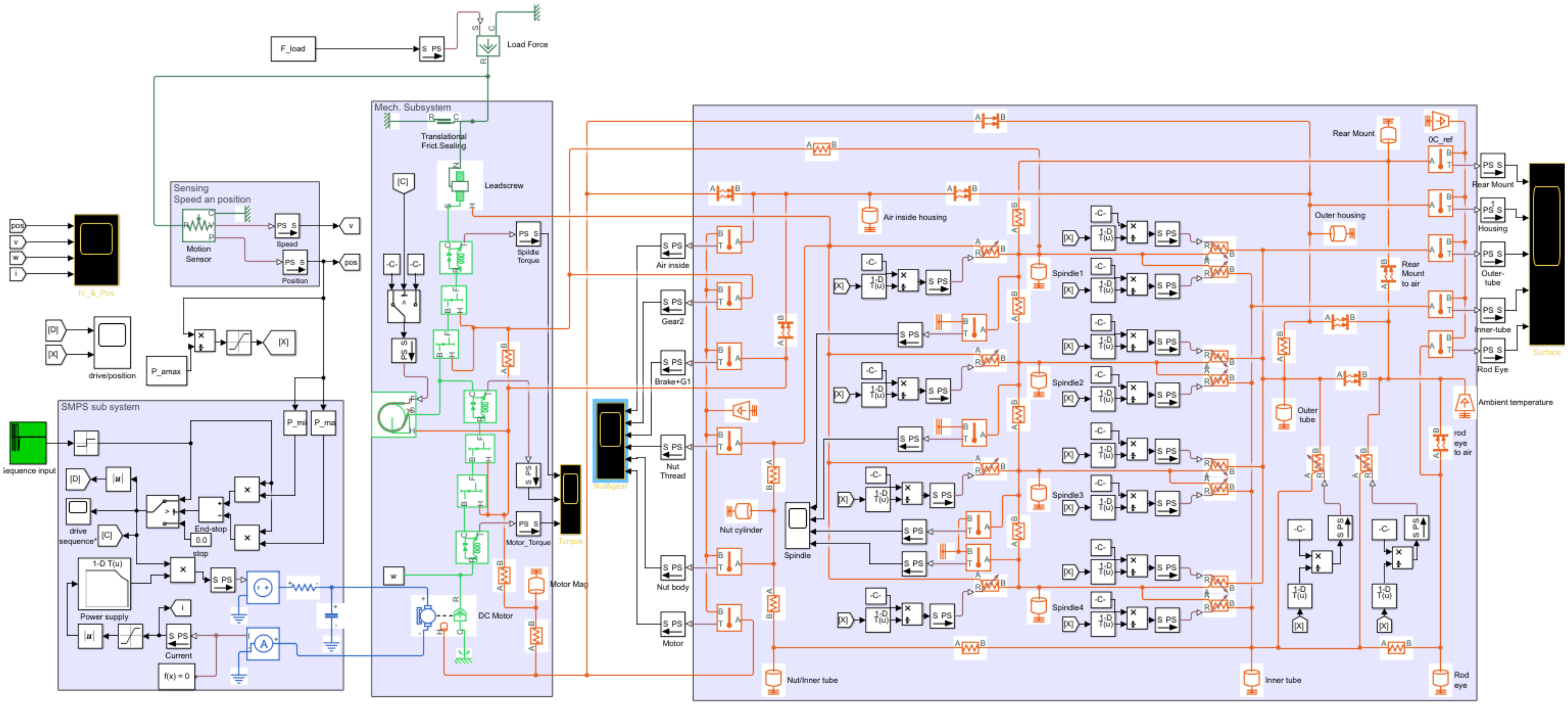
Improved motor-models BLDC-Motor



Improvements compared to DC-motor model

- Differentiate mechanical heat loss (to rotor) and Ohmic heat loss (to stator)

Solution: Actuator System model Stage 2



Improvements compared to Stage 1 model

- More accurate representation of heat transfer from motor to gear and other parts
- Use of position state of actuator to model heat transfer of moving parts during operation
- Screw subdivided in 4 segments in order to represent heat re-distribution during move

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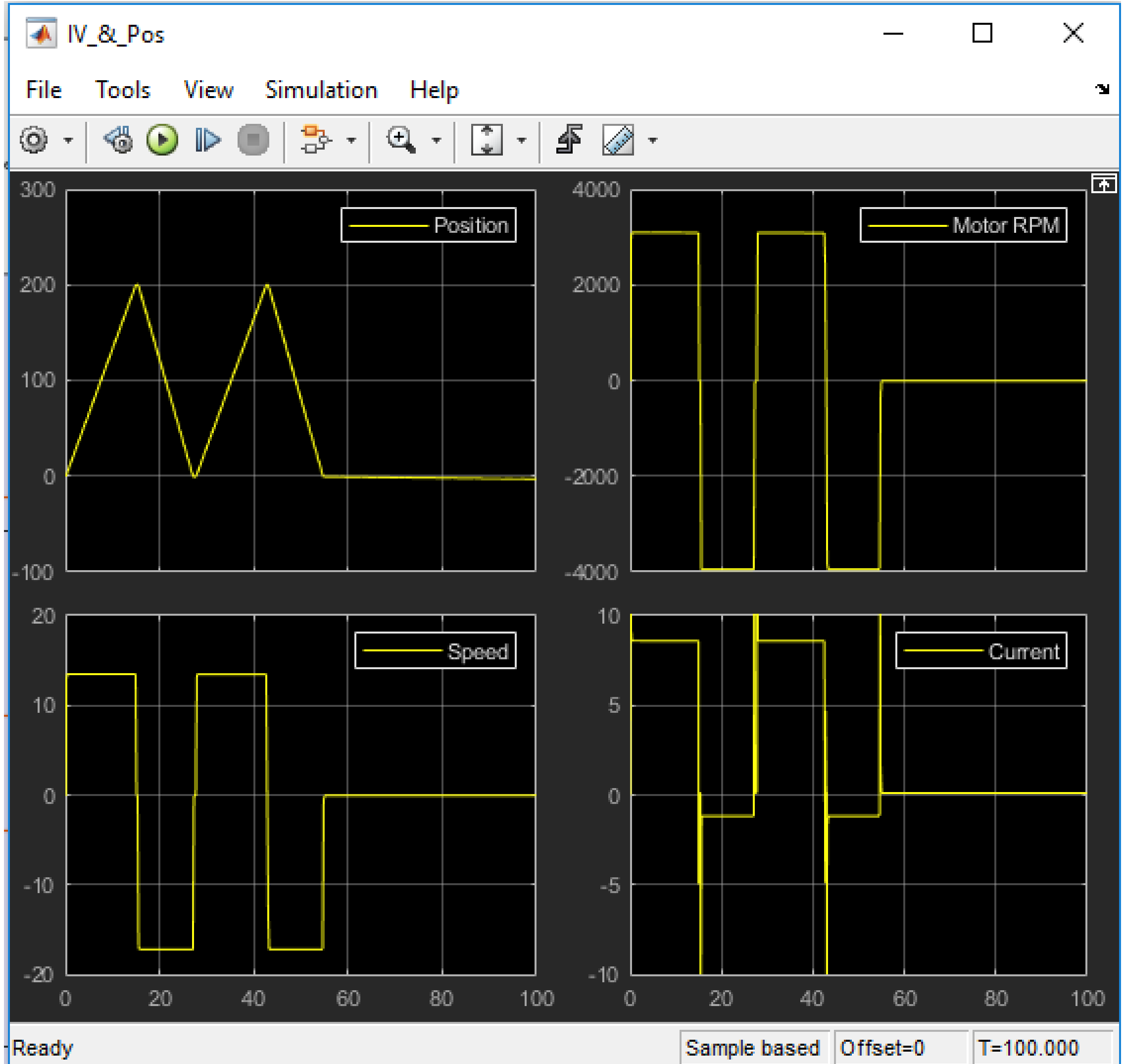
Results: Basic drive-line characteristics



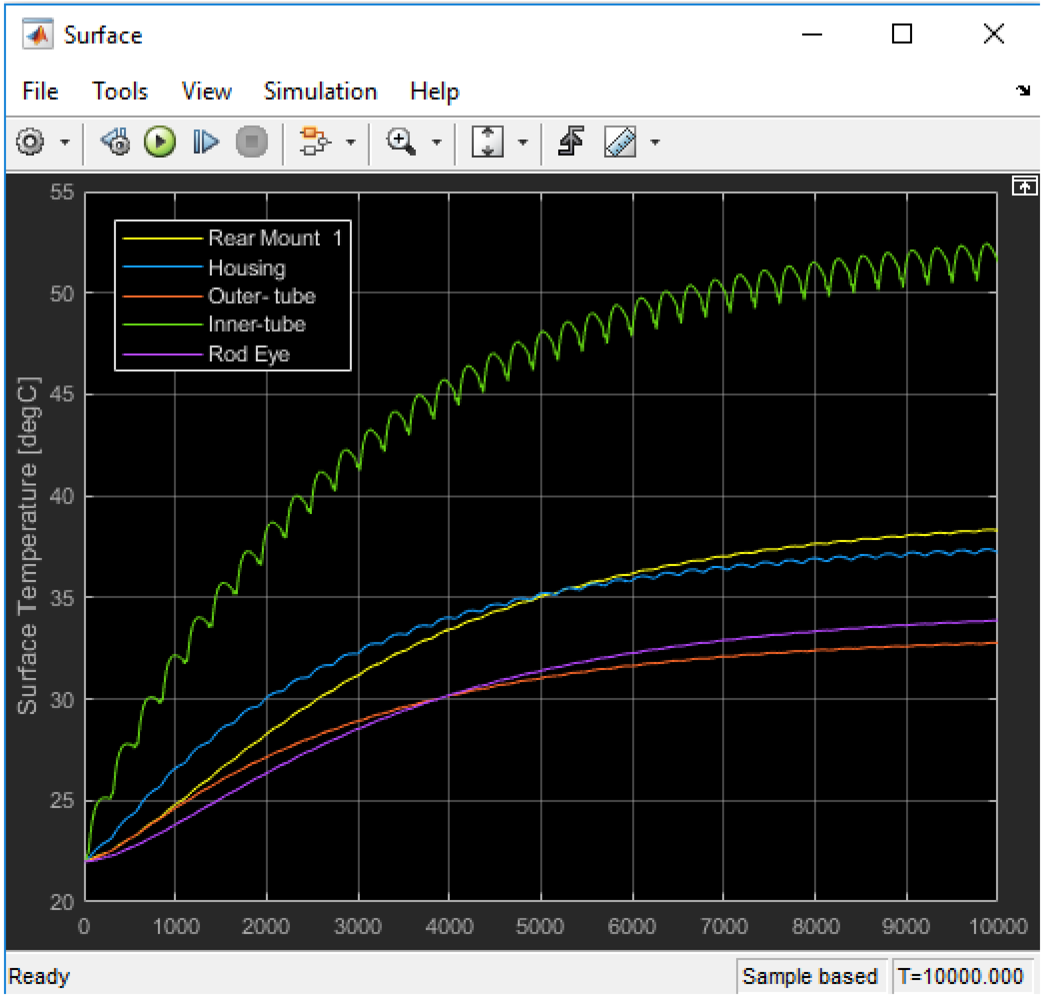
Motor
3090 RPM forward
3950 RPM backwards

8.6 A forward
1.2 A backwards

13.4 mm/s forward
17.2 mm/s backwards

Mech power: 91.1 W
Elec power: 233.9 W
System eff: 38.9%

Results: Dynamic temperature of outer surfaces



Inner tube hottest outer surface Nut end 58°C, Rod-eye 34°C, Average 52°C.

Rear Mount: 38°C

Housing: 37°C

Outer tube: 33°C

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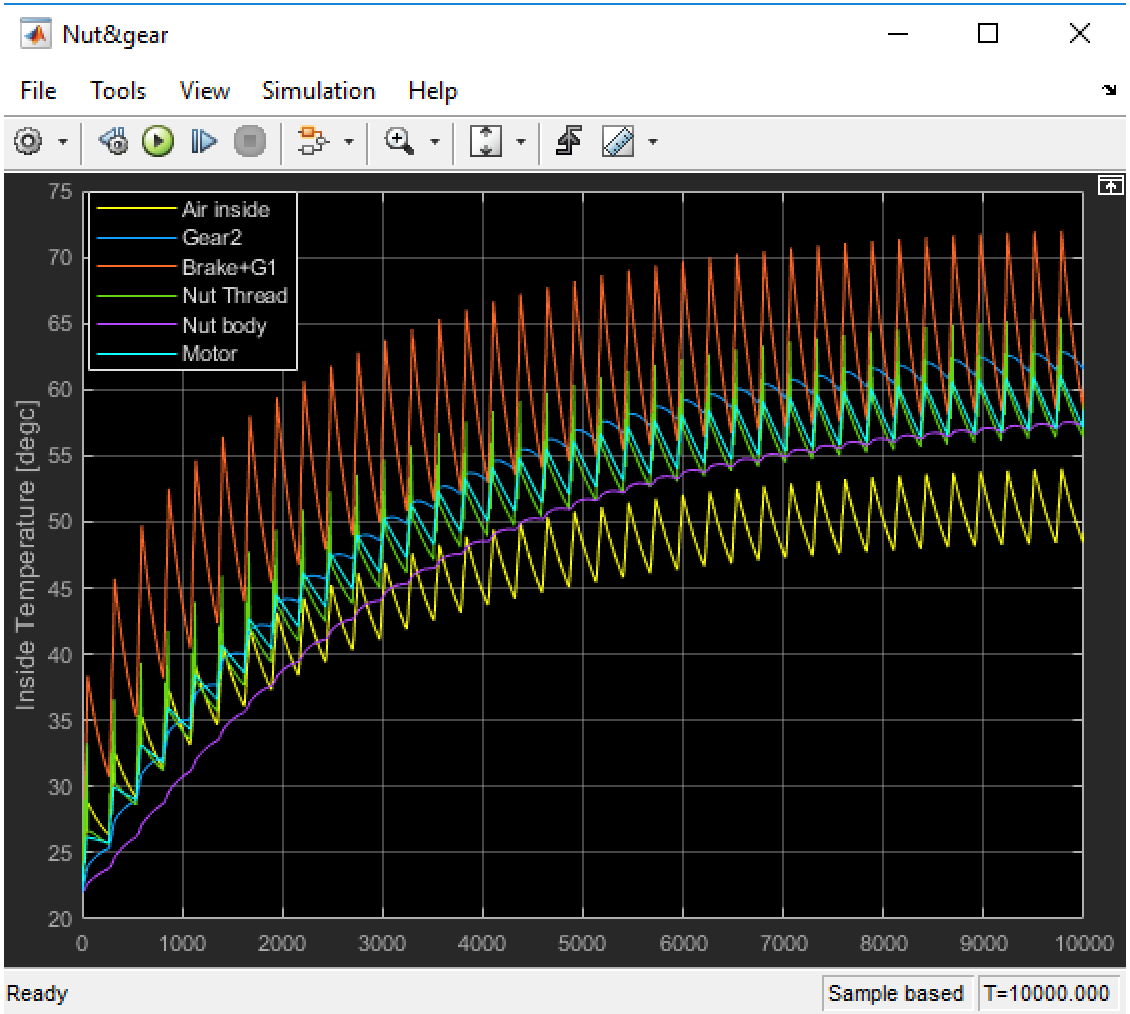
Results: Dynamic temperature of key parts



Brake and planet gear hottest in side parts: 72°C

Spindel and Nut thread: 65°C

Gear stage 3+4: 62°C

Motor stator: 61°C

Nut body: 58°C

Air inside housing 54°C

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Results: New learnings based on simulation

- Validating model against test results
  - Good agreement with results from standard lifetime test
  - Good agreement with temperature of Nut-body
- Predicting dynamic temperature of key parts
  - Explains which part of system is most prone to overheating
  - Explains number of consecutive strokes possible during so-called abuse test. (100% duty cycle).
- Form input for design og new actuators
  - Predict thermal advantage of BLDC motor versus brush DC-motor
  - Predicts dynamic temperature of single gear-wheels important for optimal choice of material.

Concluding remarks on SimScape Simulation

- Use of simscape models to reduce amount of device testing
  - Useful for calculation of thermal load of new customer mission profile, which is similar to but not identical to known validated results.
  - Useful during design of new product. Including drive-line calculations and adding thermal design predictions, which could otherwise only be obtained through experiments (save project time).
  - Allow simulation based experiments with alternative components or system solutions prior to experimental verification.
  - Adds to a deeper understanding of weak points and wear mechanisms. In particular by offering more detailed insight into dynamic localized temperatures.
- Out-look for further use of Simscape models.
  - Expect to use further development of models for lifetime prediction models and algorithms
  - Expect to make initial experiments related to digital Twin based on Simscape model.

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