Modeling and Simulating in SimScape

Laboratory Exercises 2
EL2820, Modeling of Dynamical Systems
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Goal: The goal is to gain experience and insight in modeling and simulating in SimScape

Note: You need to have a good understanding of the underlying phenomena when you develop a mathematical model of a real system. This means that modeling will take a lot of time. It is, therefore, crucial for you to **thoroughly prepare** before the laboratory exercises! Do the preparation tasks before the laboratory session.

Contents

1 Servo Motor

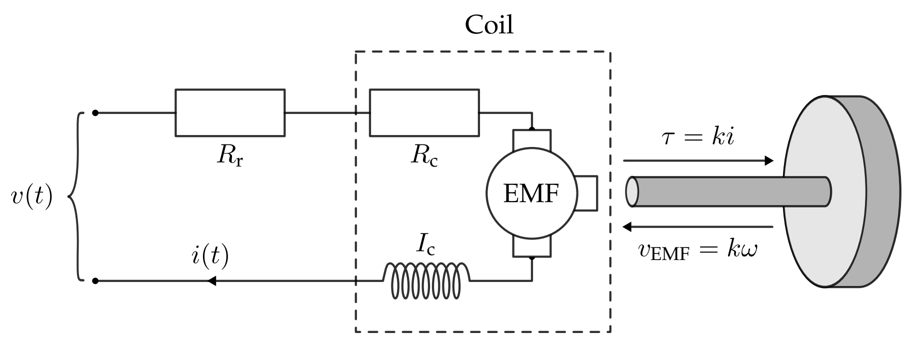


Figure 1: The motor.

The DC motor is sketched in Figure 2, and the data sheet of the motor is given in Figure 4. The model under consideration is M-586-0585. The graph in Figure 4 shows two curves for each motor model. The upper curve specifies three constraints on the motor: maximum number of revolutions per minute, maximum torque, and maximum power (try to find out how!).

The lower curve is produced as follows: The current through the motor is held constant, at the value of the *continuous stall current*.[1] An external breaking torque is applied to the motor shaft, just large enough for the motor shaft to stop accelerating and spin at a constant speed. This pair of torque and rotational speed is recorded as one point of the curve. The torque is then varied to produce all stationary speeds between zero and the maximum speed.

The component "EMF" in Figure 2 represents the conversion of electric energy into mechanical energy (and vice versa). It can be considered as a controlled voltage source in the electric circuit, providing a voltage difference between its terminals equal to $v_{\mathrm{EMF}} = k\omega$, where ω is the angular velocity of the motor shaft. At the same time, this component acts as a controlled torque source to the mechanical part of the motor, providing a torque $\tau = ki$ to the shaft, where i is the current flowing through EMF. Note that the constant k is the same in the formulas for v_{EMF} and τ; this is because EMF is an ideal component which does not accumulate, gain nor lose energy, so if the constants were different (say, $k_v \neq k_\tau$) the net power entering this component, $v_{\mathrm{EMF}} i - \tau\omega = k_v \omega i - k_\tau i \omega$, would not be zero.

In the section *winding specifications* in Figure 4, there are two resistors and one inductor. The reason for this is that the winding of the coil is not an ideal inductor. The winding is both inductive and resistive. In Figure 2, R_c corresponds to the *armature resistance*, $R_r + R_c$ corresponds to the *terminal resistance*, and I_c corresponds to the *armature inductance*.

[1]This is the highest current the motor can continuously tolerate, when stationary. The highest current the motor can tolerate, for a brief moment, is the *maximum pulse current*.

1.1 Assignment 1

In this assignment, we will model a servo motor described in the previous section.

Preparation tasks:

1. Derive a state-space model of the servo motor. Assume that the motor is driven by a voltage source.
2. Use the motor specifications in the appendix to find numerical values of the model parameters. Note that the mechanical damping of the motor can be found by looking at the slope of an appropriate curve in Figure 4.
3. Translate your state-space model to a block diagram, based on integrator elements, which can be implemented in Simulink. If you have not used Simulink before, you should briefly read through the ”Getting started guide”: `http://www.mathworks.com/help/pdf_doc/simulink/sl_gs.pdf`. Especially chapters 2 and 3 might be useful.
4. Look at the available standard components in SimScape, which you can find at `https://www.mathworks.com/help/physmod/simscape/referencelist.html?type=block&listtype=cat&category=index&blocktype=all&capability=`. A tutorial on modeling a mechanical system in SimScape can be found at `http://engineering.ju.edu.jo/Laboratories/03_2-%20Mathematical%20Modeling%20Using%20SimScape_Mechanical.pdf`

Laboratory Exercises

1. Implement your state-space model in Simulink. Simulate and verify that the model behaves as expected.
2. Construct the object-oriented model in SimScape. Please, only use components inside the Foundation Library and Utilities. Simulate and verify that the model behaves as expected.
3. Compare the simulation results from the two models. Do they match? (If they disagree, then at least one of the models is incorrect.)
4. Discuss the differences between object-oriented and block diagram based modeling. What are the benefits, and what are the drawbacks? Which one do you prefer in this case? Why?
5. Now, assume that the servo motor is driven by an ideal current source, and remove any inductor. To model these changes, would you use Simulink or SimScape? Why? (In the report, you should only explain why you would choose block diagram or object-oriented based modeling.)

In the **report**, you should include the following:

1. the state-space model (not necessary to include derivation),
2. screenshots of a block diagram in Simulink and the object-oriented model in SimScape,
3. simulation results from the two models for the angular velocity of the motor shaft,
4. the comparison of object-oriented and block-diagram based modeling (benefits and drawbacks).

1.2 Assignment 2

In this assignment, a servo motor lifts a load of mass $m = 2$ kg using a wheel with an outer diameter of 20 mm, and a thickness of 10 mm. The rotational movement of the wheel is transformed into a translation movement of load through the elastic wire, which is coiled around pulley, with the spring constant 75 N/m, and a friction coefficient $b = 25$ Ns/m. The wheel is made of aluminum, with a density of $2.7 \cdot 10^3$ kg/m3. The figure below shows the described system.

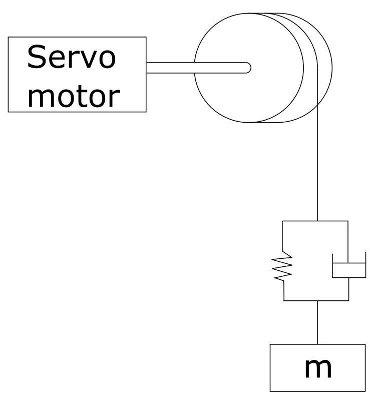


Figure 2: Servo motor runs a simple translational mechanical system.

Laboratory Exercises

1. Construct the object-oriented model in SimScape. Simulate and verify that the model behaves as expected.
2. Is the system sensitive to variations in the friction coefficients or spring constants? Which system properties change when the friction coefficients or spring constants are varied?

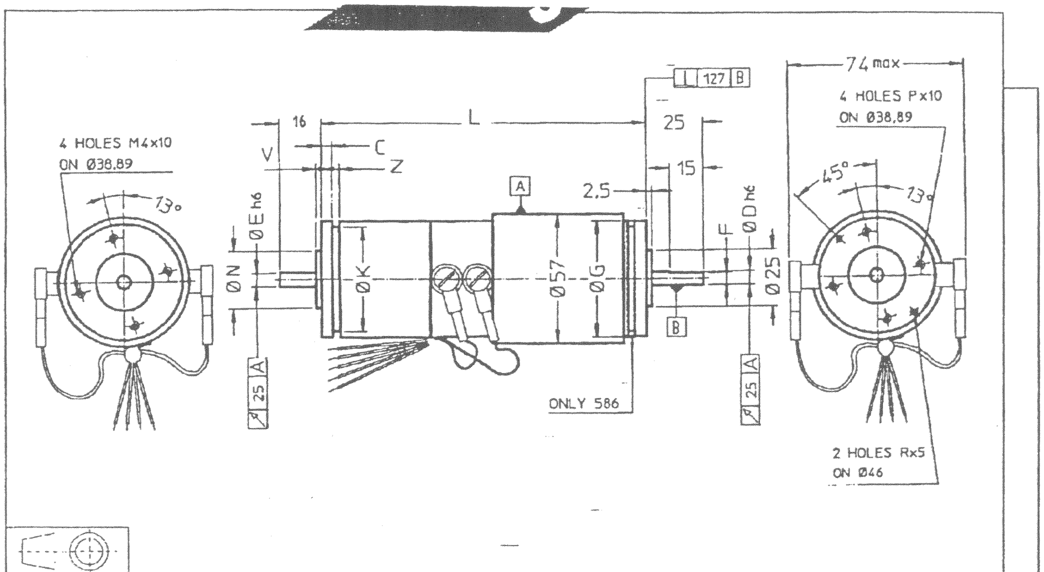
In the **report**, you should include the following:

1. screenshots of the object-oriented model in SimScape,

2. simulation results for the velocity of the load in SimScape,
3. answers to the question of how system properties are affected by a variation of the friction coefficients or spring constants.

The report should consist of a maximum 3 pages.

APPENDICES



Dimensioni in mm Tolleranze in micrometri - *Dimensions in mm Tolerances in micrometer*

TIPO/*TYPE*	L	D	E	F	G	V	C	Z	N	P	R	K
M 586 0585 0606 01 TBU	142	6	6	5,5	51	2,5	4,83	3,18	25	M4	/	46,23
M 586 0585 0606 02 TBV	142	6	6	5,5	51	2,5	4,83	3,18	25	M4	/	46,23
M 586 0585 0606 03 TPU	145	6	6	5,5	51	/	/	/	/	/	M2,5	/
M 588 1100 0606 01 TBU	167	6	6	5,5	51	2,5	4,83	3,18	25	M4	/	46,23
M 588 1100 0808 02 TBU	167	8	8	/	57	2,5	4,83	3,18	25	M4	/	46,23
M 588 1100 0606 04 TBV	167	6	6	5,5	51	2,5	4,83	3,18	25	M4	/	46,23
M 588 1100 0808 03 TBV	167	8	8	/	57	2,5	4,83	3,18	25	M4	/	46,23
M 589 1270 0808 01 TBU	180	8	8	/	57	2,5	4,83	3,18	25	M4	/	46,23
M 589 1270 0806 02 TPU	183	8	6	/	57	/	/	/	/	/	M2,5	/

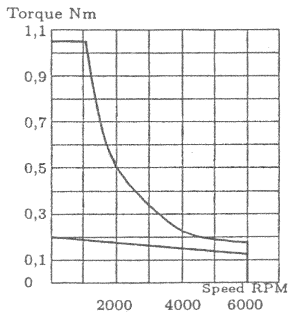
La serie 500 DT appartiene ad una più vasta famiglia di servomotori a corrente continua con eccitazione a magnete permanente, particolarmente studiati per soddisfare le esigenze in un ampio campo di applicazioni industriali e professionali, quando siano richieste alte prestazioni di precisione, di velocità e/o posizionamento.

The series 500 DT belongs to a large family of permanent magnet DC servomotors, they were studied to satisfy the demands of a broad range of industrial and professional apllications, where highly precise speed and/or positioning perfomances are required.

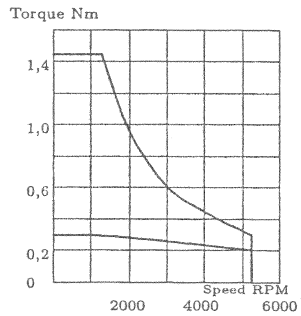
FORMA (secondo IEC 34-7) IMB5 (fissaggio con flangia)
PROTEZIONE (secondo IEC 34-5) IP 44
EQUILIBRATURA (secondo DIN 45665) classe N
POLI n. 2
MATERIALI ISOLANTI in classe F ed H
CAMPO DI FUNZIONAMENTO altitudine < 1000 m. s.l.m.
TEMPERATURA AMBIENTE MAX 40° C
TEMPERATURA AMBIENTE MIN 0° C

CONSTRUCTION (according to IEC 34-7) IMB5 (flange mounting)
PROTECTION CLASS (according to IEC 34-5) IP 44
BALANCING (according to DIN 45665) class N
POLE NUMBER 2
INSULATION CLASS F and H
OPERATING RANGE below 1000 m above sea level
MAXIMUM OPERATING AMBIENT TEMPERATURE 40° C
MINIMUM OPERATING AMBIENT TEMPERATURE 0° C

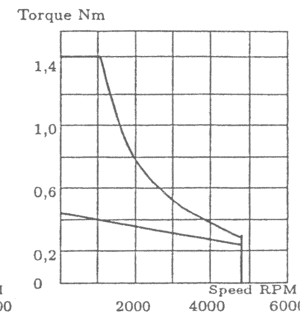
Figure 3: The servo motor.



M 586 0585



M 588 1100



M 589 1270

SPECIFICATIONS (1)		M 586 0585	M 588 1100	M 589 1270
Operating Specifications				
Continuous stall torque	Nm	0,2	0,35	0,40
Peak Stall torque	Nm	1,05	1,50	1,44
Continuous stall current	A	3,90	3,30	3,30
Maximum pulse current	A	18,7	14,2	11,9
Maximum terminal voltage	V	60	60	60
Maximum speed	RPM	6000	5200	4700
Mechanical data				
Rotor moment of inertia (including tachometer)	kg m^2	$3{,}88 \cdot 10^{-5}$	$5{,}5 \cdot 10^{-5}$	$6.8 \cdot 10^{-5}$
Mechanical time constant	ms	10,2	10	8
Motor mass (including tachometer)	kg	1,3	1,7	1,9
Thermal data				
Thermal resistance (armature to ambient)(2)	°C/W	5	4,2	4
Maximal armature temperature	°C	155	155	155
Winding specifications				
Torque constant (3) K_τ	Nm/A	0,056	0,105	0,12
Voltage constant (back emf)(3)	V/kRPM	5,8	11	12,7
Armature resistance (4)	Ω	0,8	1,6	1,8
Terminal resistance (4)	Ω	1,15	2	2,2
Armature inductance	mH	3,39	5,2	6,4
Electrical time constant	ms	2,95	2,6	2,9
Tachometer data				
Linearity (maximum deviation)	%	0,2		
Ripple (maximum peak to peak)	%	5,0		
Ripple frequency	cycles/rev	11,0		
Temperature coefficient	%/°C	-0,05		
Output voltage gradient	V/kRMP	14±10 %		

(1) Ambient temperature (if not otherwise specified): 40 °C.
(2) Test conducted with unit heatsink mounted on a 254x254x6 mm.
(3) Tolerance ±10%
(4) At 25°C.

Figure 4: Properties of the servo motor.