UNIVERSITÄT
DES
SAARLANDES

Lehrstuhl für intelligente Material Systeme

intelligent Material Systems Lab

Aktorik und Sensorik mit intelligenten Materialsystemen 3

Exam

Presentation: 22.03.2019 starting from 10:00 at ZeMA

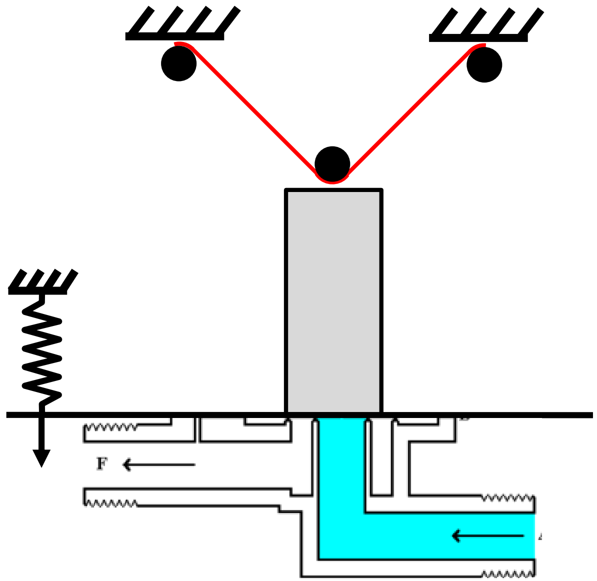
Gianluca Rizzello
gianluca.rizzello@imsl.uni-saarland.de

Felix Welsch
felix.welsch@imsl.uni-saarland.de

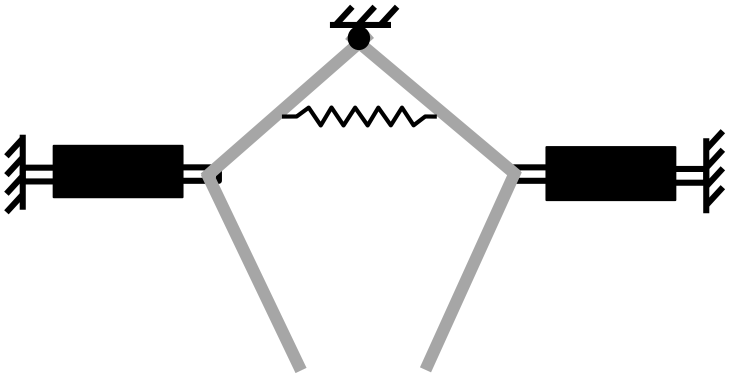
Philipp Loew
philipp.loew@imsl.uni-saarland.de

Saarland University

Task 1: SMA valve

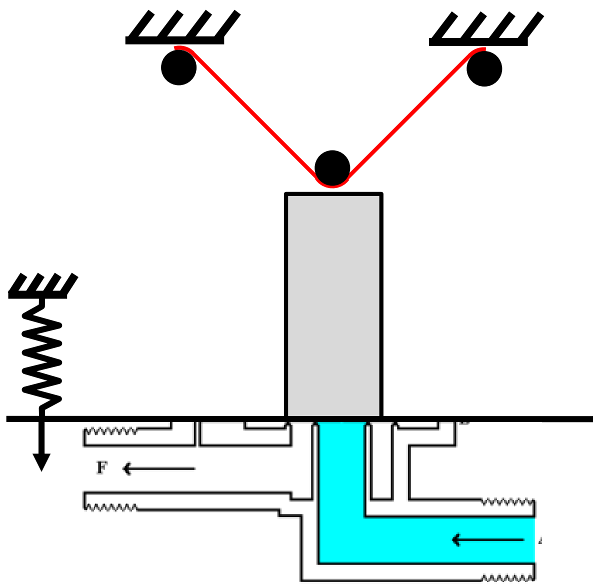


Task 2: DEA gripper



ASIM 3 – Exam overview

Task 1: SMA valve



Task 2: DEA gripper

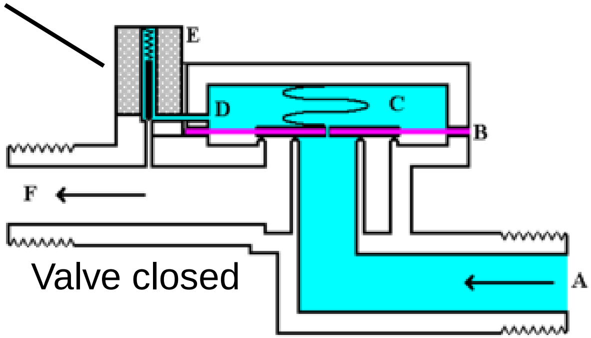
Task 1: SMA valve

An electrically-controlled actuator is used to control the opening of an orifice, to regulate the flow of a fluid (e.g., oil, air)

Applications: flowrate regulation, control of hydraulic/pneumatic pistons

Electrovalve scheme

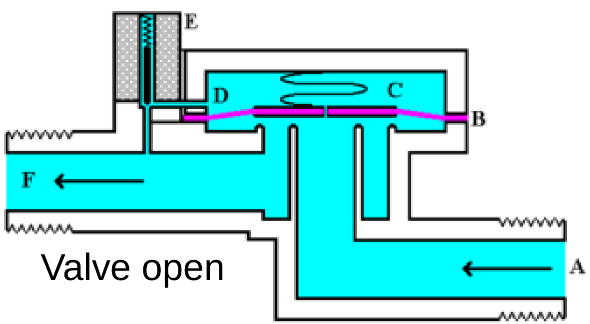
Actuator



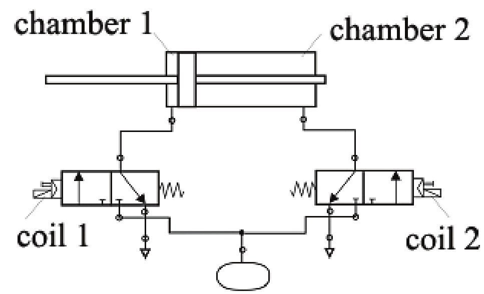
Fluid outlet

Valve closed

Fluid inlet



Valve open



Hydraulic circuit driven by electrovalves

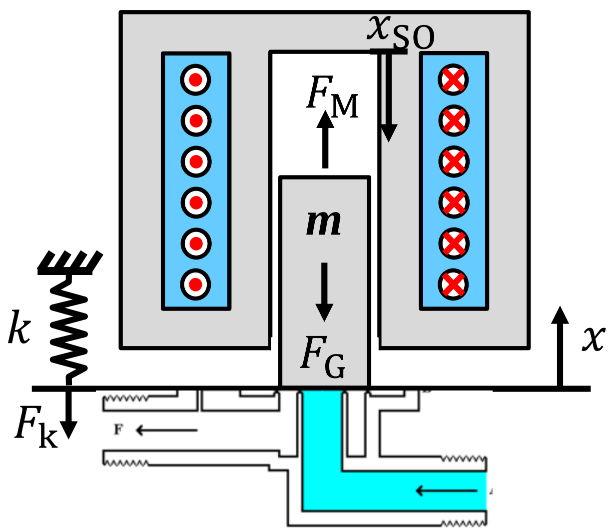
Electrovalve example

Actuator

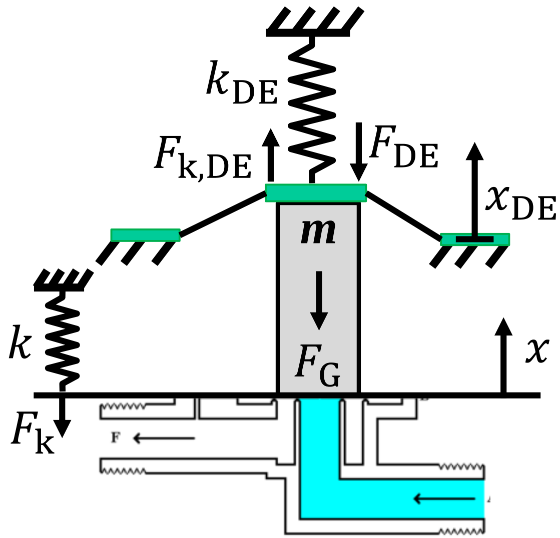
Fluid pipe

Task 1: SMA valve, actuator

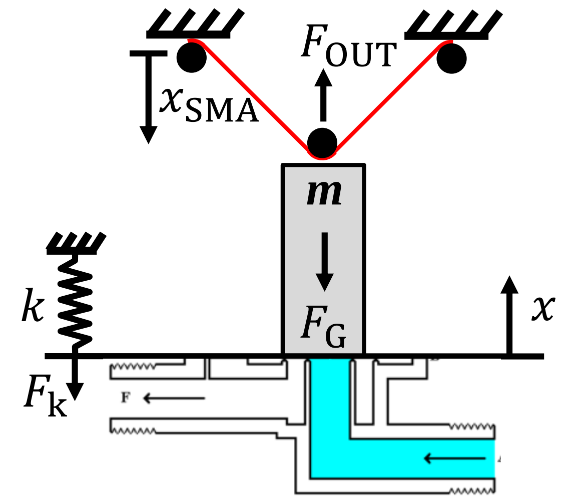
Solenoid



DE



SMA

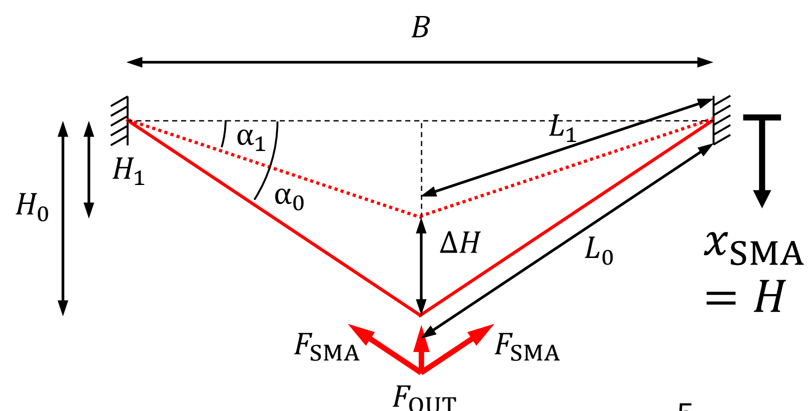


Valve closed: $x = 0$

Valve open: $x > 0$

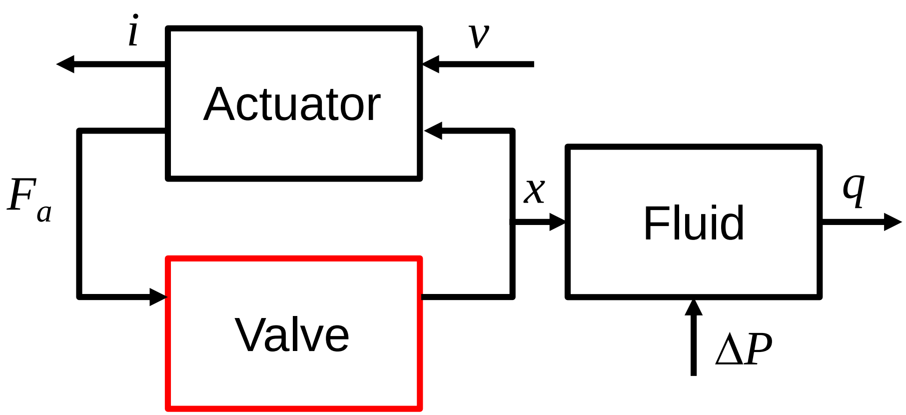
Triangular SMA wire actuator:

$$F_{OUT} = 2 \cdot F_{SMA} \cdot \sin(\alpha)$$
$$= 2 \cdot F_{SMA} \cdot \frac{H}{L}$$
$$L^2 = H^2 + (B/2)^2$$
$$L = \sqrt{H^2 + (B/2)^2}$$



Task 1: SMA valve, valve model

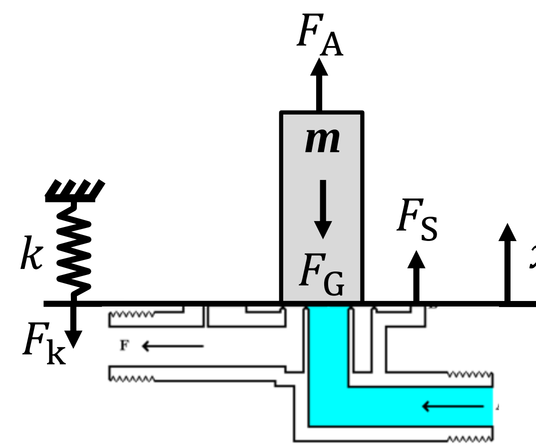
Force balance on the plunger:



- v = voltage
- i = current
- x = displacement
- F_a = actuator force
- ΔP = pressure difference
- q = flowrate

Force equilibrium equation

$$F_{\mathrm{A}} + F_{\mathrm{S}} - mg - k(x - x_0) - b_{\mathrm{D}}\dot{x} - m\ddot{x} = 0$$



Actuator force	Hard stop force	Gravitational force	Spring force	Viscous friction force	Inertia force

➢ Hard stop model: $F_{\mathrm{S}}(x) = 1\mathrm{N} \cdot \exp\left(-10^6\,\frac{1}{\mathrm{m}} \cdot x\right)$

Task 1: SMA valve, fluid, solenoid

We define the pressure difference between inlet and outlet $\Delta P = P_i - P_o$

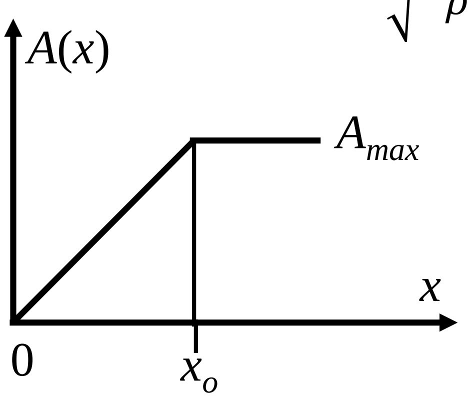
$$v = \sqrt{\frac{2\Delta P}{\rho}}$$

In practice, a loss needs to be taken into account by means of an efficiency parameter η

$$v = \eta\sqrt{\frac{2\Delta P}{\rho}}, \quad \eta \in [0, \quad 1]$$

From flowrate to velocity, where $A(x)$ is the open area which depends on the plunge position

$$q = A(x)\eta\sqrt{\frac{2\Delta P}{\rho}}$$

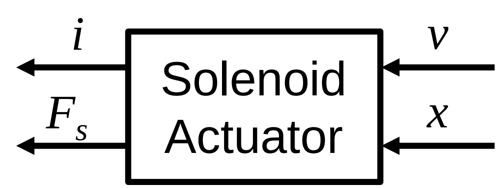


Final model of the solenoid actuator:

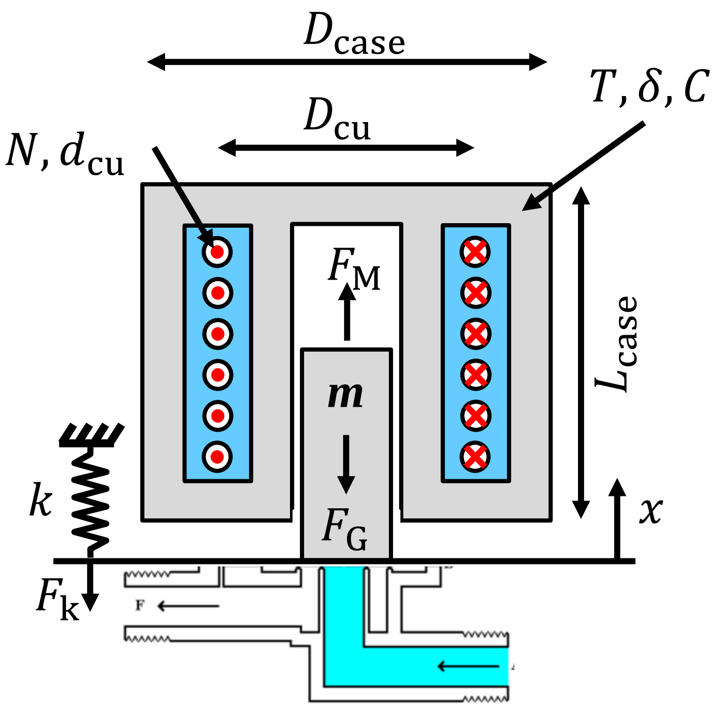
$$\begin{cases} \dot{\lambda} = -\dfrac{R}{L(x)}\lambda + v \\ i = \dfrac{\lambda}{L(x)} \\ F_s = -\dfrac{dL(x)}{dx}\dfrac{i^2}{2} = \dfrac{\mu_0 A_f {A_g}^2 N^2}{\left(A_g x + A_f l_g\right)^2}\dfrac{i^2}{2} \end{cases}$$

With $L(x)$:

$$L(x) = \frac{\mu_0 A_f A_g N^2}{A_g x + A_f l_g}$$



Task 1: SMA valve, solenoid



A large amount of the supplied energy is dissipated in the electrical resistance of the densely packed copper coil. The compact formfactor allows only a limited surface area for cooling and generates a heat accumulation.

Since the copper conductivity is temperature dependent, the temperature evolution in the valve acts on electrical and mechanical performance.

Temperature decency of copper resistance:

$$R(T) = \rho(T) \cdot \frac{L_{cu}}{A_{cu}} = \rho \cdot \frac{N \cdot \pi \cdot D_{cu}}{\frac{\pi}{4} \cdot d_{cu}^2}$$

With:

$$\rho(T) = \rho_{0.cu} \cdot (1 + \alpha_{cu} \cdot (T - T_{ref}))$$

Thermal mass of solenoid body:

$$\frac{dT}{dt} \cdot C \cdot \delta \cdot V_{case} = \underbrace{-\alpha \cdot A_{case} \cdot (T - T_{ext})}_{P_{conv}} + \underbrace{U \cdot I}_{P_{ele}}$$

With:

$$V_{case} \approx \frac{\pi}{4} \cdot D_{case}^2 \cdot L_{case}$$

$$A_{case} = \pi \cdot D_{case} \cdot L_{case} + \frac{\pi}{2} \cdot D_{case}^2$$

Task 1: SMA valve

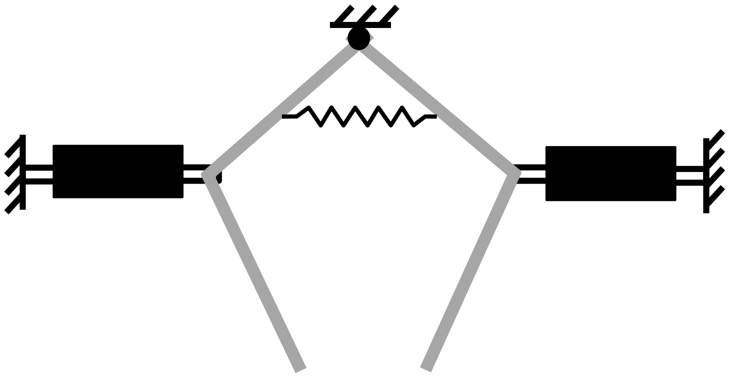
Given the Matlab script params_SMA.m, the Matlab s-function sSMA_displacementIn.m, and the Simulink file system_SOLENOID.slx.

1. Familiarize yourself with the given system_SOLENOID.slx and retrace its functionality. (hint: Consider the rotated system displacement coordinate x compared to Computer Lecture 7) Why isn't the valve able to open?
2. Implement the valve seat as hard stop and validate its behavior. What is the overall valve performance concerning flowrate, actuation speed and energy consumption per cycle?
3. Add the thermal energy balance for the solenoid body and evaluate the temperature evolution. Required parameters are given in the params_SMA.m file.
4. Extend the solenoid model by the influence of the temperature dependent copper resistance. How is the valve performance (flowrate, actuation speed, energy consumption per cycle) affected?
5. Replace the solenoid with a triangular SMA wire actuator. Use the given SMA s-function block for a straight wire and adapted it to the triangular kinematics by modifying its displacement input and force output. Assume thermal activation of the SMA by electrical heating utilizing a voltage input and the actual wire resistance given by the block.
6. Find an appropriate voltage amplitude input for the SMA actuator to ensure full opening and closing of the valve while not overheating the wire (T_{sma}<150°C).
7. Evaluate the overall SMA valve performance and compare it to the solenoid based system. How could a position monitoring be implemented in both cases?

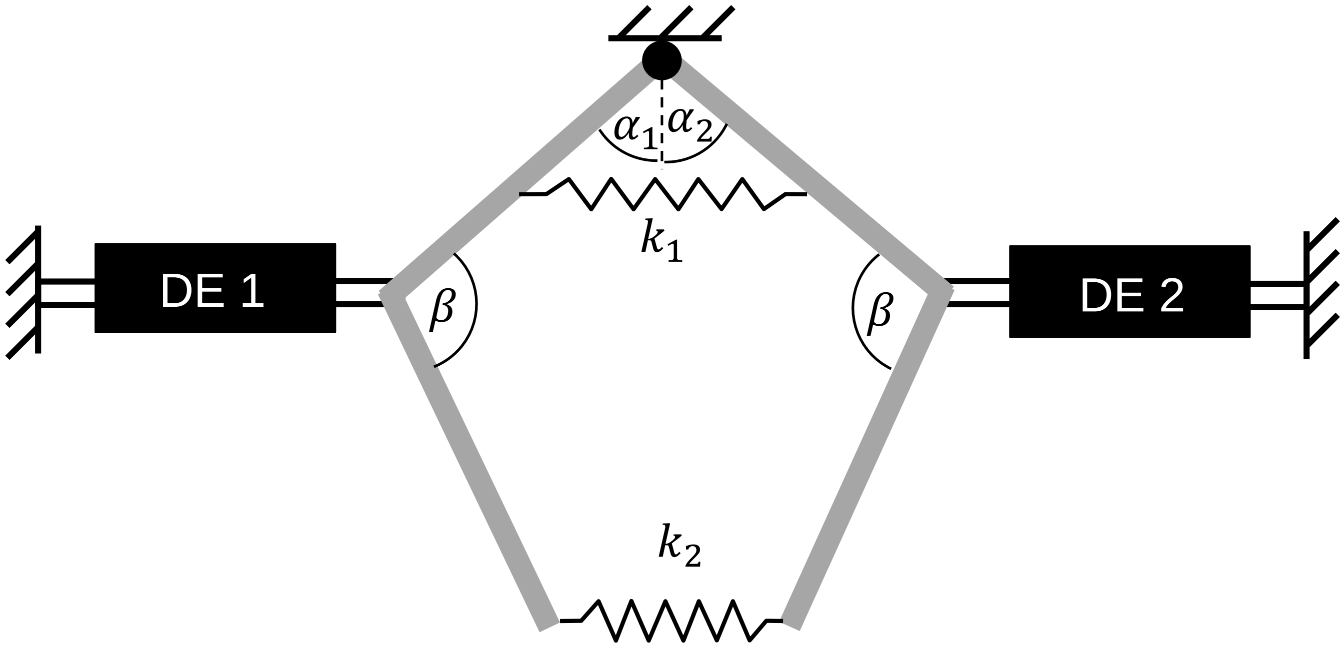
ASIM 3 – Exam overview

Task 1: SMA valve

Task 2: DEA gripper

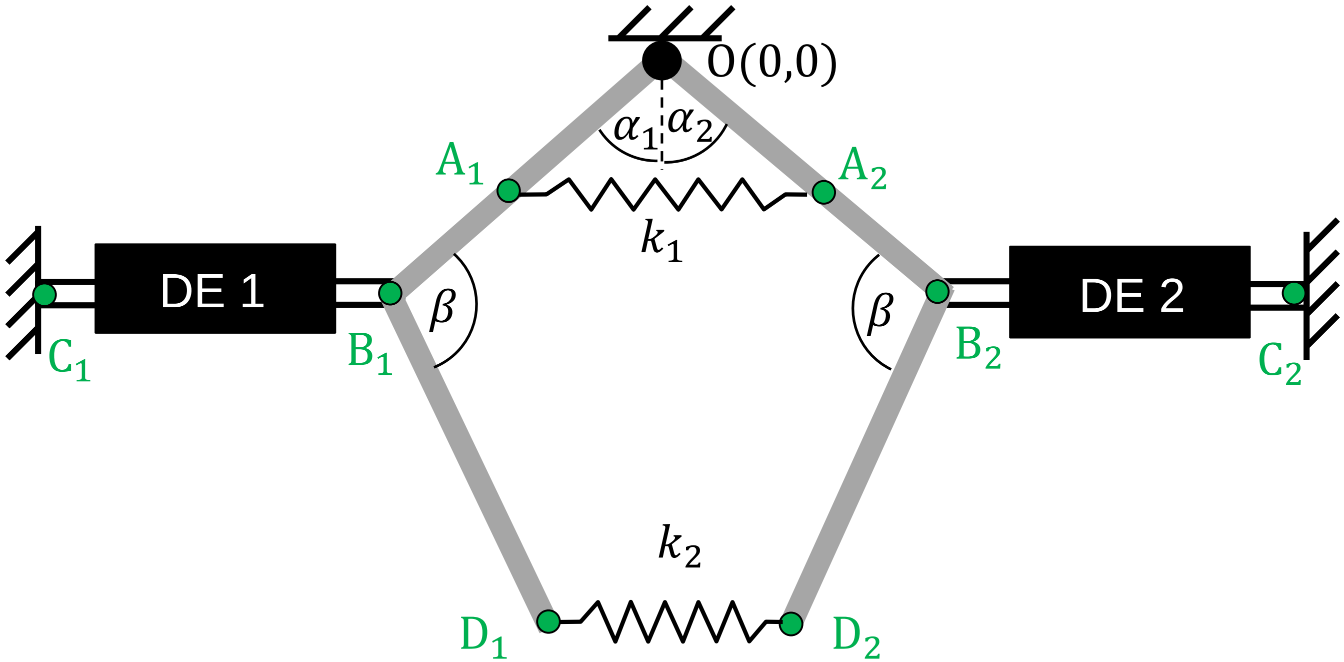


Task 2: DEA gripper



- Gripper actuated by DEAs
- consists of 2 DEA strips and a complex geometry
- Modeling the complex geometry with the Euler Lagrange formalism and couple with Simulink DE block

Task 2: DEA gripper



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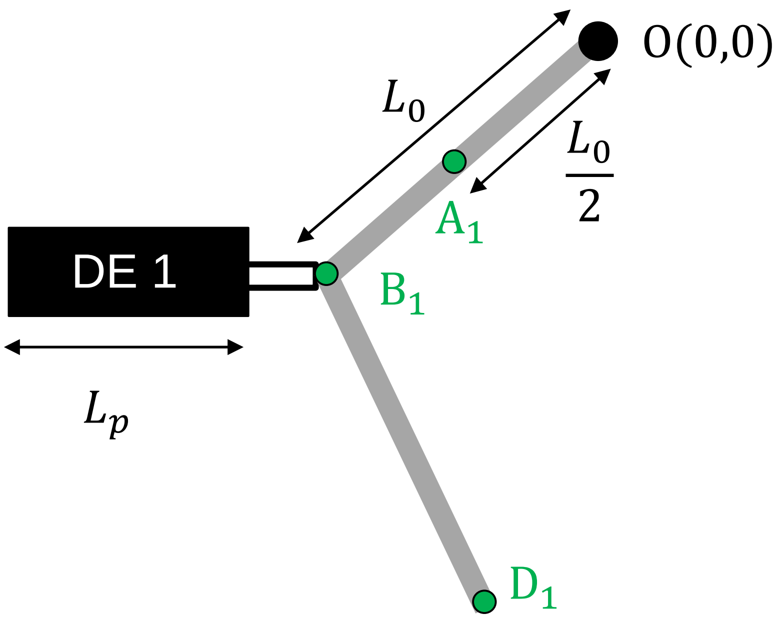
Task 2: DEA gripper



- mass of each gripper arm $m = 0.001\ \mathrm{kg}$ as a point mass in B_1/ B_2
- DE biased to $L_p = 1.2 \cdot L_1$
- gripper arm angle $\beta = 110°$
- gripper arm length $L_0 = 0.1\ \mathrm{m}$
- spring stiffnesses $k_1 = 1000\ \mathrm{N/m}$ and $k_2 = 200\ \mathrm{N/m}$
- spring biasing $d_{0,1} = 0.05\ \mathrm{m}$ and $d_{0,2} = 0.1\ \mathrm{m}$
- initial angles $\alpha_1 = \alpha_2 = 45°$
- α_1 and α_2 represent the internal variables q_i for the Euler Lagrange formalism

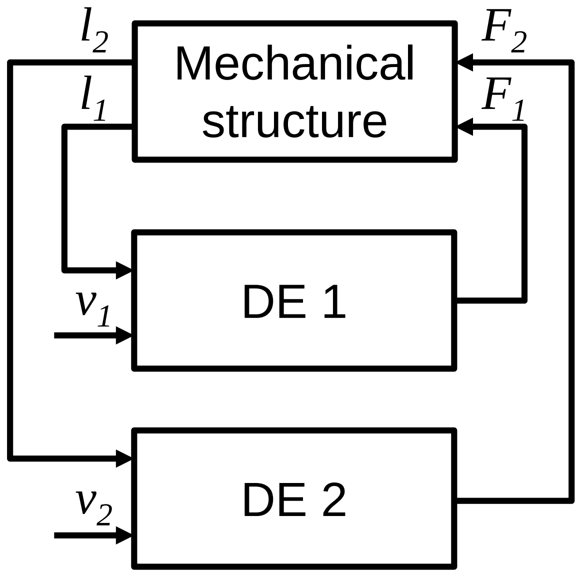
Task 2: DEA gripper

Given the Matlab script Parameter.m, the Matlab s-function sDE_displn.m and the Simulink file DEA.slx

1. Calculate all coordinates $\mathrm{A_i}, \mathrm{B_i}, \mathrm{C_i}$ and $\mathrm{D_i}$ in dependency of the gripper angles α_i. In order to validate the coordinates, plot all points into a Matlab figure and check if the resulting structure is correct for different angles α_i and β. (hint: the command “axis equal” equalizes the axis scaling)
2. Use the Euler Lagrange formalism in order to identify the equation of motion of the gripper. Calculate the DE lengths l_i and the Jacobi matrix J in dependency of the system geometry. (hint: use the Matlab symbolic toolbox)
3. Define the overall Lagrangian function L which consists of the potential energies of the linear springs and the kinetic energy which is the rotational energy of both gripper arms.
4. Calculate the equation of motion as described in Lecture 8. Calculate all nontrivial derivatives by using the Matlab symbolic toolbox.
5. Implement the mechanical structure into a Simulink model, starting with a Matlab fcn block which transforms global forces F to internal forces τ_i and a Matlab fcn block which transforms internal variables q_i to global displacements l_i.
6. Implement the equation of motion which transforms τ_i to q_i. Use a Matlab fcn block for the computation of the symbolic toolbox calculated part.

Task 2: DEA gripper

7. Combine the Simulink model which represent the mechanical structure with the DEA blocks



8. For model validation, neglect the second spring by choosing $k_2 = 0$. Run the model and monitor the angles α_i . Choose for the $3000\ \mathrm{V}$ input voltage of the DEAs a pulse function with a period of $10\ \mathrm{s}$ and a duty cycle of $50\ \%$. Simulate 5 cycles. In order to validate the model, actuate only DE 1, then actuate only DE 2 and compare both results. Due to the symmetric model structure, both simulations should yield the same results.

9. Run the model with both DEAs actuated together. Evaluate the system performance concerning the gripper angles.

Task 2: DEA gripper

10. Re-enable the second spring, evaluate the performance of the model and compare the results to the previous simulation. Add a computation of the gripper force by using the displacement of the second spring during actuation.
11. Optimize the product of gripper force and gripper angle by varying the gripper arm angle β in a meaningful range.
12. Discuss whether or not an energy harvesting implementation of this system is meaningful. How could an implementation be performed? If necessary, provide simulation results.

Presentation

- Structure: „An engineer with basic knowledge about smart materials has to be able to understand your presentation!“
  - short introduction of the exam topic
  - explanation of model structure/composition
  - discussion of results based on given exercises
- Length:
  - presentation: 20 min. (longer presentation not allowed!)
  - questions: 20-25 min.
- Date: 22.03. starting from 10:00 **at ZeMA**
- Teams of two students:
  - presentation split in half
  - questions both at the same time
- Registration: via LSF + an email to us, stating your group partner