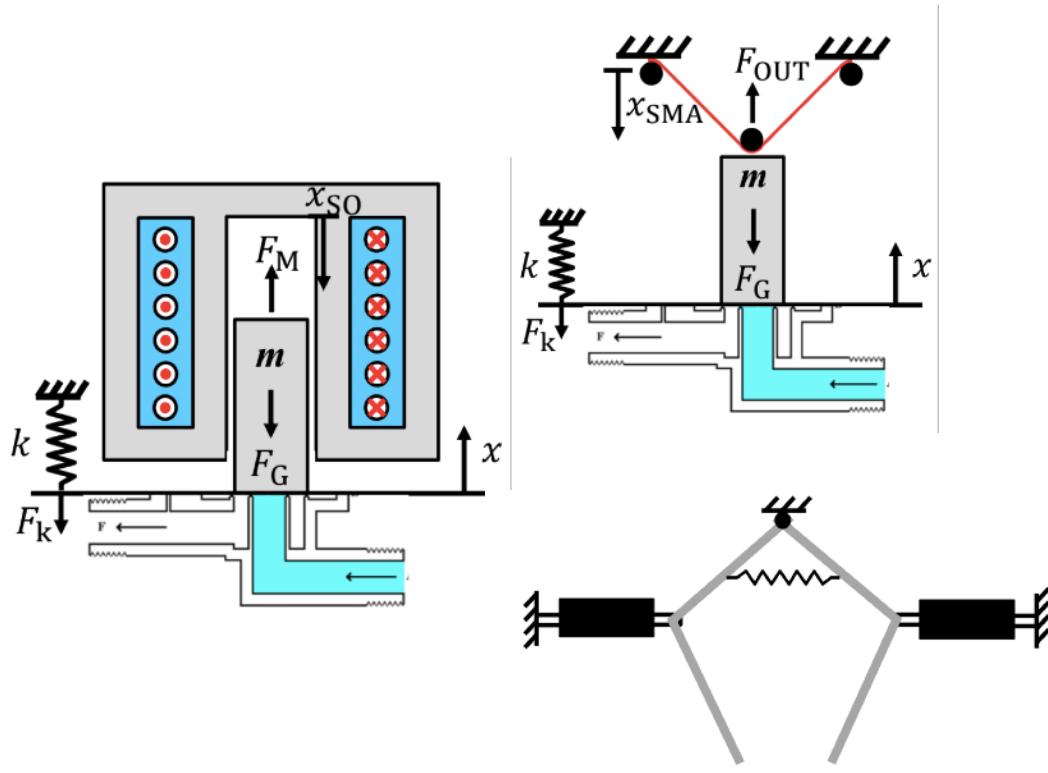


Aktorik und Sensorik intelligenter Materialsysteme 3



Matthias Baltes

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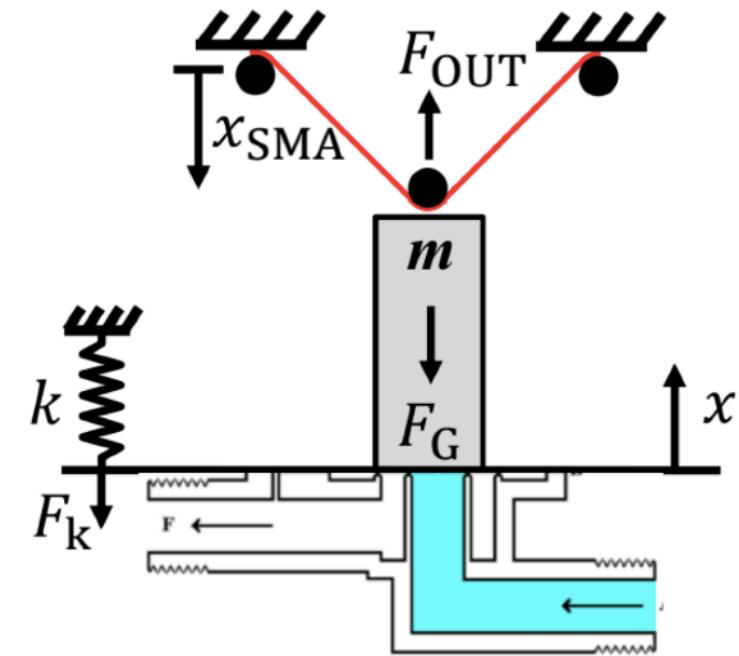
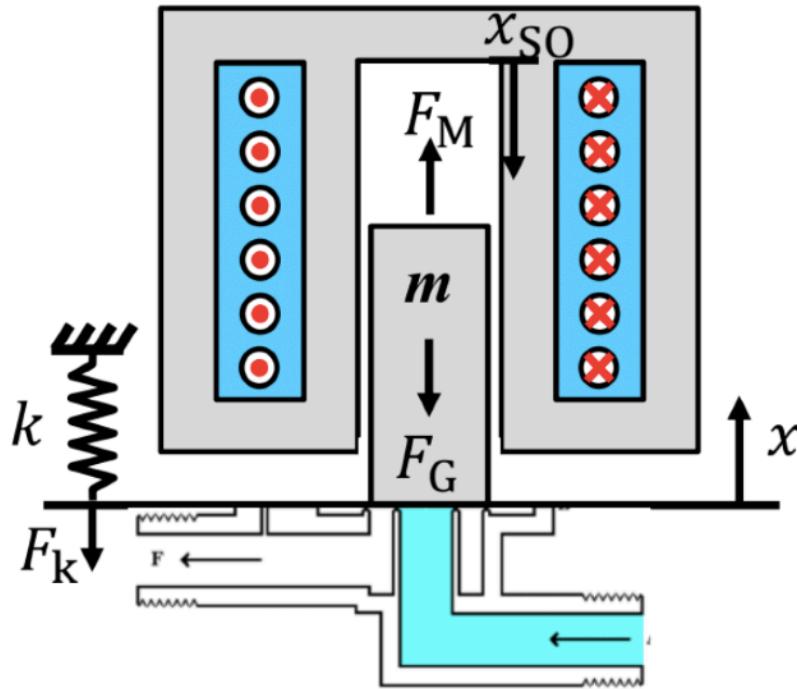
Marius Jank

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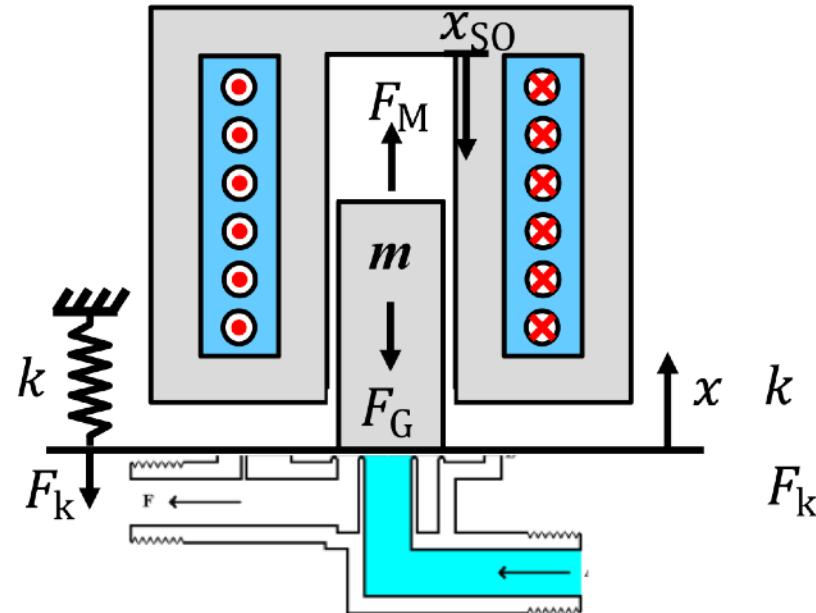
Tim Goll

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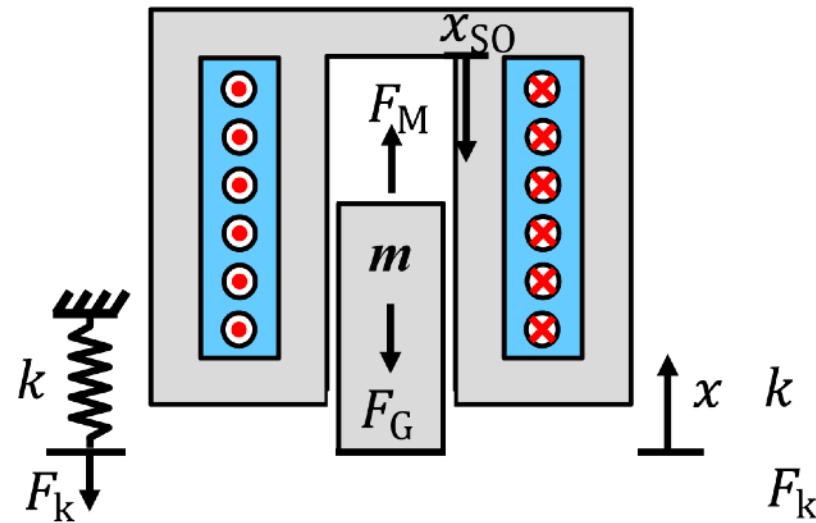
Task 1 - Valve (Solenoid vs SMA)



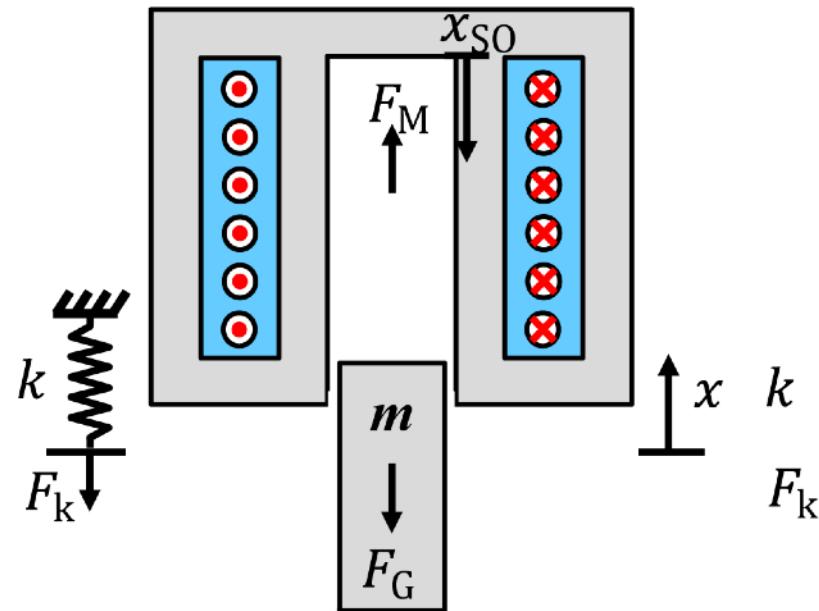
Why doesn't this valve work?



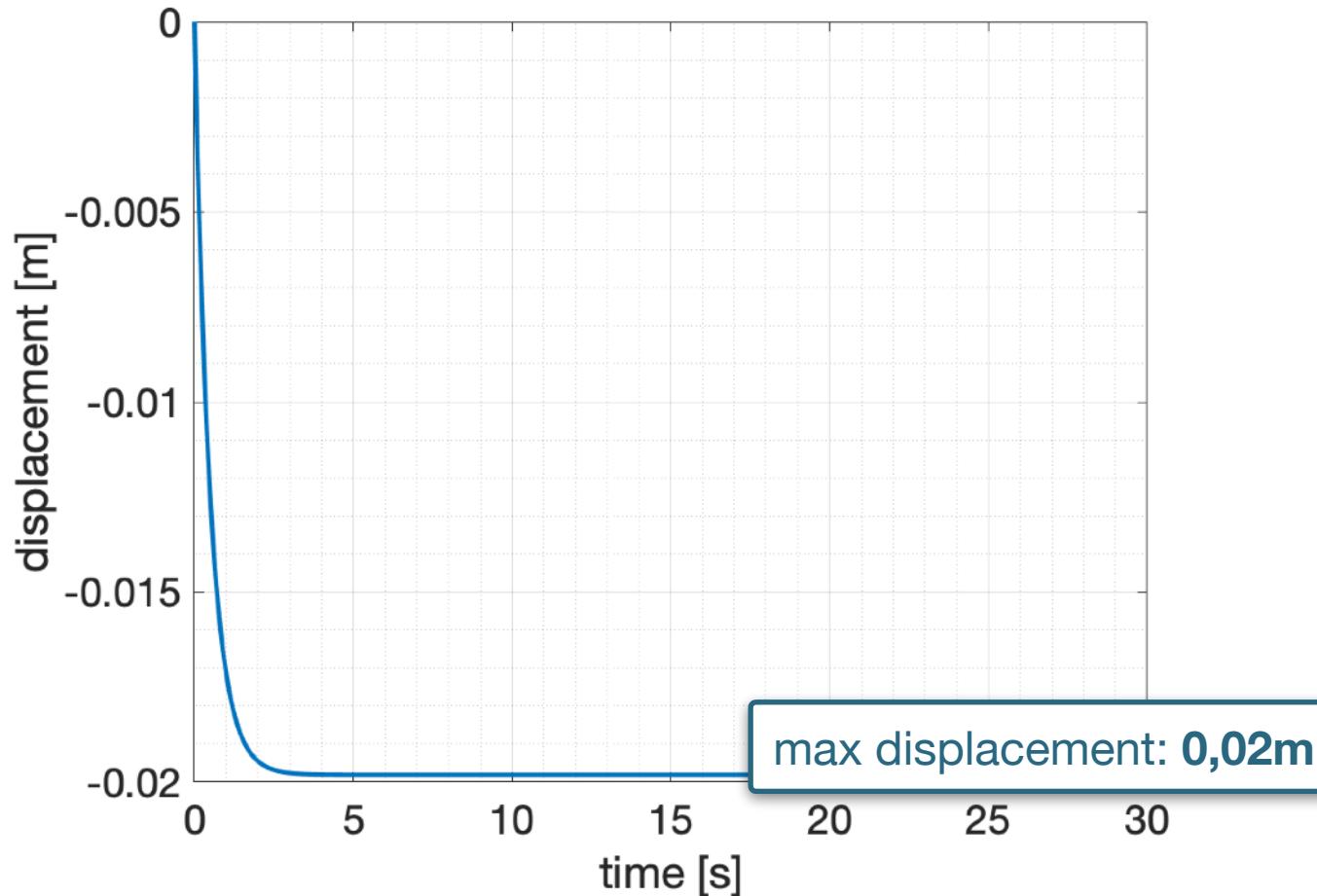
Why doesn't this valve work?



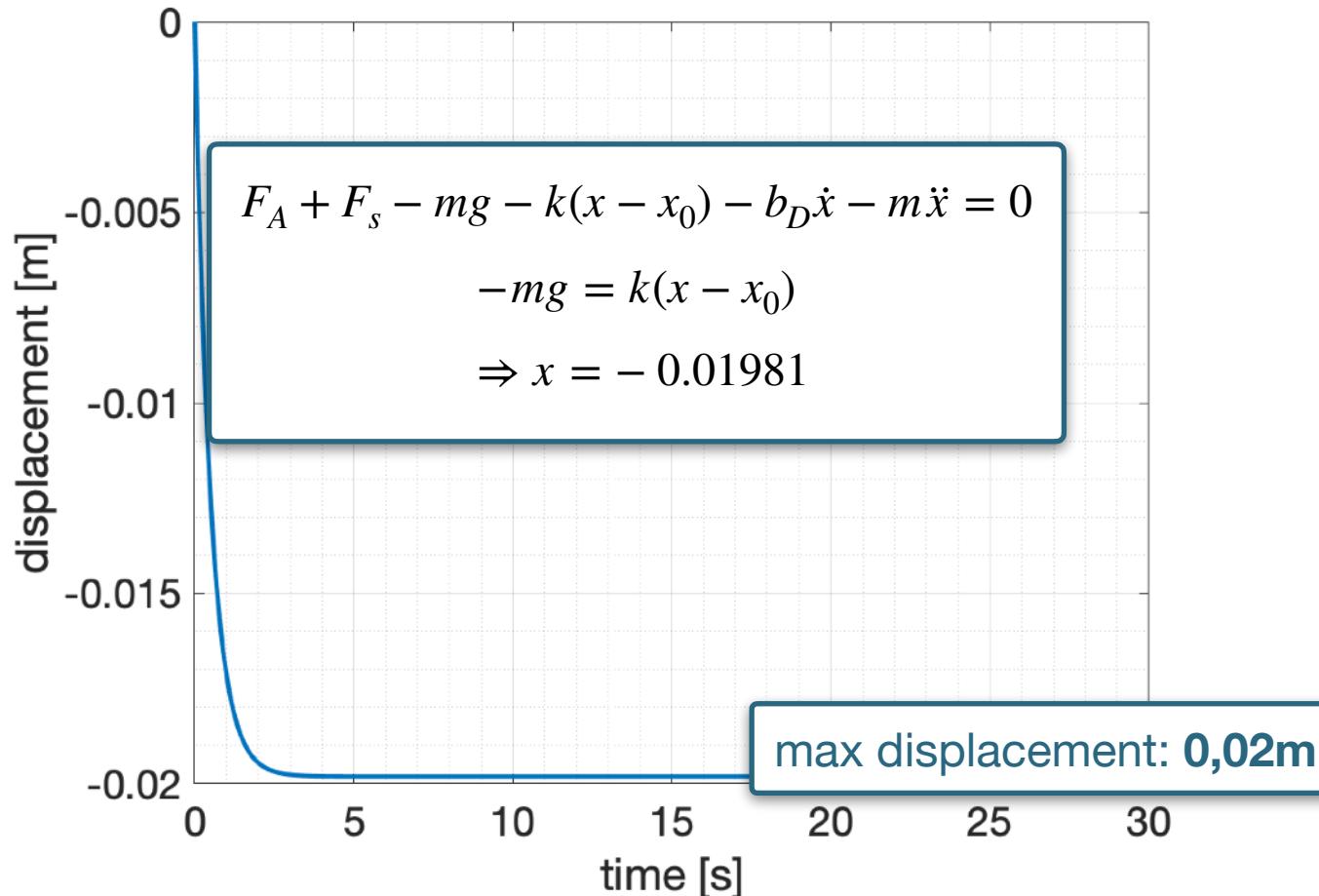
Why doesn't this valve work?



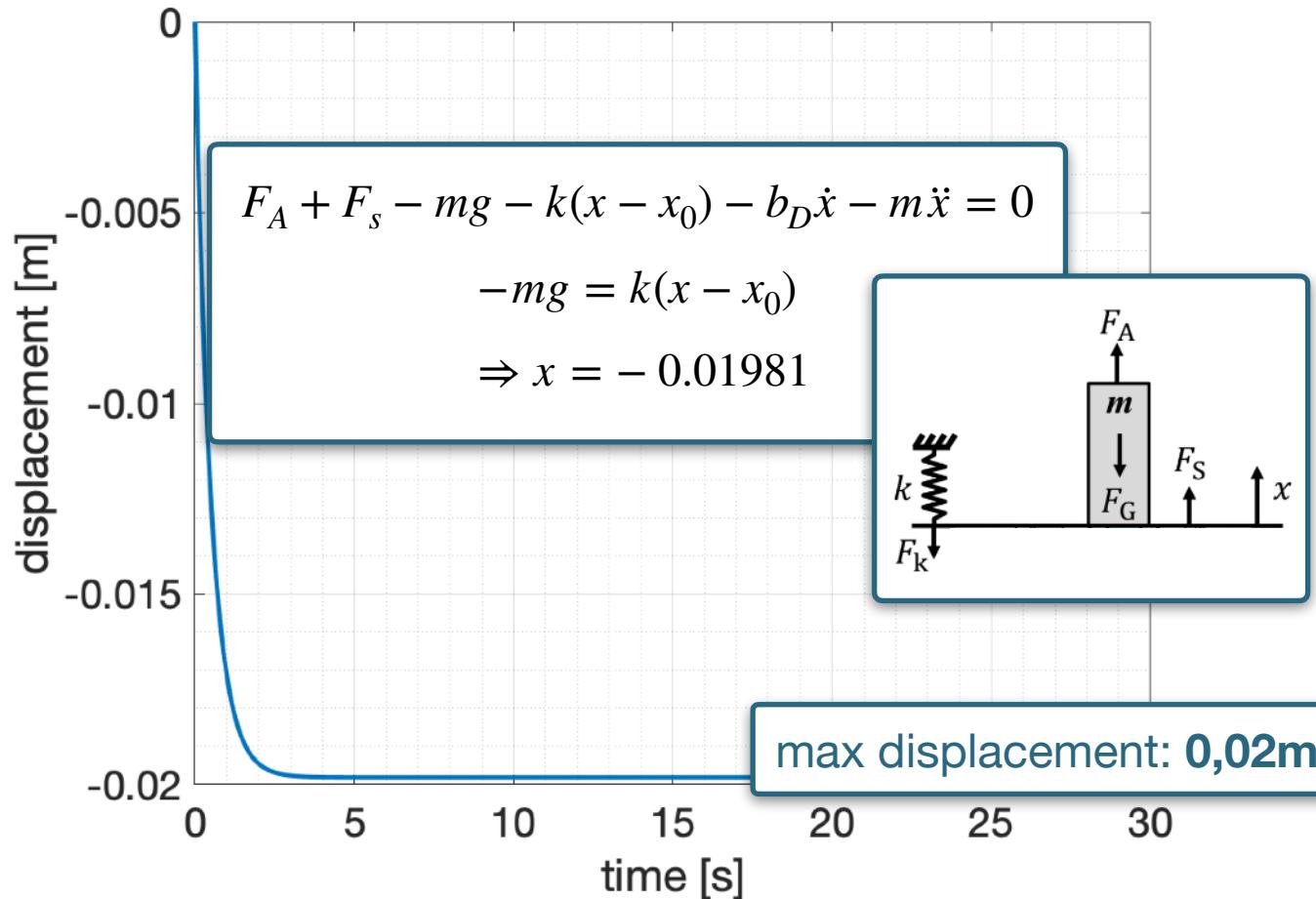
Solonoid Displacement with no applied Voltage



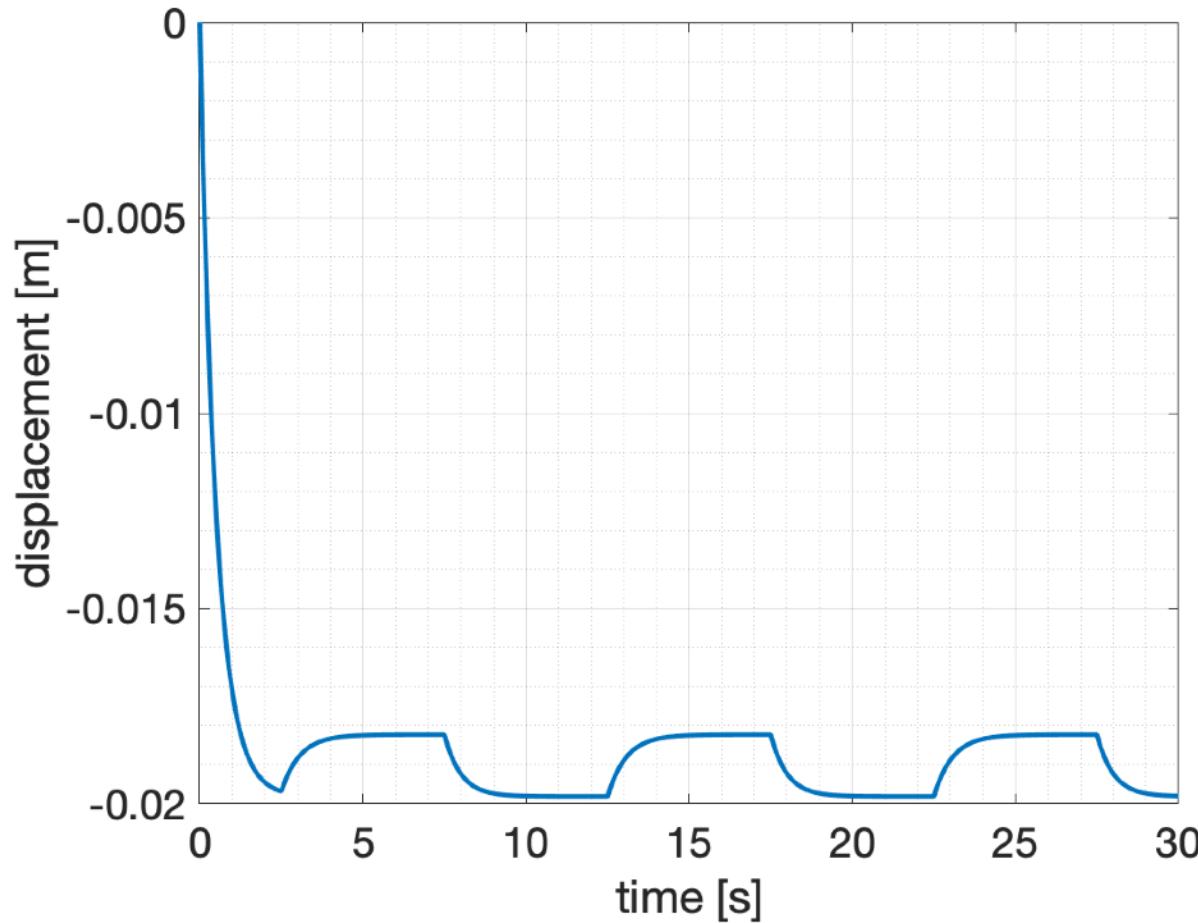
Solonoid Displacement with no applied Voltage



Solonoid Displacement with no applied Voltage

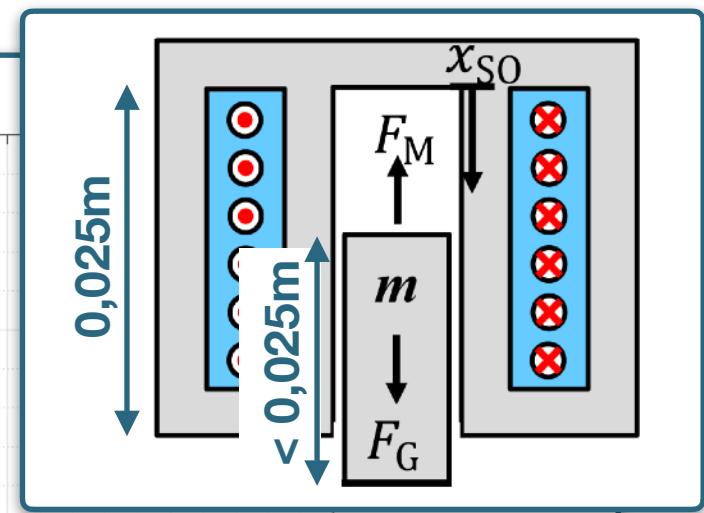
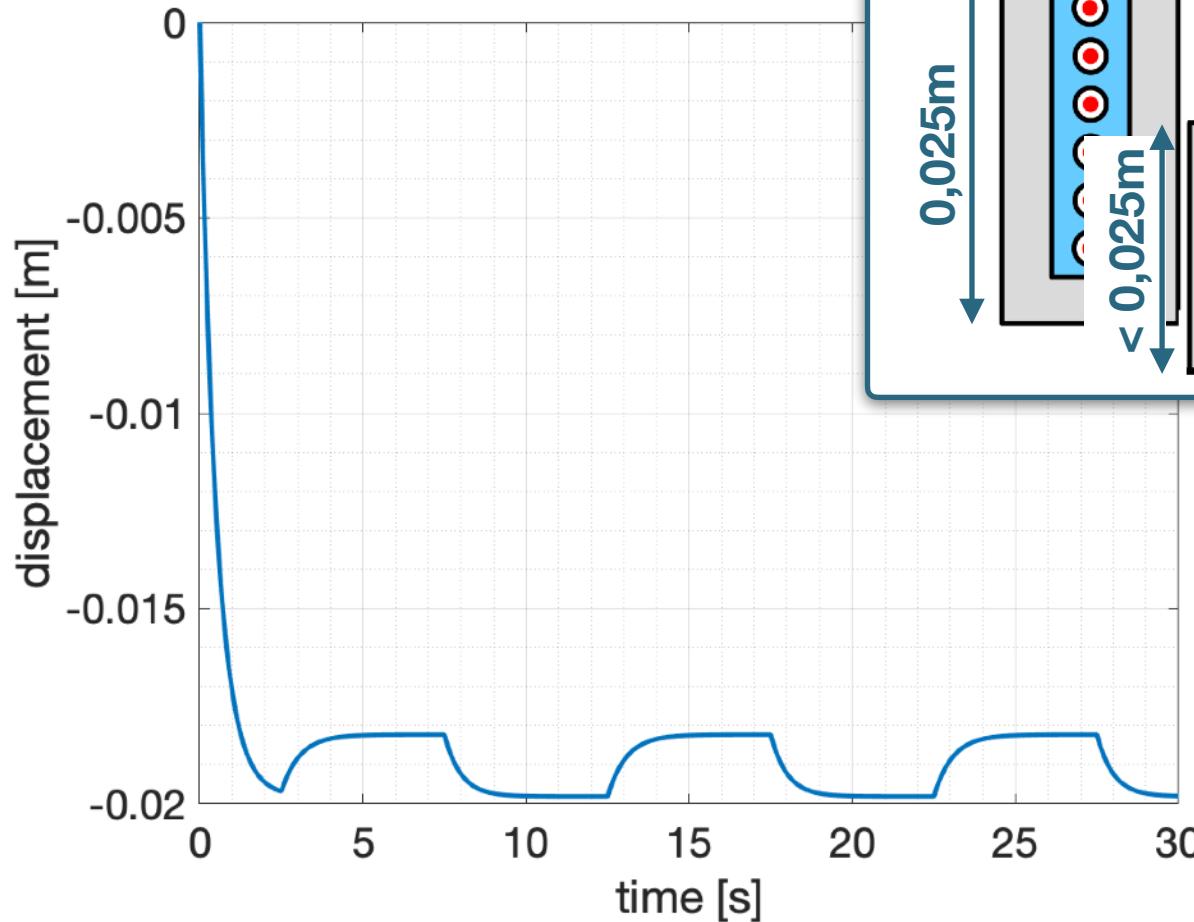


Solonoid Displacement

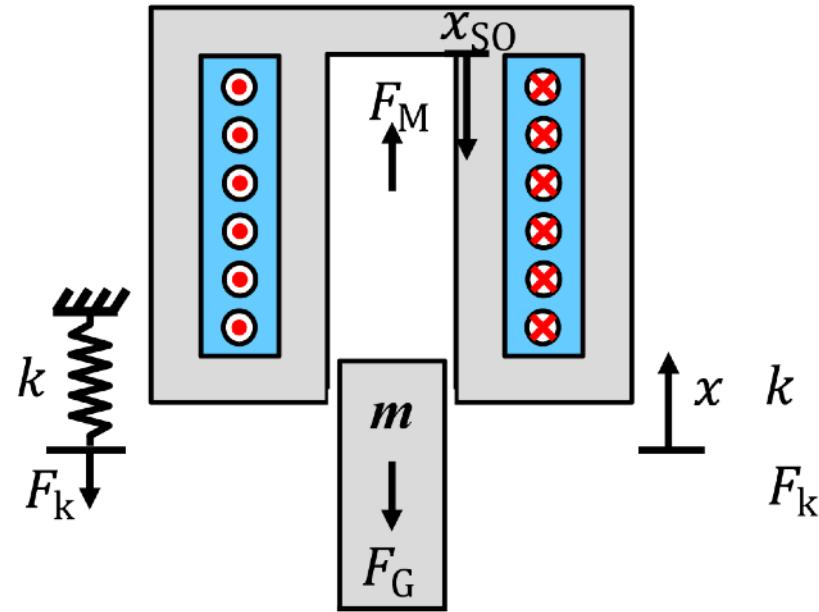


Task 1.1 - Solonoid Tests

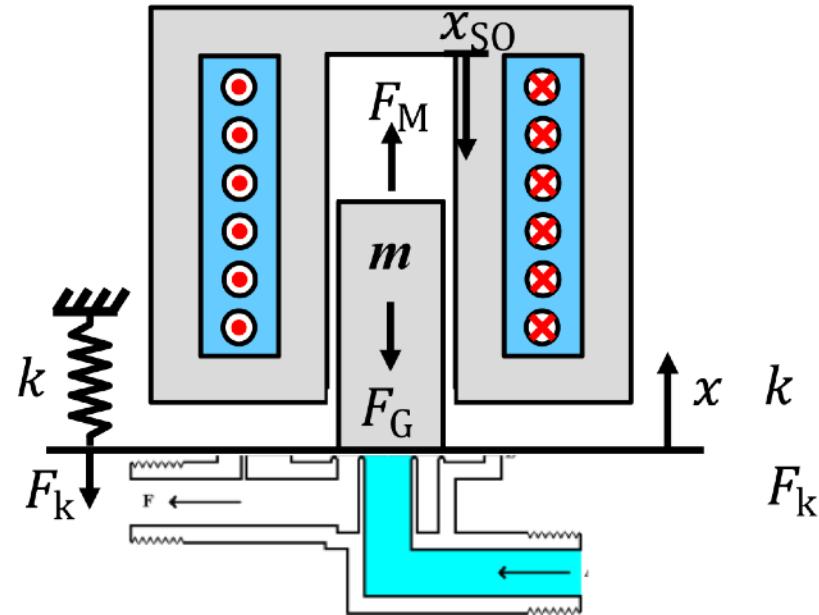
Solenoid Displacement



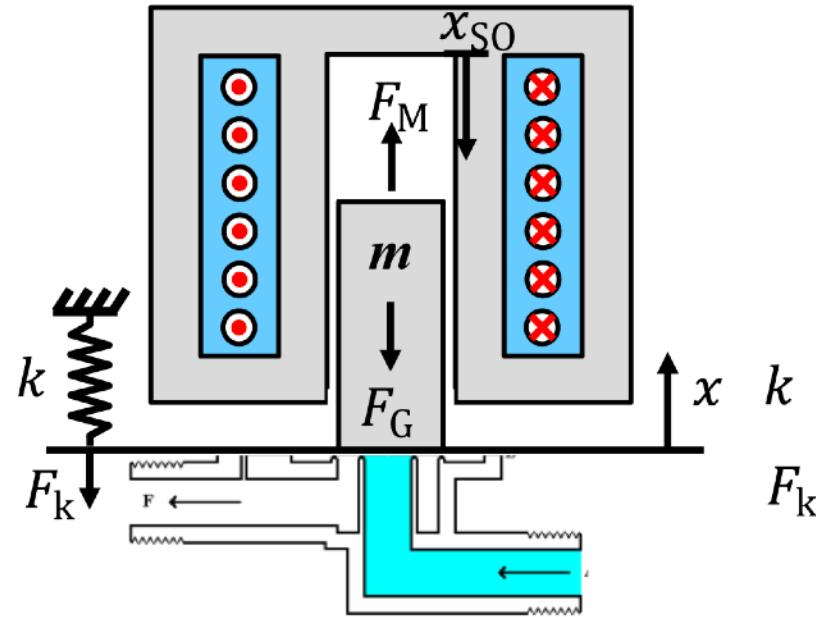
Task 1.2 - Solonoid Fixing



Task 1.2 - Solonoid Fixing



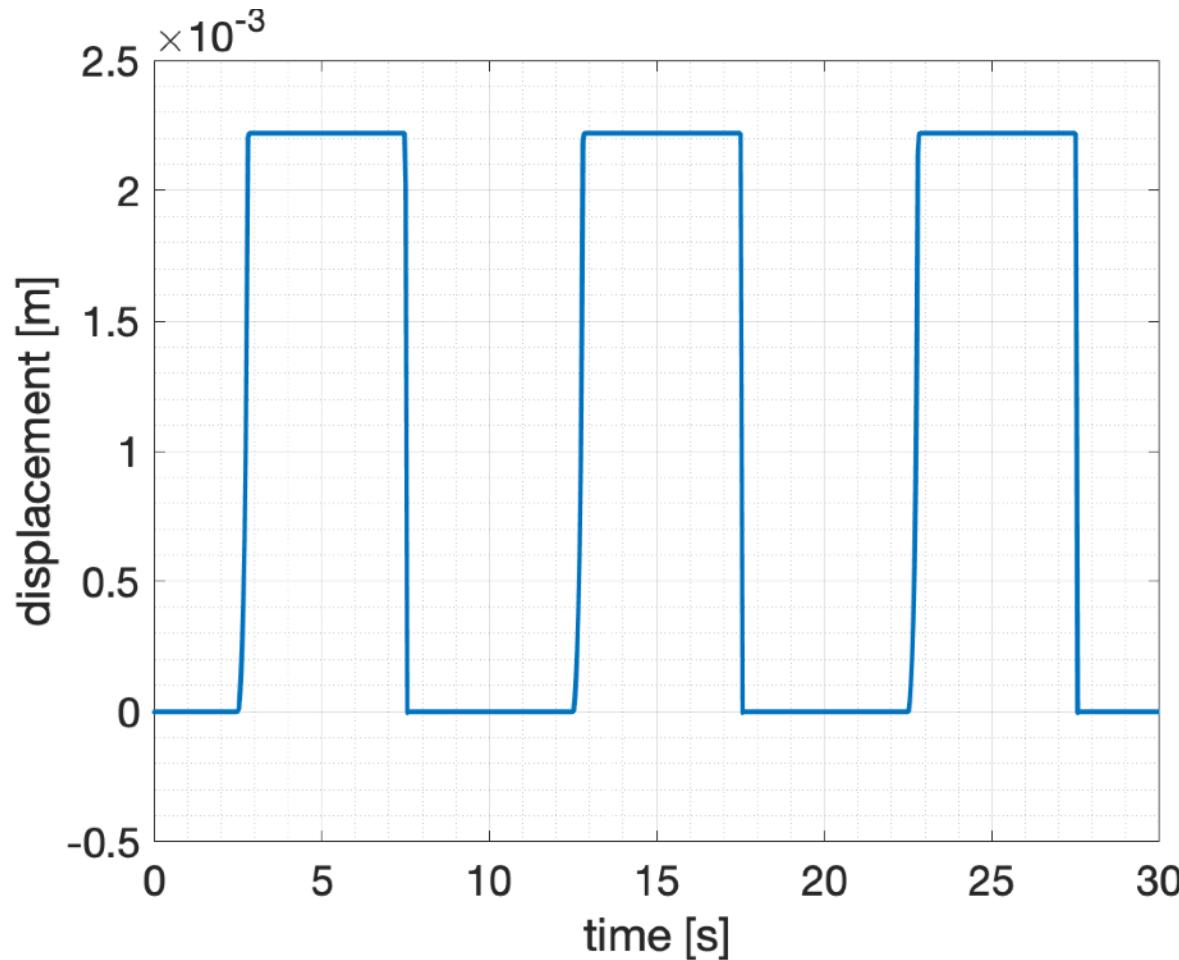
Task 1.2 - Solonoid Fixing



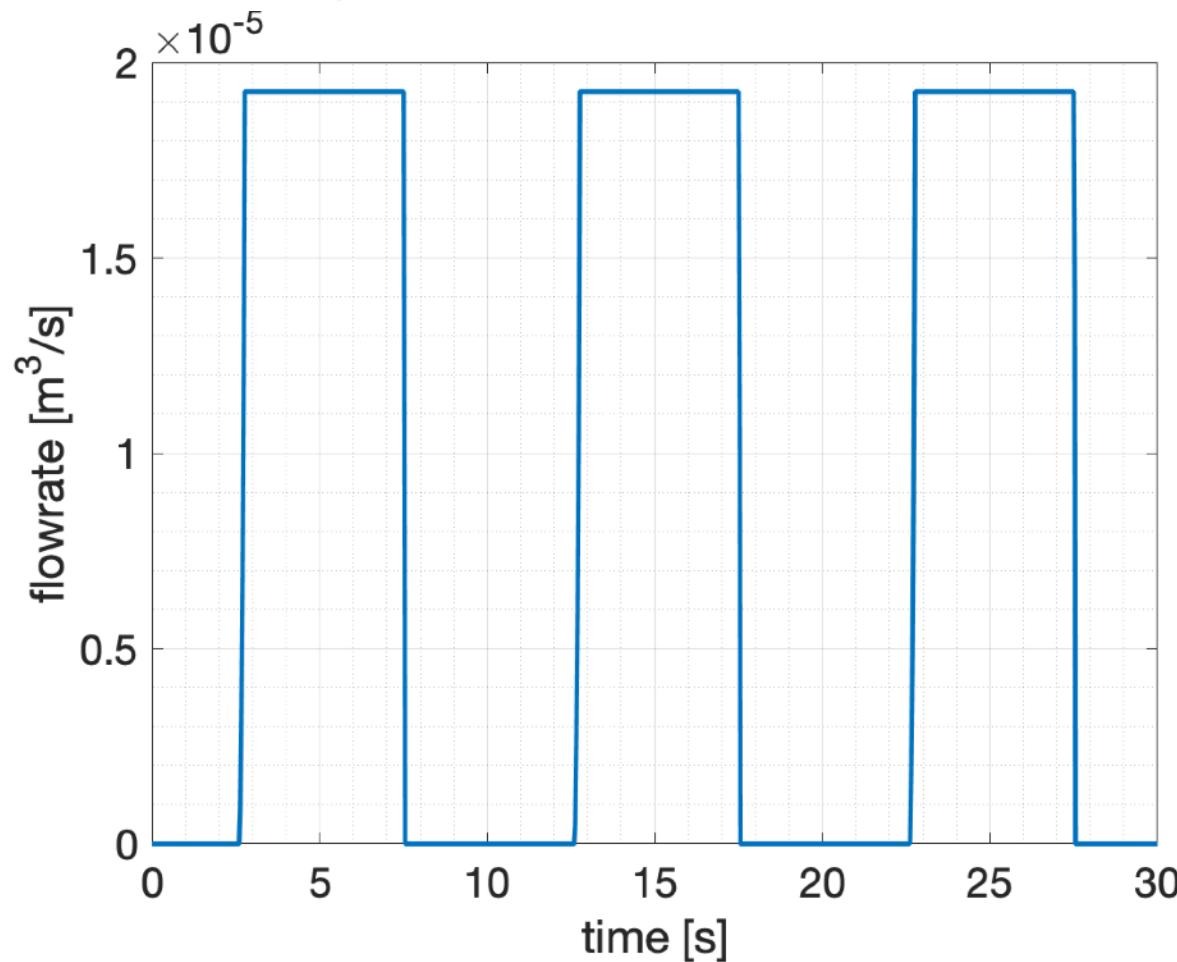
Hardstop

$$F_s(x) = 1\text{N} \cdot \exp(-10^6 \frac{1}{\text{m}} \cdot x)$$

Solenoid working Displacement



Solenoid working Flowrate





Thermal Mass of Solonoid Body

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



Thermal Mass of Solonoid Body

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

Together with these Equations

$$V_{case} \approx \frac{\pi}{4} * D_{case}^2 \cdot L_{case} \quad A_{case} = \pi \cdot D_{case} \cdot L_{case} + \frac{\pi}{2} \cdot D_{case}^2$$

Thermal Mass of Solonoid Body

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

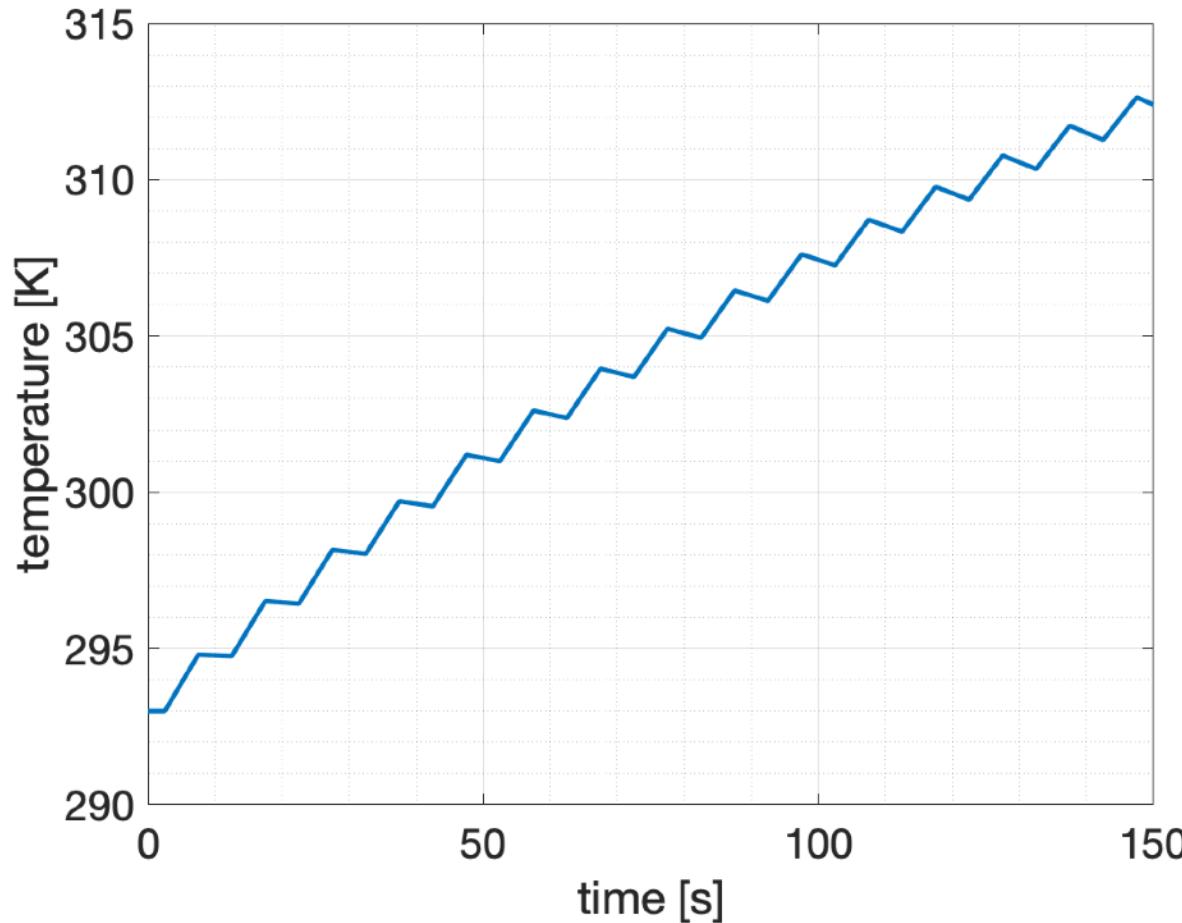
Together with these Equations

$$V_{case} \approx \frac{\pi}{4} * D_{case}^2 \cdot L_{case} \quad A_{case} = \pi \cdot D_{case} \cdot L_{case} + \frac{\pi}{2} \cdot D_{case}^2$$

Resulting Temperature Equation

$$T = \int \frac{P_{conv} \cdot P_{ele}}{C \cdot \delta \cdot V_{case}} dt \quad T_0 = 293K$$

Solenoid Temperature



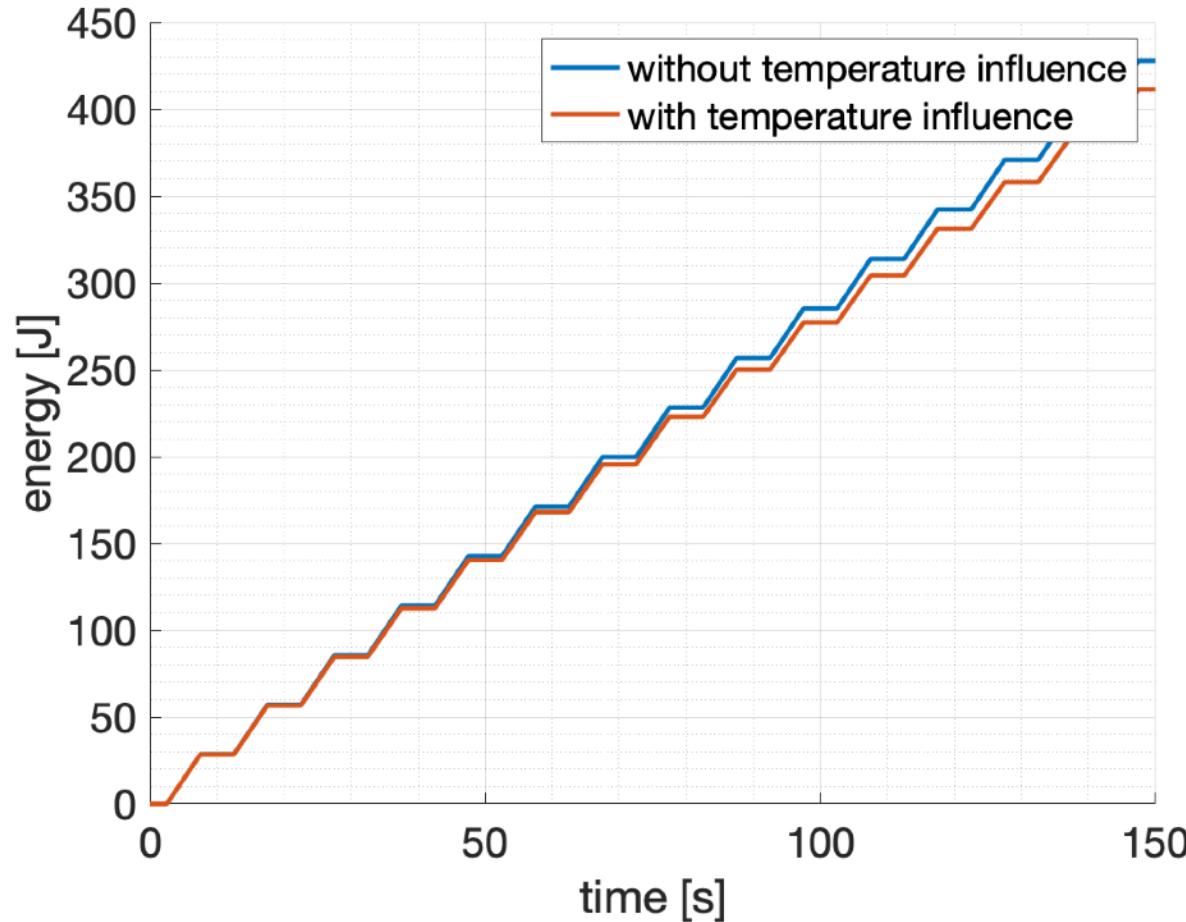


Coil Resistance in Dependency of the Temperature

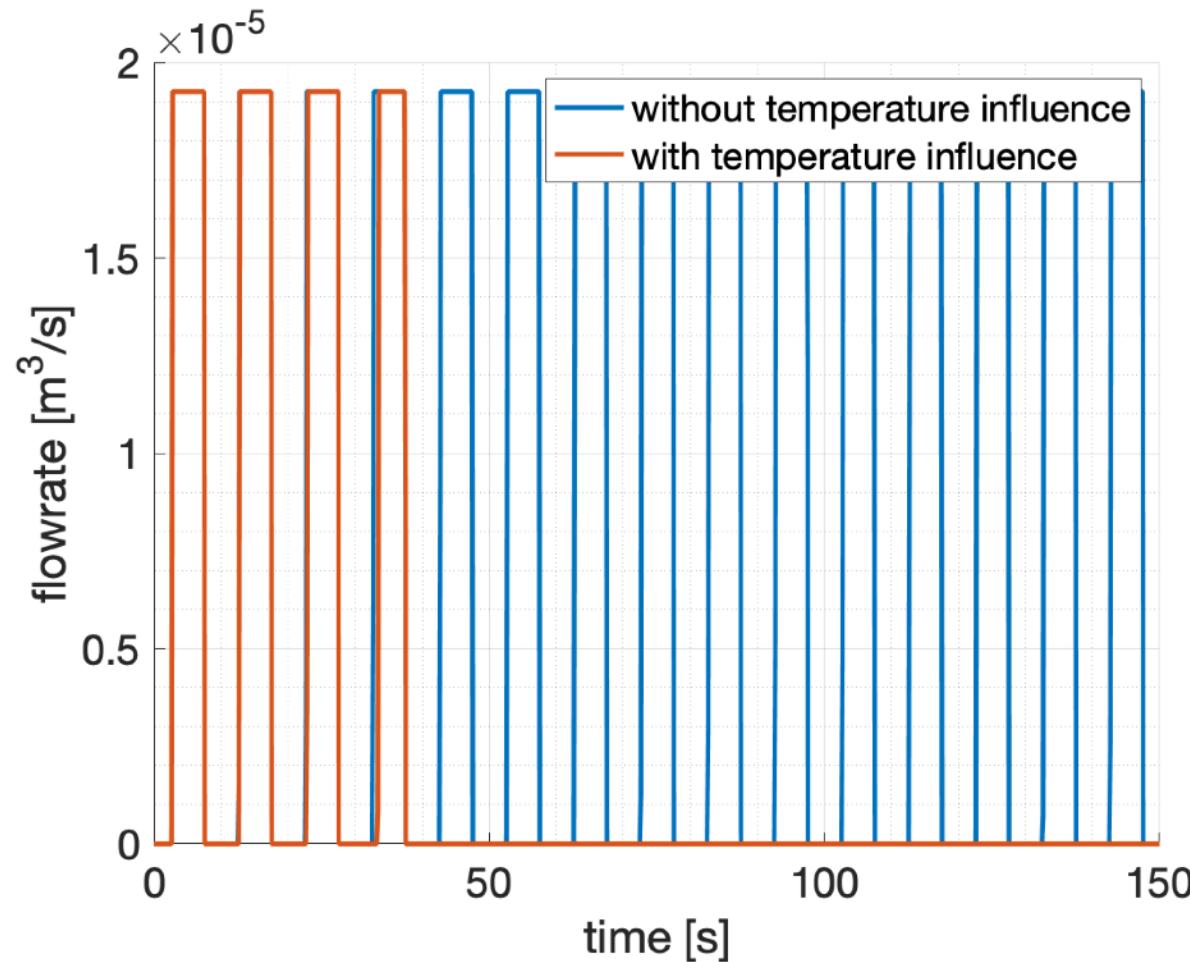
$$R(T) = \rho(T) \cdot \frac{L_{cu}}{A_{cu}} = \rho \cdot \frac{N \cdot \pi \cdot D_{cu}}{\frac{\pi}{4} \cdot d_{cu}^2}$$

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

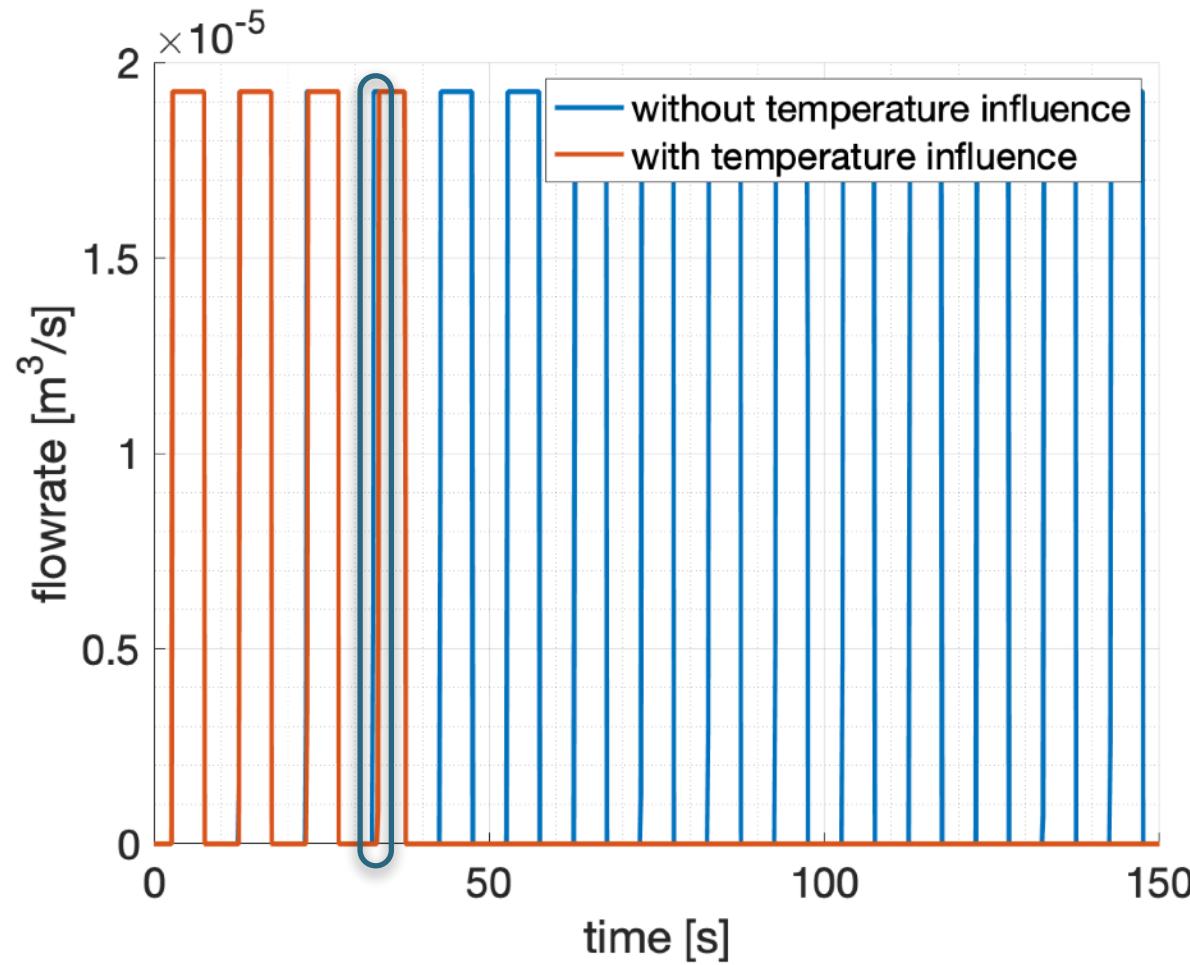
Energy Consumption



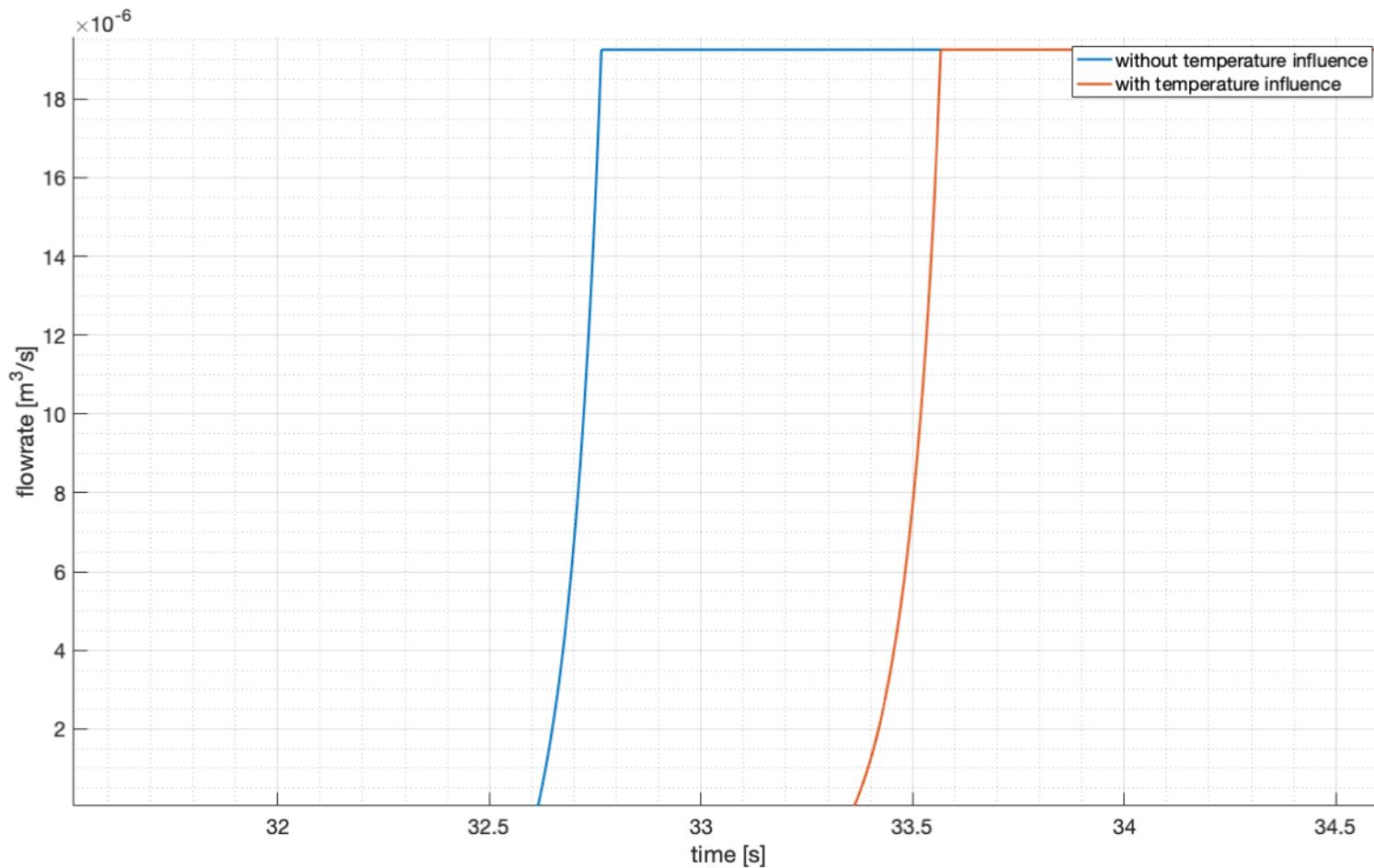
Flow Rate



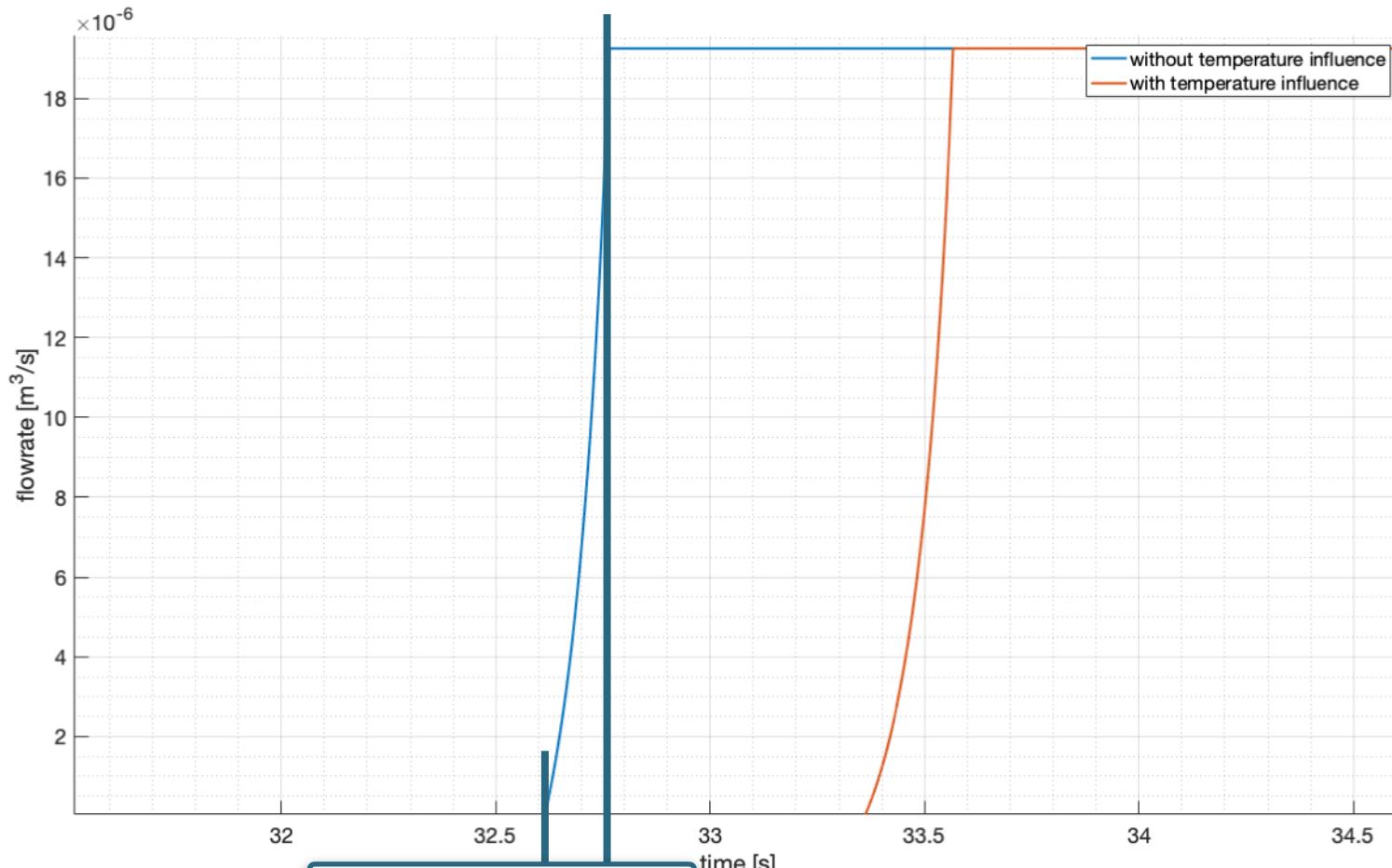
Flow Rate



Flow Rate

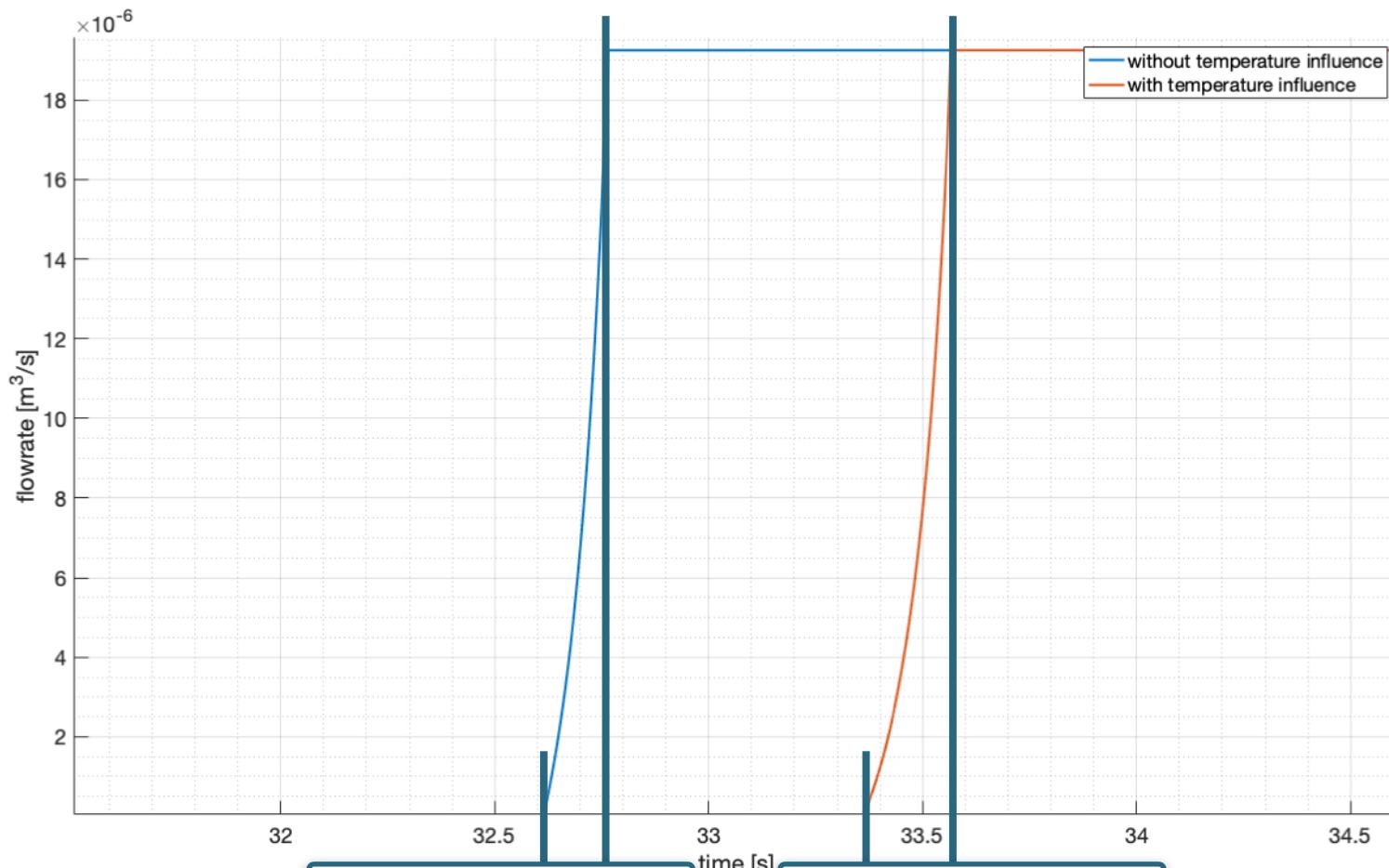


Flow Rate



rising time: 0,15s

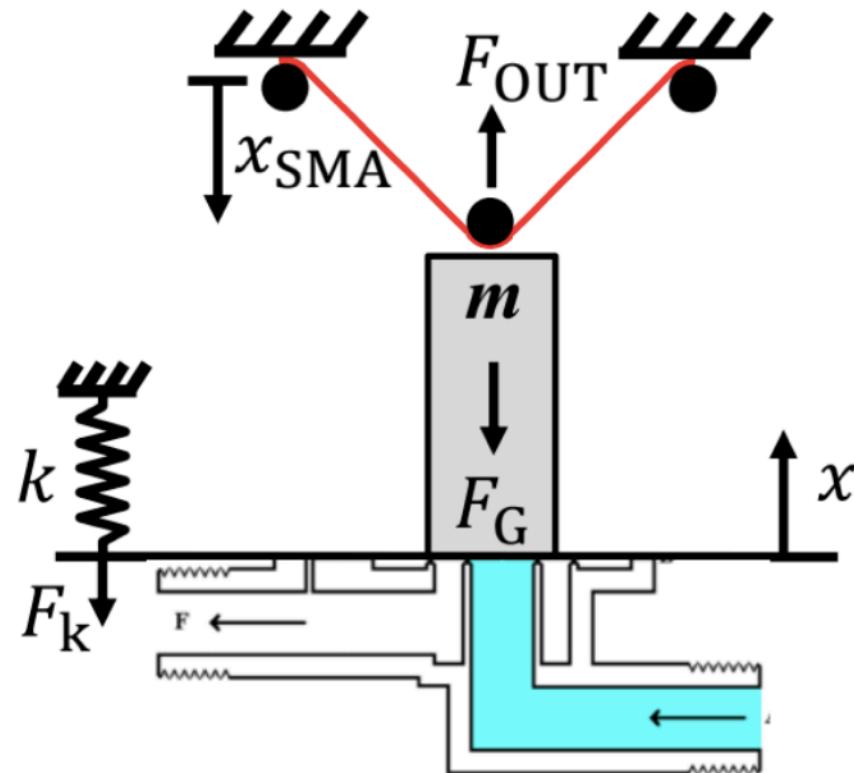
Flow Rate



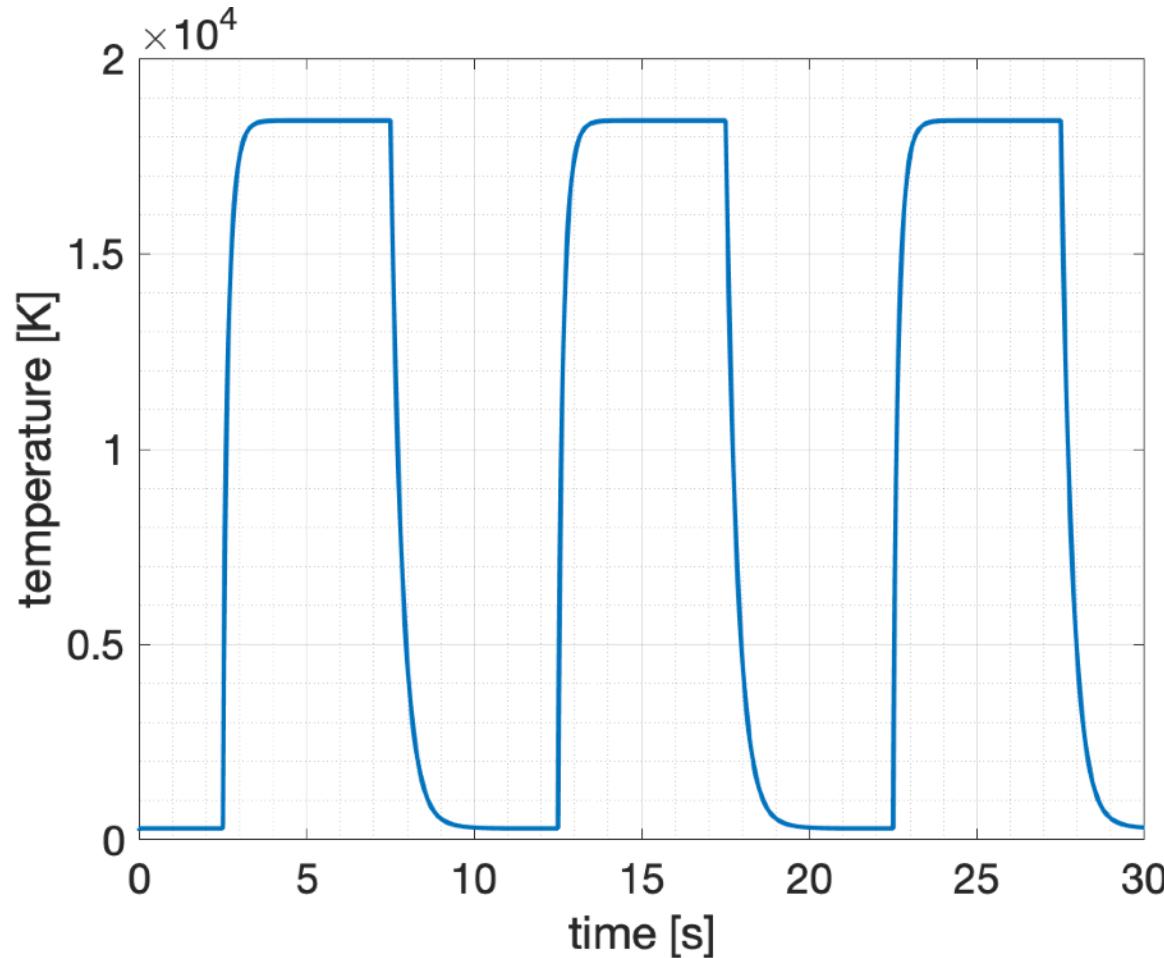
rising time: 0,15s

rising time: 0,20s

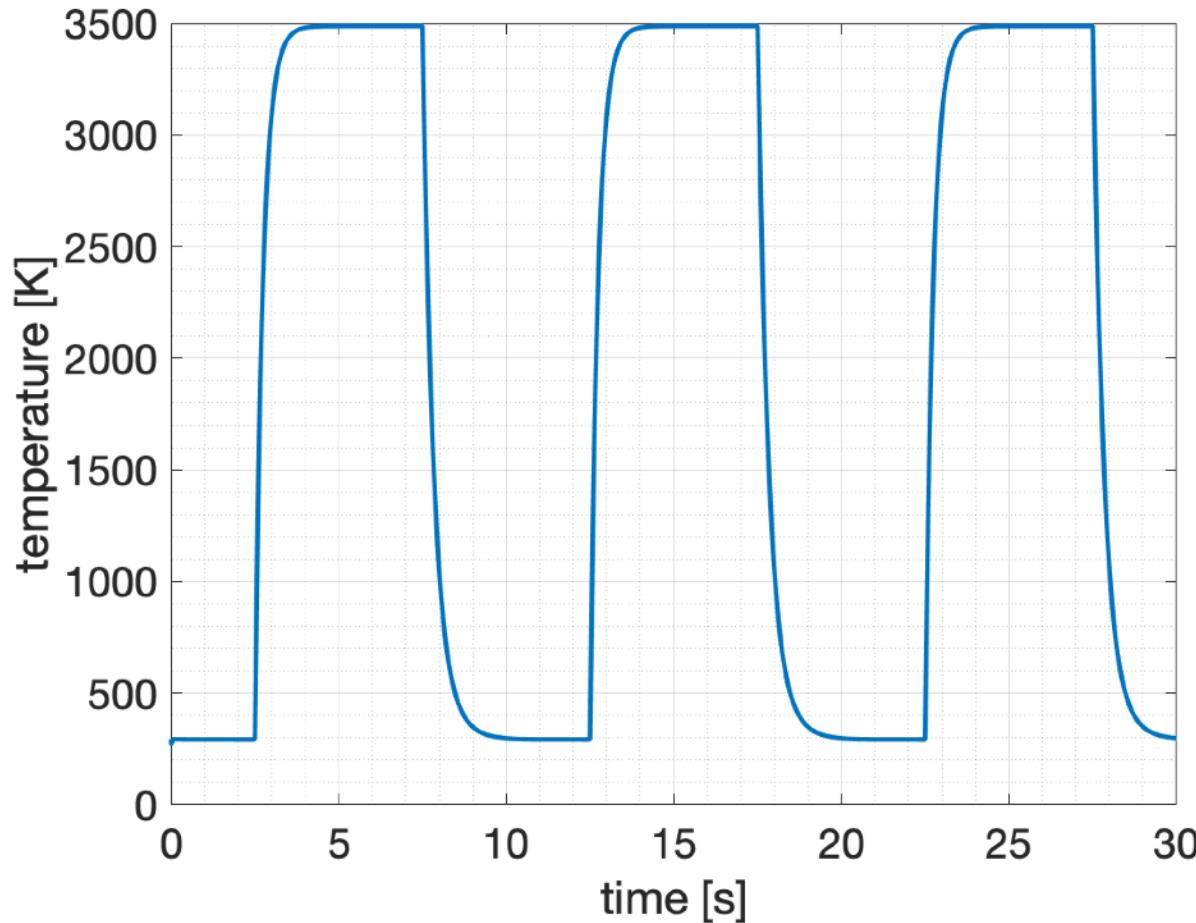
1.5 - SMA Valve

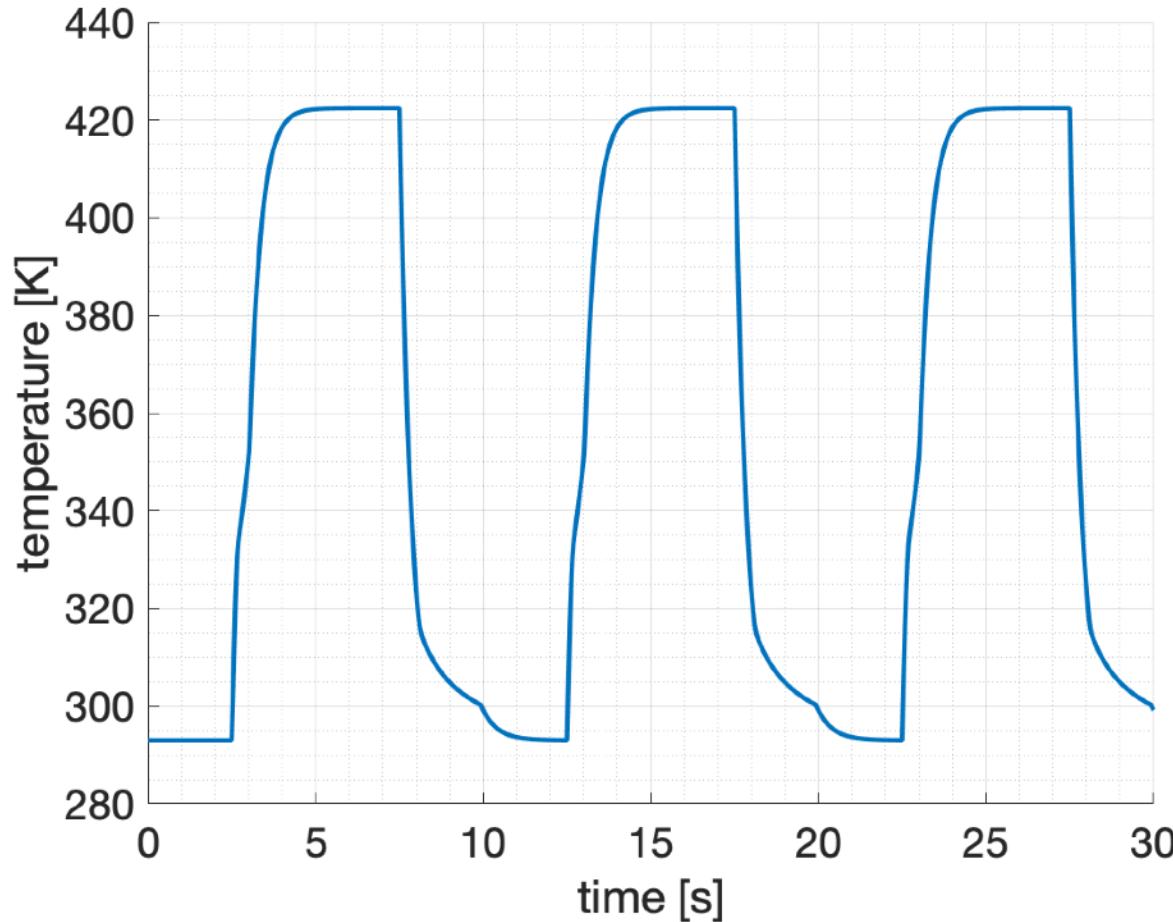


Temperature at U=12V

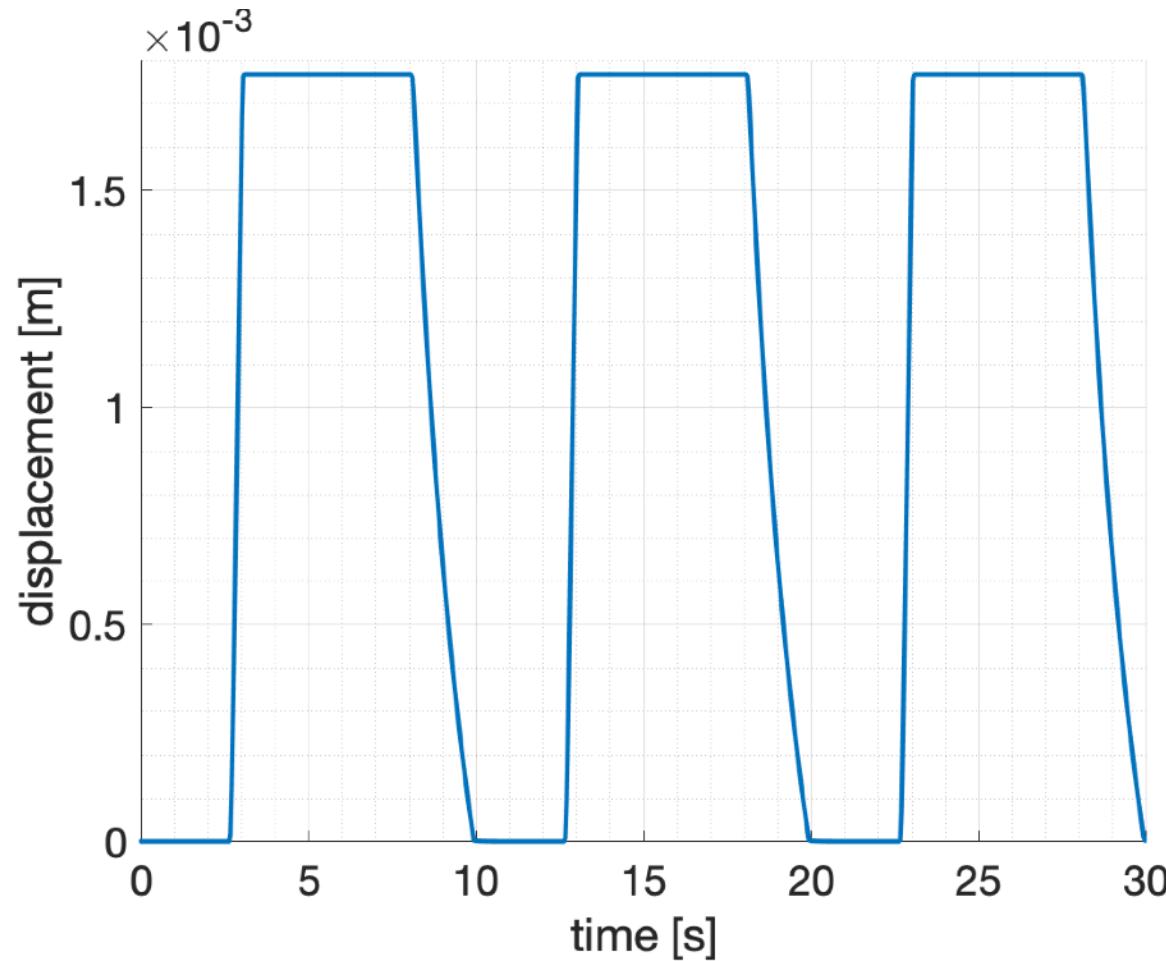


Temperature at U=3V

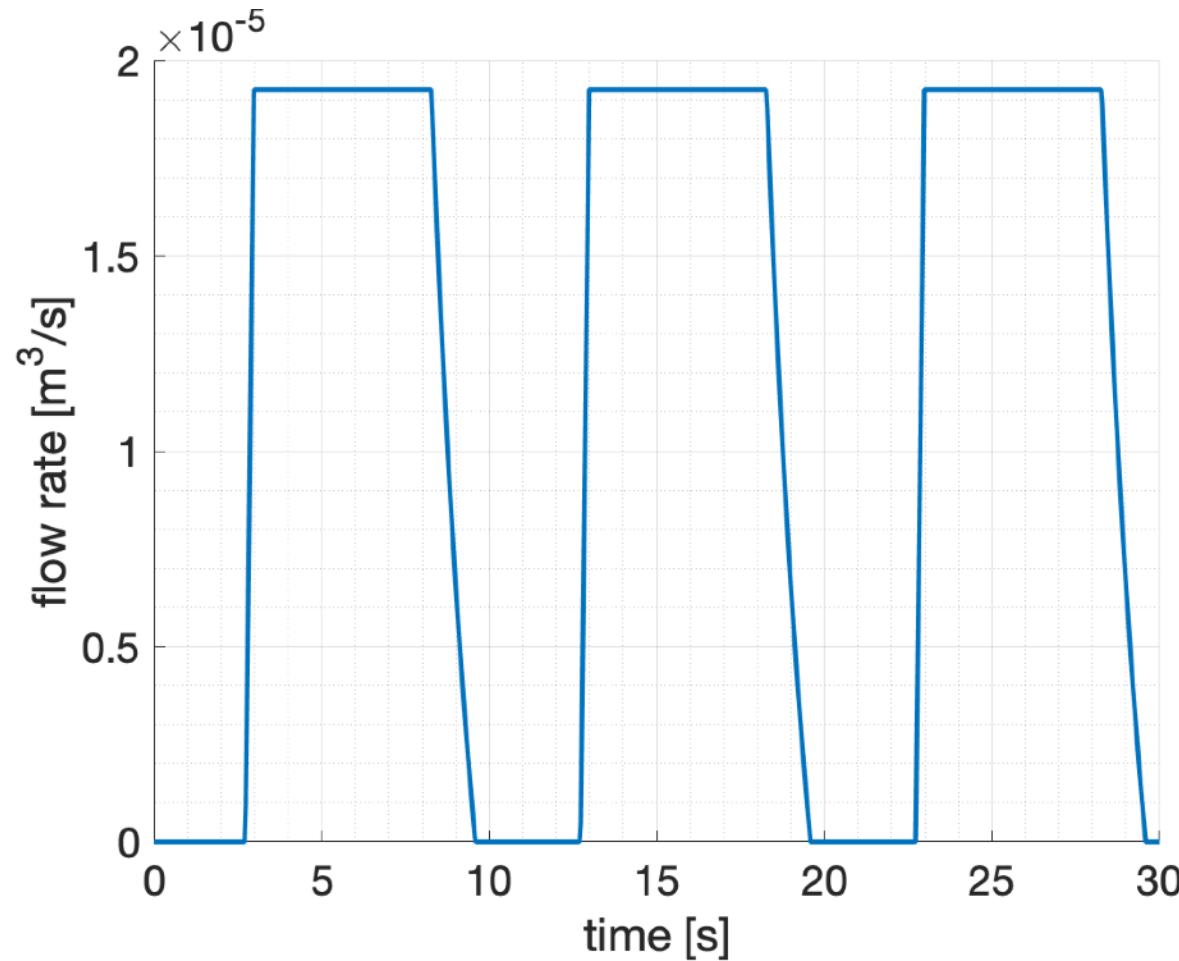


Temperature at $U=0.5V$ 

Displacement at U=0.5V

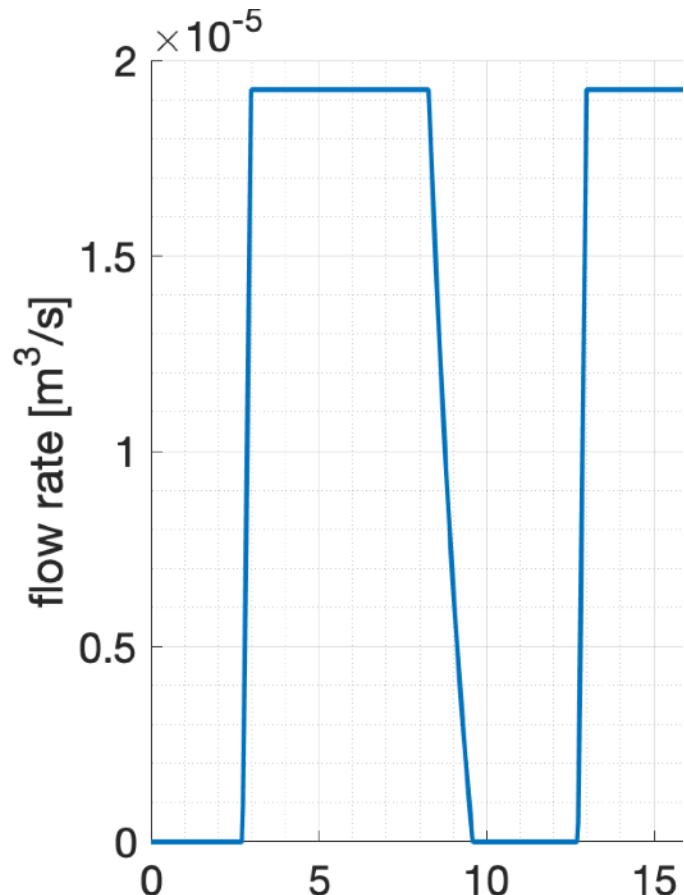


Flow Rate at U=0.5V

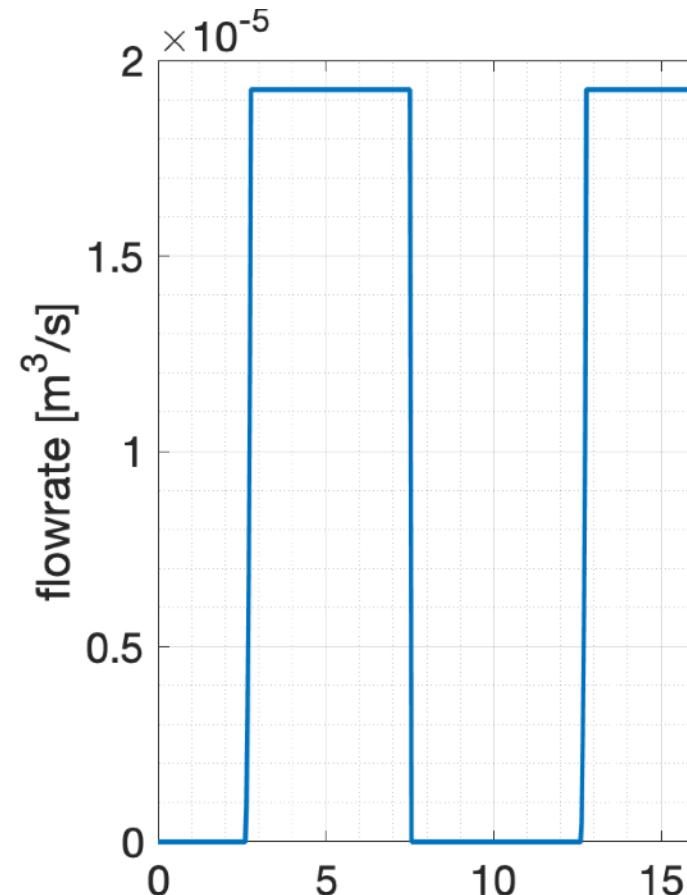


1.6 - Voltage Testing

Flow Rate SMA

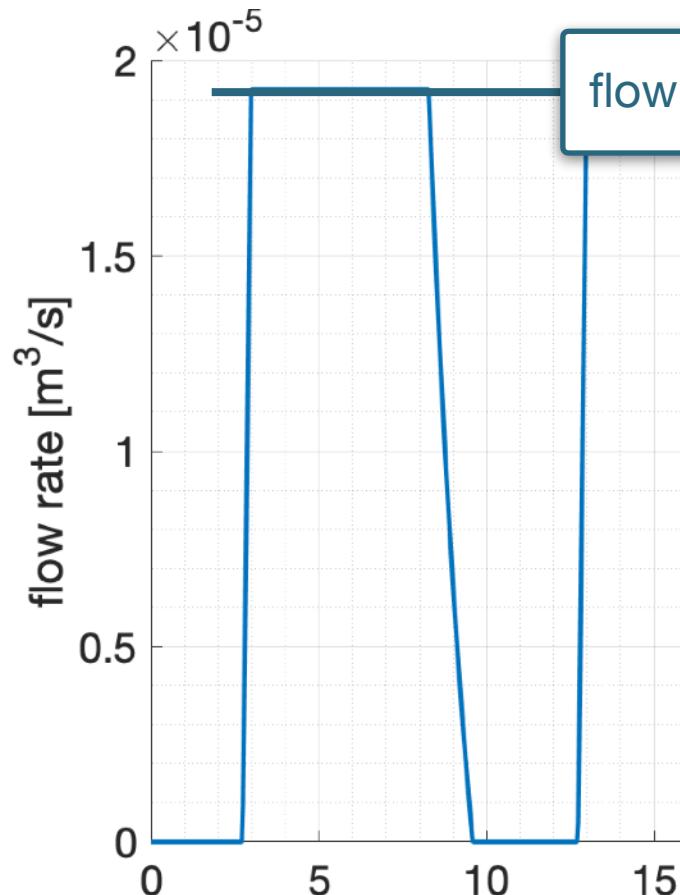


Flow Rate Solonoid

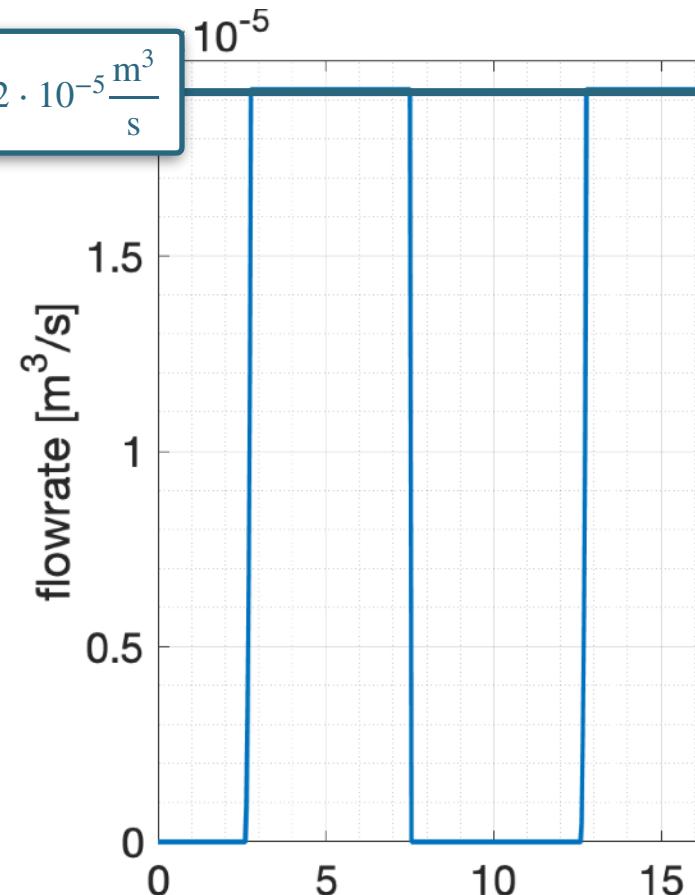


1.6 - Voltage Testing

Flow Rate SMA



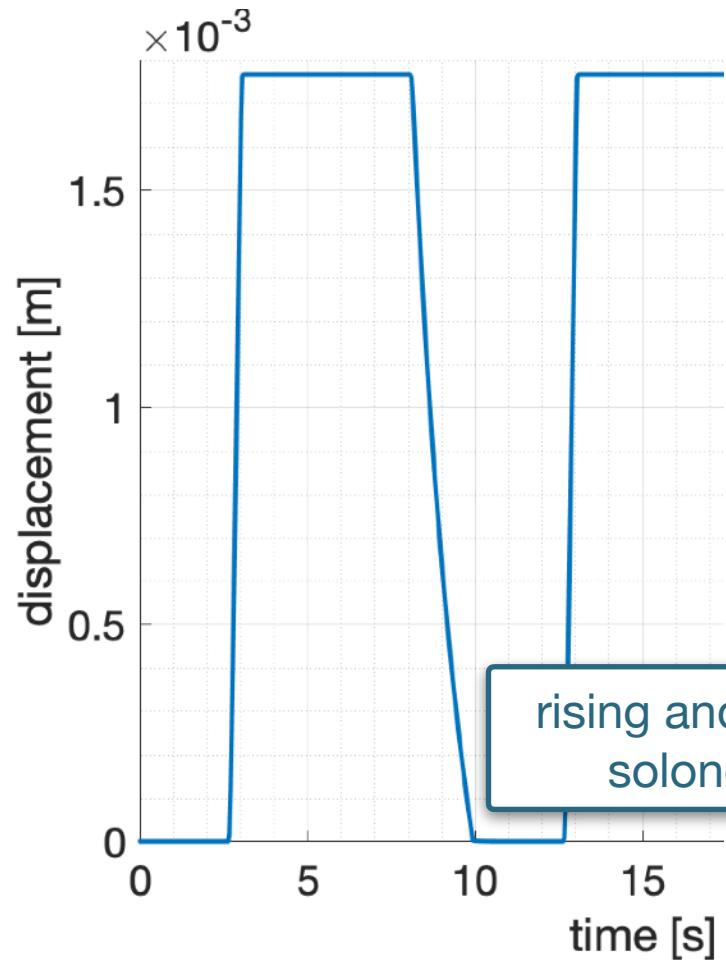
Flow Rate Solonoid



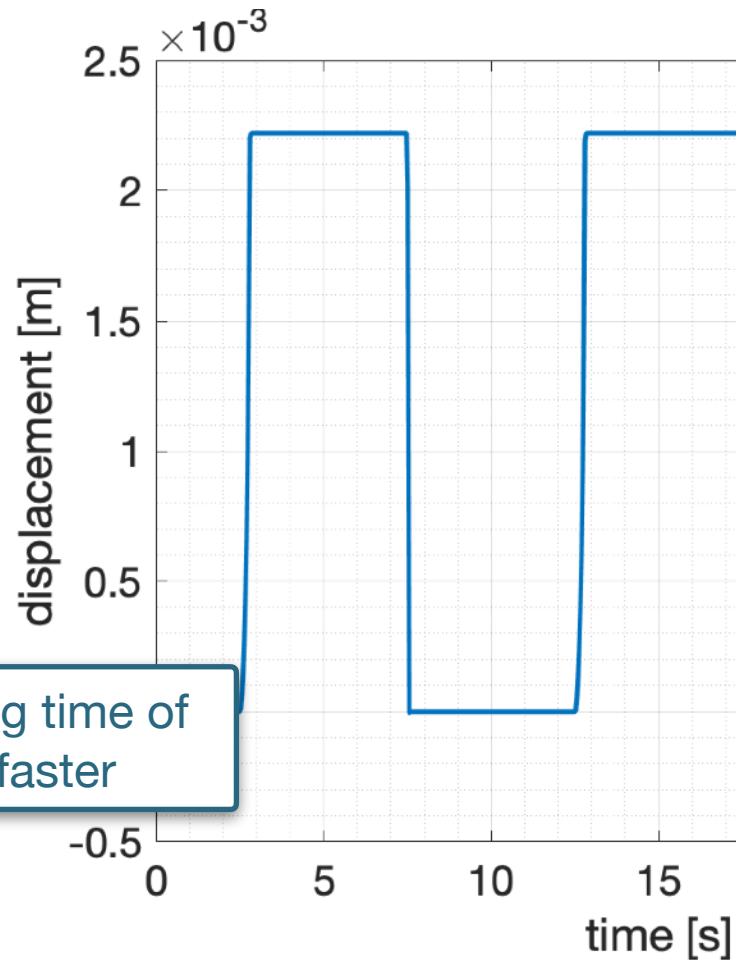
flow rate: $1.92 \cdot 10^{-5} \frac{\text{m}^3}{\text{s}}$

1.7 - Comparison

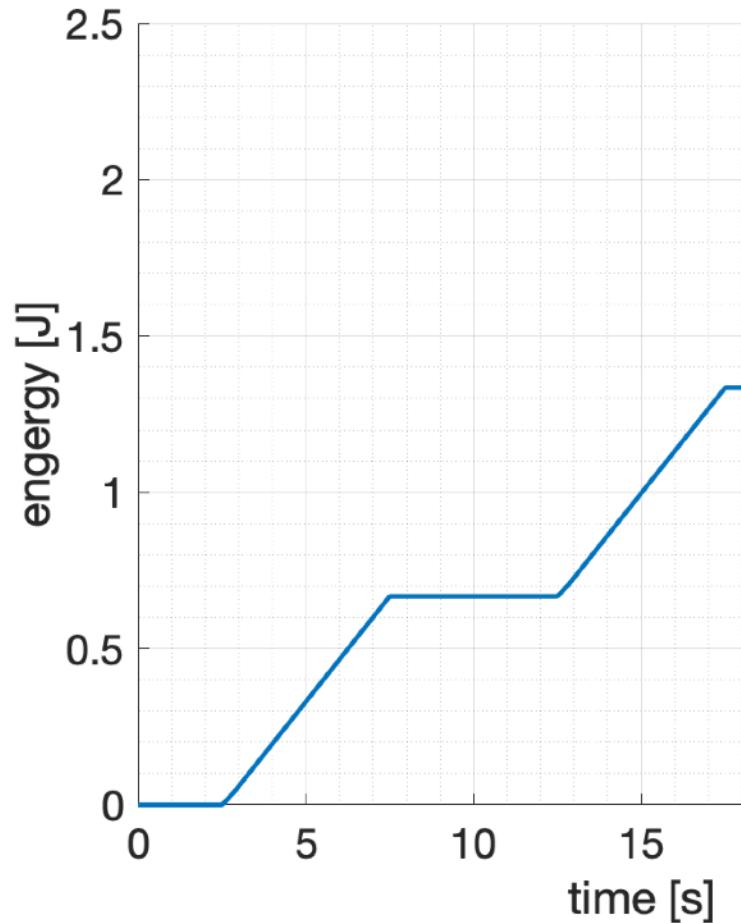
Displacement SMA



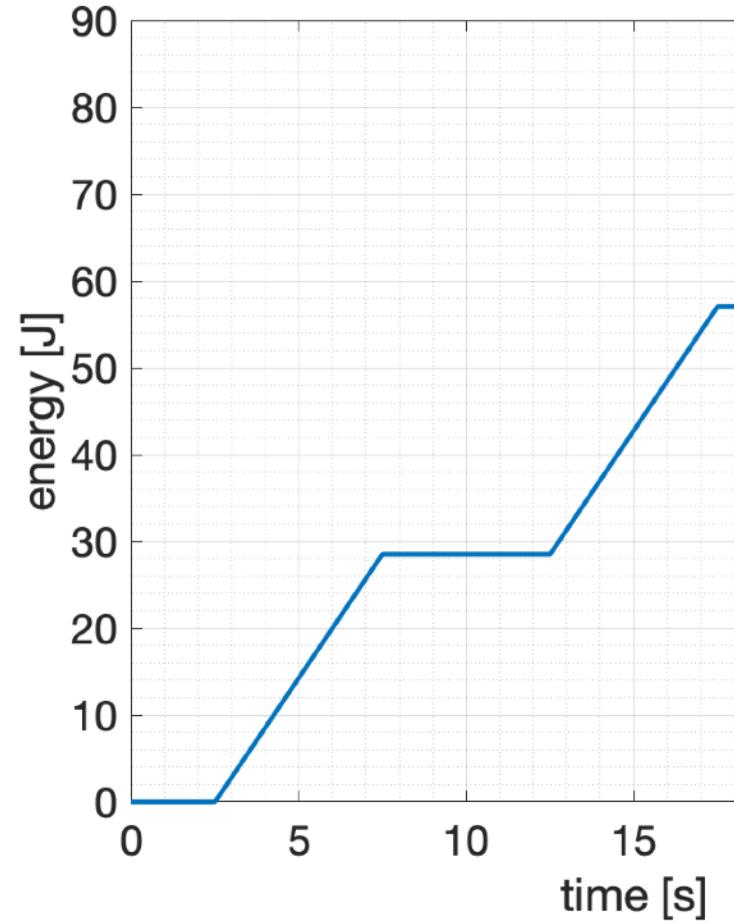
Displacement Solonoid



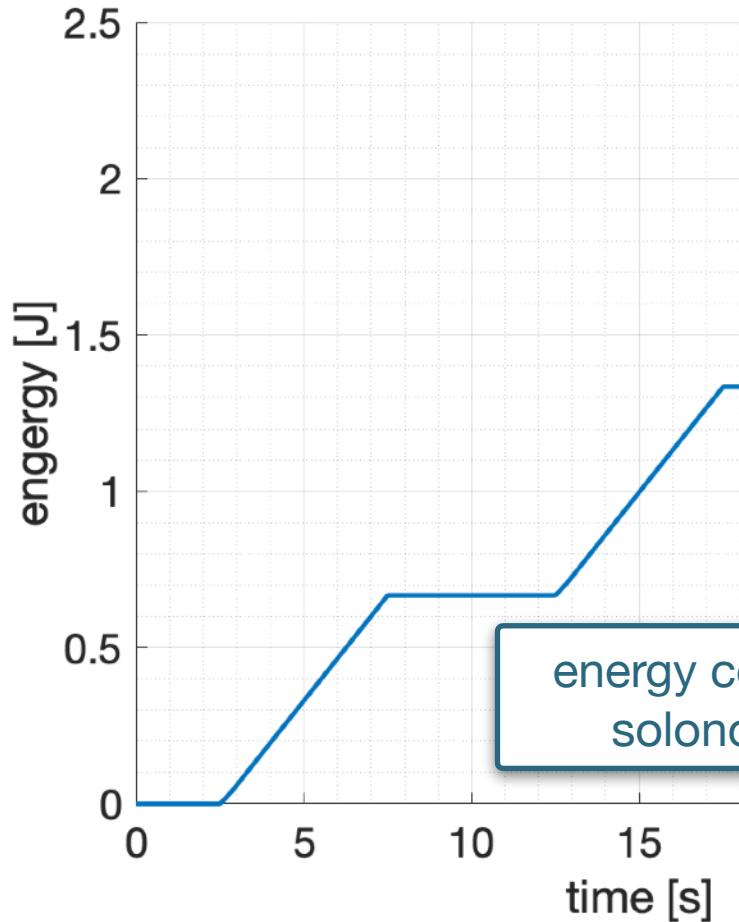
Energy SMA



Engery Solonoid

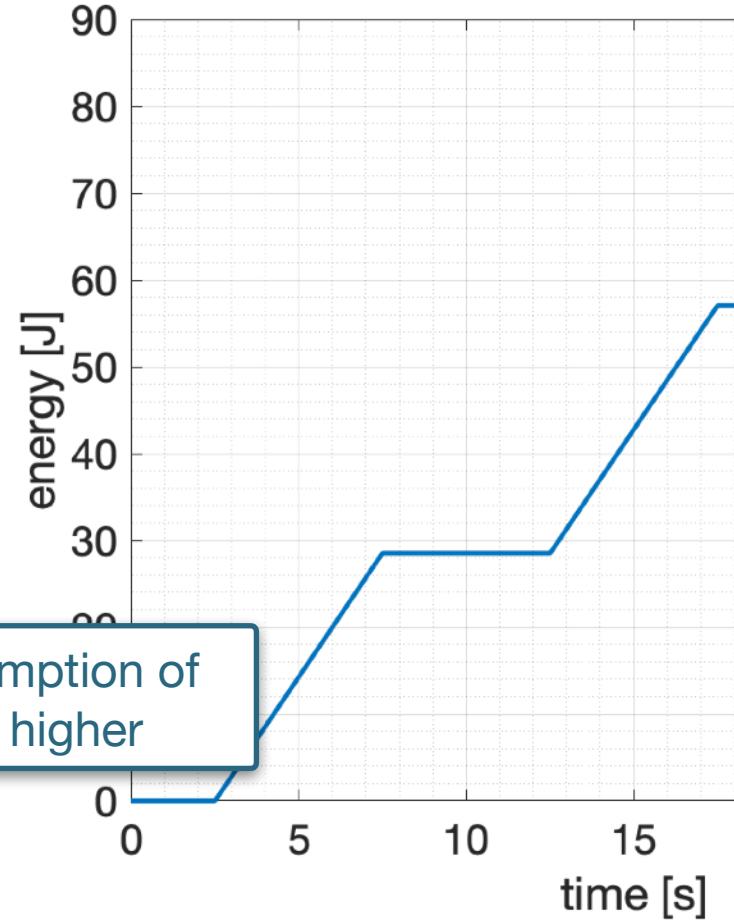


Energy SMA



energy consumption of solonoid is higher

Engery Solonoid





Monitoring?



Monitoring?

Solenoid: additional sensor needed



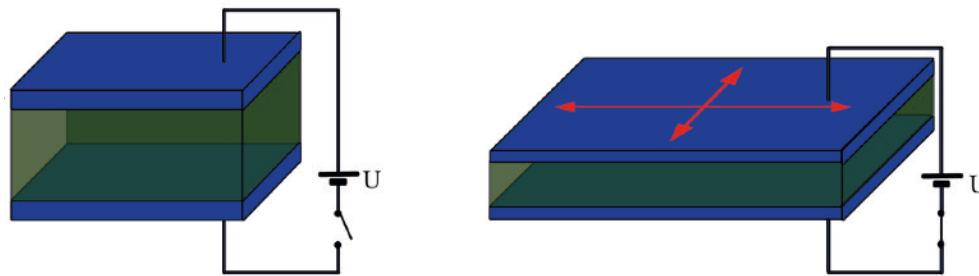
Monitoring?

Solenoid: additional sensor needed

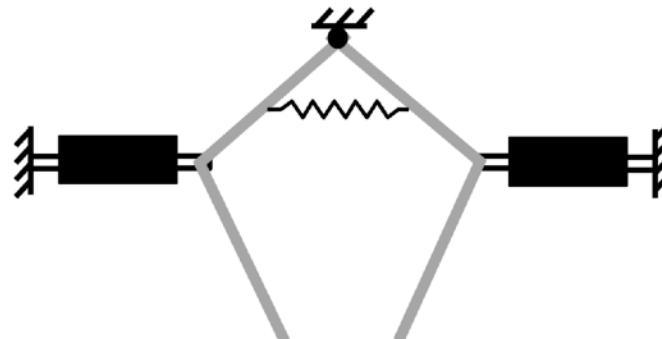
SMA: self sensing

Task 2: DEA gripper

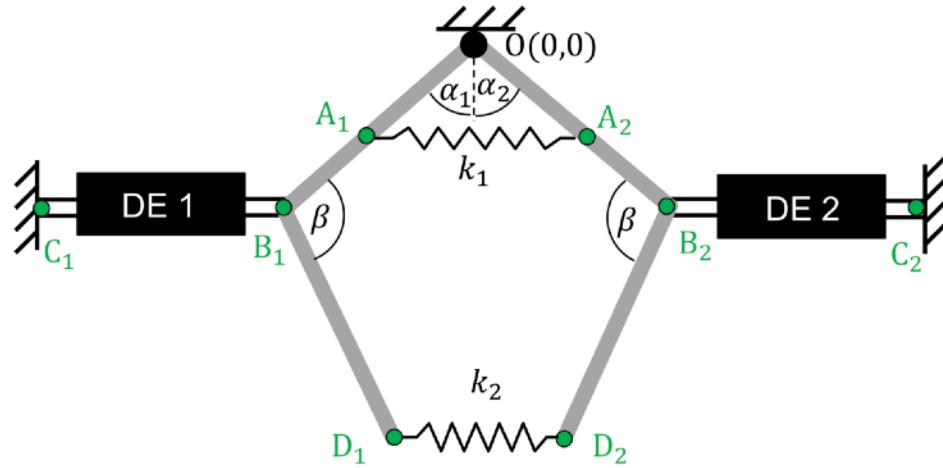
functionality DE:

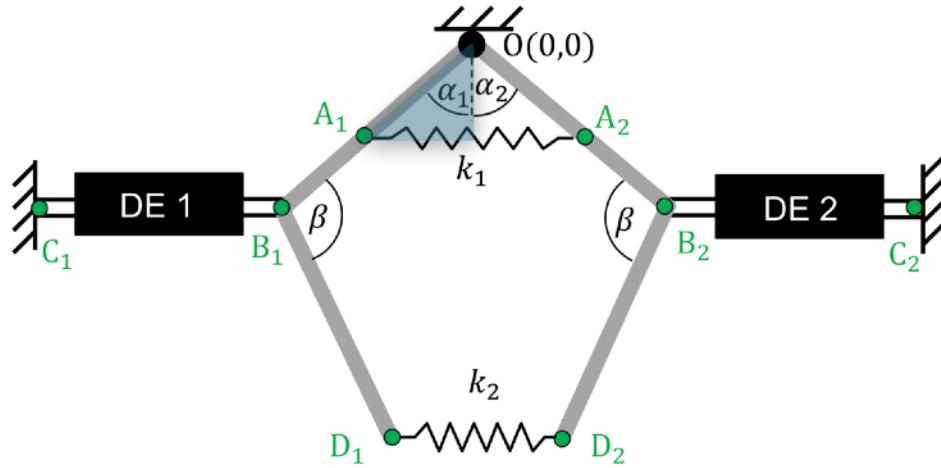


gripper with two DEs:



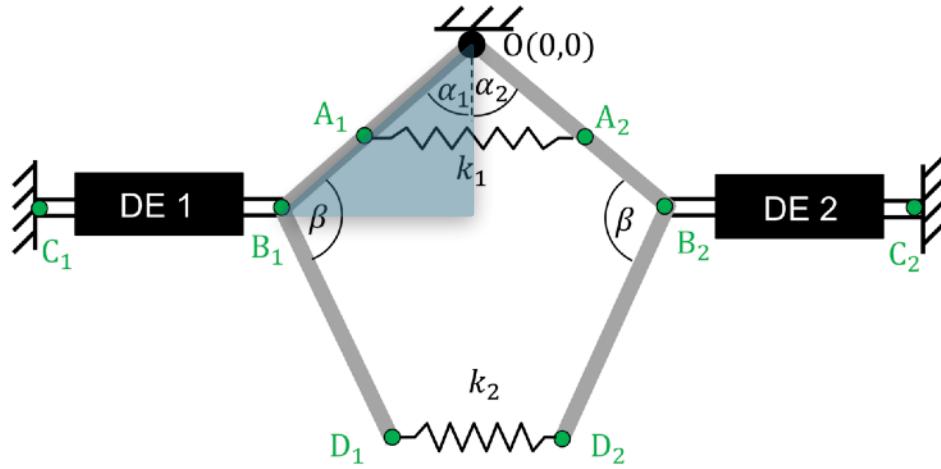
2.1 - Coordinates in Dependency of the Gripper Angles





$$\vec{A}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot \frac{l_0}{2} \\ -\cos(\alpha_1) \cdot \frac{l_0}{2} \end{pmatrix}$$

$$\vec{A}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot \frac{l_0}{2} \\ -\cos(\alpha_2) \cdot \frac{l_0}{2} \end{pmatrix}$$

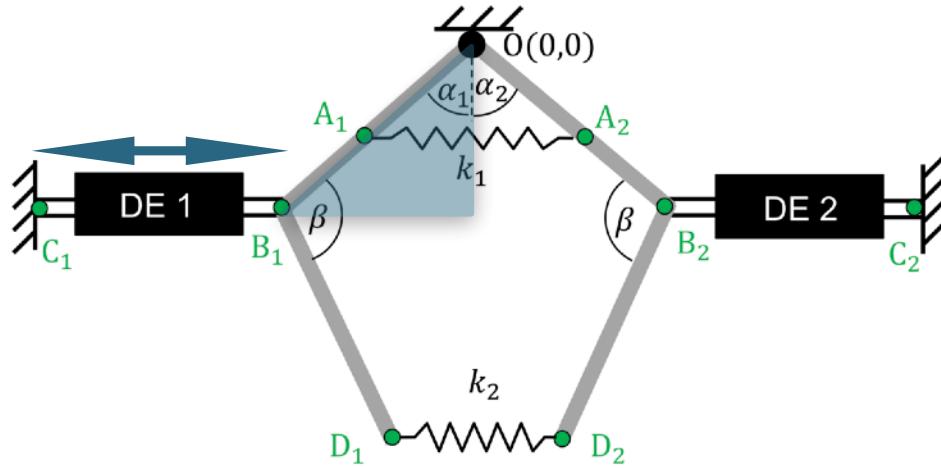


$$\vec{A}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot \frac{l_0}{2} \\ -\cos(\alpha_1) \cdot \frac{l_0}{2} \end{pmatrix}$$

$$\vec{A}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot \frac{l_0}{2} \\ -\cos(\alpha_2) \cdot \frac{l_0}{2} \end{pmatrix}$$

$$\vec{B}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot l_0 \\ -\cos(\alpha_1) \cdot l_0 \end{pmatrix}$$

$$\vec{B}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot l_0 \\ -\cos(\alpha_2) \cdot l_0 \end{pmatrix}$$



$$\vec{A}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot \frac{l_0}{2} \\ -\cos(\alpha_1) \cdot \frac{l_0}{2} \end{pmatrix}$$

$$\vec{A}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot \frac{l_0}{2} \\ -\cos(\alpha_2) \cdot \frac{l_0}{2} \end{pmatrix}$$

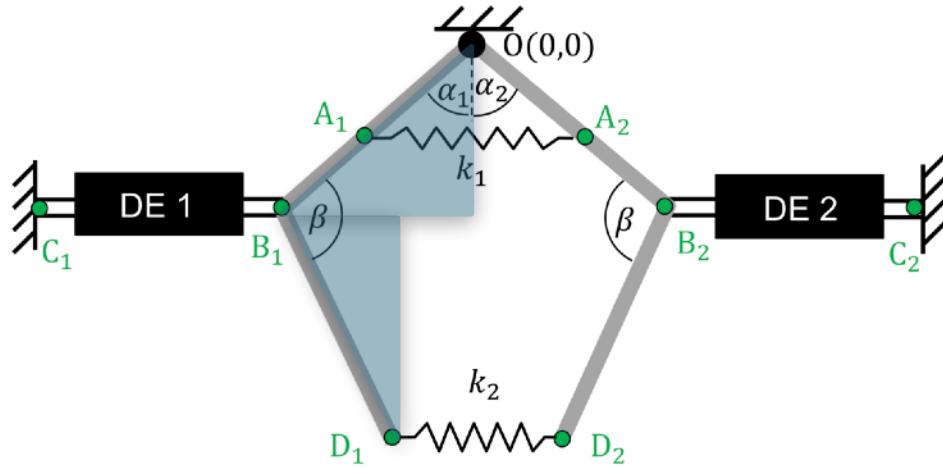
$$\vec{B}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot l_0 \\ -\cos(\alpha_1) \cdot l_0 \end{pmatrix}$$

$$\vec{C}_1 = \begin{pmatrix} -\sin(\pi/4) \cdot l_0 - l_p \\ -\cos(\pi/4) \cdot l_0 \end{pmatrix}$$

$$\vec{B}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot l_0 \\ -\cos(\alpha_2) \cdot l_0 \end{pmatrix}$$

$$\vec{C}_2 = \begin{pmatrix} \sin(\pi/4) \cdot l_0 + l_p \\ -\cos(\pi/4) \cdot l_0 \end{pmatrix}$$

2.1 - Coordinates in Dependency of the Gripper Angles



$$\vec{A}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot \frac{l_0}{2} \\ -\cos(\alpha_1) \cdot \frac{l_0}{2} \end{pmatrix}$$

$$\vec{A}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot \frac{l_0}{2} \\ -\cos(\alpha_2) \cdot \frac{l_0}{2} \end{pmatrix}$$

$$\vec{B}_1 = \begin{pmatrix} -\sin(\alpha_1) \cdot l_0 \\ -\cos(\alpha_1) \cdot l_0 \end{pmatrix}$$

$$\vec{C}_1 = \begin{pmatrix} -\sin(\pi/4) \cdot l_0 - l_p \\ -\cos(\pi/4) \cdot l_0 \end{pmatrix}$$

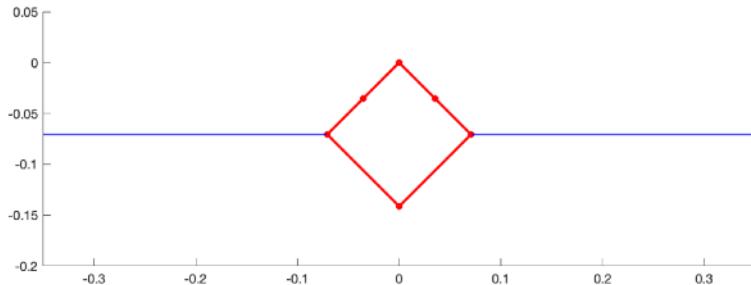
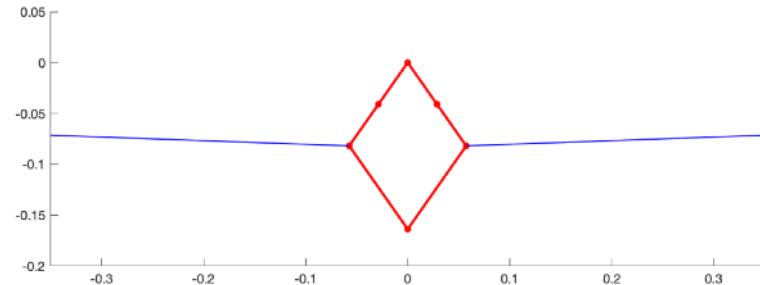
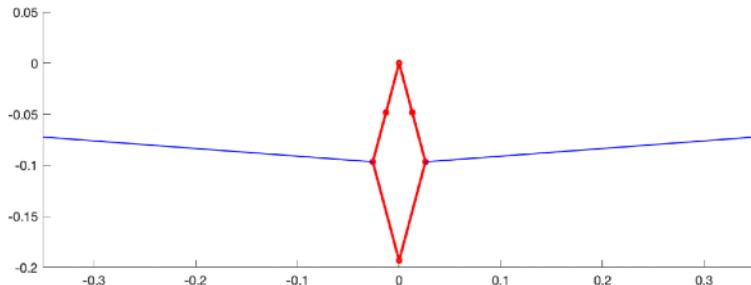
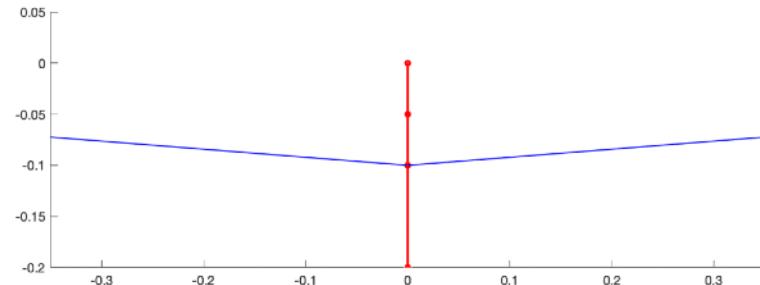
$$\vec{D}_1 = \begin{pmatrix} B_{1_x} + \cos(\beta - \pi/2 + \alpha_1) \cdot l_0 \\ B_{1_y} - \sin(\beta - \pi/2 + \alpha_1) \cdot l_0 \end{pmatrix}$$

$$\vec{B}_2 = \begin{pmatrix} \sin(\alpha_2) \cdot l_0 \\ -\cos(\alpha_2) \cdot l_0 \end{pmatrix}$$

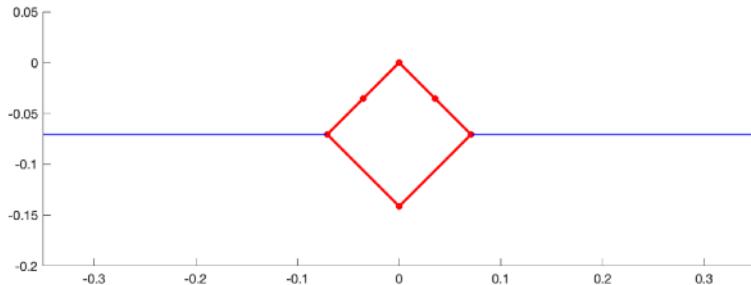
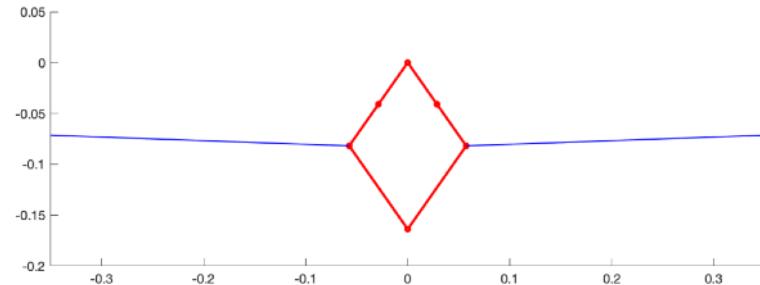
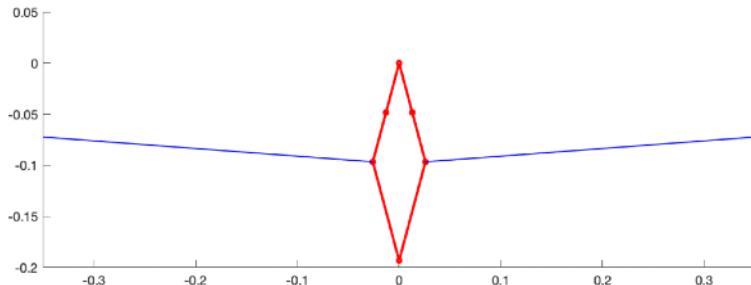
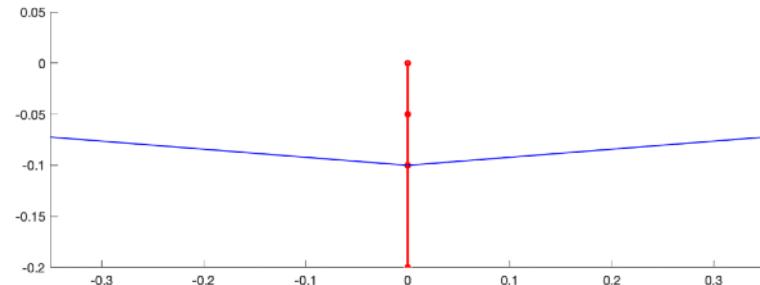
$$\vec{C}_2 = \begin{pmatrix} \sin(\pi/4) \cdot l_0 + l_p \\ -\cos(\pi/4) \cdot l_0 \end{pmatrix}$$

$$\vec{D}_2 = \begin{pmatrix} B_{2_x} - \cos(\beta - \pi/2 + \alpha_2) \cdot l_0 \\ B_{2_y} - \sin(\beta - \pi/2 + \alpha_2) \cdot l_0 \end{pmatrix}$$

2.1 - Coordinates in Dependency of the Gripper Angles

 $\beta = 90^\circ$  $\beta = 110^\circ$  $\beta = 150^\circ$  $\beta = 180^\circ$ 

2.1 - Coordinates in Dependency of the Gripper Angles

 $\beta = 90^\circ$  $\beta = 110^\circ$  $\beta = 150^\circ$  $\beta = 180^\circ$ 



length of the both DEs: $l_1 = \left\| \overrightarrow{l_1} \right\| = \left\| \overrightarrow{C_1} - \overrightarrow{B_1} \right\|$

$$l_1 = \sqrt{(l_0(\sin(\alpha_1) - \sin(\pi/4)) - l_p)^2 + (l_0(\cos(\alpha_1) - \cos(\pi/4))^2}$$

$$l_2 = \left\| \overrightarrow{l_2} \right\| = \left\| \overrightarrow{C_2} - \overrightarrow{B_2} \right\|$$

$$l_2 = \sqrt{(l_0(\sin(\pi/4) - \sin(\alpha_2)) + l_p)^2 + (l_0(\cos(\alpha_2) - \cos(\pi/4))^2}$$

Jacobi matrix:

$$J = \begin{pmatrix} \frac{\partial l_1}{\partial \alpha_1} & \frac{\partial l_1}{\partial \alpha_2} \\ \frac{\partial l_2}{\partial \alpha_1} & \frac{\partial l_2}{\partial \alpha_2} \end{pmatrix}$$

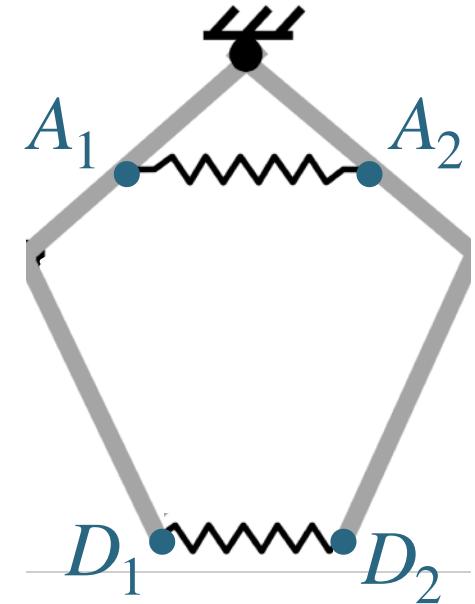
2.3-2.7 - Overall Lagrangian Function

rotational energy of the gripper arms:

$$T = \frac{1}{2} I \dot{\alpha}_1^2 + \frac{1}{2} I \dot{\alpha}_2^2$$

potential energy of the springs:

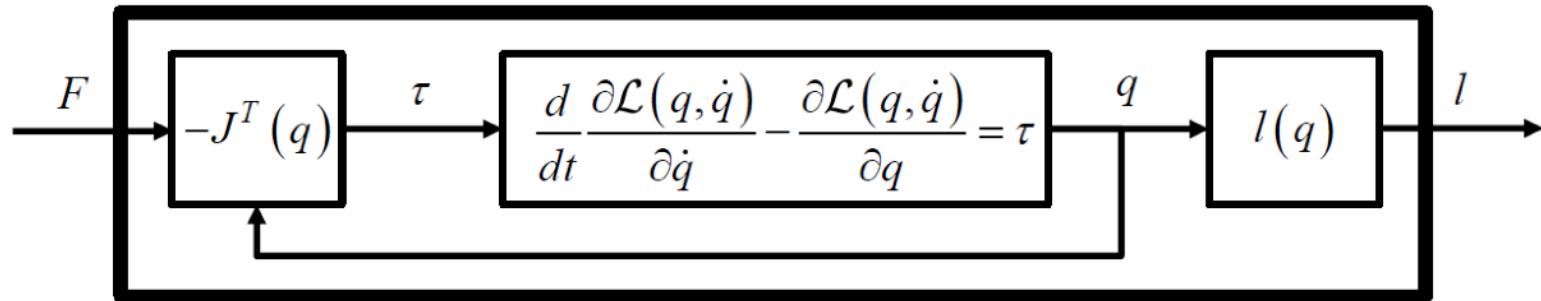
$$V = \frac{1}{2} k_1 (\| A_1 - A_2 \| - d_{10})^2 + \frac{1}{2} k_2 (\| D_1 - D_2 \| - d_{20})^2$$



→ **Lagrangian function:** $L = T - V$

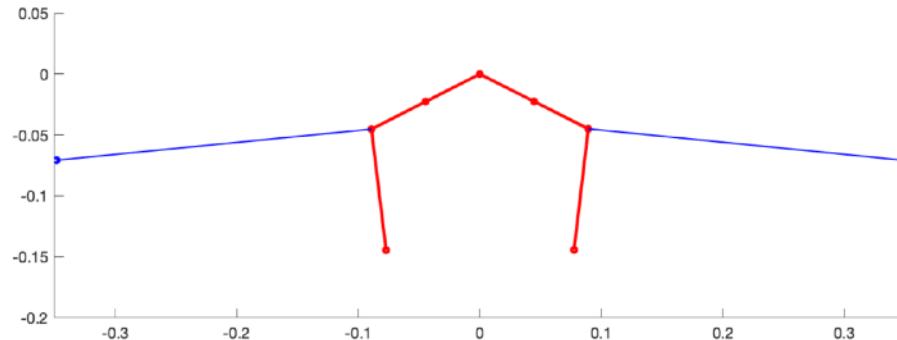
Lagrangian derivations:

$$\frac{\partial L}{\partial \vec{\alpha}} = \begin{pmatrix} \frac{\partial L}{\partial \alpha_1} \\ \frac{\partial L}{\partial \alpha_2} \end{pmatrix} \quad \frac{d}{dt} \frac{\partial L}{\partial \dot{\vec{\alpha}}} = \begin{pmatrix} \frac{d}{dt} \frac{\partial L}{\partial \dot{\alpha}_1} \\ \frac{d}{dt} \frac{\partial L}{\partial \dot{\alpha}_2} \end{pmatrix}$$

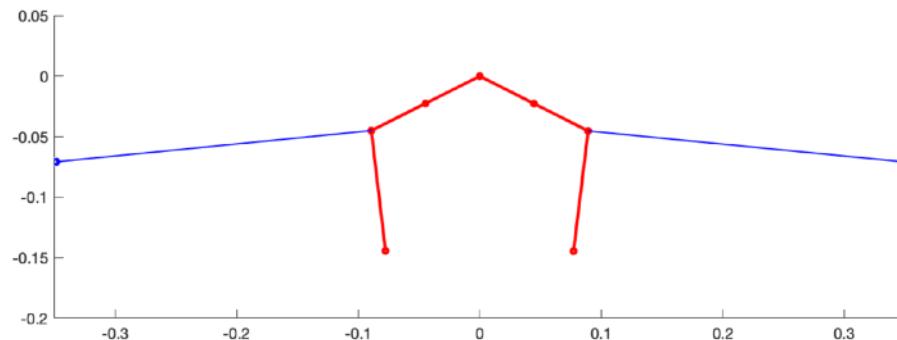


2.8 - Gripper Model Validation

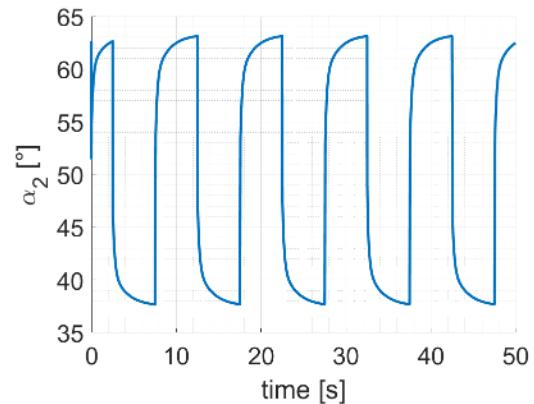
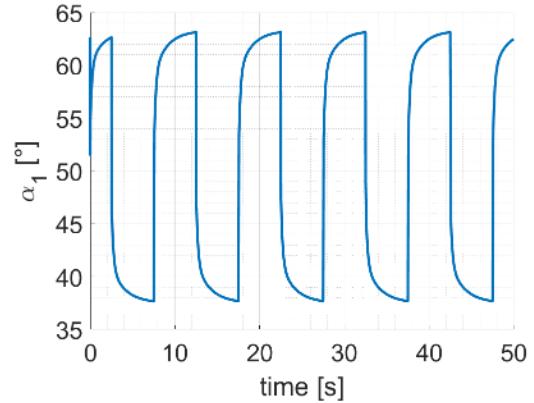
Left Gripper Arm Actuated



Right Gripper Arm Actuated

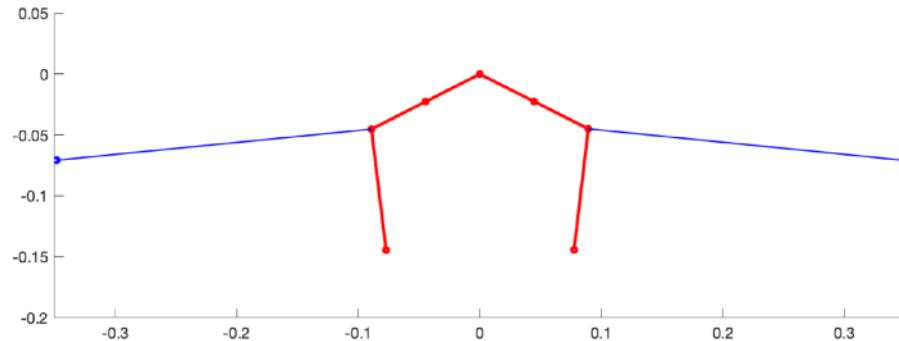


Angle Comparison

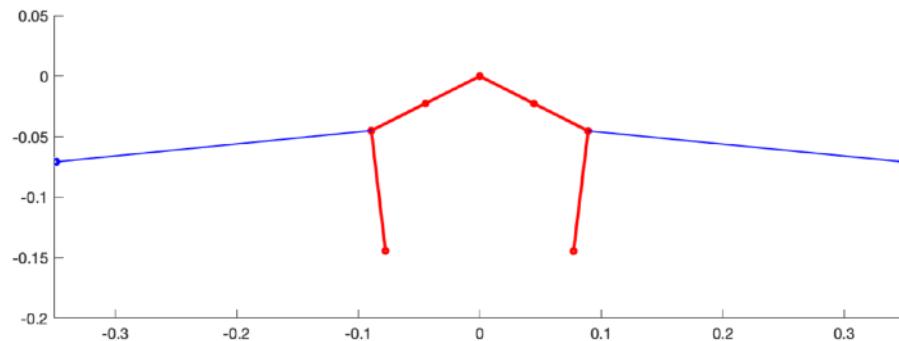


2.8 - Gripper Model Validation

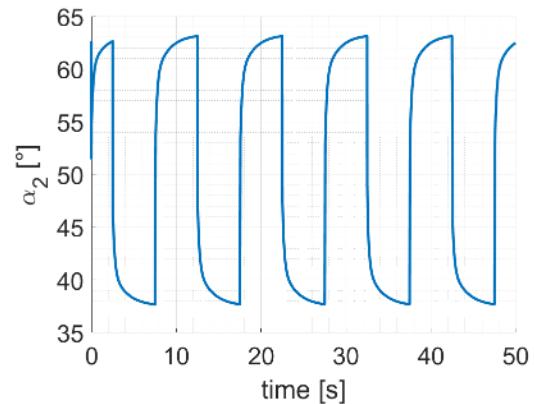
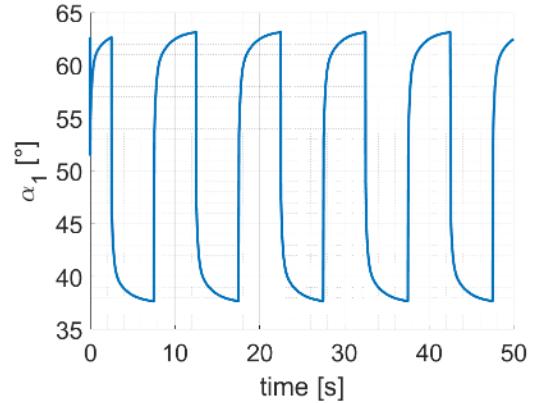
Left Gripper Arm Actuated



Right Gripper Arm Actuated

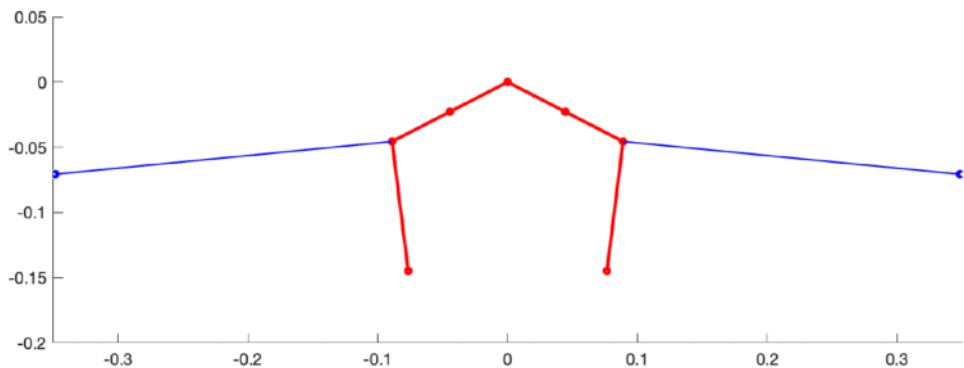


Angle Comparison

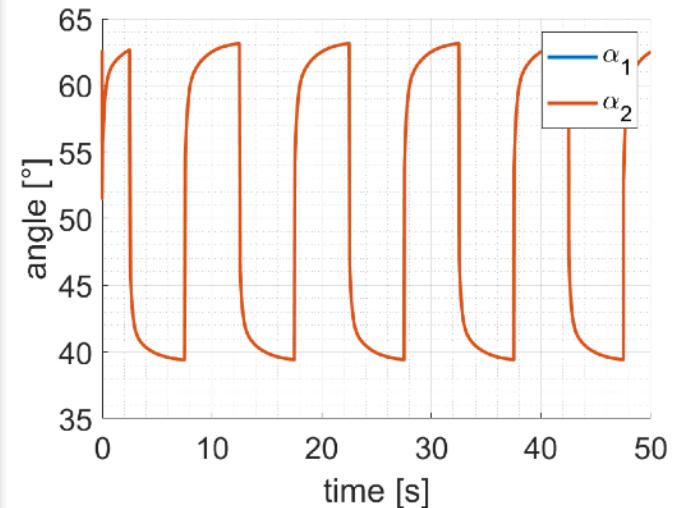


2.9 - Gripper Model Validation

Both Gripper Arms Actuated

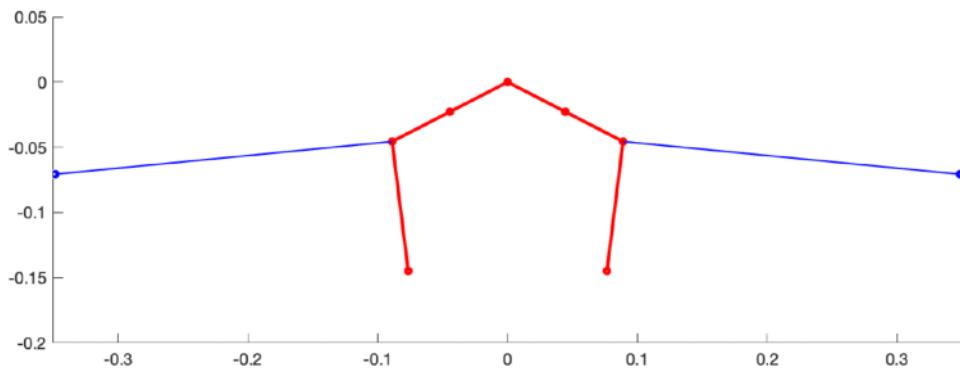


Angles

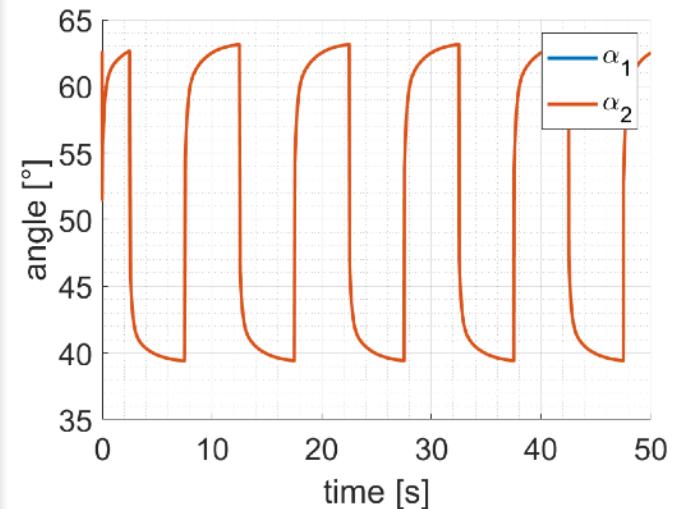


2.9 - Gripper Model Validation

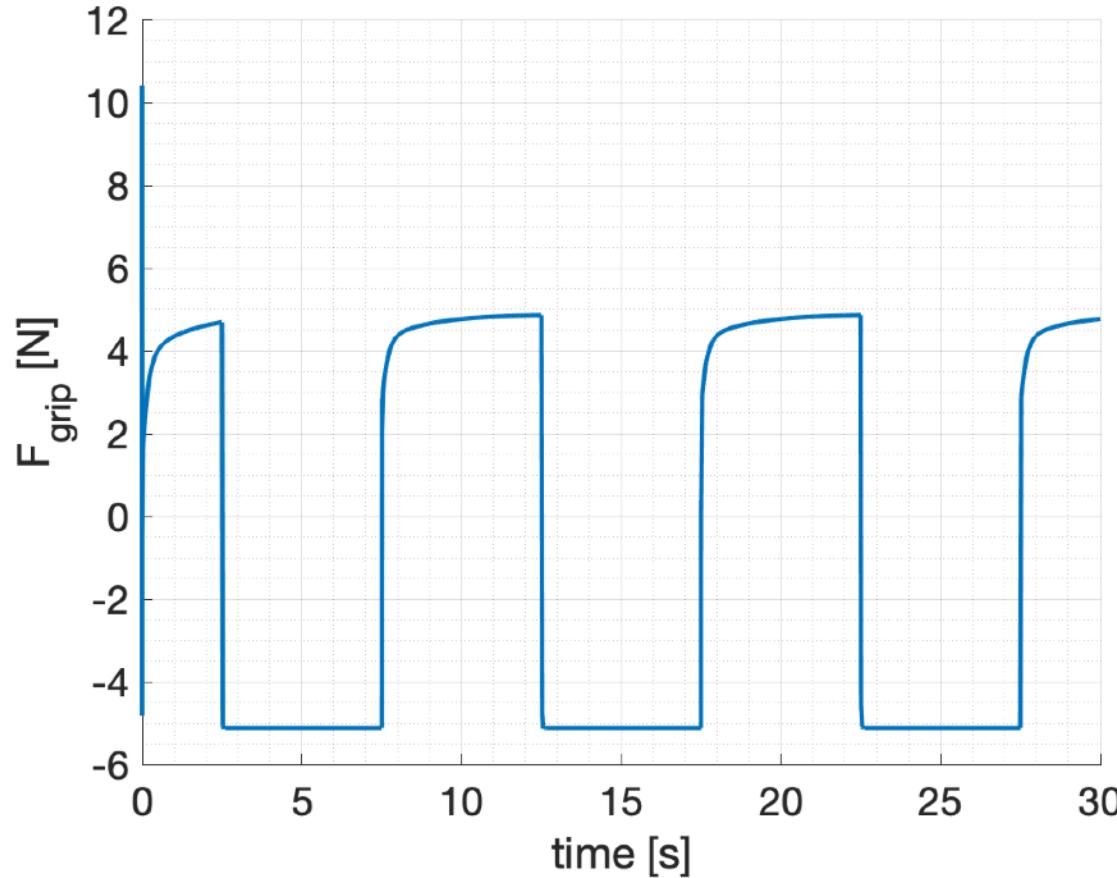
Both Gripper Arms Actuated



Angles

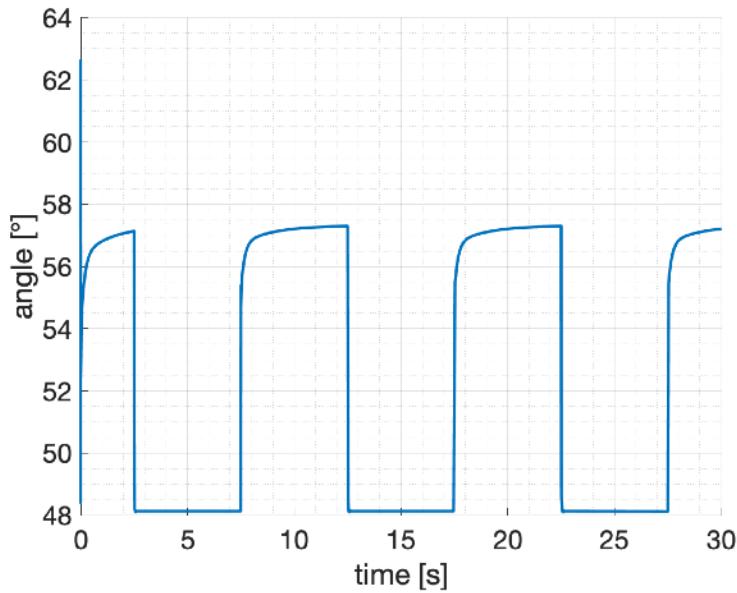


Gripper Force

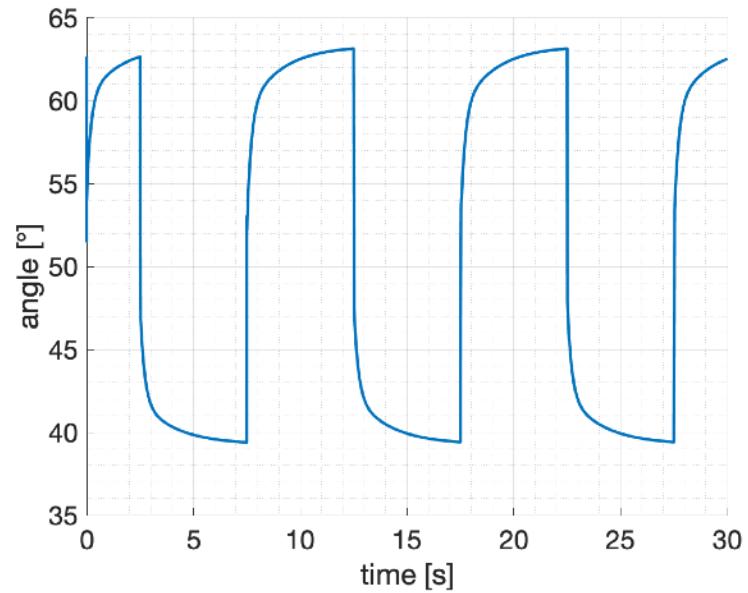


2.10 - Gripper Force Evaluation

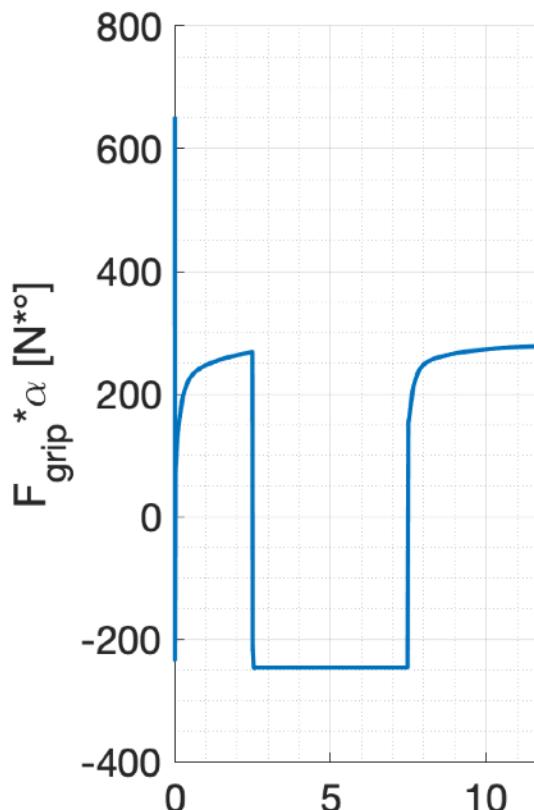
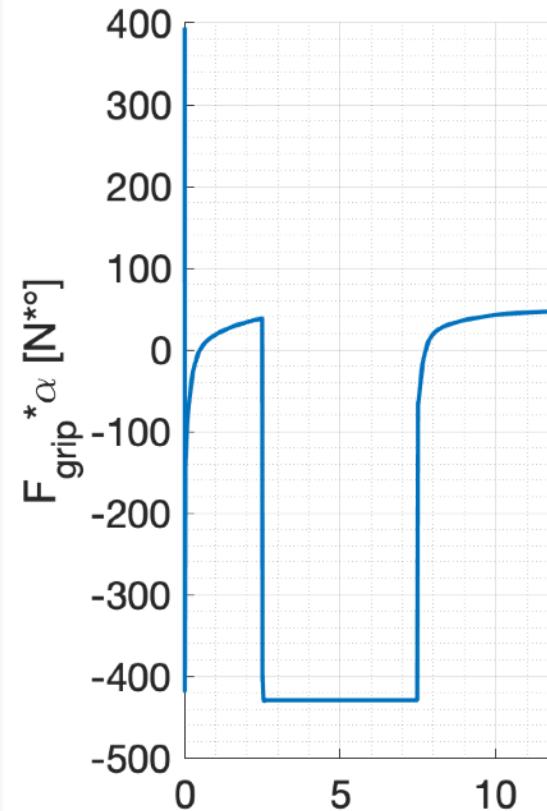
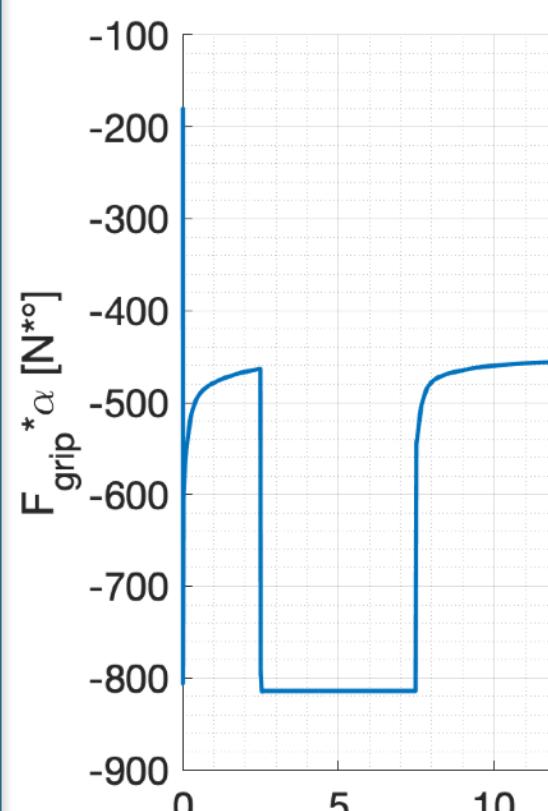
Angle 2 Springs



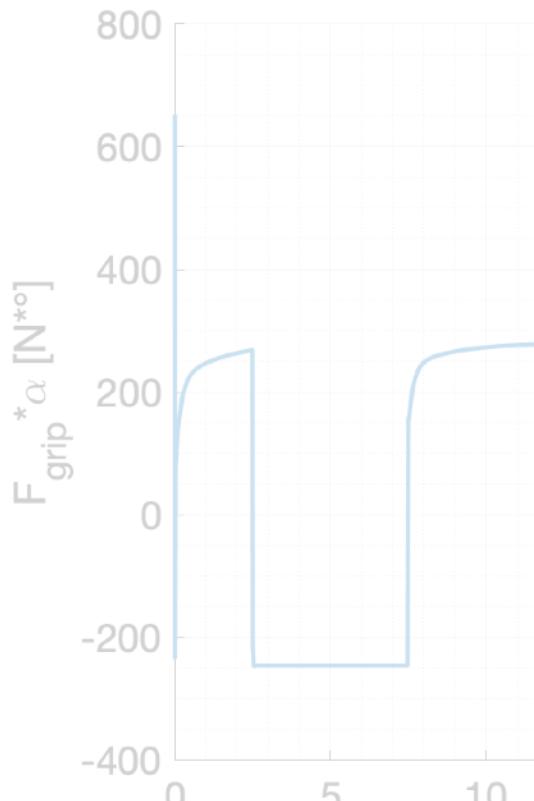
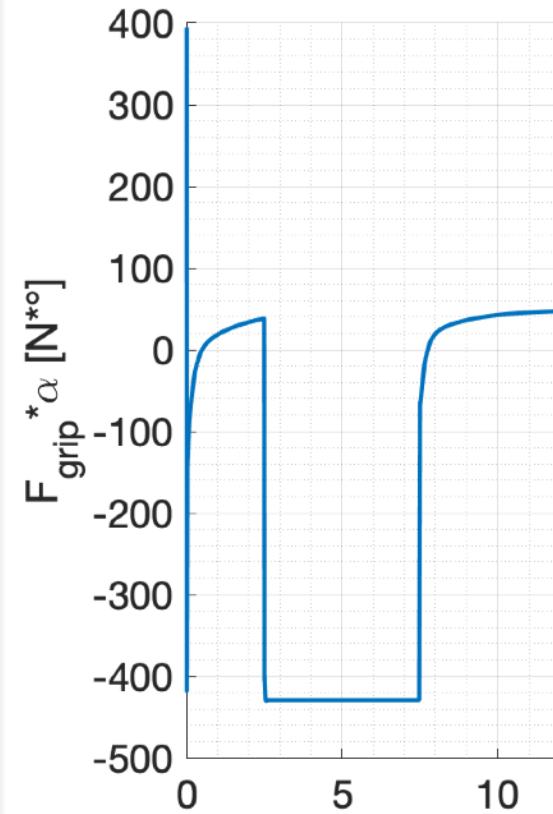
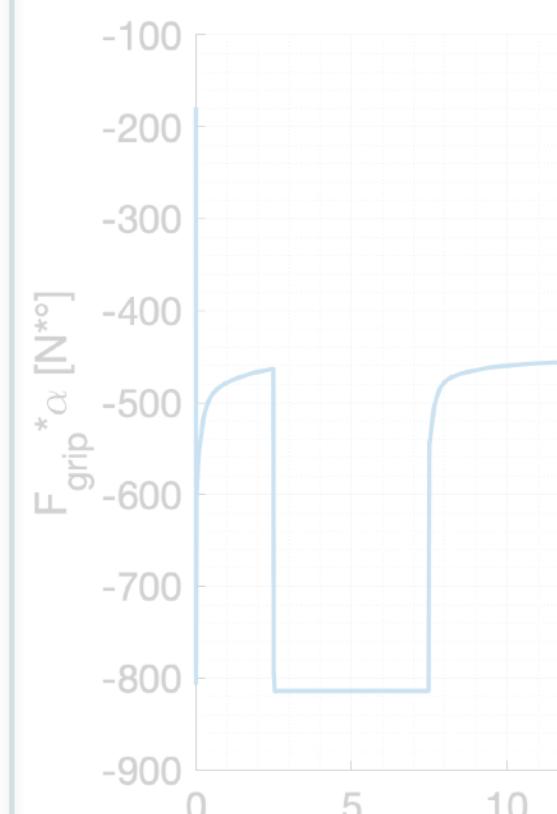
Angle 1 Spring



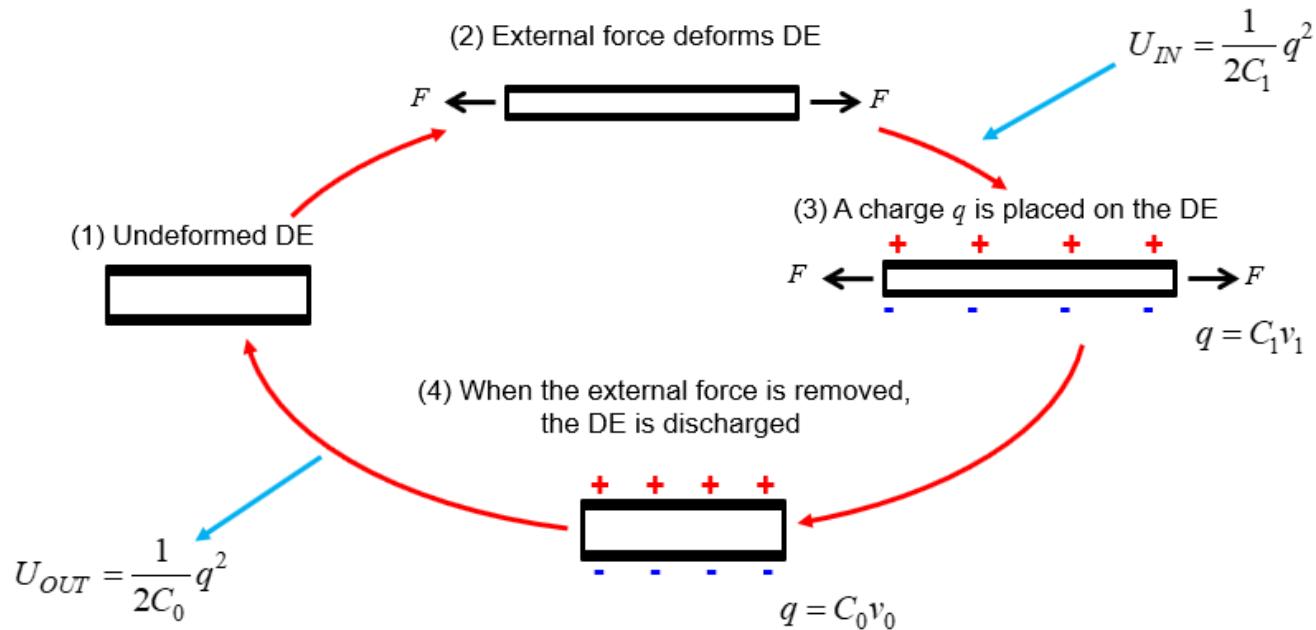
2.11 - Gripper Force Optimization

 $\beta = 110^\circ$  $\beta = 104^\circ$  $\beta = 90^\circ$ 

2.11 - Gripper Force Optimization

 $\beta = 110^\circ$  $\beta = 104^\circ$ **Highest Efficiency** $\beta = 90^\circ$ 

Basic Functionality of a DE-Generator:





- Complicated design (diverted linear movement at the actuators)
- Better to use the linear movement in a direct way

→ Membrane DE with 1 spring



Thank you for your attention!