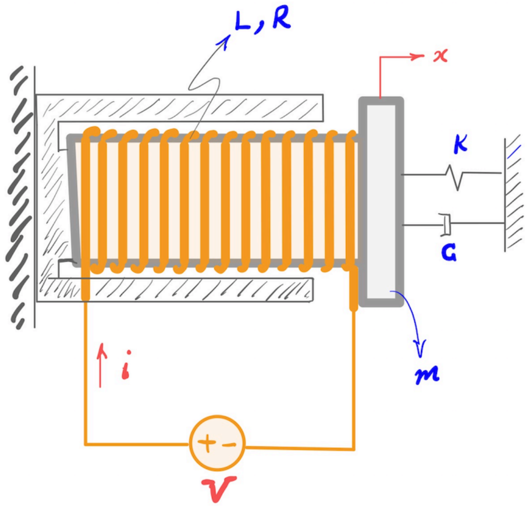
For the Lorentz Actuator shown here, the electrical and mechanical parameters are as below:

- Coil resistance: $R = 5\ \Omega$
- Coil inductance: $L = 5\ \mu H$
- Force constant: $K_t = 10\, N/A$
- Rotor mass: $m = 600\, g$
- Spring constant: $K = 25\, N/m$
- Damping: $C = 0.1\, N.s/m$



Part A. Modeling (20 points)

1) Derive dynamic equations of the system considering the linear relationship between actuator force as coil current as characterized by force constant (Here, we are neglecting the back electromotive force and so the equations will be uncoupled).
2) Find the transfer functions between voltage and current and also between current and displacement.
3) Assuming a sample time of $T = 0.02s$, derive the pulse transfer function of the plant.
4) Choose states of the system and derive continuous state space model (Hint: Use voltage as input to the plant and position as output).
5) Assuming a sample time of $T = 0.02s$, find the discrete state-space model.

Part B. Deadbeat Response Controller (20 points)

1) Assuming a sample time of $T = 0.02s$, design a deadbeat response controller to achieve zero steady-state error.
2) Plot the response to a 10-mm step command as well as the coil current. Are there any inter-sampling ripples?
3) Modify the controller to remove the inter-sampling ripples
4) Plot the response to a 10-mm step command for the new controller and show that there are no inter-sampling ripples.

Part C. Direct Design in Frequency Domain (20 points)

1) Design a digital controller to achieve rise time of $t_r = 0.1s$ and maximum overshoot of $M_p = 10\,\%$ with zero steady-state error using root locus method in $z-$domain.
2) Plot the response to a 10-mm step command as well as the coil current.

Part D. State-Space Design (30 points)

1) Verify controllability and observability of the discrete state-space model. What happens to controllability and observability of the system if you choose coil current as plant output? Explain your observation.
2) Design a servo system to meet the spec as in part C.1
3) Plot the response of states to a 10-mm step command.
4) Design a full-order deadbeat-response observer to estimate the states.
5) Modify the system designed in D.2 to use the estimated states for feedback and plot the response of the actual plant states to a 10-mm step command.

Part E. State-Space Design (10 points)

1) Design a servo system in state-space domain to track a 5-Hz sinusoidal command with zero steady-state error. (Use full-order deadbeat-response observer as designed in Part D).