Department of Mechanical Engineering

The University of British Columbia

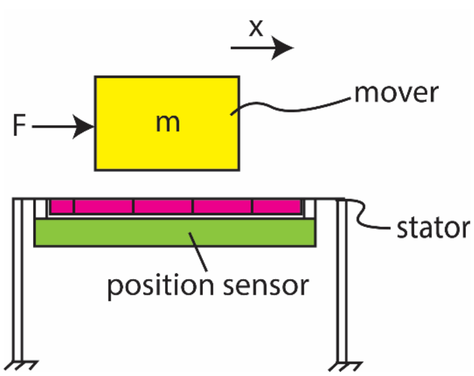
Mech 421: Mechatronics System Instrumentation

Final Exam

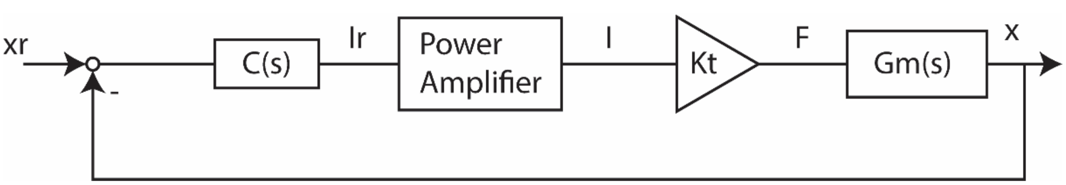
2019.4.12

12 pm - 2 pm

The planar motor technology was invented at UBC during 2012. The mover, which is a permanent magnet array, is levitated over the stator as shown in Figure 1 a). There is a coil in the stator to produce magnetic field to drive the mover. A feedback sensor, which can measure the position of the mover along X, is installed within the stator underneath the coil. The feedback control loop is designed as shown in Figure 1 b). The motor constant $K_t = 10\mathrm{N/A}$, the mass of the mover is 0.5 kg.



a)



b)

Figure 1.

Question 1 (30pts):

The frequency response of the plant (moving along X axis), $X(s)/I_r(s)$, is measured by a dynamic signal analyzer (DSA), and the results are shown in Figure 1.

1) Design a loop shaping controller for the motion control with the following requirements: a) robustly stable, and no vibration if input a step displacement; b) as fast response as possible; c) zero steady-state error for tracking a constant velocity command.
2) Draw the Bode plots of your controller and mark the key properties. If you implement the controller in Simulink, draw a block diagram of the controller.
3) If a digital controller is used to control the system, what is the sampling rate to achieve the designed bandwidth? Derive the transfer function of the designed controller in z-domain with the selected sampling rate using forward Euler discrete approximation (ODE1).

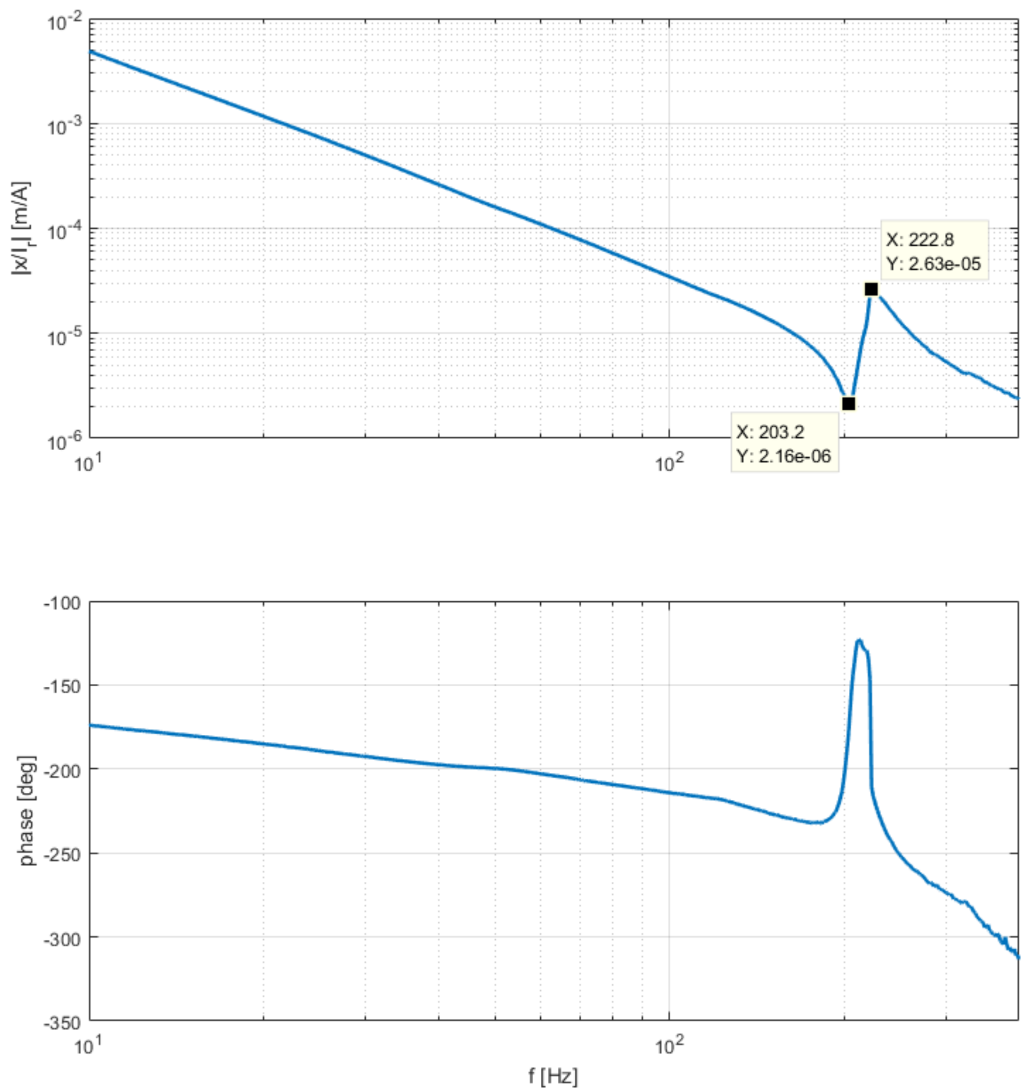


Figure 2

Question 2 (50 pts):

According to the plant frequency response as shown in Figure 2,

1) (20 pts) Draw a mechanical impedance (stiffness) network to represent the system; mark the parameters (m, k and c) in the network; mark the input force, where $F = K_t I$ and the output position (x).

2) (10 pts) Derive the transfer function between the input force (F) and output position (x).

3) (10 pts) Is that possible to calculate the values of stiffness and masses in your impedance network? If yes, please show the derivation and the values of stiffness and mass. Is that possible to estimate the damping of the system as well? If yes, what is the damping?

(Hint: use frequency response shown in Figure 2).

4) (10 pts) In the planar motor system as shown in Figure 1, if the mover is levitated, why is there a resonance around 220 Hz? Can you match the stiffness and mass, which are obtained in Question 2, to the planar motor system? (i.e. which part in planar motor is stiffness or mass?) Can you improve the bandwidth of the motion control loop by mechanically modifying the system?

Question 3 (20 pts):

An accelerometer is installed on the mover in order to measure the force generated by the motor, where $F = m\ddot{x}$, and the measurement bandwidth is 100 Hz. At one cycle of the measurement, the output from accelerometer $a = 2\mathrm{m/s^2}$, and the mover's speed is 1m/s.

Assume the planar motor is a DC motor with 24V supply voltage, and the power amplifier of the planar motor is a standard fully modulated H bridge as shown in the lecture. The PWM frequency of the power amplifier is 50 kHz. The resistance of the motor is 2Ω, and the inductance is 10 mH.

During the measurement cycle, what is the mean value of the motor current? What is the PWM duty cycle? What is the peak-to-peak ripple of the motor current? During experiments, you find the current ripple is too large, how can you reduce the ripple?