MECH 420 SENSORS AND ACTUATORS
Assignment 6

Problems 6.3, 6.5, 6.20, 6.21, 8.9, 8.35, 9.23, and 9.46 from the textbook

Problem 1 (Problem 6.3 from Textbook)

Explain why the speed resolution of a shaft encoder depends on the speed itself. What are some of the other factors that affect speed resolution? The speed of a DC motor was increased from 50 to 500 rpm. How would the speed resolution change if the speed were measured using an incremental encoder,

(a) By the pulse-counting method?
(b) By the pulse-timing method?

Problem 2 (Problem 6.5 from Textbook)

An incremental optical encoder that has *N* windows per track is connected to a shaft through a gear system with gear ratio *p*. Derive formulas for calculating angular velocity of the shaft by the

(a) Pulse-counting method
(b) Pulse-timing method.

What is the speed resolution in each case? What effect does step-up gearing have on the speed resolution?

Problem 3 (Problem 6.20 from Textbook)

Compare and contrast an optical incremental encoder against a potentiometer, by giving advantages and disadvantages, for an application involving the sensing of a rotatory motion.

A schematic diagram for the servo control loop of one joint of a robotic manipulator is given in Figure P6.20. The motion command for each joint of the robot is generated by the robot controller, in accordance with the required trajectory. An optical incremental encoder is used for both position and velocity feedback in each servo loop. For a six-degree-of-freedom robot there will be six such servo loops. Describe the function of each hardware component shown in the figure and explain the operation of the servo loop.

After several months of operation, the motor of one joint of the robot was found to be faulty. An enthusiastic engineer quickly replaced the motor with an identical one without realizing that the encoder of the new motor was different. In particular, the original encoder generated 200 pulses/rev whereas the new encoder generated 720 pulses/rev. When the robot was operated the engineer noticed an erratic and unstable behavior at the repaired joint. Discuss reasons for this malfunction and suggest a way to correct the situation.

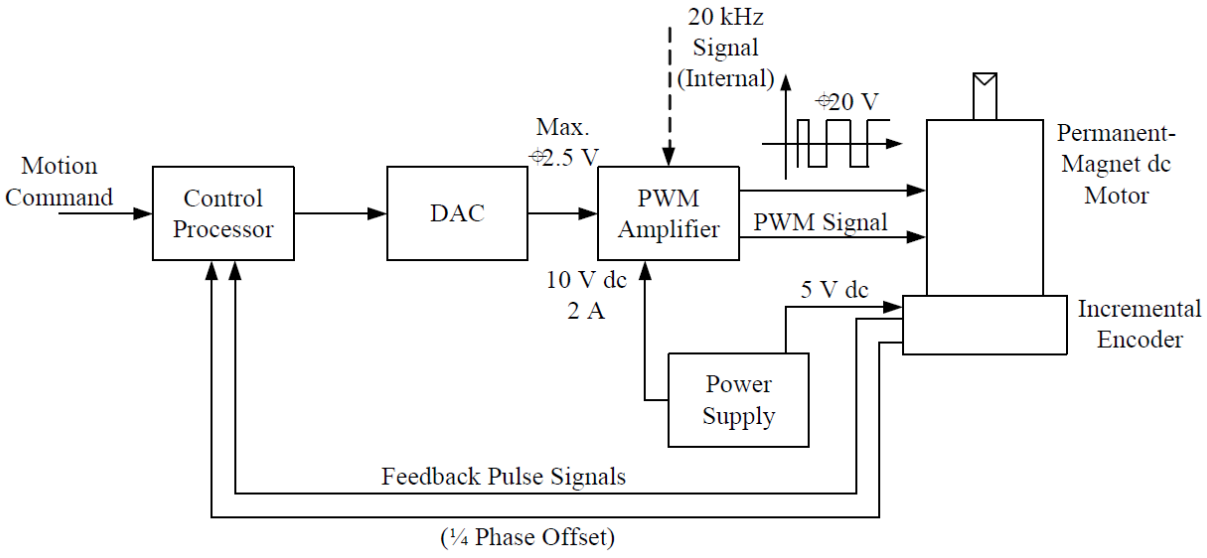

Figure P6.20: A servo loop of a robot.

Problem 4 (Problem 6.21 from Textbook)

(a) A position sensor is used in a microprocessor-based feedback control system for accurately moving the cutter blades of an automated meat-cutting machine. The machine is an integral part of the production line of a meat processing plant. What are the primary considerations in selecting the position sensor for this application? Discuss advantages and disadvantages of using an optical encoder in comparison to a linear variable differential transformer (LVDT) (see Chapter 5) in this context.

(b) Figure P6.21 illustrates one arrangement of the optical components in a linear incremental encoder.

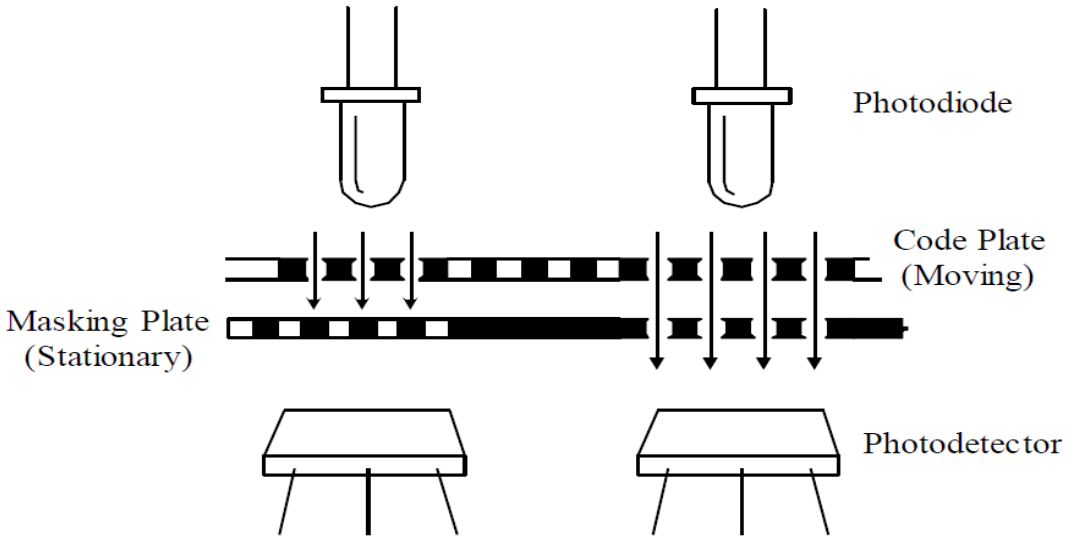

Figure P6.21: Photodiode-detector arrangement of a linear optical encoder.

The moving code plate has uniformly spaced windows as usual, and the fixed masking plate has two groups of identical windows, one above each of the two photodetectors. These two groups of fixed windows are positioned in half-pitch out of phase so that when one detector receives light from its source directly through the aligned windows of the two plates, the other detector has the light from its source virtually blocked by the masking plate.

Explain the purpose of the two sets of photodiode-detector units, giving a schematic diagram of the necessary electronics. Can the direction of motion be determined with the arrangement shown in Figure P6.21? If so, explain how this could be done. If not, describe a suitable arrangement for detecting the direction of motion.

Problem 5 (Problem 8.9 from Textbook)

8.9 Figure P8.9 shows a schematic diagram of a stepper motor.

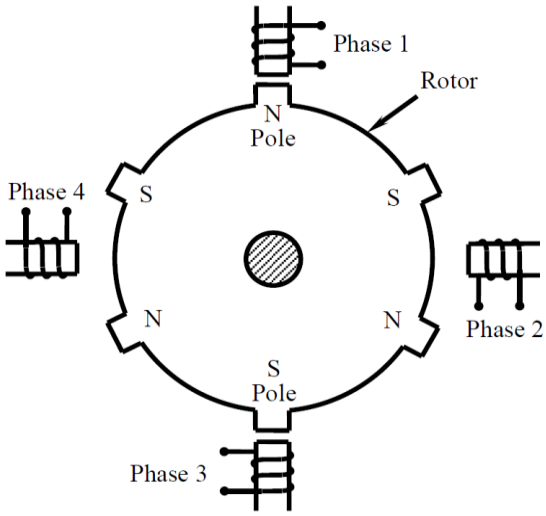

Figure P8.9: Schematic diagram of a stepper motor.

What type of stepper is this? Describe the operation of this motor. In particular, discuss whether four separate phases are needed or whether the phases of the opposite stator poles may be connected together, giving a two-phase stepper. What is the step angle of the motor

a. In full stepping?
b. In half stepping?

Problem 6 (Problem 8.35 from Textbook)

8.35 A lectern (or podium) in an auditorium is designed to adjust its height automatically, depending on the height of the speaker. An ultrasonic gage measures the height of the speaker and sends a command to the logic hardware controller of a stepper motor, which adjusts the lectern vertically through a rack-and-pinion drive. The dead load of the moving parts is supported by a bellow device. A schematic diagram of this arrangement is shown in Figure P8.35. The following design requirements have been specified: Time to adjust a maximum stroke of 1 m = 5 s. Mass of the lectern = 50 kg. Maximum resistance to vertical motion = 5 kg. Displacement resolution = 0.5 cm/step.

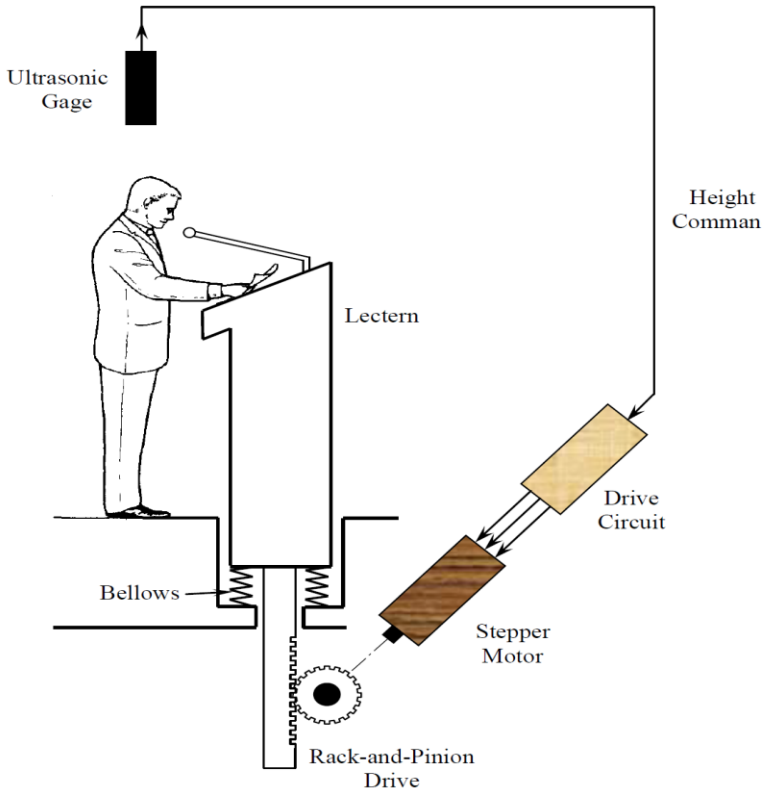

Figure P8.35: An automated lectern.

Table 8.2: Stepper Motor Data.

		Stepping Motor Specifications			
Model		**50SM**	**101SM**	**310SM**	**1010SM**
NEMA motor frame size		23	23	34	42
Full step angle	Degrees	1.8			
Accuracy	Percent	±3 (noncumulative)			
Holding torque	oz.in	38	90	370	1050
	N.m	0.27	0.64	2.61	7.42
Detent torque	oz.in	6	18	25	20
	N.m	0.04	0.13	0.18	0.14
Rated phase current	Amps	1	5	6	8.6
Rotor inertia	$oz.in.s^2$	1.66×10^{-3}	5×10^{-3}	26.5×10^{-3}	114×10^{-3}
	$kg.m^2$	11.8×10^{-6}	35×10^{-6}	187×10^{-6}	805×10^{-6}
Maximum radial load	lb	15	15	35	40
	N	67	67	156	178
Maximum thrust load	lb	25	25	60	125
	N	111	11	267	556
Weight	lb	1.4	2.8	7.8	20
	kg	0.6	1.3	3.5	9.1
Operating temperature	°C	−55 to +50			
Storage temperature	°C	−55 to +130			

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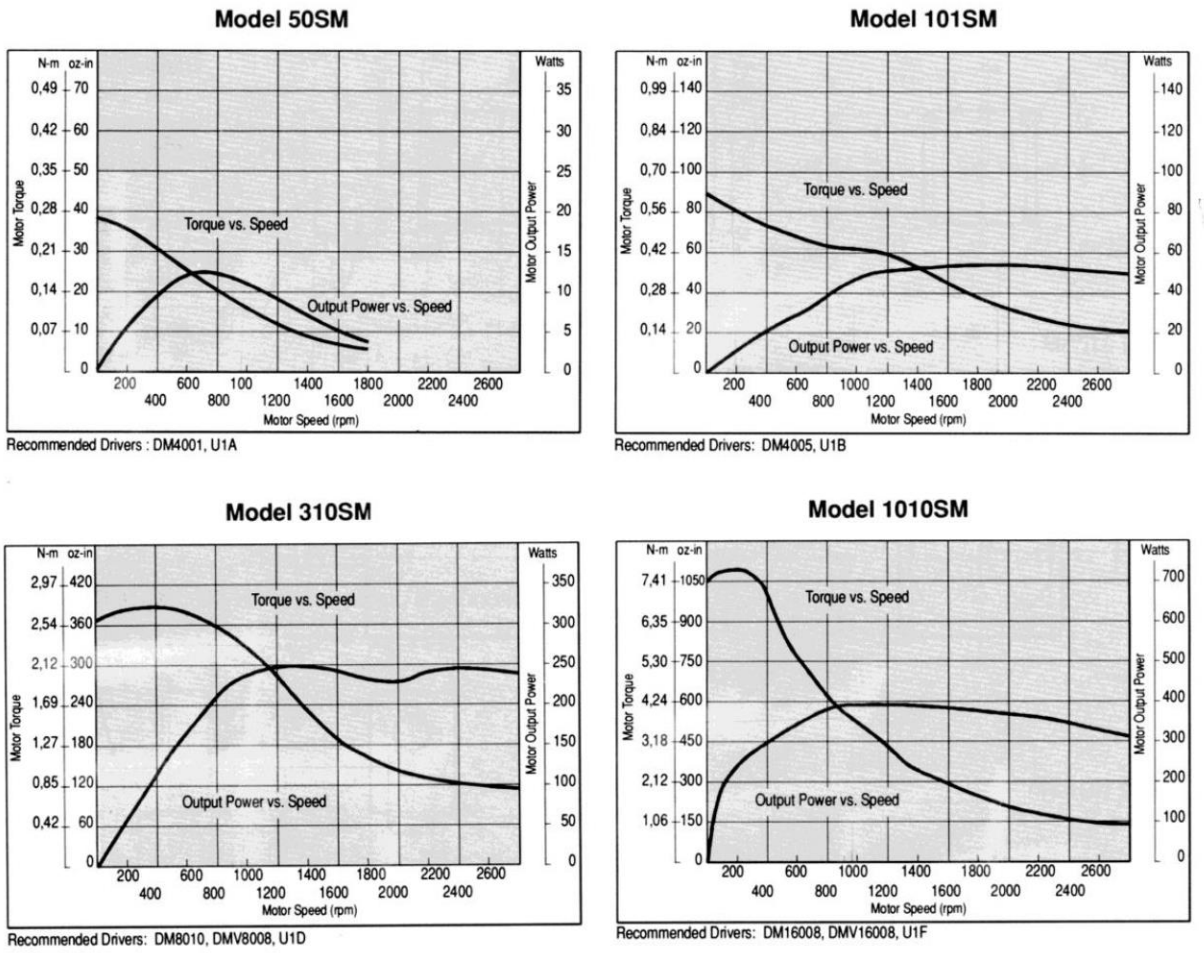

Figure 8.44: Stepper motor data.

Select a suitable stepper motor system for this application. You may use the ratings of the four commercial stepper motors, as given in Table 8.2 and Figure 8.44.

Problem 7 (Problem 9.23 from Textbook)

Prepare a table to compare and contrast the following types of motors:

(a) Conventional dc motor with brushes
(b) Brushless torque motor (dc)
(c) Stepper motor
(d) Induction motor
(e) AC synchronous motor

In your table, include terms such as power capability, speed controllability, speed regulation, linearity, operating bandwidth, starting torque, power supply requirements, commutation requirements, and power dissipation. Discuss a practical method for reversing the direction of rotation in each of these types of motors.

Problem 8 (Problem 9.46 from Textbook)

The sketch in Figure P9.46 shows a half-sectional view of a flow control valve, which is intended to keep the flow to a hydraulic load constant regardless of variations of the load pressure P_3 (disturbance input).

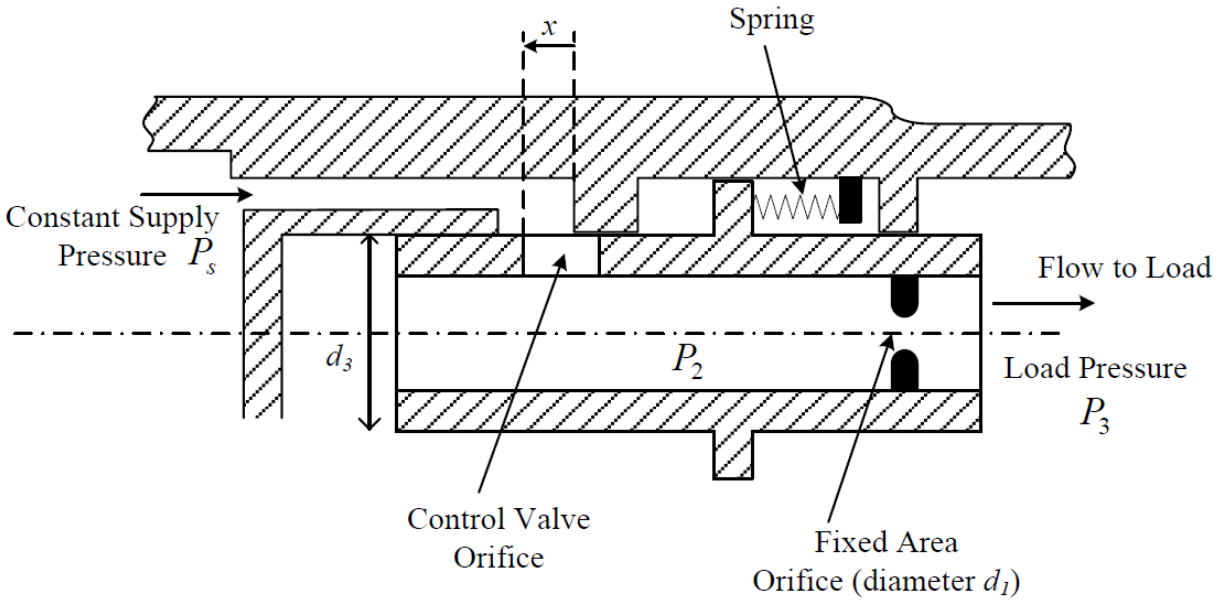

Figure P9.46: A flow control valve.

(a) Briefly discuss the physical operation of the valve, noting that the flow will be constant if the pressure drop across the fixed area orifice is constant.

(b) Write the equations that govern the dynamics of the unit. The mass, the damping constant, and the spring constant of the valve are denoted by m, b, and k, respectively. The volume of oil under pressure P_2 is V, and the bulk modulus of the oil is β. Make the usual linearizing assumptions.

(c) Set up a block diagram for the system from which the dynamics and stability of the valve could be studied.