Ex/ME(M2)/PE/H/T/424H/2023

B.E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER - 2023

Subject: INTRODUCTION TO MODERN CONTROL THEORY(HONS.)

Time : Three hours **Full Marks: 100**

Answer any __FIVE__ questions. Different parts of the same question should be answered together.
Assume any relevant data if necessary.

[1] Consider an electrohydraulic actuation system where a proportional valve **PV** drives a symmetric, double-acting cylinder **C** negotiating a spring **S** of stiffness k_s and a dashpot **D** of damping coefficient *C*. The total moving mass of the system is *m*. The fixed-displacement pump has a constant pressure p_P at its delivery port and the tank pressure is atmospheric. Take fluid to be incompressible, ignore any leakage and assume a suitable friction model.
The cylinder displacement *x* is recorded by an **LVDT** and the recorded signal is fed to the controller to estimate the control voltage *v* to the proportional valve.

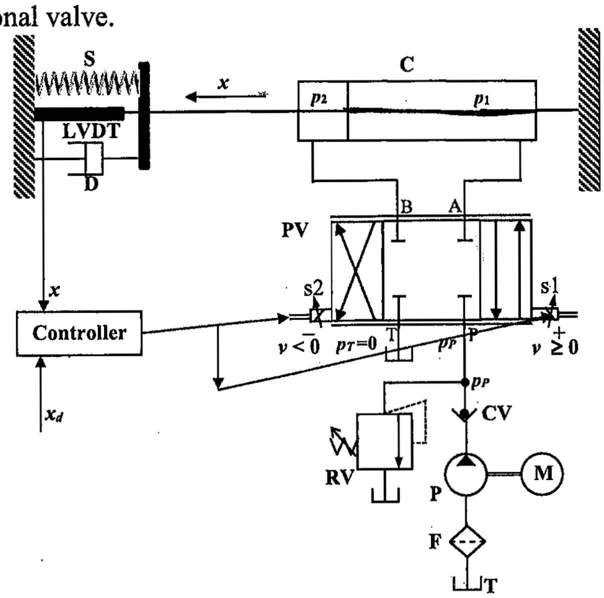

Fig: P1

(a) Construct a mathematical model of the system for $v \geq 0$.
(b) Linearize the model by suitable linearization technique.
(c) Develop a state space model of the linearized system.
(d) If the system lumped uncertainty can be expressed as $e(x, u, v, t) \leq 5$ and a sliding surface is defined as, $\sigma = 2x_1 + x_2$, where $x_1 = x$; $x_2 = \dot{x}$ – construct a sliding mode controller of the system to hold the system at the origin of the state space. [6+2+4+8=__20__]

[2] Obtain the state space model for 2 degrees of freedom (heave and pitch) half-car suspension system. Assume any symbols necessary, clearly stating their meanings. [__20__]

[3] (a) For a system with plant transfer function $G(s) = 2/(s^2+4s+5)$, obtain a state space model. Hence design a state feedback control $u = -\mathbf{k}'\mathbf{x}$ to place the closed-loop eigenvalues at $-3\pm 2j$.

(b) Design the observer matrix **L** to estimate the states of the system $\dot{\mathbf{x}} = \begin{bmatrix} -3 & 2 \\ 4 & -5 \end{bmatrix}\mathbf{x} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\mathbf{u}$; $y = [0 \quad 1]\mathbf{x}$, from the output y. Place the observer eigenvalues at –12 and –15. [10+10=__20__]

[4] (a) For an over-damped second order system, obtain the phase-plane equation and the isocline equation. Sketch the isoclines.
(b) State Sylvester's Theorem for a general quadratic form.
(c) For $Q = x_1^2 + 2x_2^2 + 3x_3^2 + 8x_1x_2 + 2x_1x_3 + 4x_2x_3$, check whether Q is positive definite. [10+4+6=__20__]

[Turn over

[5] (a) Consider a fuzzy logic controller for an electrohydraulic actuation system with position error and velocity error as the inputs and control voltage as the output. The ranges of position errors is ±0.1m, velocity error is ±1m/s and control voltage is ±10V. Define suitable membership functions for the inputs and output (3 for position error, 3 for velocity error and 3 for control voltage) and associated fuzzy rules. Show the fuzzy rules (at least 5 rules) in terms of the membership functions in a graph paper. Also using the graph paper and the *Mamdani's Inference Method*, obtain the *fuzzified* control voltage for position error of -0.06m and velocity error of +0.2m/s. How can one defuzzify the fuzzy voltage output to get a crisp value?

(b) What are the advantages of fuzzy control systems? [16+4=**20**]

[6] (a) Determine the output response of the system to the initial conditions and a unit step input:

$$\dot{\mathbf{x}} = \begin{bmatrix} -1 & 1 \\ 0 & -2 \end{bmatrix} \mathbf{x} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u; \qquad \mathbf{y} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \mathbf{x}; \qquad \mathbf{x}_0 = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

(b) What is meant by *Formal Solution* of the state space equations? What is meant by *Transition Matrix*?

(c) Explain the term *Controllability*? What is the condition that a state space model is controllable? [10+5+5=**20**]

[7] (a) State two typical features in response of a system that indicates existence of nonlinearity.

(b) State two common nonlinearities that are encountered in dynamic systems and explain with suitable examples.

(c) What is meant by learning of an Artificial Neural Network? What are the different types of learning?

(d) What is meant by a feedforward neural network?

(e) Explain with an example the difference between crisp set and fuzzy set in defining a physical variable. [4+4+4+4+4=**20**]

[8] Write short notes on any four (4) of the following:

(a) Lyapunov's Stability Theorem

(b) Companion form of system matrix

(c) State feedback control and the method of pole assignment

(d) Mamdani's Fuzzy Inference Method

(e) Robustness of sliding mode control

(f) Effect of learning rate and momentum factor in Artificial Neural Network training. [4×5=**20**]