INDIAN INSTITUTE OF TECHNOLOGY

Date: 15 September 2017 AN | **Time:** 2 Hours | **Full Marks:** 60 | **No. of Students:** 191

Semester: *Autumn* | **Department:** *Mechanical Engineering* | **Sub. Name:** *Systems and Control*

Instructions: *Answer **any four** out of the five questions. Each question carries 15 marks.*

1. Draw a bond graph model of the system shown in Fig. 1. By using gyrator equivalence, refer the magnetic domain to the equivalent electrical system model in the secondary side and then remove the ideal transformer from the circuit using transformer equivalence. Convert the final bond graph model back to the electrical circuit diagram. The primary and secondary side winding inductances are L_p and L_s, respectively (not shown in Fig. 1), and the number of turns in the primary and secondary sides are n_p and n_s, respectively. For the transformer, the mean core length is L, the average core cross-section area is A and the magnetic permeability of the core is μ. Assume that all magnetic domain losses (core loss, flux leakage, etc.) can be approximated by a single resistance R_c in the magnetic domain model. There is no need to causal the model.

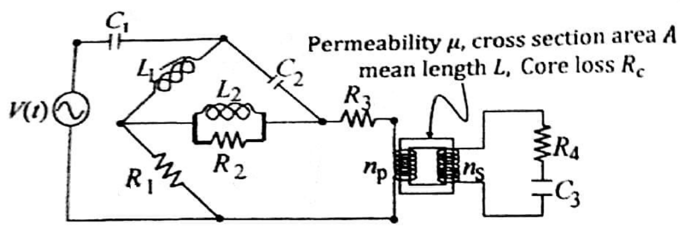

Fig. 1.

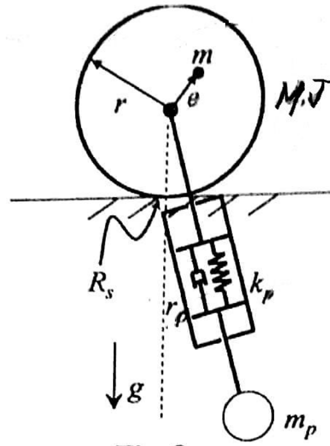

Fig. 3.

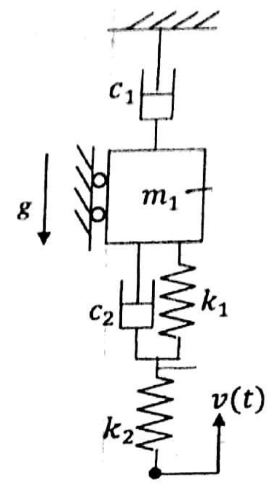

Fig. 4.

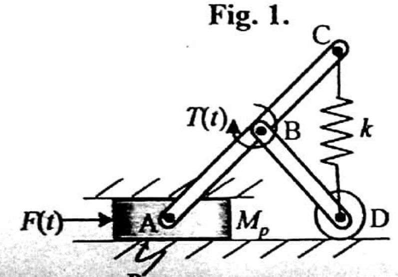

Fig. 2.

2. Draw a bond graph model (without causality) of the system shown in Fig. 2 where joints at A, B, C and D are pin joints with pin stiffness k_p and damping r_p. Pin B is at center of member AC. Slender members AC and BD have uniform cross-section and their mass centers can be assumed to be at their respective mid-span. Length of AC is $2l$ and that of BD is l, corresponding masses are $2m$ and m, and the rotary inertias at mass centers are $\frac{2ml^2}{3}$ and $\frac{ml^2}{12}$, respectively. The roller at D is friction-less and all revolute joint frictions are neglected. An external force $F(t)$ is applied on the slider of mass M_p which also experiences viscous damping R_p. A joint motor applies torque $T(t)$ on member BD and the reaction torque acts on member AC. Note that $T(t)$, though shown in the figure, is not an external torque. Clearly show the inertial (global) and body-fixed frames and the angles used in model building.

3. Draw the augmented bond graph model of the system shown in Fig. 3 and find its degrees of freedom from causality assignment. The disc has radius r, mass M, rotary inertia J and R_s is the frictional resistance at the ground contact. A small eccentric mass m is fixed to the disk at distance e from the disc center. A pendulum of mass m_p hangs from a revolute joint at the disc center. In the model, the acceleration due to gravity g needs to be considered. The pendulum rod is assumed to be mass-less and has axial flexibility with stiffness k_p and damping r_p.

4. Derive the state-space equations of the system shown in Fig. 4. Include gravity in the model. Consider vertical motions only.

5. Draw a block diagram model of the system shown in Fig. 5. The permanent magnet DC motor has a motor characteristic constant μ_m and the rotary inertia of its rotor is J_m. The disc is perfectly balanced and has a rotary inertia J_d. The armature resistance is R_a and the armature inductance is neglected because the electrical sub-system time constant is negligible in comparison to that of the mechanical sub-system. The rotary inertia of the light-weight rotor shaft is lumped at its two ends, i.e. already included in the specified values of J_m and J_d. The torsional stiffness and damping of the rotor shaft are K_t and R_t, respectively.

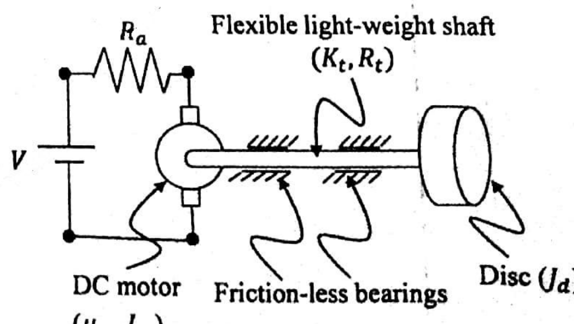

Fig. 5.