MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Mechanical Engineering

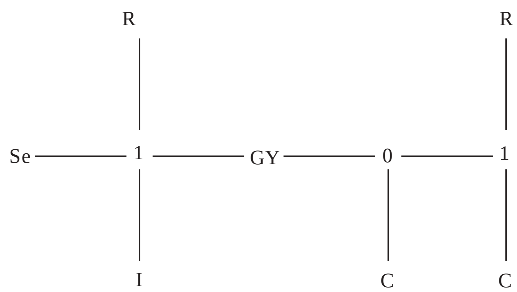
2.151: Advanced System Dynamics and Control –Spring 2003

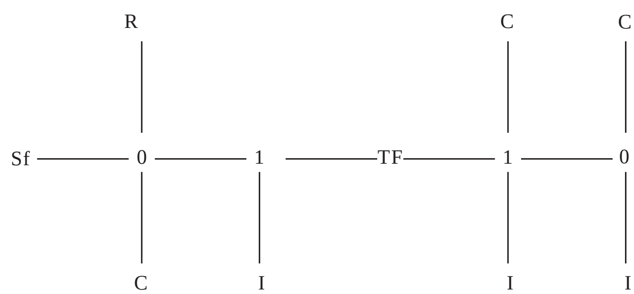
QUIZ 1

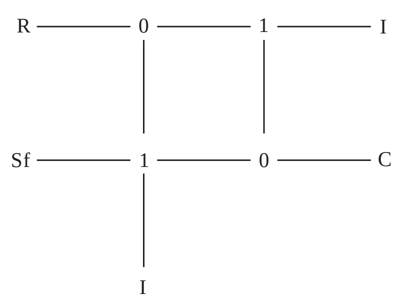
This quiz is closed-book. You have 1.5 hours to complete it.

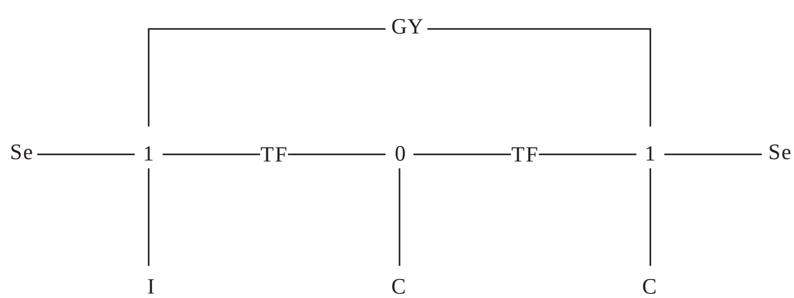
Problem 1(30pts):

For each of the following bond-graphs, determine the system's minimum order. For the first three systems, determine whether the system could exhibit oscillatory (resonant) behavior.

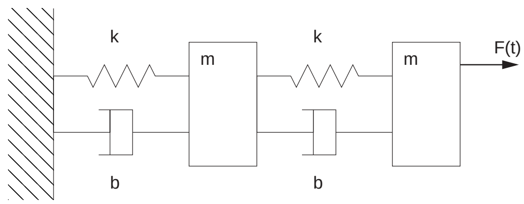




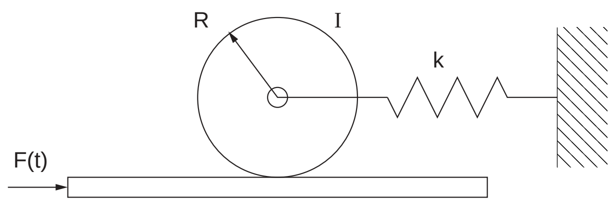




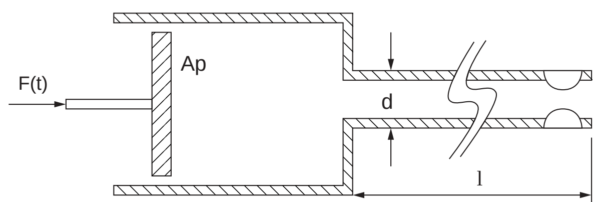
Problem 2(30pts):
For each of the following systems, draw a corresponding bond-graph and determine the system's minimum order. Assume all elements have linear constitutive relations. For the first three systems, choose appropriate state variables and write state equations.

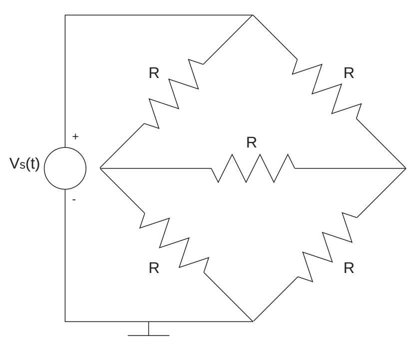


Assume the cylinder (with inertia I) rolls without slipping.



Assume no leaking, and incompressible fluid flow with density ρ.





Problem 3:

Typical examples of common linear drives are described in the attached pages taken from the Warner Electric catalog. Consider the in-line configuration shown at the bottom of the page. A permanent-magnet DC motor is used to drive a recirculating-ball screw (a nut and screw with ball-bearings interposed between the nut and screw so that frictional energy losses are minimized). The motor shaft is connected directly to the screw. The nut is prevented from rotating but may slide as the screw rotates within it.

The screw has 5 threads per inch with a pitch diameter of 0.5 inches. The screw may be considered to be a steel cylinder 18 inches long with diameter equal to the screw pitch diameter. The nut may be considered to be a steel cylinder 3 inches long, outside diameter 3 inches, with a hole though its center equal to the pitch diameter of the screw. To keep things simple, ignore all frictional losses due to the recirculating-ball screw and the sliding nut.

Parameters of the motor are given in the table below.

Excerpt from specification sheet of a direct-current permanent-magnet motor

MOTOR CONSTANTS: INTRINSIC (AT 25 DEG C)	**SYMBOL**	**UNITS**	
TORQUE CONSTANT	KT	OZ IN/AMP	5.03
BACK EMF CONSTANT	KE	VOLTS/KRPM	3.72
TERMINAL RESISTANCE	RT	OHMS	1.400
ARMATURE RESISTANCE	RA	OHMS	1.120
VISCOUS DAMPING CONSTANT	KD	OZ IN/KRPM	0.59
MOMENT OF INERTIA	JM	OZ IN SEC-SEC	0.0028
ARMATURE INDUCTANCE	L	MICRO HENRY	<100.0
TEMPERATURE COEFFICIENT OF KE	C	%/DEG C RISE	-0.02

a. First assume the DC motor is driven by a current-controlled amplifier (i.e., the current applied to the electrical terminals of the motor may be specified independent of the voltage required). Assuming all model elements have linear constitutive equations, develop a model competent to describe the linear displacement of the rod end in response to motor current input. Express your model as a bond graph, clearly identifying the different energy domains.

b. What is the order of this model?

c. Next assume the DC motor is driven by a voltage-controlled amplifier (i.e., the voltage applied to the electrical terminals of the motor may be specified independent of the current required). Assuming all model elements have linear constitutive equations, develop a model competent to describe the linear displacement of the rod end in response to motor voltage input. Express your model as a bond graph, clearly identifying the different energy domains.

d. What is the order of this model?

e. Suppose an external force is applied to the rod end. Numerically evaluate the total apparent translational inertia opposing that force (i.e., the equivalent mass “seen at” the rod end due to everything that moves).

<Pages from Warner Electric catalog referenced above have been removed due to copyright considerations.>