SOLUTIONS MANUAL TO ACCOMPANY

Third Edition

SYSTEM DYNAMICS

Modeling and Simulation of Mechatronic Systems

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Solutions Manual to Accompany System Dynamics: Modeling and Simulation of Mechatronic Systems
Third Edition

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A Wiley-Interscience Publication

JOHN WILEY & SONS, INC.
New York, Chichester, Weinheim, Brisbane, Singapore, Toronto

This book is printed on acid-free paper. ♾

Published simultaneously in Canada.

Library of Congress Cataloging-in-Publication Data:

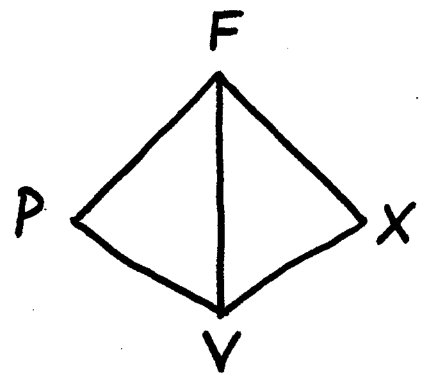
ISBN: 0-47138709-6

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

1-1 to 1-5 These are mainly discussion questions.

2-1

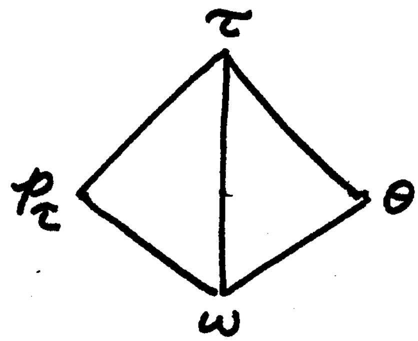


[F] - N

[V] - m/s

[P] - N·s

[X] - m

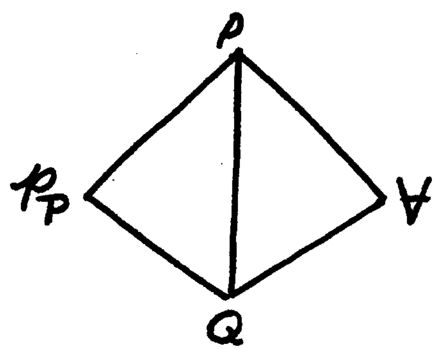


[τ] - N·m

[ω] - rad/s

[p_τ] - N·m·s

[θ] - rad

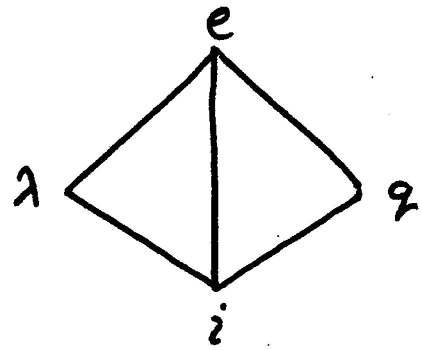


[P] - N/m²

[Q] - m³/s

[p_P] - N·s/m²

[∀] - m³



[e] - v

[i] - a

[λ] - v·s

[q] - a·s = c

2-2 $\xrightarrow[\omega]{\tau}$ Electric Motor $\xrightarrow[i]{e}$

(a)

$\xrightarrow[\omega]{\tau}$ Hydraulic Pump $\xrightarrow[Q]{P}$

(b)

$\xleftarrow[\omega_1]{\tau}$ Shaft $\xleftarrow[\omega_2]{\tau}$

(c)

$\xrightarrow[V_1]{F}$ Shock Absorber $\xrightarrow[V_2]{F}$

(d)

$\xrightarrow[i_1]{e_1}$ Transistor $\xrightarrow[i_2]{e_2}$

(e)

$\xrightarrow[i]{e}$ Speaker

(f)

$\xrightarrow[\omega]{\tau}$ Crank $\xrightarrow[V]{F}$

(g)

$\xrightarrow[V]{F}$ Wheel $\xleftarrow[\omega]{\tau}$

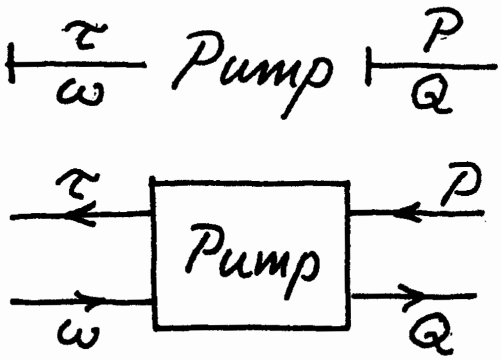
(h)

$e_f \downarrow i_f$

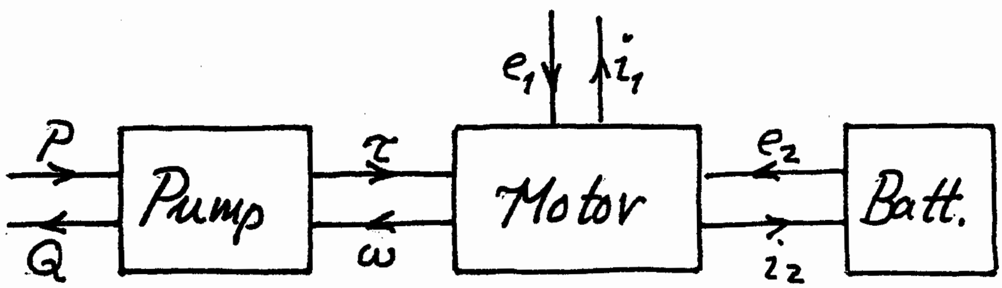
$\xrightarrow[\omega]{\tau}$ Motor $\xleftarrow[i_a]{e_a}$

(i)

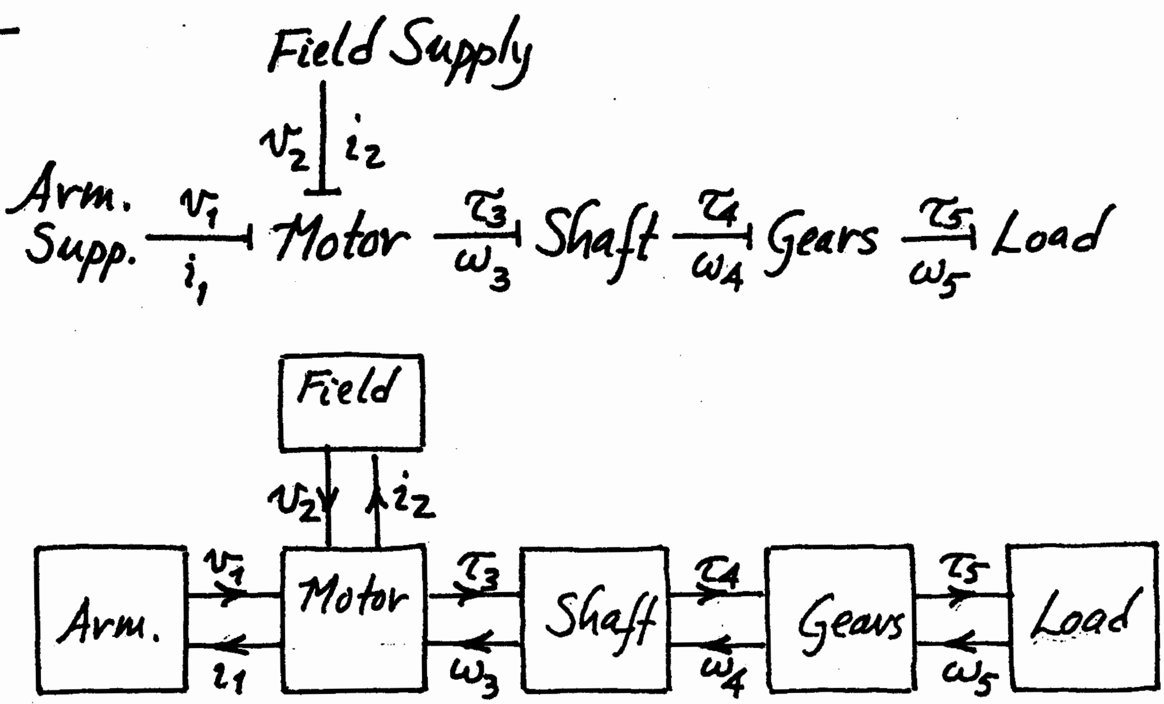
2-3


τ
ω
Pump
P
Q
τ
P
Pump
ω
Q

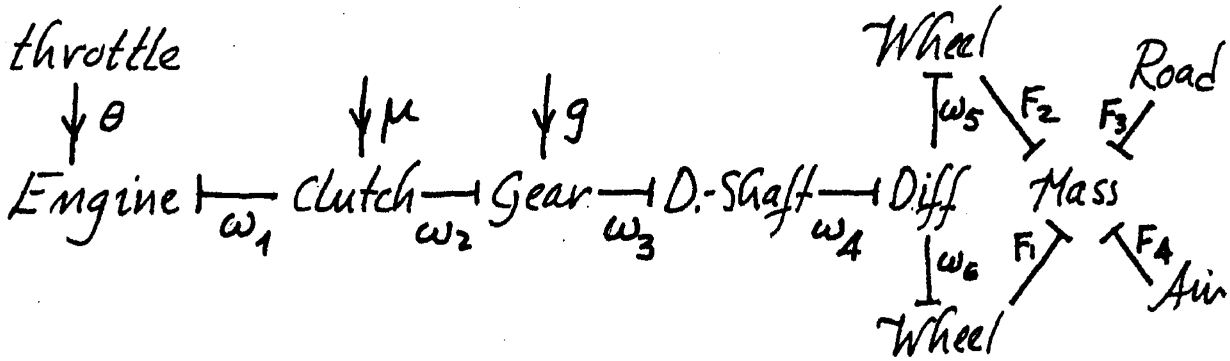
2-4

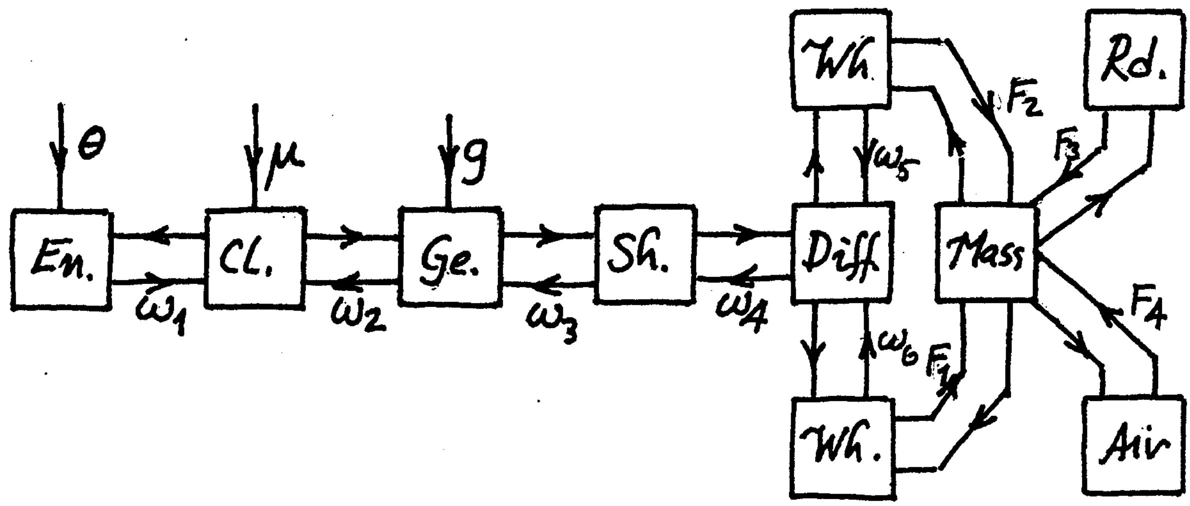

e1
i1
P
Pump
Q
τ
ω
Motor
e2
i2
Batt.

2-5


Field Supply
v2
i2
Arm. Supp.
v1
i1
Motor
τ3
ω3
Shaft
τ4
ω4
Gears
τ5
ω5
Load
Field
v2
i2
Arm.
v1
i1
Motor
τ3
ω3
Shaft
τ4
ω4
Gears
τ5
ω5
Load

2-6





2-7 Inputs: P, e_1, e_2

Outputs: Q, i_1, i_2

2-8

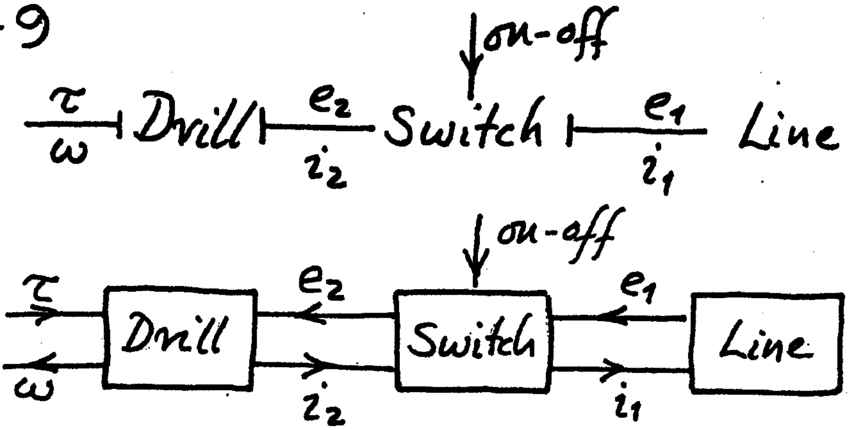
Power × Time = Energy

$$P \cdot t = mgh$$

$$100 \cdot t = 10 \cdot (9.81) \cdot 30$$

$$t = 29.43 \text{ s}$$

2-9



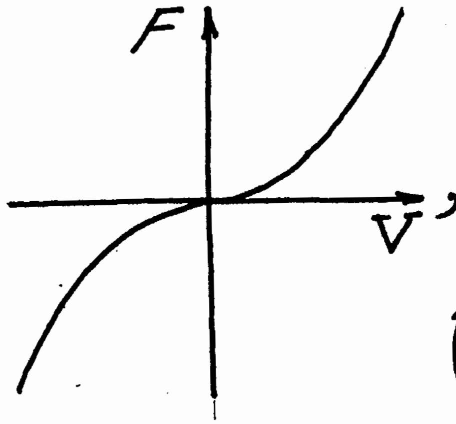
2-10 $\tau\omega = PQ$

$$\omega = \frac{P}{\tau} \cdot Q = \frac{7.0 \times 10^6}{5} Q$$

$$\omega = 1.4 \times 10^6 Q$$

$$\left[\frac{rad}{s}\right] = \left[\frac{1}{m^3}\right] \cdot \left[\frac{m^3}{s}\right]$$

3-1



$\vdash\xrightarrow[V]{F} R$,

$V = \sqrt{\dfrac{|F|}{A}} \cdot \operatorname{sgn} F$

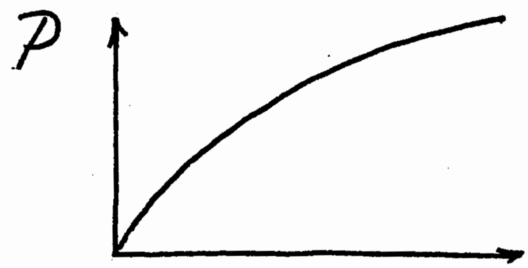
$\xrightarrow[V]{F}\!\dashv R$

3-2 $\quad hA = \forall = \int Q\,dt$,

$P = \rho g h = \dfrac{\rho g}{A} \int Q\,dt$

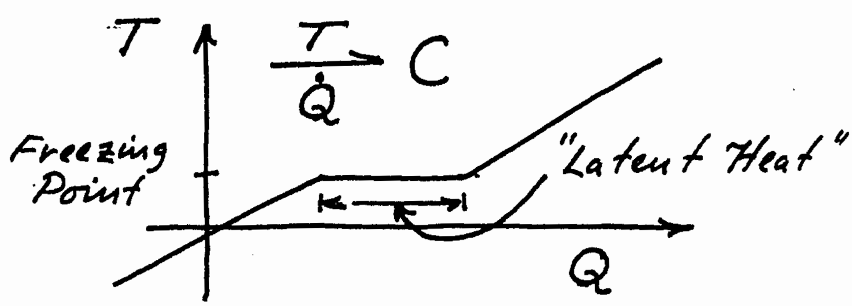
$\therefore\ C = A/\rho g$

3-3

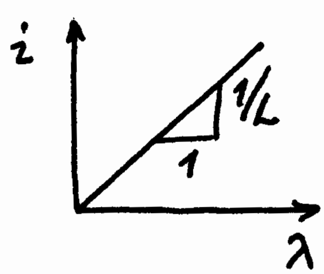


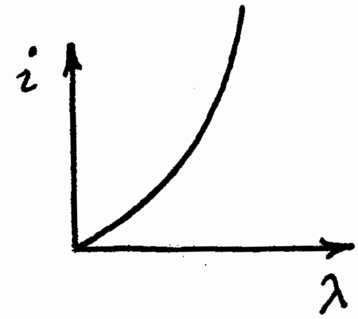
3-4 $\quad \xrightarrow[\dot{x}]{F} C \quad , \quad F = \left(\dfrac{3EI}{L^3}\right) x .$

3-5 $\quad \xrightarrow[\dot{Q}]{T} C$



3-6 $\quad Li = \lambda = \int e\,dt$



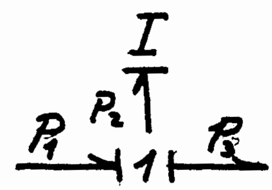


$$i = i(\lambda) \qquad \text{or} \qquad \lambda = \lambda(i)$$

$$\frac{di}{dt} = \frac{di(\lambda)}{d\lambda}\cdot\frac{d\lambda}{dt} \qquad\qquad \frac{d\lambda}{dt} = e = \frac{d\lambda(i)}{di}\cdot\frac{di}{dt}$$

$$= \frac{di(\lambda)}{d\lambda}\cdot e$$

3-7 $\quad \bar{F} = m\bar{a} = m\dot{\bar{v}}$

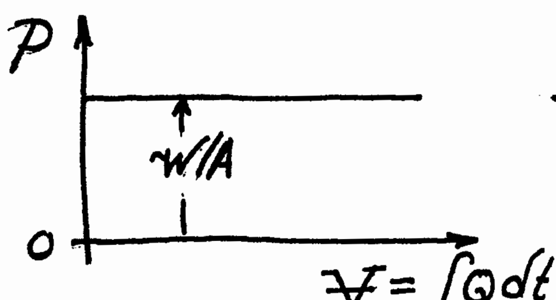


$$P_1 A - P_3 A = \rho A L \cdot \frac{dQ_2/A}{dt}$$

$$\text{or} \quad P_1 - P_3 = \left(\frac{\rho L}{A}\right)\cdot\frac{dQ_2}{dt} = P_2$$

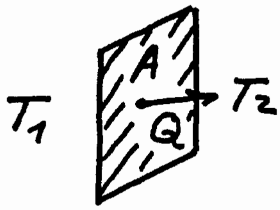
$$p_{P_2} = \int (P_1 - P_3)\,dt = \frac{\rho L}{A}\cdot Q_2$$

3-8

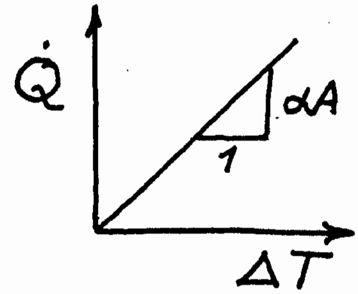


$$\overset{P}{\underset{Q}{\rightharpoonup}} C$$

3-9



$$\begin{tikzcd} & R \\ {} \arrow[r, "T_1", "\dot Q"'] & 1 \arrow[u] \arrow[r, "T_2", "\dot Q"'] & {} \end{tikzcd}$$



$$\dot Q = \alpha A (T_1 - T_2)$$

3-10

$$\tau = I\alpha, \quad p_\tau = \int \tau dt = I\omega$$

$$I = \tfrac{1}{2} m R^2 = \tfrac{1}{2}\rho \cdot \pi R^2 t \cdot R^2$$

$$= \frac{0.28 \ \pi \cdot 1 \cdot (5)^4}{2 \cdot 386} = 0.712 \ \text{lb s}^2\text{in}$$

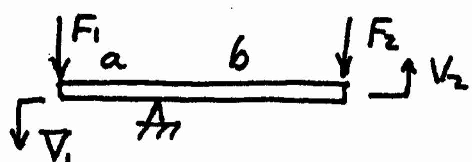
3-11

$$\xrightarrow[V]{F} TF \xrightarrow[Q]{P} \qquad \text{Area} = A$$

$$F = AP$$

$$AV = Q$$

3-12



(b)

$$\xrightarrow[V_1]{F_1} TF \xrightarrow[V_2]{F_2}$$

$$aF_1 = bF_2$$

$$\frac{V_1}{a} = \frac{V_2}{b}$$

(c) $\xrightarrow[\omega_1]{\tau_1} TF \xrightarrow[\omega_2]{\tau_2}$

$$\left.\begin{aligned} \omega_1 r_1 &= \omega_2 r_2, \\ \tau_1/r_1 &= \tau_2/r_2, \end{aligned}\right\} r_1, r_2 \text{ radii of gears}$$

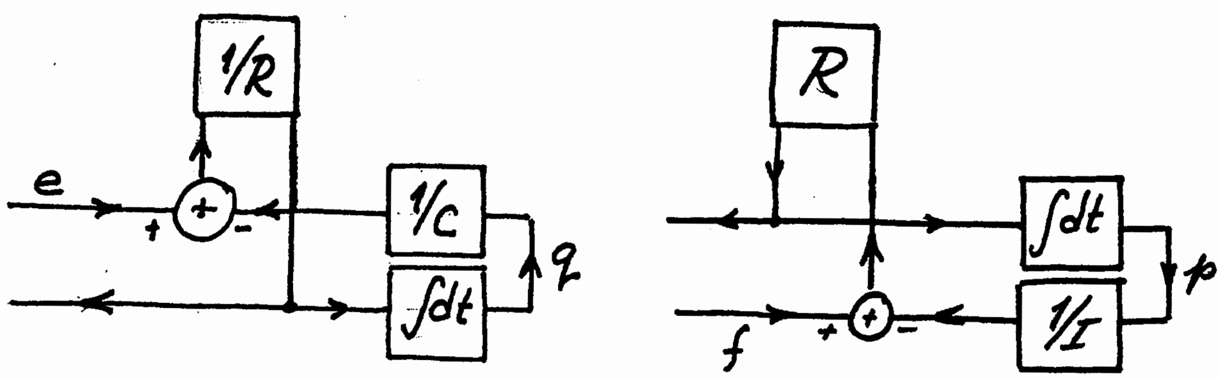
3-13 Ang. Momentum = $\bar{H}$

$|\bar{H}| \cong J\Omega$, torques associated with F_1 and F_2 cause change in direction of $\bar{H}$ not magnitude. Consider F_1 first; let shaft length be L. Torque is then $F_1 L$, $\bar{\tau} = \dot{\bar{H}}$ means that tip of $\bar{H}$ vector must move up with angular rate V_2/L. $|\dot{H}| = J\Omega \cdot V_2/L = F_1 L$

so

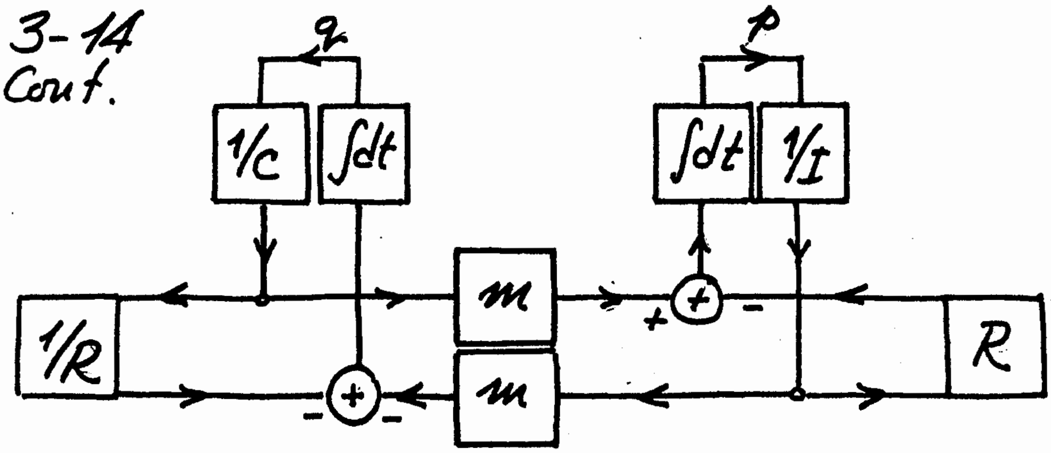
$$\left.\begin{aligned} F_1 &= \left(\frac{J\Omega}{L^2}\right) V_2 \\ \text{Similarly}\quad F_2 &= \left(\frac{J\Omega}{L^2}\right) V_1 \end{aligned}\right\} \quad \frac{F_1}{V_1}\, GY \, \frac{F_2}{V_2}$$

3-14

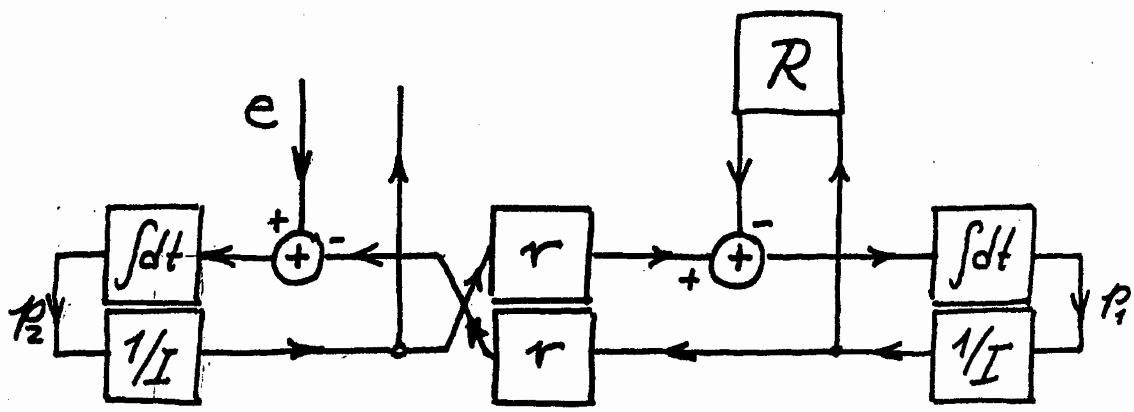


(a) (b)

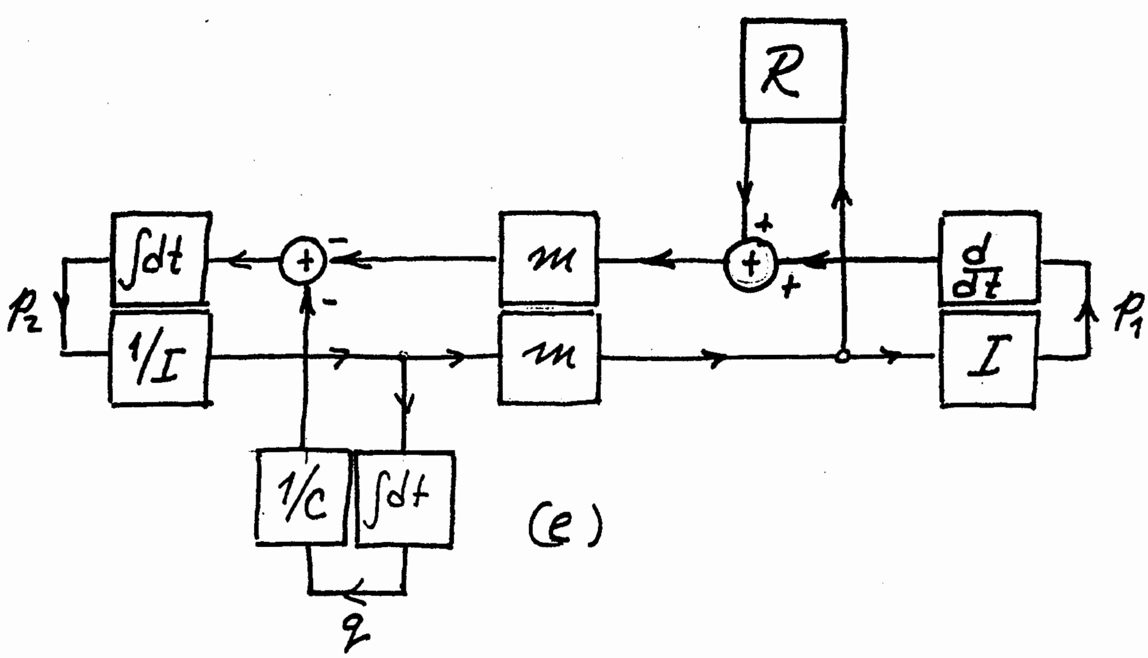
3-14 Cont.


q
1/C
∫dt
p
∫dt
1/I
1/R
m
m
R
+
−
−
−

(c)

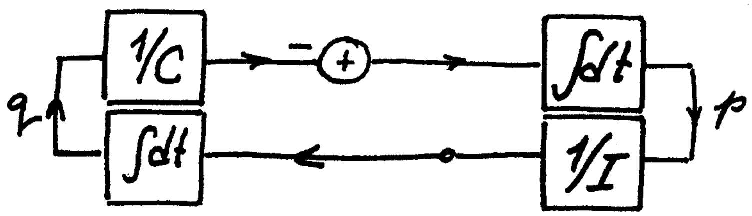

e
R
+
−
+
−
∫dt
1/I
r
r
∫dt
1/I
p_2
p_1

(d)

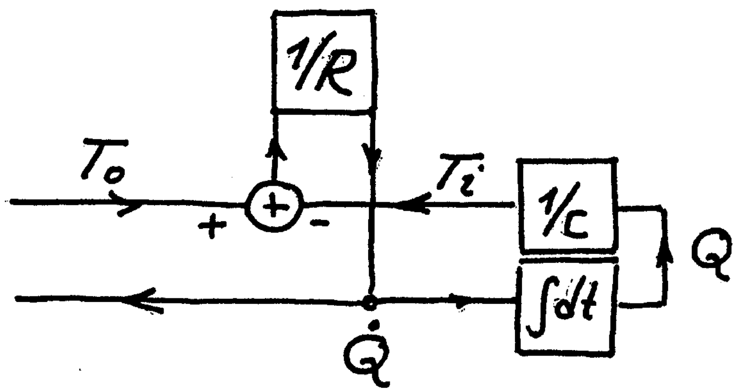

R
∫dt
1/I
m
m
d/dt
I
p_2
p_1
+
+
−
−
1/C
∫dt
q

(e)

3-15



3-16



3-17

$$\xrightarrow[\omega]{\tau} TF \xrightarrow[V]{F} \qquad \tau = rF$$
$$r\omega = V$$

3-18 $\vdash\!\xrightarrow[i]{e} \overset{T}{GY} \xrightarrow[V]{F}\!\dashv I$

$$e = TV = T\frac{p}{I} = \frac{T\int F\,dt}{I}$$
$$= \frac{T}{I}\int Ti\,dt = \frac{T^2}{I}\int i\,dt = \frac{T^2}{I}\cdot q$$

so $\quad \dfrac{1}{C} \longleftrightarrow \dfrac{T^2}{I}$

3.19

$$P = P_o \frac{V_o^\gamma}{V^\gamma} = \frac{P_o V_o^\gamma}{(V_o - A_p x)^\gamma} = \frac{P_o}{\left[1 - \frac{A_p x}{V_o}\right]^\gamma}$$

P is absolute pressure:

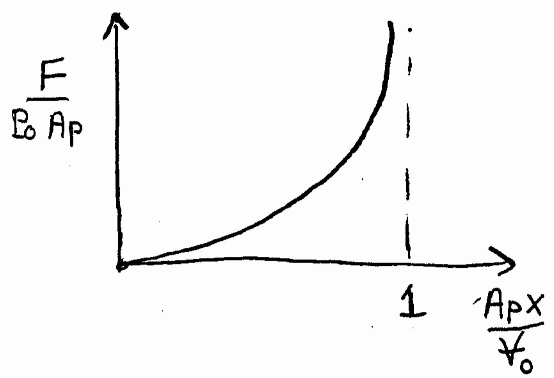
$P - P_o$ is gage pressure in cylinder,

$$(P - P_o) A_p = F$$

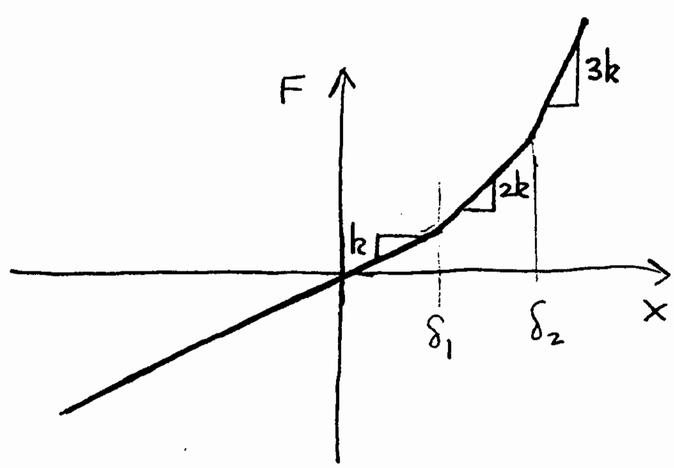
or

$$F = \left\{ \frac{P_o}{\left[1 - \frac{A_p x}{V_o}\right]^\gamma} - P_o \right\} A_p$$

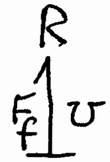
$$F = P_o A_p \left[\frac{1}{\left(1 - \frac{A_p x}{V_o}\right)^\gamma} - 1 \right]$$



3.20



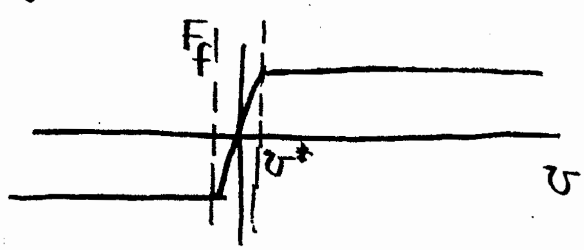
3.21

a) 

The only possible causality for the friction model shown in the problem is "effort" out, "flow" in. For any specified velocity, F_f can be computed, but if F_f is specified, v is indeterminant.

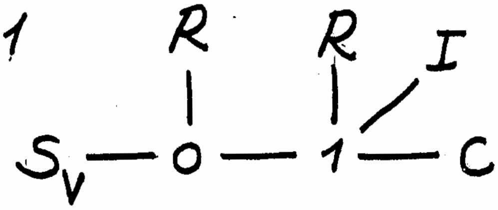
(b) If used simply as $F_f = \mu N$, then F_f will be applied when $v=0$, which is not correct. When $v=0$, the mass "sticks", and the friction force exactly balances all other forces on the mass. When the other forces exceed the "stick" force, then F_f returns to $F_f = \mu N$.

A possible change in the constitutive law might be,

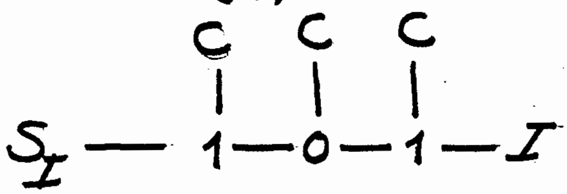


For v^* very small, the fundamental character of friction is maintained.

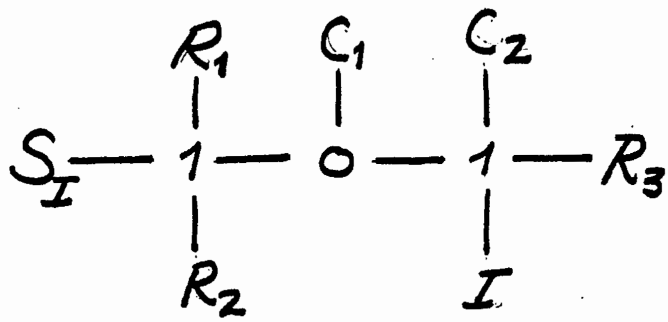
4-1



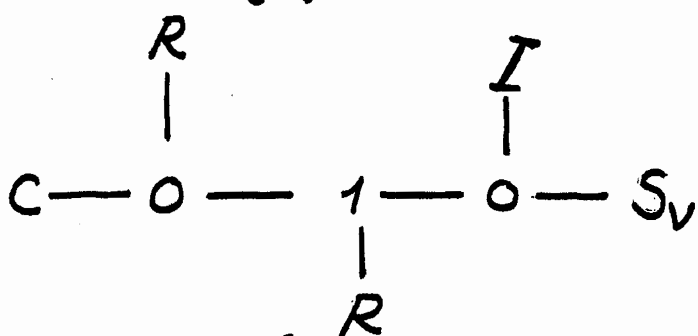
(a)



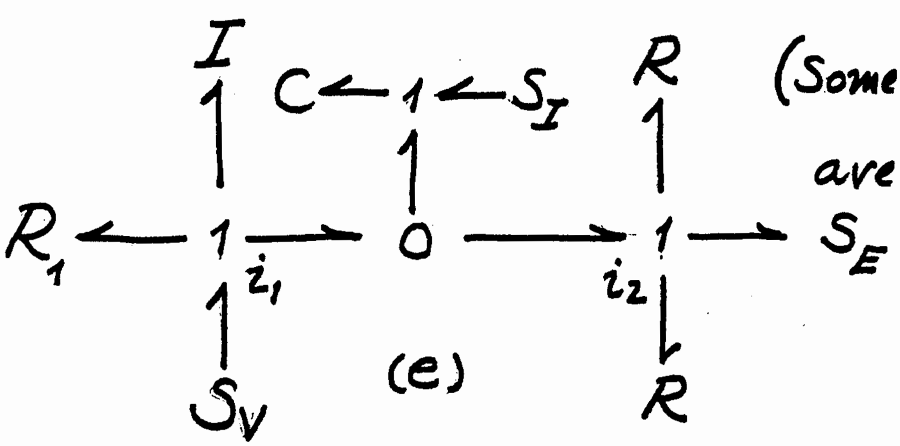
(b)



(c)



(d)



(Some signs are not defined in problem)

(e)