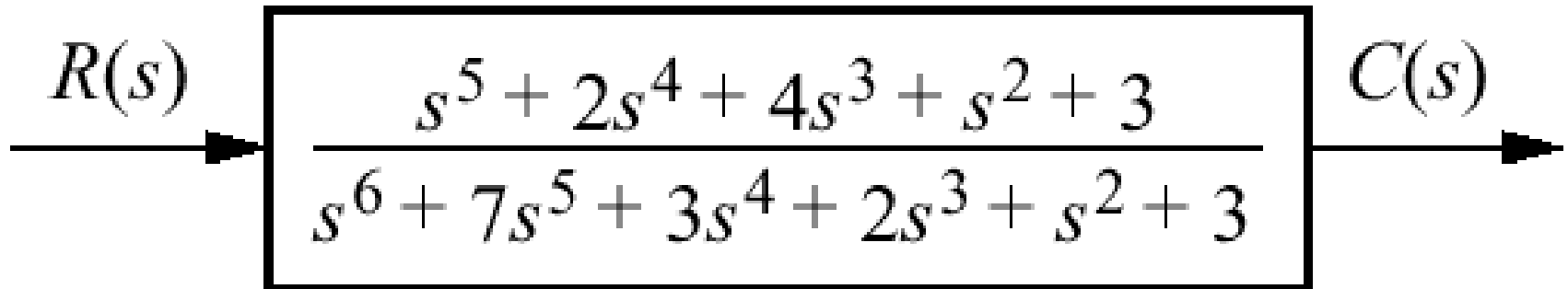
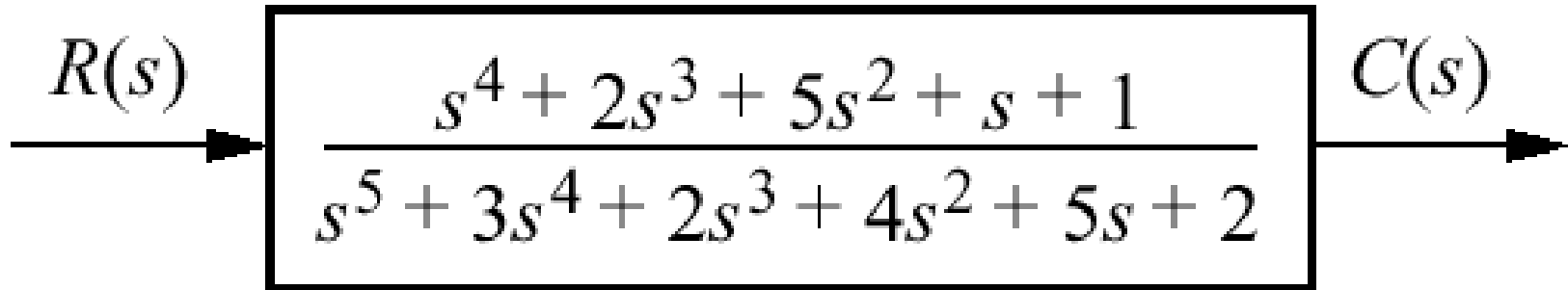


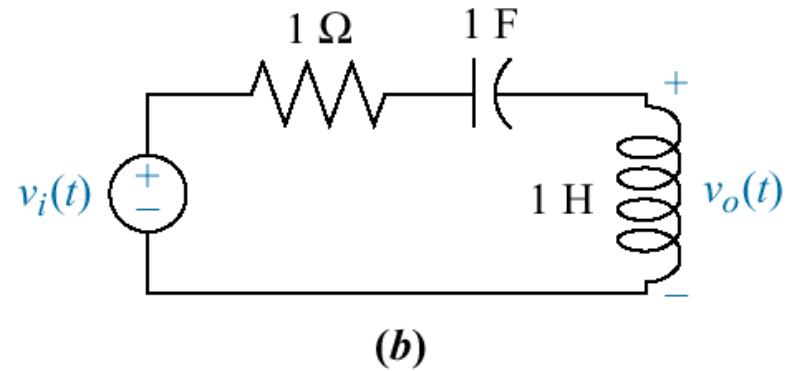
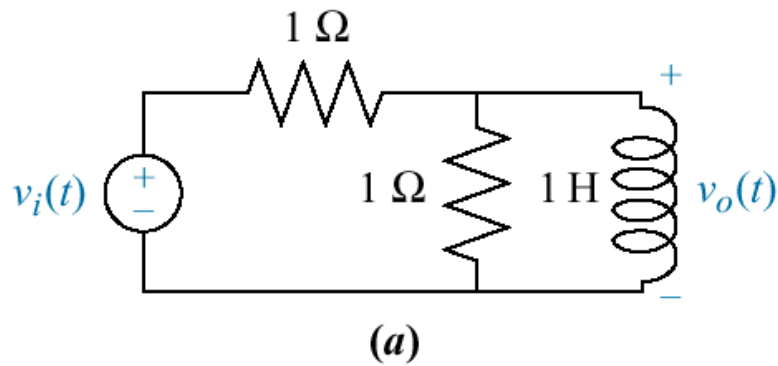
# Capítulo 2

(Problemas)

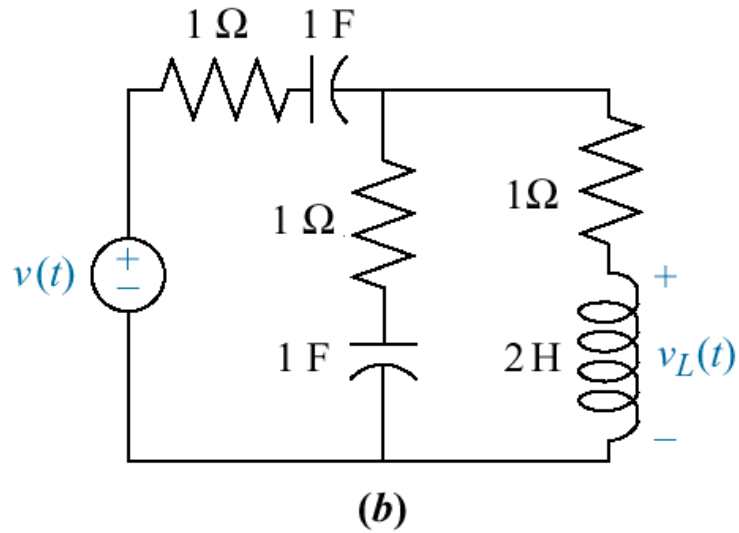
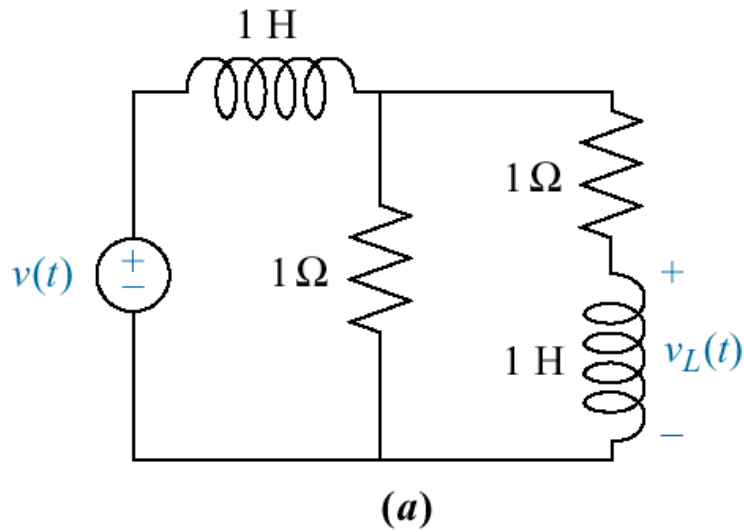
**Fig. P2.1**

**Fig. P2.2**

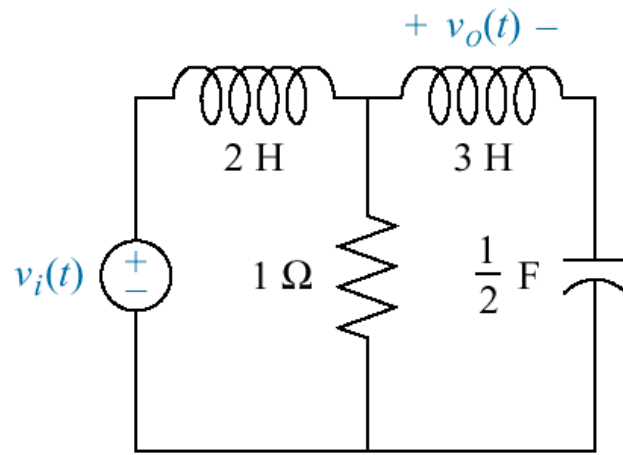
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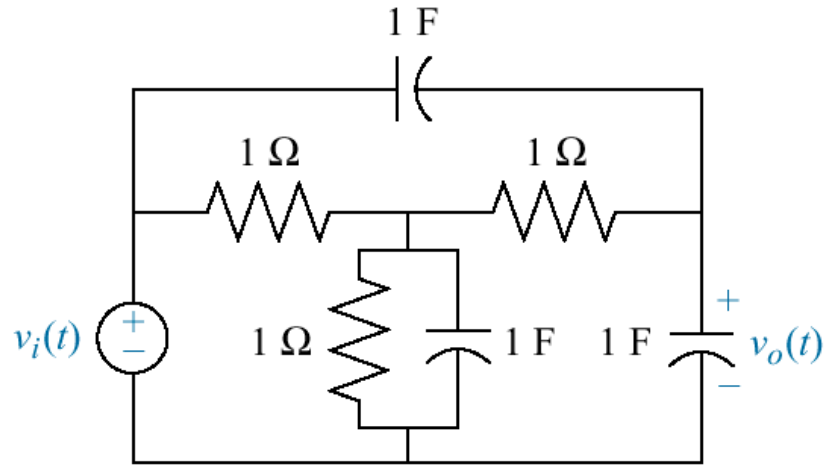
**Fig. P2.4**



**Fig. P2.5**

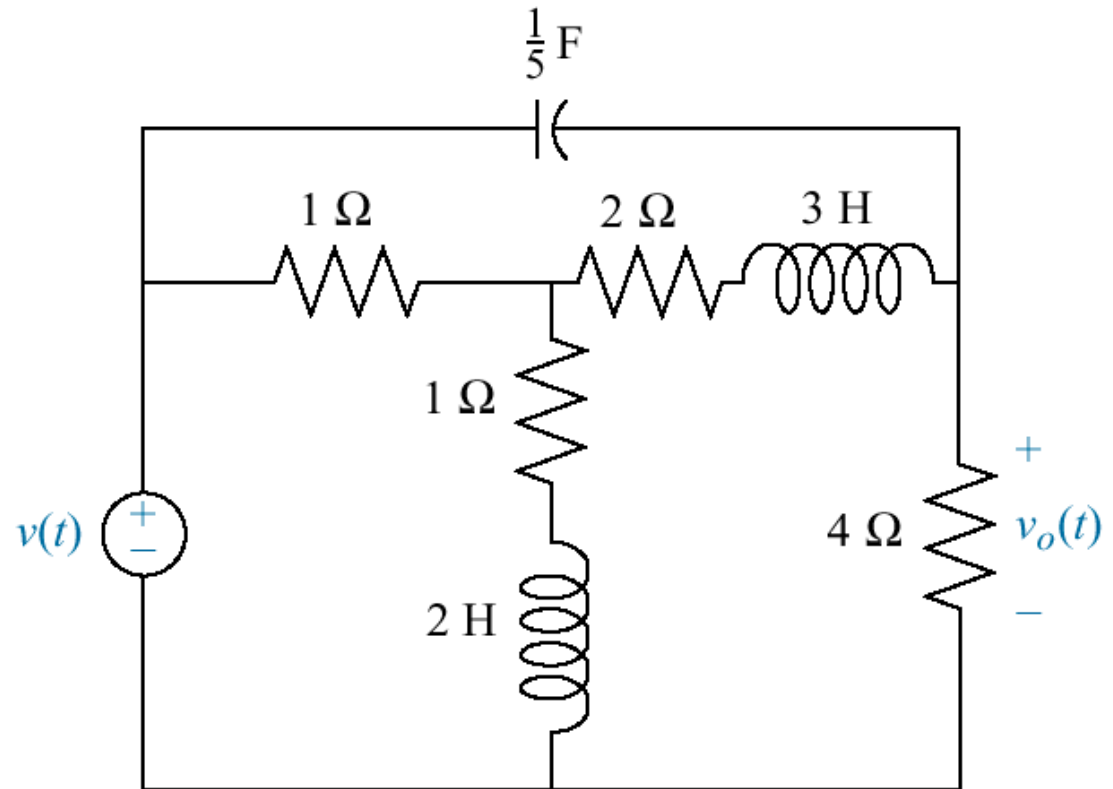


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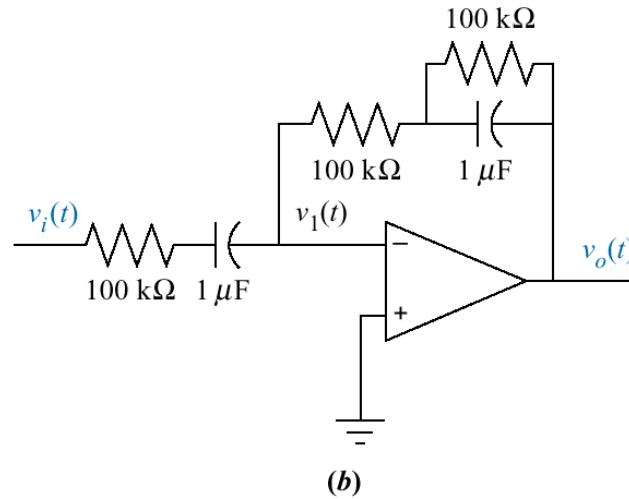
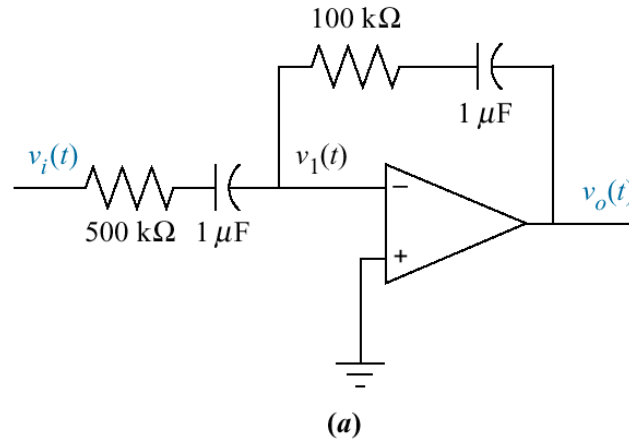


(b)

**Fig. P2.6**

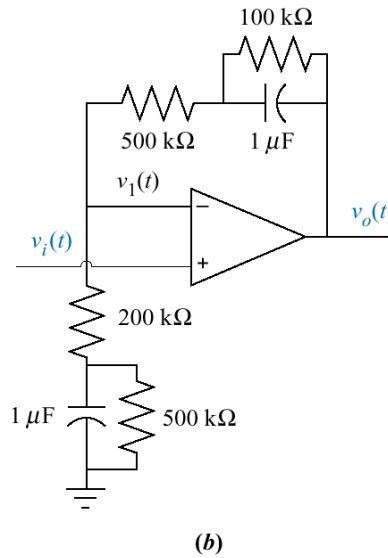
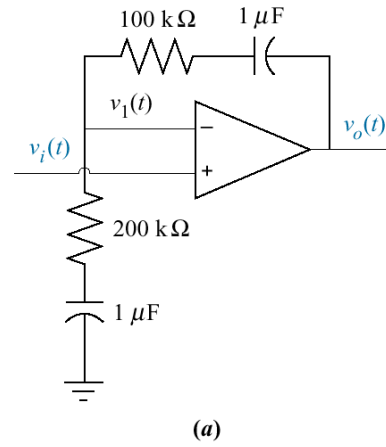


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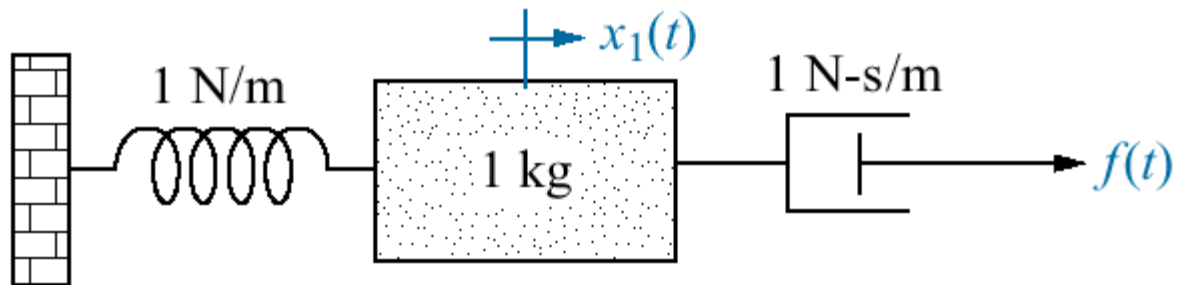




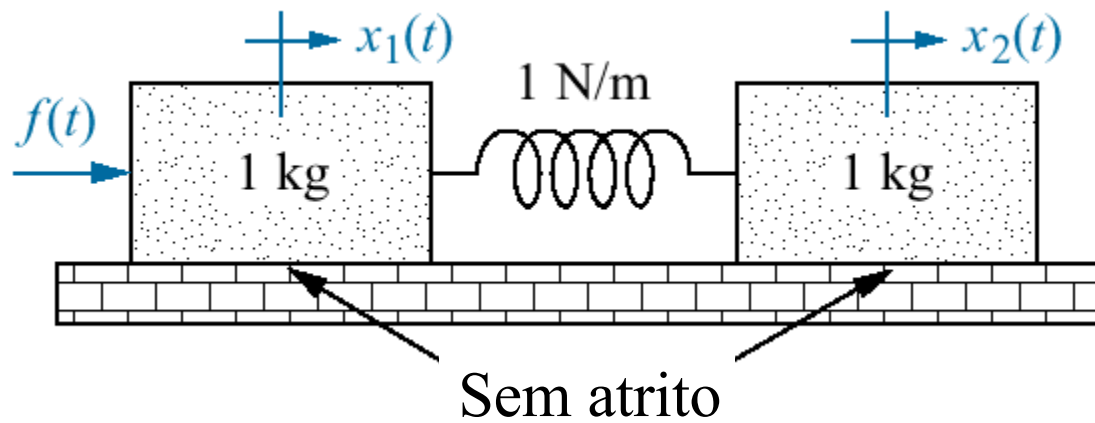
**Fig. P2.8**



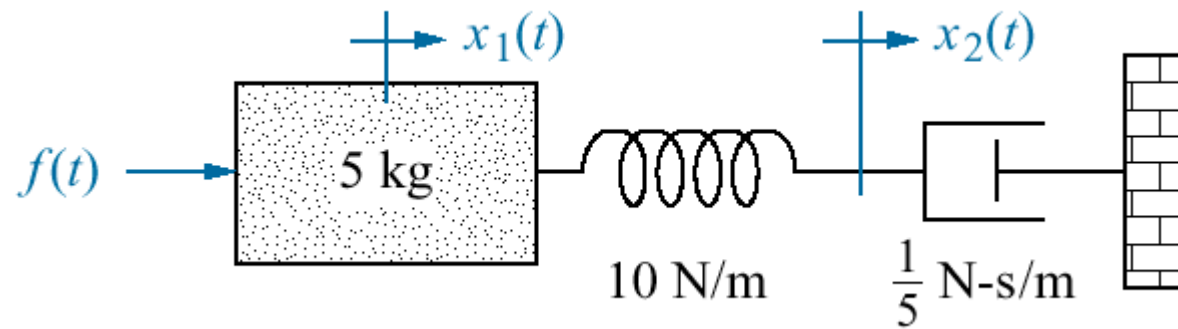
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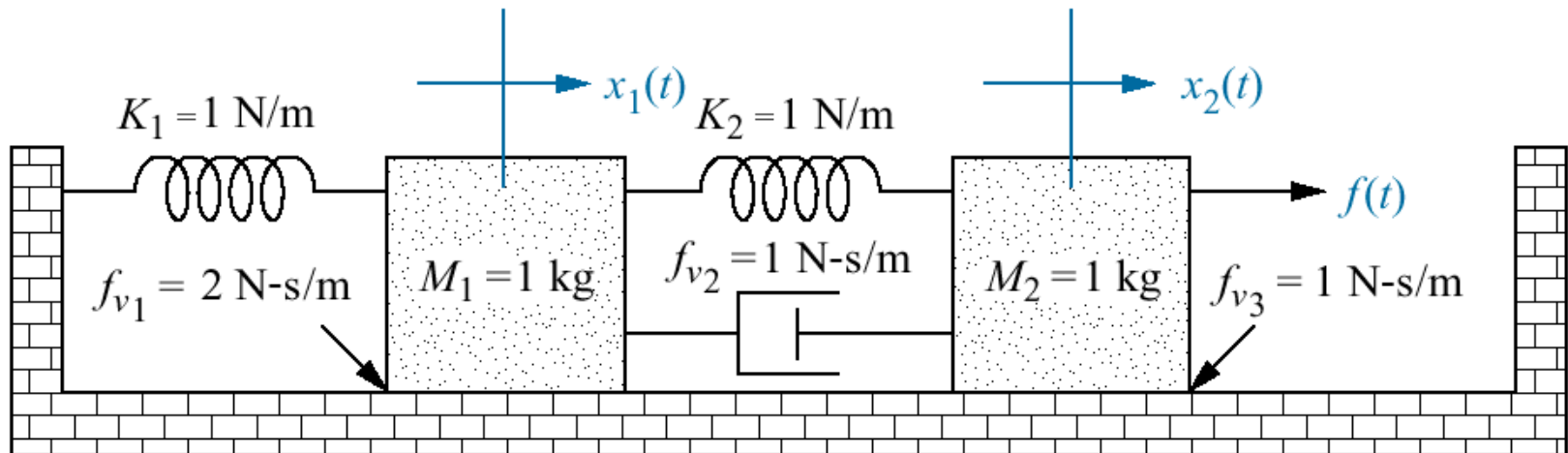
**Fig. P2.10**



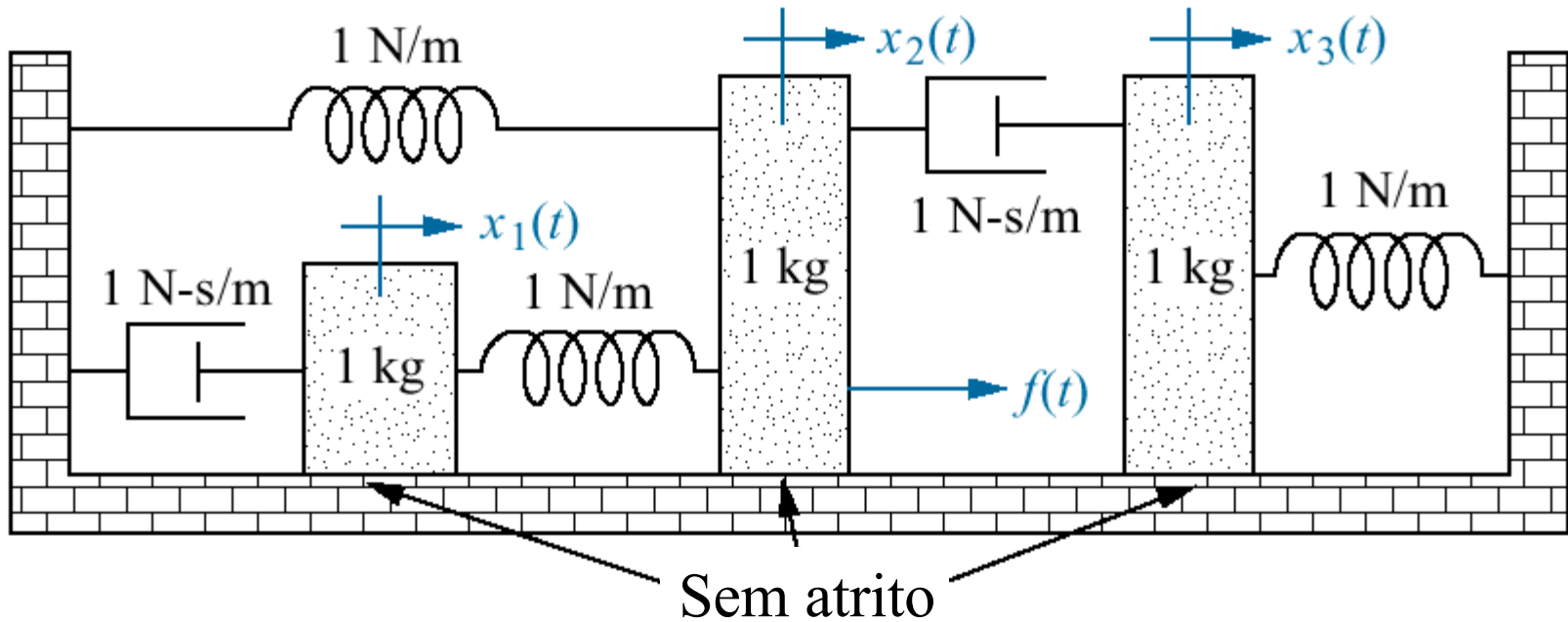
**Fig. P2.11**



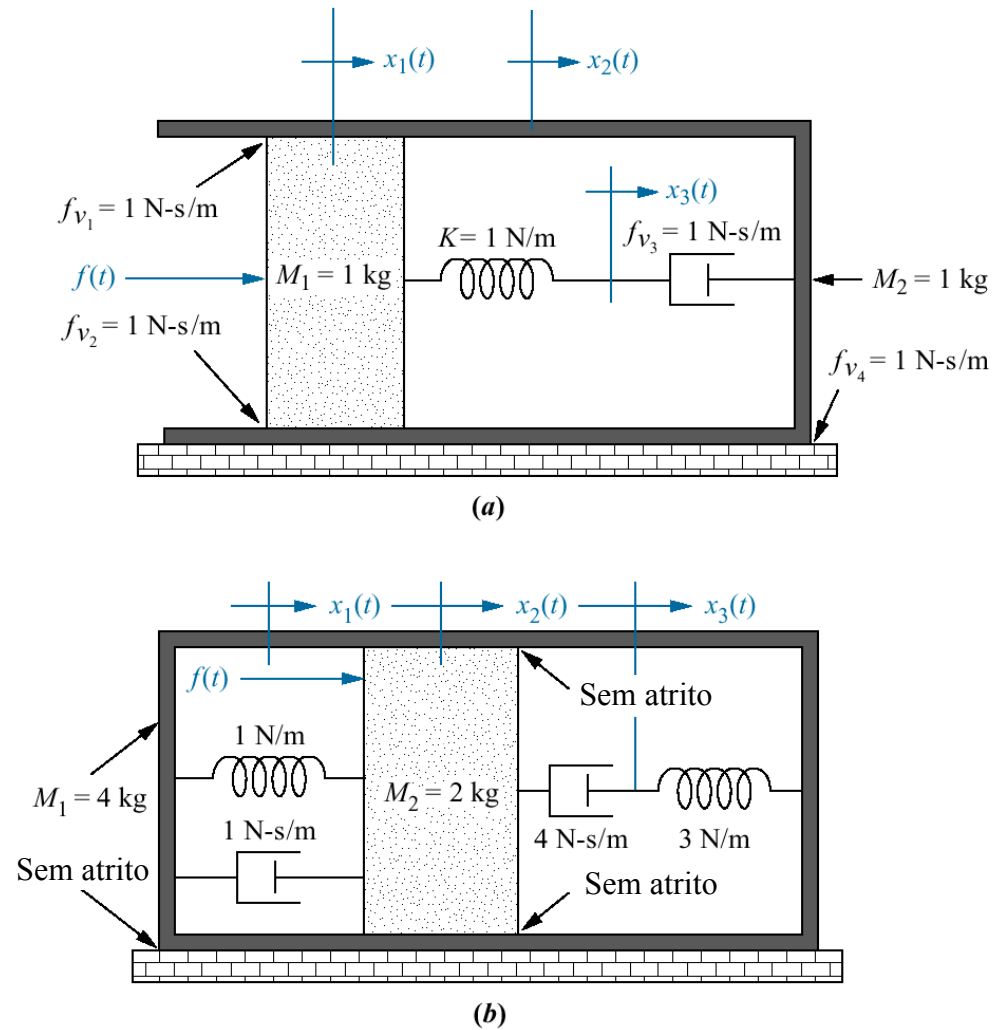
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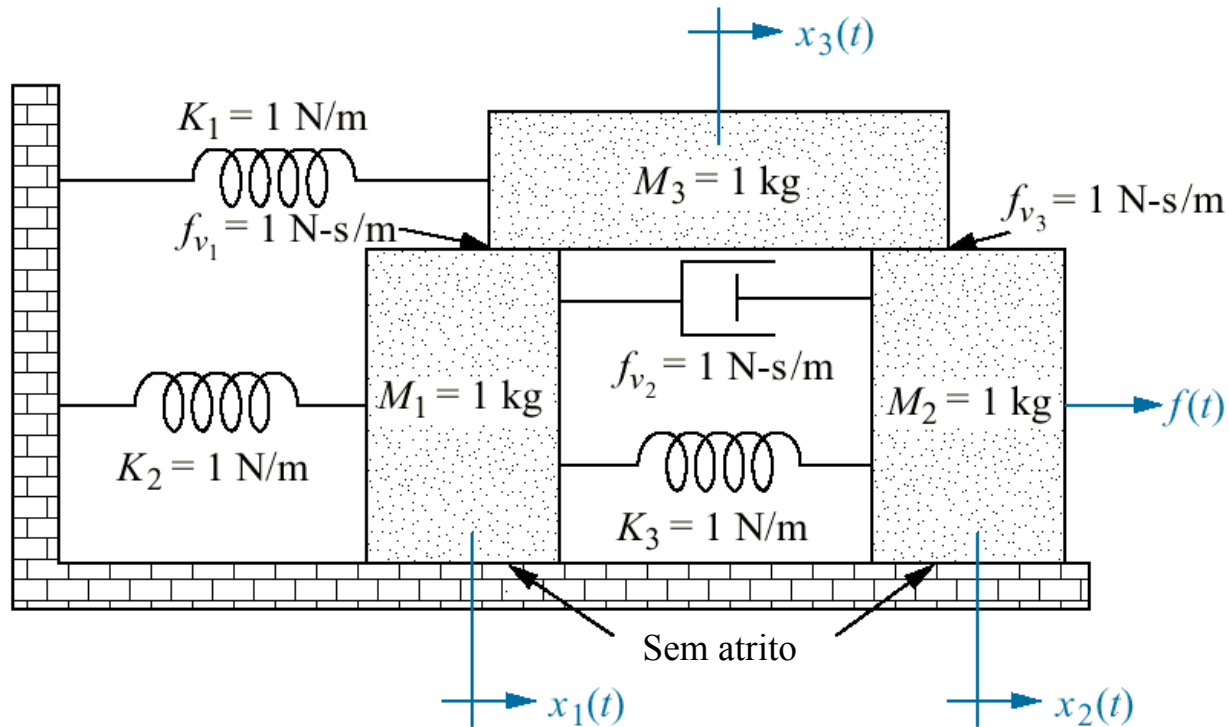
**Fig. P2.13**



**Fig. P2.14**

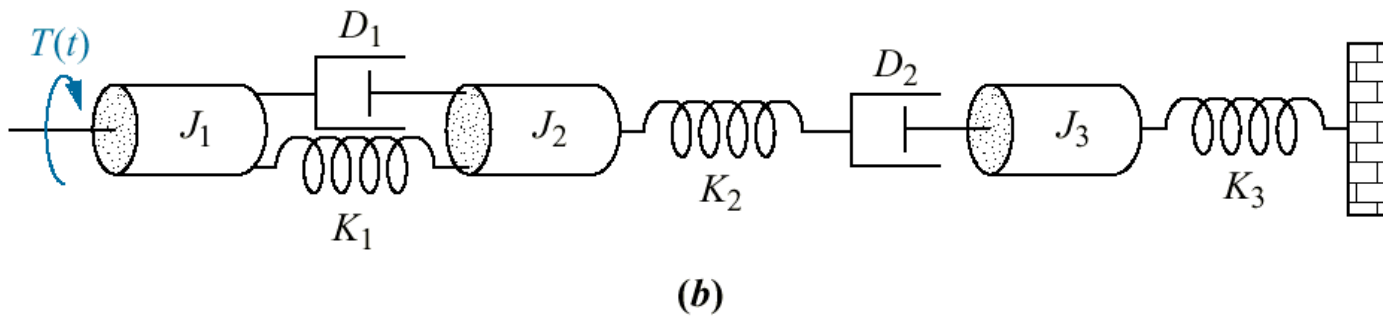
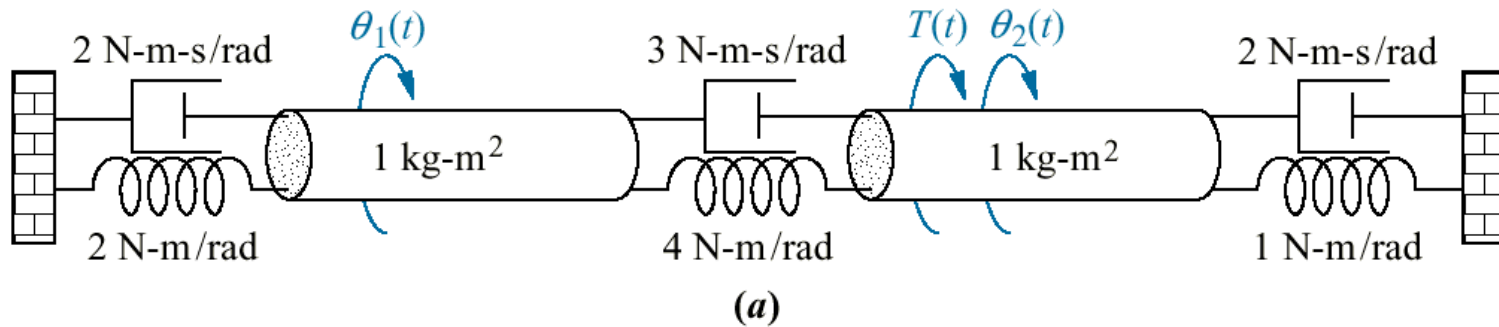


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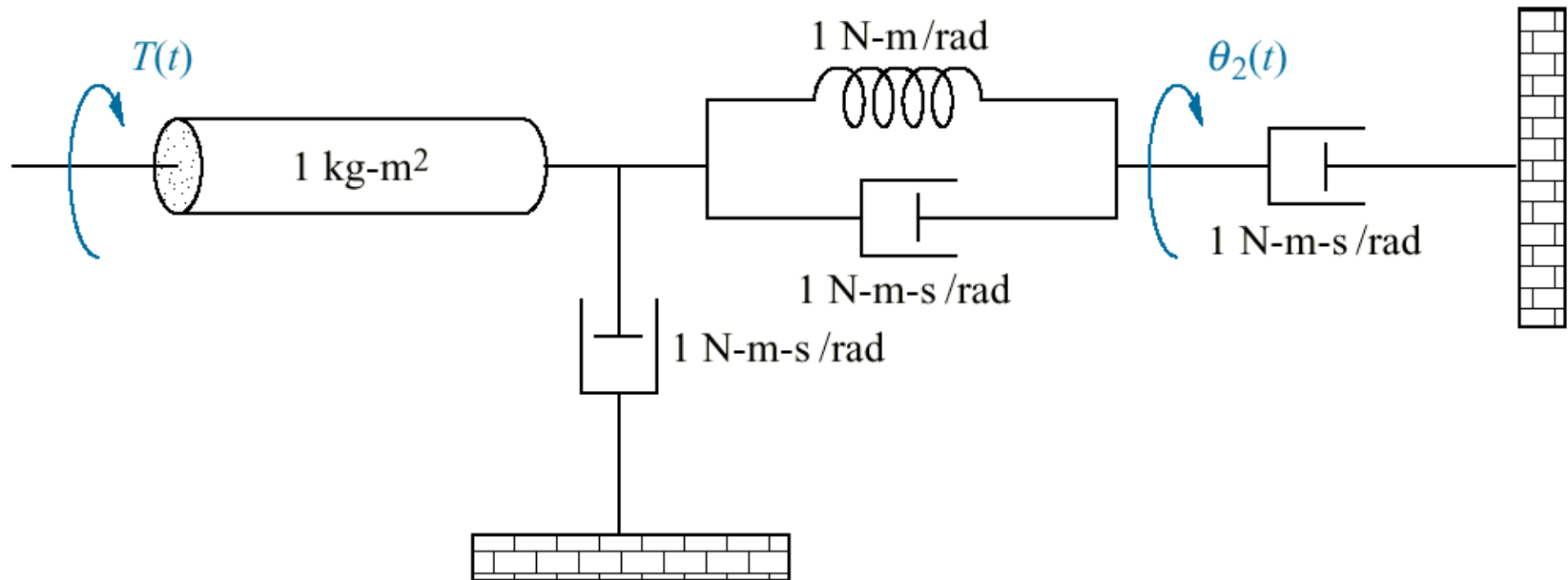




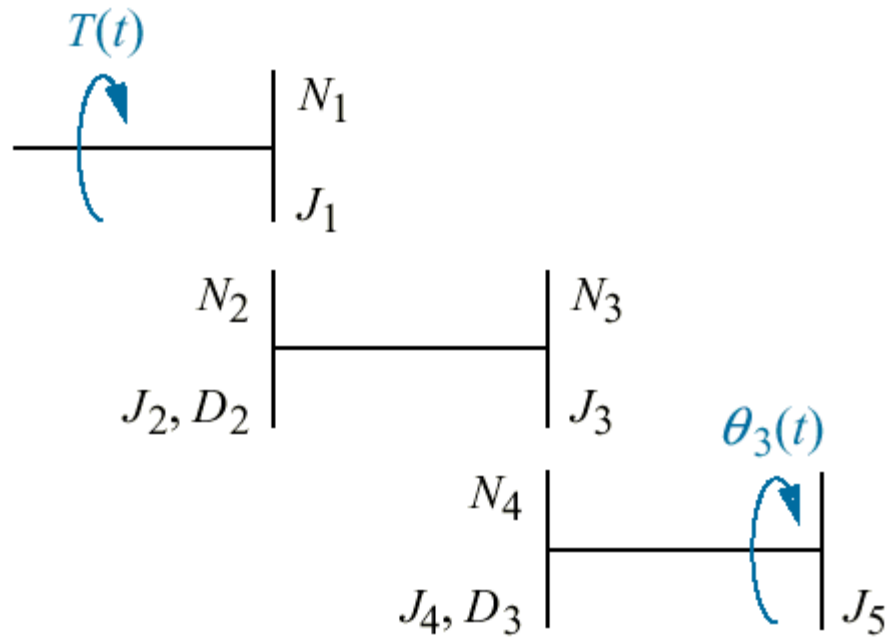
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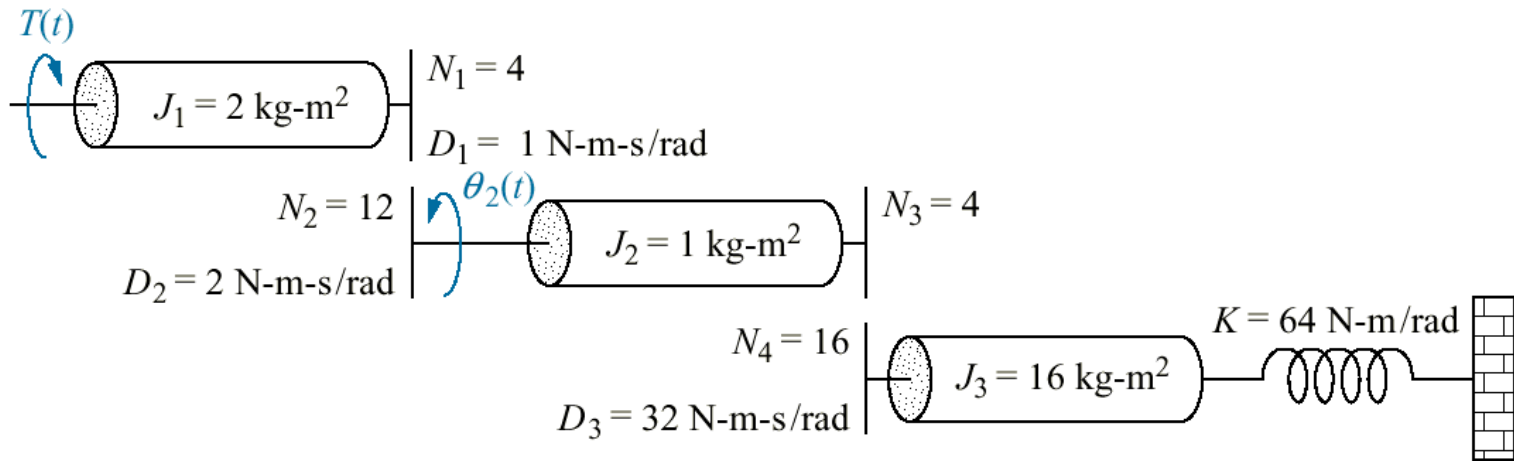
**Fig. P2.17**



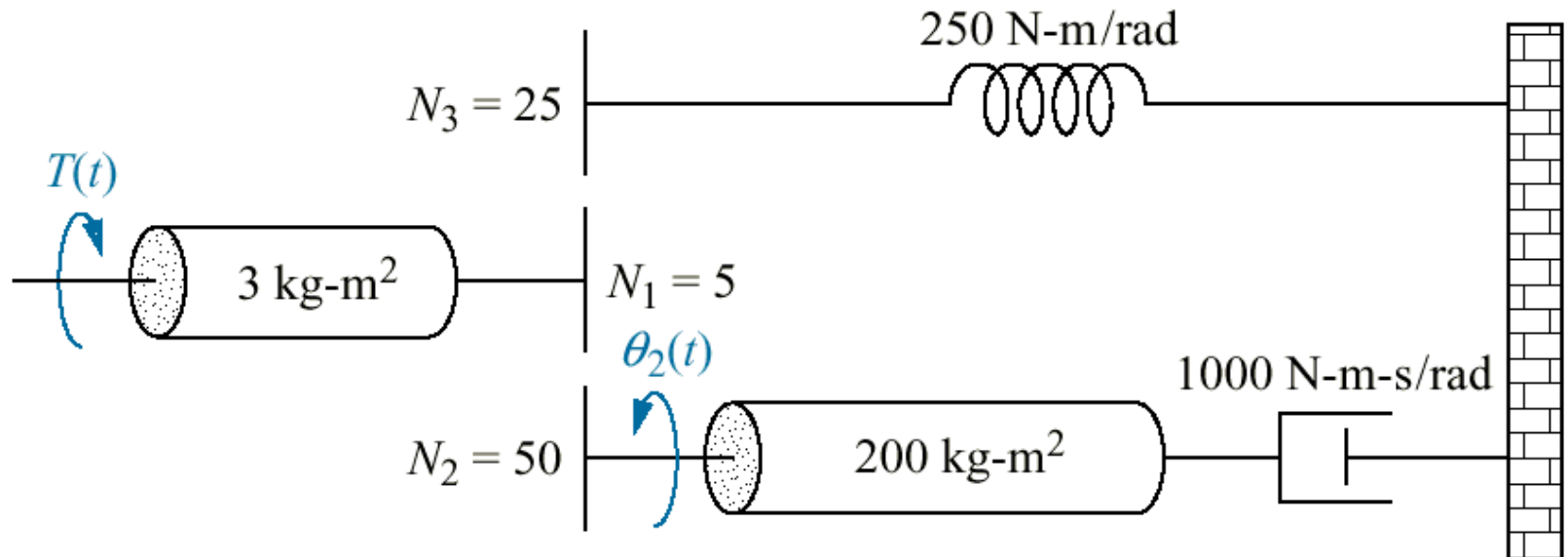
**Fig. P2.18**



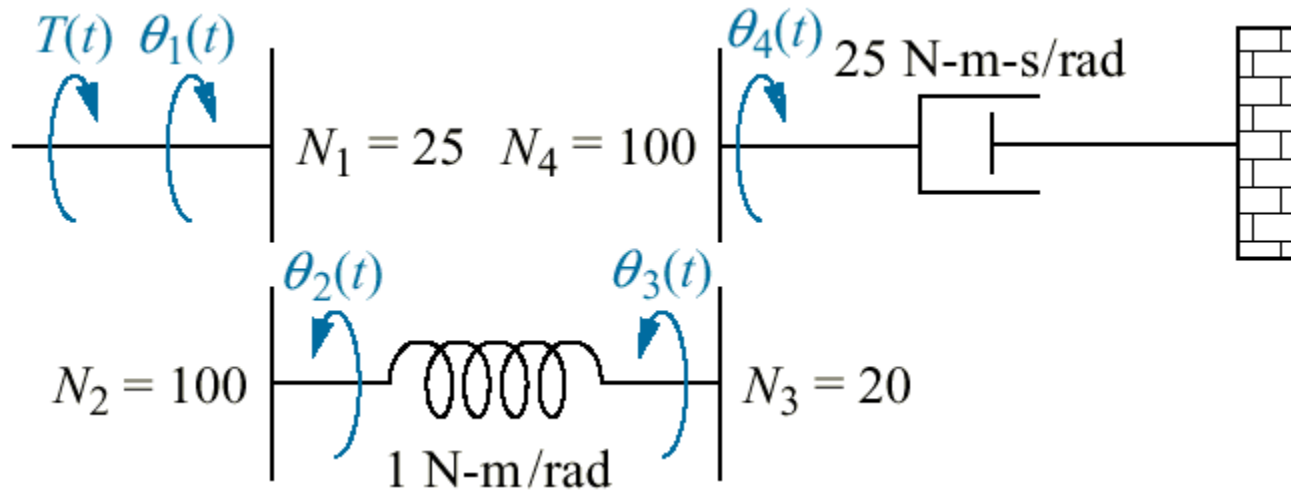
# Fig. P2.19



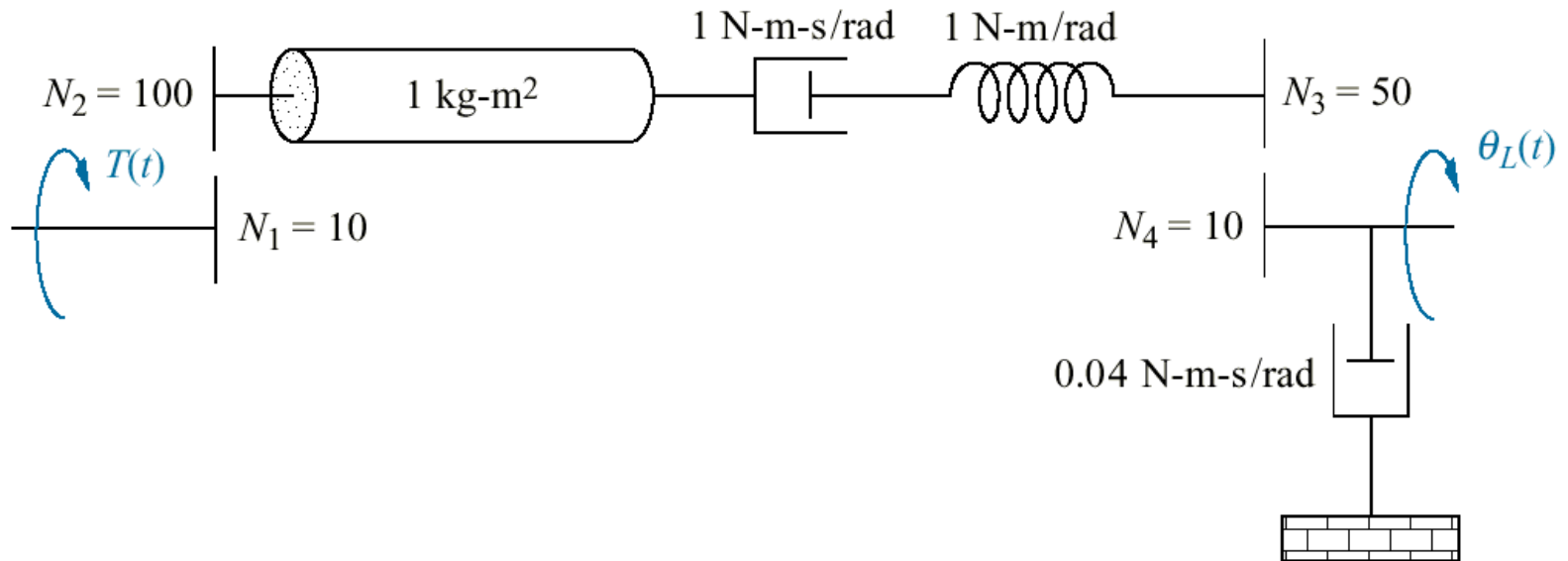
**Fig. P2.20**



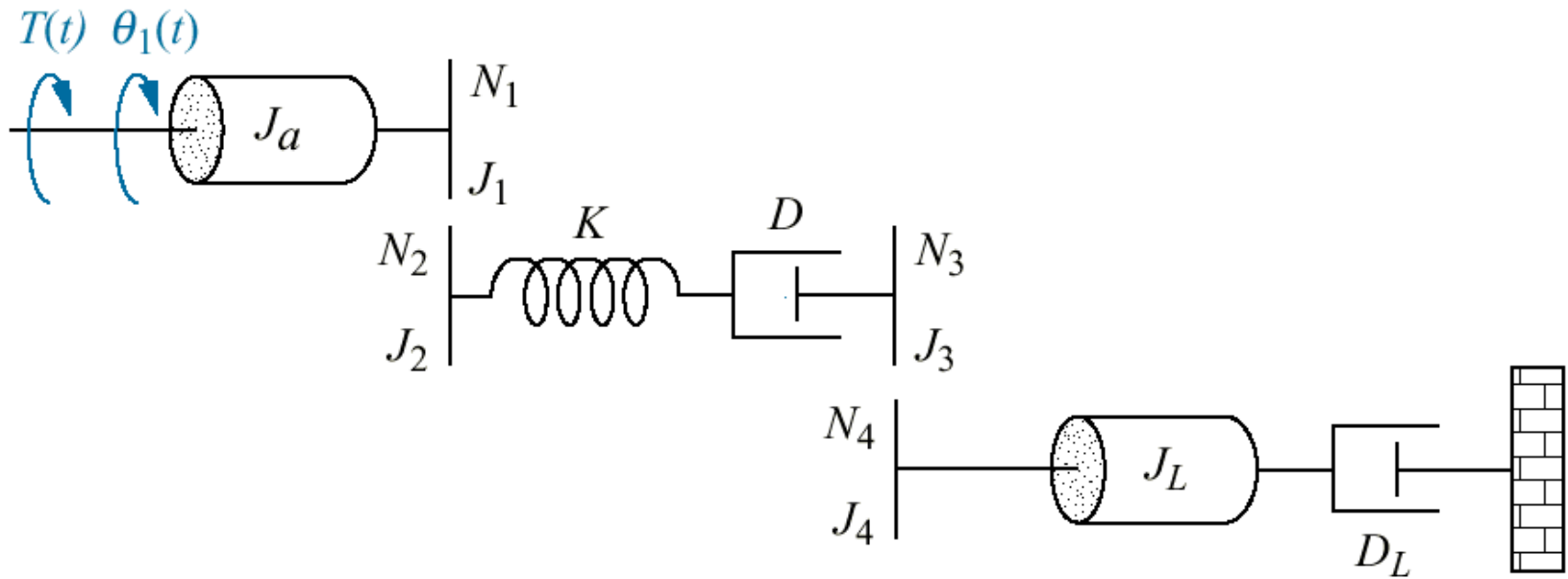
**Fig. P2.21**



**Fig. P2.22**

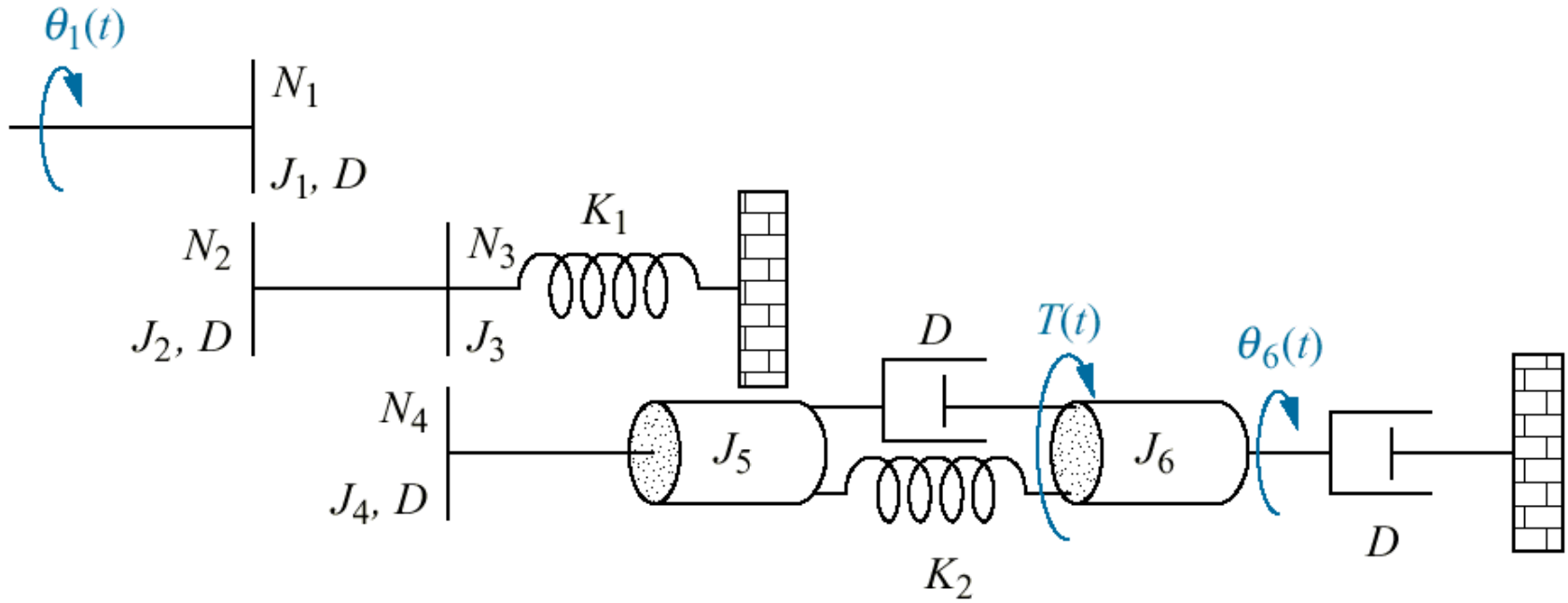


**Fig. P2.23**

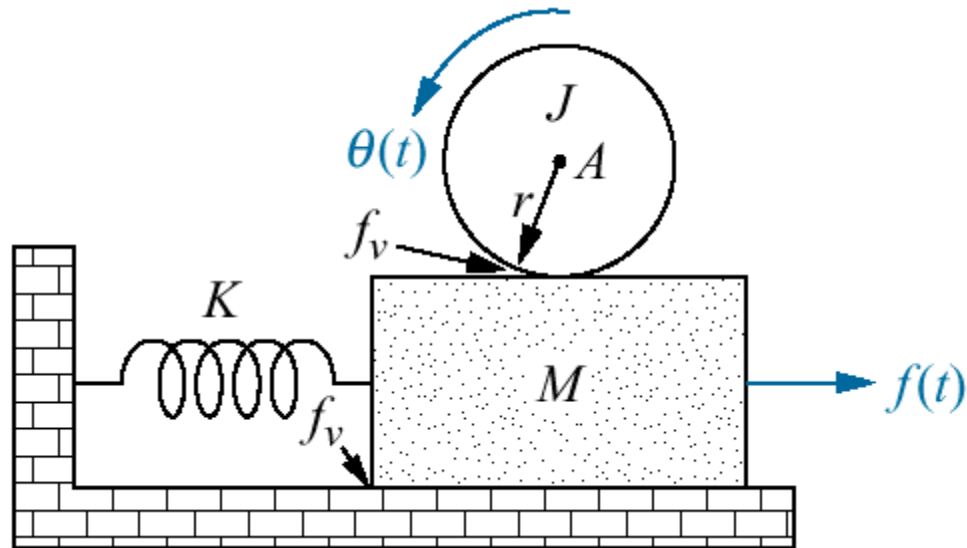




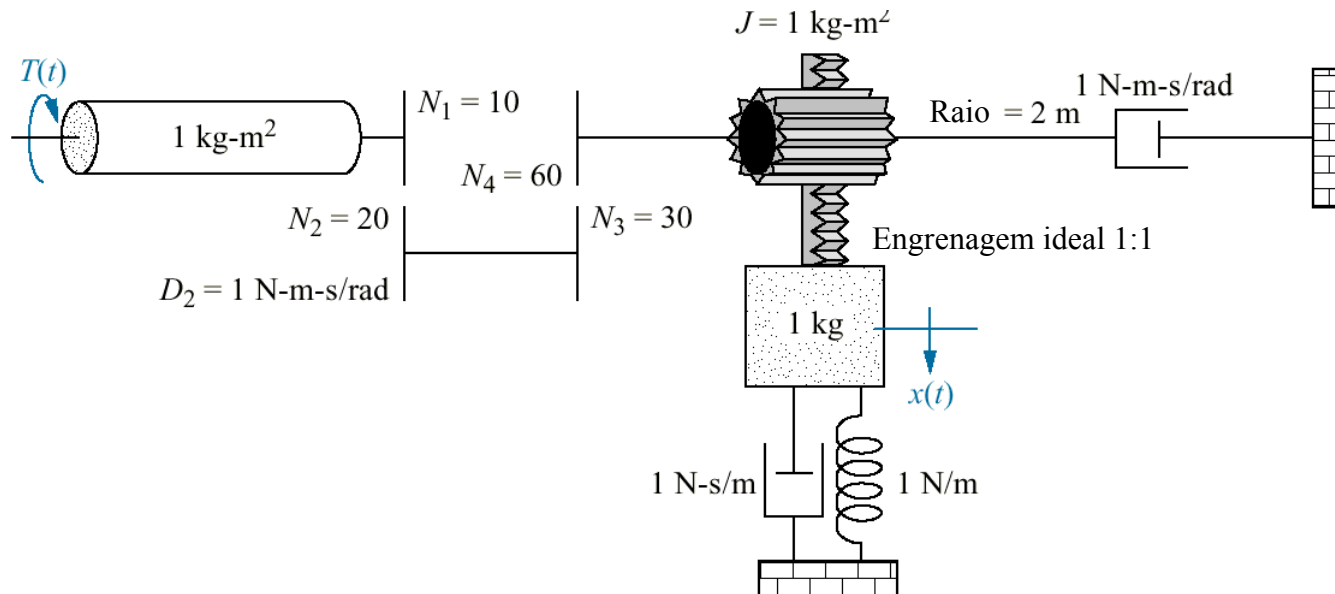
**Fig. P2.24**



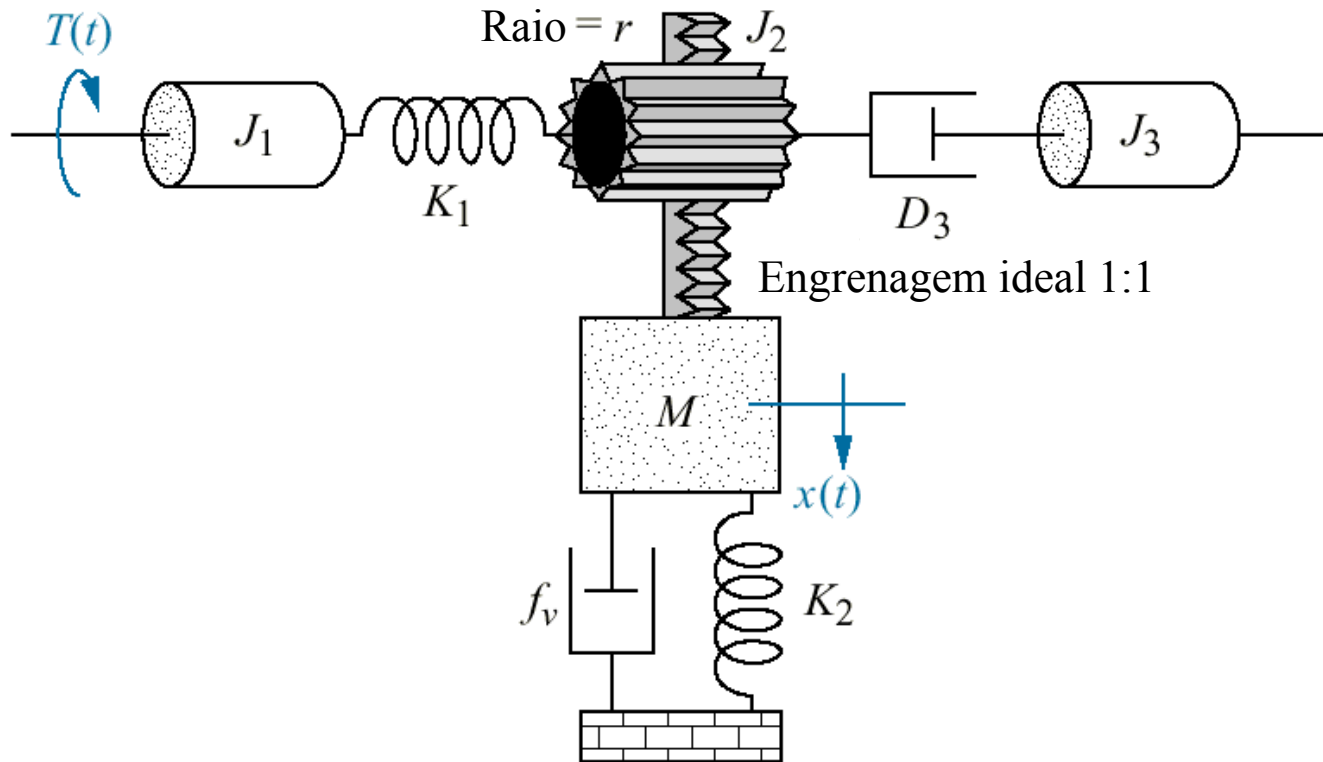
**Fig. P2.25**



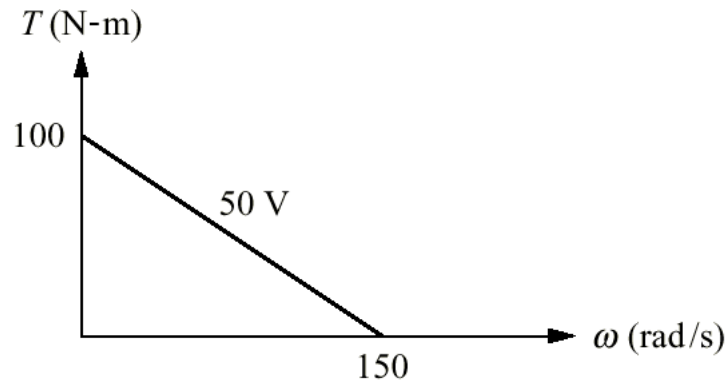
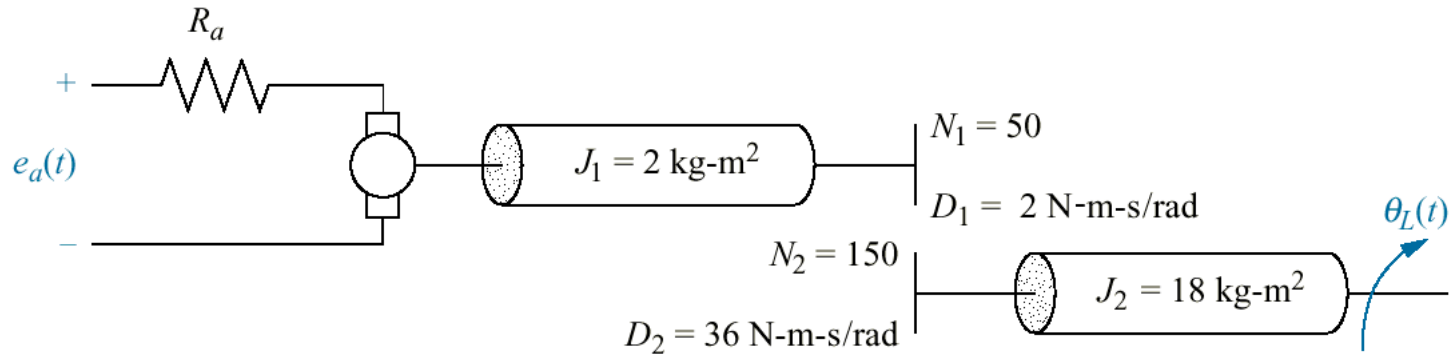
# Fig. P2.26



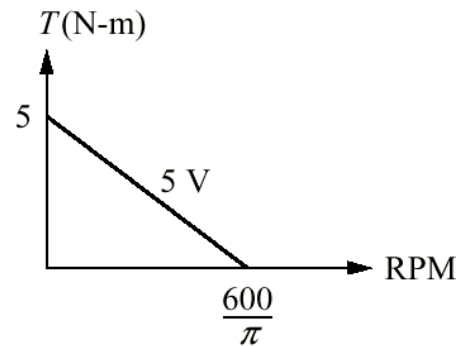
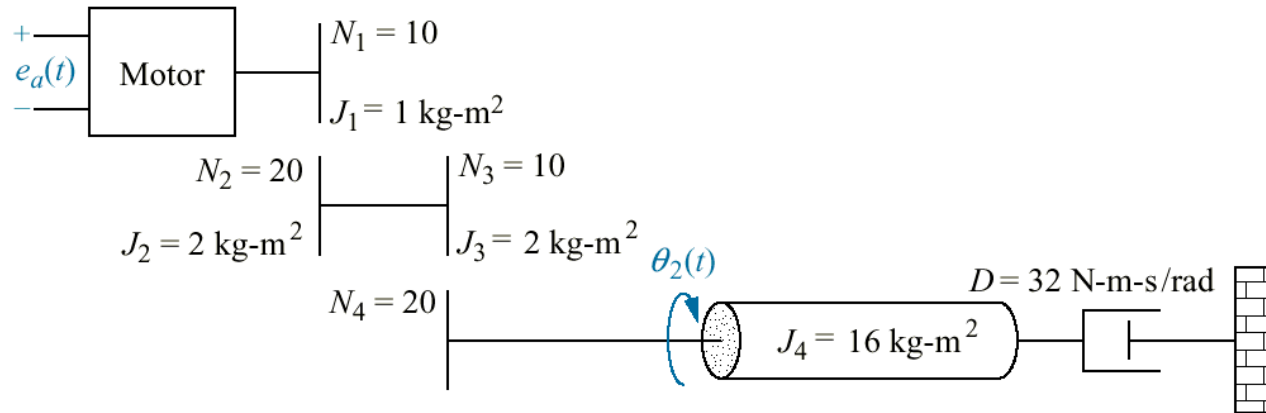
**Fig. P2.27**



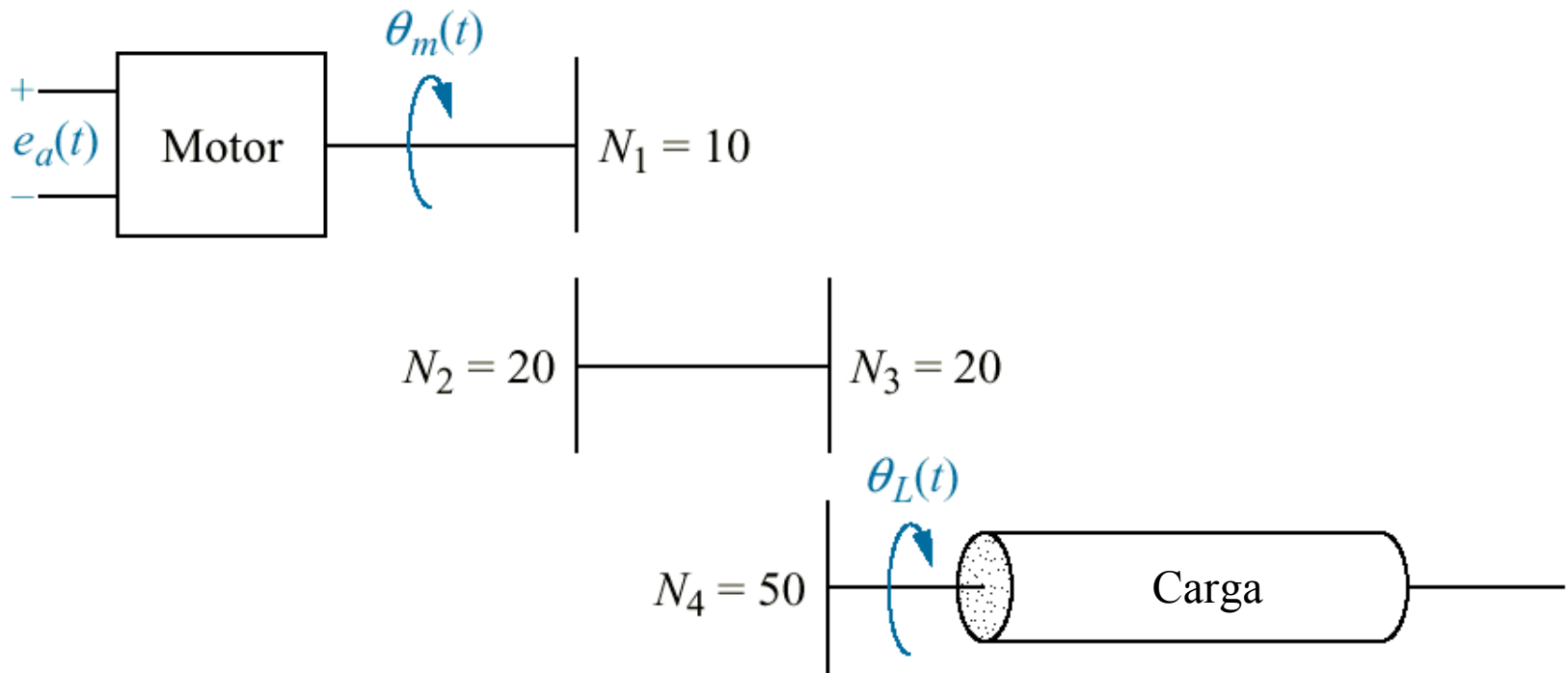
# Fig. P2.28



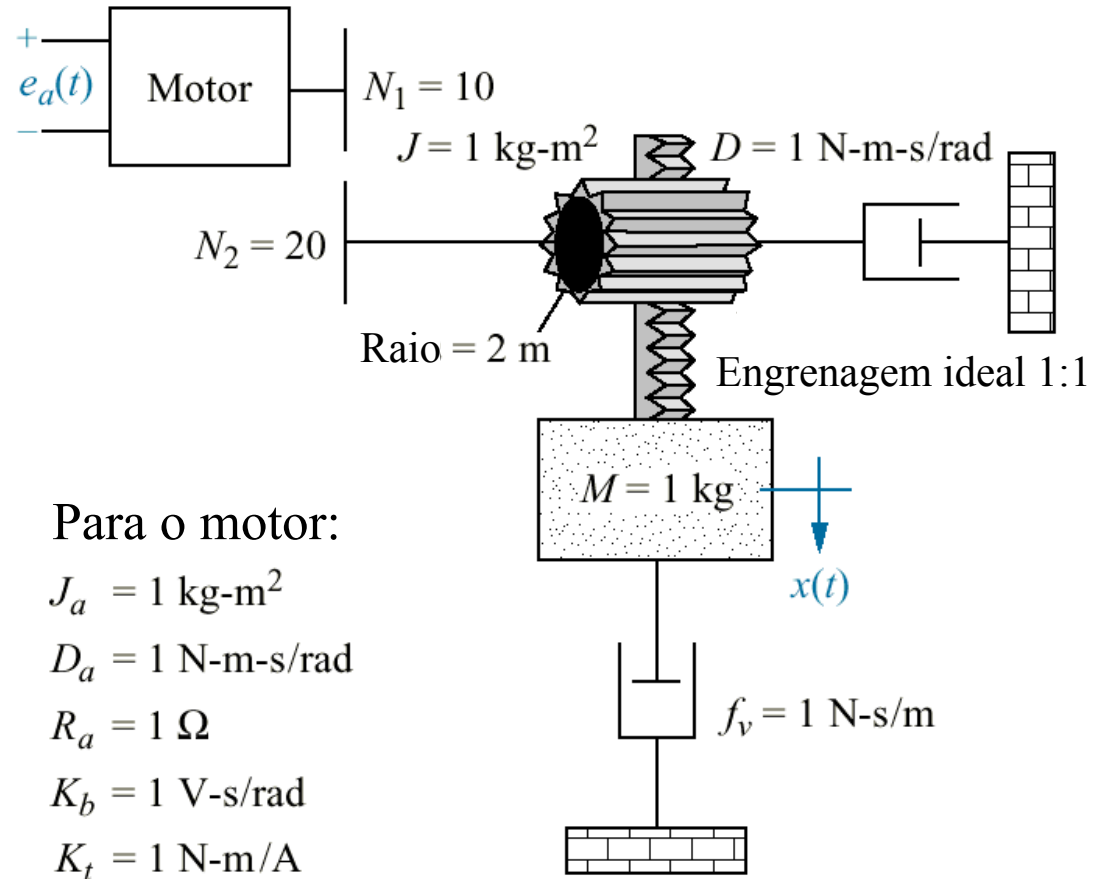
# Fig. P2.29



**Fig. P2.30**

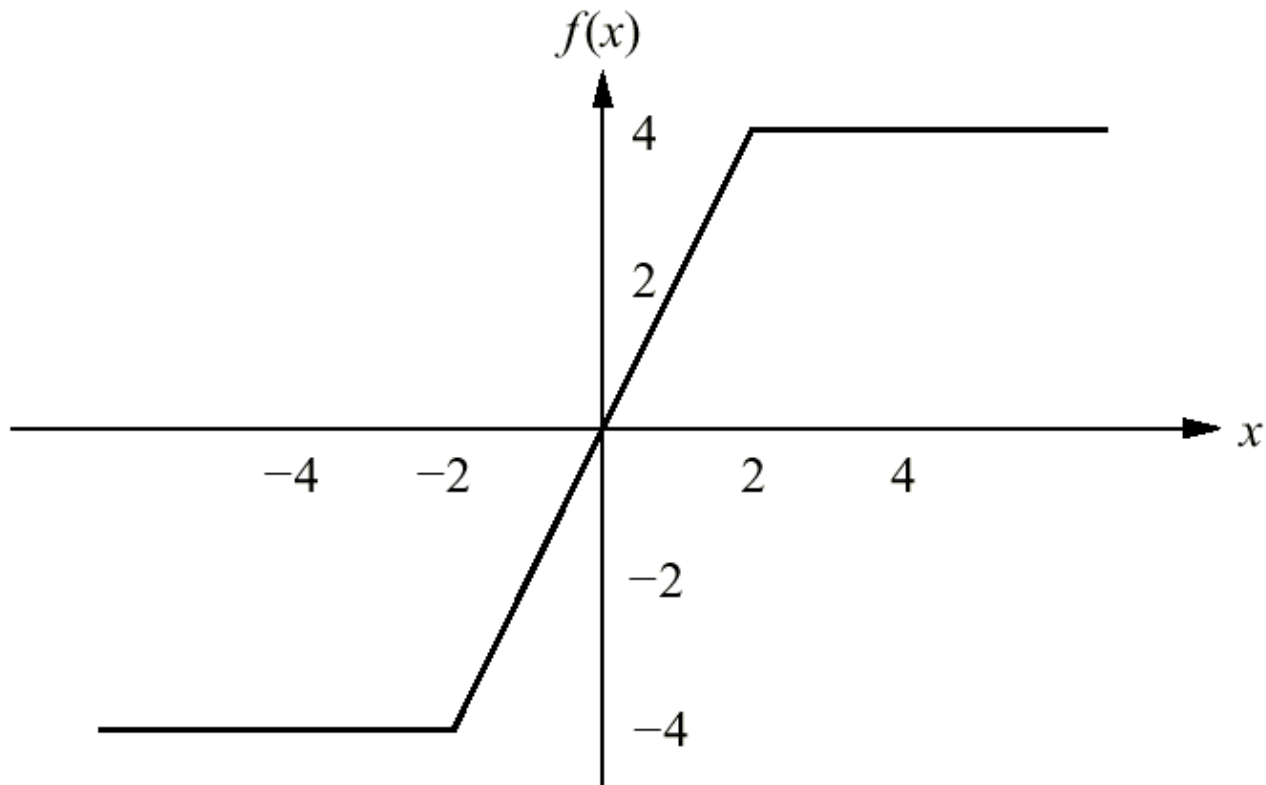


**Fig. P2.31**

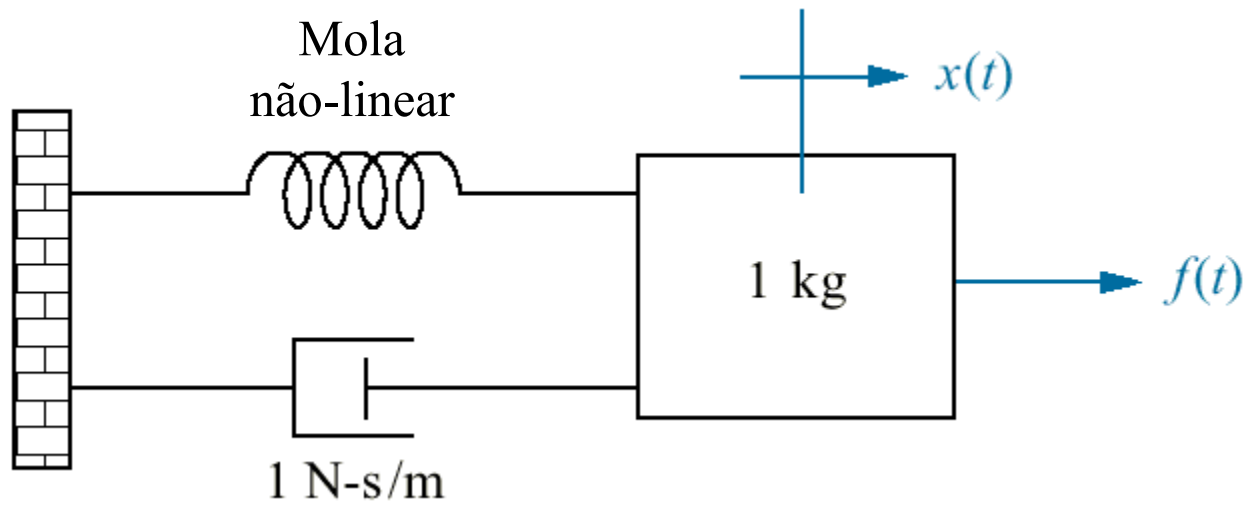




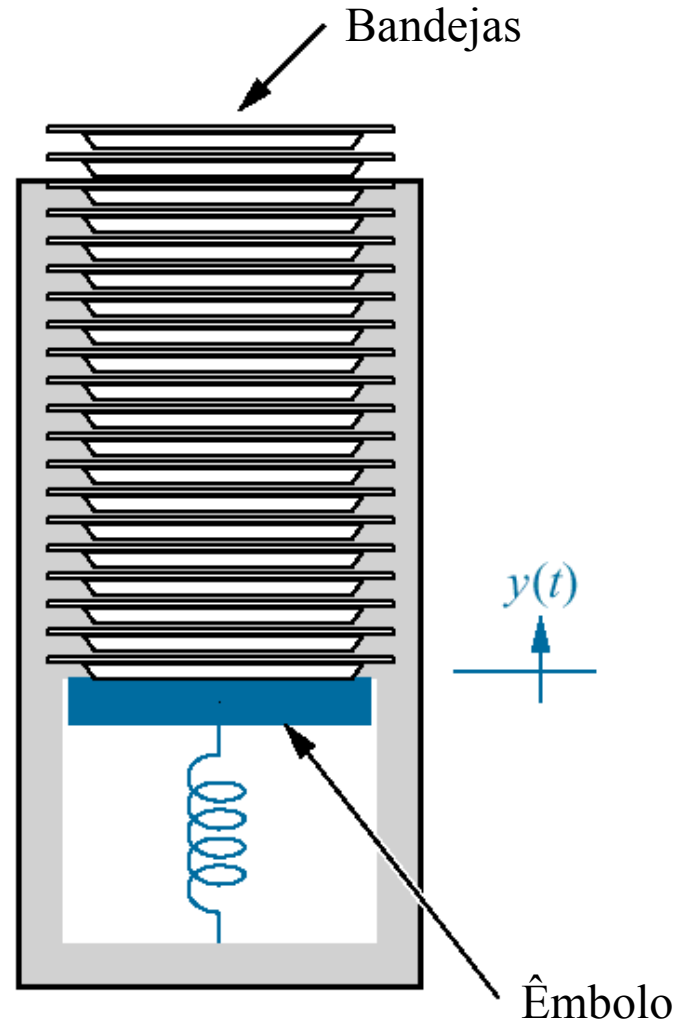
**Fig. P2.32**



**Fig. P2.33**



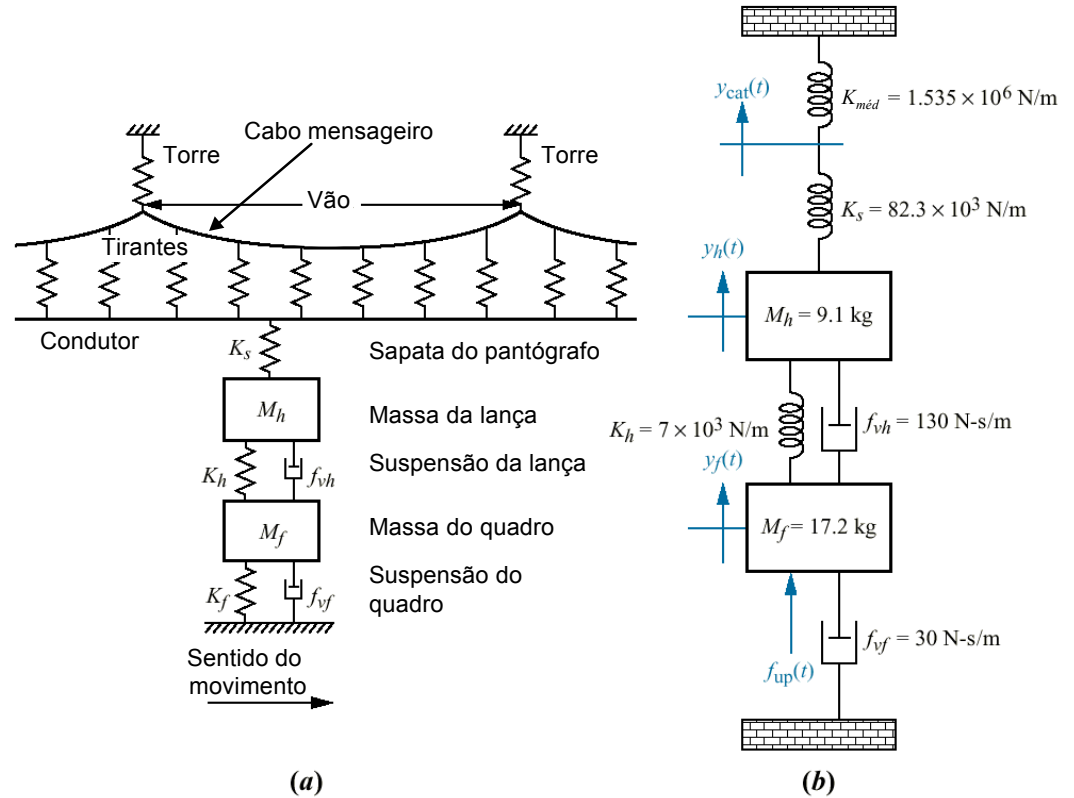
**Fig. P2.34**  
Distribuidor de bandejas



# Fig. P2.35

a. Acoplamento do pantógrafo com a catenária;

b. representação simplificada mostrando a força de controle ativa



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# Tabela 2.1

Tabela de transformadas de Laplace

Item no.	$f(t)$	$F(s)$
1.	$\delta(t)$	1
2.	$u(t)$	$\frac{1}{s}$
3.	$tu(t)$	$\frac{1}{s^2}$
4.	$t^n u(t)$	$\frac{n!}{s^{n+1}}$
5.	$e^{-at} u(t)$	$\frac{1}{s+a}$
6.	$\text{sen } \omega t u(t)$	$\frac{\omega}{s^2 + \omega^2}$
7.	$\text{cos } \omega t u(t)$	$\frac{s}{s^2 + \omega^2}$

# Tabela 2.2

## Teoremas da Transformada de Laplace

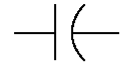

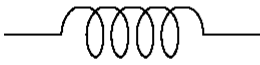
Item no.	Teorema	Nome
1.	$\mathcal{L}[f(t)] = F(s) = \int_{0-}^{\infty} f(t)e^{-st} dt$	Definição
2.	$\mathcal{L}[kf(t)] = kF(s)$	Teorema da linearidade
3.	$\mathcal{L}[f_1(t) + f_2(t)] = F_1(s) + F_2(s)$	Teorema da linearidade
4.	$\mathcal{L}[e^{-at}f(t)] = F(s + a)$	Teorema do deslocamento de frequência
5.	$\mathcal{L}[f(t - T)] = e^{-sT}F(s)$	Teorema do retardo
6.	$\mathcal{L}[f(at)] = \frac{1}{a}F\left(\frac{s}{a}\right)$	Teorema da escala
7.	$\mathcal{L}\left[\frac{df}{dt}\right] = sF(s) - f(0-)$	Teorema da derivação
8.	$\mathcal{L}\left[\frac{d^2f}{dt^2}\right] = s^2F(s) - sf(0-) - \dot{f}(0-)$	Teorema da derivação
9.	$\mathcal{L}\left[\frac{d^nf}{dt^n}\right] = s^nF(s) - \sum_{k=1}^n s^{n-k}f^{k-1}(0-)$	Teorema da derivação
10.	$\mathcal{L}\left[\int_{0-}^t f(\tau) d\tau\right] = \frac{F(s)}{s}$	Teorema da integração
11.	$f(\infty) = \lim_{s \rightarrow 0} sF(s)$	Teorema do valor final <sup>1</sup>
12.	$f(0+) = \lim_{s \rightarrow \infty} sF(s)$	Teorema do valor inicial <sup>2</sup>

<sup>1</sup>Para que este teorema forneça resultados finitos corretos, todas as raízes do denominador de  $F(s)$  devem ter parte real negativa e nenhuma delas pode estar situada na origem.

<sup>2</sup>Para que este teorema seja válido,  $f(t)$  deve ser contínua ou ter, no máximo, uma descontinuidade em degrau em  $t = 0$  (isto é, não pode apresentar impulsos ou suas derivadas em  $t = 0$ )

# Tabela 2.3

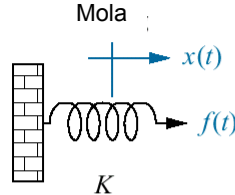
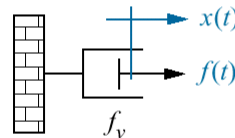
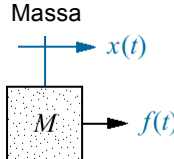
## Relações Tensão-corrente, Tensão-carga, e Impedâncias de capacitores, resistores e indutores

Componente	Tensão-corrente	Corrente-tensão	Tensão-carga	Impedância $Z(s) = V(s)/I(s)$	Admitância $Y(s) = I(s)/V(s)$
 Capacitor	$v(t) = \frac{1}{C} \int_0^t i(\tau) d\tau$	$i(t) = C \frac{dv(t)}{dt}$	$v(t) = \frac{1}{C} q(t)$	$\frac{1}{Cs}$	$Cs$
 Resistor	$v(t) = Ri(t)$	$i(t) = \frac{1}{R} v(t)$	$v(t) = R \frac{dq(t)}{dt}$	$R$	$\frac{1}{R} = G$
 Indutor	$v(t) = L \frac{di(t)}{dt}$	$i(t) = \frac{1}{L} \int_0^t v(\tau) d\tau$	$v(t) = L \frac{d^2 q(t)}{dt^2}$	$Ls$	$\frac{1}{Ls}$

Nota: Os seguintes conjuntos de símbolos e unidades são usadas ao longo deste livro:  $v(t) = V$  (volts),  $i(t) = A$  (ampères),  $q(t) = Q$  (coulombs),  $C = F$  (farads),  $R = \Omega$  (ohms),  $G = \text{S}$  (mhos),  $L = H$  (henries)

# Tabela 2.4

Relações força-velocidade, força-deslocamento, e impedância de translação de molas, amortecedores e massas

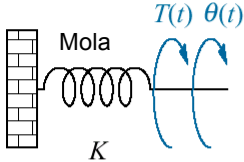
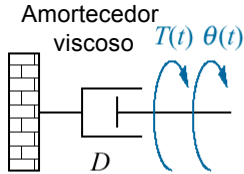
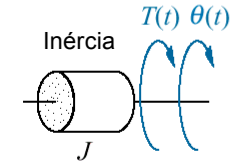
Componente	Força-velocidade	Força-deslocamento	Impedância $Z_m(s)=F(s)/X(s)$
<p>Mola</p> 	$f(t) = K \int_0^t v(\tau) d\tau$	$f(t) = Kx(t)$	$K$
<p>Amortecimento viscoso</p> 	$f(t) = f_v v(t)$	$f(t) = f_v \frac{dx(t)}{dt}$	$f_v s$
<p>Massa</p> 	$f(t) = M \frac{dv(t)}{dt}$	$f(t) = M \frac{d^2x(t)}{dt^2}$	$M s^2$

**Nota:** Os seguintes conjuntos de símbolos e unidades são usadas ao longo deste livro:  $f(t) = N$  (newtons),  $x(t) = m$  (metros),  $v(t) = m/s$  (metros/segundo),  $K = N/m$  (newtons/metro),  $f_v = N \cdot s/m$  (newton.segundo/ metro),  $M = kg$  (quilogramas = newton.segundo<sup>2</sup> / metro).



# Tabela 2.5

Relações torque-velocidade angular, torque-deslocamento angular, e impedância de rotação de molas, amortecedores viscosos e inércia

Componente	Torque - velocidade angular	Torque - deslocamento angular	Impedância $Z_m(s) = T(s) / q(s)$
 <p>Mola <math>K</math></p>	$T(t) = K \int_0^t \omega(\tau) d\tau$	$T(t) = K\theta(t)$	$K$
 <p>Amortecedor viscoso <math>D</math></p>	$T(t) = D\omega(t)$	$T(t) = D \frac{d\theta(t)}{dt}$	$Ds$
 <p>Inércia <math>J</math></p>	$T(t) = J \frac{d\omega(t)}{dt}$	$T(t) = J \frac{d^2\theta(t)}{dt^2}$	$Js^2$

**Nota:** Os seguintes conjuntos de símbolos e unidades são usadas ao longo deste livro:  $T(t) = \text{N.m}$  (newton.metro),  $Q(t) = \text{rad}$  (radianos),  $\omega(t) = \text{rad/s}$  (radianos /segundo),  $K = \text{N.m /rad}$  (newton.metro / radiano),  $D_n = \text{N.m.s/ rad}$  (newton.metro.segundo/ radiano),  $J = \text{kg.m}^2$  (quilograma.metro<sup>2</sup> = newton.metro.segundo<sup>2</sup> / radiano).

## Tabela 2.6

### Subsistemas do sistema de controle de posição de uma antena em azimute

Subsistema	Entrada	Saída
Potenciômetro de entrada	Rotação angular desejada $\theta_i(t)$	Tensão para o pré-amplificador $v_i(t)$
Pré-amplificador	Tensão dos potenciômetros $v_e(t) = v_i(t) - v_o(t)$	Tensão do amplif. de potência $v_p(t)$
Amplificador de Potência	Tensão do pré-amplificador $v_p(t)$	Tensão aplicada ao motor $e_a(t)$
Motor	Tensão do amplif. de potência $e_a(t)$	Rotação angular da carga $\theta_o(t)$
Potenciômetro de saída	Rotação angular da carga $\theta_o(t)$	Tensão aplicada ao pré-amplif. $v_o(t)$