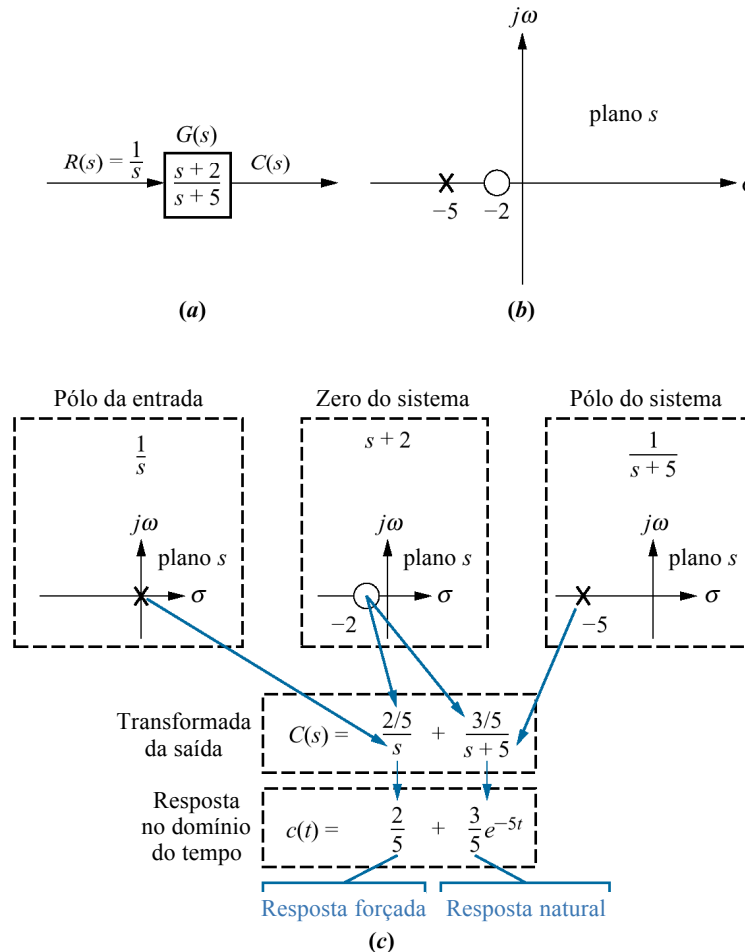


# Capítulo 4

Resposta no Domínio do Tempo

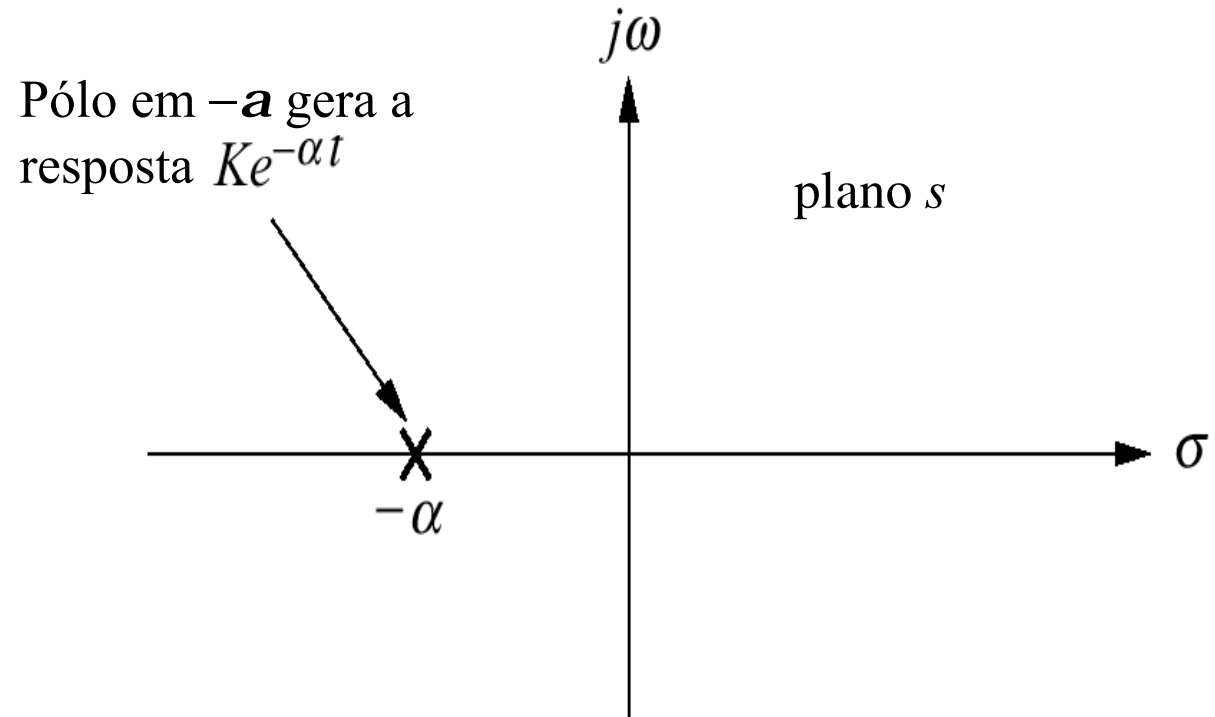
# Fig. 4.1

**a.** Sistema mostrando entrada e saída;  
**b.** diagrama de pólos e zeros do sistema;  
**c.** evolução de uma resposta de sistema. Siga as setas voltadas para baixo para ver a evolução dos componentes da resposta gerada pelo pólo ou pelo zero.



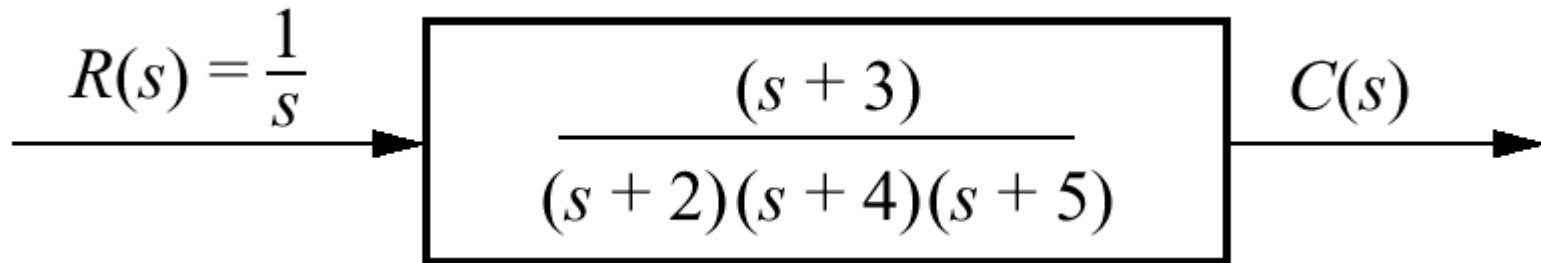
# Fig. 4.2

Efeito de um pólo real sobre a resposta transitória



# Fig. 4.3

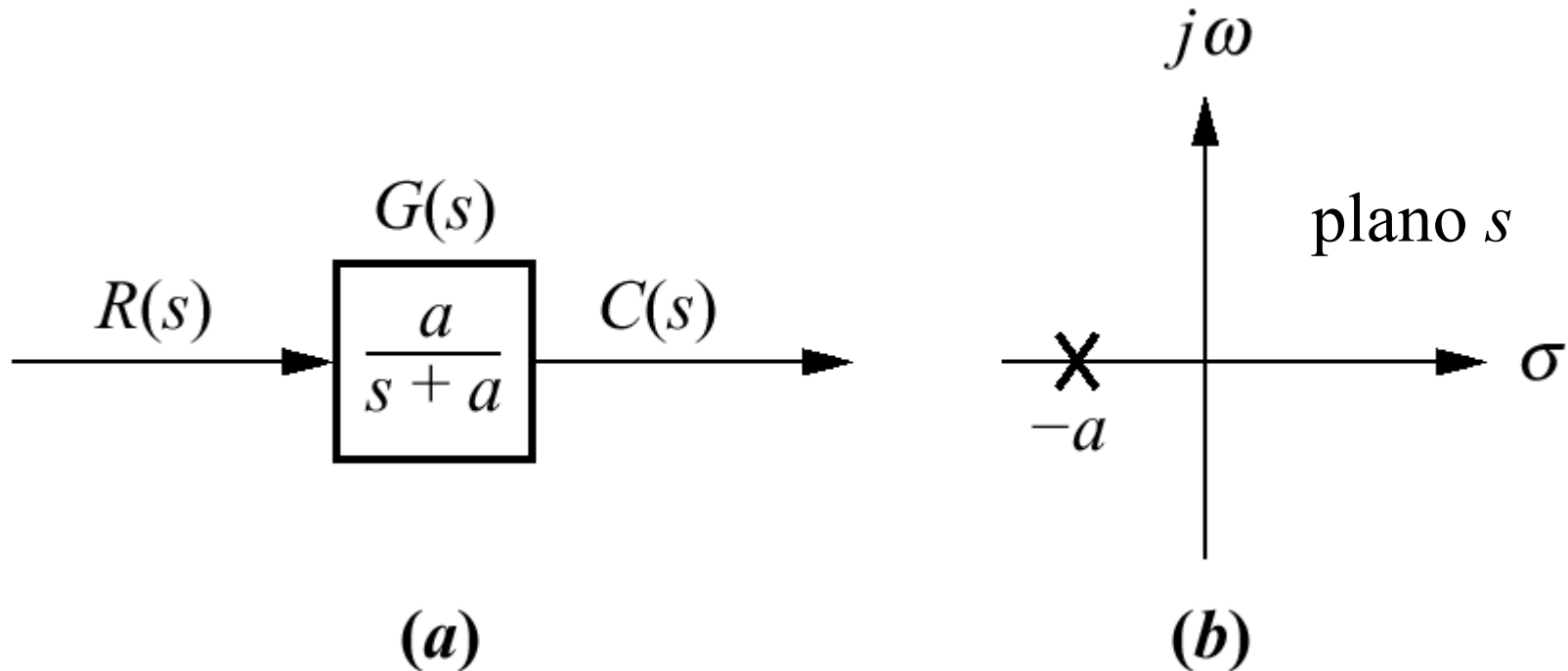
Sistema para  
o Exemplo 4.1



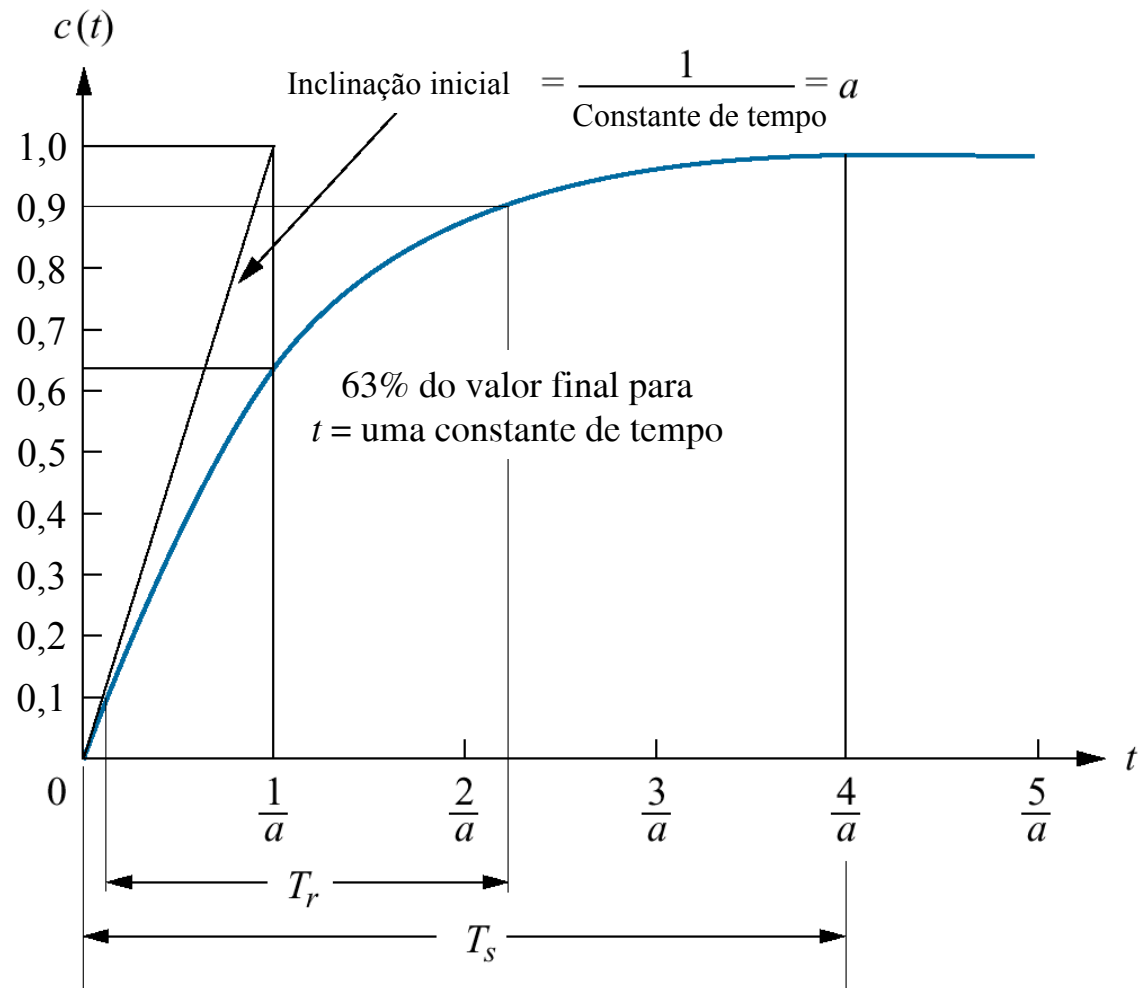
**Fig. 4.4**

a. Sistema de primeira ordem;

b. gráfico do pólo

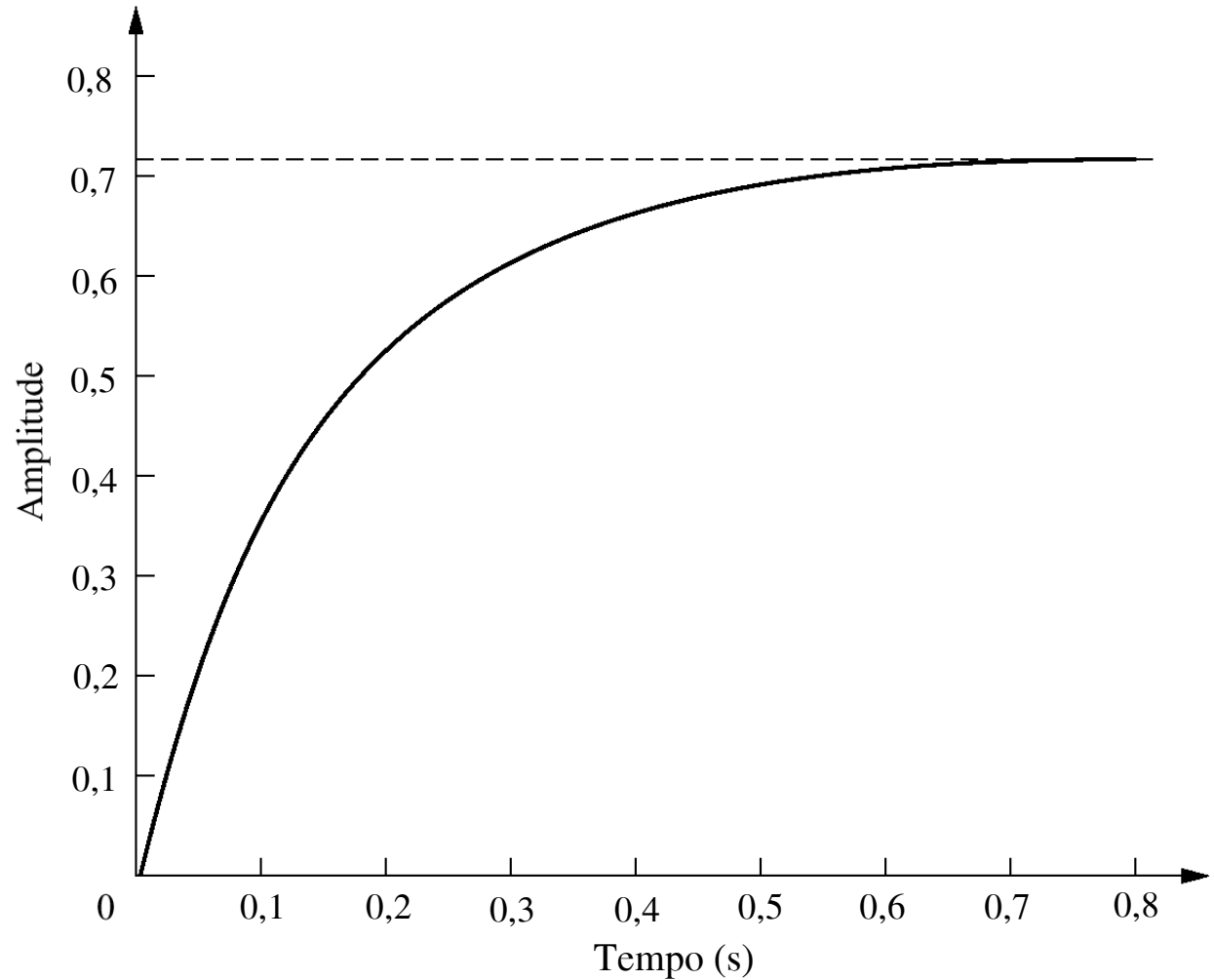


**Fig. 4.5**  
 Resposta de um sistema de primeira ordem a um degrau unitário



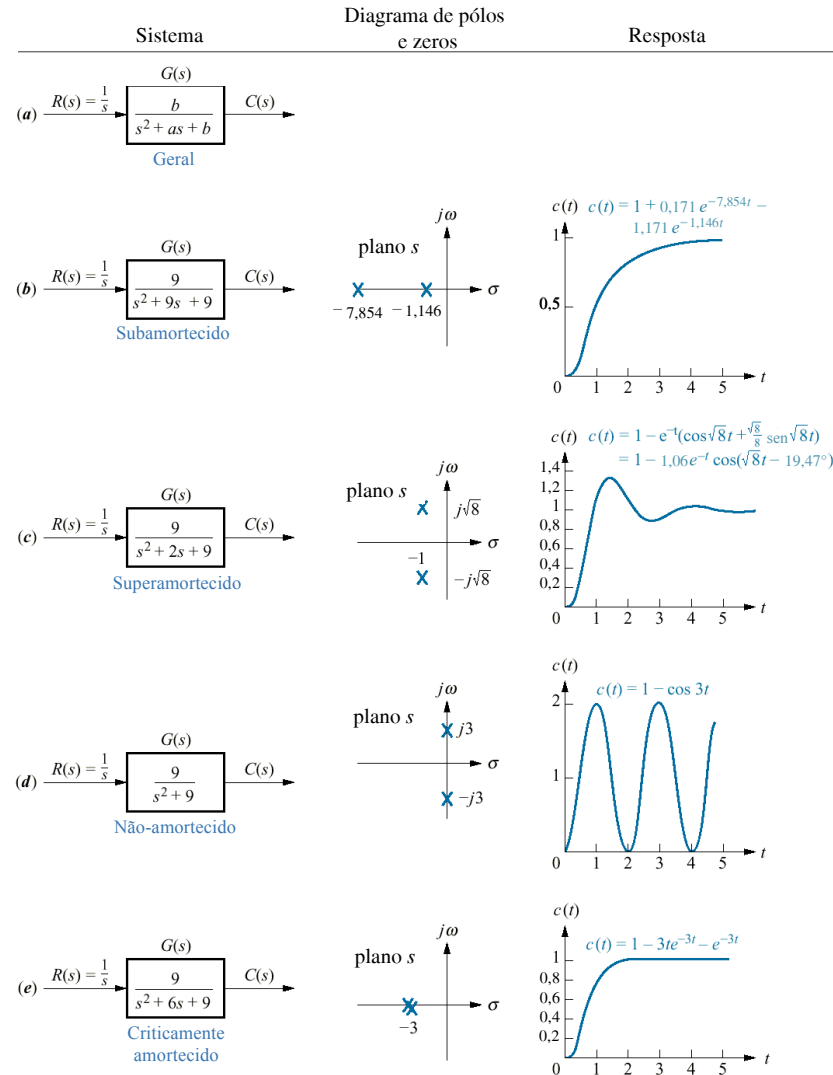
**Fig. 4.6**

Resultados de laboratório de um ensaio com resposta de um sistema ao degrau



# Fig. 4.7

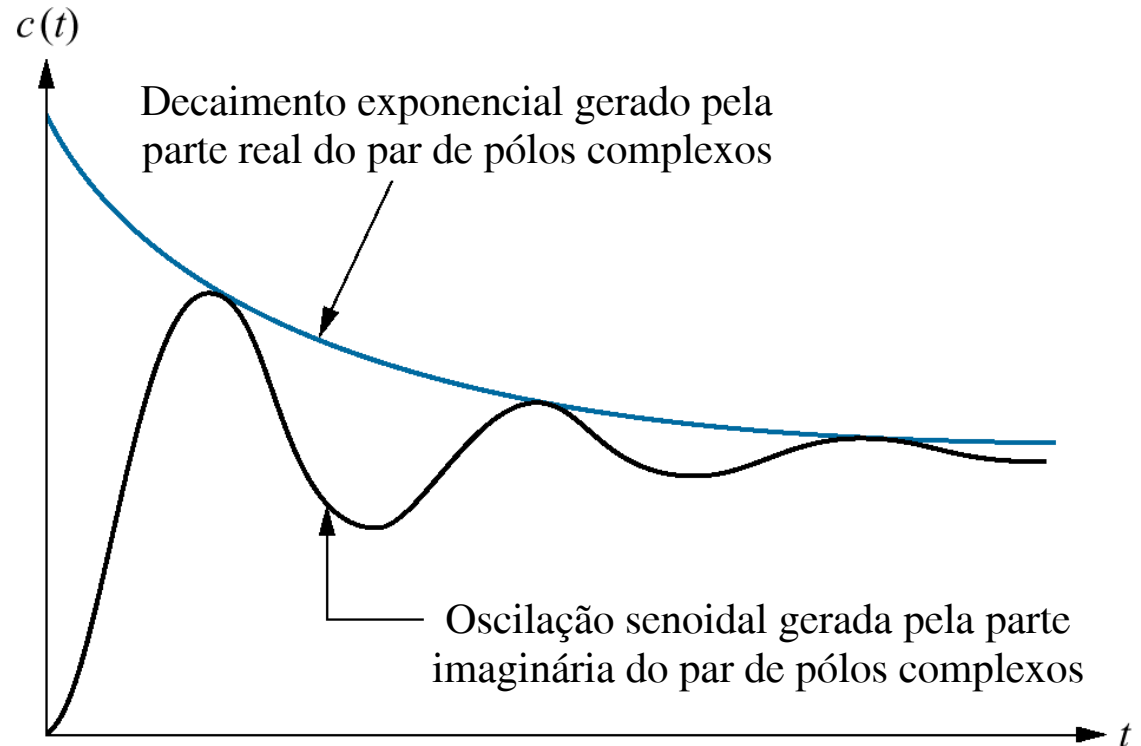
Sistemas de segunda ordem, gráficos de pólos e respostas ao degrau





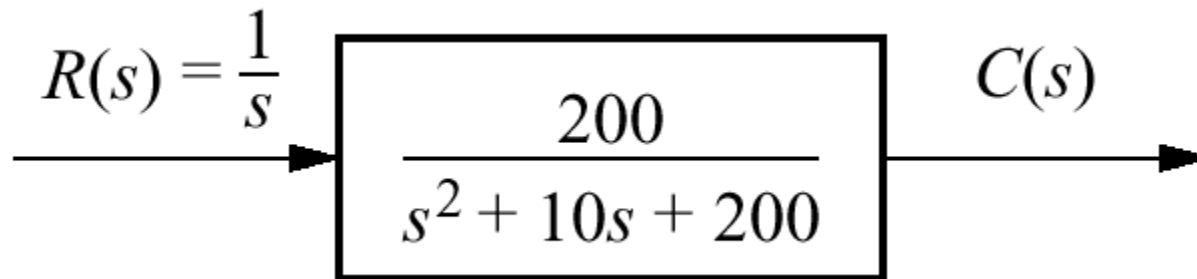
**Fig. 4.8**

Componentes da resposta ao degrau de sistema de segunda ordem gerados por pólos complexos

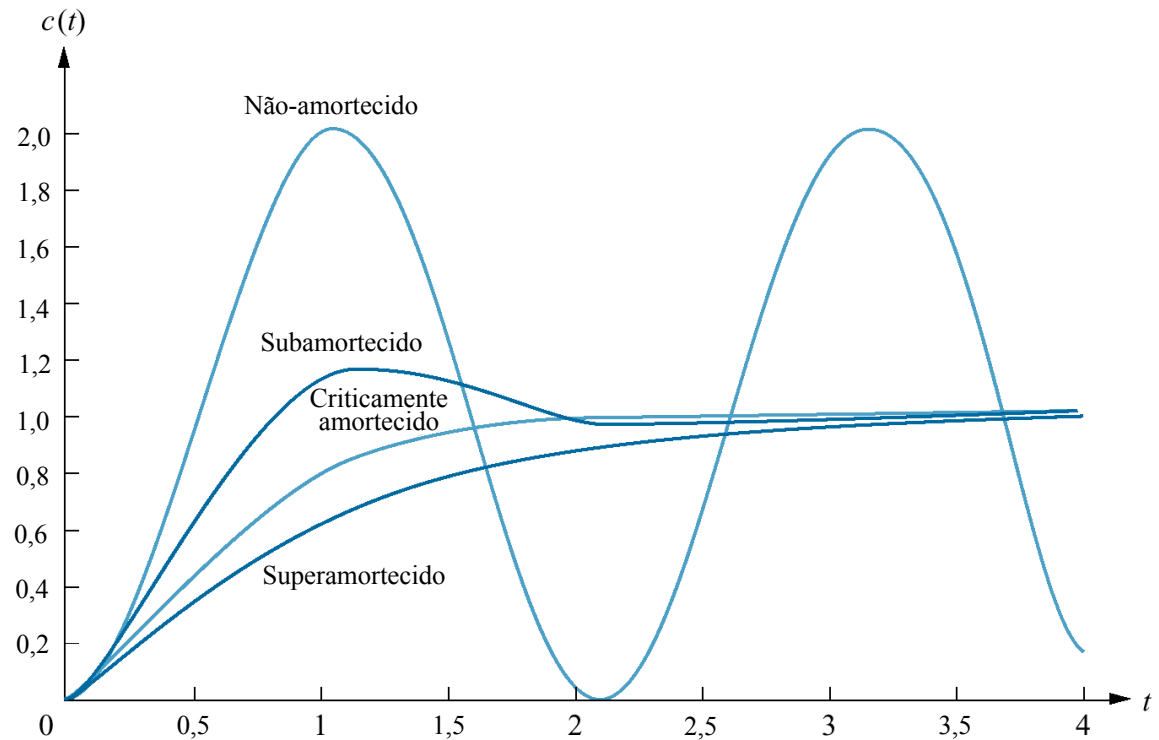


# Fig. 4.9

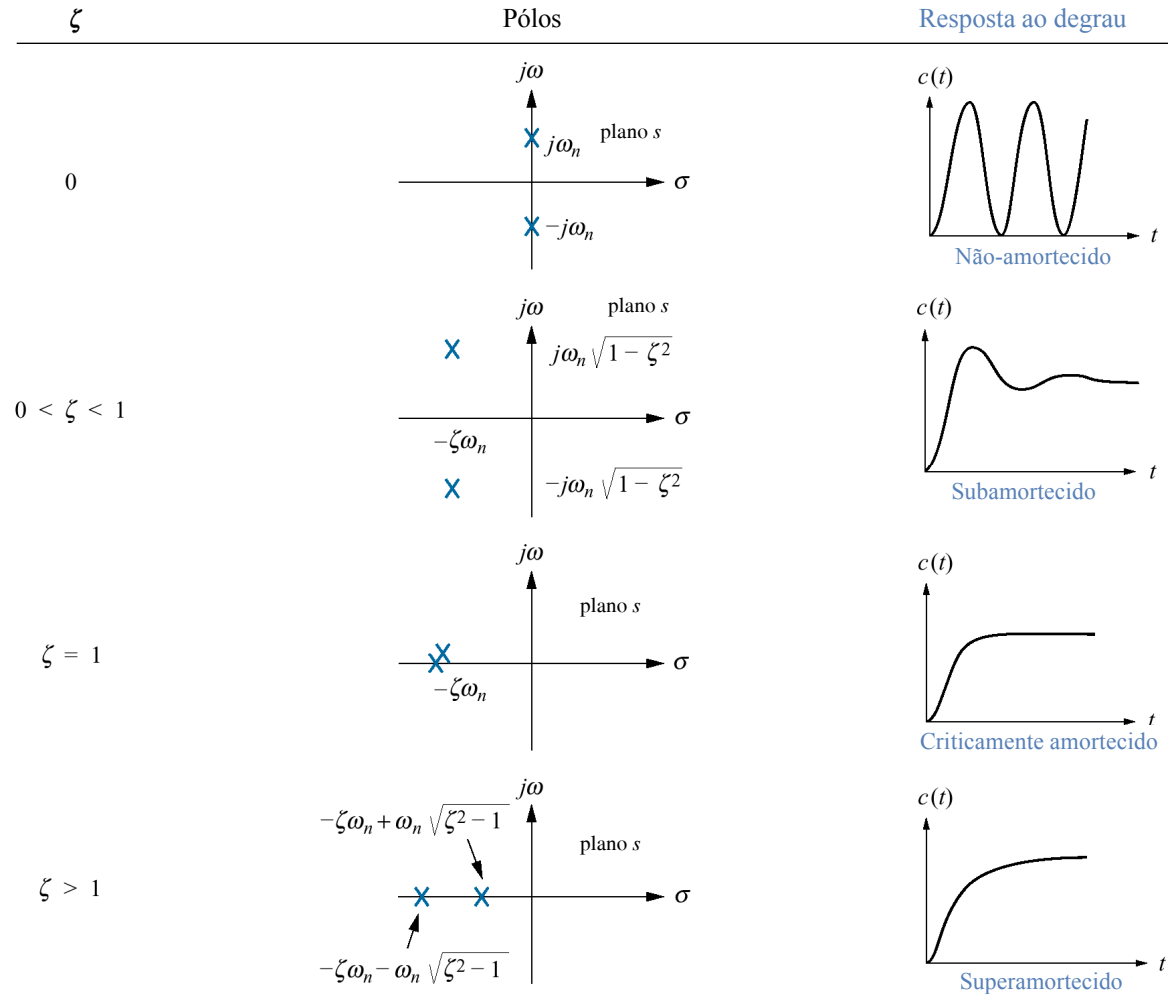
Sistema para o  
Exemplo 4.2



**Fig. 4.10**  
 Respostas ao degrau de sistemas de segunda ordem para os casos de amortecimento

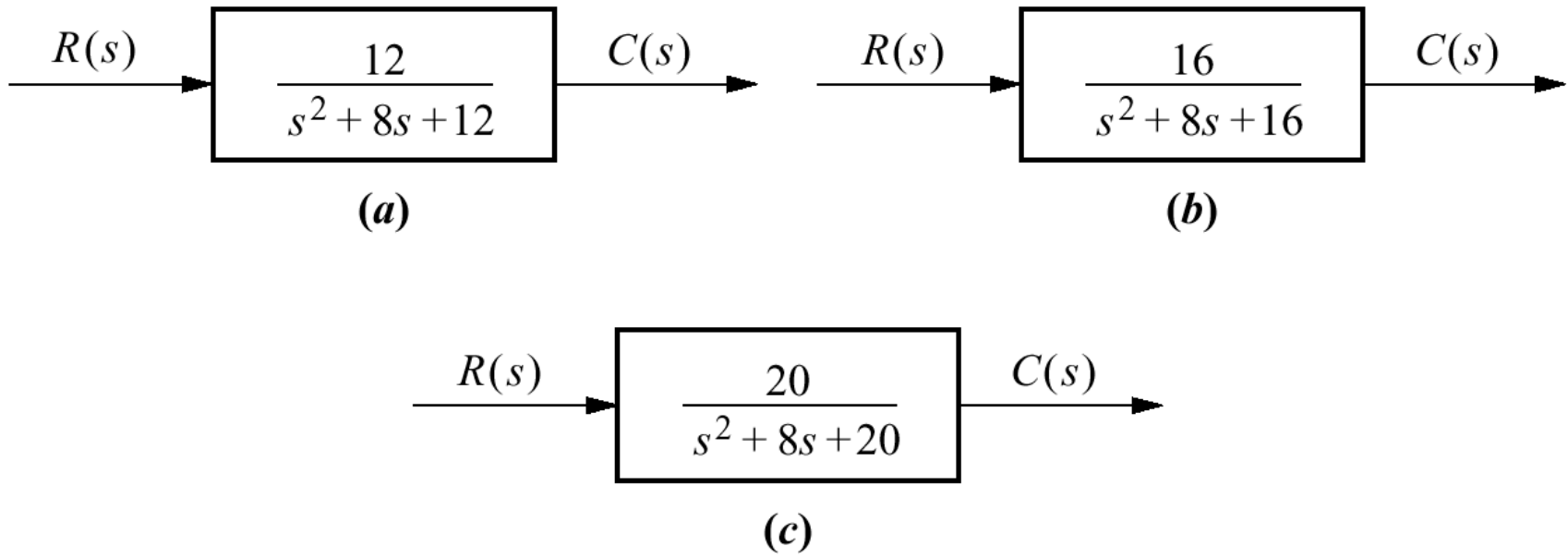


**Fig. 4.11**  
Respostas de segunda ordem em função da relação de amortecimento



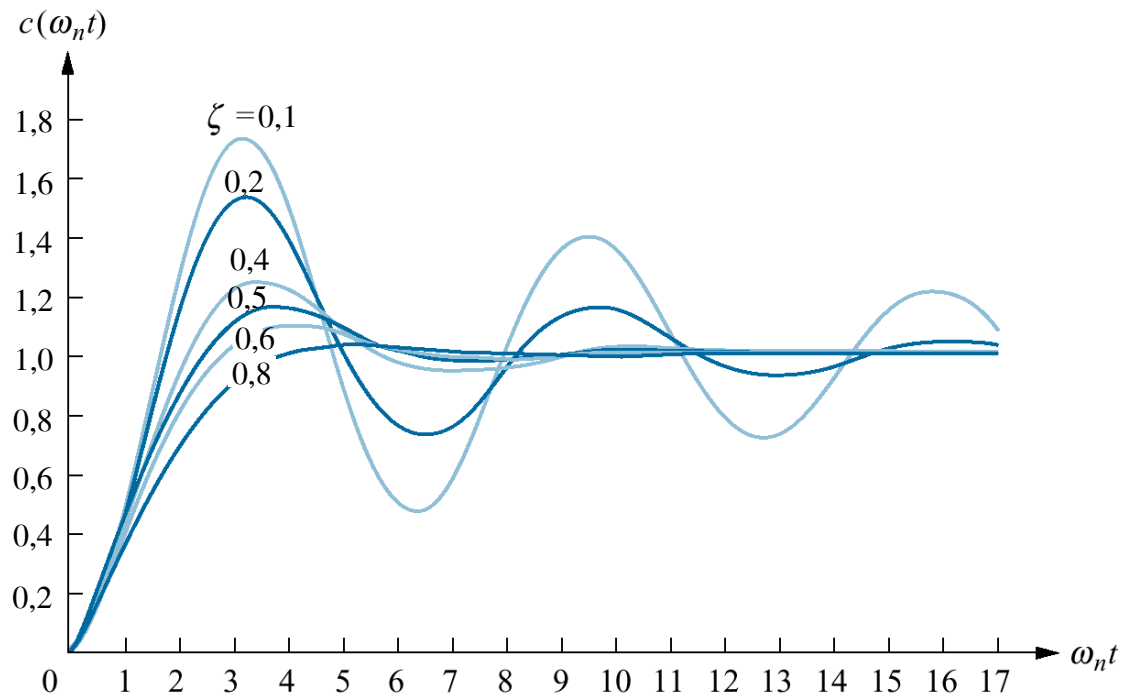
# Fig. 4.12

## Sistemas para o Exemplo 4.4

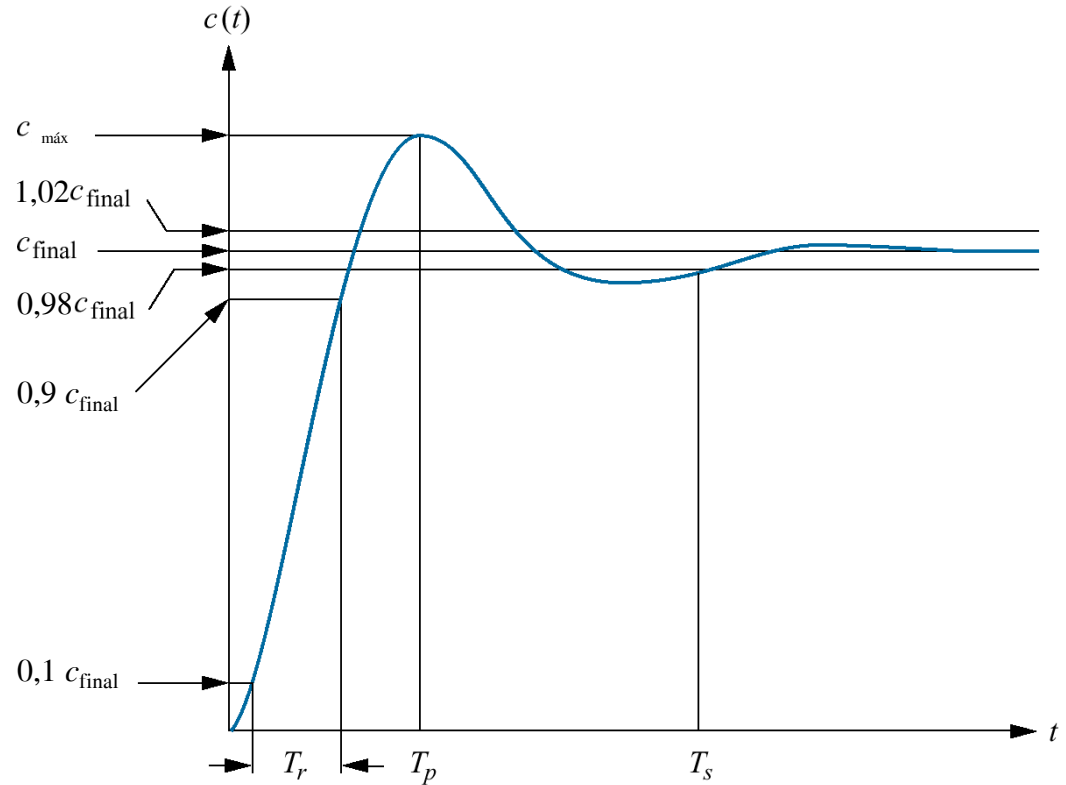


**Fig. 4.13**

Respostas de segunda ordem subamortecidas com os valores da relação de amortecimento

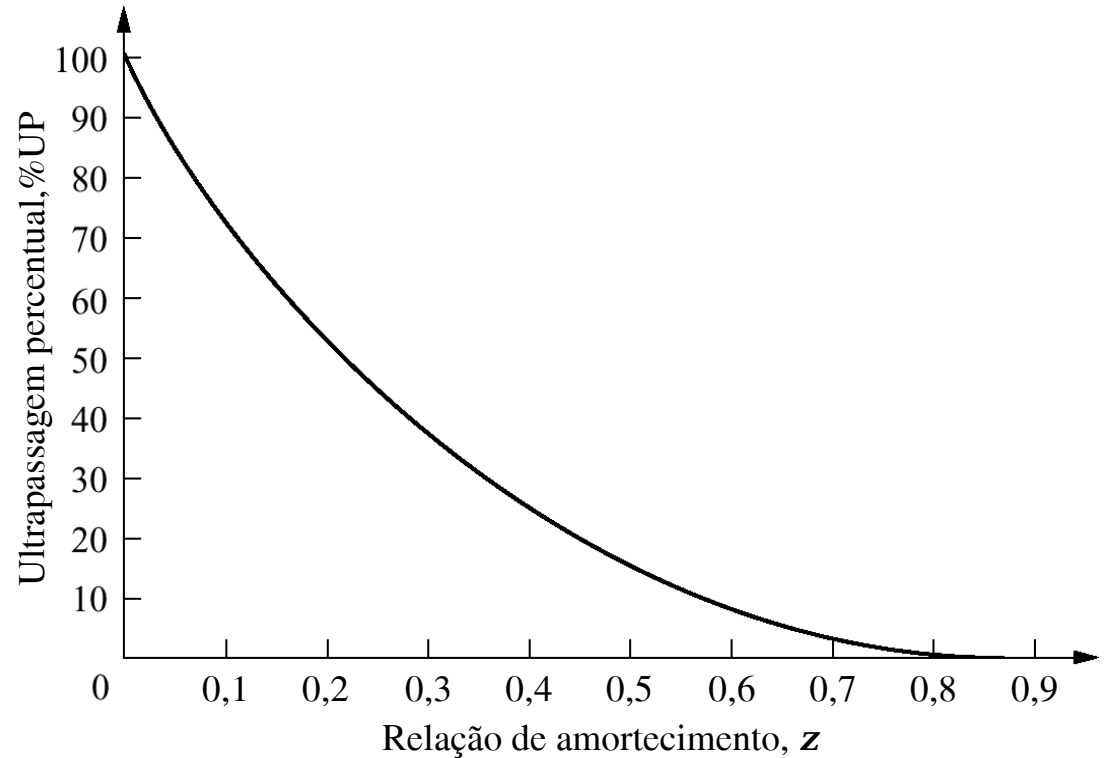


**Fig. 4.14**  
 Especificações da resposta de segunda ordem subamortecida



## Fig. 4.15

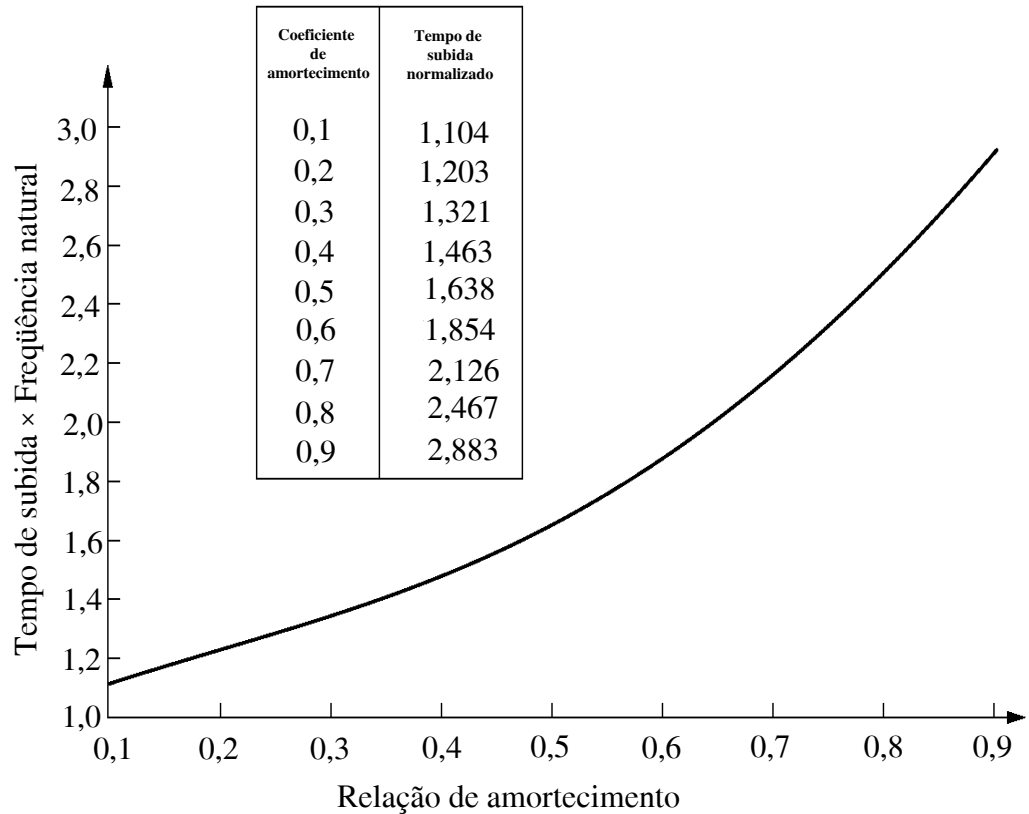
Ultrapassagem percentual em função da relação de amortecimento



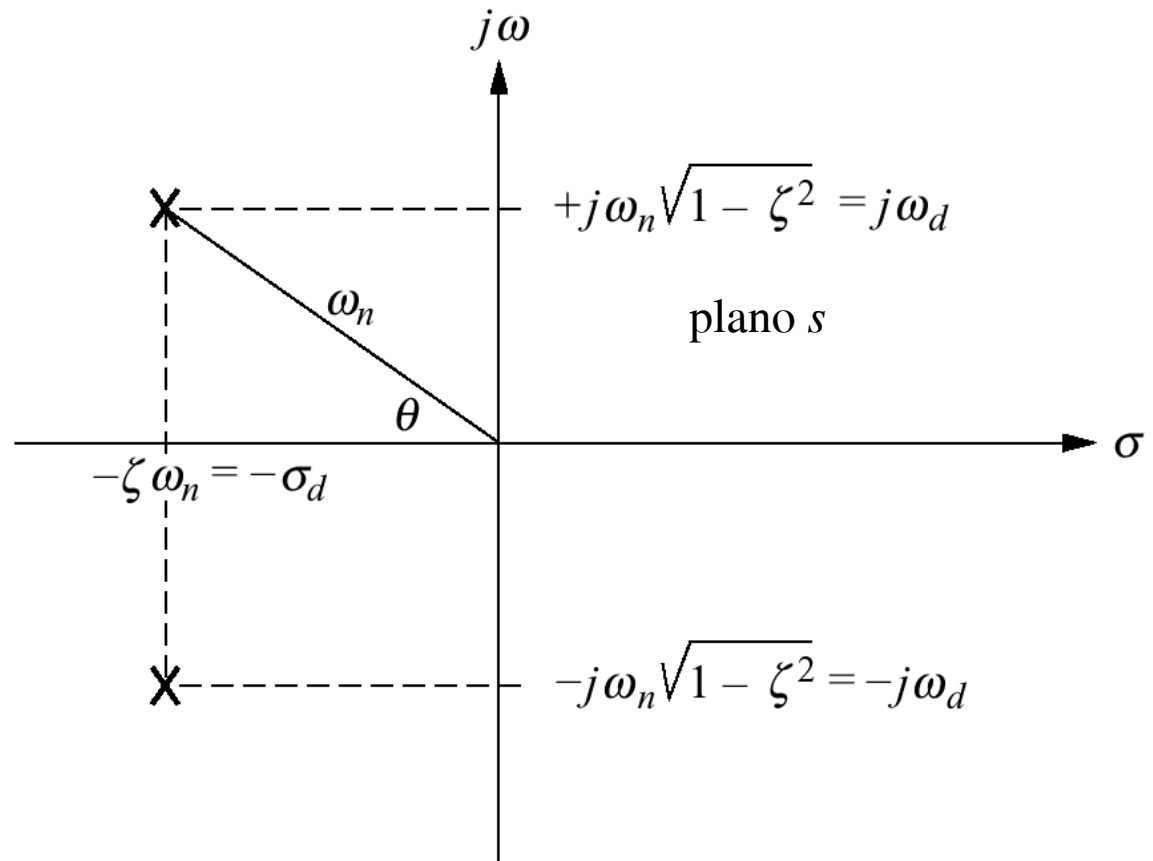


# Fig. 4.16

Tempo de subida normalizado versus relação de amortecimento para uma resposta de segunda ordem subamortecida



**Fig. 4.17**  
 Diagrama de pólos de um sistema de segunda ordem subamortecido

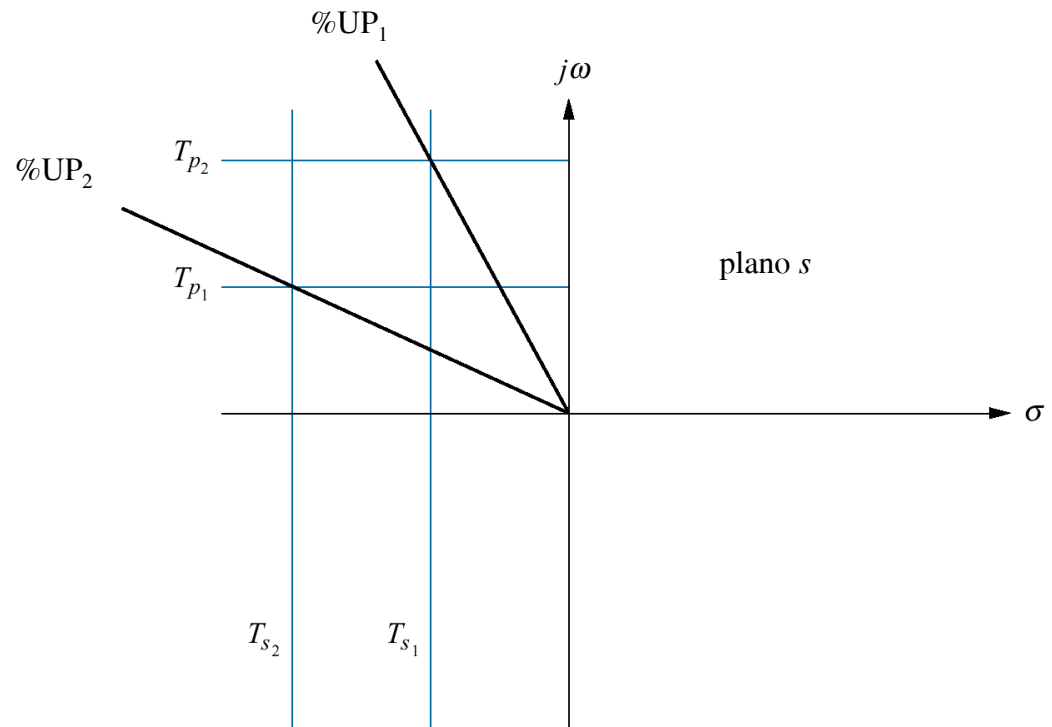


## Fig. 4.18

Linhas de valores constantes para tempo de pico,  $T_p$ , tempo de assentamento,  $T_s$ , e ultrapassagem percentual, %UP

Nota:

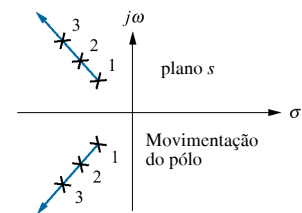
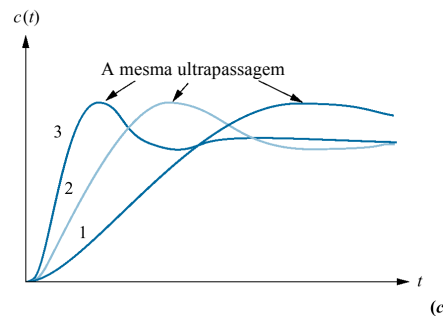
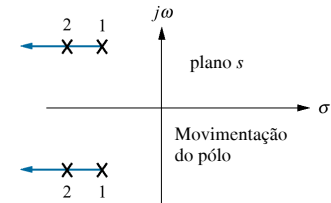
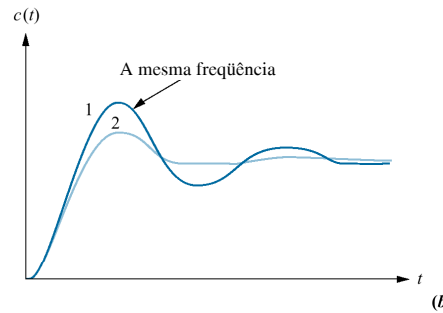
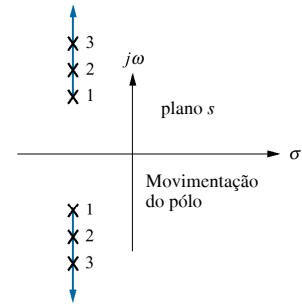
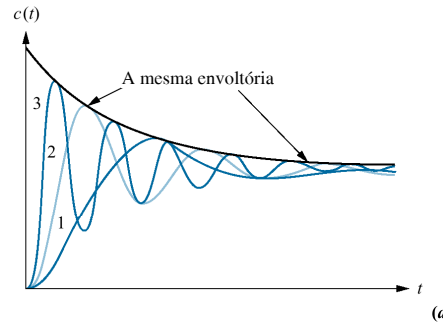
$$\%UP_1 < \%UP_2$$



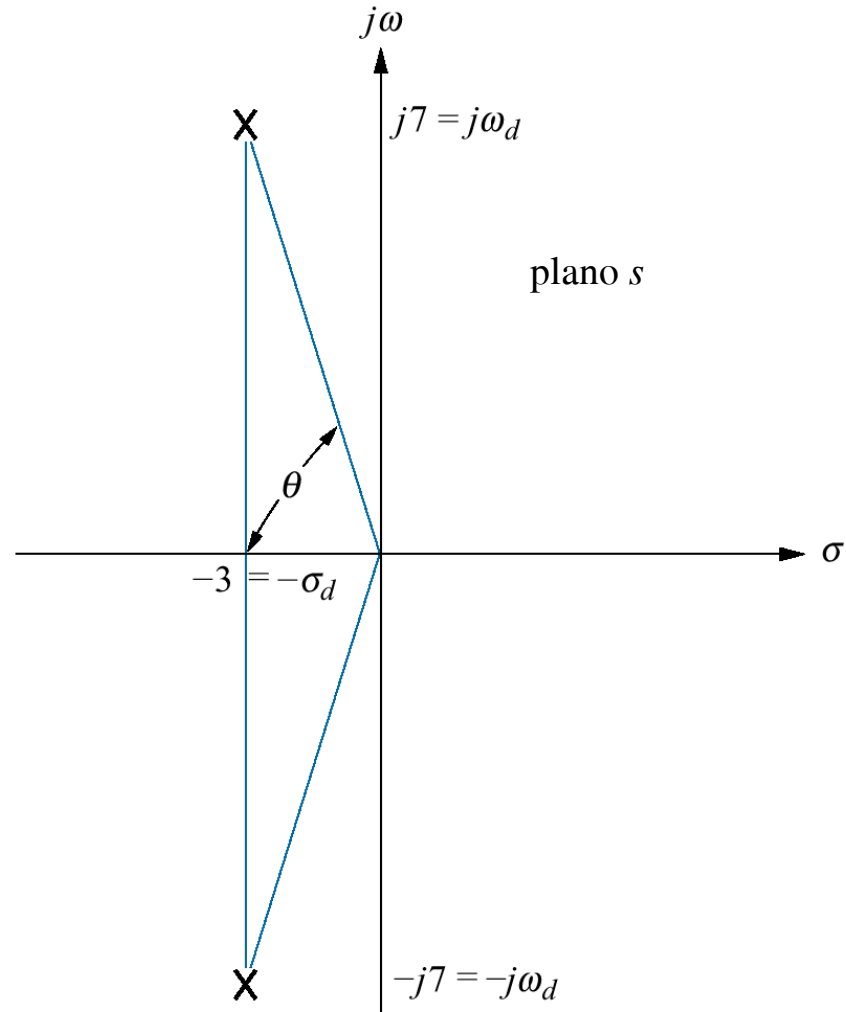
# Fig. 4.19

Respostas ao degrau de sistemas de segunda ordem subamortecidos à medida que os pólos se movem:

- a.** com parte real constante;
- b.** com parte imaginária constante;
- c.** com relação de amortecimento constante.

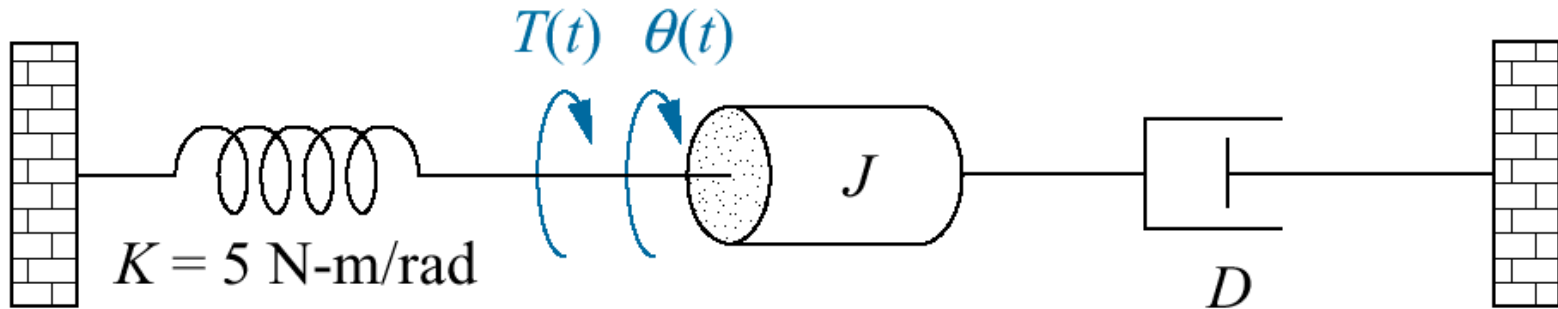


**Fig. 4.20**  
 Diagrama de pólos para o Exemplo 4.6



# Fig. 4.21

Sistema  
mecânico em  
rotação para o  
Exemplo 4.7



## Fig. 4.22

Robô de segurança Cybermotion SR3 em serviço. O robô se desloca usando um sistema de navegação por ultra-sons e percursos definidos por programas transmitidos a partir de um computador, eliminando a necessidade de guiamento por meio de tiras sobre o piso. Possui recursos de vídeo bem como sensores de temperatura, umidade, detecção de incêndio, intrusão e gases



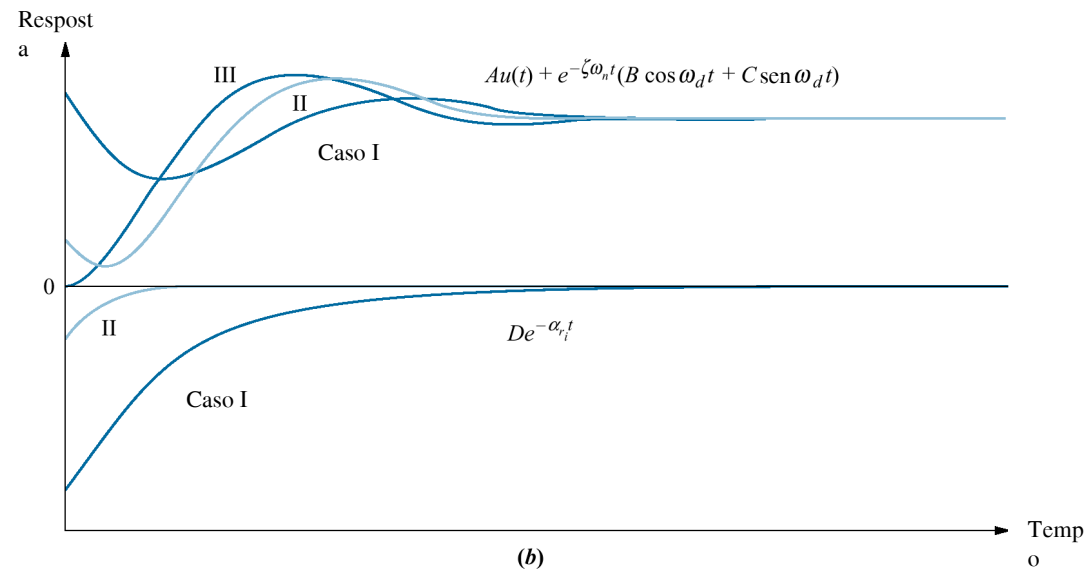
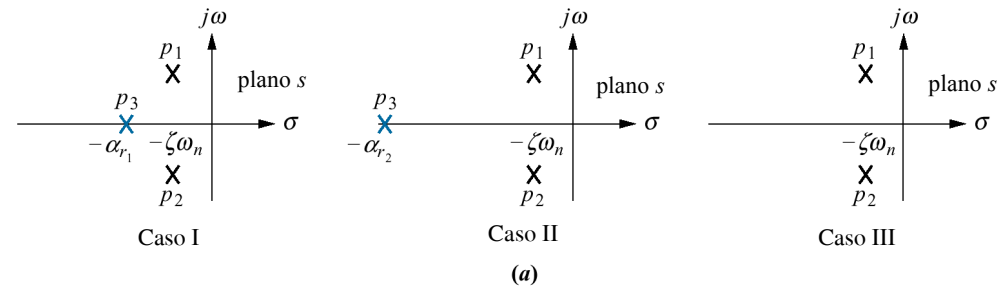
Cortesia de Cybermotion, Inc.

# Fig. 4.23

Respostas dos componentes de um sistema com três pólos:

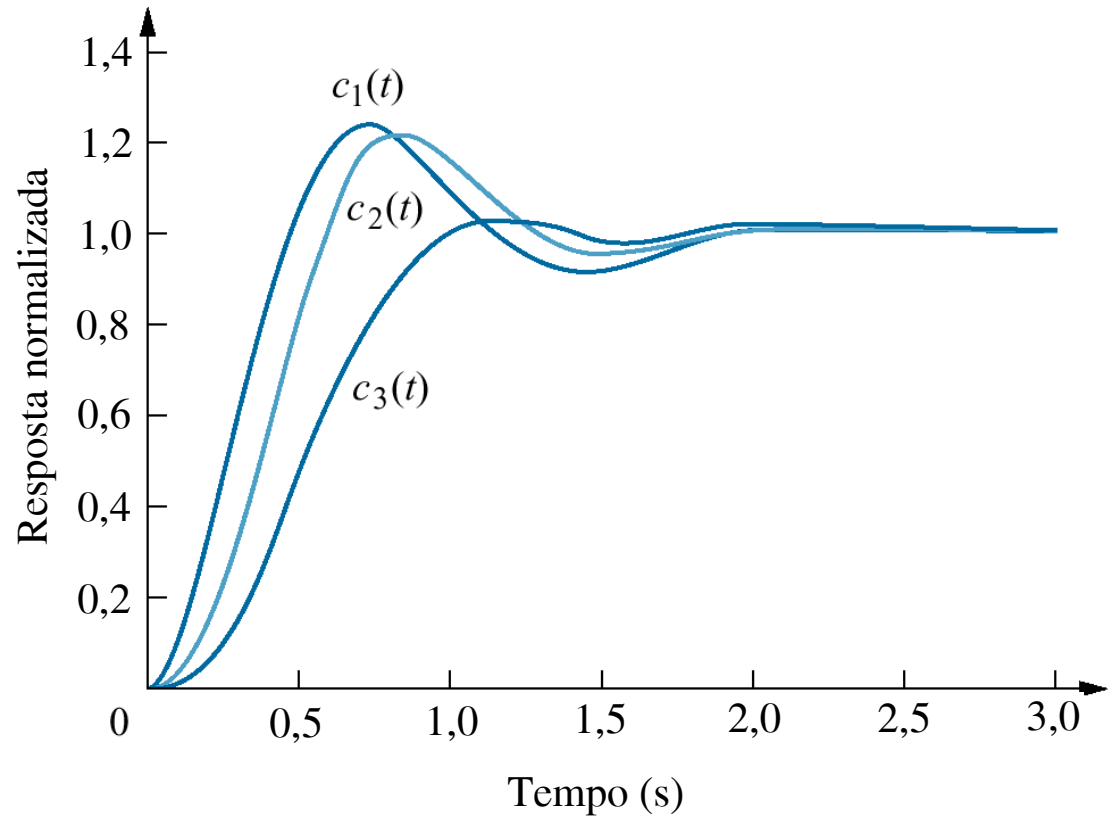
**a.** diagrama de pólos;

**b.** respostas dos componentes: o pólo não-dominante está próximo de um par de segunda ordem dominante (Caso I), longe do par (Caso II) e no infinito (Caso III)



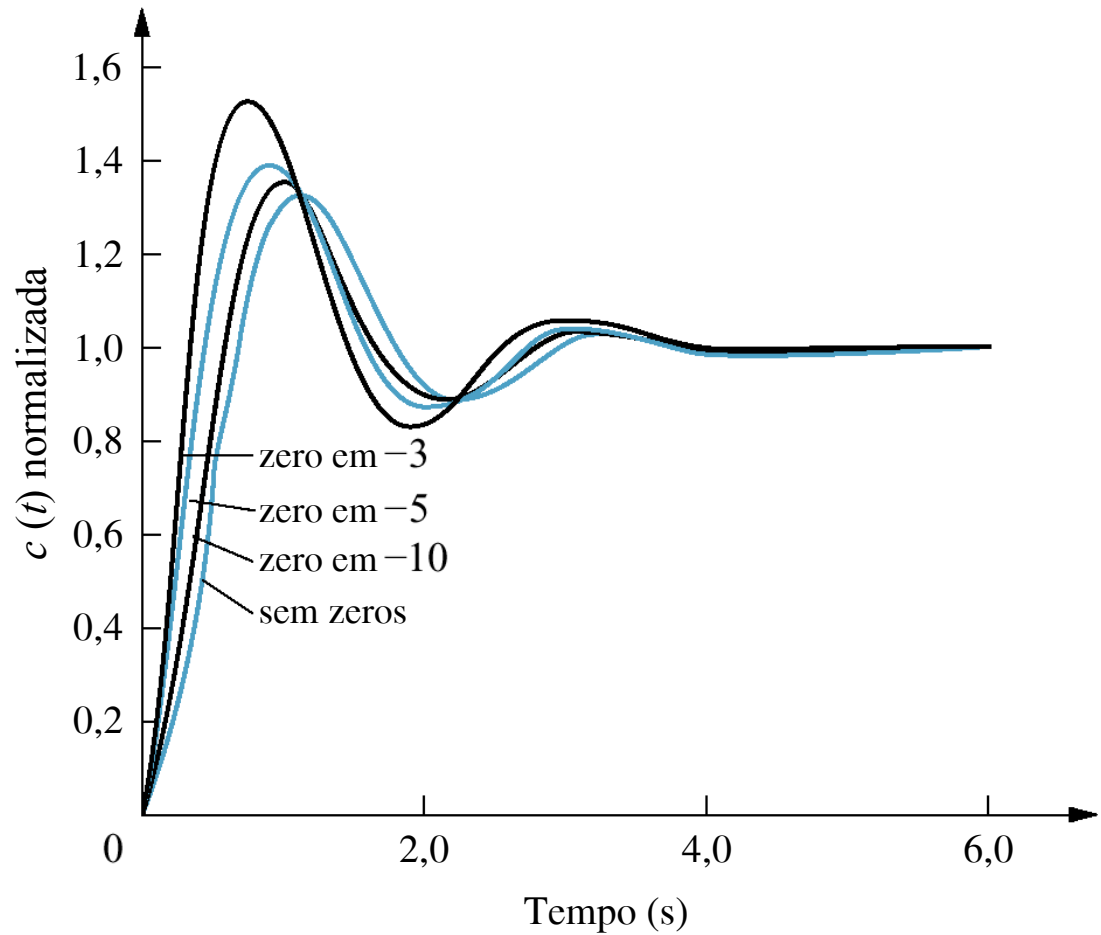


**Fig. 4.24**  
Respostas ao degrau dos sistemas  $T_1(s)$ ,  $T_2(s)$  e  $T_3(s)$



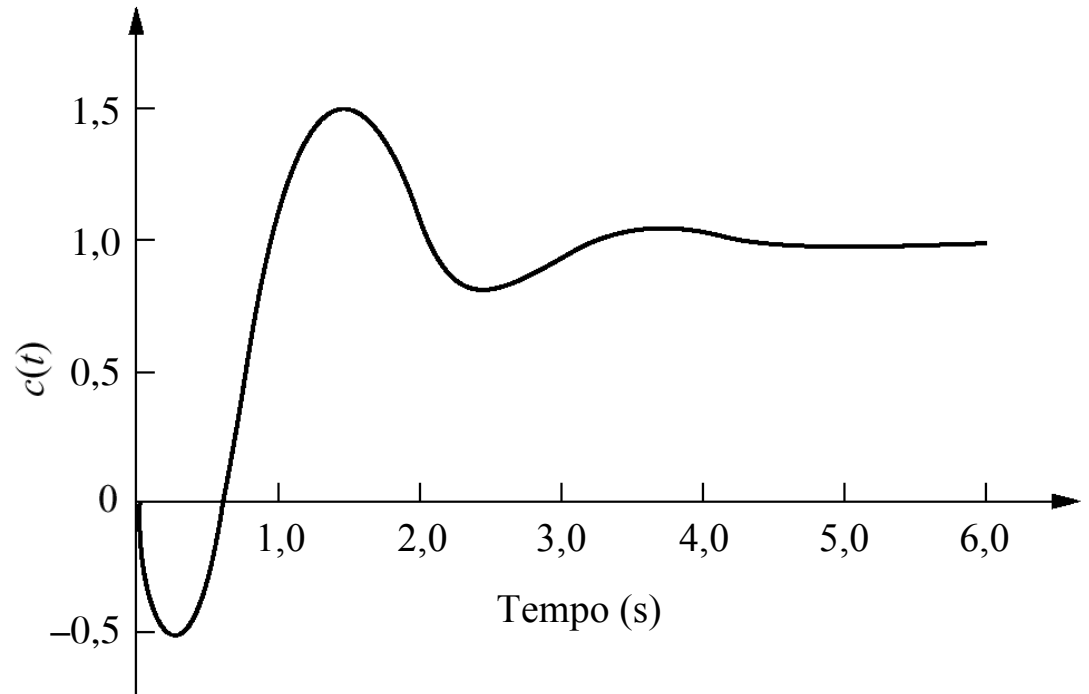
# Fig. 4.25

Efeito de adicionar um zero a um sistema com dois pólos



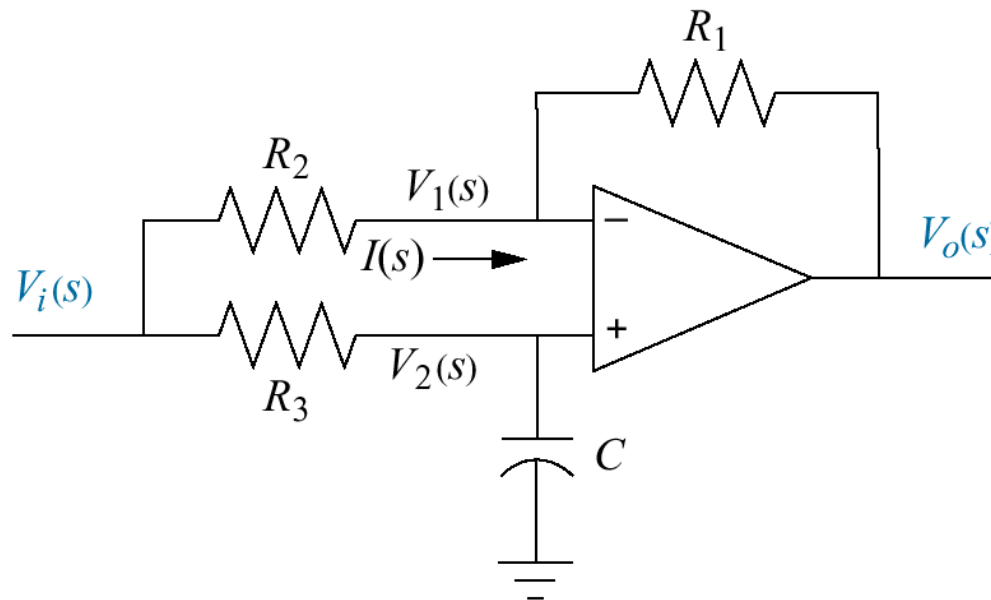
**Fig. 4.26**

Resposta ao degrau de um sistema de fase não-mínima



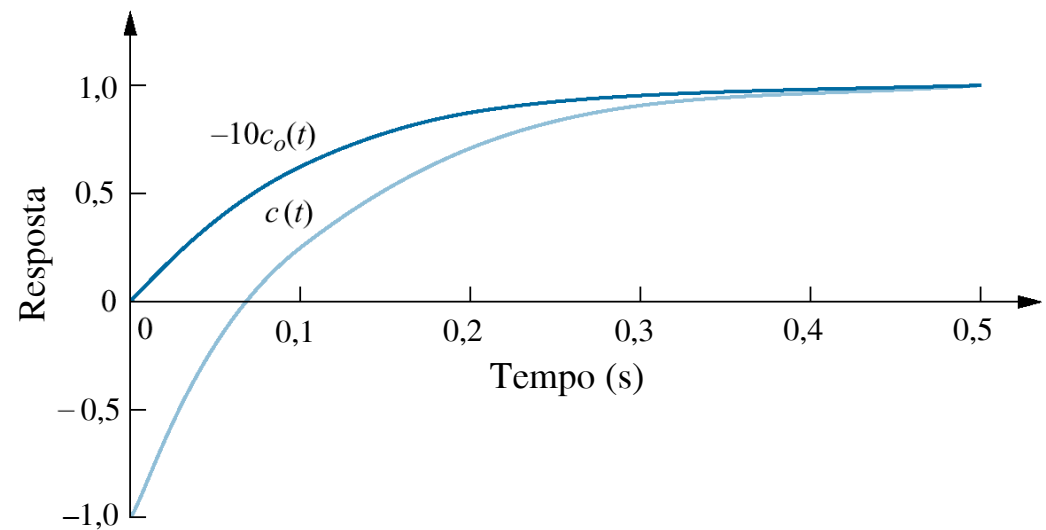
# Fig. 4.27

## Circuito elétrico de fase não-mínima



## Fig. 4.28

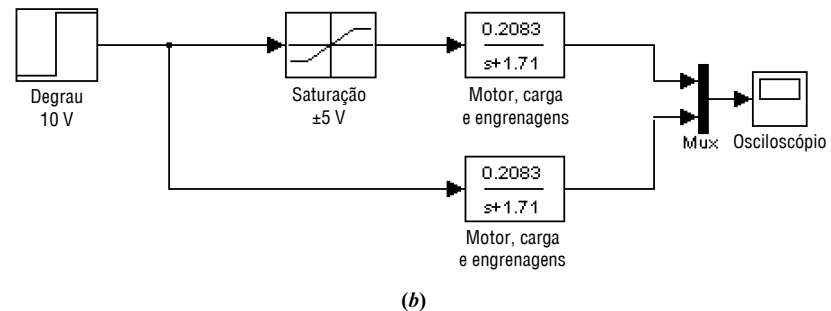
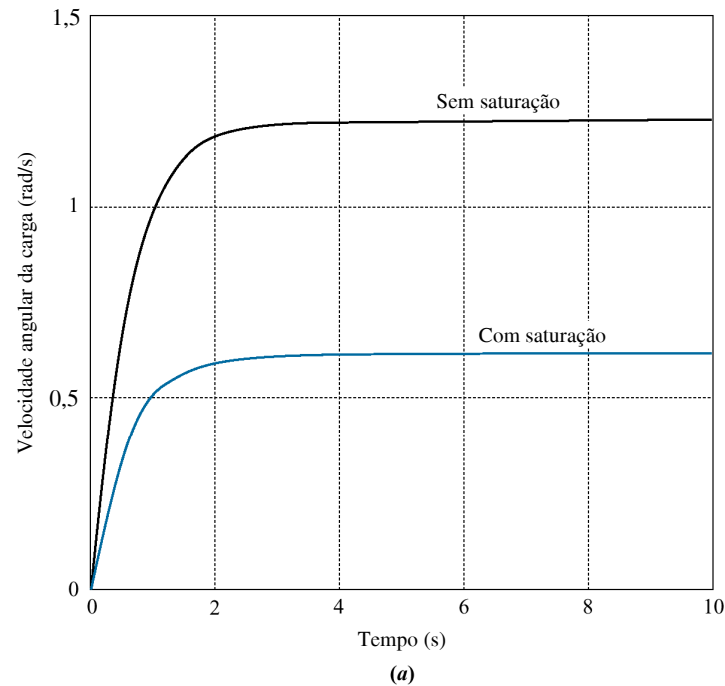
Resposta ao degrau do circuito de fase não-mínima da Fig. 4.27 ( $c(t)$ ) e a resposta ao degrau normalizada de um circuito equivalente sem o zero ( $-10c_o(t)$ )



# Fig. 4.29

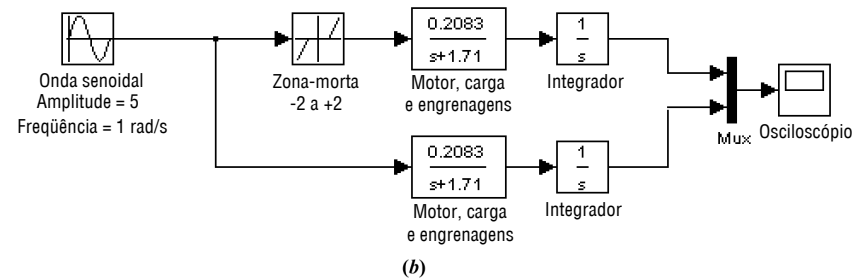
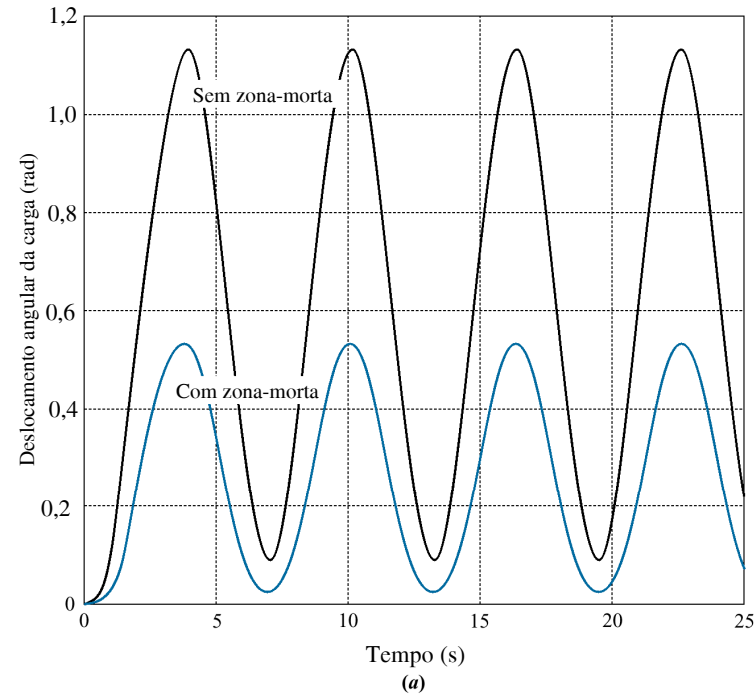
a. Efeito da saturação do amplificador sobre a resposta de velocidade angular da carga;

b. diagrama de blocos em Simulink



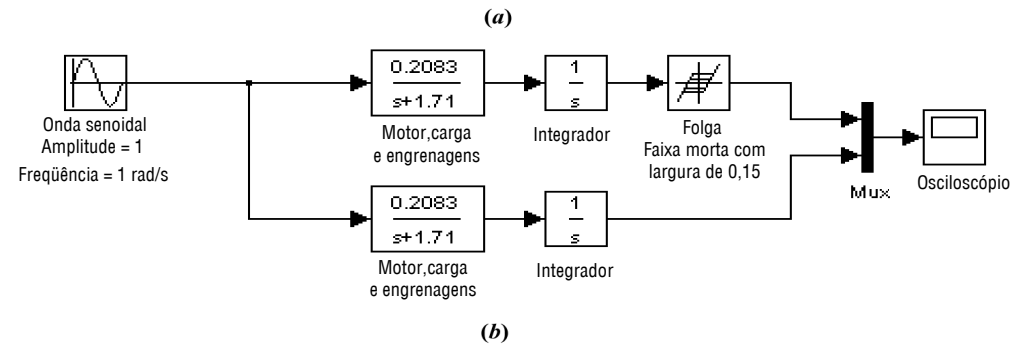
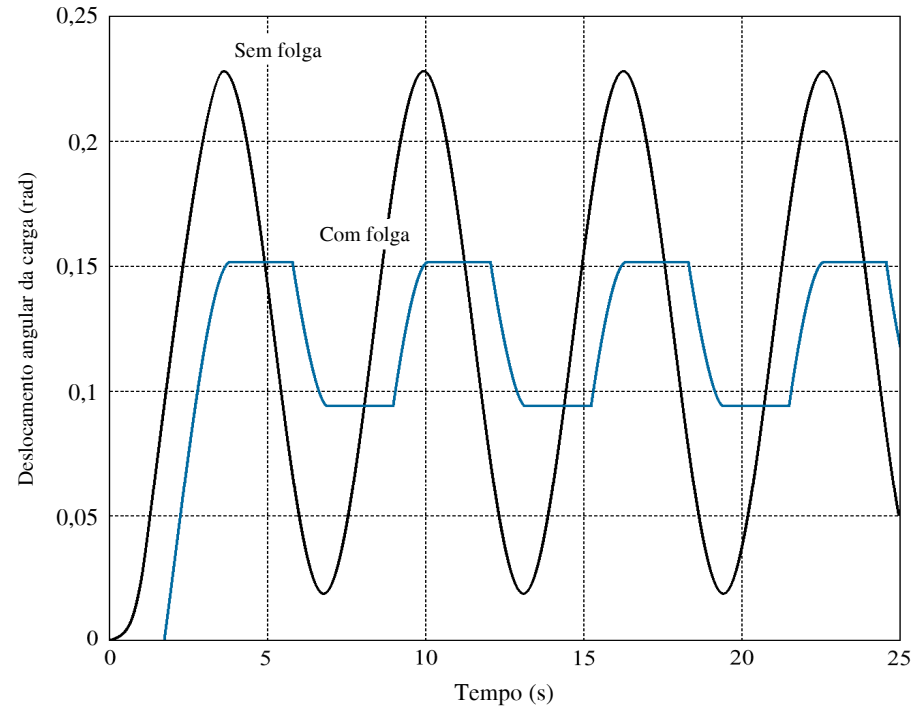
# Fig. 4.30

**a.** Efeito da zona morta sobre a resposta de deslocamento angular da carga;  
**b.** diagrama de blocos em Simulink



# Fig. 4.31

**a.** Efeito da folga sobre a resposta de deslocamento angular da carga;  
**b.** diagrama de blocos em Simulink



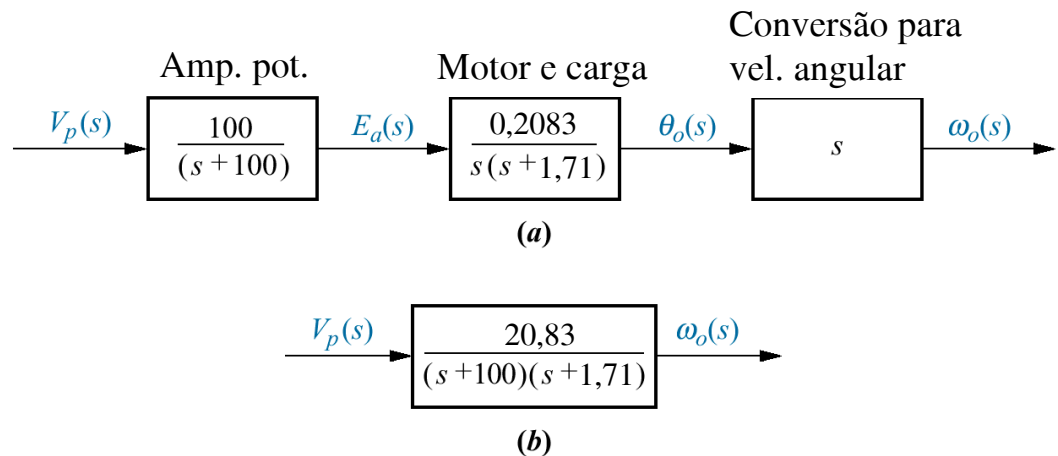


## Fig. 4.32

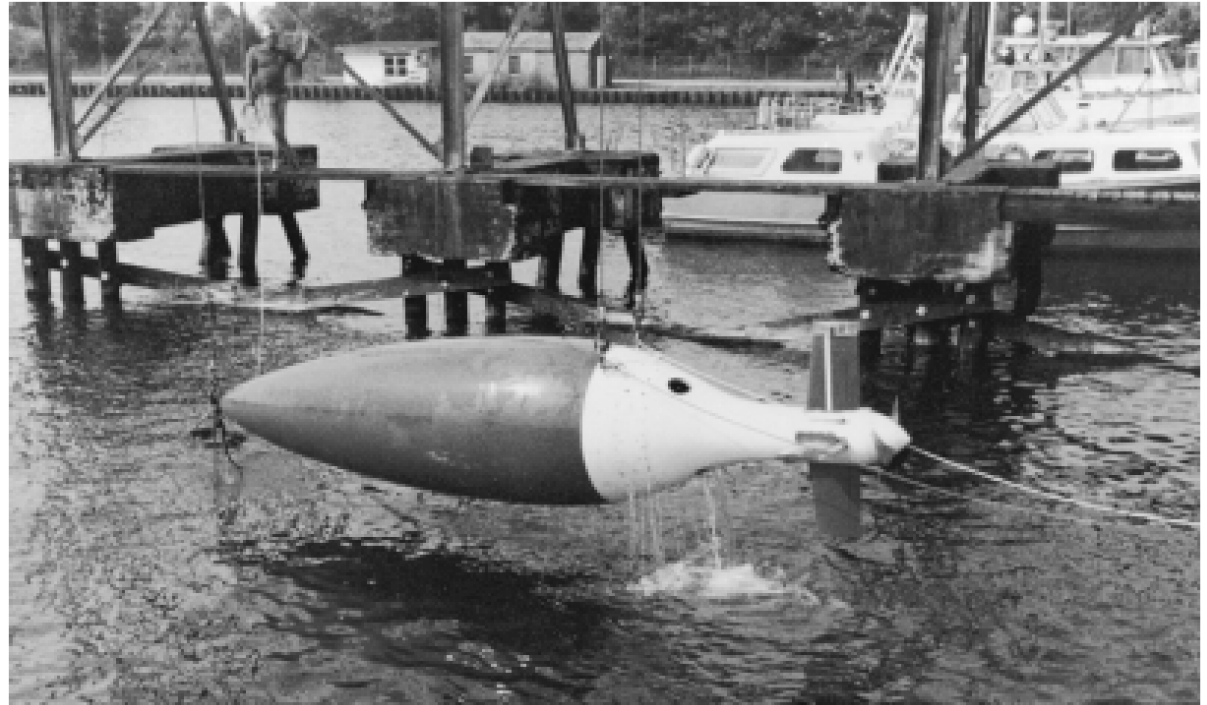
Sistema de controle de posição de uma antena em azimute para velocidade angular:

a. percurso à frente;

b. percurso à frente equivalente



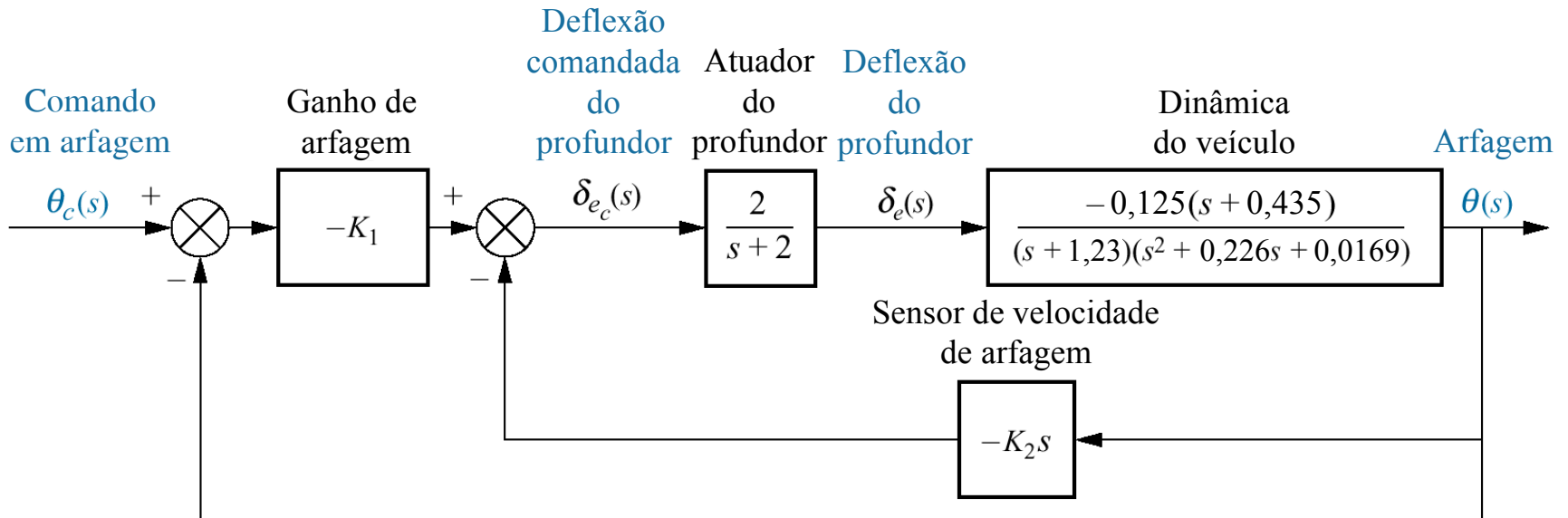
**Fig. 4.33**  
Veículo  
Submersível  
Não Tripulado  
(UFSS)



Cortesia do Naval Research Laboratory.

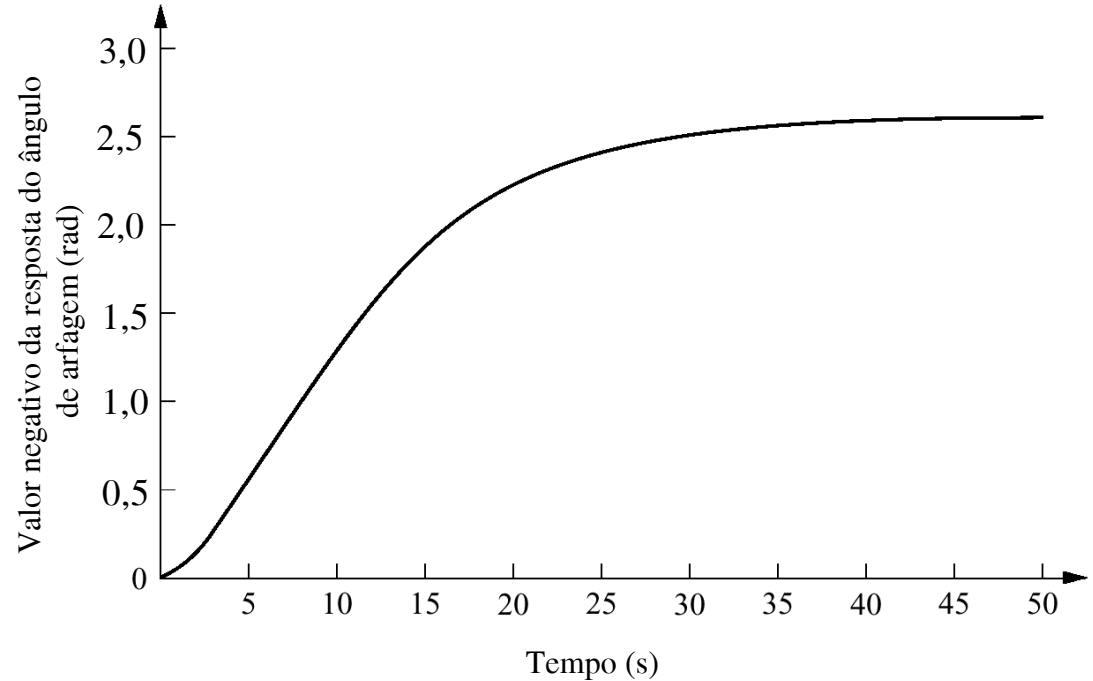
# Fig. 4.34

## Malha de controle em arfagem do veículo UFSS



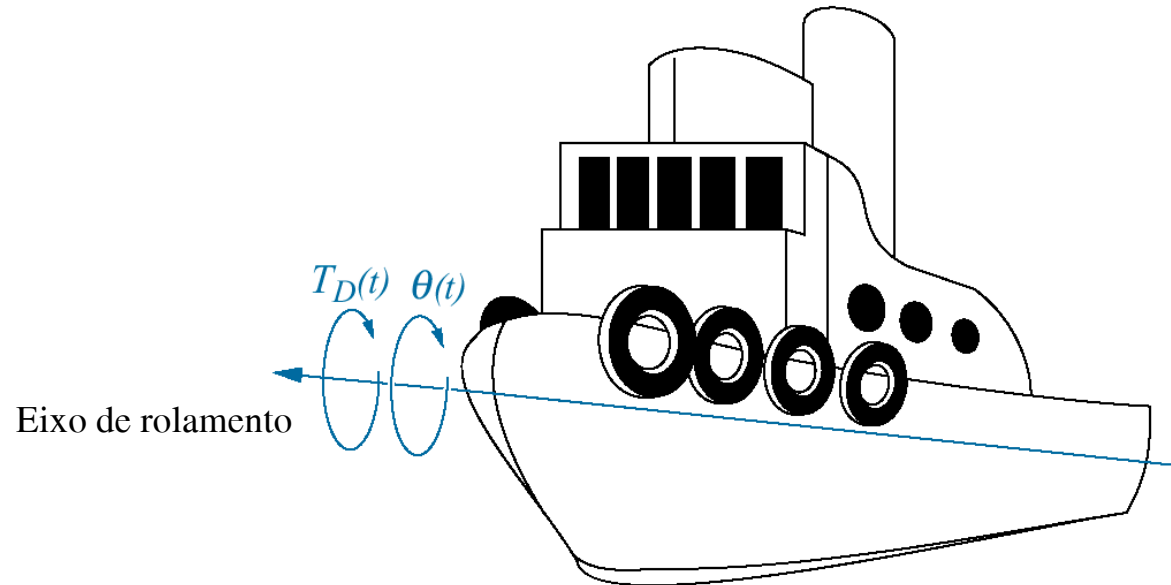
**Fig. 4.35**

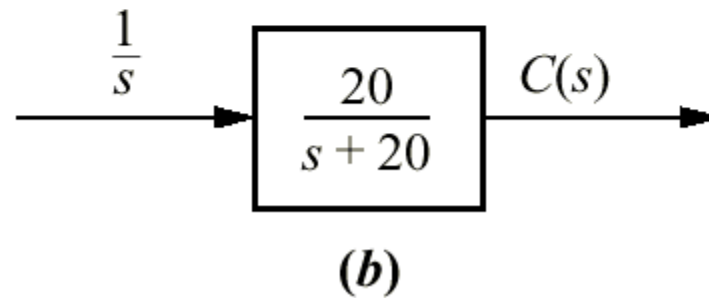
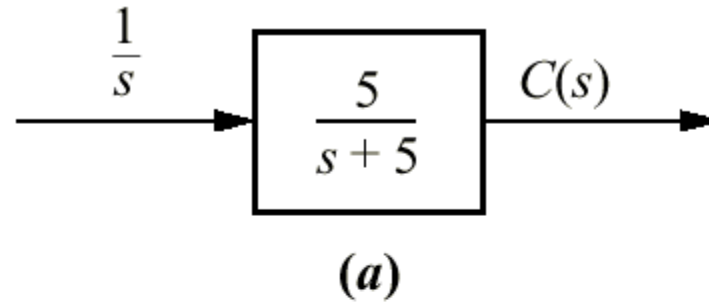
Resposta do controle em arfagem do veículo UFSS a um degrau negativo



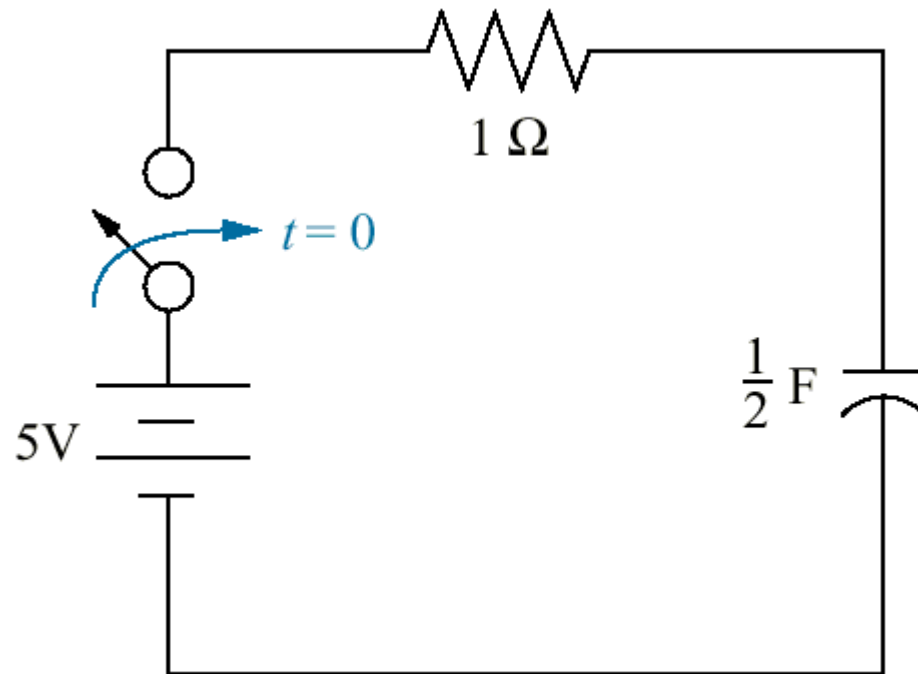
## Fig. 4.36

Uma embarcação no mar, mostrando o eixo de rolamento

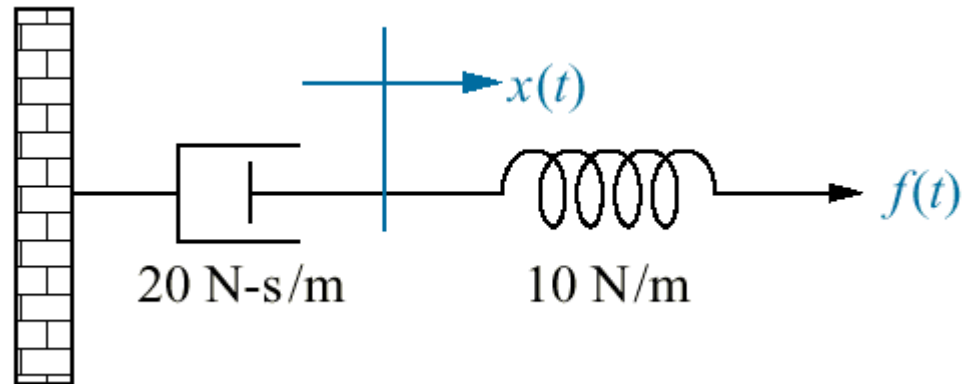


**Fig. P4.1**

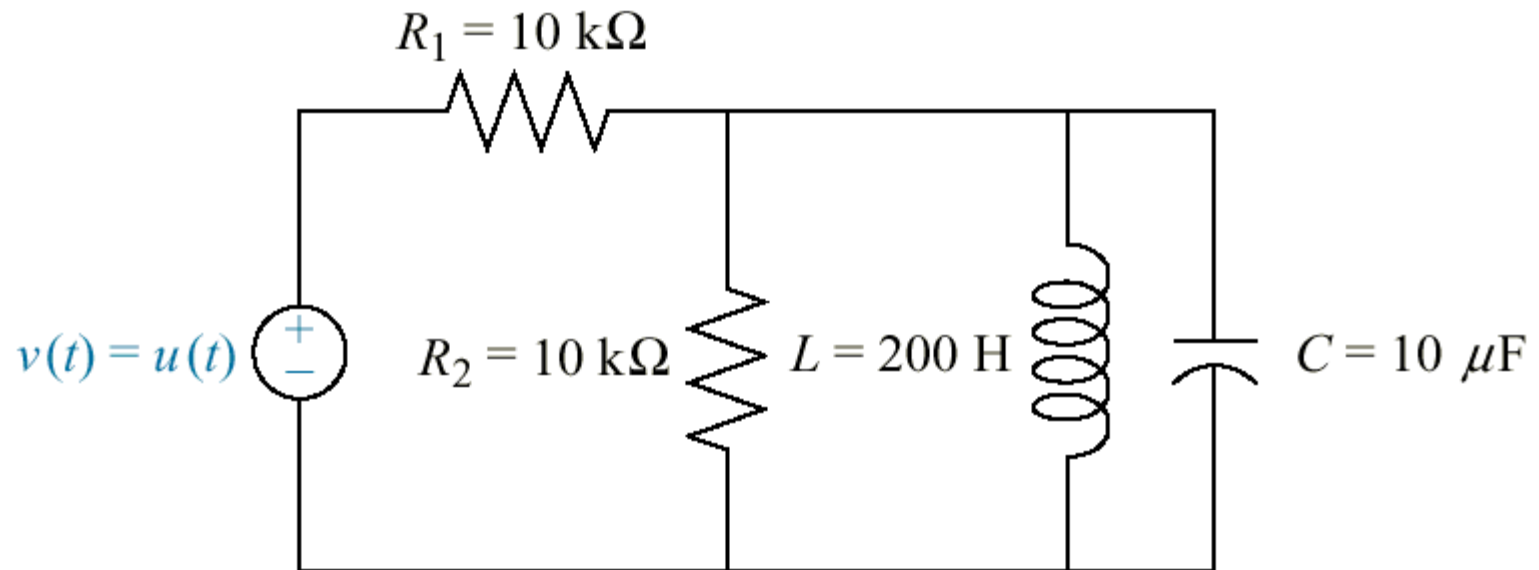
**Fig. P4.2**



# Fig. P4.3

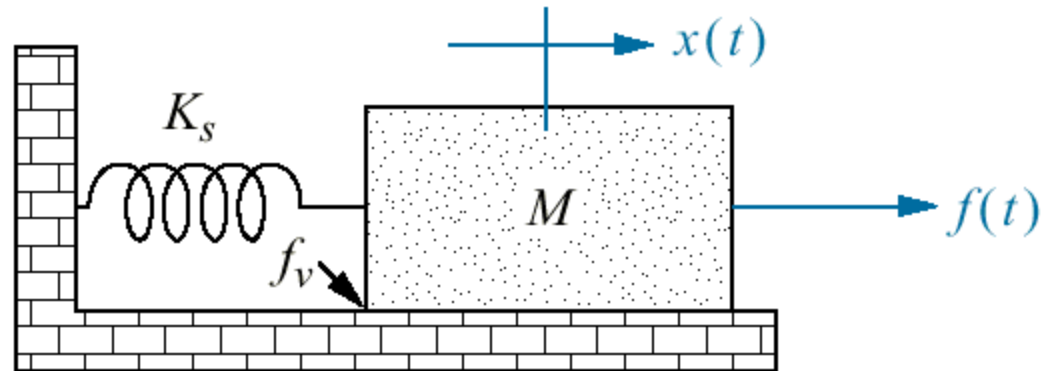


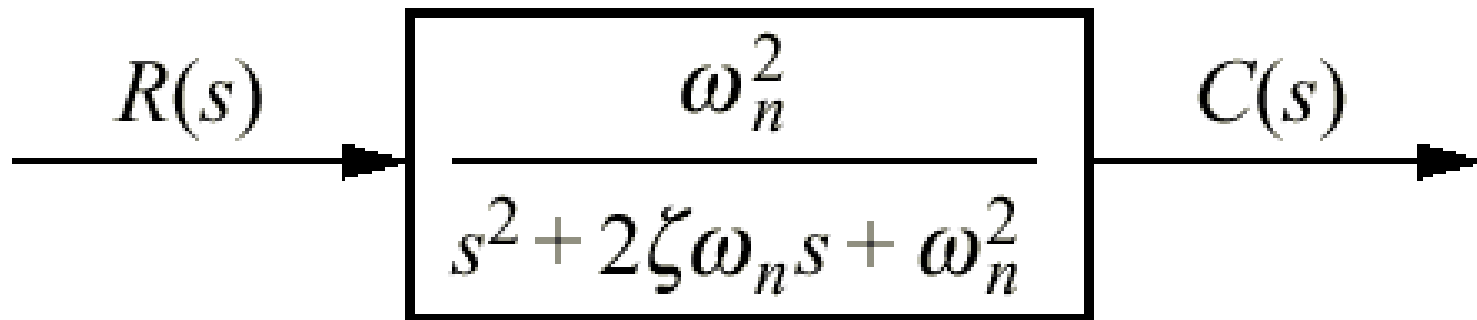


**Fig. P4.4**

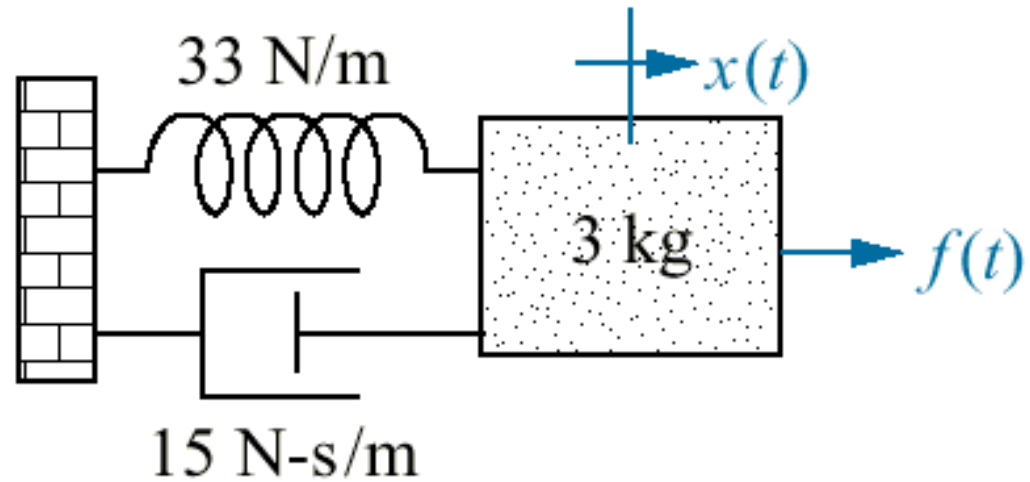
**Fig. P4.5**

$$M = 1 \text{ kg}$$
$$K_s = 5 \text{ N/m}$$
$$f_v = 1 \text{ N-s/m}$$
$$f(t) = u(t) \text{ N}$$

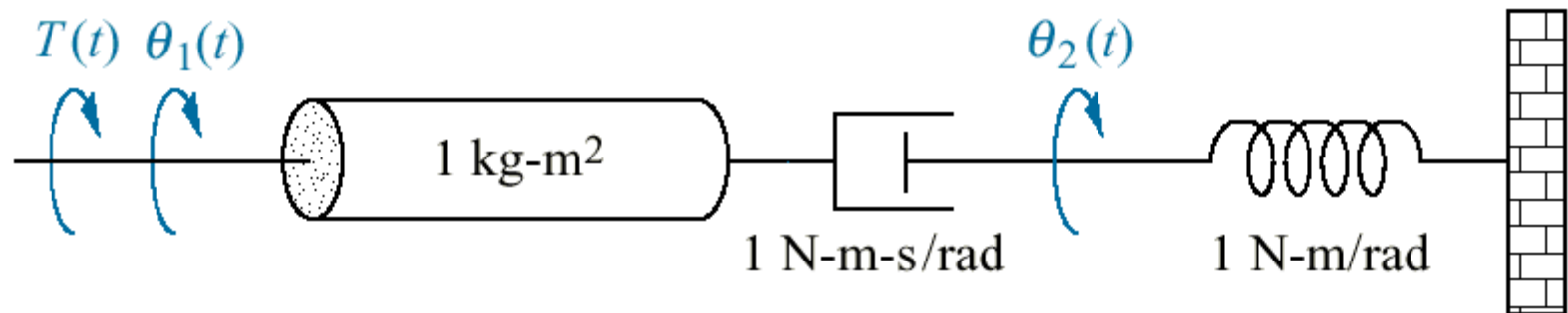


**Fig. P4.6**

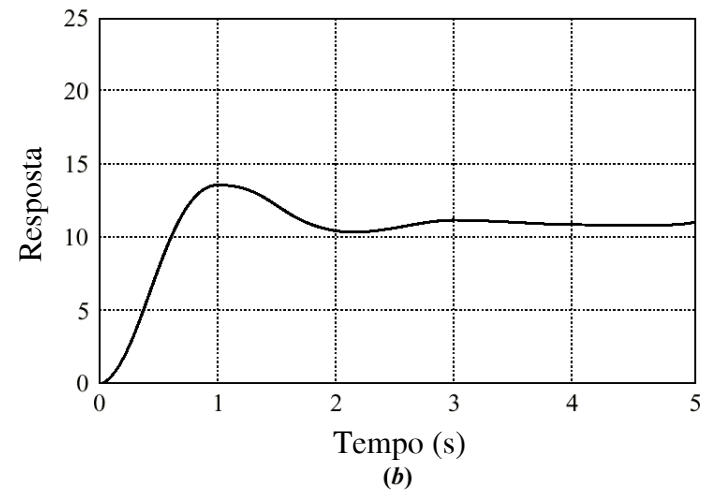
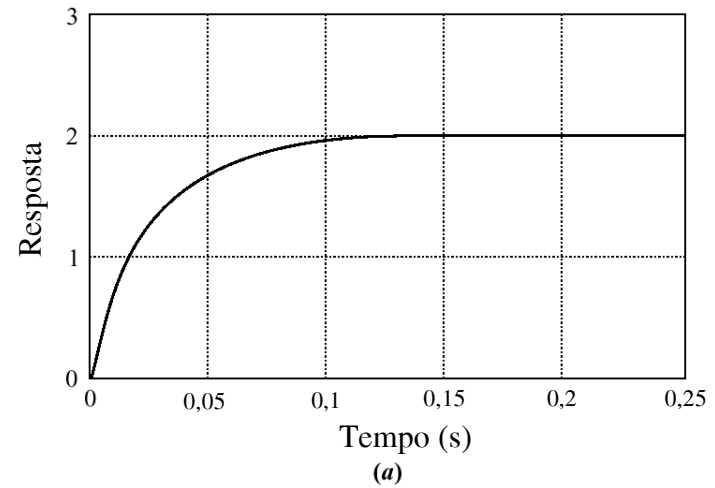
**Fig. P4.7**



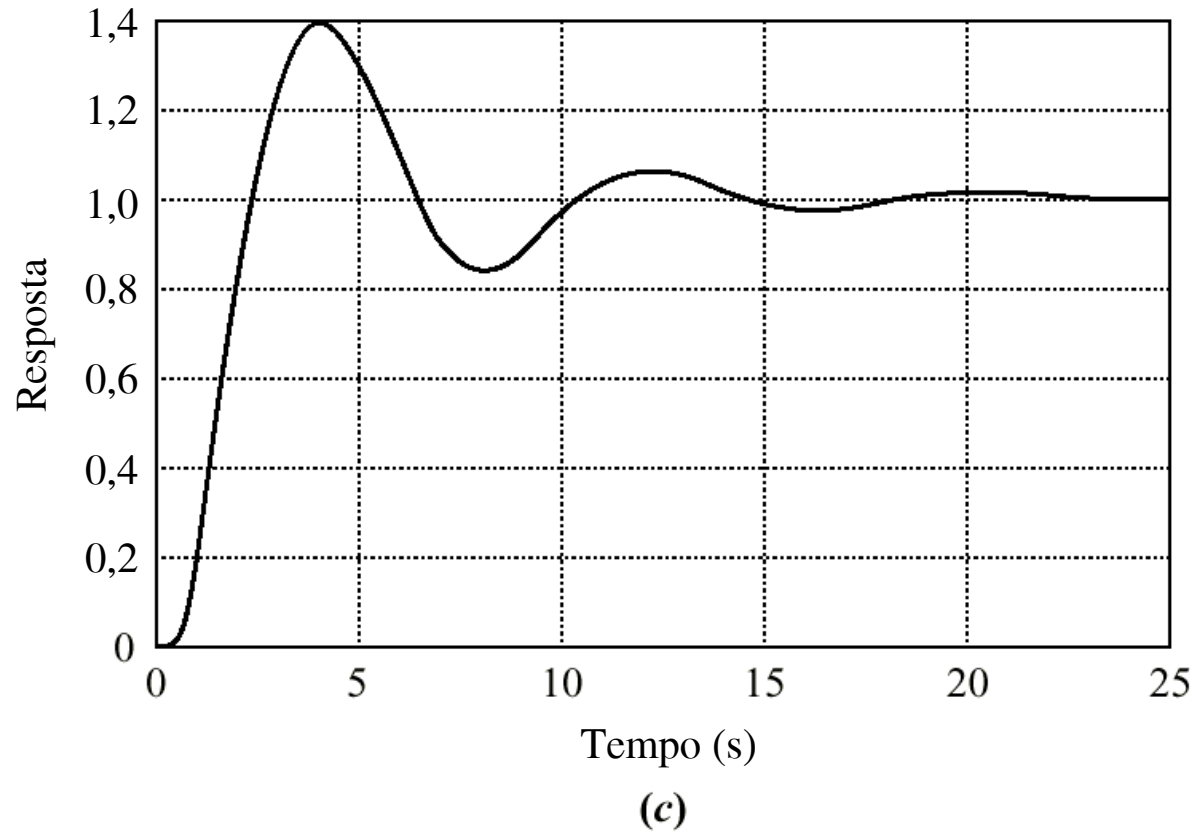
**Fig. P4.8**



**Fig. P4.9**  
(A figura continua)

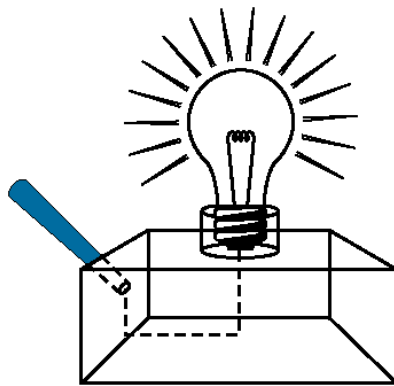


**Fig. P4.9**  
(*continuação*)



## Fig. P4.10

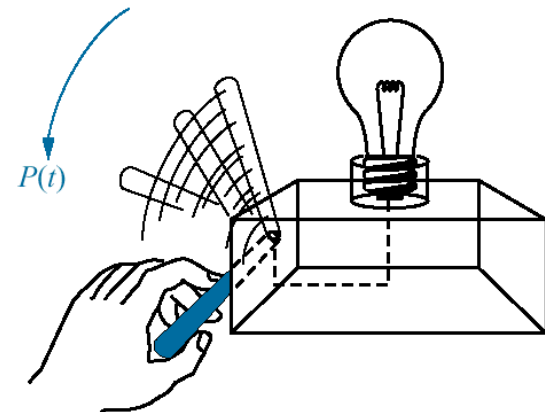
Passos para determinar a função de transferência relacionando a saída física de um sistema a um comando visual de entrada



Passo 1: Ligar a fonte luminosa



Passo 2: Reconhecer a fonte luminosa

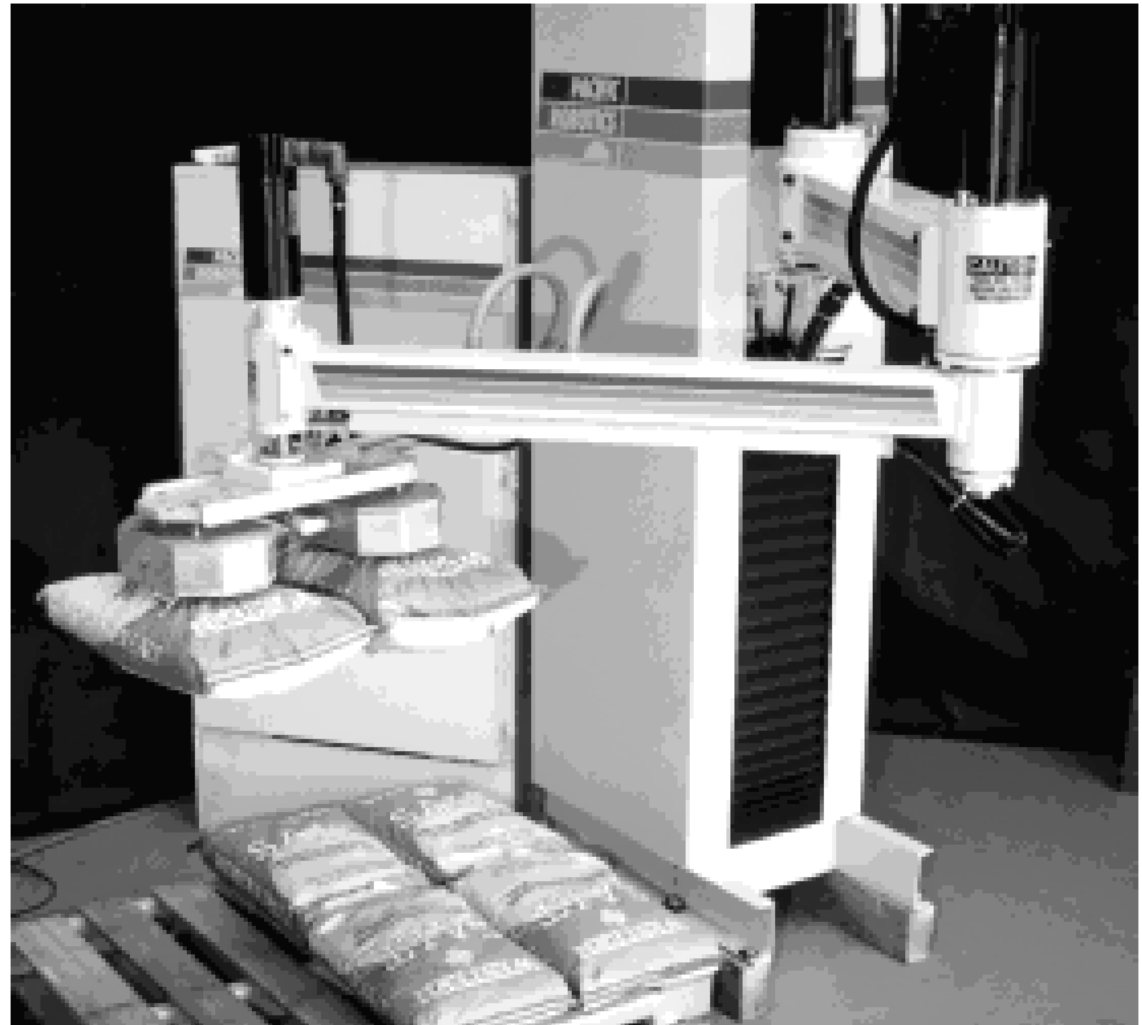


Passo 3: Responder à fonte luminosa



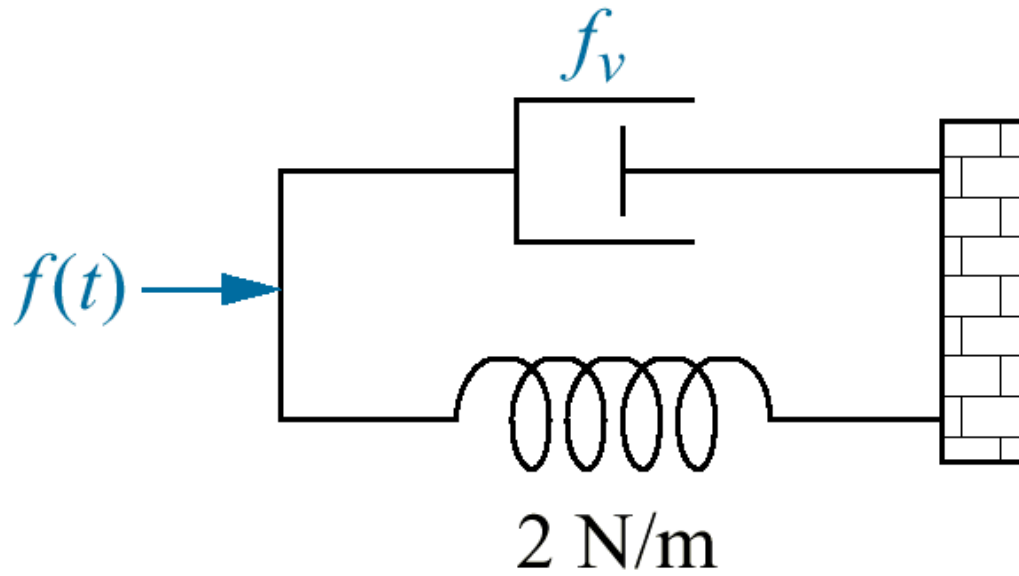
## Fig. P4.11

O sistema de vácuo do robô suspende duas sacas de sal

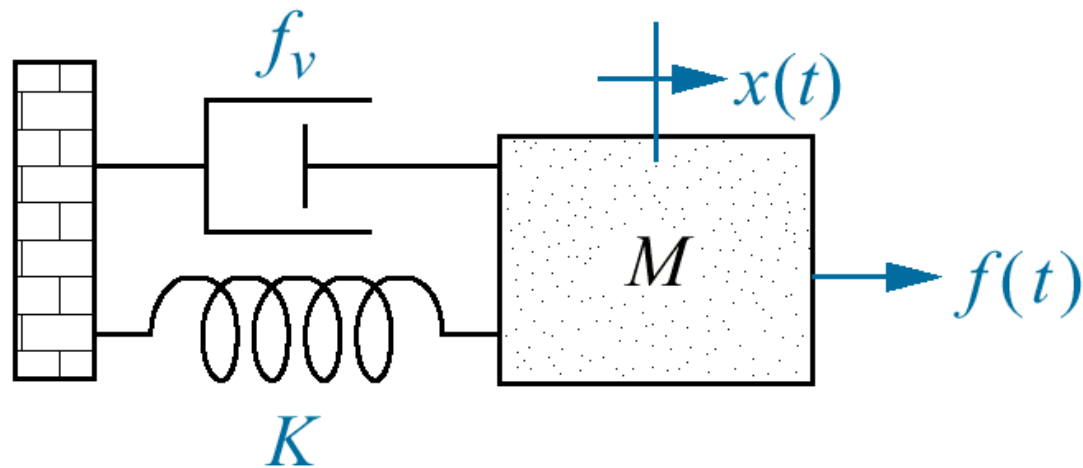


Cortesia de Pacific Robotics, Inc.

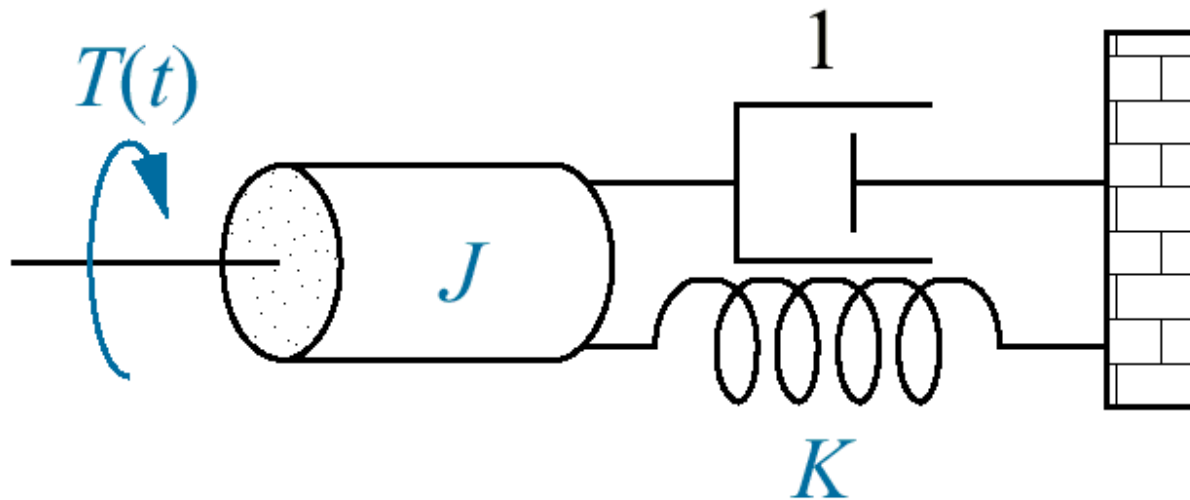
**Fig. P4.12**



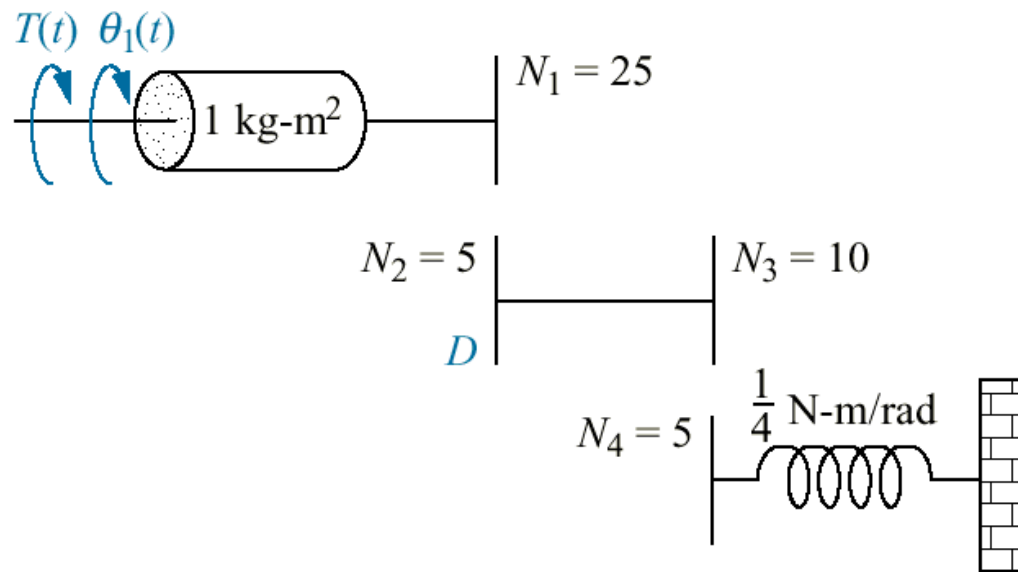
**Fig. P4.13**



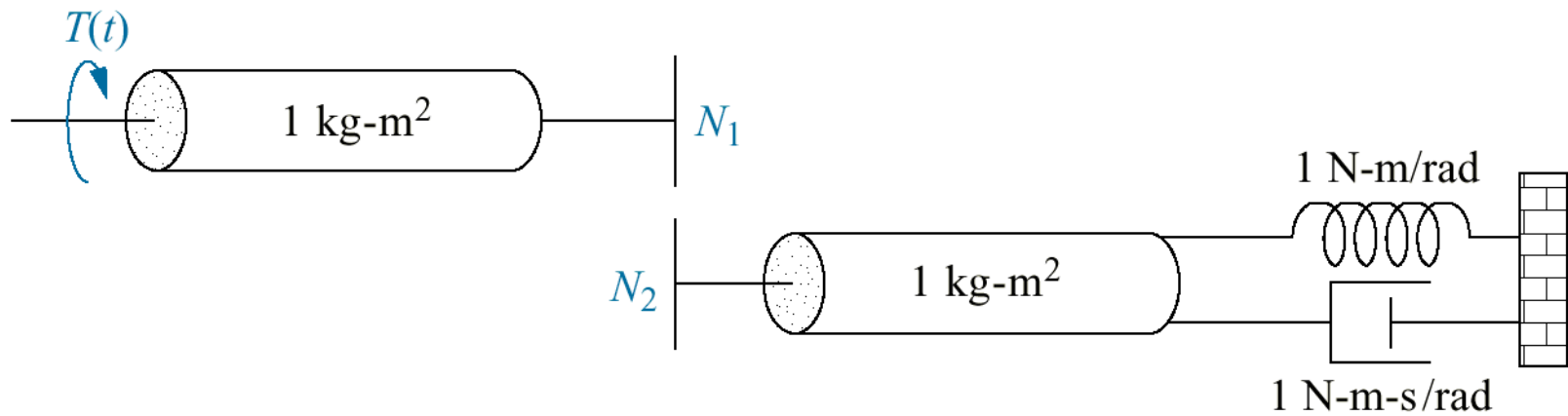
**Fig. P4.14**



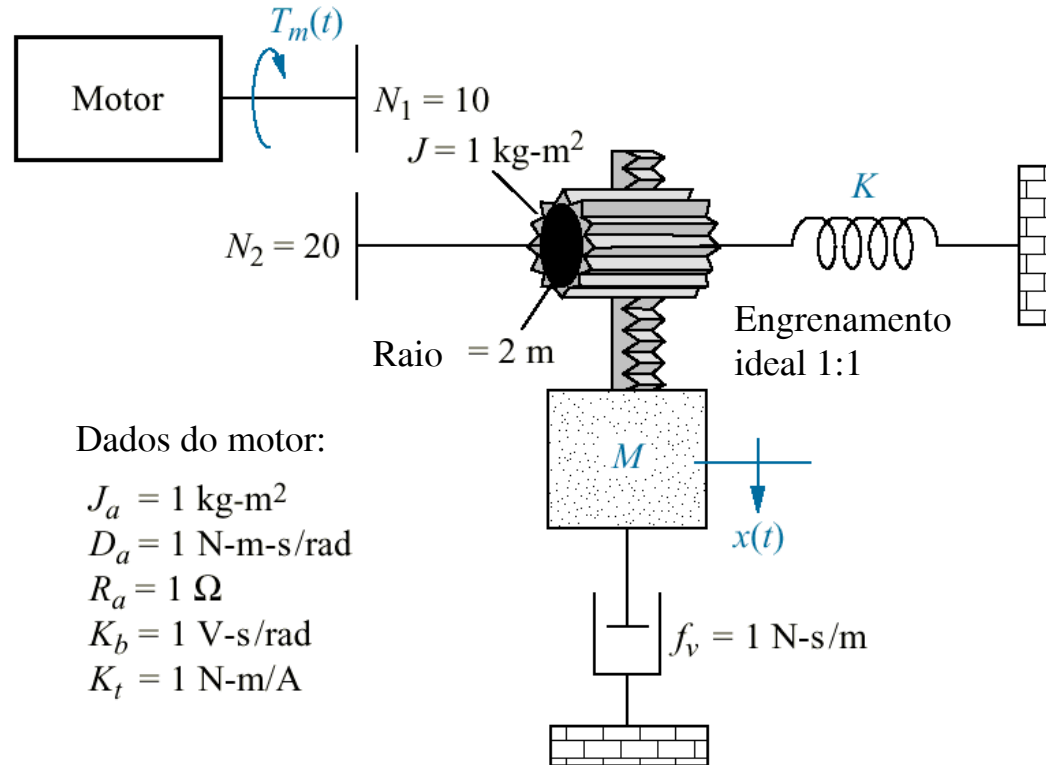
# Fig. P4.15



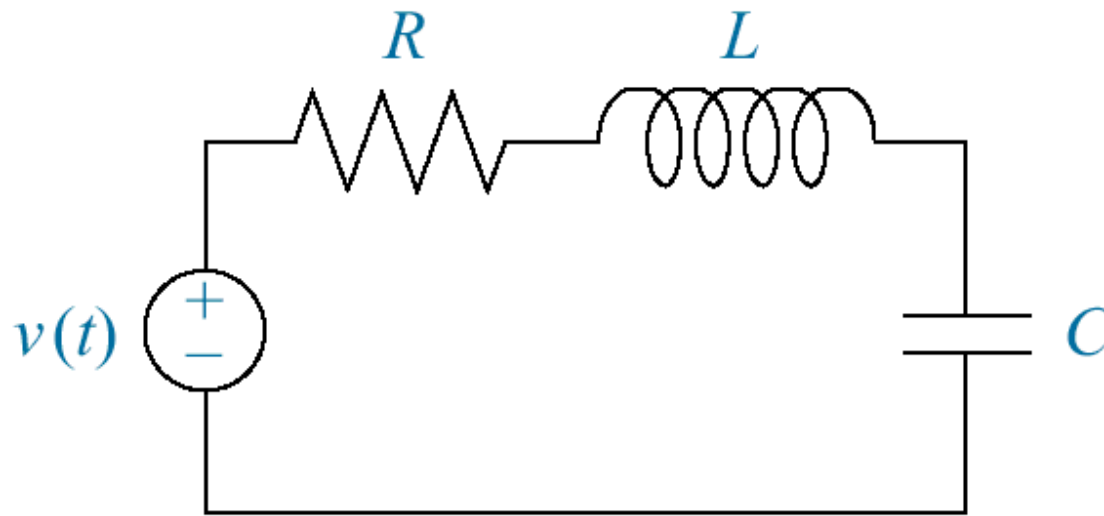
# Fig. P4.16



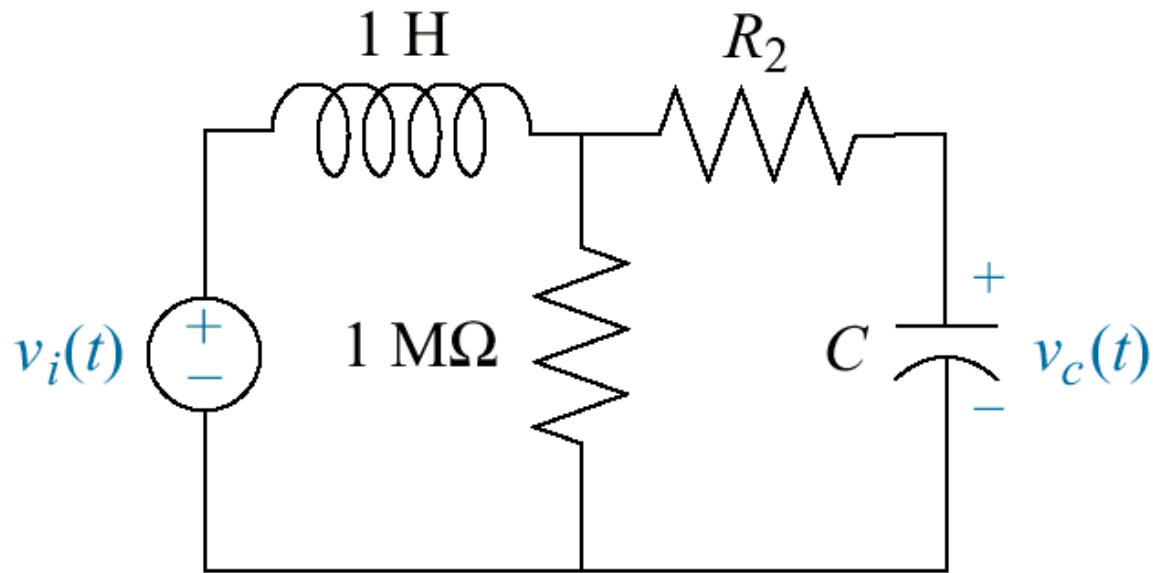
# Fig. P4.17



**Fig. P4.18**

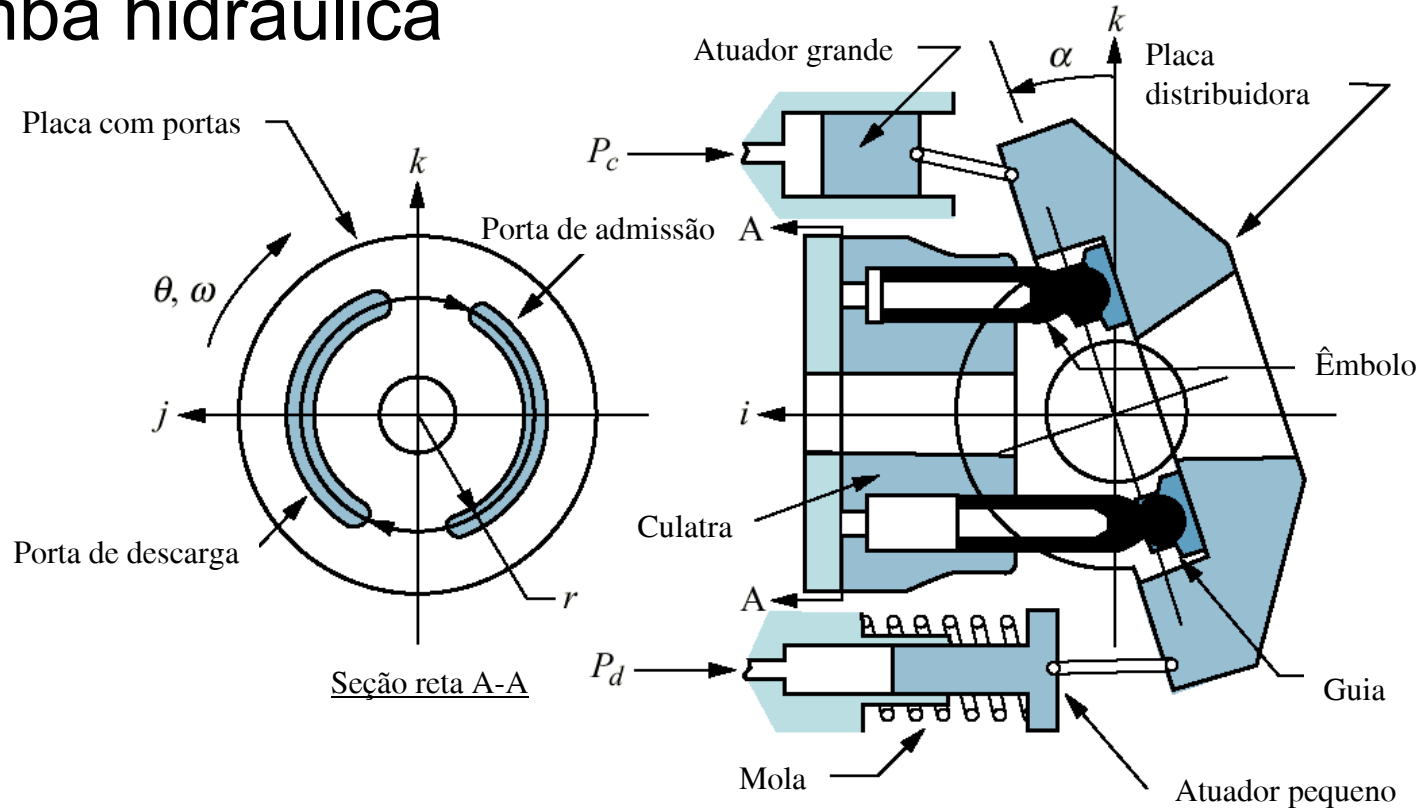




**Fig. P4.19**

# Fig. P4.20

## Diagrama de uma bomba hidráulica



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