

● 블록선도(block diagram)

실제 물리 시스템의 각 요소가 서로 어떻게 연관을 가지며 전 시스템의 성능에 어떻게 영향을 미치는가를 도식적으로 나타낸 선도.

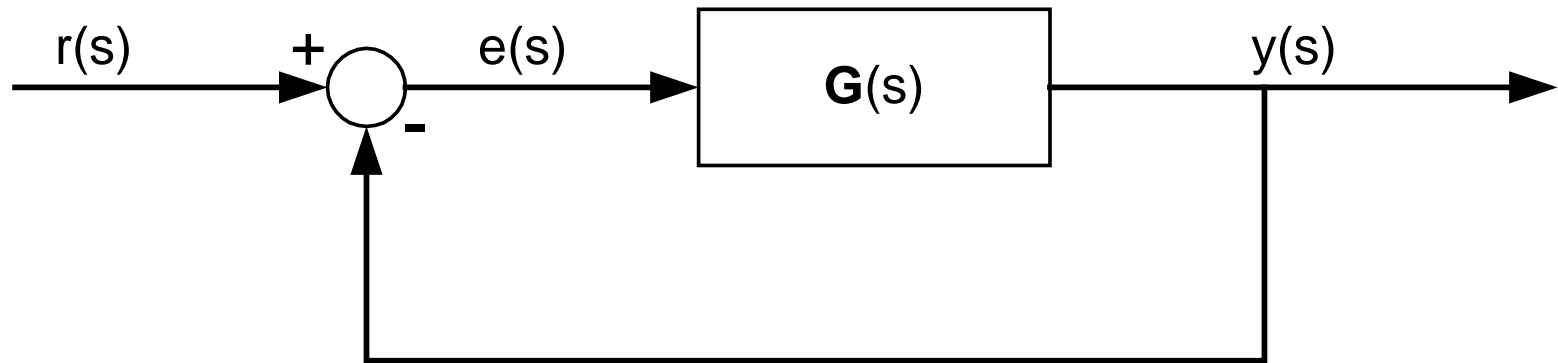


그림 2.6 폐루프 시스템의 블록선도

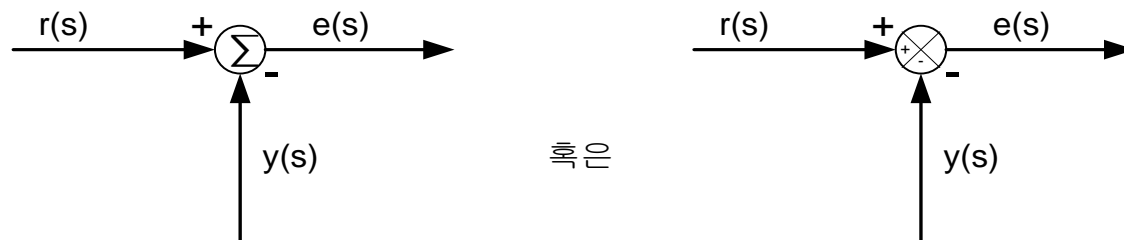


그림 2.7 블록선도에서 합산기호의 다른 표현방법

- 블록선도에 곱셈 연산이나 나눗셈 연산의 표시

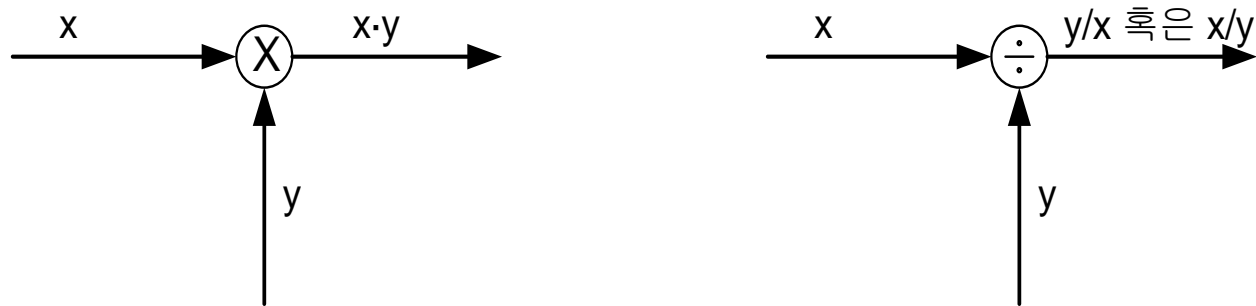


그림 2.8 블록선도에서 곱셈 및 나눗셈 연산의 표현방법

- 입력 및 출력의 개수가 2개 이상인 다변수 시스템

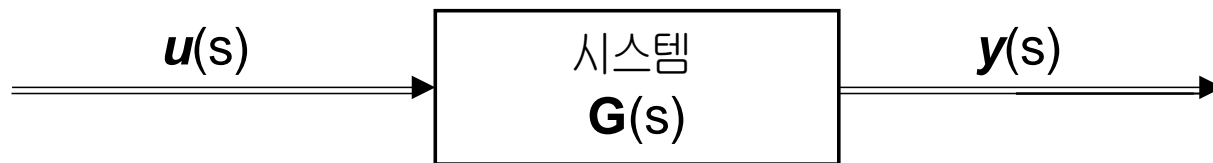


그림 2.9 다변수 시스템의 블록선도

● 피드백 제어시스템의 입출력 전달함수

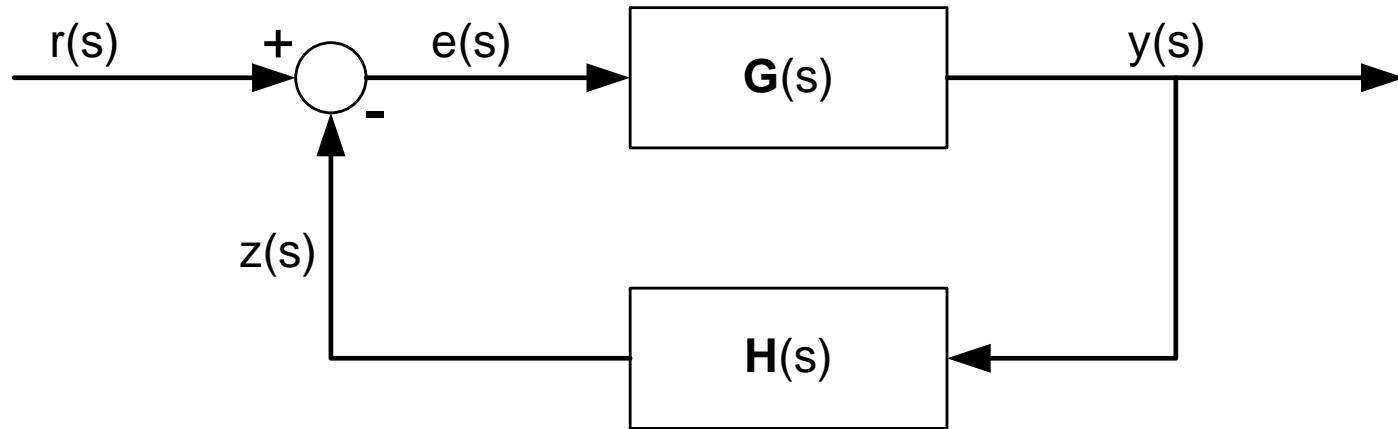


그림 2.11 피드백 제어시스템

제어입력 $u(s)$ 는

$$\begin{aligned} e(s) &= r(s) - z(s) \\ &= r(s) - H(s)y(s) \end{aligned} \quad (2.57)$$

출력 $y(s)$ 와 제어입력 $u(s)$ 사이의 관계식은

$$y(s) = G(s)e(s) \quad (2.58)$$

식 (2.57)을 식 (2.58)에 대입함으로써 전달함수 $T(s)$ 는

$$T(s) = \frac{y(s)}{r(s)} = \frac{G(s)}{1 + G(s)H(s)} \quad (2.59)$$

$H(s) = 1$ 인 경우 : 단위 피드백 제어시스템

● 등가의 단위 피드백 제어시스템으로 변환

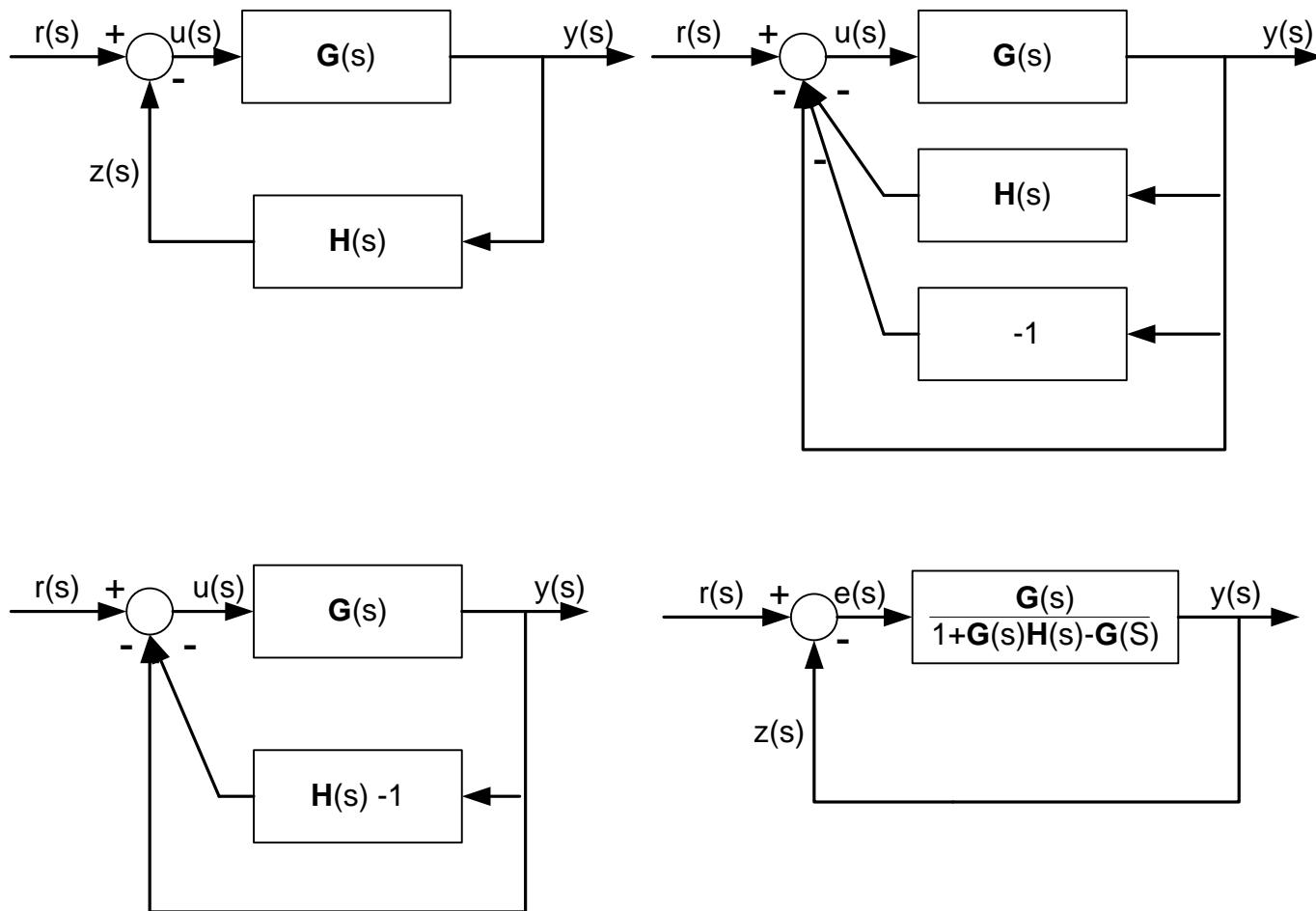


그림 2.12 비단위 피드백 제어시스템과 이와 등가인 단위 피드백 제어시스템

[예제 2.12] 다음과 같은 다루프 피드백 제어시스템의 블록선도를 간략화하여 폐루프 전달함수 $T(s)$ 는?

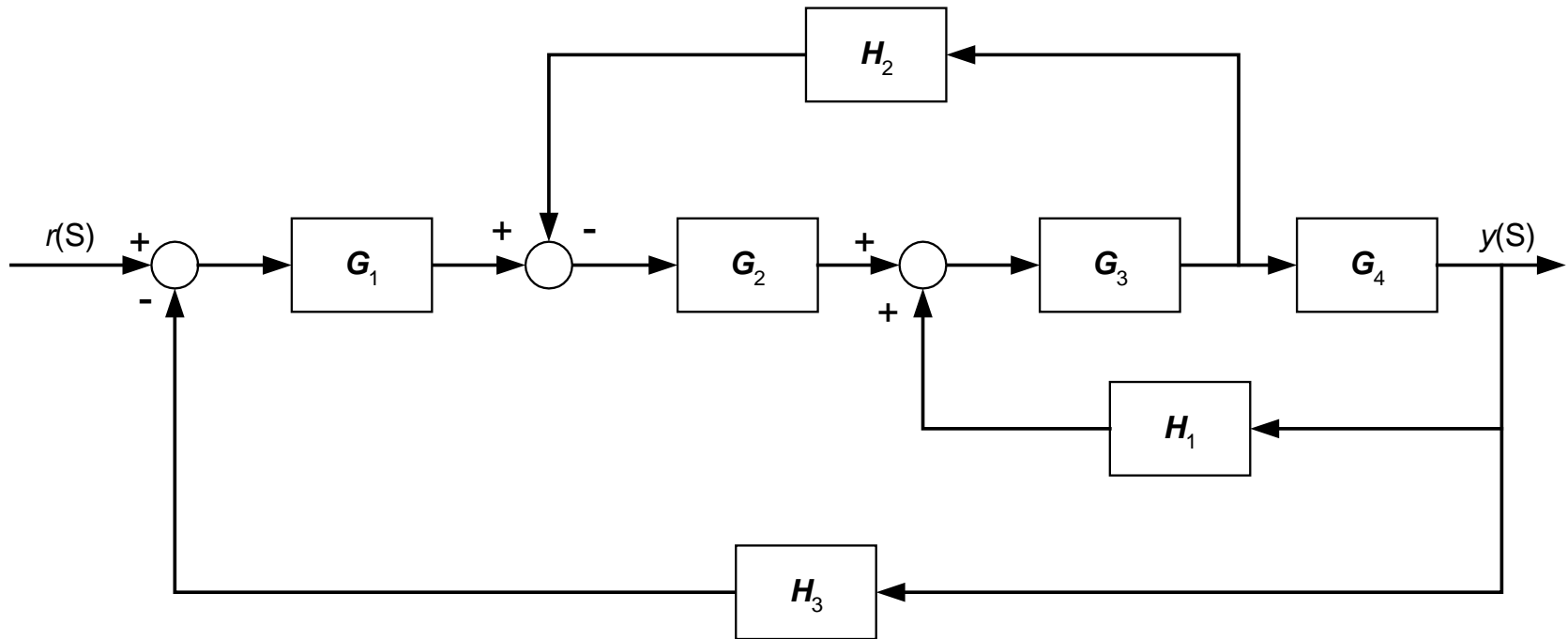
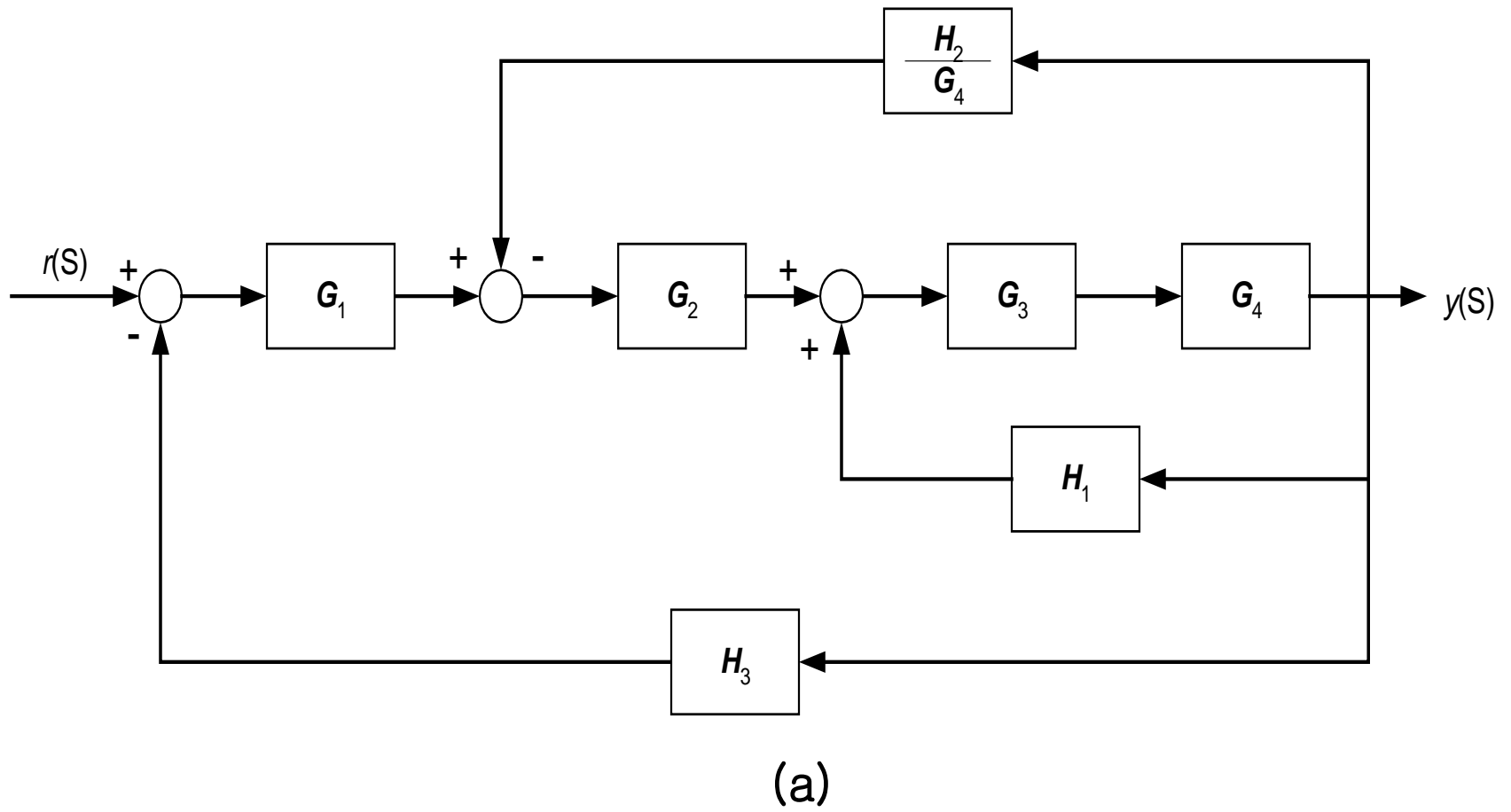
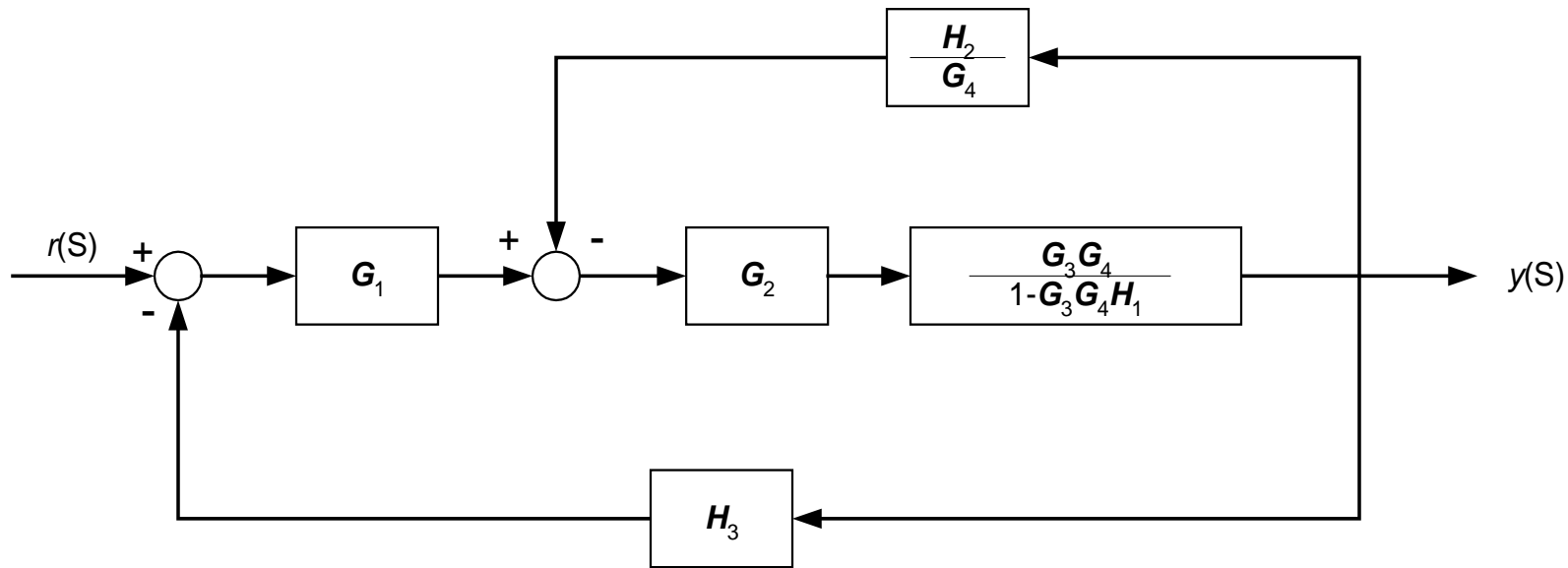


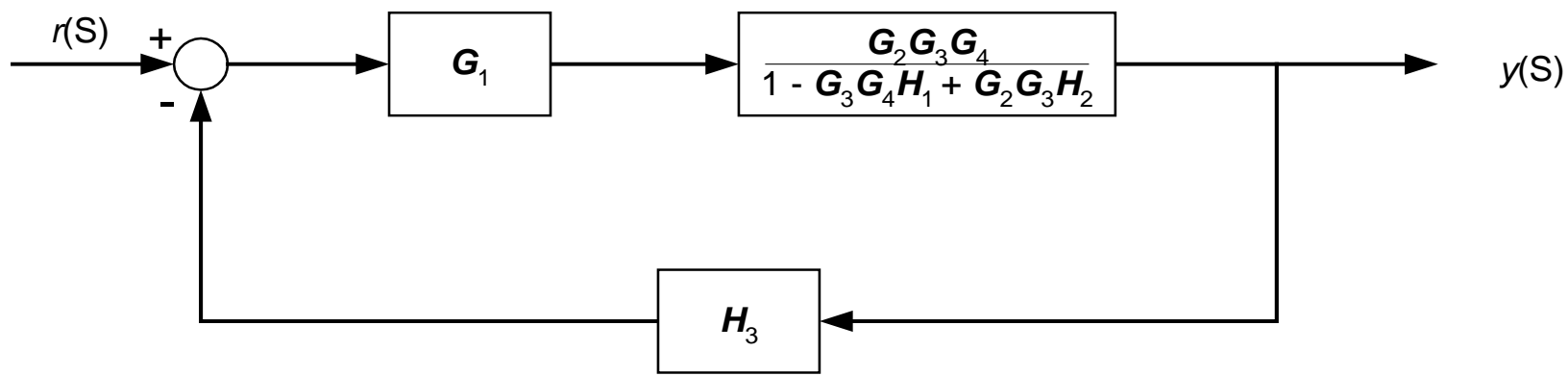
그림 2.15 다루프 피드백 제어시스템

(Sol)





(b)



(c)

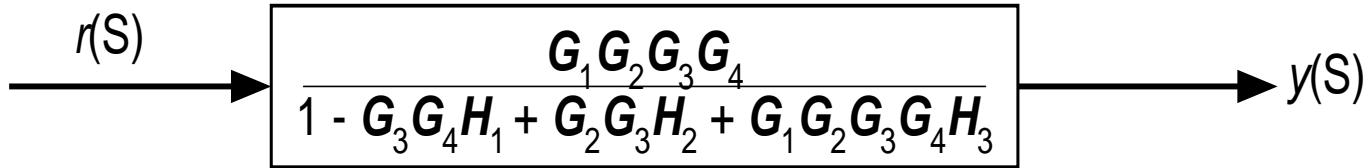


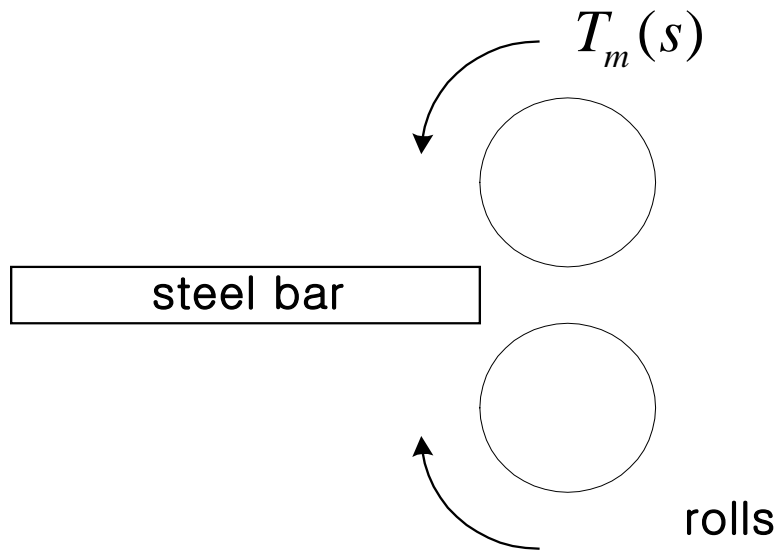
그림 2.16 그림 2.15의 피드백 제어시스템에 대한 블록선도의 간략화

따라서 폐루프 전달함수 $T(s)$ 는

$$T(s) = \frac{G_1 G_2 G_3 G_4}{1 - G_3 G_4 H_1 + G_2 G_3 H_2 + G_1 G_2 G_3 G_4 H_3}$$

* *Disturbance signals in Feedback Control systems*

Example: steel rolling mill

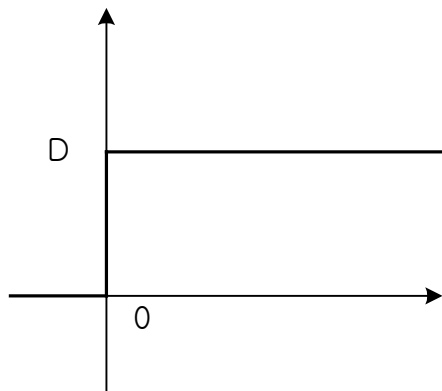


$$T_m(s) = T_L(s) + T_d(s)$$

* *Steel passing through the rolls produces a large load change (disturbance)*

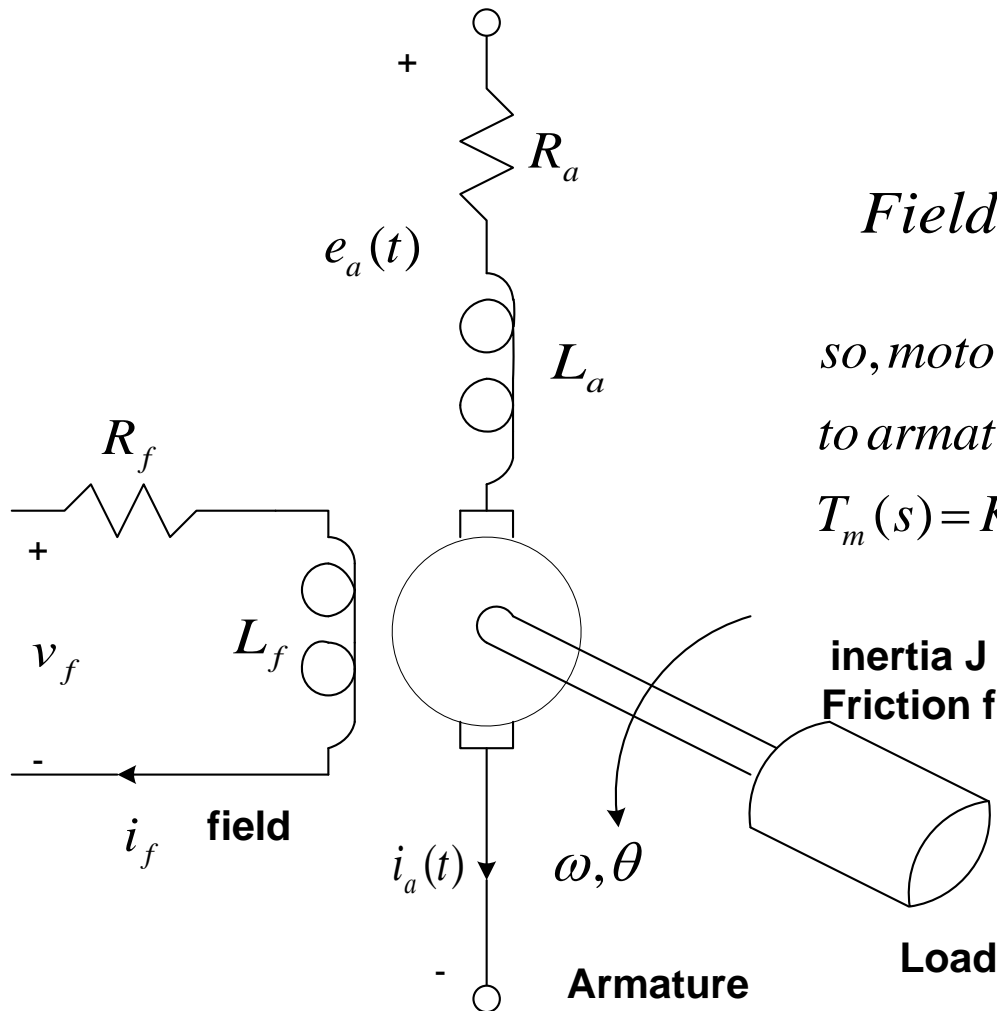
Approximate the load change by a step change in disturbance torque;

i.e. $T_d = \frac{D}{s}$, *D: the magnitude of the step change*



Typically, an armature-controlled D.C motor might be used to drive the rollers.

Recall : Armature-Controller D.C motor



Field Current i_f is constant

*so, motor torque T_m is proportional
to armature current i_a ; i.e.*

$$T_m(s) = K_t I_a(s) \quad (1)$$

Armature currents is in turn related to armature voltage

$$E_a(s);$$

$$\text{i.e. } E_a(s) = (L_a s + R_a) I_a(s) + V_b(s) = V_m(s) + V_b(s) \quad (2)$$

where $V_b(s)$ is the back emf (electromotive force) and is proportional to motor speed

$$\text{i.e. } V_b(s) = K_b \omega(s) \quad (3)$$

so, from (2) and (3)

$$I_a(s) = \frac{E_a(s) - K_b \omega(s)}{(L_a s + R_a)} \quad (4)$$

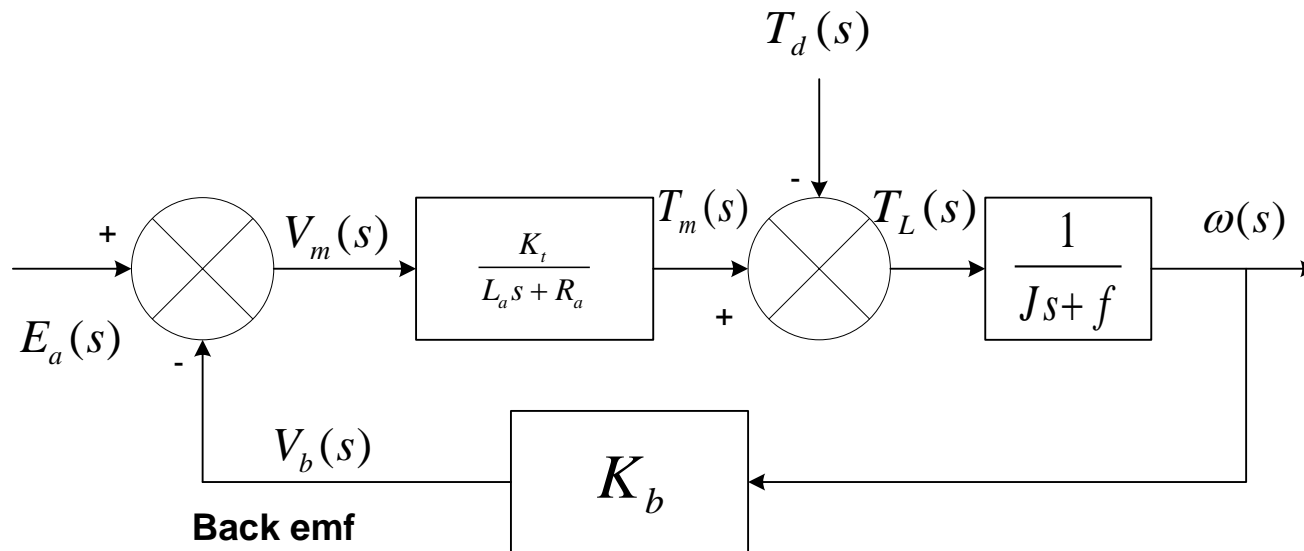
Now, the load torque $T_L(s)$ is

$$\begin{aligned} T_L(s) &= s^2 J \theta(s) + s f \theta(s) = T_m(s) - T_d(s) \\ &= J s \omega(s) + f \omega(s) \end{aligned} \quad (5)$$

so, the armature – controlled DC motor takes the following form

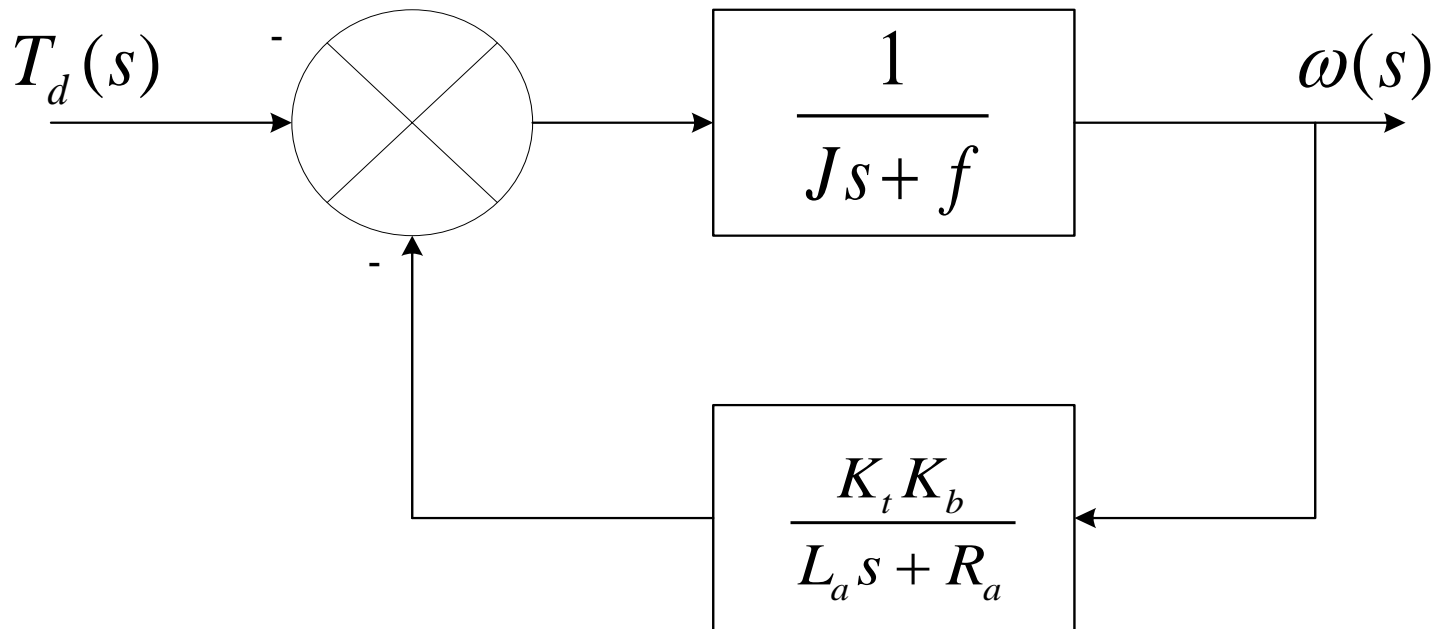
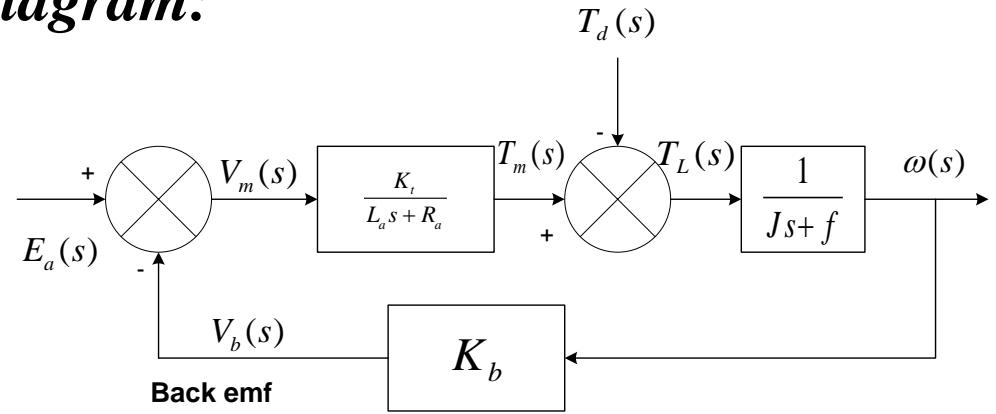
$$T_m(s) = K_t I_a(s) = K_t \frac{E_a(s) - K_b \omega(s)}{(L_a s + R_a)}$$

$$T_L(s) = T_m(s) - T_d(s) = s^2 J \theta(s) + s f \theta(s) = J s \omega(s) + f \omega(s)$$



The transfer function for load torque disturbance can be obtained by reducing the block diagram:

Assume $E_a(s) = 0$



$$\text{Thus, } \frac{\omega(s)}{T_d(s)} = - \frac{\frac{1}{Js + f}}{1 + \frac{K_t K_b}{L_a s + R_a} \frac{1}{Js + f}} = - \frac{1}{Js + f + \frac{K_t K_b}{L_a s + R_a}}$$

It is customary to neglect L_a , so

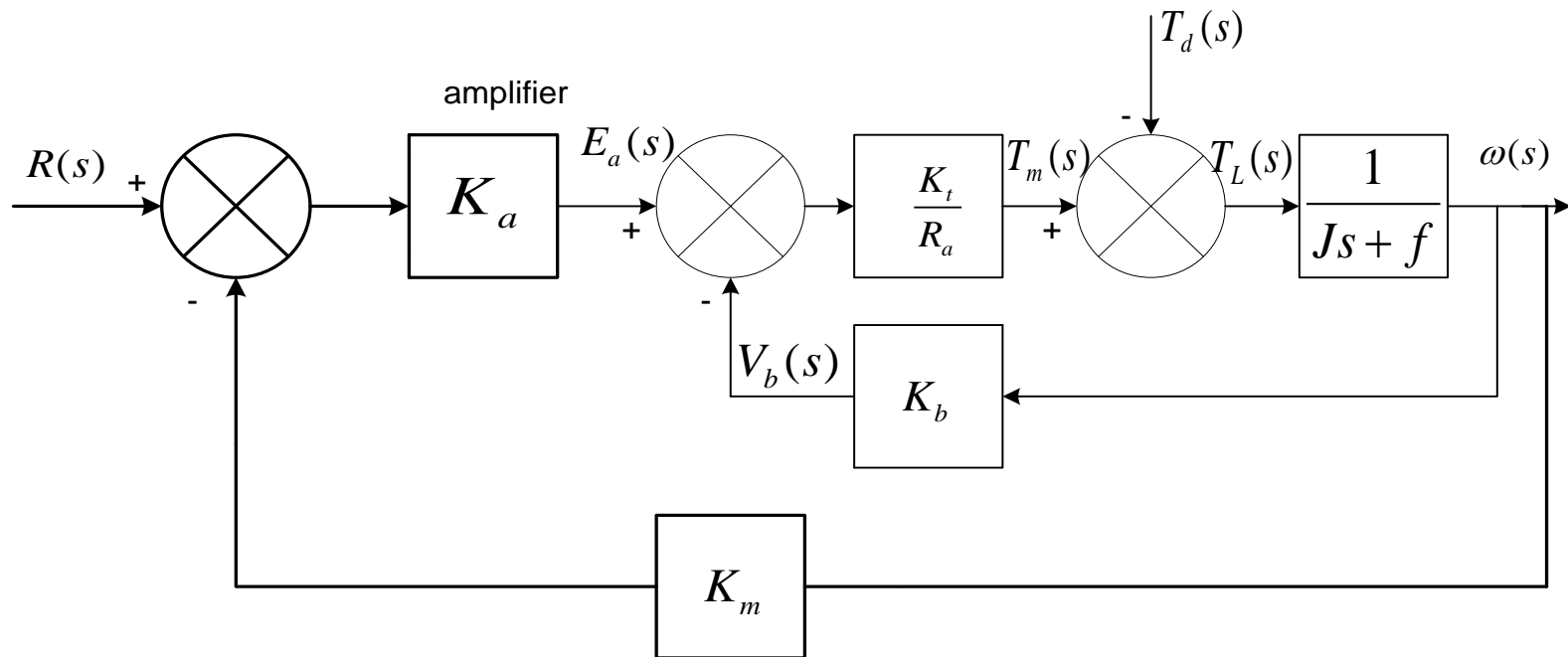
$$\frac{\omega(s)}{T_d(s)} = - \frac{1}{Js + f + \frac{K_t K_b}{R_a}}$$

The steady – state speed error due to $T_d(s) = \frac{D}{s}$ is then

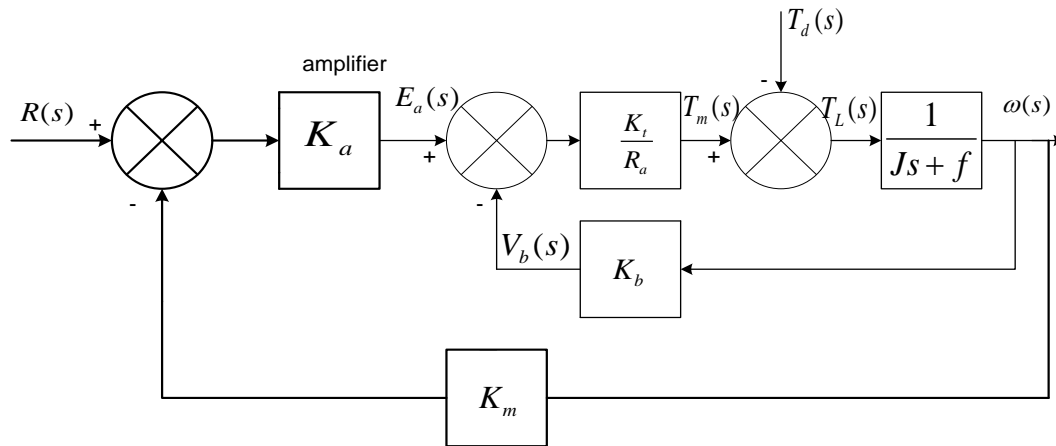
$$\begin{aligned} \lim_{t \rightarrow \infty} \omega(t) &= \lim_{s \rightarrow 0} s \omega(s) = \lim_{s \rightarrow 0} s \left[\frac{-1}{Js + f + \frac{K_t K_b}{R_a}} \right] \left(\frac{D}{s} \right) \\ &= \frac{-D}{f + \frac{K_t K_b}{R_a}} \end{aligned}$$

Now, consider a closed – loop control system where a Tachometer is used as the measuring element, and where the controller is an amplifier of gain K_a

The block diagram for the closed-loop system is



The block diagram for the closed-loop system is



The output speed resulting from a load disturbance $T_d(s)$ can be obtained by block reduction:

Let $R(s)=0$

$$i.e. \frac{\omega(s)}{T_d(s)} = - \frac{\frac{1}{Js + f}}{1 + \left(\frac{1}{Js + f} \right) \left(\frac{(K_m K_a + K_b) K_t}{R_a} \right)}$$

$$= \frac{-1}{Js + f + (K_m K_a + K_b) \left(\frac{K_t}{R_a} \right)}$$

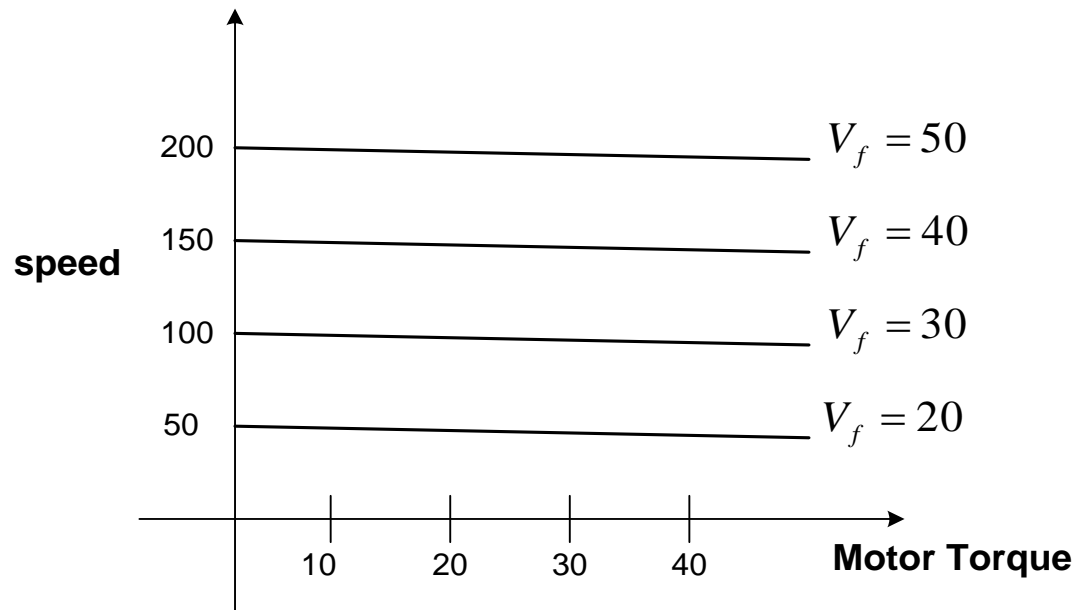
so, in the steady - state, for $T_d(s) = \frac{D}{s}$

$$\begin{aligned} \lim_{t \rightarrow \infty} \omega(t) &= \lim_{s \rightarrow 0} s \omega(s) = \lim_{s \rightarrow 0} s \left[\frac{-1}{Js + f + (K_m K_a + K_b) \left(\frac{K_t}{R_a} \right)} \right] \left(\frac{D}{s} \right) \\ &= \frac{-D}{f + (K_m K_a + K_b) \left(\frac{K_t}{R_a} \right)} \end{aligned}$$

Thus, for large K_a

$$\omega(\infty) \cong - \frac{R_a}{K_t K_m K_a} D$$

If we were to plot a typical set of speed vs. torque curves for the closed – loop system, we might get



The near – horizontal curves indicate that speed is essentially independent of disturbance torque.

Home Work #5 (Due date: one week from today)

5. Solve Problem 16(16) on page 281(283) in the text book 7th ed

*(6th edition)

6. Solve Problem 19(19) on page 282(283) in the text book.