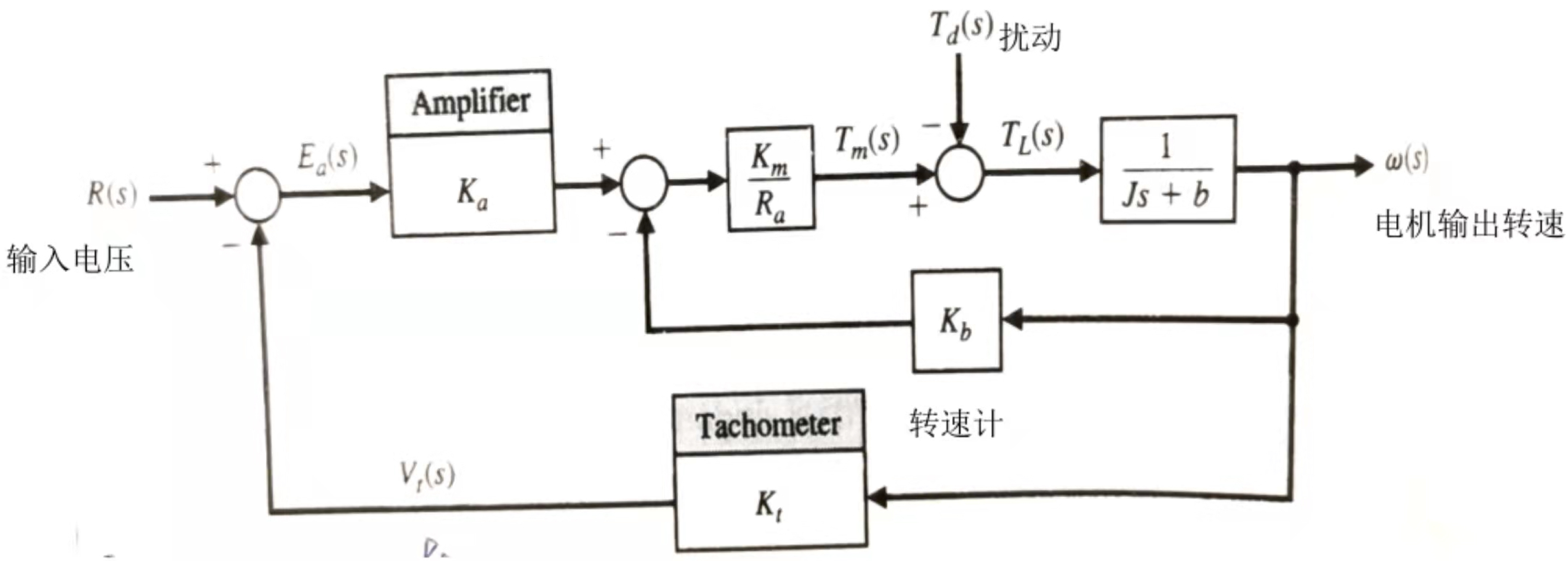
上机实验1：开环系统和闭环系统的抗扰动性能对比

电机转速控制系统框图和参数表如下，



Ra	Km	J	b	Kb	Ka	Kt
1	10	2	0.5	0.1	54	1

实验目的： 设输入电压为0时，扰动信号为Td(s)=1/s，分别比较在无转速计开环控制状态下和有转速计闭环控制状态下电机输出转速稳定误差。

Tachometer Control System Parameters

K_m	J	b	K_b	K_a	K_t
10	2	0.5	0.1	54	1

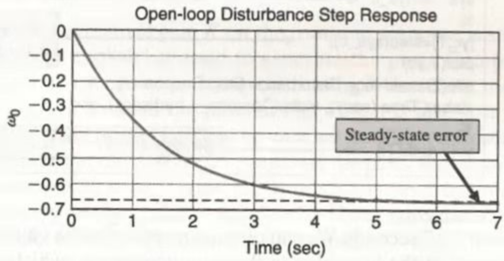
If our system displays good disturbance rejection, then we expect the disturbance $T_d(s)$ to have a small effect on the output $\omega(s)$. Consider the open-loop system in Fig. 4.11 first. We can use MATLAB to compute the transfer function from $T_d(s)$ to $\omega(s)$ and evaluate the output response to a unit step disturbance (that is, $T_d(s) = 1/s$). The time response to a unit step disturbance is shown in Fig. 4.27(a). The script opentach.m, shown in Fig. 4.27(b), is used to analyze the open-loop speed tachometer system.

The open-loop transfer function is

$$\frac{\omega(s)}{T_d(s)} = \frac{-1}{2s + 1.5} = \text{sys\_o},$$

where sys_o represents the open-loop transfer function in the MATLAB script. Since our desired value of $\omega(t)$ is zero (remember that $V_a(s) = 0$), the steady-state error is just the final value of $\omega(t)$, which we denote by $\omega_o(t)$ to indicate open-loop. The steady-state error, shown on the plot in Fig. 4.27(a), is approximately the value of the speed

(a)



(b)

opentach.m

```
%Speed Tachometer Example
%
Ra=1; Km=10; J=2;b=0.5; Kb=0.1;
num1=[1]; den1=[J,b]; sys1=tf(num1,den1);
num2=[Km*Kb/Ra]; den2=[1]; sys2=tf(num2,den2);
sys_o=feedback(sys1,sys2);
%
sys_o=-sys_o
%
[yo,T]=step(sys_o);
plot(T,yo)
title('Open-loop Disturbance Step Response')
xlabel('Time (sec)'),ylabel('\omega_o'), grid
%
yo(length(T))
```

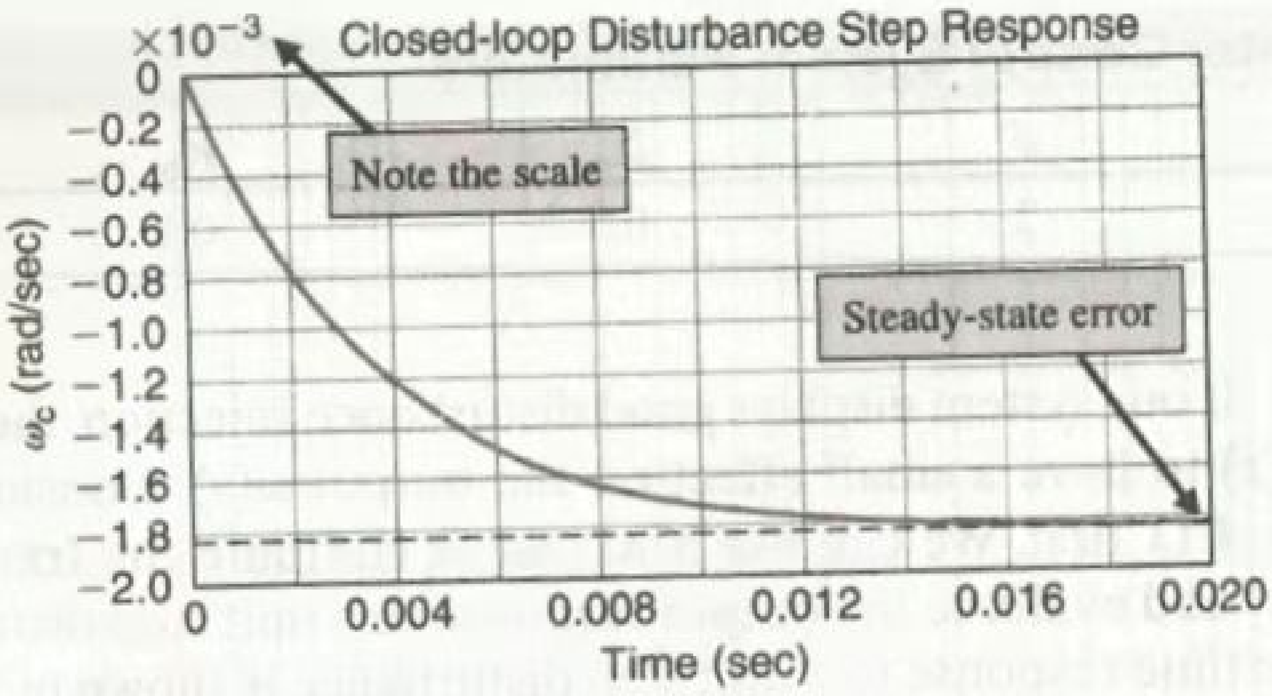
Change sign of transfer function since the disturbance has negative sign in the diagram.

Compute response to step disturbance.

Steady-state error → last value of output yo.

...RE 4.27 ...s of the ...-loop speed ...l system. ...esponse and ... script.

(a)



(b)

closedtach.m

```
%Speed Tachometer Example
%
Ra=1;  Km=10; J=2; b=0.5; Kb=0.1; Ka=54; Kt=1;
num1=[1]; den1=[J,b]; sys1=tf(num1,den1);
num2=[Ka*Kt]; den2=[1]; sys2=tf(num2,den2);
num3=[Kb]; den3=[1]; sys3=tf(num3,den3);
num4=[Km/Ra]; den4=[1]; sys4=tf(num4,den4);
sysa=parallel(sys2,sys3);
sysb=series(sysa,sys4);
sys_c=feedback(sys1,sysb);
%
sys_c=-sys_c
%
[yc,T]=step(sys_c);
plot(T,yc)
title('Closed-loop Disturbance Step Response')
xlabel('Time (sec)'), ylabel('\omega_c (rad/sec)'), grid
%
yc(length(T))
```

Block diagram reduction

Change sign of transfer function since the disturbance has negative sign in the diagram.

Compute response to step disturbance.

Steady-state error → last value of output yc.

FIGURE 4.28 Analysis of the closed-loop speed control system. (a) Response and (b) MATLAB script.

when $t = 7$ seconds. We can obtain an approximate value of the steady-state err[...] looking at the last value in the output vector $\mathbf{y}_o$, which we computed in the pr[...] of generating the plot in Fig. 4.27(a). The approximate steady-state value of ω_o [...]

$$\omega_o(\infty) \approx \omega_o(7) = -0.66 \text{ rad/s}.$$

The plot verifies that we have in fact reached steady state.

In a similar fashion, we begin the closed-loop system analysis by computin[g the] closed-loop transfer function from $T_d(s)$ to $\omega(s)$ and then generating the tim[e re]sponse of $\omega(t)$ to a unit step disturbance input. The output response and the scr[ipt] cltach.m are shown in Fig. 4.28. The closed-loop transfer function from the dis[tur]bance input is

$$\frac{\omega(s)}{T_d(s)} = \frac{-1}{2s + 541.5} = \text{sys\_c}.$$

As before, the steady-state error is just the final value of $\omega(t)$, which we denote by [...] to indicate closed-loop. The steady-state error is shown on the plot in Fig. 4.28(a)[...]

can obtain an approximate value of the steady-state error by looking at the last value in the output vector $\mathbf{y}_c$, which we computed in the process of generating the plot in Fig. 4.28(a). The approximate steady-state value of ω is

$$\omega_c(\infty) \approx \omega_c(0.02) = -0.002 \text{ rad/s}.$$

We generally expect that $\omega_c(\infty)/\omega_o(\infty) < 0.02$. The ratio of closed-loop to open-loop steady-state speed output due to a unit step disturbance input, in this example, is

$$\frac{\omega_c(\infty)}{\omega_o(\infty)} = 0.003.$$

We have achieved a remarkable improvement in disturbance rejection. It is clear that the addition of the negative feedback loop reduced the effect of the disturbance on the output. This demonstrates the **disturbance rejection property** of closed-loop feedback systems. ■