Robotics

Lecture 12

Control

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http://www.aast.edu/cv.php?disp_unit=346&ser=68525

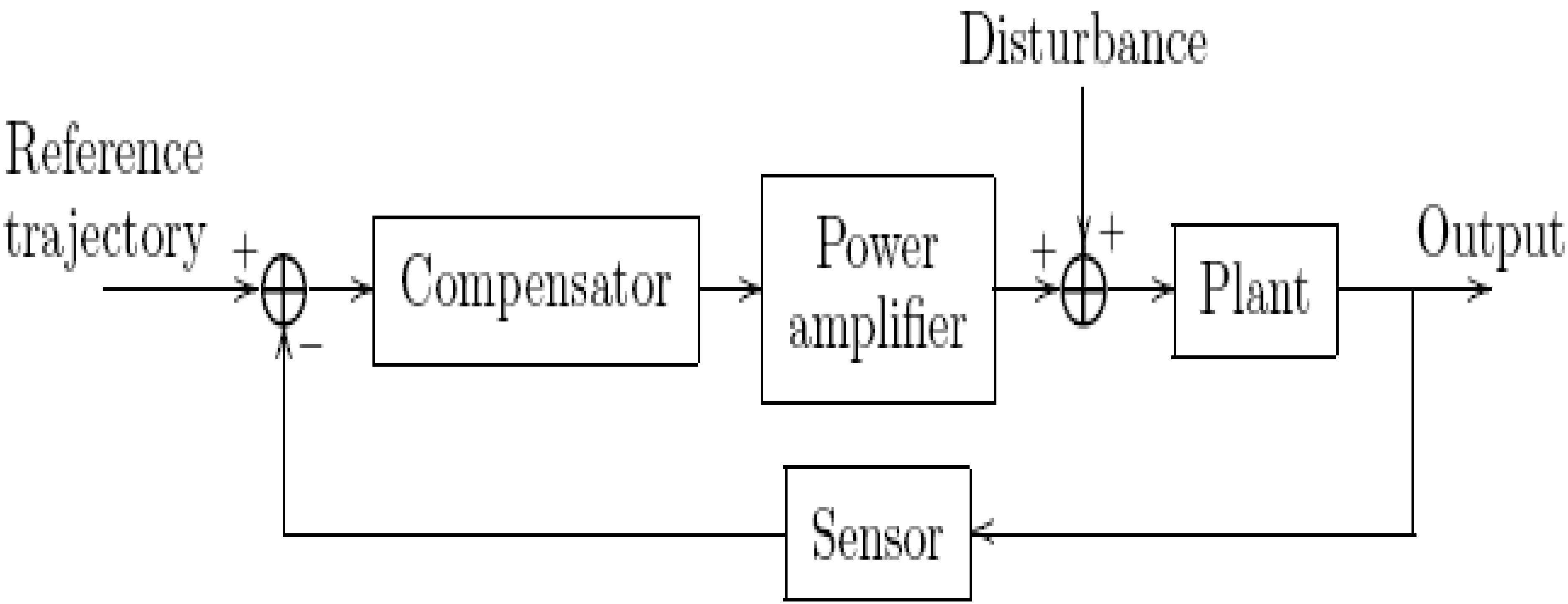
- Using inverse kinematics, we can calculate the joint kinematics for a desired geometric path of the end-effector of a robot.
- Substitution of the joint kinematics in equations of motion provides the ***actuator commands***.
- Applying the commands will move the end-effector of the robot on the desired path ***ideally***.
- However, because of perturbations and non-modeled phenomena, the robot will not follow the desired path.
- The techniques that minimize or remove the difference are called the ***control techniques***.

- There are many control techniques and methodologies that can be applied to the control of manipulators.

- In this lecture we consider the simplest type of control strategy, namely, independent joint control.

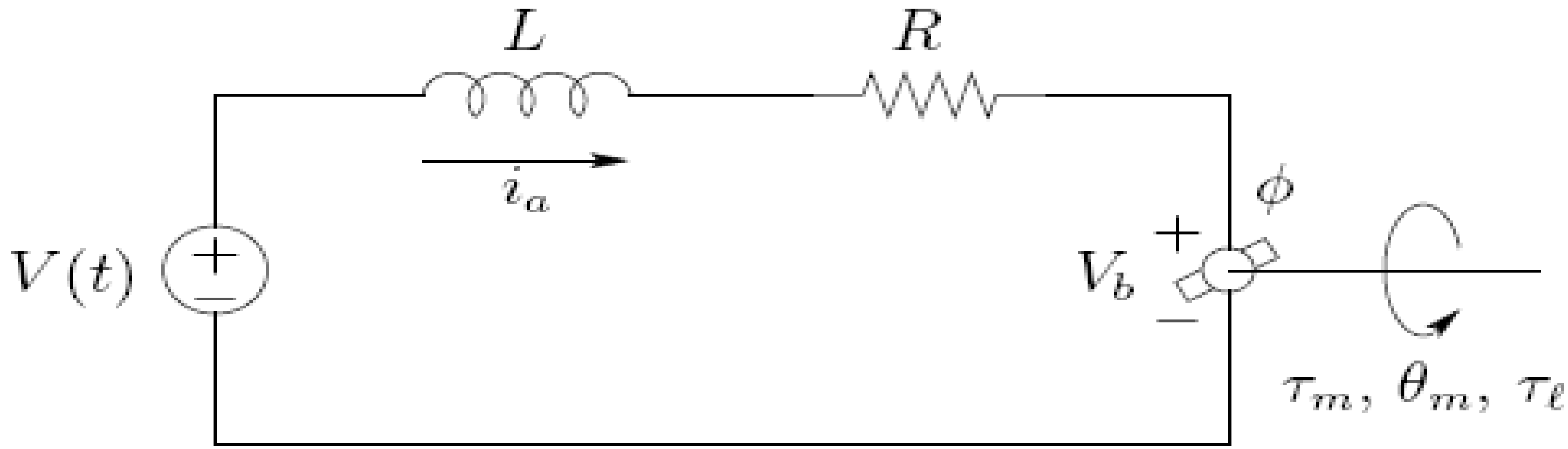
- In this type of control each axis of the manipulator is controlled as a single input/single-output (SISO) system.

- Any coupling effects due to the motion of the other links is treated as a disturbance.

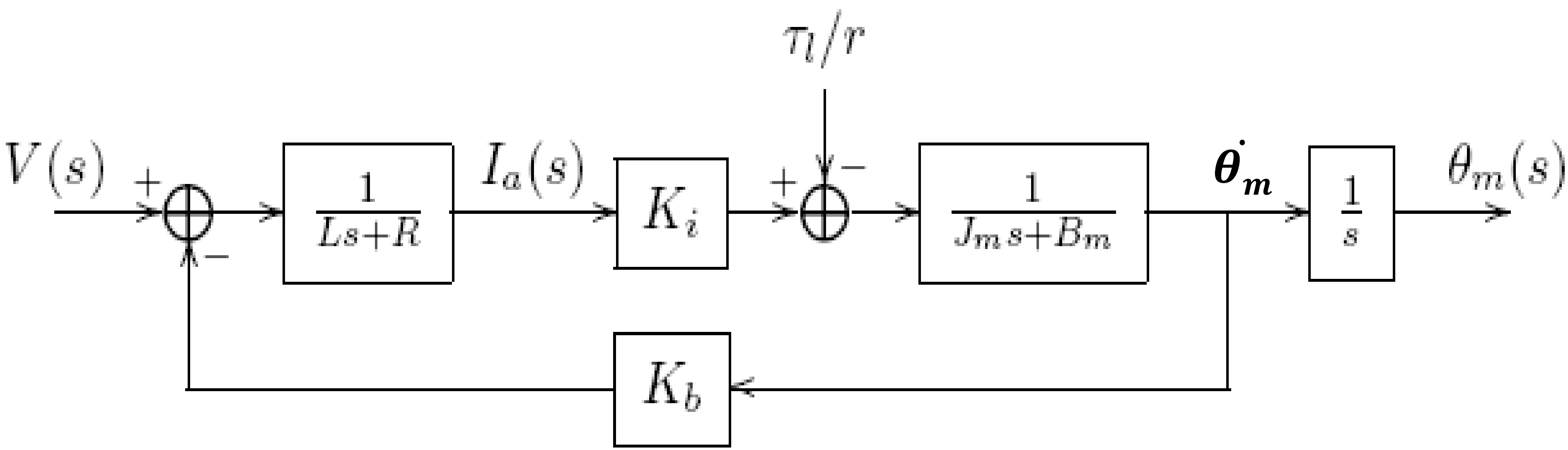

Disturbance
Reference
trajectory
+
−
Compensator
Power
amplifier
+
+
Plant
Output
Sensor

Independent Joint Control

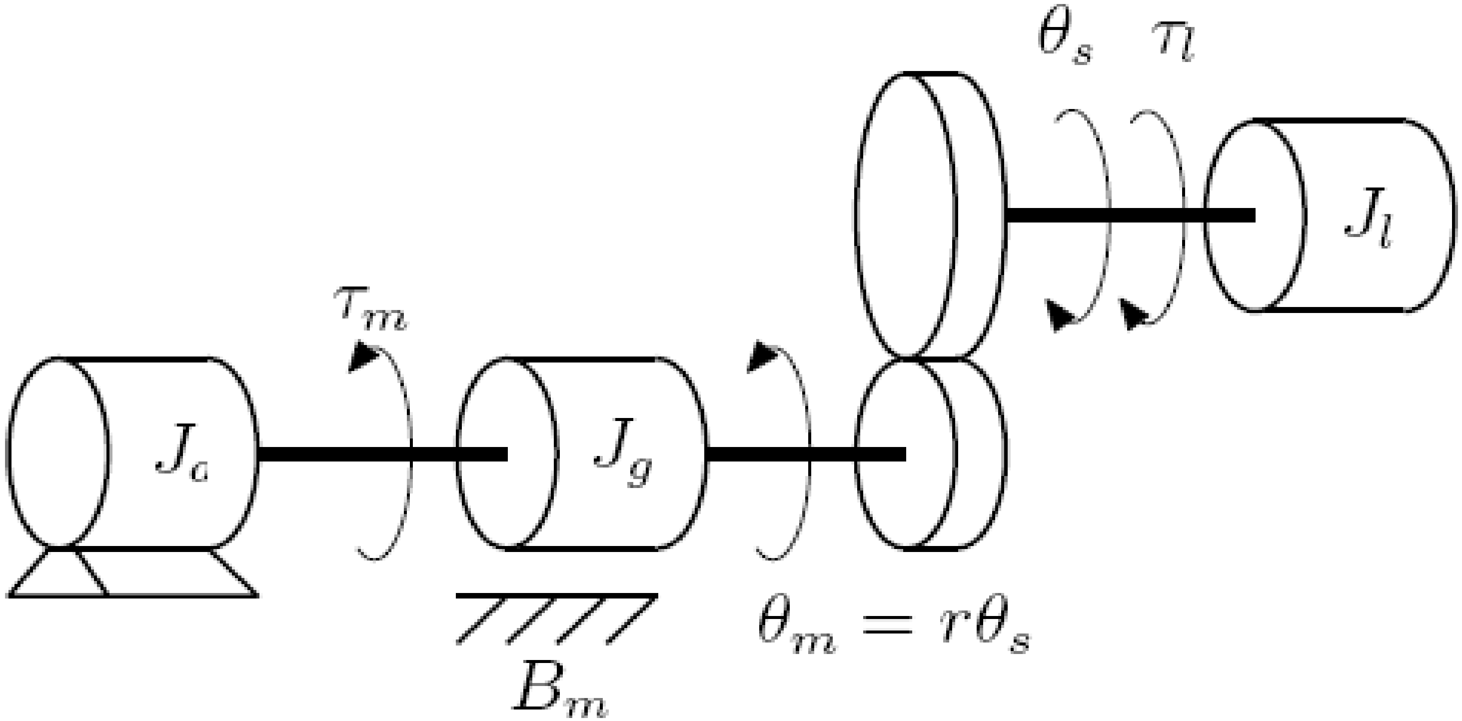
- We will consider the dynamics of permanent magnet DC-motors, as these are common for use in present-day robots.

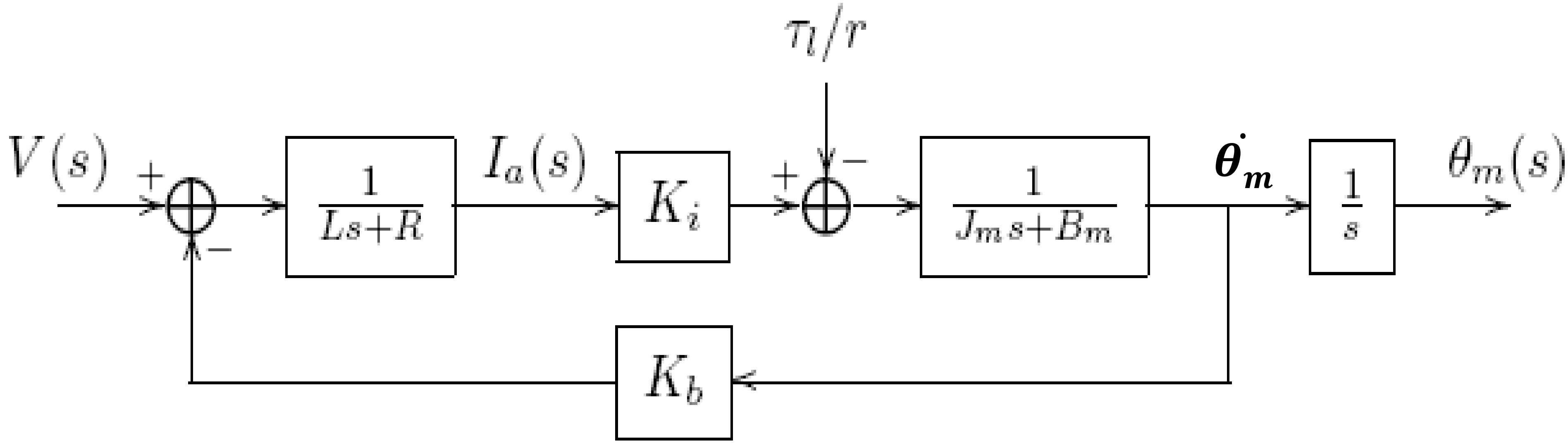


Circuit diagram for armature controlled DC motor

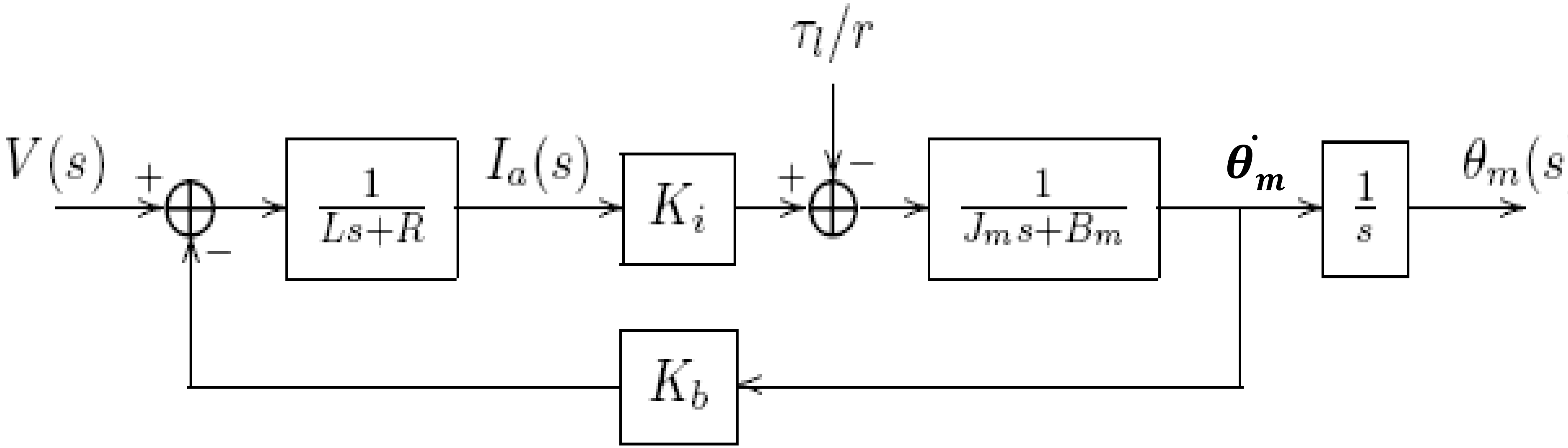


Block diagram for a DC motor system


θ_s
τ_l
J_l
τ_m
J_c
J_g
$\theta_m = r\theta_s$
B_m



$$
\begin{aligned}
V &= \text{armature voltage} \\
L &= \text{armature inductance} \\
R &= \text{armature resistance} \\
V_b &= \text{back emf} \\
i_a &= \text{armature current} \\
\theta_m &= \text{rotor position (radians)} \\
\tau_m &= \text{generated torque} \\
\tau_\ell &= \text{load torque} \\
\phi &= \text{magnetic flux due to stator}
\end{aligned}
$$



$V(s)$ to $\Theta_m(s)$ is then given by (with $\tau_\ell = 0$)

$$\frac{\Theta_m(s)}{V(s)} = \frac{K_m}{s\left[(Ls+R)(J_m s + B_m) + K_b K_m\right]}.$$

The transfer function from the load torque τ_ℓ/r to Θ_m is given by (with $V = 0$)

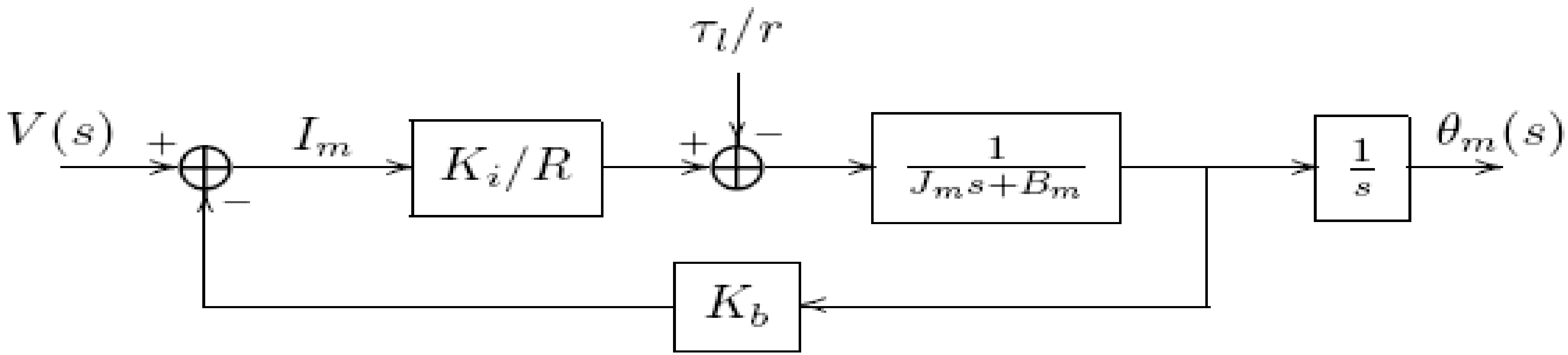
$$\frac{\Theta_m(s)}{\tau_\ell(s)} = \frac{-(Ls+R)}{s\left[(Ls+R)(J_m s + B_m) + K_b K_m\right]}.$$

- it is assumed that the "electrical time constant" L/R is much smaller than the "mechanical time constant" J_m/B_m.
- This is a reasonable assumption for many electromechanical systems and leads to a reduced order model of the actuator dynamics.

$$\frac{\Theta_m(s)}{V(s)} = \frac{K_m/R}{s(J_m s + B_m + K_b K_m/R)} \quad \text{with } \tau_l = 0$$

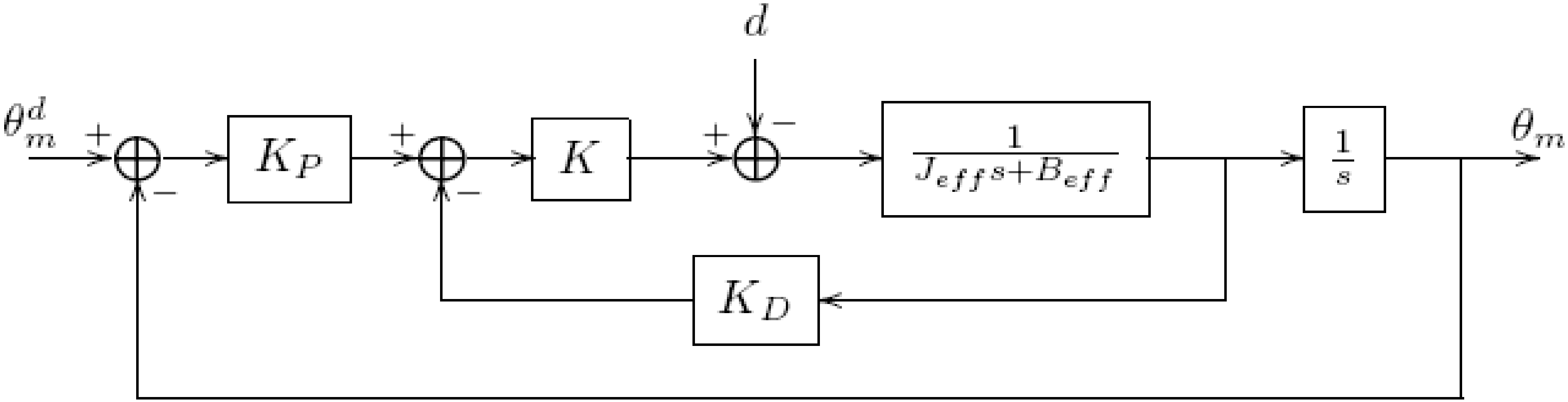
$$\frac{\Theta_m(s)}{\tau_\ell(s)} = -\frac{1}{s(J_m(s) + B_m + K_b K_m/R)} \quad \text{with } V = 0$$

- The block diagram corresponding to the reduced order system is:



Block diagram for reduced order system

PD Compensator



Closed loop system with PD-control

The gains K_D and K_p can be found from the following characteristic equation

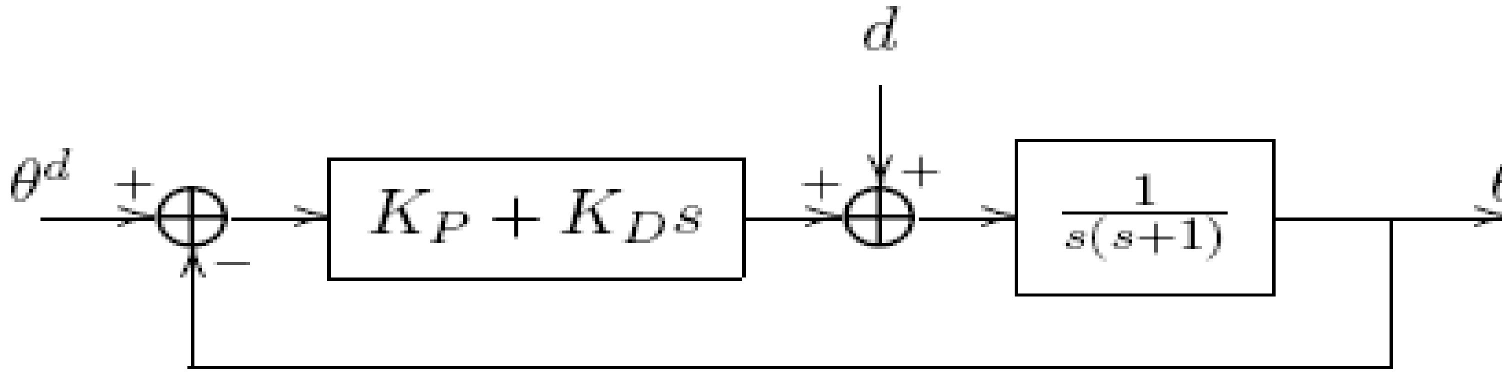
$$s^2 + \frac{(B_{eff} + KK_D)}{J_{eff}}s + \frac{KK_p}{J_{eff}} = s^2 + 2\zeta\omega s + \omega^2$$

$$K_p = \frac{\omega^2 J_{eff}}{K}, \qquad K_D = \frac{2\zeta\omega J_{eff} - B_{eff}}{K}.$$

Take $\zeta = 1$ so that the response is critically damped. This produces the fastest non-oscillatory response. In this context ω determines the speed of response.

Example

- Consider the second order system of the following figure.



- The closed loop characteristic polynomial is

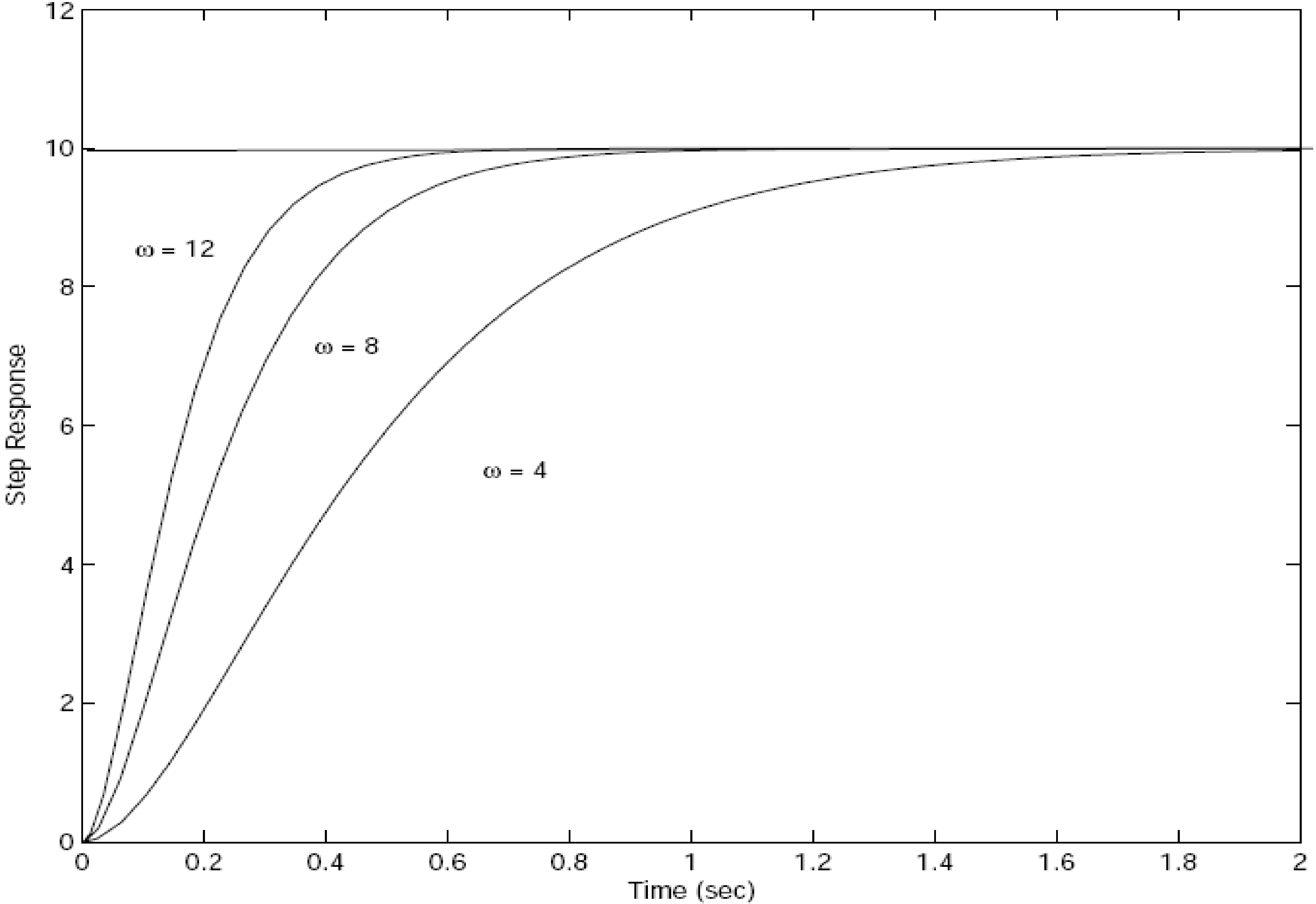
$$p(s) = s^2 + (1 + KD)s + Kp$$

- Suppose θ^d = 10 and there is no disturbance (d = 0). With ζ = 1,

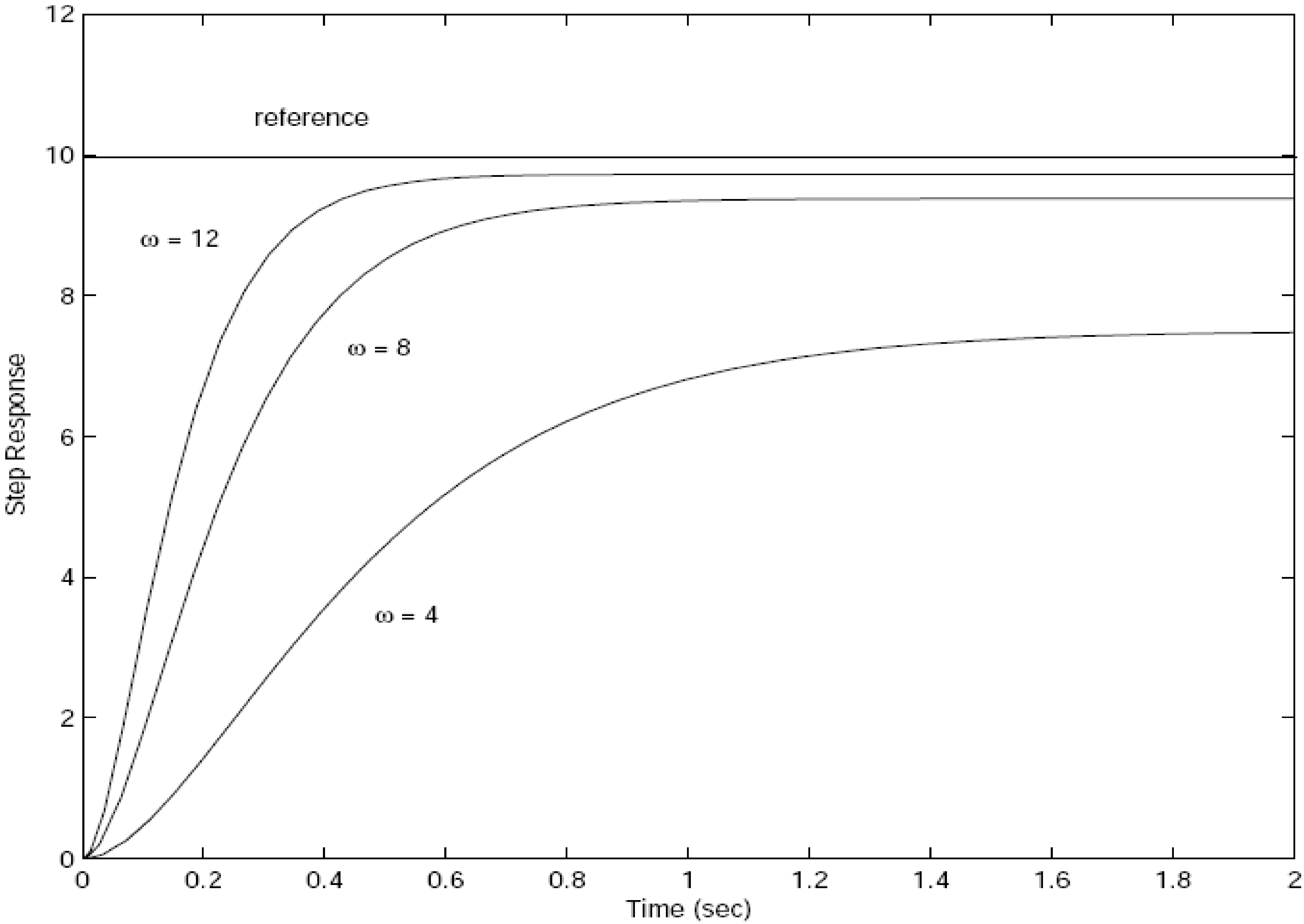
- Suppose $\theta^d = 10$ and there is no disturbance (d = 0). With $\zeta = 1$,
- the required PD gains for various values of ω are shown in as:

ω	K_P	K_D
4	16	7
8	64	15
12	144	23

- The corresponding step responses are:



If a constant disturbance d = 40, the corresponding step responses are:



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