Control System Basics

Control Problem Definition

Control Strategies

Feedback Control Structures

Nature of Control Tasks

Performance Augmentation

In **most** dynamical systems, the **performance** attributes e.g. stability, tracking and disturbance rejection, **need augmentation** due to system **deficiencies.**

However, there are **other situations** where the **role** of a system gets **modified**, resulting in different **requirements** on these attributes

In all such **cases**, we need **additional** entities, e.g. **control**, which help us to achieve **desired** objectives.

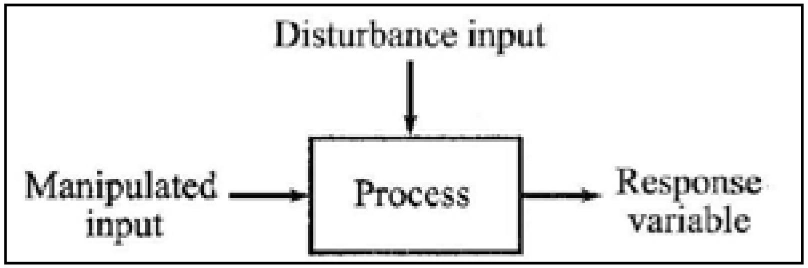
Concept of Control System

Control System, or controller, is an object or a process, for ensuring a **desirable response** from the system, under specified operating **conditions** & **disturbances.**

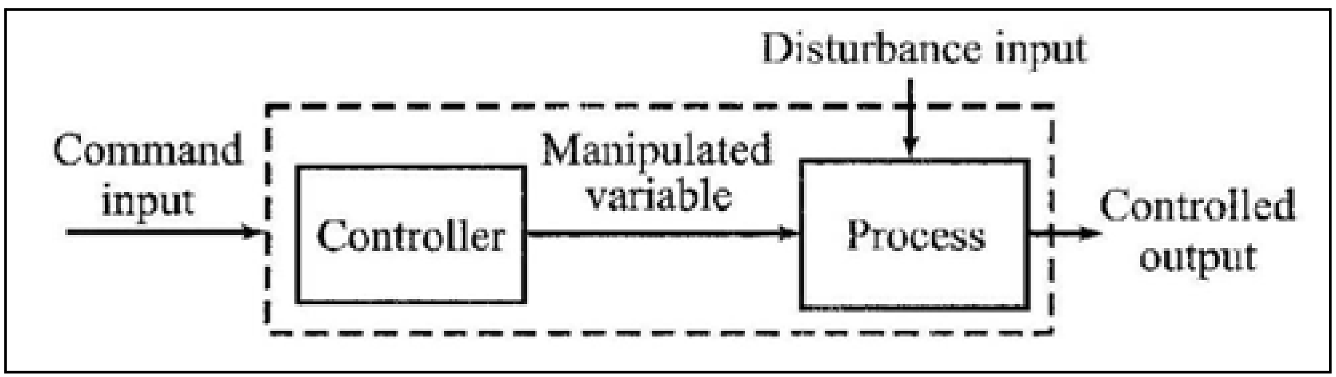
Control problems can be **generically** described by **considering** any system in its **input – output** form.

Control Problem Description

Given below is a **generic structure** of a control **action.**



Controller is an element that generates **manipulated** input**,** based on the **command** , as shown below.



Control Action Strategies

In general, **control action** is of two broad **categories**, which are;

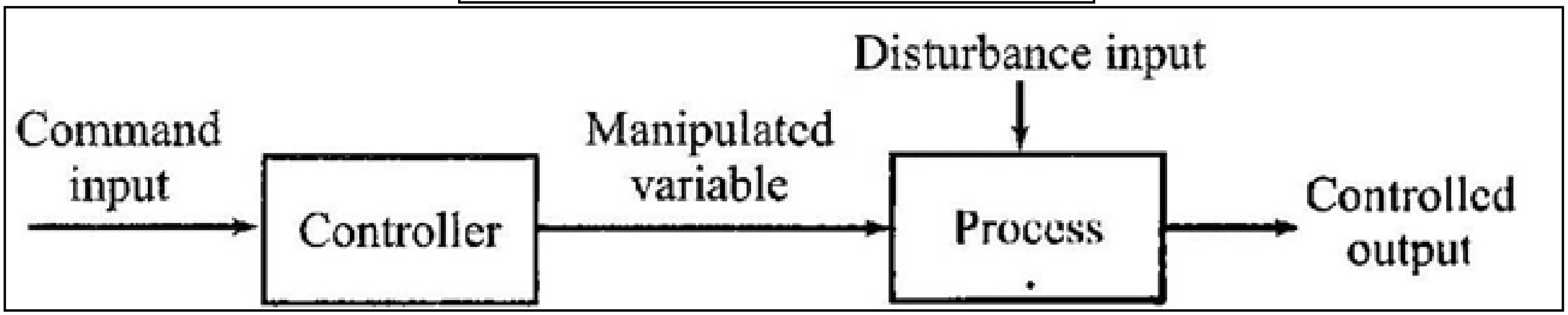
Open Loop: In this case, a **pre-set action** is taken based on **system** features and **desired** performance, **without** any reference to the **actual** performance.

Closed Loop: In this case, the control **action** is based on the **current** state of the **output,** which is measured and then **fed back** as modification to the **input.**

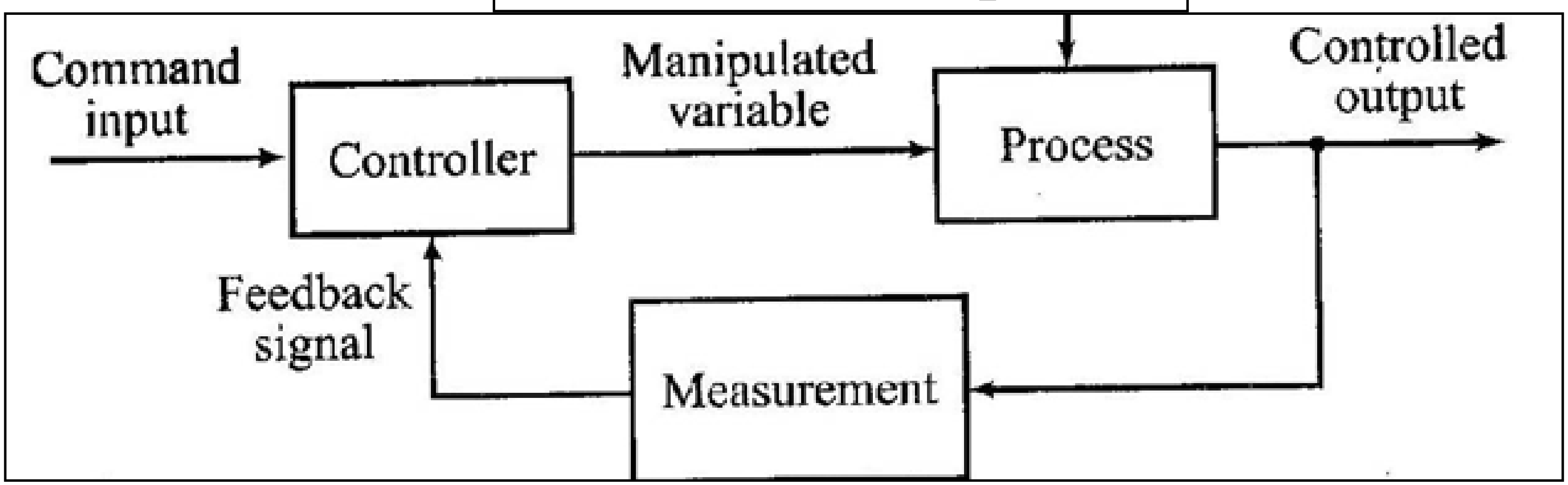
In some **special** cases, a **variant** of **open** loop control **action** category, called '**feed forward**' is also employed.

Control Action Structures

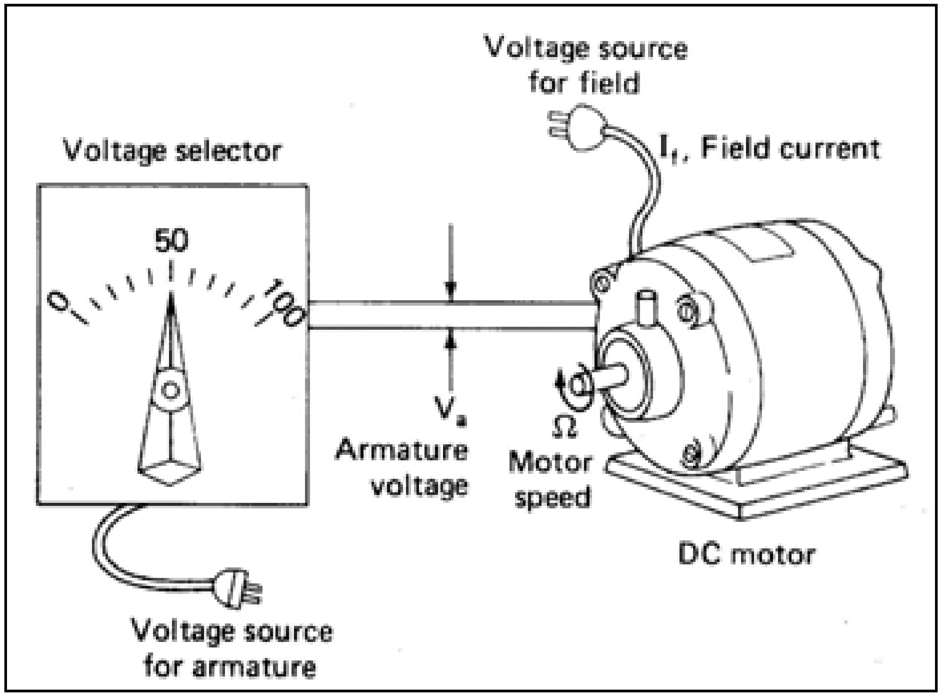
Open Loop



Closed Loop

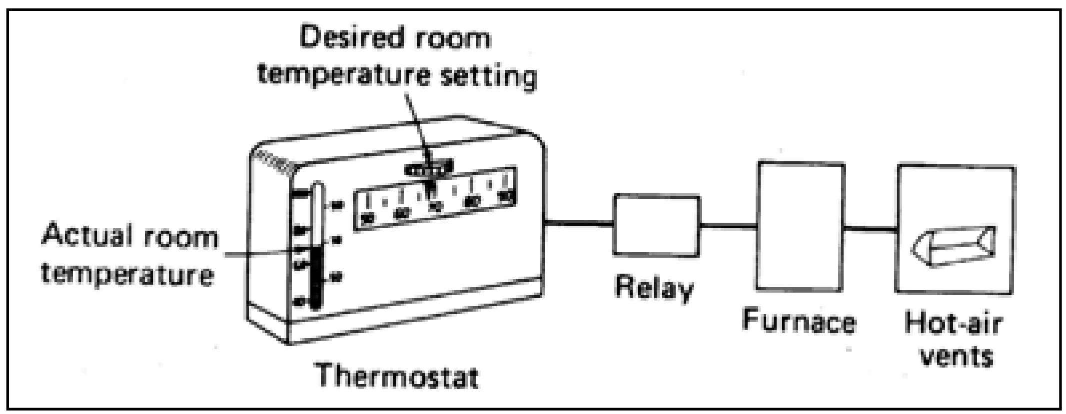


Open & Closed Loop Examples



Open Loop System

Closed Loop System



Open Vs. Closed Loop Control

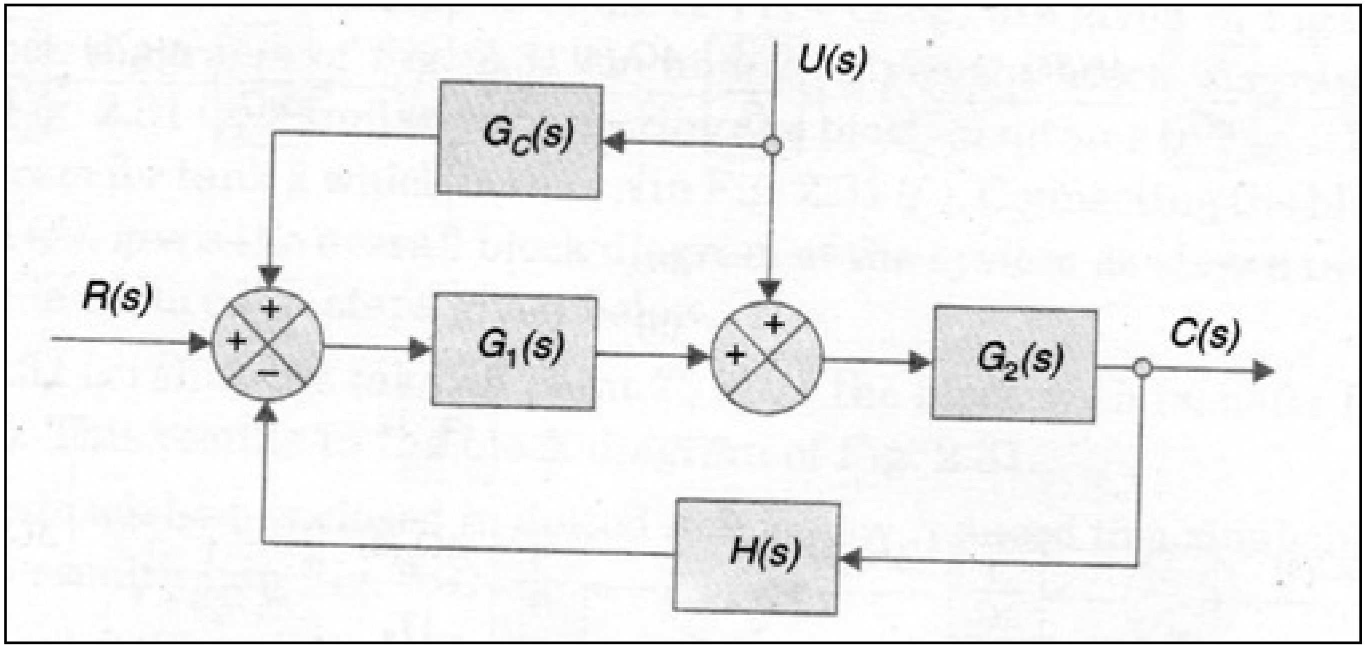
Attribute	**Open Loop**	**Closed Loop**
Calibration	Yes	No
Implementation	Simple	Complex
Impact on Stability	Largely No	Yes
Output Monitoring	No	Yes
Control Action	Independent	Dependent
Recalibration	Yes	No
Requirements	Yes	Yes

Control practices usually **employ** both the **options.**

However, **closed loop** is considered **better** when we need **greater** assurance under **uncertain** conditions.

Feed-forward Control Concept

Given below is a **schematic** of feed-forward **action.**



Here, **U(s)** is a known **disturbance**, which is sought to be **nullified** by the feed-forward controller, **G_c(s).**

Summary

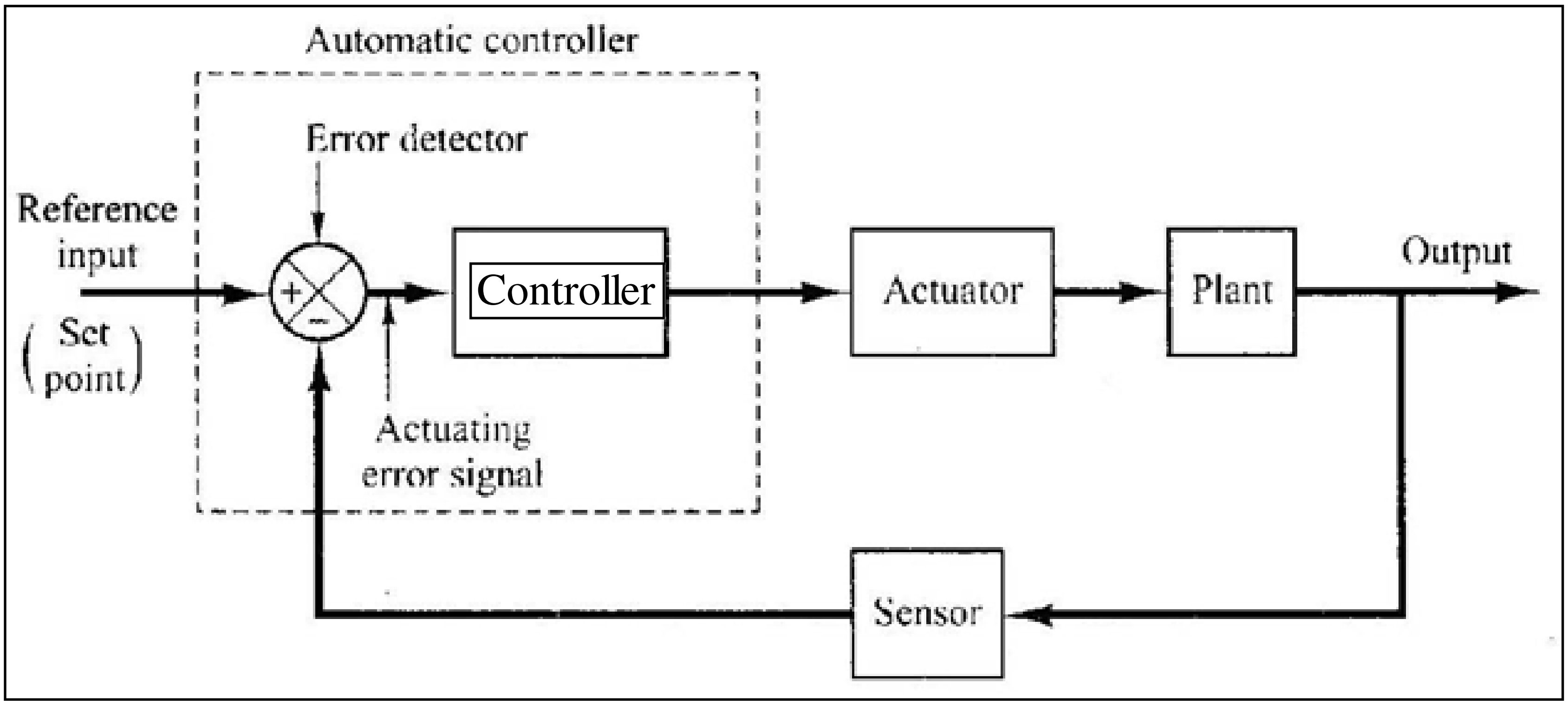
Open loop strategies are **simpler** but **error prone**, while **closed loop** strategies are more **complex** but provide **better** accuracy and control authority.

Feed-forward action is a **variant** of open loop action, which **aims** to improve the transient **response.**

Feedback Control Structures

Feedback Control Structure

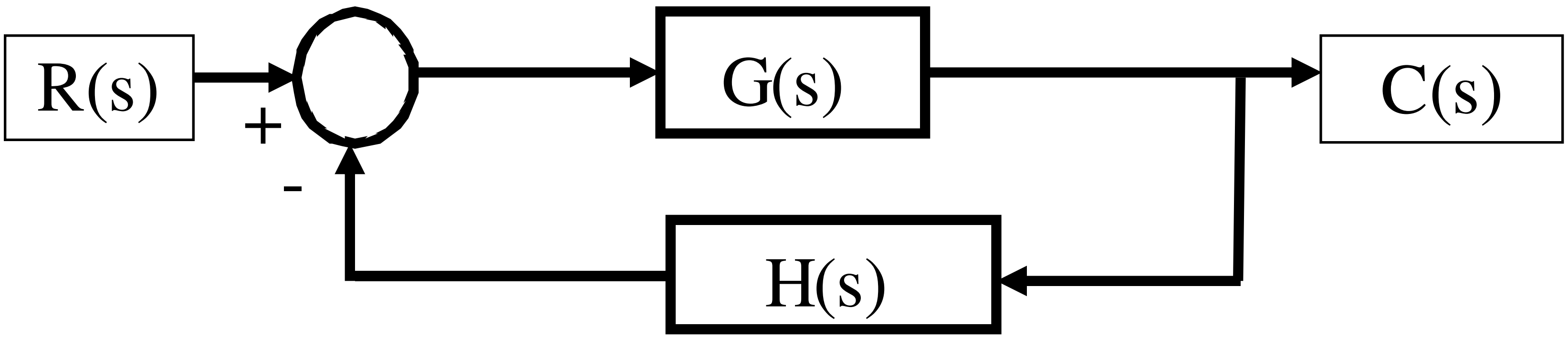
The most **commonly** used feedback control **structure** is the **single** loop negative **feedback**, as shown below.



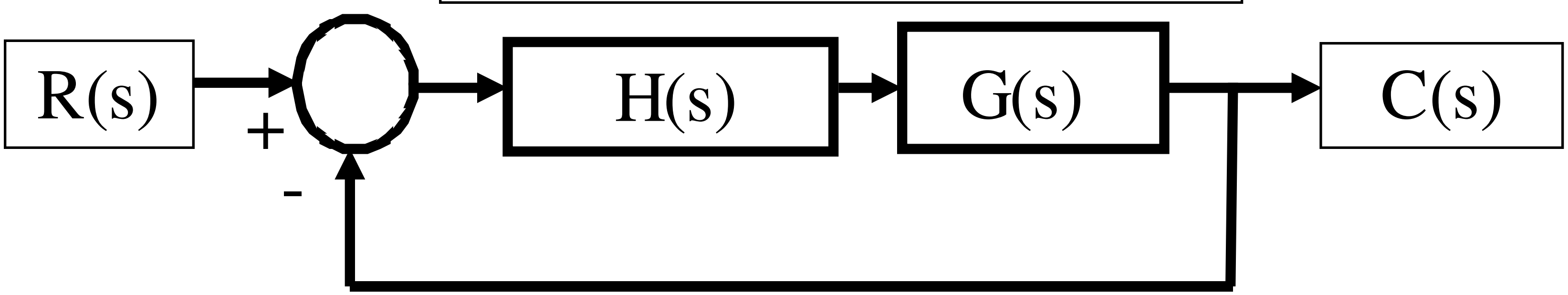
Single Loop Control Options

Further, **single loop** structure can be both **non-unity** as well as **unity feedback** type, as shown below.

Non-unity Feedback Structure



Unity Feedback Structure



Unity Vs. Non-unity Structure

Closed loop transfer functions for **both** unity and non-unity feedback **structures** are as given below.

$$\frac{C(s)}{R(s)}\Big|_{Unity} = \frac{G(s)H(s)}{1+G(s)H(s)}; \quad \frac{C(s)}{R(s)}\Big|_{Non-unity} = \frac{G(s)}{1+G(s)H(s)}$$

We note that for a **given input**, the structures will give **different types** of responses, so that we can **satisfy** different **requirements.**

Unity Vs. Non-unity Structure

In **general**, it is found that **unity feedback** form is the simplest, **intuitive**, and hence, is the most **widely** used in a **large** number of control **applications.**

Further, in **many** cases, results from **unity feedback** are also **applicable** to non-unity feedback**.**

Therefore, in the **present course**, we will **focus** only on the **unity** feedback control **structure.**

However, wherever **applicable**, correspondence with **non-unity** feedback form will be **highlighted.**

Summary

Single loop **unity** negative **feedback** form is a commonly employed control **structure.**

Performance through Feedback Control

It was **seen** earlier that performance **attributes** e.g. stability, tracking etc. **depend** on the transfer function.

In this **context**, we know that a **feedback** structure modifies the **relation** between the output and the input.

Therefore, an **appropriate** feedback control **structure** should be able to also **modify** the performance **attributes** as per the **requirements.**

Let us **explore** this aspect through **simple examples.**

Stability Augmentation

We know that for any **system** to be **stable**, all its **poles** must have **negative** real part.

For **unity feedback** structure, this **requirement** can be stated on **closed loop** transfer function, as follows.

$$C(s) = \frac{G(s)H(s)}{1+G(s)H(s)}R(s); \quad D(s) = 1+G(s)H(s) = 0$$

$$G(s)H(s) = -1 \rightarrow \text{ All roots must have negative real part.}$$

Thus, we can employ a **suitable H(s)** to achieve closed loop system **stability**, even for **unstable** plants.

Stability Augmentation Example

Unstable Plant:

$$G(s) = \frac{1}{(s^2 + s - 2)}$$

$$D(s) = 1 + G(s) = s^2 + s - 1 = 0$$

$$\rightarrow s = 0.618, -1.618$$

$\rightarrow$ Closed Loop Unstable

Unstable Plant with Controller:

$$G(s) \cdot H(s) = \frac{1}{(s^2 + s - 2)} \times 5$$

$$D(s) = 1 + G(s)H(s) = (s^2 + s - 2) + 5$$

$$s^2 + s + 3 = 0 \rightarrow s = -0.5 \pm j1.658$$

Stable Closed Loop

Tracking

Tracking requires **following** a given input, for which **applicable** closed loop **response** is as **shown** below.

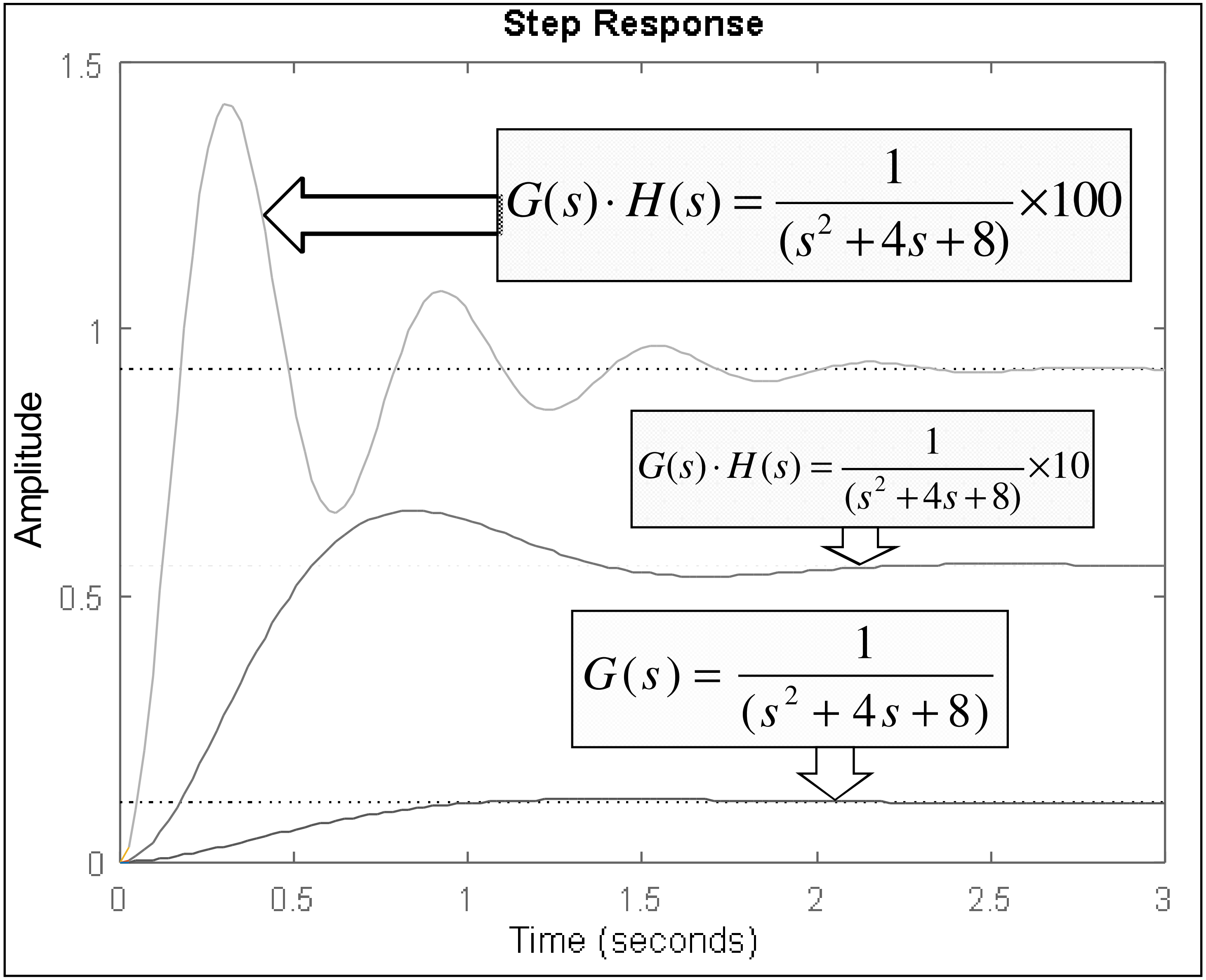
$$\text{Tracking: } \lim_{t\to\infty} c(t) = r(t) \to \lim_{t\to\infty}\left[r(t)-c(t)\right]=0$$

$$C(s) = \frac{G(s)H(s)}{1+G(s)H(s)}R(s); \quad R(s)-C(s) = \frac{R(s)}{1+G(s)H(s)} = 0$$

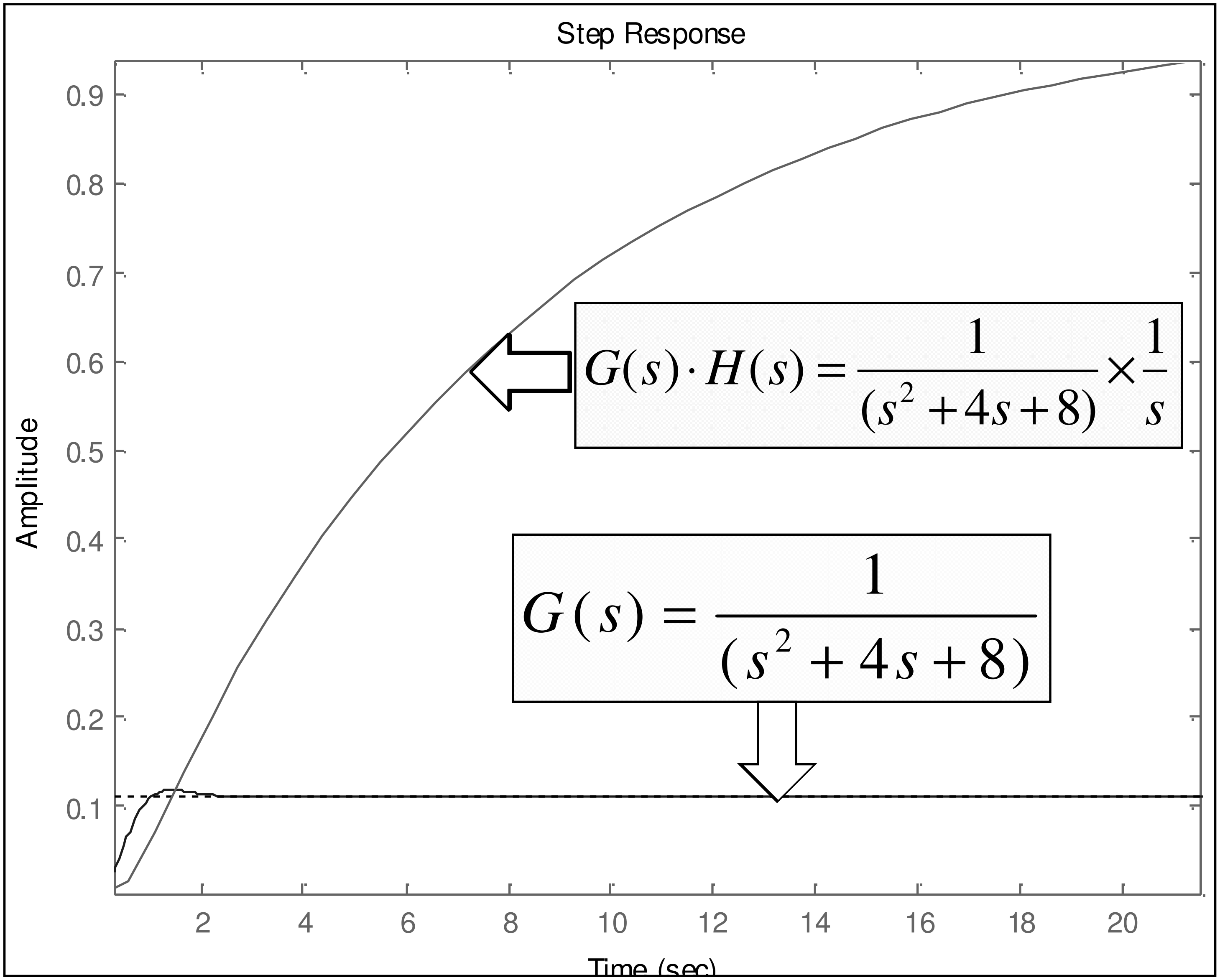
$$\lim_{s\to 0} s\left[R(s)-C(s)\right] = \lim_{s\to 0}\left(\frac{sR(s)}{1+G(s)H(s)}\right) = 0$$

It can be seen that **exact tracking** depends on both input **R(s)** and the controller **H(s)**.

Step Tracking Through Gain

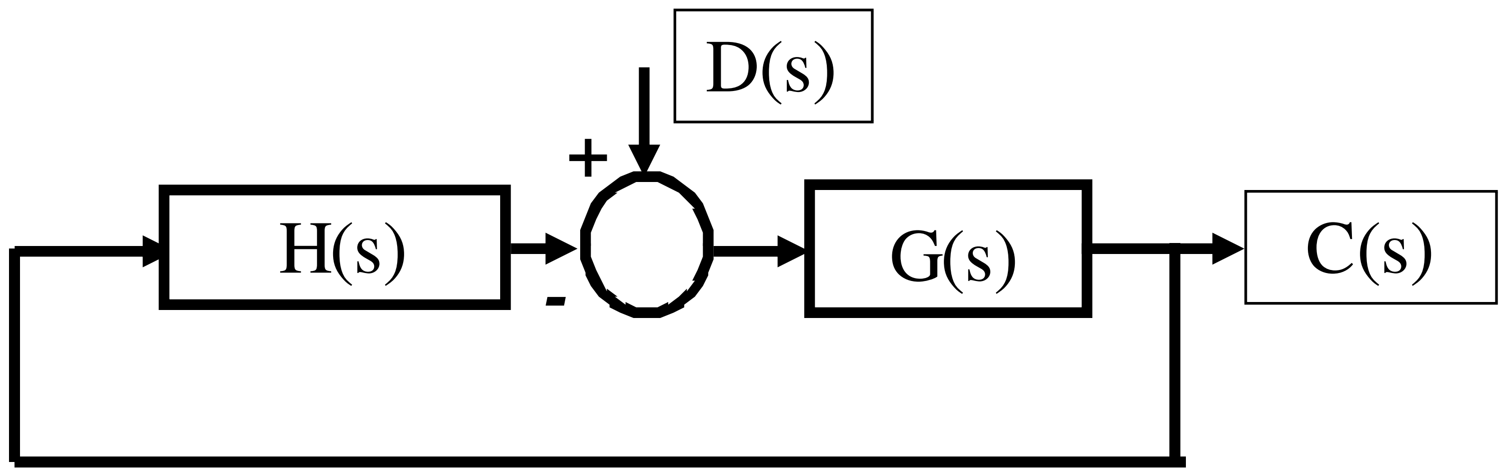


Step Tracking Through Integral



Disturbance Rejection

Disturbance **rejection** is the counterpart of **tracking**, in which the applied **input** is to be **rejected** (or not tracked). Following schematic shows the **overall** context.



In this structure, **D(s)** is the disturbance input, and is to be **rejected** so that C(s) is **zero** for non-zero **D(s)** as **t** $\rightarrow \infty$**.**

Disturbance Rejection

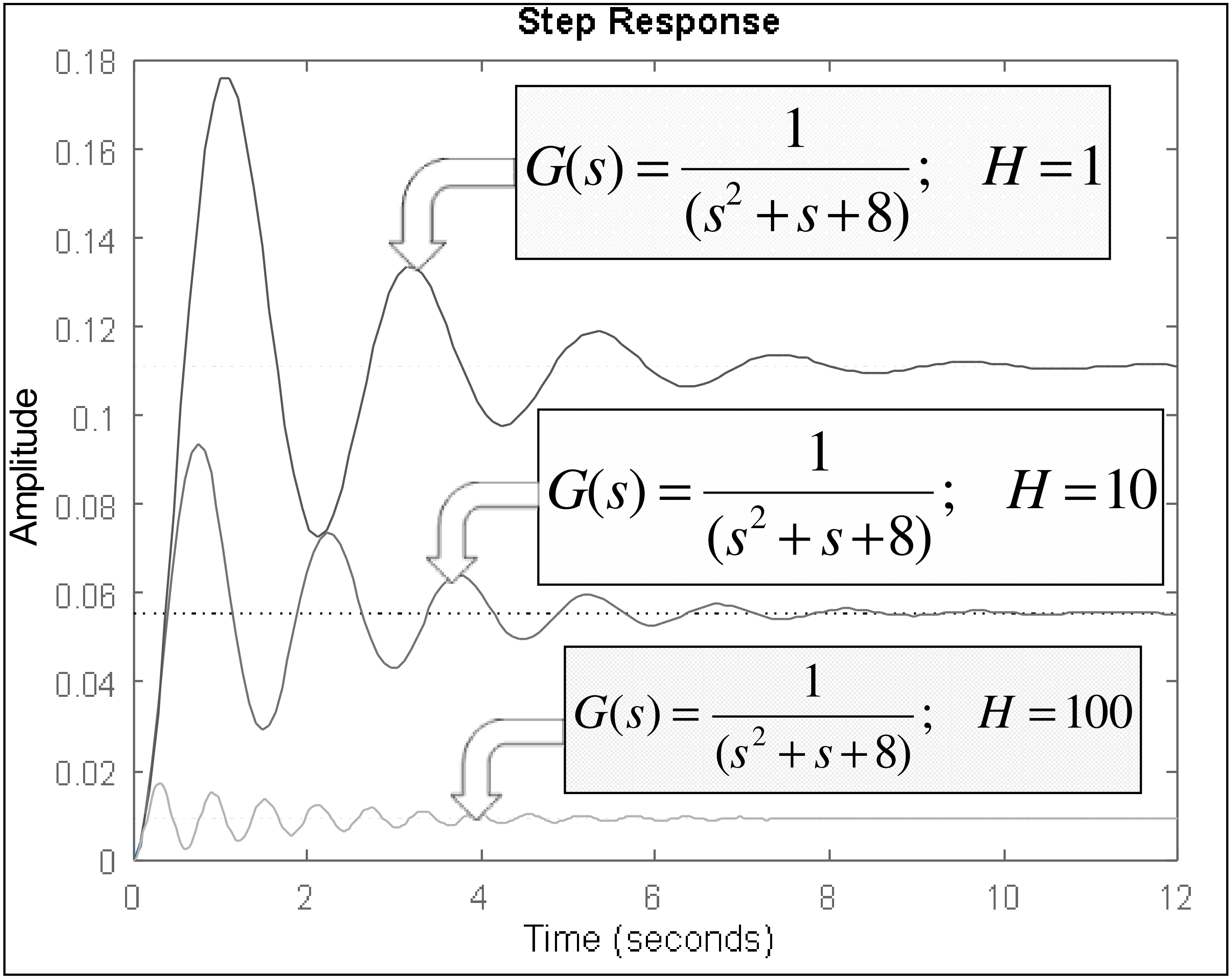
Resulting closed loop response, **C(s)** is as shown below.

$$C(s) = \frac{G(s)}{1+G(s)H(s)} D(s); \quad \text{Rejection: } \lim_{t \to \infty} c(t) = 0$$

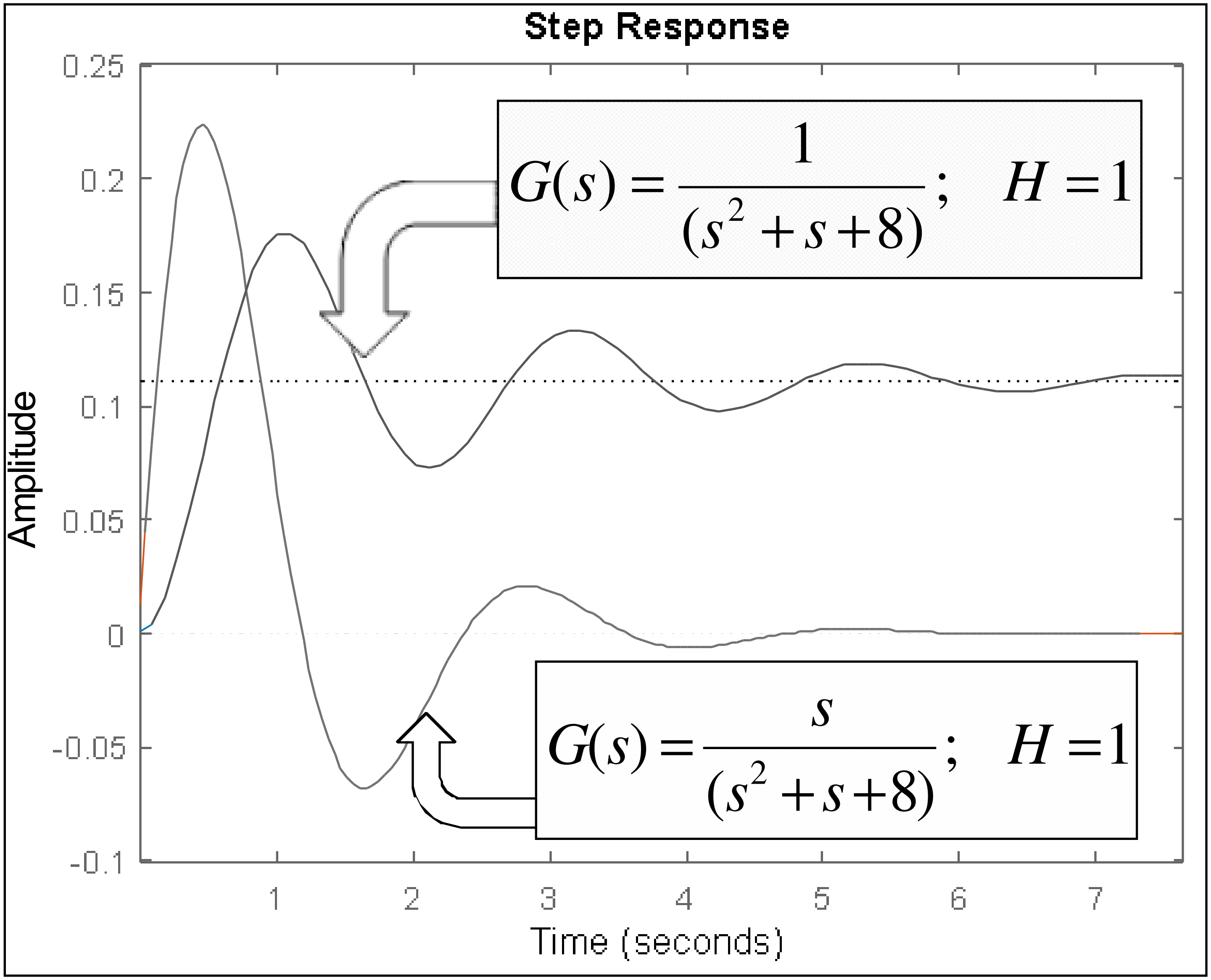
$$\lim_{s \to 0} sC(s) = 0 \to \lim_{s \to 0} \left(\frac{sG(s)D(s)}{1+G(s)H(s)} \right) = 0 \to \lim_{s \to 0} sG(s)D(s) = 0$$

We see that **quality** of disturbance **rejection** will depend on **nature** of disturbance and **G(s).**

Step Rejection Through Gain



Step Rejection Through Derivative



Summary

We can **improve** stability, tracking and rejection **performance** through feedback **control**, by suitable **choice** of control **element.**