COMPENSATOR DESIGN.

(TIME DELAY COMPENSATOR, INVERSE RESPONSE COMPENSATOR, DECOUPLING COMPENSATOR.)

Experiment no. 3
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PROBLEM STATEMENT:

To analyse and design Time Delay Compensator, Inverse Response Compensator and Decoupling Compensator.

THEORY

Time Delay Compensator:

Modern process control systems need to be highly distributed, highly integrated and should support operational flexibility. The distribution of control systems induces delays in the control loop that degrade the control performance.

These delays are usually variable from iteration to iteration of the control loop and depend on several factors as the scheduling of the processes in the network nodes or the scheduling of traffic in the network. Classic control solutions do not account for the effect of such variable delays.

Control problems with time-delay elements are:

1. Measuring device delay: control action is based on delayed, obsolete, process information that is not representative of the current situation.

2. Process input delay: the process will not feel the control action immediately.

The delay compensator principle was proposed in order to deal with the variable sampling to actuation delay effect in real-time distributed control systems. The delay compensator principle proposes the addition of a compensator to an existing distributed control system to overcome the effect of the variable sampling to actuation delay introduced in the loop, allowing the achievement of a better control performance. The compensator action is based on the knowledge of the sampling to actuation delay that affects the control loop and it can have any other input needed to generate the correction output that will be added to the output of the existing controller. This approach can be applied to any distributed control system provided that the sampling to actuation delay is known for each control cycle. The delay compensator principle is generic and can be implemented using different techniques.

The general transfer function of a system with delay is given by,

$$G(s) = \frac{k}{\tau s+1} e^{-Ls}$$

The existing approaches of overcoming network transmission delay or mechanical switching delay mainly focus on designing a model based time-delay compensator or a state observer to reduce the effect of the transmission delay. We see the application of this theory hugely in Control Systems that involve the use of internet, this method is preferred, however, this method may be very unstable for certain control intervals due to its inevitable dependence on the process parameters.

When we do a stability analysis of the transfer function using the Routh-Hurwitz criteria, we will see that the plant transfer function, containing the time delay element is cancelled and we are left with the Model Transfer function only,

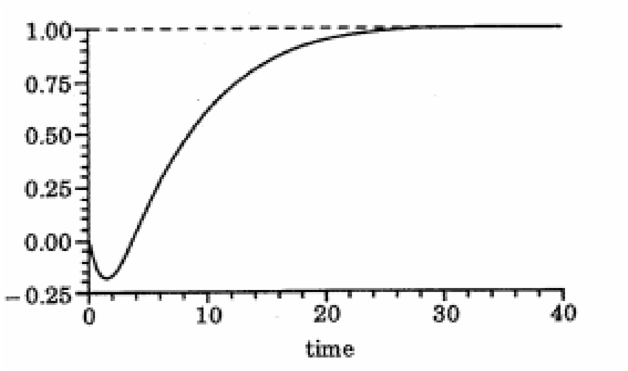
The characteristic equation is as follows,

$$1 + plantG_C + modelG_C + (model)e^{-Ls}G_C = 0$$
$$1 + (model)K_C = 0$$

From here, we can infer that $K_c = \infty$.

<u>Inverse Response Compensator:</u>

When the initial direction of a process systems step response is opposite to the direction of the final steady state, it exhibits inverse response.



Inverse response occurs due to two main reasons:

• when the response is in opposite direction with respect to the ultimate steady state value

• presence of right half plane zeros for any other reason as well.

The examples where this process is used are like in distillation columns, drum boiler, boost converter, etc.

The controller used is a PI controller which is tuned according to the model. The compensation is basically done on the basis of four parameters i.e. integral square error(ISE), integral of time weighted square error(ITSE), integral of absolute error(IAE), integral of time weighted absolute error(ITAE).

To eliminate the effect of inverse response, one additional measurement signal must be added that excludes the information of inverse response. This can be achieved by the loop through the compensator Gc(s) that gives an additional output.

Here is an example transfer function that gives inverse response, we will analyse it and make necessary comments.

$$G(s) = \frac{-s+1}{4s+1}$$
$$1 + k\left(\frac{-s+1}{4s+1}\right) = 0. using\ RH\ criteria.$$
$$(4-k)s + (1+k) = 0;$$
$$we\ intend\ to\ remove\ the\ first\ term\ (co-efficient\ of\ s).$$

Now, when we design the compensator, we can see that the term (4-k) will be cancelled. The compensator design depends hugely on the original transfer function. **The value of λ is the**

coefficient of s in the denominator of the transfer function (N.B. Do not consider the negative sign).

Let us consider,

$$G_{compensator}(s) = \frac{\lambda s}{4s+1}, \text{ here, } \lambda = 1.$$

Decoupling Compensator.:

An idealized requirement in MIMO control-system design is that of decoupling. If a plant is dynamically decoupled, then changes in the set-point of one process variable lead to a response in that process variable but *all other* process variables remain constant. The advantages of such a design are intuitively clear: e.g., a temperature may be required to be changed, but it may be undesirable for other variables (*e.g., pressure*) to suffer any associated transient. Full dynamic decoupling is a very stringent requirement.

Generally, in multivariable control system, there are interferences in output signal. In order to cancel the interference, diagonalizing of control plant matrix is required by decoupling compensator. In this paper, two schemes of diagonalization of control plant are approached, one is general scheme and the other is diagonalization over low frequency bands. Here, we assume 2 by 2 multivariable system:

Control Plant: $P = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}$

Decoupling Compensator: $G_C = \begin{bmatrix} G_{C11} & G_{C12} \\ G_{C21} & G_{C22} \end{bmatrix}$

As might be expected, full dynamic decoupling is a strong requirement and is generally not cost-free. We will thus also quantify the performance cost of decoupling by using frequency-domain procedures. These allow a designer to assess *a-priori* whether the cost associated with decoupling is acceptable in a given application.

Of course, some form of decoupling is a very common requirement. For example, static decoupling is almost always a design requirement. The question then becomes, over what bandwidth will decoupling (*approximately*) be asked for? It will turn out that the additional cost of decoupling is a function of open-loop poles and zeros in the right-half plane. Thus if one is restricting decoupling in some bandwidth, then by focusing attention on those open-loop poles and zeros that fall within this bandwidth, one can get a feel for the cost of decoupling over that bandwidth.

Procedure:

1. We carefully simulate the transfer function given to us with a step input.
2. We then analyze its response and find out its drawbacks.
3. Next, we design a suitable compensator to counteract the drawback faced by the given transfer function.

4. We analyze the performance of the Transfer function when the compensator is applied to it and comment on its improved response.
5. Some commonly used MATLAB functions are:

margin(sys), [Gm,Pm,Wgm,Wpm]=margin(sys) and bode(sys).

SIMULATIONS :

1. Time Delay Compensator:

We shall demonstrate the response of the given transfer function with time delay, with and without a compensator.

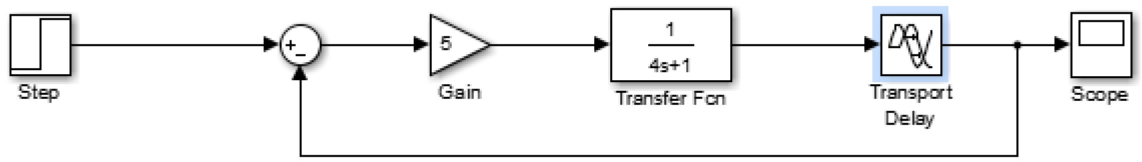
The transfer function used for simulation is,

$$G(s) = \frac{1}{4s+1}e^{-s}$$

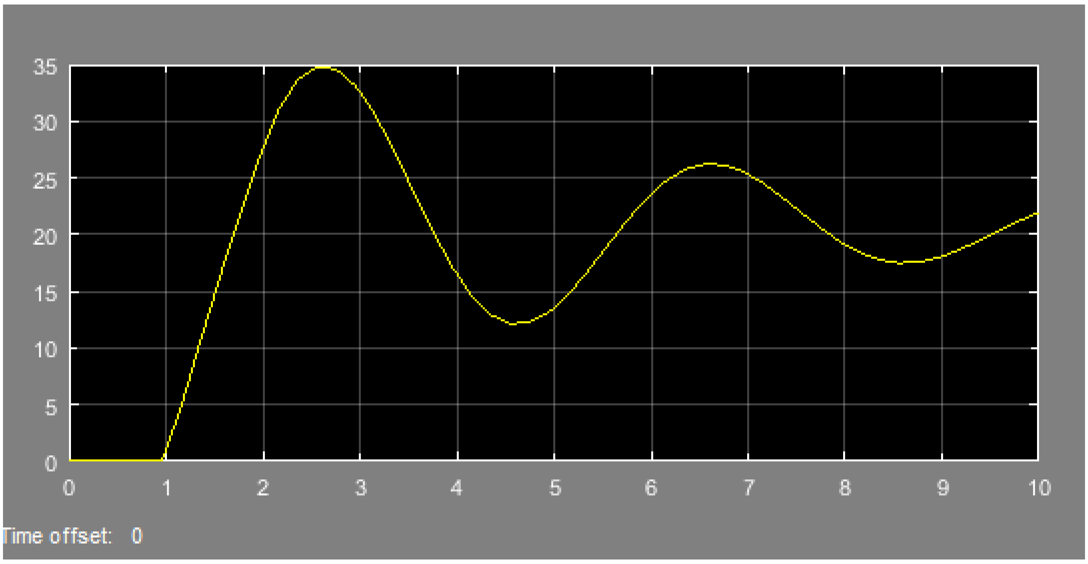
The stability margins of the transfer functions are:

```
>> g= tf(1,[4 1], 'ioDelay', 1);
>> [Gm,Pm,Wgm,Wpm]=margin(g)

Gm =

    6.9345


Pm =

  -180


Wgm =

    1.7155


Wpm =

     0
```

The block diagram without the compensator looks like,

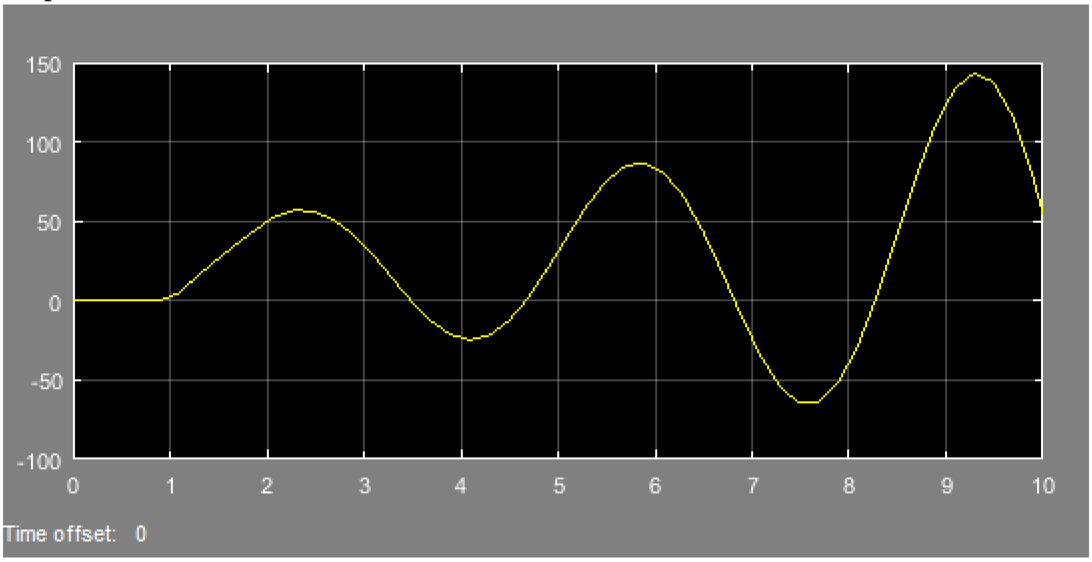


This is the output of the transfer function, when the gain is less than its gain margin, is as follows:



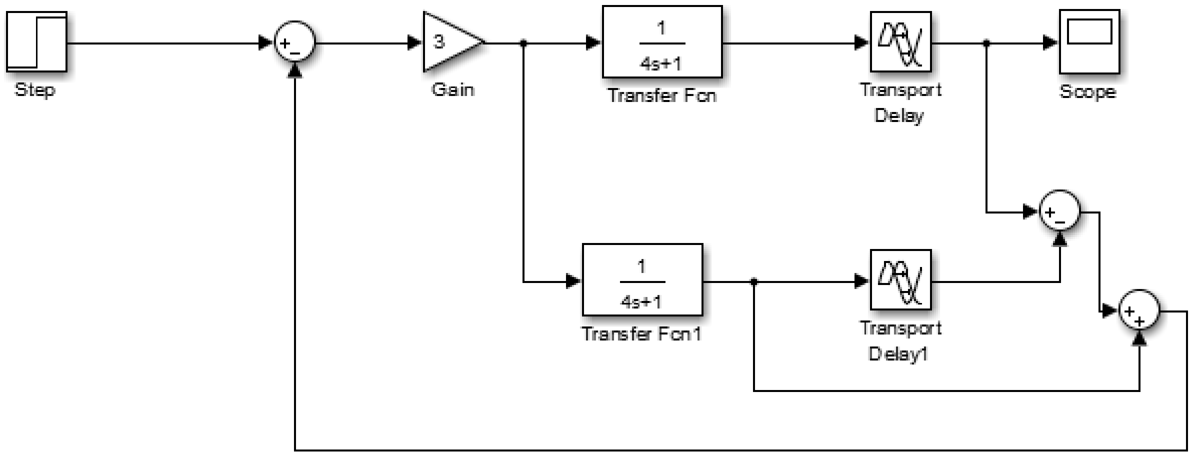
The output settles at around 25. Which is ideal, because the final value of the step input is set to 25.

Now, if we set the gain to 9, which is greater than the gain margin, we get the following output:



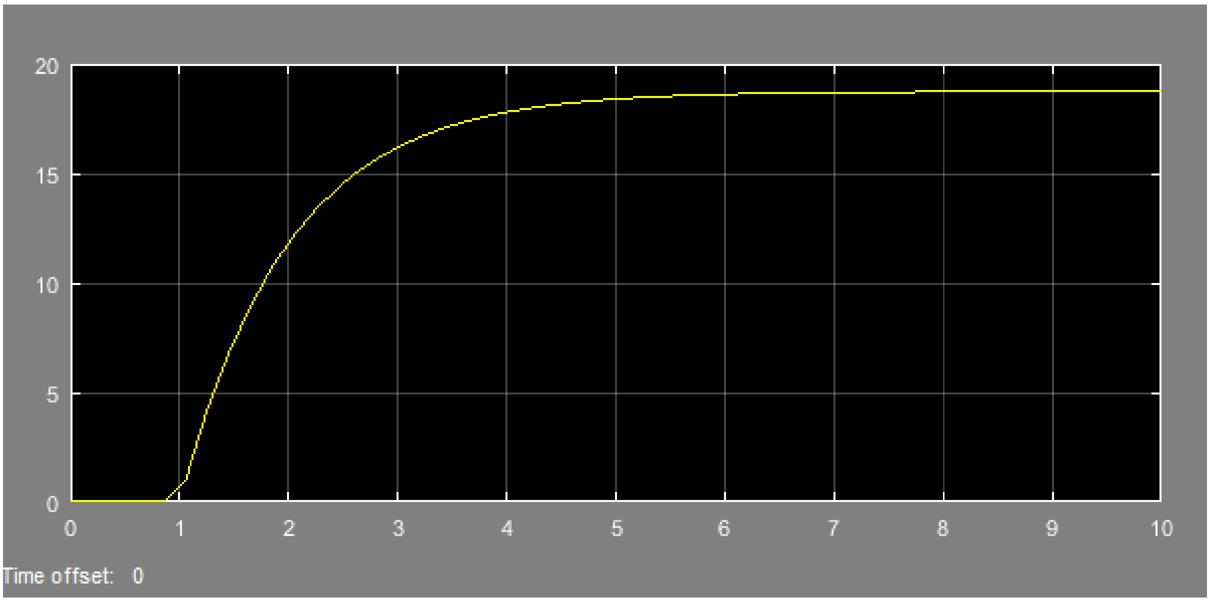
The system experiences sustained oscillation. This limitation is seen because of the e^{-ls} factor which imparts the effect of a cosine and sine function (Euler's formula) on the response.

Now, we design the **Time Delay compensator**. The block diagram is as follows,



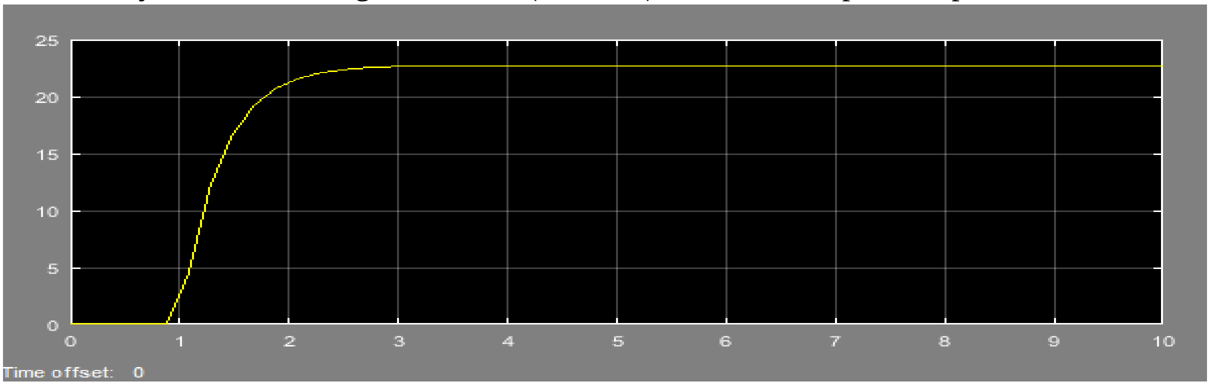
This is separate the transfer function response from the harmonics imparted from the time delay.

The transfer function response with a gain of 3, which is less than the gain margin is as follows:



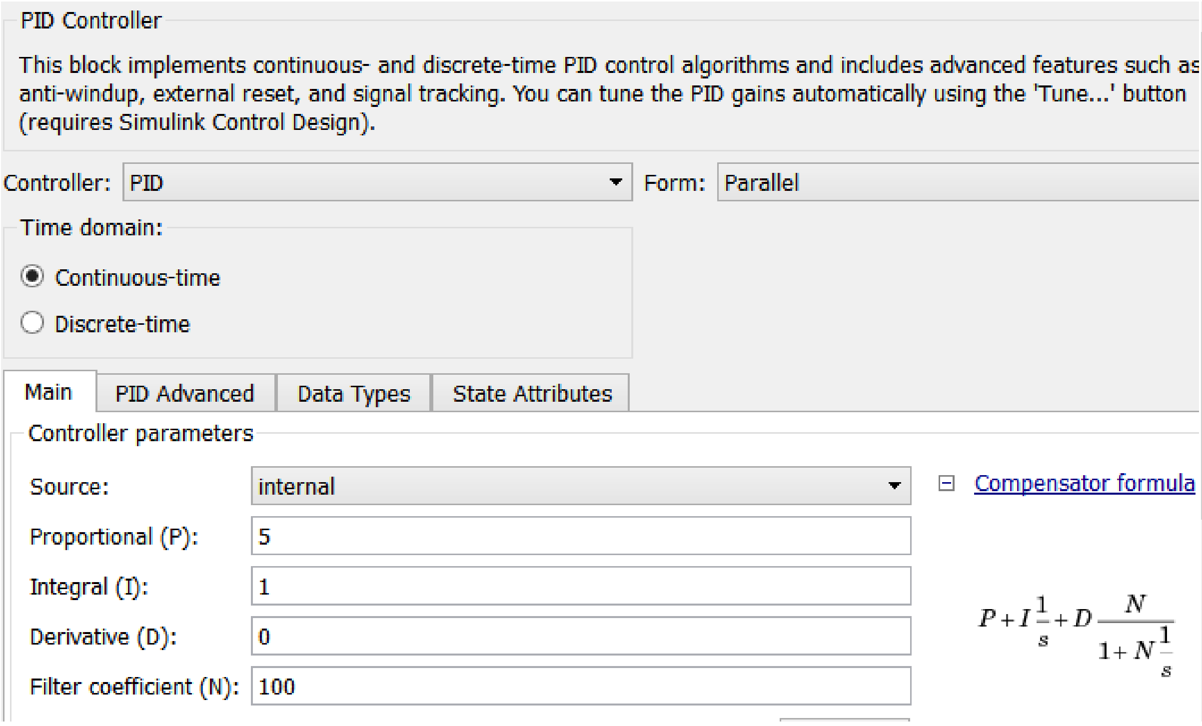
Which is desired, but the steady state is obtained at 19.7, however, the ideal value will be 25.

We now try to increase the gain above 7 (set to 12) and see if the plant response is desirable.

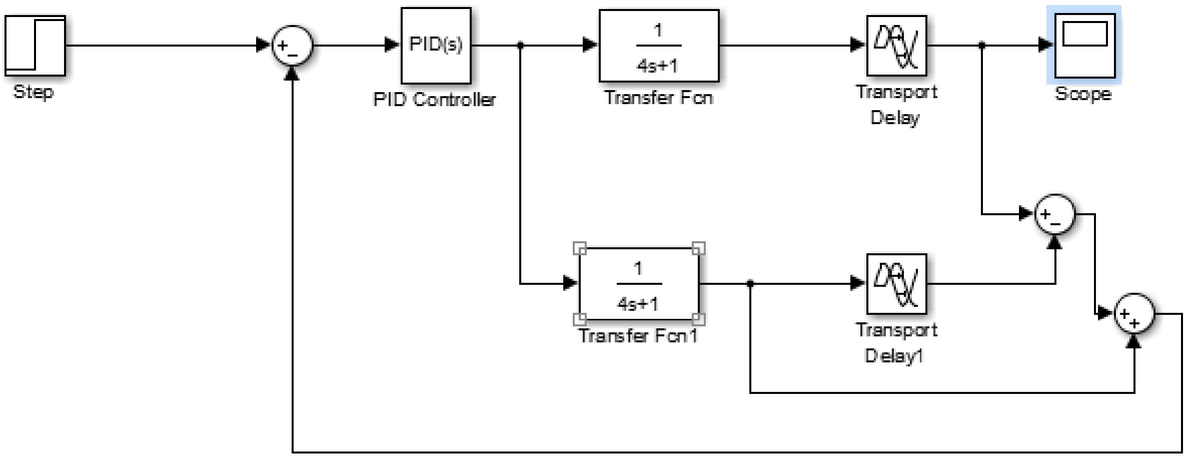


In spite of a little overshoot, the response is still ideal. However, the response is not settling at 25. To solve this problem we use a PI controller. The integrator will help the plant to track the set point.

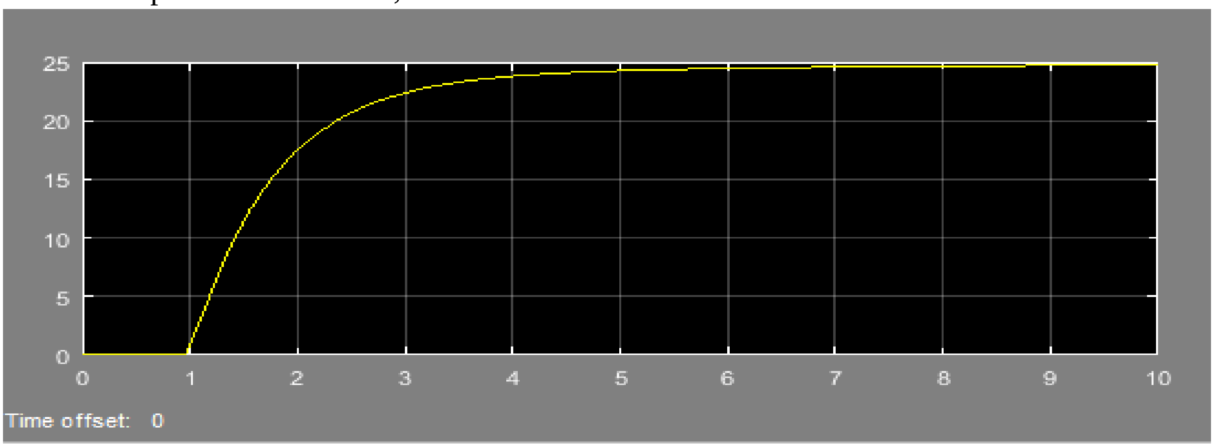
Specifications of PI controller,



Here is the block diagram,



And the response is as follows,



2. Inverse Response Compensator:

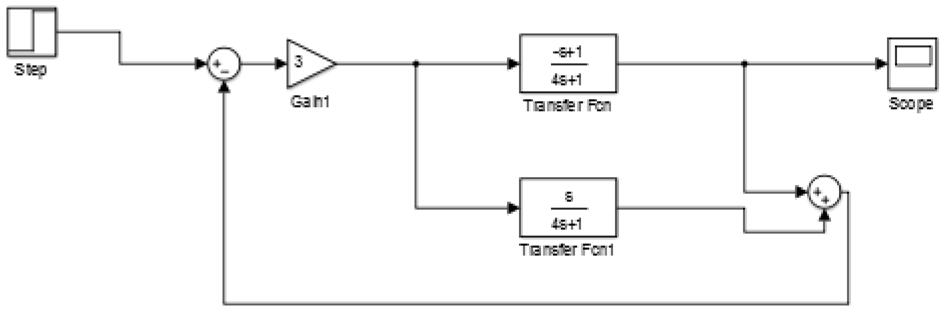
The aim is to make the inverse-response system immune to any drastic change in its gain. Given transfer function:

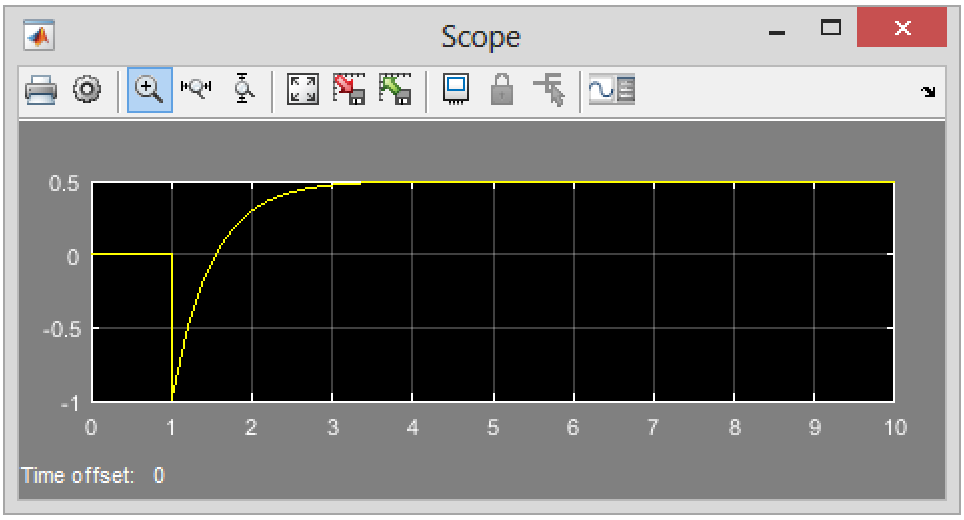
$$G(s) = \frac{-s+1}{4s+1}$$

The system specifications are as follows:

```
>> [Gm,Pm,Wgm,Wpm]=margin(h)

Gm =

     4


Pm =

  -180


Wgm =

   Inf


Wpm =

     0
```

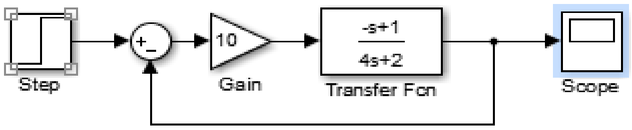
We first simulate the system alone, without compensator and at a gain below the gain margin. The block diagram and its response are as follows:

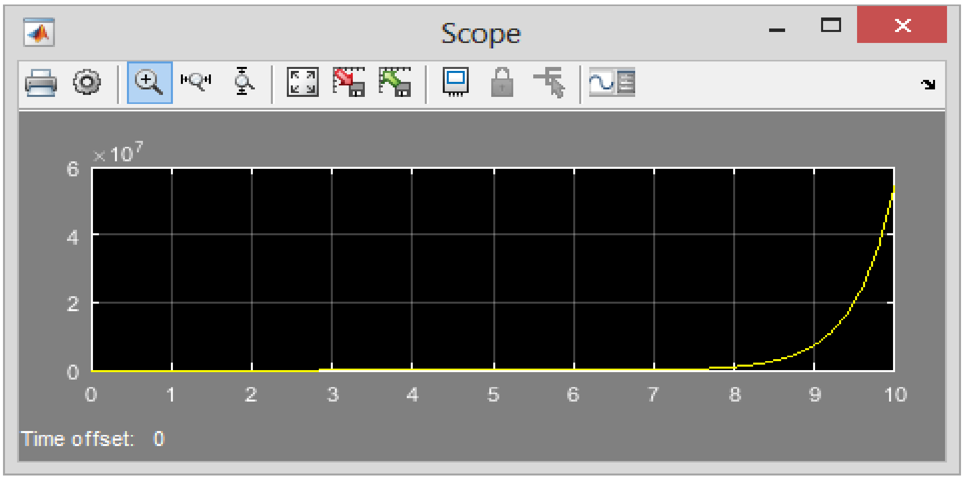




We see that, even if there is an inverse response, the output is pretty steady. But the response is settling at 0.5, which is not correct because the final value is 1 (as specified in the step input).

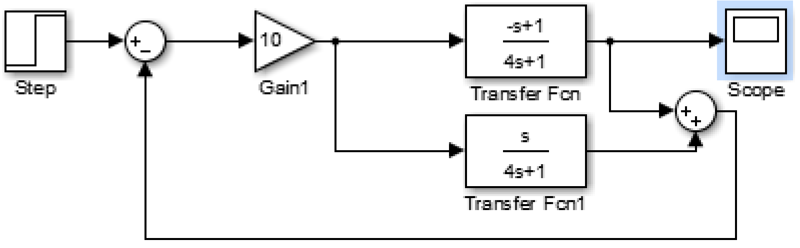
Now, we try to give a gain of 10 (more than the gain margin). The response is as follows:

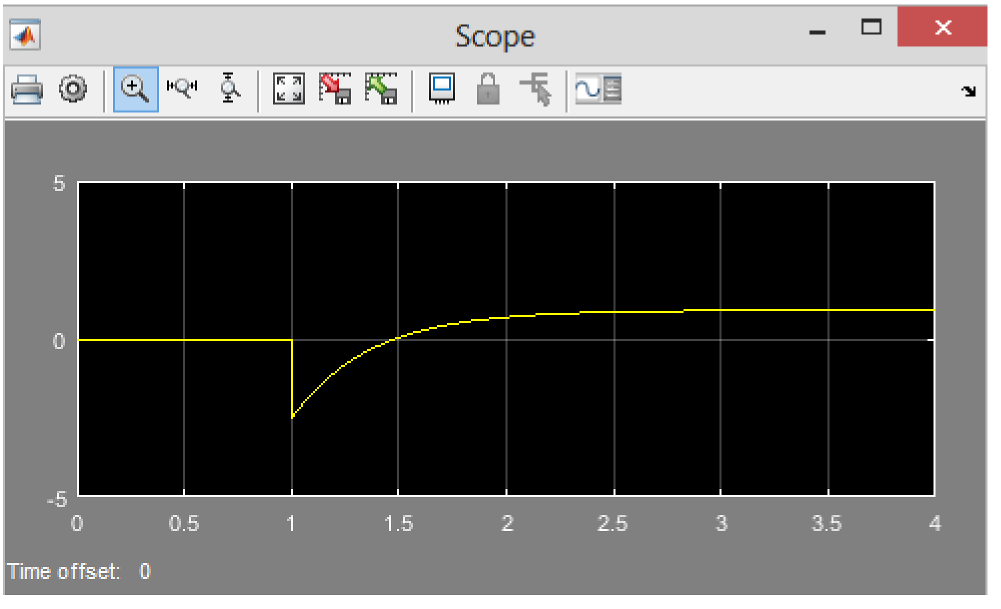




The output is totally undesirable. Thus we design a compensator to take care of this drawback.

The compensator makes the system immune to variation in gain and also makes the output response very close to the desired value.

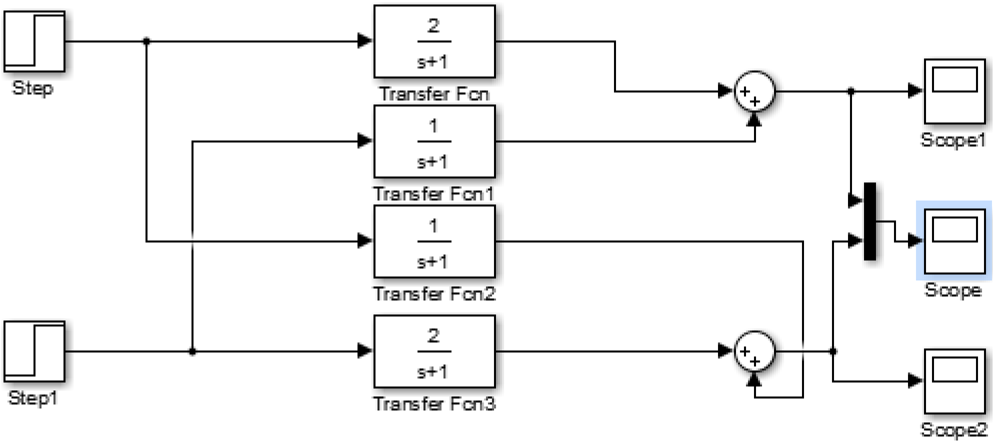


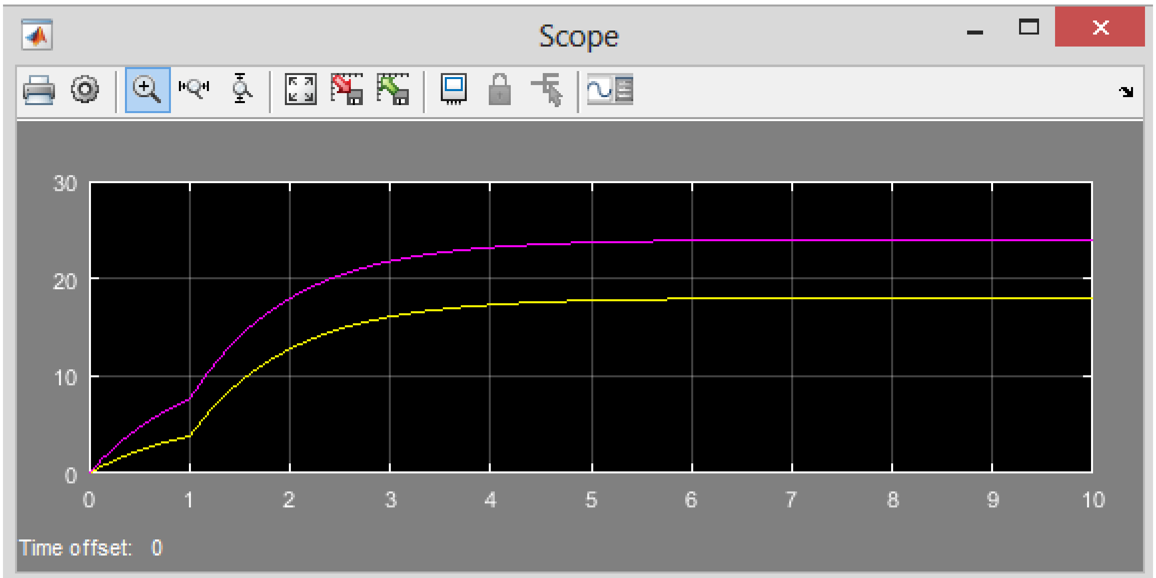


<u>Decoupling compensator:</u>

In chemical process industries, we will come across processes that effect the operation of other process as they act. This problem is counteracted by a Decoupling compensator, the compensator design is done using **Internal Model Controller Design.**

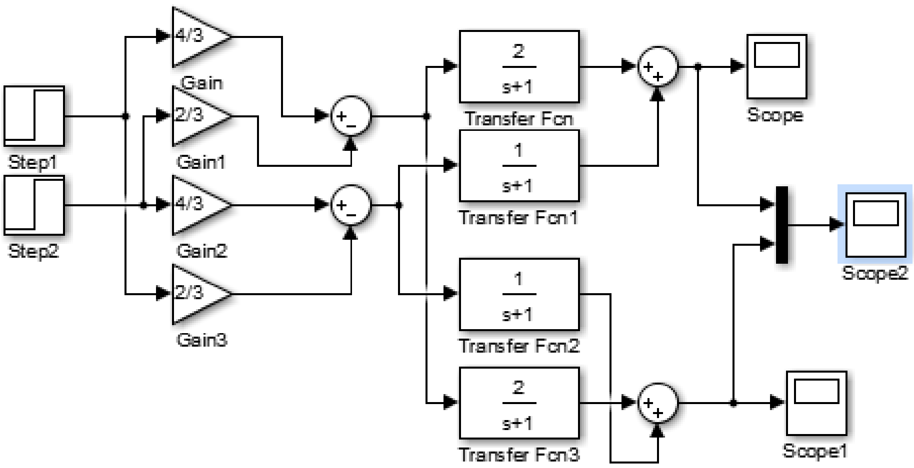
Here is the block diagram of a system where Coupling is exhibited. The corresponding response is also seen.

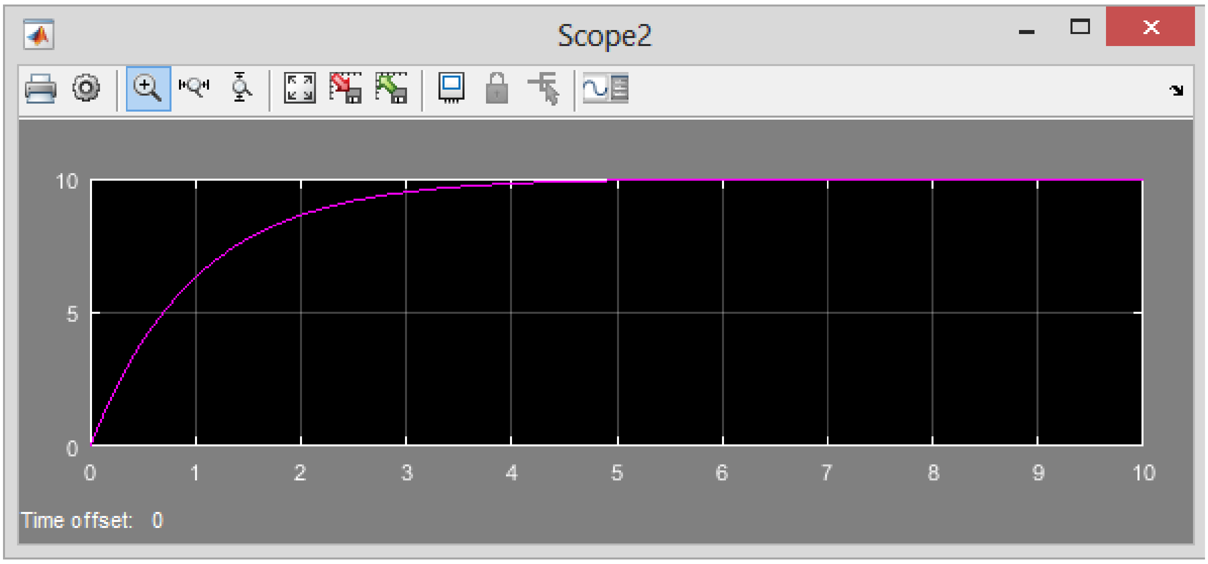




We can see that the response is totally unacceptable. The response is basically a scalar sum of each input.

Now, we design a compensator. This compensator will take care of the Coupling effect. Thus, the name is Decoupling Compensator.





We can see that the response is perfect. Thus, the design of the decoupling compensator is done.

RESULT:

Hence, we successfully completed the analysis and design of Time Delay, Inverse Response and Decoupling Compensator.

INFERENCE:

1. We need to have a very good understanding of the Internal Model Controller deign to have a meaningful knowledge of Compensator design.
2. We must choose of model design very close to that of our plant to have better compensation.
3. We can always use an integrator to make the system track the set point.