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COMPENSATOR DESIGN FOR TAMING INVERSE RESPONSE

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Abstract: An inverse response has always been an evergreen challenge for the instrumentation engineers. The efficiency of an industrial plant like in boilers plants directly depends upon the way inverse response is handled. The inverse response is controlled by manipulating its parameters so that the errors and the offset are minimal. This paper presents a novel method to compensate the inverse response of the process comprising of two opposite first order systems with a delay element. The compensator for inverse response designed with both accurately and inaccurately estimated parameters. This is simulated in MATLAB SIMULINK and checked for its efficacy.

Keywords: inverse response, compensator, dead time

1. INTRODUCTION

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 [1]

The examples where this process is used are like in distillation columns, drum boiler, boost converter, etc. In this paper a whole model is simulated in MATLAB SIMULINK. The process used is the arrangement of two first order transfer functions with a delay element. Their output goes to the controller. [2] The feedback is given to complete the loop. 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). [3] The model for inverse response of two first order transfer function is given in figure 1.

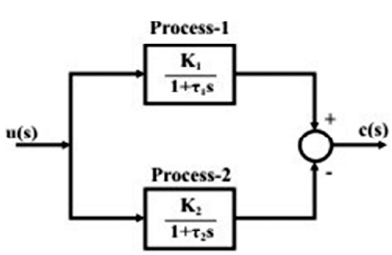

Figure 1: Block Diagram of Two Opposing First Order Systems

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The control of a system with inverse response is difficult like for control of a system with large time lag. For a closed loop time lag system with a simple feedback controller, the controller does not see any effect of control action till a time ?d has elapsed. On the other hand, for an inverse system, the controller will see an opposite effect to the expected one. So a special arrangement, similar to a Smith Predictor scheme is needed for control of inverse systems. Such an arrangement is shown in Figure 2.

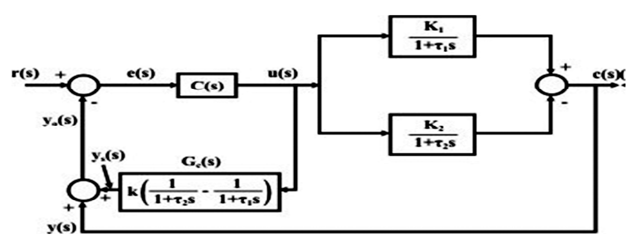

Figure 2: Scheme for Controlling a System with Inverse Response

The overall output for the compensator is given in equation 1.

$$Y(S) = \frac{c(S)\,(k_1\tau_2 - k_2\tau_1)s + (k_1 - k_2)}{(1+\tau_1 s)(1+\tau_2 s)} e(S) \qquad (1)$$

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 [1]

$$y_s(s) = c(s)\, Gc(s)\, e(s) \qquad (2)$$

$$= c(S) = k\left(\frac{1}{1+\tau_2 s} - \frac{1}{1+\tau_1 s}\right) e(S) \qquad (3)$$

Combining both the equations (1 & 2)

$$y_0(s) = y(s) + y_s(s) \quad (4)$$

$$= c(s)\,\frac{(k_1\tau_2 - k_2\tau_1)\,s + k(\tau_1 - \tau_2)s + (k_1 - k_2)}{(1+\tau_1 s)\,(1+\tau_2 s)}\,e(S) \quad (5)$$

Now the loop transfer function, *i.e.* transfer function between y_0 and e will have a zero on the left half of s-plane, if the coefficient of s in the numerator of (2) is positive. This gives the lower limit of K.

$$k \geq \frac{k_2\tau_1 - k_1\tau_2}{\tau_1 - \tau_2}$$

For this value of K, we find that zeros of the resulting open loop transfer function is non-positive:

$$Z = \frac{k_1 - k_2}{(k_1\tau_2 - k_2\tau_1) + k(\tau_1 - \tau_2)} \leq 0$$

So, the compensator $G_c(s)$ nullifies the inverse behaviour of the process. The basic controller normally chosen is of P-I type [1].

2. PROBLEM DEFINITION

Whenever material, information or energy is physically transmitted from one place to another, there is a delay associated with the transmission. The value of the delay is determined by the distance and the transmission speed. Some delays are short, some are very long [4].

Time delays occur frequently in process control loops due to distance velocity lags, recycle loops, delay in measurements, etc. The principal difficulty with the time-delay systems is in the increased phase lag, which limits the possible amount of control action.

Here the problem is to compensate the process having inverse response on account of two opposing first order system along with delay, using MATLAB SIMULINK.

3. METHOD

The impulse response of the overall system is compared on the basis of four performance indices. These indexes differentiate the system in different manner. Generally, it so happens that during the control system design process one or more parameters are selected to give best performance. For this purpose a measure called performance index is build [5].

The various criteria for performance indices in terms of error function $e(t)$ are as follows:

1. Integral square error criterion:

$$\text{ISE} = \int_0^\infty e^2(t)\,dt$$

2. Integral of time weighted square error criterion

$$\text{ITSE} = \int_0^\infty te^2(t)\,dt$$

3. Integral absolute error criterion :

$$\text{IAE} = \int_0^\infty |e(t)|\,dt$$

4. Integral of time weighted absolute error criterion :

$$\text{IATE} = \int_0^\infty t\,|e(t)|\,dt$$

Where $e(t)$ is the error in the system [6].

As per above explanation the performance index will be determined as finite number for a stable system. The model used is two first order transfer functions system. Its parameters like the values of k_1, k_2, τ_1, and τ_2 are evaluated with the help of mathematical and graphical methods. This evaluation is done by Mandeep Singh and Dhruv Saksena which is for a first order transfer function and a capacitive system [7]. Then the same evaluation is done by Mandeep Singh and Abhay Sharma on two first order transfer functions. In this paper compensation is done on the basis of their evaluation of parameters and further study has been done [8].

4. SIMULATION RESULTS

As process as described in equation 1 with the actual parameters as $k_1 = 10$, $k_2 = 13$, $\tau_1 = 2$, $\tau2 = 3$ and $\tau_d = 1$ is simulated, along with the transportation delay of 1 sec is simulated on MATLAB SIMULINK as shown in figure 3. Necessary blocks are incorporated to compute and plot IAE of the uncompensated system in response to the step change loading of the system.

Case 1: On the basis of IAE

Suitable compensation is designed by estimating the parameters as proposed by Mandeep Singh and Dhruv Saksena [7] and Mandeep Singh and Abhay Sharma [8]. We have deliberately introduced a slight error in the estimated parameters. To study the effect of increasing gain

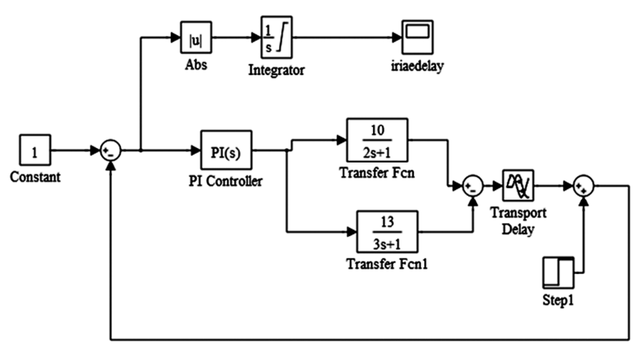

Figure 3: IAE of Process Having Uncompensated Inverse Response with Delay

of compensator *K*. the value of τ_1 and τ_2 are therefore taken as 1.5 and 2.5 respectively instead of 2 and 3. Further the value of transport delay τ_d is estimated as 1.5 instead of actual value 1. The compensated system block as simulated in MATLAB SIMULINK as shown in figure 4. The comparative graph of IAE for the uncompensated and the compensated system, as simulated for the lowest limit of *K* = 4 as shown in figure 5.

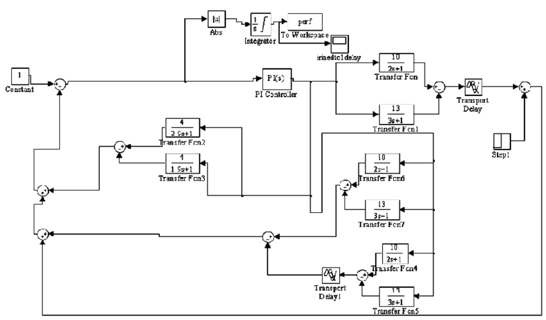

Figure 4: IAE for Dead Time Compensator with Inverse Response and a Delay

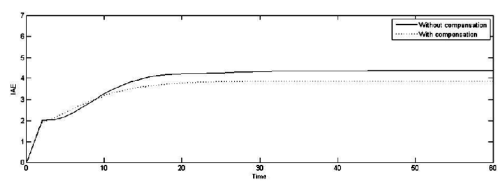

Figure 5: Comparison of IAE of Uncompensated and Compensated Systems

Table 1 shows the final IAE for different values of *K* when the parameters are exactly estimated at $\tau_1 = 2$, $\tau_2 = 3$ and $\tau_d = 1$. Table 2 shows the final IAE for different values of *K* when the parameters have a slight in accuracy deliberately introduced at $\tau_1 = 1.5$, $\tau_2 = 2.5$ and $\tau_d = 1.5$.

Table 1
Results of Inverse Response Compensation for Accurately Estimated Parameters

K	*IAE Without Compensation*	*IAE With Compensation*
4	4.351	0.9
8	4.351	0.78
12	4.351	0.698
16	4.351	0.634

Table 2
Results of Inverse Response Compensation for in Accurately Estimated Parameters

K	*Without Compensation*	*With Compensation*
4	4.351	1.226
8	4.351	3.24
12	4.351	3.44
16	4.351	3.46

5. CONCLUSION

Inverse response in any process creates a challenge for control engineers. When transportation delay is added to this process, the challenge becomes more forbidding. Many resarchers have proposed compensators for these two aspects seperately. In our scheme, the inverse response and the transport delay are taken together, compensated for these two, and the effect of increasing compensation gain (*K*) is observed. It may be concluded that if the parameters are estimated accurately, then increasing the value of *K* decreases the error. On the other hand , if the parameters are estimated inaccurately, then increasing the value of *K* increases the error. Hence it is always safer to keep the value of *K* as small as possible, though slightly higher or equal to the minimum value calculated.

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