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Dead time Compensating PID Controller Structure and Robust Tuning for Water Bath Process

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Abstract:
This paper mainly deals with the dead time compensation. Theoretically smith predictor is a good solution for the problem of system with time delay. But smith predictor is often used, since it is almost impossible to find out precise model of the system and cannot be used for unstable plants. The aim of this paper is to compensate the dead time using disturbance observer approach. This approach helps to obtain better stability and robustness. The simulation result shows that the proposed PID has faster settling time and greater advantages over the smith predictor.
Keywords: *deadtime compensation, disturbance observer, smith predictor, robustness.*

1. Introduction:
Processes with significant dead time are difficult to control using standard feedback controllers. It is because of the effect of the perturbations is not felt until a considerable time has elapsed and also, the effect of the control action takes some time to be felt in the controlled variable. The control action that is applied based on the actual error, tries to correct a situation that originated some time before. The dead time introduces an extra decrease in the system's phase which makes the process more difficult to control[4].
Dead time compensators are effective for controlling dead-time processes as they eliminate the effect of the dead time in the nominal set-point response. The smith predictor is a simple and effective controller for dead-time processes. It can offer better responses than a PID controller, but shows disturbances. It has many drawbacks like; smith predictor is unstable when primary controller is not properly tuned. It also becomes unstable when there is small mis-match in delay. The disturbance observer based deadtime compensator offers much better performance than the smith predictor. They offer better stability, performance and robustness. This is analyzed below and compared using the MATLAB simulations. Various controller characteristics are analyzed and compared to determine the efficiency of the disturbance observer based dead time compensator.

2. System description:

2.1 Water bath system:

The water bath process consist of several things mainly water tank, sensor, data acquisition system, computer, labVIEW controller and heater as shown in fig 3.1. Here thermocouple is used as the sensor. DAQ is used for inter connection between sensor and controller as well as controller and driver circuit. The thermocouple output is in terms of mille volt range so we use an amplifier circuit for increasing the voltage range. The working of the system is, when the temperature is measured by the thermocouple is converted into the voltage, which is going to the controller through DAQ. The difference between set point and actual value is applied to the controller, nothing but error.The PWM signal is produced corresponding to the 10 output voltage of the sensor.

Figure 1:Real time water bath system implementation

2.2 Block diagram:

The disturbance observer DTC is used to estimate disturbances by means of inverted nominal model. The estimated disturbance is used to correct the output value. Its analysis is given in fig.2.In the given structure Gn(s) indicate the model and V(s) a filter, f(s) indicates reference pre-filter. Reference prefilter f(s) is used to shape reference response of the closed-loop system.

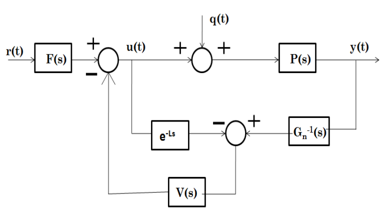


Figure 2: Block diagram of disturbance observer based method

2.3 Process model

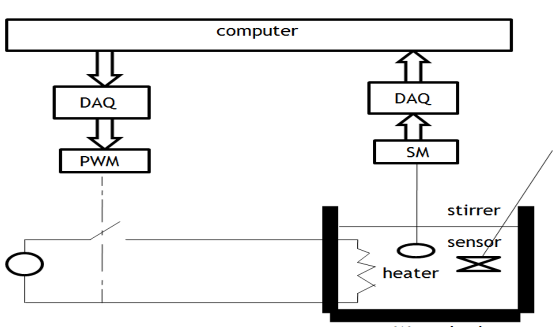


Figure 3: Process model of proposed system

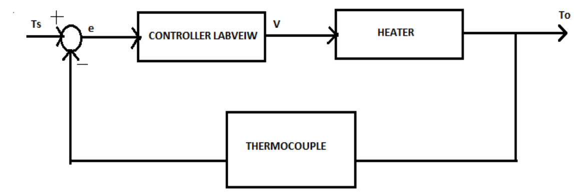


Figure 4: block diagram of proposed system

Where
PWM : Pulse Width Modulator.
DAQ : Data Acquisition Card.
Ts : Setpoint Temperature.
e : Error.
V : Voltage.
To : Observed Temperature.

3. System Identification:

3.1 Steps for performing system identification

1. Give a noticeable change in step input.
2. Observe the change in process variable and note down the steady state.
3. Find out the total change in PV (Process variable) that is going to occurs
4. Compute the value of 63.2% of PV
5. Note down the time (t1) when it pass through the value
6. Subtract this from the time (t2) When the PV starts to build up, when input change is given
7. Time constant (t) =t2-t1
8. KP= $\frac{\text{Change in steady state}}{\text{Change in input}}$
9. Time delay time td is the time taken to getting the output from the system, when we applying the input.
10. The general form of the first order transfer function is given

$$\frac{Y(s)}{X(s)} = \frac{k_p e^{-\theta s}}{ts+1}$$

According to the open loop test, the readings are listed above. The transfer function obtained from this reading is given by:

$$\frac{Y(s)}{X(s)} = \frac{0.566e^{-0.3s}}{7.5s+1}$$

4. Disturbance Observer design [6]:

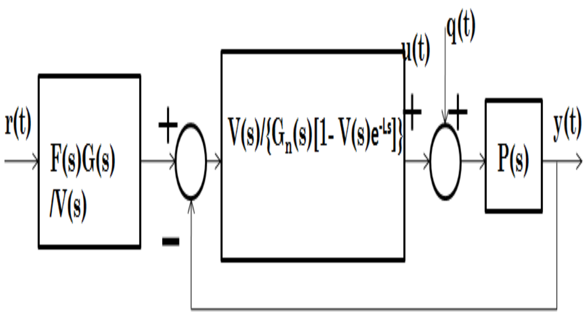


Figure 5: structure for implementation of disturbance observer.

For analysis we consider the system model

$$Y(s)=P(s)[U(s)+Q(s)]$$

Where an input disturbance used

The disturbance can be computed ideally as

$$Q(s)=P^{-1}(s)Y(s)-U(s)$$

Delayed disturbance

$$e^{-Ls}Q(s)= G_n^{-1}(s)Y(s)-e^{-Ls}U(s)$$

The estimated delayed disturbance

$$Q^{\sim}(s)=V(s)[G_n^{-1}(s)Y(s)-e^{-Ls}U(s)]$$

The nominal transfer function between the reference, the disturbance and the output of this system is given by

$$\frac{Y(s)}{R(s)} = F(s)G_n^{-1}(s)\, e^{-Ls}$$

$$\frac{Y(s)}{Q(s)} =P_n(s)[1-V(s)\, e^{-Ls}]$$

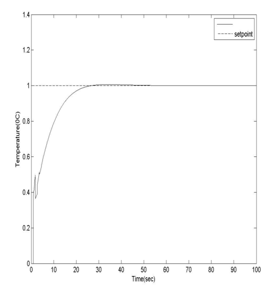
These are obtained using block diagram reduction.

In this new structure it is clear that if Gn $^{-1}$(s) has poles on the right-hand side of the s-plane, V(s) has to be designed to eliminate these poles from the controller. This condition is achieved if V(s) has the same zeros as Gn(s) on the right-hand side of the s-plane. Furthermore, for the implementation, V(s) must guarantee that V(s)/Gn(s) is proper. Thus, the relative degree of V(s) must be same as the relative degree of Gn(s)[6].

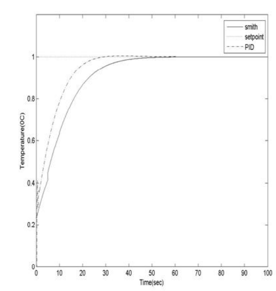
The settling time and overshoot of the set-point response can be modified with an appropriate choice of F(s) which must be proper.

6. Results and discussion:

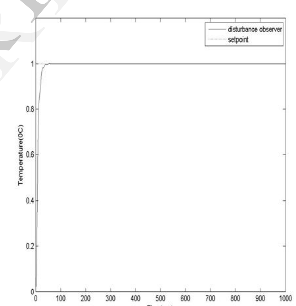
1. PID response



2. Comparison of smith predictor response with PID response



3. Disturbance observer based PID response.



4. Comparison of smith predictor response and disturbance observer based PID response

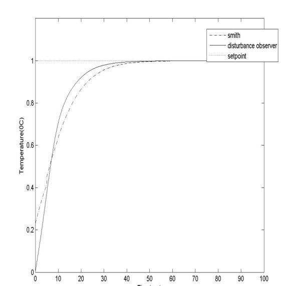


Figure 6: Responses of closed loop systems

The PID controllers are designed using Zeigler Nichol's tuning method. The smith predictor based deadtime compensator shows a better response than the PID. But the disturbance observer based dead time compensating about which this paper deals with reduces the deadtime than other two controllers.

6.1 Discussions:

The disturbance observer based deadtime compensator gives better response and compensated deadtime than the other two methods discussed in this paper. The smith predictor based dead time compensator has better deadtime compensation than the PID. Further, the smith predictor method has longer settling time and it has disturbances compared to the disturbance observer based method.

7. Conclusion and Future Work:

Deadtime compensators eliminate the effect of the dead time in the nominal set-point response, thus compensate the deadtime in processes. When the dead time is estimated with a small error, the deadtime compensator clearly allows better performance. The Smith predictor is a simple and effective controller for dead-time processes. For a smith predictor, a good trade-off between robustness and performance can be obtained by appropriate tuning of the primary controller and predictor[7]. It can offer better responses than a PID controller, mainly in the case where the dead time is dominant and well known.

The tuning of the controller for all cases is simpler with the structure of the disturbance observer approach. Furthermore, it also gives the best results. In this paper the comparison between the smith predictor and disturbance observer based deadtime compensator is done. The result shows that the disturbance observer based approach provides the best result compared to the conventional PID and smith predictor. Moreover, the disturbance observer approach is easy to analyze and tune because of the decoupling properties of its structure.

When a discrete platform is used, the disturbance observer approach is again the best option.

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