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Modified Smith Predictor Based Control Of Cascaded Chemical Reactor

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ABSTRACT
A cascade control with modified smith predictor is used for controlling an open loop unstable time delay process. It has three controllers, one is for servo response other two are for regulatory response. For two disturbance rejection controllers an analytical design method is used by proposing closed loop complementary sensitivity function. These two controllers are PID controller cascaded with second order lead/lag filter. Setpoint tracking controller is designed by using direct synthesis method. The main advantage of this control scheme is that the servo response can be decoupled from the regulatory response.
Keywords – Cascade control, Disturbance rejection, Servo response, Smith predictor, Regulatory response

I. INTRODUCTION

Cascade control usually used in process control industries-one of the most commonly used multi loop control method, for the control of parameters like temperature, pressure, flow etc. It utilizes two loops- slave loop and master loop. Slave loop is embedded within the master loop. Cascade controllers are used when single loop controllers are difficult to regulate the output in load disturbance.

The inner loop takes speeder response as compared to the outer loop because inner loop provides faster disturbance attenuation and minimizes the disturbance before they affect the primary loop. A better regulatory response is obtained by cascade control than that existing in the slave loop. But if a long time delay occurs in the outer loop it may not give the satisfactory response to setpoint changes. In order to avoid that problem a smith predictor scheme is used in the outer loop of the cascade control structure.

II. SYSTEM DESCRIPTION

2.1 Temperature process system

The temperature process is a nonlinear process whose parameters vary with respect to the process variable .In this air is drawn from atmosphere by centrifugal blower is driven past a heater grid. And the air is flowing through length of tube to atmosphere again. Process is temperature level. Control equipment measure the air temperature, compare it with the value set by the operator and generate a control signal which determine the amount of electric power delivered to correcting element.

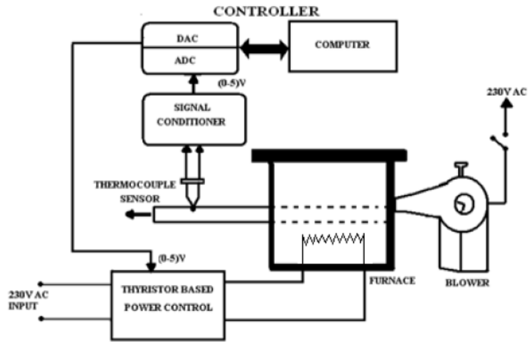

Figure1: Block Diagram of a Temperature Process

Figure 2: Hardware setup for Temperature Process

2.2 Block diagram:

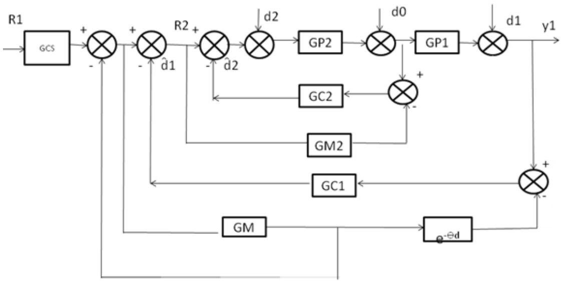

Figure 3: Block diagram of proposed method

Cascade control structure with modified smith predictor for open loop unstable process is shown Fig.3 Gp_1 and Gp_2 are primary and secondary process and Gm_1 and Gm_2 are the primary and secondary model. G_{cs} is the setpoint tracking controller for servo response, Gc_1 and Gc_2 are the disturbance rejection controller for regulatory response.

2.3 Process model

The Fig.4 shows the stirred chemical reactor where cooling water flows through reactor jacket to regulate the reactor temperature. The disturbance variables such as reactant feed temperature and feed composition is caused to change the reactor temperature. The disturbance is handled by adjusting cooling water on the inlet stream. However an increase in cooling water temperature cause a increase in reactor temperature cause the reduction in the heat removal rate.

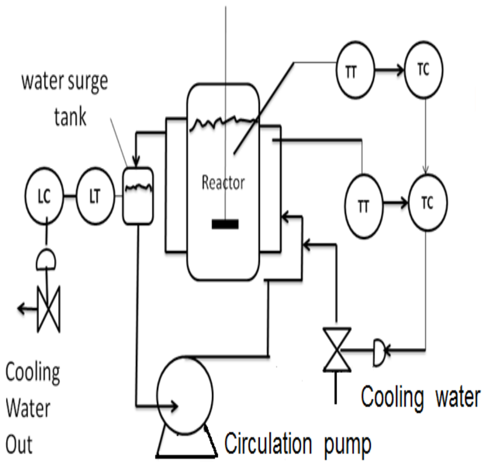

Figure 4: Process model of proposed system

If dynamic lag occur in the jacket as well as in the reactor a feedback controller for the jacket temperature whose setpoint is determined by reactor temperature controller is added for cascade control where reactor temperature controller is the primary controller and jacket temperature controller is the secondary controller.

LT : Level transmitter.
TT : Temperature transmitter
LC : Level controller
TC : temperature controller

III. MATHEMATICAL MODELLING:

The chemical reactor [2] is the process considered which is given in Figure 5.

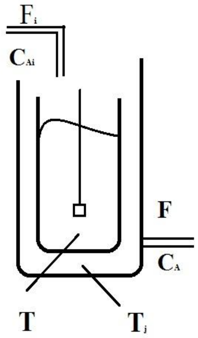

Figure 5: chemical reactor

H_A : Partial molar enthalpies
ρ_i, ρ : Density of inlet and outlet
n_A : Number of moles of A in the mixture
F_i, F : Volumetric flow rates of inlet and outlet
R : Rate of reaction per unit volume
C_p : Specific heat energy
P : Potential energy
K : Kinetic energy
U : Internal energy
E : Total energy

Using the law of conservation of mass,

$$\left[\frac{\text{accumulation of total mass}}{\text{time}}\right]=\left[\frac{\text{input of total mass}}{\text{time}}\right]-\left[\frac{\text{output of total mass}}{\text{time}}\right]$$

$$\frac{d}{dt}(\rho V)=\rho_i-\rho \text{.............(1)}$$

Using law of conservation of energy

$$\left[\frac{\text{accumulation of total energy}}{\text{time}}\right]=\left[\frac{\text{input of total energy}}{\text{time}}\right]-\left[\frac{\text{output of total energy}}{\text{time}}\right]-\left[\frac{\text{energy removed by coolant}}{\text{time}}\right]$$

$$\frac{dH}{dt}=\rho_i F_i h_i(T_i)-\rho F h(T)-Q \text{ ……………..(2)}$$

Summarizing the above steps in the modeling of a chemical reactor, we have

State Variables are V, T, C_A

State Equations are

$$\frac{dV}{dt} = F_i - F \text{...}(3)$$

$$\frac{dC_A}{dt} = \frac{F_i}{V}\left(C_{Ai} - C_A\right) - k_{0e}^{-E/RT} C_A - \frac{Q}{\rho C_p V} .(4)$$

IV. CONTROLLER DESIGN:

4.1 Design of slave loop controller:

For disturbance rejection the nominal complementary sensitivity function for slave loop is

$$T_{dslave} = \frac{\hat{d}_2}{d_2} = \frac{G_{c2}Gp_2}{1 + Gc_2Gp_2} \text{............................}(5)$$

The asymptotic constraint for rejecting step load disturbance is

$$\lim_{s \to 1/\tau_2} (1 - T_{dslave}) = 0 \text{.....................................}(6)$$

should be satisfied. Based on IMC theory complimentary sensitivity function is

$$T_{dslave} = \frac{\alpha_2 s + 1}{(\lambda_2 s + 1)^2} e^{-\theta 2s} \text{..............................}(7)$$

The inner loop controller

$$G_{c2} = \frac{T_{dslave}}{1 - T_{dslave}} \frac{1}{G_{p2}} \text{……………………}(8)$$

$$G_{p2} = \frac{k_2}{\tau_2 s + 1} e^{-\theta_2 s} \text{……………………………}(9)$$

And finally the inner loop controller

$$G_{c2} = \frac{(\alpha_2 s + 1)(\tau_2 s + 1)}{k_2[(\lambda_2 s + 1) - (\alpha_2 s + 1)e^{-\theta_2 s}]} \text{………}(10)$$

4.2. Design of master loop controller:

For disturbance rejection nominal regulatory response transfer function for master loop is

$$T_{dslave} = \frac{G_{c1}G_{p1}G_{p2}}{1 + G_{c1}G_{p1}G_{p2}} \text{...........................}(11)$$

The asymptotic constraint for rejecting load disturbance is

$$\lim_{s \to 1/\tau_1} (1 - T_{dslave}) = 0 \text{................................}(12)$$

Based on the IMC the desired closed loop complementary sensitivity [3] function is

$$T_{dslave} = \frac{\alpha_1 s + 1}{(\lambda_1 s + 1)^3} e^{-\theta ms} \text{...........................}(13)$$

and $\theta_m = \theta_{1+}\theta_2$. The primary process

$$G_{p1} = \frac{k_1}{\tau_1 s - 1} e^{-\theta 1s} \text{………………………………...}(14)$$

Finally the primary controller from the above result

$$G_{c1} = \frac{(\alpha_1 s + 1)(\tau_1 s - 1)(\tau_2 s + 1)}{k_1 k_2[(\lambda_1 s + 1)(\alpha_1 s + 1)e^{-\theta ms}]} \text{.........}(15)$$

4.3 Design of setpoint tracking controller:

The setpoint response transfer function is taken in the form of low pass filter with time delay for a unit step setpoint. The sepoint tracking controller G_{cs} is obtained as

$$G_{cs} = \frac{\tau_1 \tau_2 s + (\tau_1 - \tau_2)s + k_1 k_2 - 1}{k_1 k_2(\lambda_{cs} + 1)} \text{...........}(16)$$

V. RESULTS AND DISCUSSIONS:

MATLAB is a high performance programming language for technical computation. It integrates computation, visualization and programming in an easy to use environment.

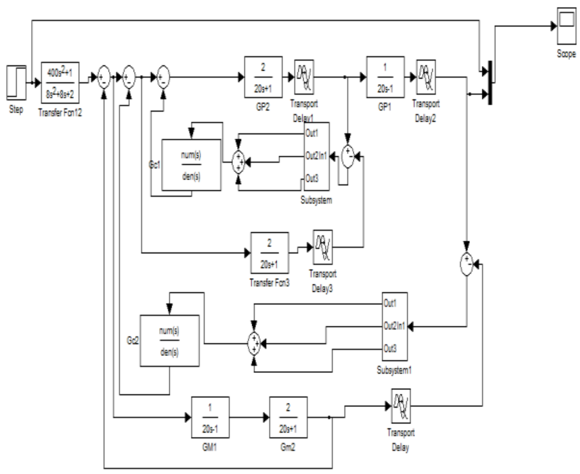

Fig6: Block diagram of cascade with smith predictor

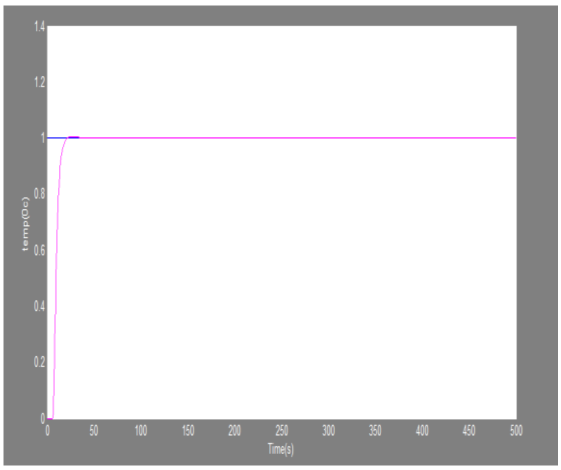

Fig7: Nominal response of cascade with smith predictor

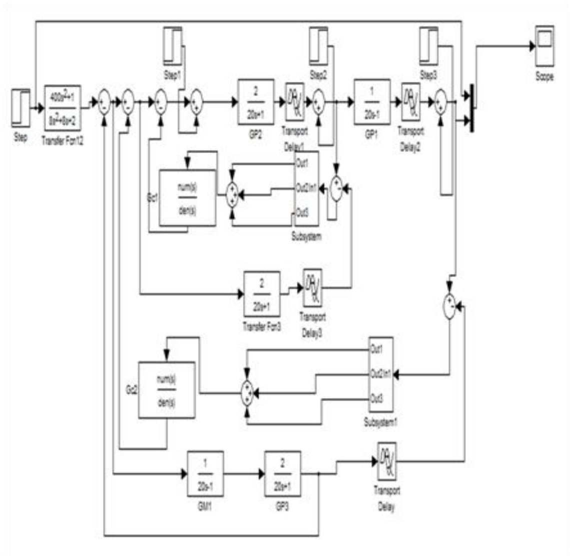

Fig8: Cascaded smith with disturbance

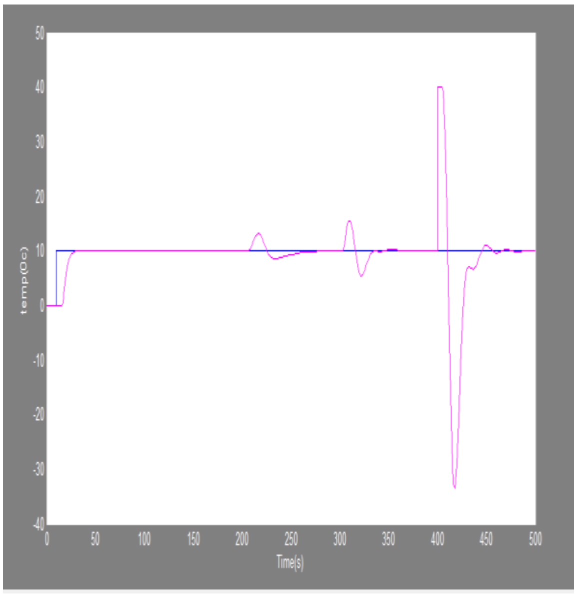

Fig9: Response of cascaded smith with disturbance

5.1 Explanation:

The two controllers here are in the form of PIDF ie.PID controller in series with lead/lag filter. These two controllers rejects disturbances entering in the two loops.ie the proposed control scheme gives smoother control signals. It is clear that this scheme provides robust performance in load disturbance rejection.

VI. CONCLUSION AND FUTURE WORK:

The controlling problem of an open loop unstable process with time delay has been avoided by proposing this control scheme. The cascade control structure has ability to improve regulatory response and the modified smith predictor compensate the dead time.

This project can be extended using PSO algorithm in order to obtain optimized results.

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