<u>National Institute of Technology, Silchar.</u>

<u>Summer Internship</u>

<u>Title of the Project:</u> Survey of Two Degrees of Freedom Control Schemes

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Abstract

The project deals with the survey of various two degrees of freedom control schemes. A lot of work has been done on the given topic. In this article, the gist of various research papers dealing with the same topic has been provided. A 1DOF control scheme produces a large overshoot. Hence, a 2DOF control scheme has gained more popularity. In this work, a plant design of the research paper titled "2DOF Robust PID Controller Design for Industrial Large Time-constant Plus Dead-Time Processes" has been solved for values of its various parameters.

Introduction

The degree of freedom (DOF) in a control system is defined as the number of closed-loop transfer functions that can be handled independently. It has two main objectives (i.e., set-point tracking and disturbance rejection). 2DOF system mainly has two components, namely serial or main compensator, and feed-forward controller.

A 2-DOF PID controller is capable of fast disturbance rejection without a significant increase of overshoot in setpoint tracking. 2-DOF PID controllers are also useful to mitigate the influence of changes in the reference signal on the control signal.

Survey:

Surveying through various papers on 2DOF control scheme, we find the given results:

1. The paper titled "Integral Criteria for Optimal Tuning of PI/PID Controllers for Integrating Processes" deals with the tuning formulas for PI/PID controllers for integrating processes. In this paper, the controller parameters are obtained by minimizing various integral performance index. A new algorithm called Bacterial Foraging strategy is used for minimization to avoid the local minima in the optimization procedure. A large overshoot is reduced by using a set-point filter.

2. The paper titled "Modified Smith predictor and controller for time-delay processes" deals with modified Smith predictor control scheme for controlling stable, integrating and unstable processes with time delay. The two degrees-of-freedom control structure along with its simple tuning rules result in improved servo and regulatory performances by

independently tuning a single control parameter. A property of the proposed control scheme is that it decouples the setpoint response from the load response. The H_2 optimal control method is used to design the setpoint tracking controller and an optimal IMC filter is proposed to design a PID controller that produces good disturbance rejection performances. Simulation results show the simplicity and superiority of the proposed method compared with some reported methods.

3. The paper titled "I–PD controller for integrating plus time-delay processes" deals with an integral–proportional derivative (I–PD) control strategy for integrating plus time-delay processes. According to the scheme, an inner PD loop and an outer I-loop takes care of the servo as well as the regulatory action. The formulas required for tuning of the proposed controller are derived in terms of gain margin, phase margin, and critical gain. Moreover, pole-placement and frequency loop-shaping design methods are also determined for designing the I–PD controller. The simulation results show that the proposed I–PD controller is superior to the conventional P/PI/PID ones for integrating processes. The design is validated through experiments on a temperature control process.
4. The paper titled "Two-Degree-of-Freedom PID Controllers" deals with the important results about 2DOF PID controllers, including equivalent transformations, various explanations about the effect of the 2DOF structure, relation to the preceded derivative PID and I-PD controllers, and an optimal tuning method.

Observation

In order to control a stable process, no challenge is encountered. But controlling astable processes pose various challenges. The processes which contain a pole on the origin give a large overshoot in set-point tracking. Hence, to resolve this problem a 2DOF control is employed. This control comprises two loops: one inner and one outer. The inner loop shifts the pole from the origin to the desired location in order to make the system stable. The outer loop takes care of tracking system responses.

A 1DOF control scheme is shown. Here the process G□(s) is controlled with the help of Gc(s) to achieve the desired set-point at the output.

Let us consider a process as:

$$Gp(s) = N(s)/D(s).e^{-Ls} \tag{1}$$

The output equation for a PID controller can be given as:

$$Gc(s) = K_1 + k_2/s + k_3 * s \qquad (2)$$

Design is proposed for a PID controller. Here, the PID design has been carried out with the proper selection of phase margin and gain crossover frequency. The aim of this method is to calculate controller gain such that the desired phase margin and gain crossover frequency can be obtained for the open-loop transfer function G(s).

$$G(s) = Gc(s) * Gp(s) \qquad (3)$$

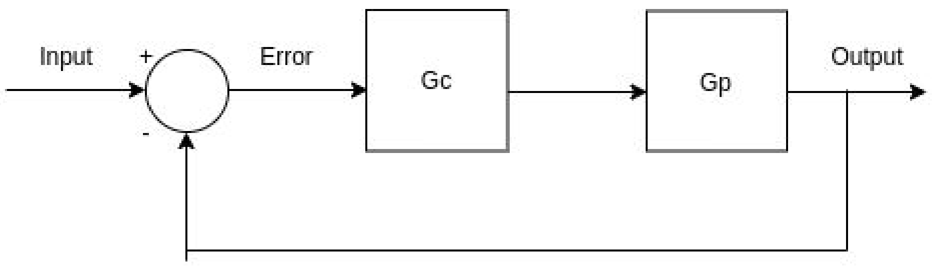

Fig: 1 DOF Feedback Control Scheme

With s = jω, the open-loop transfer function may be represented as:

$$G(j\omega) = a + jb \qquad (4)$$

Where a and b are the real and imaginary part of G(jω). Now, the stability margin of the above system can be expressed as:

$$Re[G(j\omega)] = -\cos\varphi \qquad (5)$$

$$Im[G(j\omega)] = -\sin\varphi \qquad (6)$$

$$\frac{dRe[G(j\omega)]}{d\omega} = 0 \qquad (7)$$

Note that, (7) is an additional equation that has been taken to match the equation and unknown variable number.

Here, φ and ω are the phase margin and gain crossover frequency respectively. Now, with the proper choice of the tuning parameters φ and ω, one may obtain the controller parameters for a general class of processes. Even though, this method yields good performance and robustness for a general class of processes, a poor regulatory response have been observed for the processes having a large time constant or integrator in it.

In order to overcome the above short-comings, the design has been extended to a 2DOF control. The structure is shown in Fig.

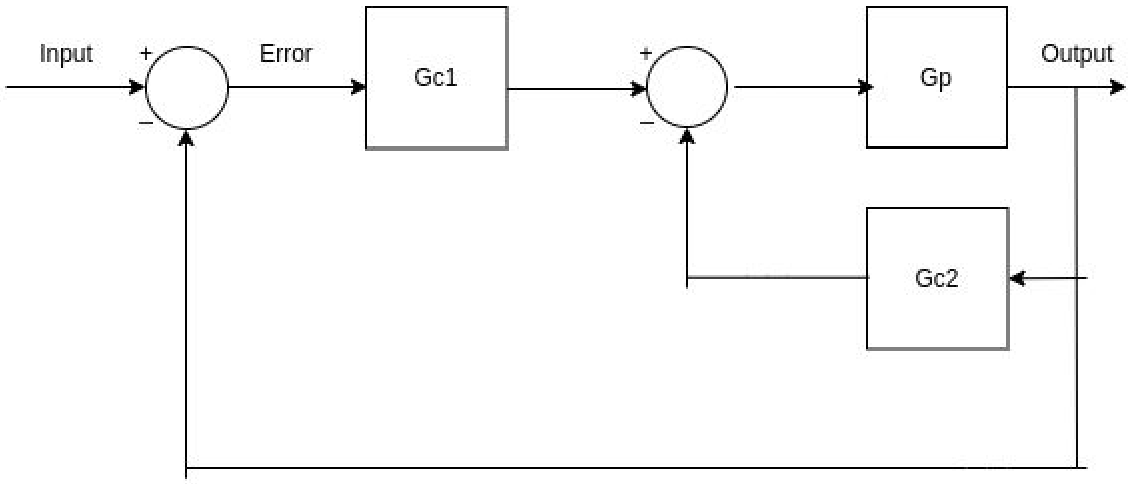

Fig: 2DOF Control Scheme

Here, Gp(s) is considered as a first-order plus dead time process having large time-constant(τ) and can be expressed as:

$$Gp(s) = k/(\tau s + 1) * e^{-Ls} \tag{8}$$

$Gc_2(s)$ is a PD controller used in the inner-loop to shift the pole of the process to the desired position and then the entire inner-loop is to be controlled by an outer-loop PID controller $Gc_1(s)$. The PD controller is chosen as:

$$Gc_2(s) = P + Ds \tag{9}$$

The outer-loop PID controller can be chosen as same as (2), i.e,

$$Gc_1(s) = Gc(s) = K_1 + k_2/s + k_3 * s \tag{10}$$

Now, to achieve the desired responses, the choice of the controller parameters is important.

The Controller Design

A PD controller is designed with pole-placement for the inner-loop. Then, a PID controller is to be designed for the entire loop.

A. Design of $Gc_2(s)$:

The main aim of the PD controller in the inner-loop is to shift the pole of the large time constant process to the desired locations. Considering $Gc_2(s)$ in feedback with plant Gp(s), the closed-loop characteristic equation can be obtained as:

$$s^2 + (\tau + L + kD)/\tau L * s + (1 + P)/\tau L = 0, \tag{11}$$

To achieve the above closed-loop characteristic equation, the delay term has approximated with first-order Taylor series expansion as:

$$e^{-Ls} \cong 1/(Ls + 1) \tag{12}$$

Considering the desired closed-loop characteristic equation as:

$$s^2 + \beta_1 s + \beta_2 = 0 \tag{13}$$

One can obtain controller parameters as:

$$P = \beta_2 \tau L - 1 \tag{14}$$
$$D = (\beta_1 \tau L - \tau - L)/k \tag{15}$$

For the above design, the choice of the β_is is important to attain desired closed-loop performance. For a second-order underdamped system, $\beta\omega\tau_{1\,2\,3}\zeta$□ $\beta_1 = 2\zeta\omega n$ and $\beta_2 = \omega^2 n$. Here, $\zeta = 0.7$ can be chosen. β_2 is now a function of settling time (Ts) and Ts is proportional to time-constant (τ) expressed as:

$$Ts = ks\tau = ks/(0.7 * \omega n) \tag{16}$$

where the natural frequency is denoted by ωn and ks > 0 is to be chosen. With a proper choice of Ts one may obtain $\beta_3 = \omega n^2$.

B. Design of $Gc_1(s)$

Since the poles of the Gp(s) have already been shifted to the desired location by the inner-loop PD controller. So, the PID controller design has to be carried out for the inner-loop $Gc_1(s)$. Where,

$$Gc_1(s) = k(Ls + 1)/[\tau Ls^2 + (\tau + L + kD)s + (1 + P)] * e^{-Ls} \tag{17}$$

Let us consider a process with a large time constant plus dead time as:

$$Gp(s) = 1/(500s + 1) * e^{-5s} \tag{18}$$

The specifications are Ts = 25, ζ = 0.7 and ks = 2.6. With the given specifications, the PD controller parameters have been obtained as P = 54.18 and D = 15. Now, if $\varphi = 60^\circ$ and $\omega = 0.1$, outer-loop PID controller parameters have been obtained as $k_1 = 28.5$, $k_2 = 5.39$ and $k_3 = 82.7$. With the same setting, the controller parameters for the process in (18) have been obtained as $k_1 = 50$, $k_2 = -0.0305$, and $k_3 = -24.8$.

Conclusion:

In this report, a survey summary of 4 research papers has been drafted. An interpretation of the paper titled “2DOF Robust PID Controller Design for Industrial Large Time-constant Plus Dead-Time Processes” has been also compiled. The fact that a 2DOF control scheme is better than a 1DOF control has been validated with the help of explicit controller parameters.

References:

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