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Design of IMC based PID Controller and Optimization of Proposed Process Control

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***Abstract*: The Internal Model Control (IMC)-based approach is one of the controller designing method used in control applications in industries. Also the IMC-PID controller allows good set-point tracking but sulky disturbance response especially for the process with a small time-delay/time-constant ratio. But, for many process control applications, disturbance rejection for the unstable processes is much more important than set point tracking. Hence, controller design that emphasizes disturbance rejection rather than set point tracking is an important design problem that needs to be taken into consideration. This paper presents an approach to IMC and IMC based PID controller to be used in industrial process control applications, which states that an optimum filter structure exists for each specific process model so as to give the best PID performance.**

***Keywords*: IMC, PID, Time Delay.**

1. Introduction

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple, straightforward manner. As the name suggests, PID algorithm consists of three basic coefficients; proportional, integral and derivative which are varied to get optimal response. Closed loop systems, the theory of classical PID and the effects of tuning a closed loop control system can be implemented by the PID toolset.

A. Control system

The basic idea behind a PID controller is to read a sensor, then compute the desired actuator output by calculating proportional, integral, and derivative responses and summing those three components to compute the output.

B. PID theory

The PID theory is as stated below:

1) Proportional response

The proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The proportional gain (Kc) determines the ratio of output response to the error signal. For instance, if the error term has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate. If Kc is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.

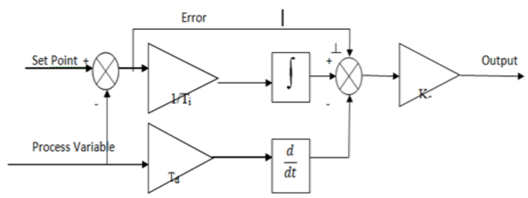

Fig. 1. Block diagram of a basic PID control algorithm.

2) Integral response

The integral component sums the error term over time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process variable and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero.

3) Derivative response

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing the derivative time (Td) parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time (Td), because the Derivative Response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable.

4) Tuning

The process of setting the optimal gains for P, I and D to get an ideal response from a control system is called tuning. The

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gains of a PID controller can be obtained by trial and error method. Once an engineer understands the significance of each gain parameter, this method becomes relatively easy. In this method, the I and D terms are set to zero first and the proportional gain is increased until the output of the loop oscillates. As one increases the proportional gain, the system becomes faster, but care must be taken not make the system unstable. Once P has been set to obtain a desired fast response, the integral term is increased to stop the oscillations. The integral term reduces the steady state error, but increases overshoot. Some amount of overshoot is always necessary for a fast system so that it could respond to changes immediately. The integral term is tweaked to achieve a minimal steady state error. Once the P and I have been set to get the desired fast control system with minimal steady state error, the derivative term is increased until the loop is acceptably quick to its set point. Increasing derivative term decreases overshoot and yields higher gain with stability but would cause the system to be highly sensitive to noise. Often times, engineers need to tradeoff one characteristic of a control system for another to better meet their requirements. The Ziegler-Nichols method is another popular method of tuning a PID controller. It is very similar to the trial and error method wherein I and D are set to zero and P is increased until the loop starts to oscillate. Once oscillation starts, the critical gain Kc and the period of oscillations Pc are noted. The P, I and D are then adjusted as per the tabular column shown below.

Table 1
PID values

Control	P	Ti	Td
P	0.5Kc	-	-
PI	0.45Kc	Pc/1.2	-
PID	0.60Kc	0.5Pc	Pc/8

2. Design and implementation of PID controllers

PID tuning and implementation involve several tasks that include:

- Selecting an appropriate PID algorithm (P, PI, or PID)
- Tuning controller gains
- Simulating the controller against a plant model
- Implementing the controller on a target processor

A. IMC Based PID controllers

1) IMC Background

Internal Model Control (IMC) is a commonly used technique that provides a transparent mode for the design and tuning of various types of control. The ability of proportional-integral (PI) and proportional-integral-derivative (PID) controllers to meet most of the control objectives has led to their widespread acceptance in the control industry. The Internal Model Control (IMC)-based approach for controller design is one of them using IMC and its equivalent IMC based PID to be used in control applications in industries. It is because, for practical applications or an actual process in industries PID controller algorithm is simple and robust to handle the model inaccuracies and hence using IMC-PID tuning method a clear trade-off between closed-loop performance and robustness to model inaccuracies is achieved with a single tuning parameter. Also the IMC-PID controller allows good set-point tracking but sulky disturbance response especially for the process with a small time-delay/time-constant ratio. But, for many process control applications, disturbance rejection for the unstable processes is much more important than set point tracking. Hence, controller design that emphasizes disturbance rejection rather than set point tracking is an important design problem that has to be taken into consideration. An optimum IMC-PID controller can be designed using IMC filter for better set-point tracking of unstable processes. The controller works for different values of the filter tuning parameters to achieve the desired response As the IMC approach is based on pole zero cancellation, methods which comprise IMC design principles result in a good set point responses. However, the IMC results in a long settling time for the load disturbances for lag dominant processes which are not desirable in the control industry. Several transfer functions for the model of the actual process or plant can be used as we have exactly little or no knowledge of the actual process which incorporates within it the effect of model uncertainties and disturbances entering into the process. Also, the parameters of the physical system vary with operating conditions and time and hence, it is essential to design a control system that shows robust performance in the case of the above mentioned situations. Then the IMC controller is tuned for different values of the filter tuning factor. Since all the IMC-PID approaches involve some kind of model reduction techniques to convert the IMC controller to the PID controller so approximation error usually occurs. This error becomes severe for the process with time delay. For this transfer functions with significant time delay or with non-invertible portions can be taken i.e. containing RHP poles or the zeroes. Here different techniques like factorization are being used to get rid of these error containing stuffs. It is because if these errors are not removed then even if IMC filter gives best IMC performance but structurally causes a major error in conversion to the PID controller, then the resulting PID controller could have poor control performance. IMC and IMC based PID controller can be used in industrial process control applications and there exists the optimum filter structure for each specific process model to give the best PID performance. For a given filter structure, as λ decreases, the inconsistency between the ideal and the PID controller increases while the nominal IMC performance improves. It indicates that an optimum λ value also exist which compromises these two effects to give the best performance. Thus the best filter structure is the filter that gives the best PID performance for the optimum λ value. In process control applications, model based control systems are often used to track set points and reject low disturbances. The internal model control (IMC) philosophy relies on the internal model principle which states that if any control system contains within it, implicitly or explicitly, some representation of the process to be controlled then a perfect control is easily achieved. In particular, if the control scheme has been developed based on the exact model of the process then perfect control is theoretically possible.

Fig. 2. General Open loop control system

For above open loop control system:
Output = Gc .Gp. Set-point (multiplication of all three parameters)
Gc = controller of process
Gp = actual process or plant
Gp* = model of the actual process or plant
A controller Gc is used to control the process Gp. Suppose Gp* is the model of Gp then by setting:
Gc =inverse of Gp* (inverse of model of the actual process)
And if
Gp = Gp* (the model is the exact representation of the actual process)
And if Gp = Gp* (the model is the exact representation of the actual process)

Now it is clear that for these two conditions the output will always be equal to the set point. It show that if we have complete knowledge about the process (as encapsulated in the process model) being controlled, we can achieve perfect control.

3. Conclusion

The IMC provides a transparent frame work for control system design and tuning. The IMC based PID controller design is simple and robust to handle the model uncertainties and disturbances and less sensitive to noise than PID controller for an actual process in industries. The IMC based PID controllers design results in only one tuning parameter which is closed loop time constant λ IMC filter factor. The IMC based PID tuning parameters are then a function of closed loop time constant. The selection of the closed-loop time constant is directly related to the robustness sensitivity to model error of the closed-loop system. The IMC based PID design procedure can be implemented in industrial processes using existing PID control equipment. The IMC based PID controller design is used for open loop unstable processes because the IMC suffers from internal stability and also various tuning parameters have been found based on the different orders of transfer functions. The standard IMC filter from $f(s) = 1 / (\lambda s + 1)$ shows good set point tracking. Thus IMC based PID controller is able to compensate for disturbances and model uncertainty while open loop control is not. IMC is also detuned to assure stability even if there is model uncertainty.

Future Scope

The IMC based PID controller design is conventional controller. So due to speed in their execution, accuracy of control, ease of configuration, low energy consumption, probability etc, artificial intelligence based controllers such as Fuzzy logic based controllers and Artificial Neural Network based controller can be used.

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