An Approach to design Proportional Integral Derivative Controller using Internal Model Control for Optimisation of proposed Process Control

Thesis submitted in partial fulfilment of the requirement for the award of
Degree of

MASTER OF ENGINEERING

In
Electronic Instrumentation and Control Engineering

Submitted By
Bhavi Bhatia

(801151009)

Under the Guidance of

Dr. Gagandeep Kaur

Assistant Professor

July 2013
Department of Electrical and Instrumentation Engineering,
Thapar University,
Patiala
(Established under the section 3 of UGC act, 1956)
Patiala, 147004

DEDICATED

TO

MY PARENTS

CERTIFICATE

I hereby certify that the work being presented in this thesis entitled **"An Approach to design PID Controller using IMC for Optimisation of proposed Process Control"** in partial fulfilment of award of degree of **Master of Engineering in Electronic Instrumentation and Control,** submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala, is an authentic record of my own work carried under the supervision of **Dr. Gagandeep Kaur,** Assistant Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, Punjab.

Bhavi Bhatia

Date: 15-7-2013

Bhavi Bhatia

801151009

I certify that the above statement made by the student is correct to the best of my knowledge and belief.

Date: 15-7-2013

Dr. Gagandeep Kaur

Assistant Professor Department of
Electrical and Instrumentation
Engineering
Thapar University, Patiala,
Punjab

Countersigned By

S. Ghosh

Dr. Smarajit Ghosh

Head of Department
Department of Electrical and
Instrumentation Engineering
Thapar University, Patiala,
Punjab

Dr. S.K. Mohapatra

Dean of Academic Affairs
Thapar University, Patiala,
Punjab

ACKNOWLEDGEMENT

First of all, I render my gratitude to the ALMIGHTY who bestowed self-confidence, ability and strength in me to complete this work. Without his grace this would never come to be today's reality.

With deep sense of gratitude I would like to thank our College Director, **Dr. K.K. Raina** for his valuable support. I am also thankful to our Head of the Department, **Dr. Smarajit Ghosh** as well as, the entire faculty and staff members of Electrical and Instrumentation Department who devoted their valuable time and helped me in all the possible ways towards successful completion of this work. I would like to express my deep gratitude to **Dr. Gagandeep Kaur,** Assistant Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala for her patient guidance and support throughout this dissertation work. I am truly fortunate to have the opportunity to work with her. I am greatly indebted to all my friends, who have graciously applied themselves to the task of helping me with ample morale support and valuable suggestions. Finally, I would like to thank my parents for their years of unyielding love and encouragement. They have always wanted the best for me and I admire their determination and sacrifice.

Bhavi Bhatia

Bhavi Bhatia

(801151009)

ABSTRACT

The Internal Model Control (IMC)-based approach is one of the controller designing method 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.

In this dissertation, we propose an optimum IMC filter to design an IMC-PID controller for better set-point tracking of unstable processes. The proposed 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.

Thus in our approach to IMC and IMC based PID controller to be used in industrial process control applications, 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 what we mean by the best filter structure is the filter that gives the best PID performance for the optimum λ value.

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CHAPTER 1

INTRODUCTION

1.1 Overview of PID controller

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 proportional integral derivative 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.

Proportional integral derivative algorithm consists of three basic coefficients; proportional, integral and derivative which are varied to get optimal response. Closed loop systems the theory of classical proportional integral derivative and the effects of tuning a closed loop control system can be implemented by the proportional integral derivative toolset present in MATLAB.

1.1.1Control System

The basic idea behind a proportional integral derivative 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. A closed loop system is and some of the terminologies associated with it explained below.

Closed Loop System

In a typical control system the process variable is the system parameter that needs to be controlled such as temperature (ºC), pressure (psi), or flow rate (liters/minute). A sensor is used to measure the process variable and provide feedback to the control system.

The set point is the desired or command value for the process variable, such as 100 degrees Celsius in the case of a temperature control system. The difference between the process variable and the set point is used by the control system algorithm compensator to determine the desired actuator output to drive the system or plant. If the measured temperature process variable is 100 ºC and the desired temperature set point is 120 ºC, then the actuator output specified by the control algorithm might be to drive a heater. Driving an actuator to turn on a heater causes the system to become warmer, and results in an increase in the temperature process variable. This is called a closed loop control system because the process of reading sensors to provide constant feedback and calculating the desired actuator output is repeated continuously and at a fixed loop rate as illustrated in Fig. 1.1.

In many cases the actuator output is not the only signal that has an effect on the system. In a temperature chamber there might be a source of cool air that sometimes blows into the chamber and disturbs the temperature. Such a term is referred to as disturbance. The design of the control system is such that the effect of disturbances on the process variable becomes minimum.

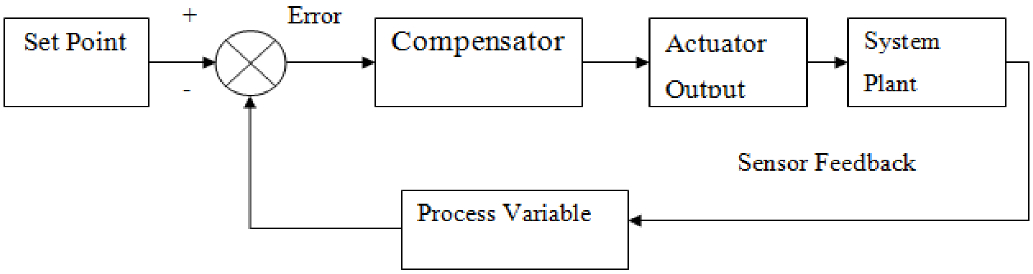

Fig. 1.1 Block diagram of a typical closed loop system.

1.1.2 Definition of Terminologies

The control design process begins by defining the performance requirements. Control system performance is often measured by applying a step function as the set point command variable, and then measuring the response of the process variable. Commonly, the response is quantified by measuring defined waveform characteristics. Rise Time is the amount of time the system takes to go from 10% to 90% of the steady-state or final value. Percent Overshoot is the amount that the process variable overshoots the final value expressed as a percentage of the final value. Settling time is the time required for the process variable to settle to within a certain percentage commonly 5% of the final value. Steady-State Error is the final difference between the process variable and set point. The exact definition of these quantities will vary in industry and academia.

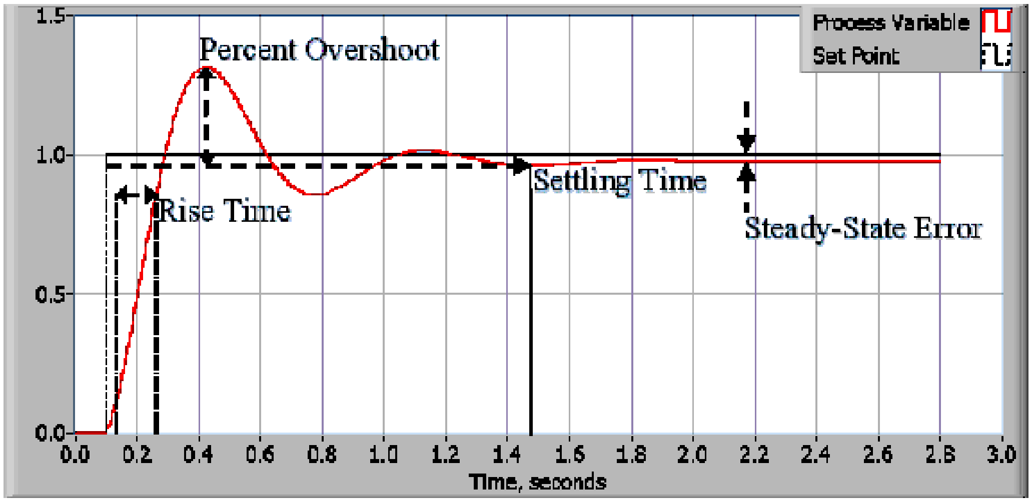

Fig. 1.2 Response of a typical proportional integral derivative closed loop system.

After using one or all of these quantities to define the performance requirements for a control system it is useful to define the worst case conditions in which the control system will be expected to meet these design requirements. There is a disturbance in the system that affects the process variable or the measurement of the process variable. It is important to design a control system that performs satisfactorily during worst case conditions. The measure of how well the control system is able to overcome the effects of disturbances is referred to as the disturbance rejection of the control system.

The response of the system to a given control output may change over time or in relation to some variable in some cases. A nonlinear system is a system in which the control parameters that produce a desired response at one operating point might not produce a satisfactory response at another operating point. For instance a chamber partially filled with fluid will exhibit a much faster response to heater output when nearly empty than it will when nearly full of fluid. The measure of how well the control system will tolerate disturbances and nonlinearities is referred to as the robustness of the control system.

Some systems exhibit an undesirable behavior called dead time. Dead time is a delay between when a process variable changes and when that change can be observed. If a temperature sensor is placed far away from a cold water fluid inlet valve it will not measure a change in temperature immediately if the valve is opened or closed. Dead time can also be caused by a system or output actuator that is slow to respond to the control command for instance a valve that is slow to open or close. A common source of dead time in chemical plants is the delay caused by the flow of fluid through pipes.

Loop cycle is also an important parameter of a closed loop system. The interval of time between calls to a control algorithm is the loop cycle time. Systems that change quickly or have complex behavior require faster control loop rates.

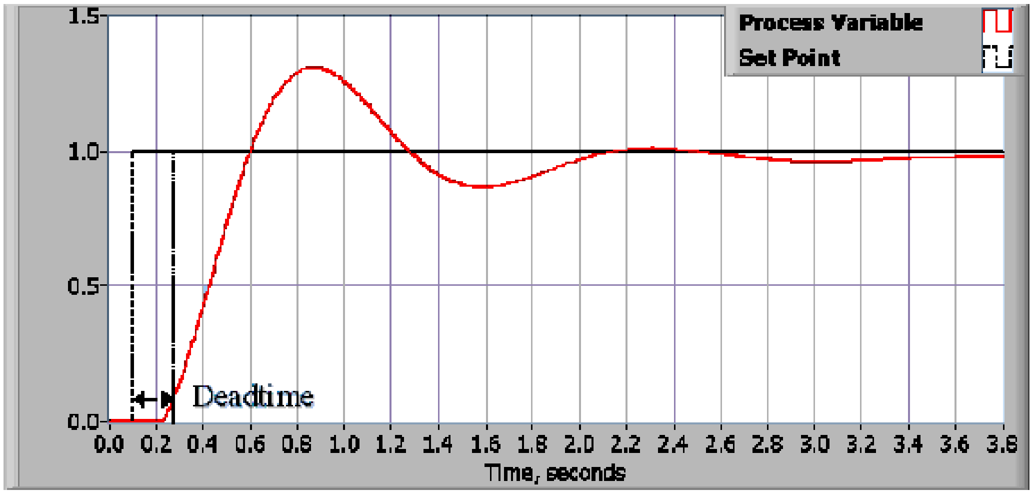

Fig. 1.3 Response of a closed loop system with deadtime.

Once the performance requirements have been specified, it is time to examine the system and select an appropriate control scheme. In the vast majority of applications a proportional integral derivative control will provide the required results.

1.1.3. Proportional Integral Derivative Theory

The proportional integral derivative theory is as stated below:

1.1.3.1Proportional 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 (K_c) determines the ratio of output response to the error signal. If the error term has a magnitude of 10 a proportional gain of 5 would produce a proportional response of 50. Increasing the proportional gain will increase the speed of the control system response. If the proportional gain is too large, the process variable will begin to oscillate. If K_c is increased further the oscillations will become larger and the system will become unstable and may even oscillate out of control.

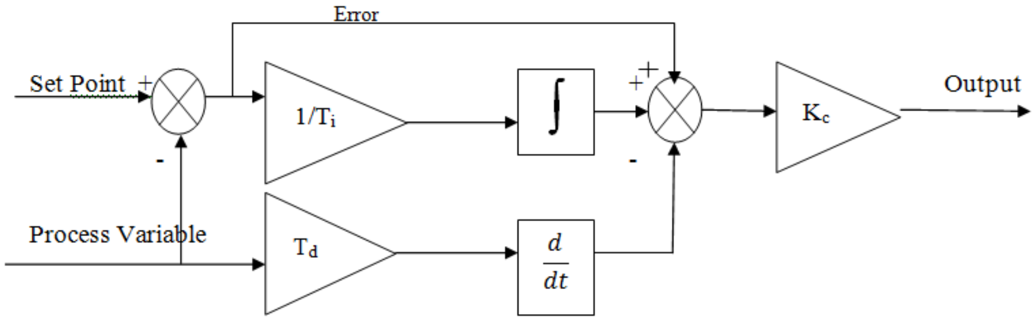

Fig. 1.4 Block diagram of a basic proportional integral derivative control algorithm.

1.1.3.2Integral 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.

1.1.3.3 Derivative Response

The derivative component causes the output to decrease if the process variable is increasing proportional integral derivative. The derivative response is proportional to the rate of change of the process variable. Increasing the derivative time T_d 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 T_d 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

1.1.4. 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. There are different methods of tuning of which the guess and check method and the Ziegler Nichols method will be discussed.

The gains of a proportional integral derivative 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 proportional integral derivative 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 K_c and the period of oscillations P_c are noted. The P, I and D are then adjusted as per the tabular column shown below.

Table 1.1 Ziegler-Nichols tuning, using the oscillation method

Control	P	Ti	Td
P	0.5Kc	-	-
PI	0.45Kc	Pc/1.2	-
Proportional Integral Derivative	0.60Kc	0.5Pc	Pc/8

1.1.5 Design and Implementation of Proportional Integral Derivative Controllers

Proportional integral derivative tuning and implementation involve several tasks that include:

i. Selecting an appropriate proportional integral derivative algorithm (P, PI, or PID)
ii. Tuning controller gains
iii. Simulating the controller against a plant model
iv. Implementing the controller on a target processor

1.2 Internal Model Control Based Proportional Integral Derivative Controllers

1.2.1 Internal Model Control Background

Internal model control 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 and proportional integral derivative controllers to meet most of the control objectives has led to their widespread acceptance in the control industry. The internal model control based approach for controller design is one of them using internal model control and its equivalent internal model control based proportional integral derivative to be used in control applications in industries. It is because for practical applications or an actual process in industries proportional integral derivative controller algorithm is simple and robust to handle the model inaccuracies and hence using internal model control proportional integral derivative tuning method a clear trade-off between closed-loop performance and robustness to model inaccuracies is achieved with a single tuning parameter.

Also the internal model control proportional integral derivative 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. The 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 internal model control proportional integral derivative controller can be designed using internal model control 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 internal model control approach is based on pole zero cancellation methods which comprise internal model control design principles result in a good set point responses. The internal model control 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. 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 internal model control controller is tuned for different values of the filter tuning factor.

Since all the internal model control proportional integral derivative approaches involve some kind of model reduction techniques to convert the internal model control controller to the proportional integral derivative 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 internal model control filter gives best internal model control performance but structurally causes a major error in conversion to the proportional integral derivative controller then the resulting proportional integral derivative controller could have poor control performance.

Internal model control and internal model control based proportional integral derivative 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 proportional integral derivative performance. For a given filter structure as λ decreases the inconsistency between the ideal and the proportional integral derivative controller increases while the nominal internal model control 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 proportional integral derivative 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 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.

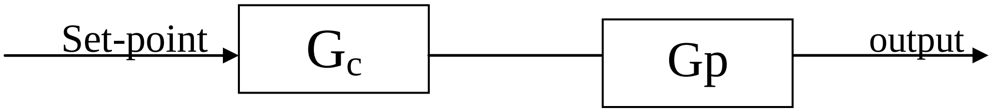

Fig. 1.5 General Open loop control system

For above open loop control system:

Output = G_c. G_p. Set-point (multiplication of all three parameters)

G_c = controller of process

G_p = actual process or plant

G_{p*} = model of the actual process or plant

A controller G_c is used to control the process G_p. Assume G_{p*} is the model of G_p then by setting:

G_c =inverse of G_{p*} (inverse of model of the actual process)

And if

G_p = G_{p*} (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. After having complete knowledge about the process as encapsulated in the process model being controlled and perfect control can be achieved.

This ideal control performance is achieved without feedback which signifies that feedback control is necessary only when knowledge about the process is inaccurate or incomplete. Although the internal model control design procedure is identical to the open loop control design procedure, the implementation of internal model control results in a feedback system. Thus internal model control is able to compensate for disturbances and model uncertainty while open loop control is not. Also internal model control must be detuned to assure stability if there is model uncertainty.

The feedback equivalence to internal model control by using block diagram manipulation is derived in this section. The internal model control structure shown in Fig. 1.6; the point of comparison between the model and process output can be moved as shown in Fig. 1.7.

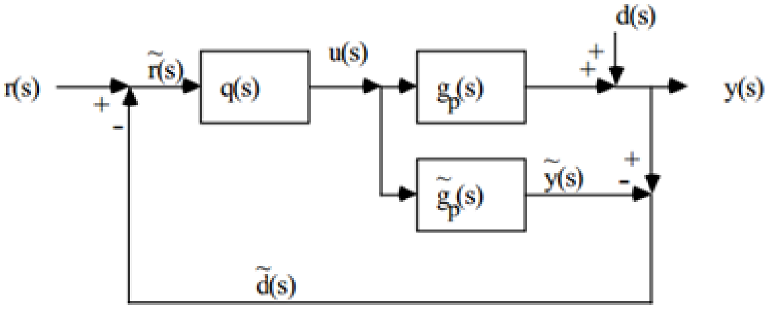

Fig. 1.6 The internal model control structure

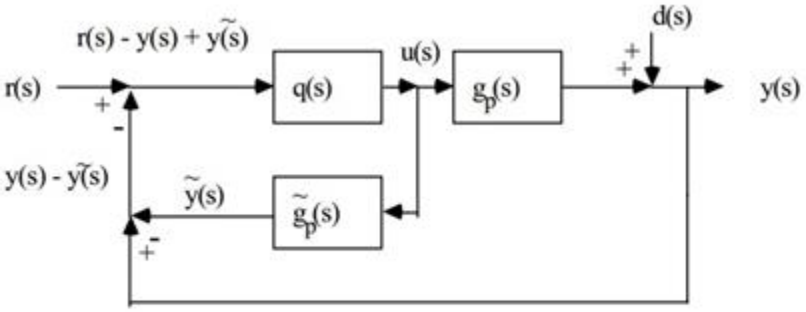

Fig. 1.7 Cosmetic change in internal model control structure

The above shown internal model control structure in Fig. 1.7 can be further reduced as shown in Fig. 1.8.

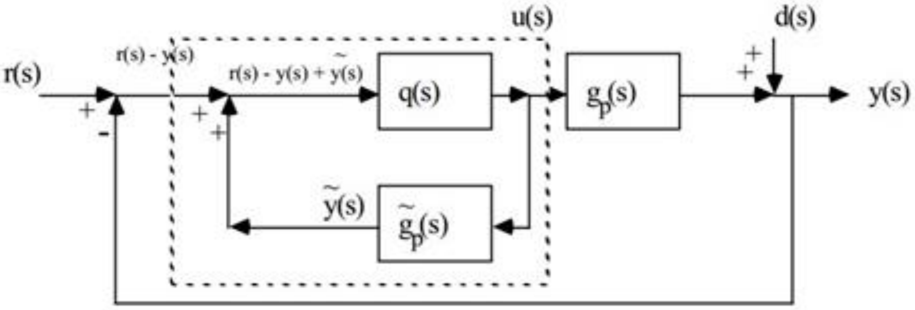

Fig. 1.8 Rearrangement of internal model control structure

The arrangement shown inside the dotted line of Fig. 1.8 is shown below in Fig. 1.9.

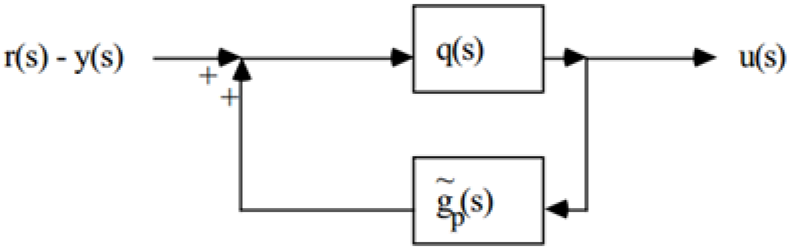

Fig. 1.9 Inner-loop of the rearranged internal model control structure

The above shown internal model control structure in Fig. 1.9 can be rearranged to the form of Fig. 1.10 as shown below.

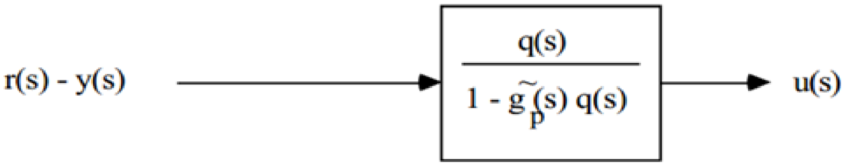

Fig. 1.10 Equivalent block to Fig. 1.9

Notice that r(s) − y(s) is simply the error term used by a standard feedback controller. Therefore the internal model control structure can be rearranged to the feedback control structure as shown in Fig. 1.11. This reformulation is advantageous because a proportional integral controller often results when the internal model control design procedure is used. Also the standard internal model control block diagram cannot be used for unstable systems so this feedback form must be used for those cases.

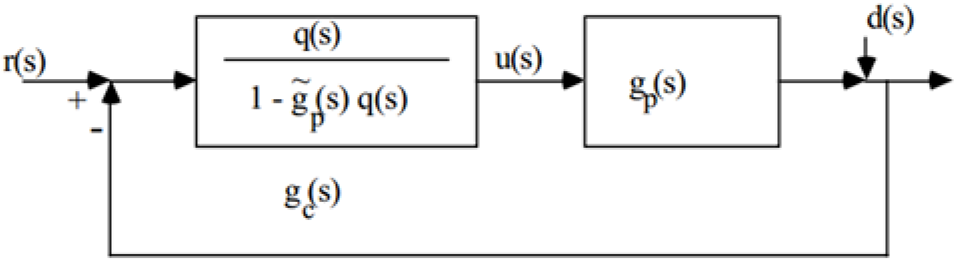

Fig. 1.11 Standard feedback diagram illustrating the equivalence with internal model control

The feedback controller $g_c(s)$ contains the both internal model $\hat{g}_p(s)$ and internal model controller q(s). A standard feedback controller can be designed using the internal model control design procedure. The standard feedback controller is a function of the internal model, $g^f{}_p(s)$, and internal model controller q(s) as shown in equation 1.1.

The standard feedback controller which is equivalent to internal model control is

$$g_c(s) = \frac{q(s)}{1-g_p^f(s)q(s)} \qquad 1.1$$

Refer to equation (1.1) as the internal model control based proportional integral derivative relationship because the form of G_c (s) is often that of a proportional integral derivative controller. The internal model control based proportional integral derivative procedure is similar to the internal model control procedure of the previous handout with some additional steps. Step 1 of the internal model control based proportional integral derivative procedure contains steps 1-3 of the internal model control procedure. One major difference is that the internal model control based procedure will many times not require that the controller be proper.

1.2.2 The Internal Model Control Based Proportional Integral Derivative Control Design Procedure

The proportional integral derivative controller has three principal control effects. The proportional (P) action gives a change in the input (manipulated variable) directly proportional to the control error. The integral (I) action gives a change in the input proportional to the integrated error, and its main purpose is to eliminate offset. The less commonly used derivative (D) action is used in some cases to speed up the response or to stabilize the system, and it gives a change in the input proportional to the derivative of the controlled variable. The overall controller output is the sum of the contributions from these three terms. The corresponding three adjustable proportional integral derivative parameters are most commonly selected to be

i. Controller gain Kc (increased value gives more proportional action and faster control)
ii. Integral time I [s] (decreased value gives more integral action and faster control)
iii. Derivative time D [s] (increased value gives more derivative action and faster control)

The proportional integral derivative controller has only three parameters, it is not easy, without a systematic procedure, to find good values (tunings) for them. In fact, a visit to a process plant will usually show that a large number of the proportional integral derivative controllers are poorly tuned. There is a need to provide simple model-based tuning rules that give insight into how the tuning depends on the process parameters based on very simple process information. These rules may then be used to assist in retuning the controller if, for example, the production rate is changed.

The following steps are used in the internal model control based proportional integral derivative control system design:

1. Find the internal model control controller transfer function, q(s), which includes a filter, f(s), to make q(s) semi proper or to give it derivative action (order of the numerator of q(s) is one order greater that the denominator of q(s)). Notice that this is a major difference from the internal model control procedure. Here, in the internal model control based procedure, may allow q(s) to be improper, in order to find an equivalent proportional integral derivative controller.

2. Find the equivalent standard feedback controller using the transformation

$$g_c(s) = \frac{q(s)}{1 - g_p^f(s)q(s)} \qquad 1.2$$

3. Show this in proportional integral derivative form and find k_c , τ_I, τ_D . Sometimes this procedure results in a proportional integral derivative controller cascaded with a lag term τ_F :

$$g_c(s) = \left[\frac{k_c[\tau_I \tau_D S^2 + \tau_1 S + 1}{\tau_I S}\right]\left[\frac{1}{\tau_F S + 1}\right] \qquad 1.3$$

4. Perform closed-loop simulations for both the perfect model case and cases with model mismatch. Choose the desired value for λ as a trade-off beten performance and robustness.

Chapter2

Literature Review

2.1 Introduction

Controlling the process is the main issue that rises in the process industry. It is very important to keep the process working probably and safely in the industry, for environmental issues and for the quality of the product being processed. In order for the controllers to work satisfactorily, they must be tuned probably [1]. Tuning of controllers can be done in several ways, depending on the dynamics desired strengths of the system, and many methods have been developed and refined in recent years. The proportional integral derivative (PID) controller is widely used in the process industries. The main reason is their simple structure, which can be easily understood and implemented in practice. Finding design methods that lead to the optimal operation of proportional integral derivative controllers is therefore of significant interest.

2.2 Related research in this field

Gong Xiaofeng et al. presented that Rivera et al. introduced a proportional integral derivative controller design method based on internal model control internal model control that is attractive to industrial users because it has only one tuning parameter. The parameter relates directly to the closed loop speed of response and the robustness of the control loop. For a system with dead time, if used as an approximation for the time delay, the internal model control controller includes implicitly integral action and has a proportional integral derivative structure in cascade with a filter. In addition significant improvements in model matching and controller tuning can be obtained. Especially for those processes that have significant dead time [2].

Syder J et al. has compared a number of proportional integral derivative and predictive controller strategies to compensate processes modeled in first order lag plus time delay

(FOLPD) form. The performance and robustness of the resulting compensated systems are evaluated analytically (where appropriate) and in simulation [3].

Sigurd Skogestad et al. presented rules for proportional integral derivative controller tuning that are simple and still result in good closed loop behavior. The starting point has been the internal model control proportional integral derivative tuning rues that have achieved widespread industrial acceptance. The rule for integral term has been modified to improve the disturbance rejection for integrating processes. Furthermore, rather than deriving separate rules for each transfer function model, there is just a single tuning rule for a first order or second order model. Simple analytic rules for model reduction re presented to obtain a model in this form, including the ‘half rule’ for effective time delay [4].

R. Farkh et al. presented in his paper about the control of time delay system by Proportional-Integral (PI) controller. By Using the Hermite-Biehler theorem, which is applicable to quasi-polynomials, a stability region of the controller for first order delay systems was found. The essence of this work resides in the extension of this approach to second order delay system, in the determination of its stability region and the computation of the PI optimum parameters. He used the genetic algorithms to lead the complexity of the optimization problem [5].

Qing-Guo Wang et.al. has explained about newly developed control methods for unstable processes with time delays are revived. Seven existing controller design methods re evaluated regarding their applicability, control performance and robustness. The comparison was shown by simulations results and data statistics [6].

Dan Chen et al. presented a design method for proportional integral derivative controllers based on the direct synthesis approach and specification of the desired closed-loop transfer function for disturbances is proposed. Analytical expressions for proportional integral derivative controllers re derived for several common types of process models, including first-order and second-order plus models and an integrator model. Although the controllers are designed for disturbance rejection, the set-point responses are usually satisfactory and can be tuned independently via a set-point ighting factor. Nine simulation examples demonstrated that the proposed design method results in very good control for a wide variety of processes including those with integrating and/or non-minimum phase characteristics. The simulations shod that the proposed design method provides better disturbance rejection than the standard direct synthesis and internal model control methods when the controllers are tuned to have the same degree of robustness [7].

Ding-Li et al. presented a fault tolerant control scheme composing an auto-tuning proportional integral derivative controller based on an adaptive neural network model. The model was trained online using the extended Kalman filter (EKF) algorithm to learn system post-fault dynamics. Based on this model, the proportional integral derivative controller adjusts its parameters to compensate the effects of the faults, so that the control performance is recovered from degradation. The auto-tuning algorithm for the proportional integral derivative controller was derived with the Lyapunov method and therefore, the model predicted tracking error was guaranteed to converge asymptotically. The method was applied to a simulated two-input two-output continuous stirred tank reactor (CSTR) with various faults, which demonstrated the applicability of the developed scheme to industrial processes [8].

Emami et al. proposed a graphical technique for finding all proportional integral derivative (PID) controllers that stabilize a given single-input-single-output (SISO) linear time invariant (LTI) system of any order system with time-delay. In his paper, a method was introduced that finds all proportional integral derivative controllers that also satisfy an H-∞ sighted sensitivity constraint. This problem was solved by finding all proportional integral derivative controllers that simultaneously stabilize the closed-loop characteristic polynomial and satisfy constraints defined by a set of related complex polynomials. A key advantage of this procedure is the fact that it does not require the plant transfer function, only its frequency response [9].

Astrom et.al proposed the design of proportional integral derivative controllers for systems with interacting loops. It is important to deal with the interaction at the lower-level loops, since supervisory control based on for instance MPC seldom has sufficient bandwidth. A new scheme based on modified scalar proportional integral derivative design and static decoupling was developed, where the frequency characteristics of the coupling between the lower-level loops is taken into account. This leads to a design method emphasizing the trade-off between the individual loop performances and the so called interaction indices. The controller was easily implemented, due to its simple configuration based on standard components [10].

Juang et al. presented a new approach using switching grey prediction proportional integral derivative controller to an experimental propeller setup which is called the twin rotor multi-input multi-output system (TRMS). The goal of this study was to stabilize the TRMS in significant cross coupling condition and to experiment with set-point control and trajectory tracking. The proposed scheme enhanced the grey prediction method of difference equation, which is a single variable second order grey model (DGM (2, 1) model). It was performed by real-value genetic algorithm (RGA) with system performance index as fitness function. He applied the integral of time multiplied by the square error criterion (ITSE) to form a suitable fitness function in RGA. Simulation results shod that the proposed design can successfully adapt system nonlinearity and complex coupling condition [11].

Garcia et al. presented a method to design decentralized proportional integral derivative controllers for MIMO systems. Each loop was designed separately, but the Gershgorin bands re considered to take interactions into account. The method used different design parameters: The infinity norms of the complementary sensitivity function as ll as the crossover frequency re considered to represent the closed-loop system performances. A third design parameter, defined as the minimal distance from the critical point to the Gershgorin band was used to provide the desired stability robustness to the MIMO closed-loop system [12].

Tamura et al. considered adaptive proportional integral derivative control for the asymptotic output tracking problem of MIMO systems with unknown system parameters under existence of unknown disturbances. The proposed proportional integral derivative controller had constant gain matrices and adjustable gain matrices. The proposed adaptive tuning laws of the gain matrices are derived by using Lyapunov theorem. That is a Lyapunov function based on characteristics of the proposed proportional integral derivative controller is constructed. His method guarantees the asymptotic output tracking even if the controlled MIMO system is unstable and has uncertainties and unknown constant disturbances. Finally, the effectiveness of the proposed method was confirmed with simulation results for the 8-state, 2-input and 2-output missile control system and the 4-state, 2-input and 2-output unstable system [13].

Rajabioun et al. utilized CCA to optimize the coefficients of a decentralized proportional integral derivative controller for a MIMO evaporator system. Recently, Colonial Competitive Algorithm (CCA) has proven its superior capabilities, such as faster convergence and better global minimum achievement in optimization problems. The optimization criterion was considered as the Integral Absolute Error (IAE) to minimize the tracking error. As the first step, the evaporator’s three input-three output transfer matrix was identified using measured dataset based on the prediction error model method. In order to design decentralize controllers, input-output pairing was performed based on the relative Gain Array method. Decentralized proportional integral derivative controllersare then designed using Ziegler-Nichols, Genetic Algorithm, and the proposed CCA techniques. The simulation results verify the superiority of CCA to the Ziegler-Nichols and Genetic Algorithm tuning techniques for decentralized proportional integral derivative controllers [14].

Chang et al. presented the closed-loop stabilization with guaranteed stability margins using proportional integral derivative controllers. A sufficient condition was presented for existence of proportional integral derivative controllers that stabilize linear, time-invariant, MIMO stable plants, where the closed-loop poles are guaranteed to have real-parts less than a pre-specified. A systematic design procedure was proposed and illustrated with several numerical examples. The choice of the free parameters can be optimized with a chosen cost function. Although stability margin can be considered as an important performance measure, there are other factors affecting the performance of the system and hence, “good” choice for the design parameters for overall performance is case-specific and cannot be generalized [15]. Thus, closed-loop stabilization with guaranteed stability margin using Proportional Integral Derivative controllers was investigated for a class of linear multi-input multi output plants. A sufficient condition for existence of such proportional integral derivative controllers was derived.

Nguyen et al. proposed a new method of designing multi-loop proportional integral derivative controllers. By using the generalized internal model control proportional integral derivative method for multi-loop systems, the optimization problem involved in finding the proportional integral derivative parameters is efficiently simplified to find the optimum closed-loop time constant in a reduced search space. A ighted sum Mp criterion is proposed as a performance cost function to cope with both the performance and robustness of a multi-loop control system. Several illustrative examples are included to demonstrate the improved performance of the multi-loop proportional integral derivative controllers obtained by the proposed design method [16].

Yokoyama et al. applied a closed-loop balanced truncation technique to an integral-type optimal servomechanism (IOS) expressed in graph-operator form of normalized right co-prime factorization to produce a reduced-size state-feedback gain matrix, which is then converted into proportional-derivative (PD) gain matrices. On the other hand, the states of the integral of control error in the IOS re not truncated, so that the feedback gain matrix of the IOS for the states becomes the integral (I) gain matrix. All the design procedure was completed with the state-space approach, which is convenient especially in dealing with multiple-input multiple-output (MIMO) systems. Application of the proposed method to the boiler system of the proportional integral derivative’12 benchmark problem demonstrated the effectiveness of the design method [17].

Yadykin et al. presented a technique for optimal tuning of continuous time proportional integral derivative controller for bilinear MIMO plant with piecewise constant input signals. The proposed technique was based on minimization of quadratic proximity criterion applied for transient processes of open-loop control system and its implicit reference model (internal model control). The tuning algorithm for controller parameters uses estimates of bilinear MIMO plant parameters. The algorithm of parametric identification was used for determining the bilinear plant parameters. The proportional integral derivative controller optimal tuning algorithm for bilinear continuous time MIMO system was presented. A numerical example of two-channel bilinear MIMO plant control using two-channel PI controller was considered. It shod good controller performance within given range of coordinate and parametric disturbance [18].

Chapter3

INTERNAL MODEL CONTROL, PROPORTIONAL INTEGRAL DERIVATIVE AND INTERNAL MODEL CONTROL based PROPORTIONAL INTEGRAL DERIVATIVE

3.1Introduction

Internal model control (IMC) gives the control engineer a different perspective on the controller design problem. The internal model control structure can be rearranged to form a standard feedback control system that can easily handle open loop unstable system as not the case with internal model control. This modification of the internal model control design procedure is developed to improve the input disturbance rejection [18]. The internal model control based proportional integral derivative structure which uses a standard feedback structure uses the process model in an implicit manner i.e. proportional integral derivative tuning parameters are often adjusted based on the transfer function model but it is not always clear how the process model affects the tuning decision. In the internal model control procedure the controller Qc(s) is directly based on the good part of the process transfer function [20]. Also the internal model control formulation generally results in only one tuning parameter, the close loop time constant (filter tuning factor).

The internal model control based proportional integral derivative tuning parameters are then the function of this time constant. The selection of the closed loop time constant is directly related to the robustness (sensitivity to the modular of the closed loop system). Also, for open loop unstable processes it is necessary to implement the internal model control strategy in standard feedback form, because the internal model control suffers from internal stability problems [21]. Though the internal model control based proportional integral derivative controller will not give the same performance when there are process time delays because the internal model control based proportional integral derivative procedures uses an approximation for the dead time. But if the process has no time delays and the inputs do not hit a constraint then the internal model control based proportional integral derivative controller give the same performance as does the internal model control [22].

3.2 Internal Model Control Based Proportional Integral Derivative Structure

In the internal model control structure the point of comparison beten the process and the model output can be moved as shown in the figure below to form a standard feedback structure which is nothing but another equivalent feedback form of internal model control structure known as internal model control based proportional integral derivative structure. The basic idea of internal model control is to use a model of the open loop process $G_{M(s)}$ transfer function in such a way that the selection of the specified closed loop response yields a physically realizable feedback controller.

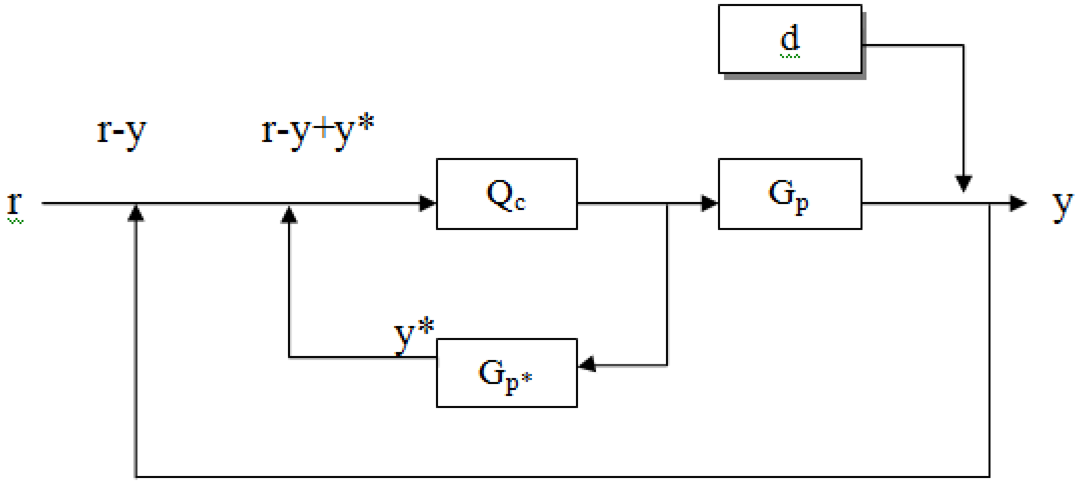

Fig. 3.1 Internal model control based proportional integral derivative design [23]

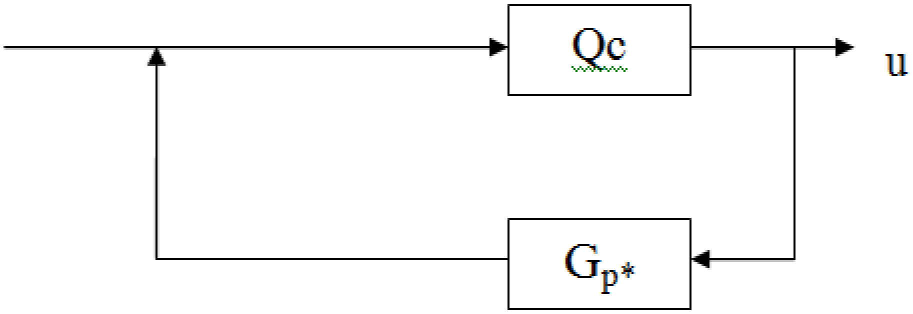

Fig. 3.2 Inner loop of rearranged internal model control structure [23]

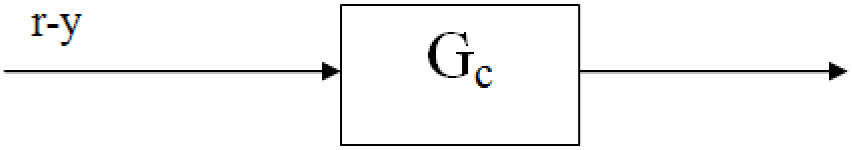

Fig. 3.3 Equivalent internal model control rearranged structure [24]

3.3 Internal Model Control Based Proportional Integral Derivative Design Procedure

Consider a process model $G_p^*(s)$ for an actual process or plant $G_p(s)$. The controller $Q_c(s)$ is used to control the process in which the disturbances D(s) enter into the system. The various steps in the internal model control system design procedure are:

3.3.1 Factorization

It means factoring a transfer function into invertible (good stuff) and non invertible (bad stuff) portions. The factor containing right hand plane (RHP) or zeros or time delays become the poles in the inverts of the process model when designing the controller. So this is non invertible portion which has to be removed from the system. Mathematically it is given as [25]

$$G_p^*(s) = G_p^*(+)(s)\, G_p^*(-)(s) \qquad 3.1$$

Where, $G_p^*(+)$ (s) is non-invertible portion and $G_p^*(-)$ (s) is invertible portion. Usually use all pass factorization.

3.3.2 Ideal INTERNAL MODEL CONTROL Controller

The ideal internal model control controller is the inverse of the invertible portion of the process model. It is given as:

$$Q_c^*(s) = \text{inv}\ [G_p^*(-)\ (s)] \tag{3.2}$$

3.3.3 Adding Filter

Now add a filter to make our controller proper. A transfer function is said to be proper if the order of the denominator is at least as great as the order of the numerator. If they are exactly of the same order the transfer function is said to be semi-proper [26].

If the order of the denominator is greater than the order of the numerator the transfer functions is strictly proper. Thus a controller can be physically implemented if it is proper. So to make the controller proper mathematically it is given as:

$$Q_c(s) = Q_c^*(s) \times f(s) = \text{inv}\ [G_p^*(-)\ (s)] \times f(s) \tag{3.3}$$

Where; f(s) is a low pass filter.

3.3.4 Low Pass Filter [f(s)]

In order to improve the robustness of the system the effect of model mismatch should be minimized. Since mismatch between the actual process and the model usually occur at high frequency end of the systems frequency response, a low pass filter f(s) is usually added to attenuate the effects of process model mismatch [28]. Thus the internal model controller is usually designed as the inverse of the process model in series with the low pass filter i.e.

$$Q_c(s) = Q_c^*(s) \times f(s) = \text{inv}\ [\ G_p^*(-)(s)] \times f(s) \qquad 3.4$$

Where; $f(s) = 1/(\ \lambda^*\ s+1)\ ^\wedge\ n$

Where; λ is the filter tuning parameter to vary the speed of the response of closed loop system.

Now the low pass filter can be of three types:

a) If focus on set point changes, the form of filter used is

$$f(s) = 1/(\ \lambda^*\ s+1)\ ^\wedge\ n \qquad 3.5$$

Here n is the order of the process.

b) If focus on good tracking of ramp set point changes the filter of the form used is

$$f(s) = (n.\ \lambda.\ s + 1)/\ (\lambda^*\ s+1)\ ^\wedge\ n \qquad 3.6$$

c) If focus on good rejection of step input load disturbances the filter of the form use is

$$f = (\text{gamma}.s+1)/\ (\lambda^*\ s+1)\ ^\wedge\ n \qquad 3.7$$

Where; gamma is any constant.

3.3.5 Equivalent standard feedback controller

By rearranging the internal model control obtain equivalent standard feedback controller using transformation.

$$G_c=Q_c/(1-Q_c \times G_p^*) \qquad 3.8$$

write this expression in the form of a ratio beten two polynomials.

3.3.6 Comparison With Standard Proportional Integral Derivative Controller

Now compare with proportional integral derivative Controller transfer function for first order:

$$G_c(s) = [K_c . (T_i .s + 1)]/ (T_i. s) \qquad 3.9$$

And find K_c and T_i (PI tuning parameters)

Similarly for 2nd order compare with the standard proportional integral derivative controller transfer function given by:

$$G_c(s) = K_c. [(T_i. T_d. s^{2\,+} T_i. s +1)/T_i . s] \times [1/ T_f. s + 1] \qquad 3.10$$

Where; T = Tau (any constant)

T_i = integral time constant

T_d = derivative time constant

T_f = filter tuning factor

K_c = controller gain

Now perform closed loop simulations for above procedure and adjust λ considering a tradeoff between performance and robustness (sensitivity to model error).

3.4 Internal Model Control Based Proportional Integral Derivative for 1^{st} Order System

Now apply the above internal model control based proportional integral derivative design procedure for a first order system with a given process model.

Given process model [28]:

i. $G_p^*(s) = K_p^*/[T_p^*(s)+1]$
ii. $G_p^*(s) = G_p^*(+)\ (s) \times G_p^*(-)\ (s) = 1.\ K_p^*/[T_p^*(s)+1]$
iii. $Q_c^*(s) = \mathrm{inv}[G_p^*(-)\ (s)\ ] = [T_p^*(s)+1]\ /\ K_p^*$
iv. $Q_c(s) = Q_c^*(s).\ f(s) = [T_p^*(s)+1]\ /\ [\ K_p^*.\ (\lambda(s) + 1)]$
v. $f(s) = 1\ /\ (\lambda.\ s + 1)$

Equivalent feedback controller using transformation:

$$G_c(s) = Q_c\ (s)/(1-Q_c(s)\ G_p^*(s)) \qquad 3.11$$

$$= [\{T_p^*(s)+1\}/\ \{\ K_p^*.\ (\lambda(s) + 1)\}]/\ [\{1-\ K_p^*/\ (T_p^*(s)\ +1)\}.\ \{T_p^*(s)\ +1\}\ /\ \{\ K_p^*.\ (\lambda(s) + 1)\}]$$

i. $G_c(s) = \{T_p(s)+1\}\ /\ K_p\ .\ \lambda.\ s$ (it is standard feedback controller for internal model control)
ii. $G_c(s) = [K_c\ .\ (T_i\ .s + 1)]/\ (T_i\ .\ s)$ (transfer function for PI controller)
iii. PI tuning parameters

$K_c = T_p\ /\ K_p.\ \lambda$

$T_i = T_p$

3.5 Internal Model Control Based Proportional Integral Derivative for 2nd Order System

Now apply the above internal model control based proportional integral derivative design procedure for a second order system with a given process model [29].

i. Given process model : $G_p^*(s) = K_p^*/[(T_{p1}^*(s)+1).(T_{p2}^*(s)+1)]$
ii. $G_p^*(s) = G_p^*(+)(s)\ .\ G_p^*(-)\ (s) = 1\ .\ K_p^*/[T_p^*(s)+1]$
iii. $Q_c^*(s) = \mathrm{inv}[G_p^*(-)\ (s)\ ] = [T_p^*(s)+1]\ /\ K_p^*$
iv. $Q_c(s) = Q_c^*(s).\ f(s) = [T_p^*(s)+1]\ /\ [\ K_p^*.\ (\lambda(s) + 1)]$

v. $f(s) = 1 / (\lambda . s + 1)$

Equivalent feedback controller using transformation:

$$G_c(s) = Q_c (s)/(1-Q_c(s) G_p^*(s)) \quad 3.12$$

$$= [T_{p1} . T_{p2} s^2 + (T_{p1} +T_{p2})s+1] / [K_p . \lambda . s] \quad 3.13$$

(It is the transfer function for the equivalent standard feedback controller)

i. $G_c(s) = [K_c. (T_i .T_d.s^2 + T_i.s+1)]/ [T_i . s]$ (transfer function for ideal proportional integral derivative controller for second order)

ii. proportional integral derivative tuning parameters (on comparison)

$K_c = (T_{p1} + T_{p2}) / (K_p. \lambda)$

$T_i = T_{p1} + T_{p2}$

$T_d=T_{p1}. T_{p2}/ (T_{p1} + T_{p2})$

CHAPTER4

SIMULATION AND RESULTS

4.1 System Implementation

The internal model control based proportional integral derivative controller design without time delay is implemented using Matlab. The version of Matlab used here is R2011b. The standard Matlab package is useful for linear systems analysis. The version of simulink used is 7.8 (R2011b). The simulink is far more useful for control system simulation. Simulink enables the proportional integral derivative construction and simulation of control block diagrams.

4.2 Ideal Internal Model Control Based Proportional Integral Derivative Controller

It is necessary to use two transfer function representations of the process because the actual process transfer function is never known exactly. First transfer function is process or plant which is never known exactly and the second transfer function is process model which is known exactly. In internal model controller process model is kept in parallel with the actual process. The ideal internal model control based proportional integral derivative controller means the model is perfect and there is no disturbance and delay [29]. So the feedback is also nil. Thus the system is open loop system. For the model to be perfect,

$$Gp(s) = \tilde{G}p(s) \tag{4.1}$$

$$d(s) = 0 \tag{4.2}$$

Here,

Gp(s) is the process transfer function.

$\hat{G}p(s)$ is the process model.

d(s) is the disturbance.

4.2.1 Simulation of Ideal Internal Model Control Based Proportional Integral Derivative Design

The internal model controller provides a transparent frame work for control system design and tuning. For simulation of ideal internal model control based proportional integral derivative controller. The first order transfer function of the process has been adopted as a reference [29]. The derivation to calculate the parameters of ideal internal model control based proportional integral derivative controller is given below.

$$G_p(s) = \frac{k_p}{\tau_p s+1} \qquad 4.3$$

$G_p(s)$ is the transfer function of the process

$$G_p(s) = 16/(2s+16) \qquad 4.4$$

The ideal internal model control controller transfer function Q(s) which includes the filter f(s) to make a Q(s) semi proper is given below

$$Q(s) = G_{p^{-1}}(s)f(s) \qquad 4.5$$

$$f(s) = \frac{1}{\lambda s+1} \qquad 4.6$$

$$Q(s) = \left(\frac{2s+16}{16}\right) * \frac{1}{\lambda s+1} \qquad 4.7$$

Here, λ is the tuning parameter of the filter f(s)

Take the value of λ as 3, which is practically one fifth of time constant and put it in equation (4.6) to get the value of ideal internal model control controller Q(s). The equation becomes

$$Q(s) = \left(\frac{2s+16}{16}\right) * \frac{1}{3s+1} \qquad 4.8$$

$$Q(s) = \left(\frac{2s+16}{16}\right)/(48s+16) \qquad 4.9$$

From the above equation (4.6), the value for the proportional integral tuning parameters is given by

$$k_c = \tau_p / k_p\lambda \qquad 4.10$$

k_c=2/48=0.04

$\tau_i = \tau_p = 2$

So the transfer function of proportional integral controller is now given by

$$G_c(s) = k_c(\frac{\tau_i s+1}{\tau_i s}) \qquad 4.11$$

G_c(s) =0.04((2s +1) / (2s))

The above transfer function without delay and disturbance results in proportional integral control only.

The Simulink block diagram of ideal internal model control based proportional integral derivative controller is shown in Fig. 4.1.

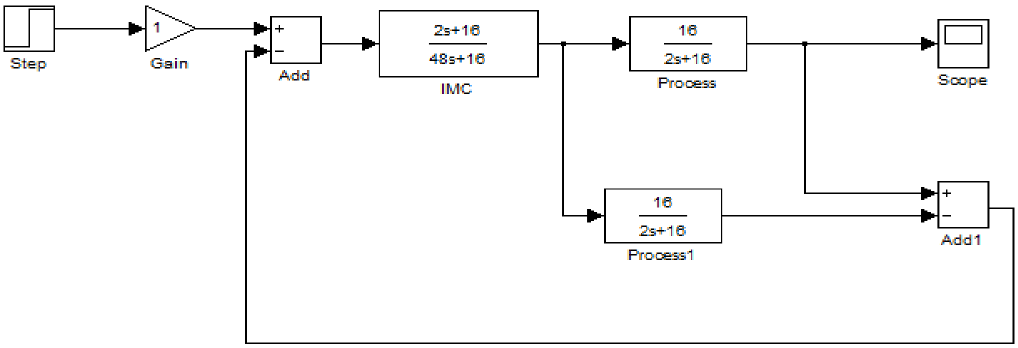

Fig. 4.1 Design of ideal internal model control based proportional integral derivative controller

The unit step response of ideal internal model control based proportional integral derivative controller with no disturbance and no time delay is shown in Fig. 4.2

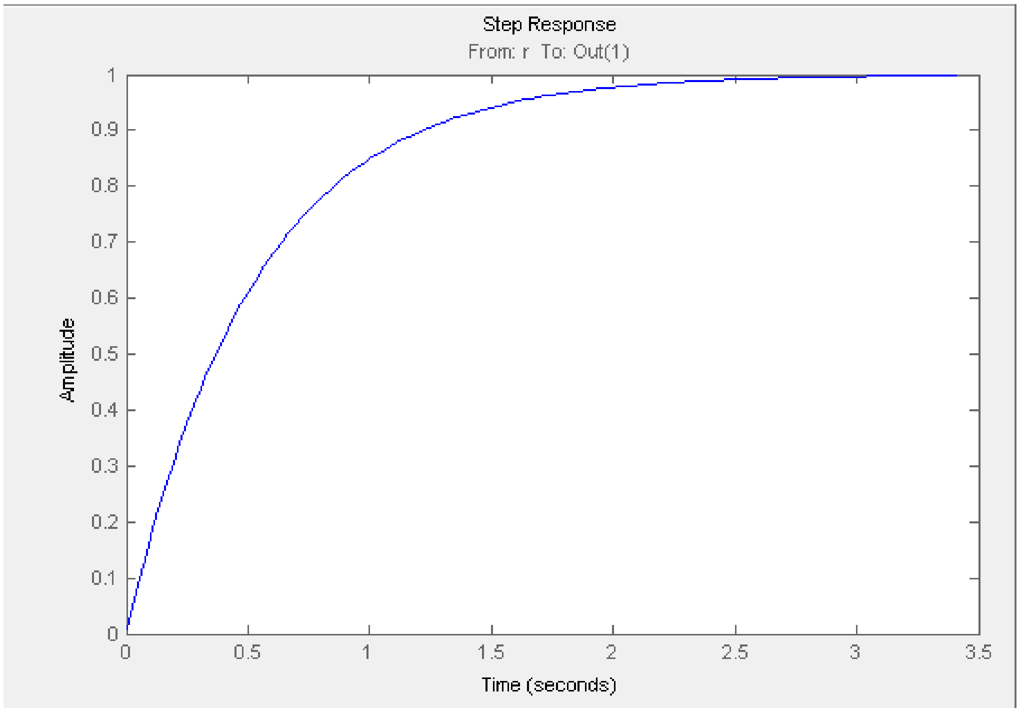

Fig. 4.2: Unit step response of ideal internal model control based proportional integral derivative with no disturbance and no time delay

4.2.2 Simulation of Internal Model Control Based Proportional Integral Derivative Design For A First Order System With First Order Disturbance

The transfer function of an internal model control based proportional integral derivative controller for a first order with first order disturbance is given below. The transfer function is taken from the reference papers [30].

The Simulink block diagram of internal model control based proportional integral derivative controller for a first order with first order disturbance is shown in Fig. 4.3

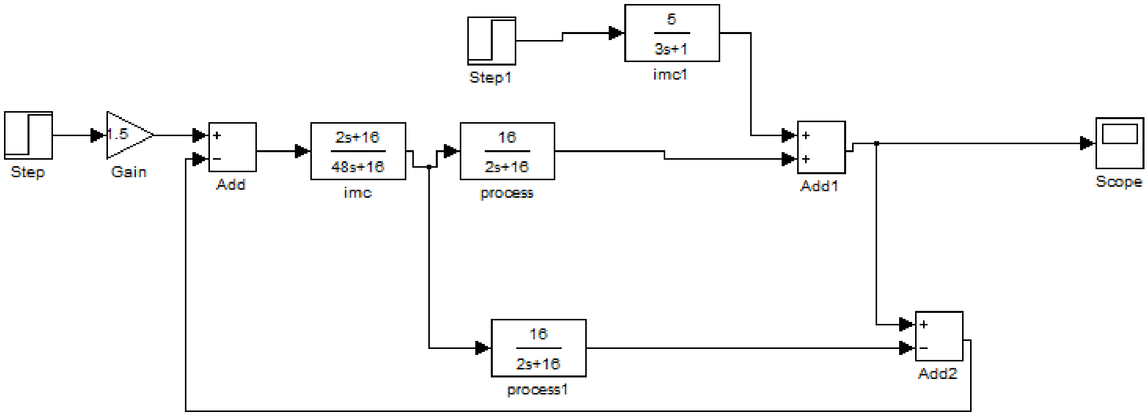

Fig. 4.3: Block diagram of internal model control based proportional integral derivative controller for a first order with first order disturbance with λ=3

$$G_p(s) = \frac{16}{2s+1}$$

The ideal internal model control controller transfer function Q(s) which includes the filter f(s) to make a Q(s) semi proper is given below

$$Q(s) = G_{p^{-1}}(s)f(s) \tag{4.12}$$

$$f(s) = \frac{1}{\lambda s+1} \tag{4.13}$$

$$Q(s) = \left(\frac{2s+16}{16}\right) * \left(\frac{1}{\lambda s+1}\right)$$

Here, λ is the tuning parameter of the filter f(s)

Take the value of λ as 3, which is practically one fifth of time constant and put it in equation (4.6) to get the value of ideal internal model control controller Q(s). The equation becomes

$$Q(s) = \left(\frac{2s+16}{16}\right) * \left(\frac{1}{3s+1}\right)$$

$$Q(s) = \left(\frac{2s+16}{48s+16}\right) \qquad 4.14$$

From the above equation (4.14), the value for the proportional integral tuning parameters is given by

$$k_c = \tau_p / k_p\lambda \qquad 4.15$$

$$k_c=2/48=0.04$$

$$\tau_i = \tau_p = 2$$

The unit step response of internal model control based proportional integral derivative controller for a first order with first order disturbance is shown in Fig. 4.4.

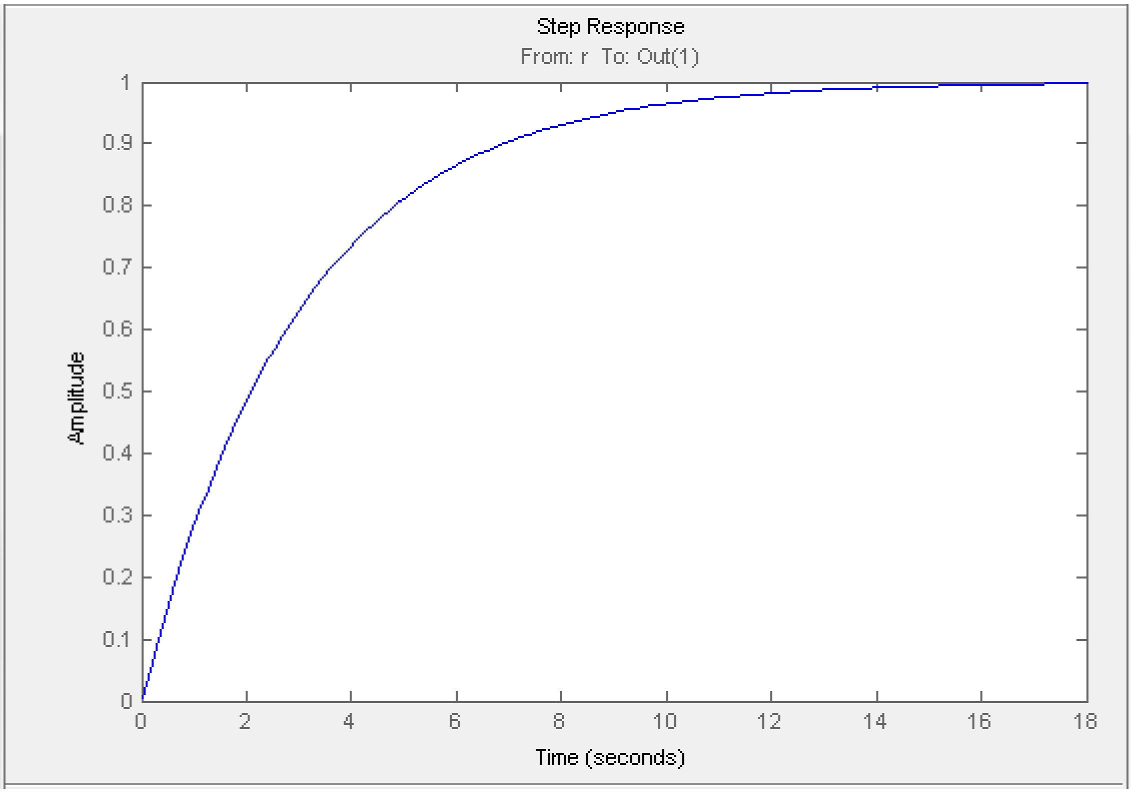

Fig. 4.4: Unit step response of internal model control based proportional integral derivative for a first order with first order disturbance with λ=3

Take the value of λ as 6, which is practically one fifth of time constant and put it in equation (4.6) to get the value of ideal internal model control controller Q(s). The equation becomes

$$Q(s) = \left(\frac{2s + 16}{16}\right) * \left(\frac{1}{6s + 1}\right)$$

$$Q(s) = \left(\frac{2s+16}{96s+16}\right) \qquad 4.16$$

The Simulink block diagram of internal model control based proportional integral derivative controller for a first order with first order disturbance is shown in Fig. 4.5

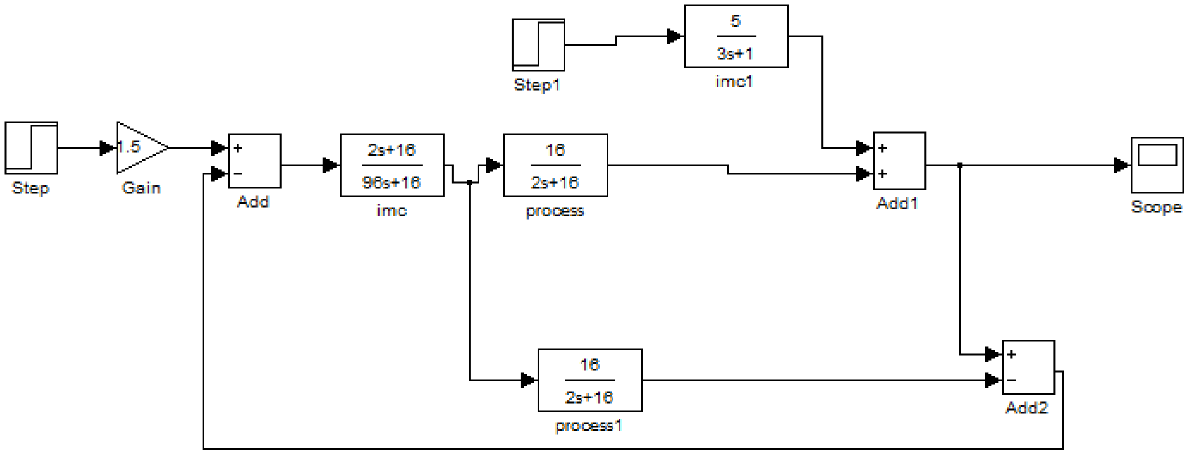

Fig. 4.5: Block diagram of internal model control based proportional integral derivative controller for a first order with first order disturbance with λ=6

From the above equation (4.16), the value for the proportional integral tuning parameters is given by

$$k_c = \tau_p / k_p\lambda \qquad 4.17$$

$$k_c=2/96=0.02$$

$$\tau_i = \tau_p = 2$$

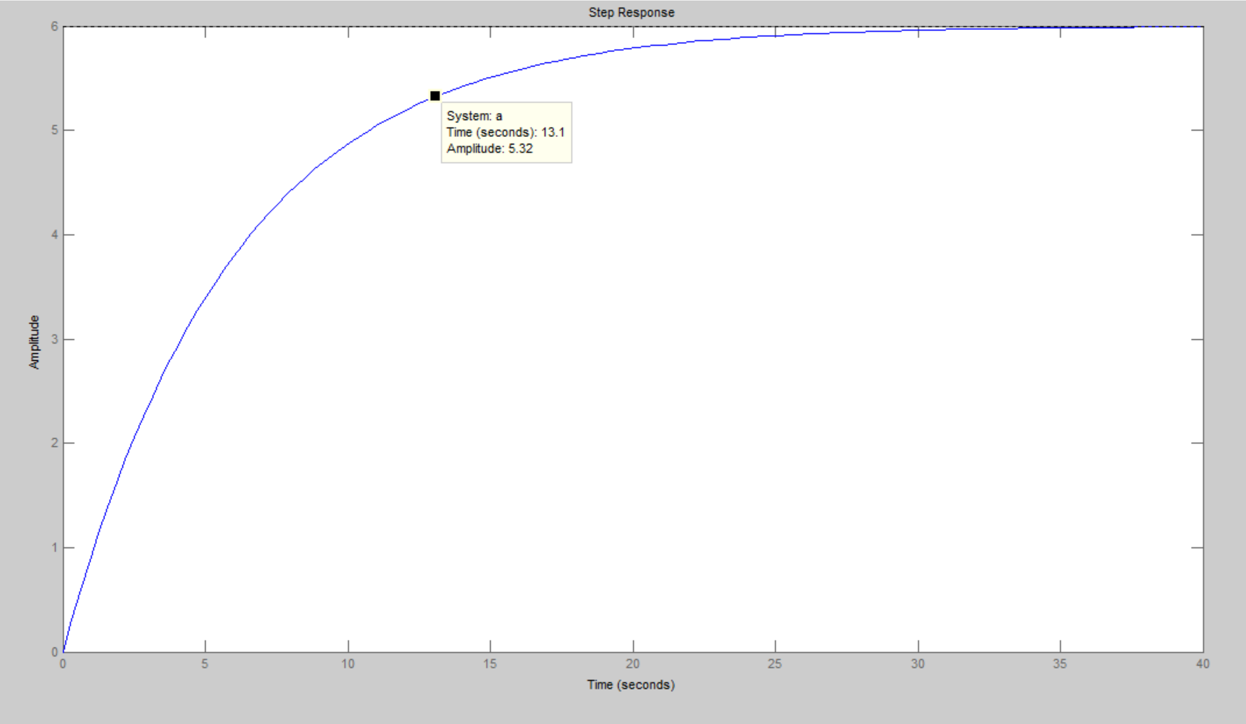

Fig. 4.6: Unit step response of internal model control based proportional integral derivative for a first order with first order disturbance with λ=6

4.2.3 Simulation of Internal Modal Controller Based Proportional Integral Derivative Design for a First Order with Second Order Disturbance

The transfer function of an internal model control based proportional integral derivative controller for a first order with second order disturbance is given below. The transfer function is taken from the reference paper [31]. The rest of the procedure to find out and the value of the parameters of proportional integral derivative controller is the same as mentioned above

$$G_d(s) = \frac{5}{s^2+3s+2} \tag{4.18}$$

The Simulink block diagram of internal model control based proportional integral derivative controller for the first order with second order disturbance is shown in Fig. 4.5

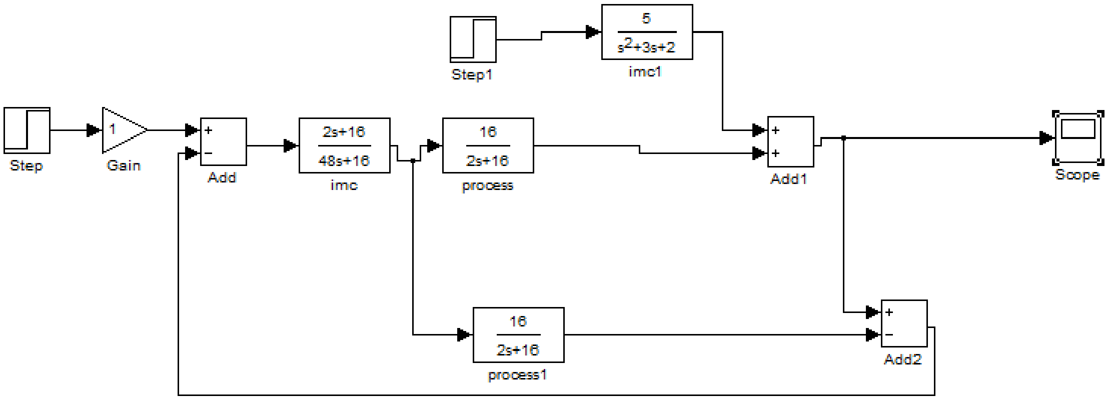

Fig. 4.7: Block diagram of internal model control based proportional integral derivative controller for a first order with second order disturbance with λ=3

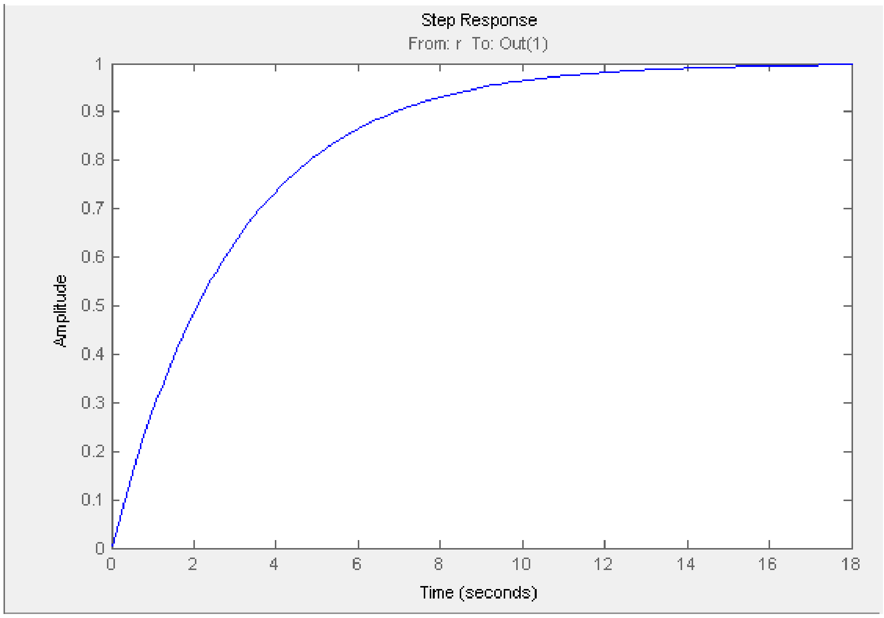

Fig. 4.8: Unit step response of internal model control based proportional integral derivative controller for a first order with second order disturbance with λ=3

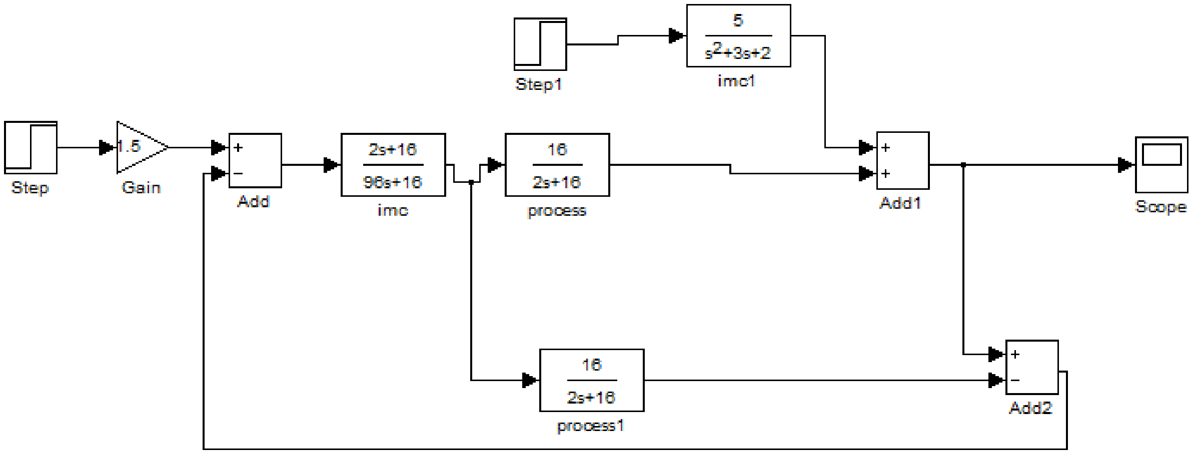

Fig. 4.9: Block diagram of internal model control based proportional integral derivative controller for a first order with second order disturbance with λ=6

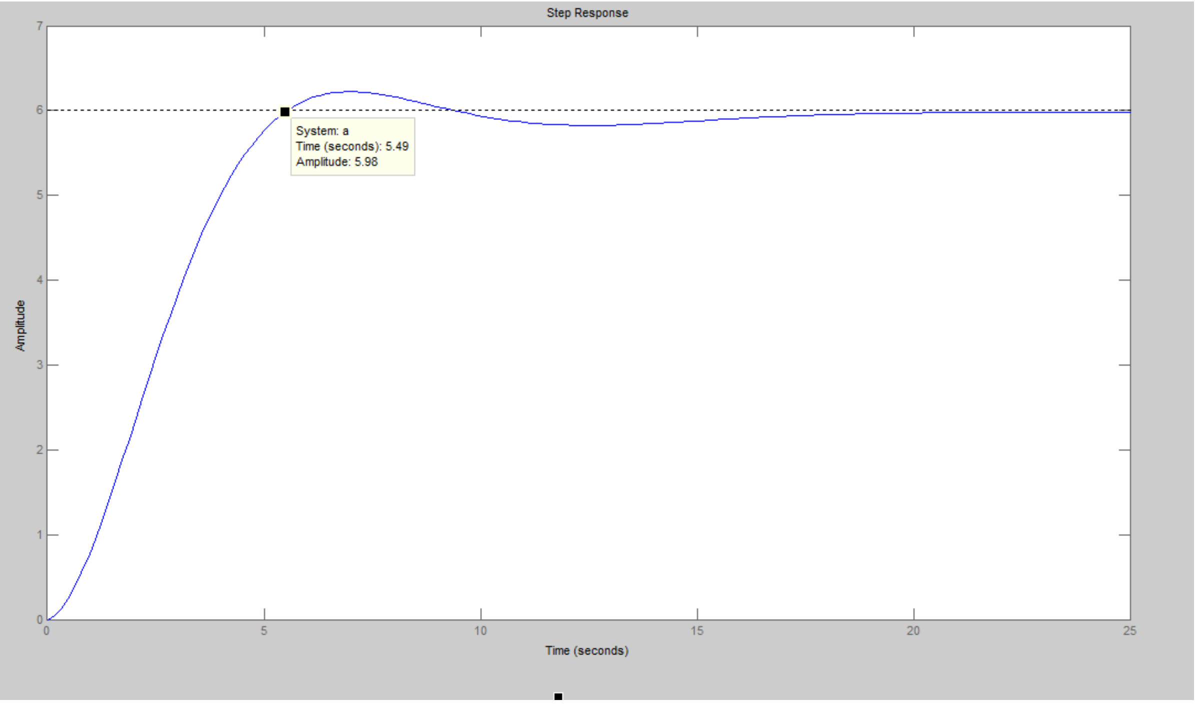

Fig. 4.10: Unit step response of internal model control based proportional integral derivative controller for a first order with second order disturbance with λ=6

4.2.4 Simulation of Internal Model Control Based Proportional Integral Derivative Design for a First Order with Third Order Disturbance

The transfer function of an internal model control based proportional integral derivative controller for a first order with third order disturbance is given below. The transfer function is taken from the reference paper [32]. The rest of the procedure to find out and the value of the parameters of proportional integral derivative controller is the same as mentioned above

$$G_d(s) = \frac{5}{s^3+3s^2+1}$$

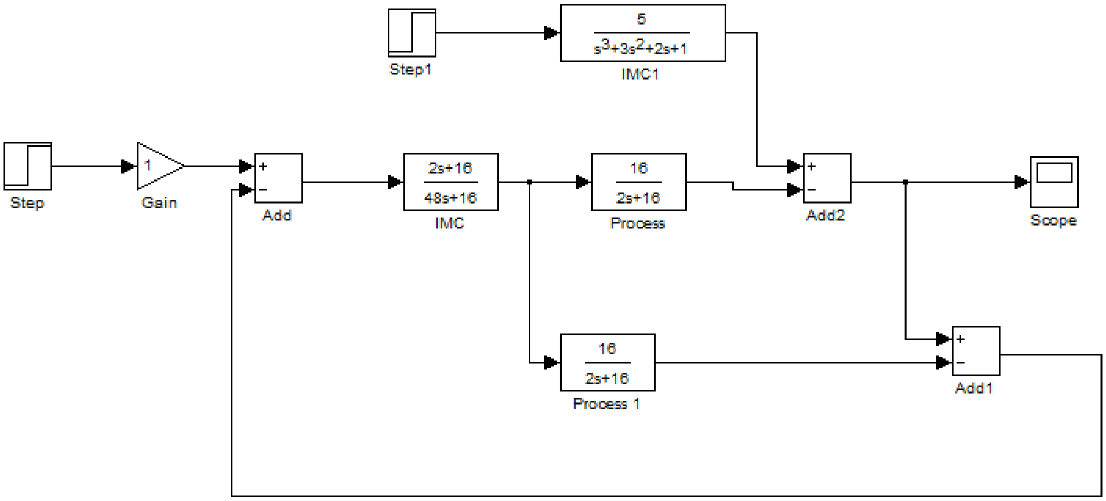

Fig. 4.11: Block diagram of internal model control based proportional integral derivative controller for a first order with third order disturbance with λ=3.

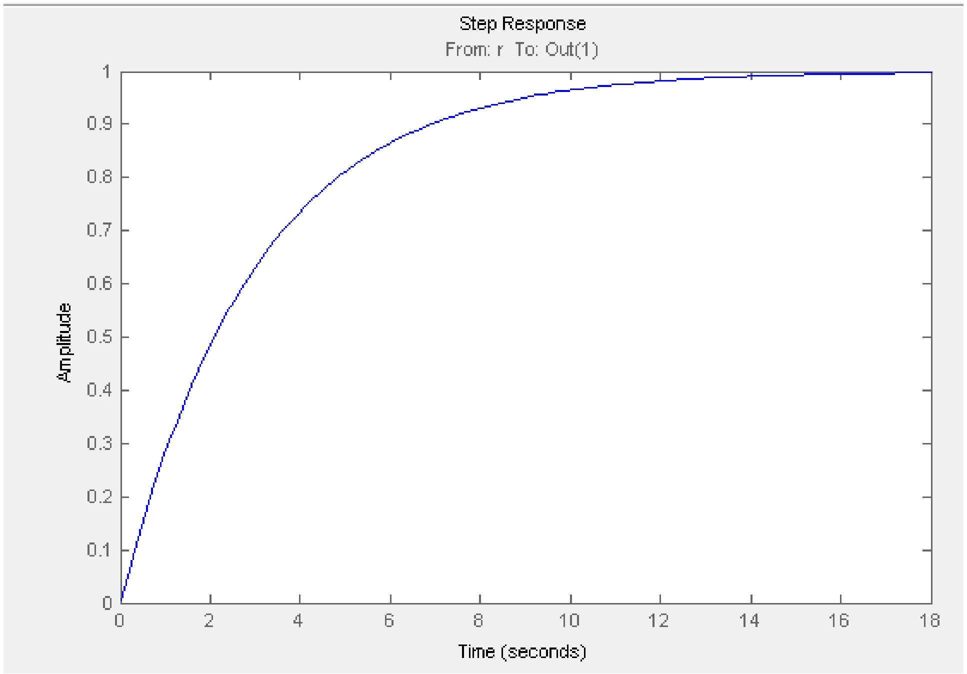

Fig. 4.12: Unit step response of internal model control based proportional integral derivative controller for a first order with third order disturbance with λ=3

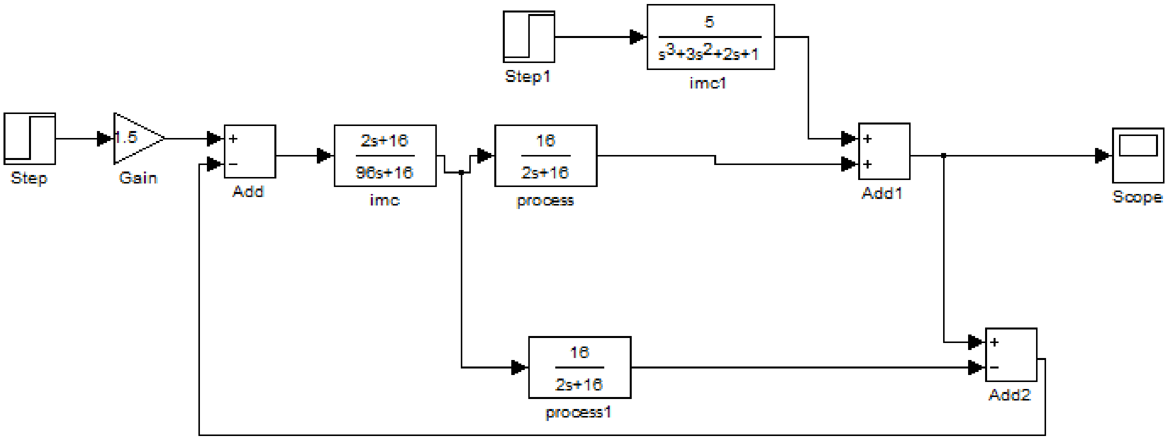

Fig. 4.13: Block diagram of internal model control based proportional integral derivative controller for a first order with third order disturbance with λ=6.

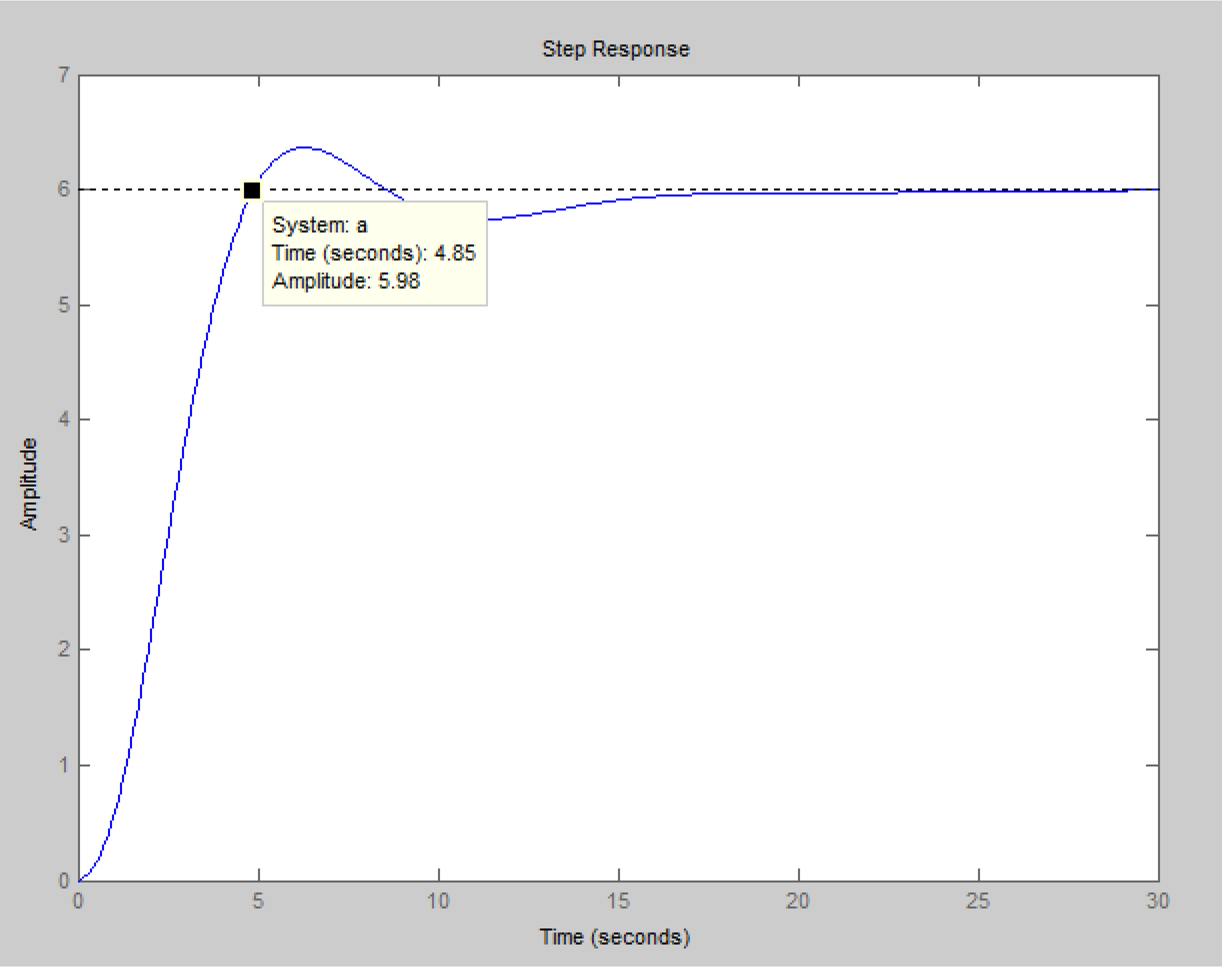

Fig. 4.14: Unit step response of internal model control based proportional integral derivative controller for a first order with third order disturbance with λ=6

4.2.5 Simulation of Internal Model Control Based Proportional Integral Derivative Design for a Second Order System with First Order Disturbance

The transfer function of an internal model control based proportional integral derivative controller for a second order with time plus first order disturbance is given below. The transfer function is taken from the reference papers [33].

$$G_p(s) = \frac{16}{s^2+2s+16} \qquad 4.19$$

The ideal internal model control controller transfer function Q(s) which includes the filter f(s) to make a Q(s) semi-proper is given below

$$Q(s) = G_{p^{-1}}(s)f(s) \qquad 4.20$$

$$f(s) = \frac{1}{(\lambda s+1)^2} \qquad 4.21$$

$$Q(s) = (\frac{s^2+2s+16}{16}) * \frac{1}{(\lambda s+1)^2} \qquad 4.22$$

Here, λ is the tuning parameter of the filter f(s)

Take the value of λ as 3, which is practically one fifth of time constant and put it in equation (4.21) to get the value of ideal internal model control controller Q(s). The equation becomes

$$Q(s) = \left(\frac{s^2+2s+16}{16}\right) * (\frac{1}{9s^2+6s+1}) \qquad 4.23$$

$$Q(s) = \left(\frac{s^2+2s+16}{144s^2+96s+16}\right) \qquad 4.24$$

From the above equation (4.24), the value for the proportional integral tuning parameters is given by

$$k_c = \tau_p / k_p\lambda \qquad 4.25$$

k_c=1/24 = 0.0416

$\tau_i = 2, \tau_d = 0.5$

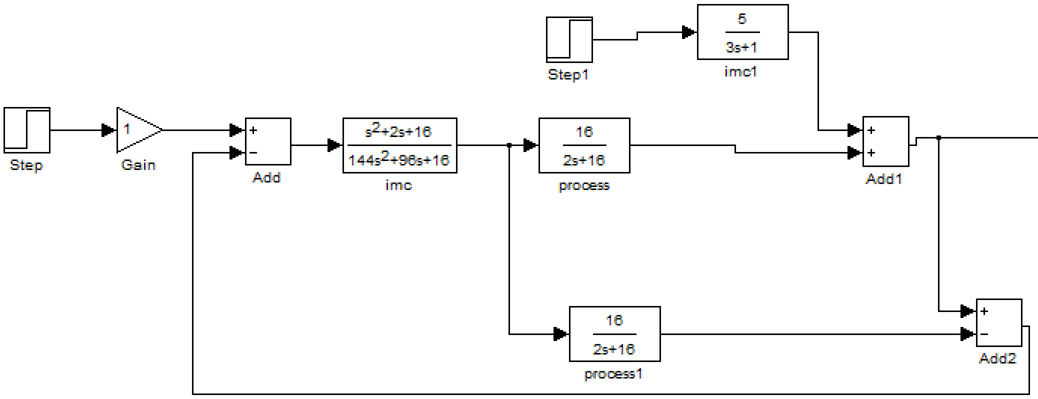

Fig. 4.15: Block diagram of internal model control based proportional integral derivative controller for a second order with first order disturbance with λ=3

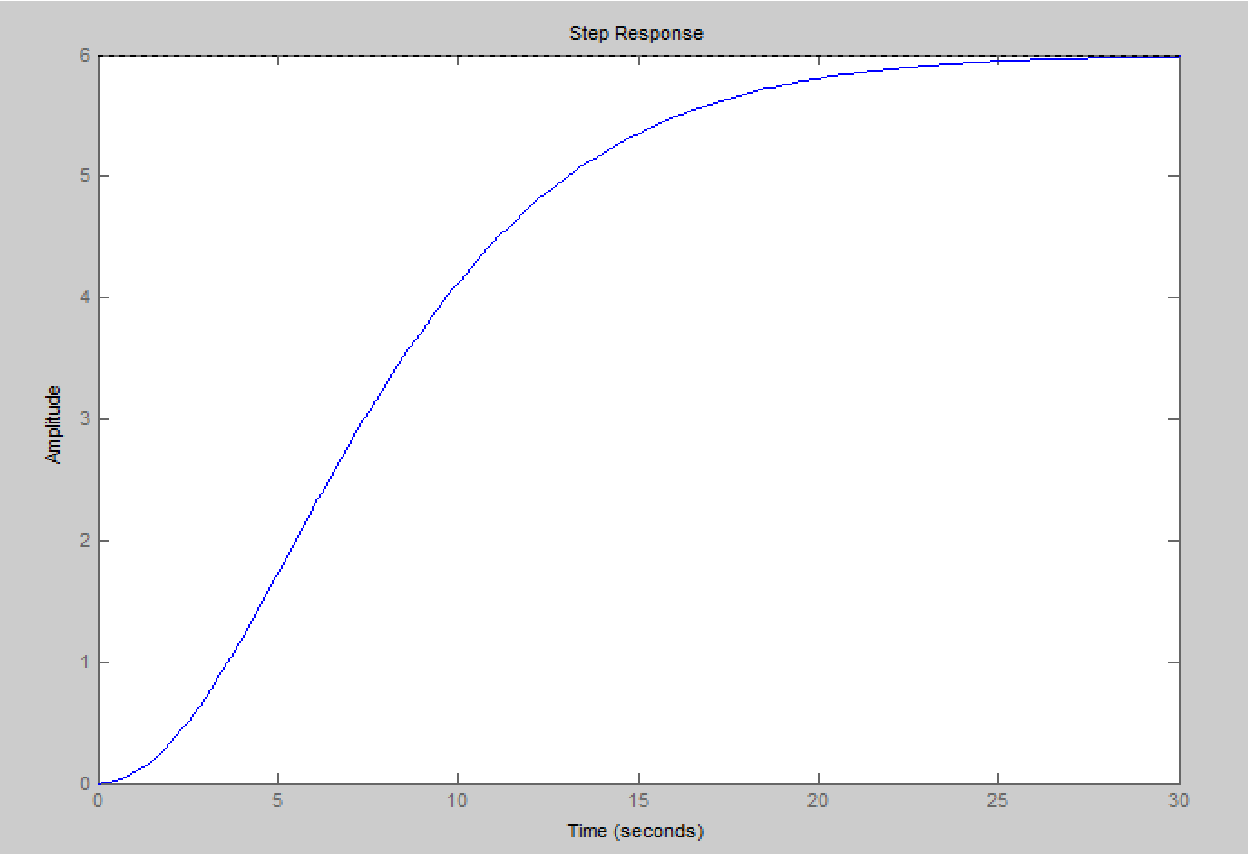

Fig. 4.16: Unit step response of internal model control based proportional integral derivative controller for a second order with first order disturbance with λ=3

The Simulink block diagram of internal model control based proportional integral derivative controller for the second order with first order disturbance is shown in Fig. 4.9

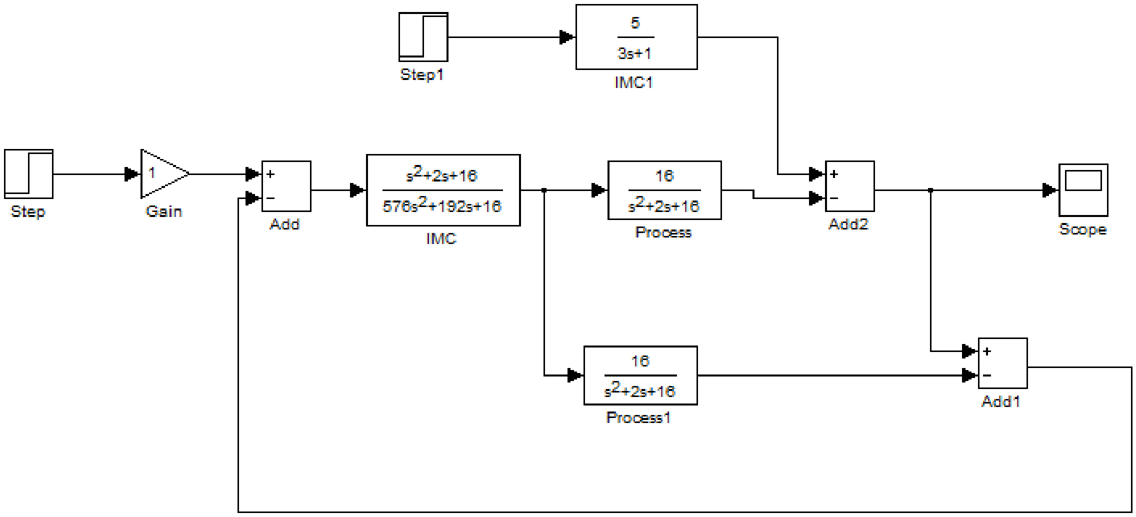

Fig. 4.17: Block diagram of internal model control based proportional integral derivative controller for a second order with first order disturbance with λ=6

Take the value of λ as 6, which is practically one fifth of time constant and put it in equation (4.26) to get the value of ideal internal model control controller Q(s). The equation becomes

$$Q(s) = \left(\frac{s^2+2s+16}{16}\right) * \left(\frac{1}{36s^2+12s+1}\right) \quad 4.26$$

$$Q(s) = \left(\frac{s^2+2s+16}{576s^2+192s+16}\right) \quad 4.27$$

From the above equation (4.27), the value for the proportional integral tuning parameters is given by

$$k_c = \tau_p / k_p\lambda \quad 4.28$$

k_c=1/48 = 0.0208

$\tau_i = 2, \tau_d = 0.5$

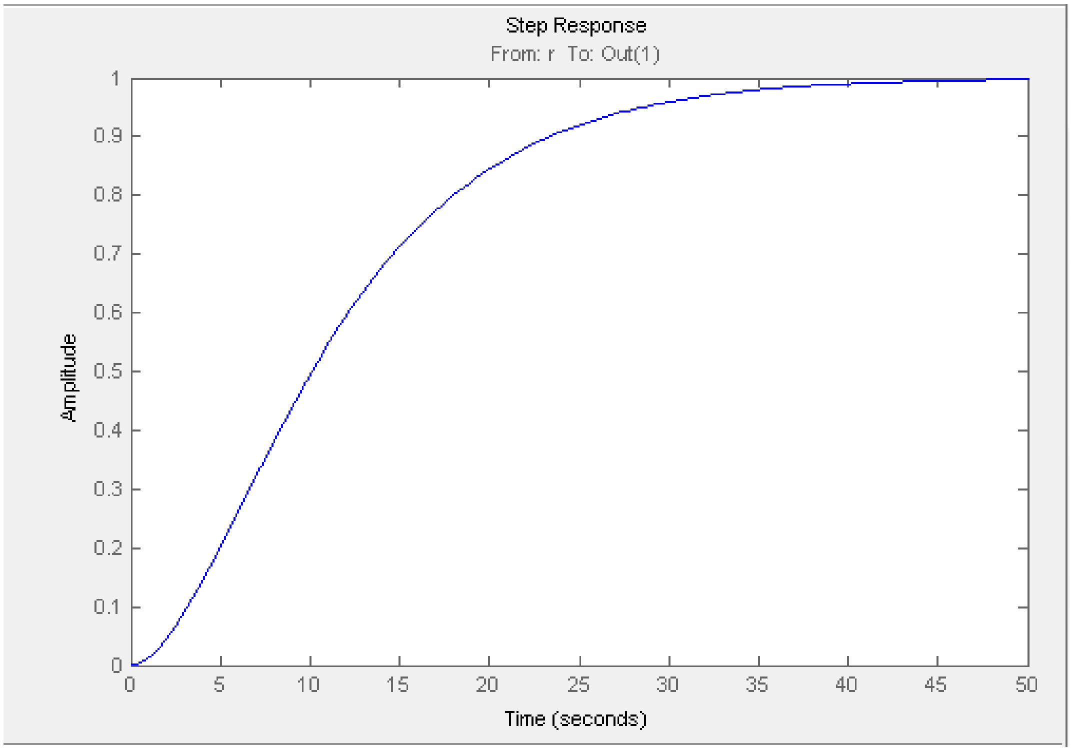

Fig. 4.18: Unit step response of internal model control based proportional integral derivative controller for a second order with first order disturbance with λ=6

4.2.6 Simulation of Internal Model Control Based Proportional Integral Derivative Design for a Second Order with Second Order Disturbance

The transfer function of an internal model control based proportional integral derivative controller for a second order with second order disturbance is given below. The transfer function is taken from the reference paper [33]. In it disturbance of second order is taken which is given below and the rest of the procedure to find out and the value of the parameters of proportional integral derivative controller is the same as mentioned above

$$G_d = \frac{5}{s^2+3s+2} \qquad 4.29$$

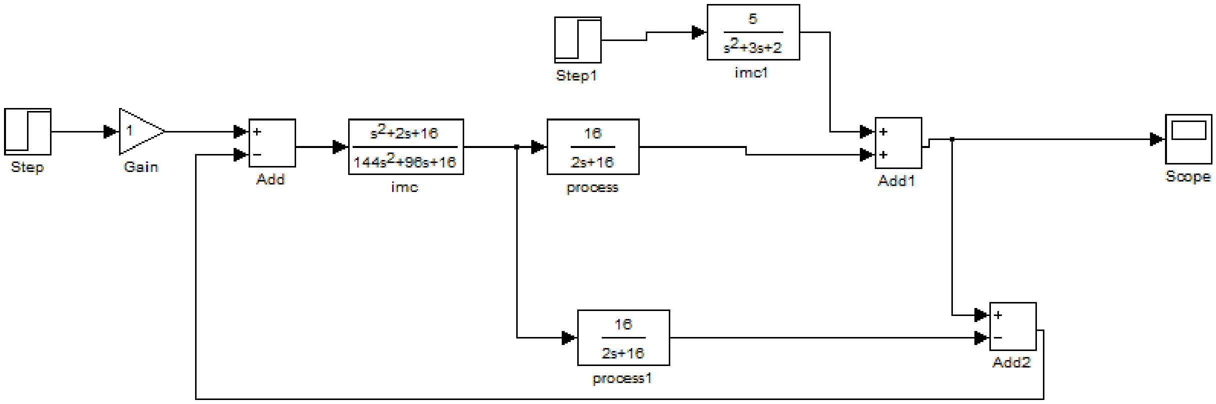

Fig. 4.19: Block diagram of internal model control based proportional integral derivative controller for the second order with second order disturbance with λ=3

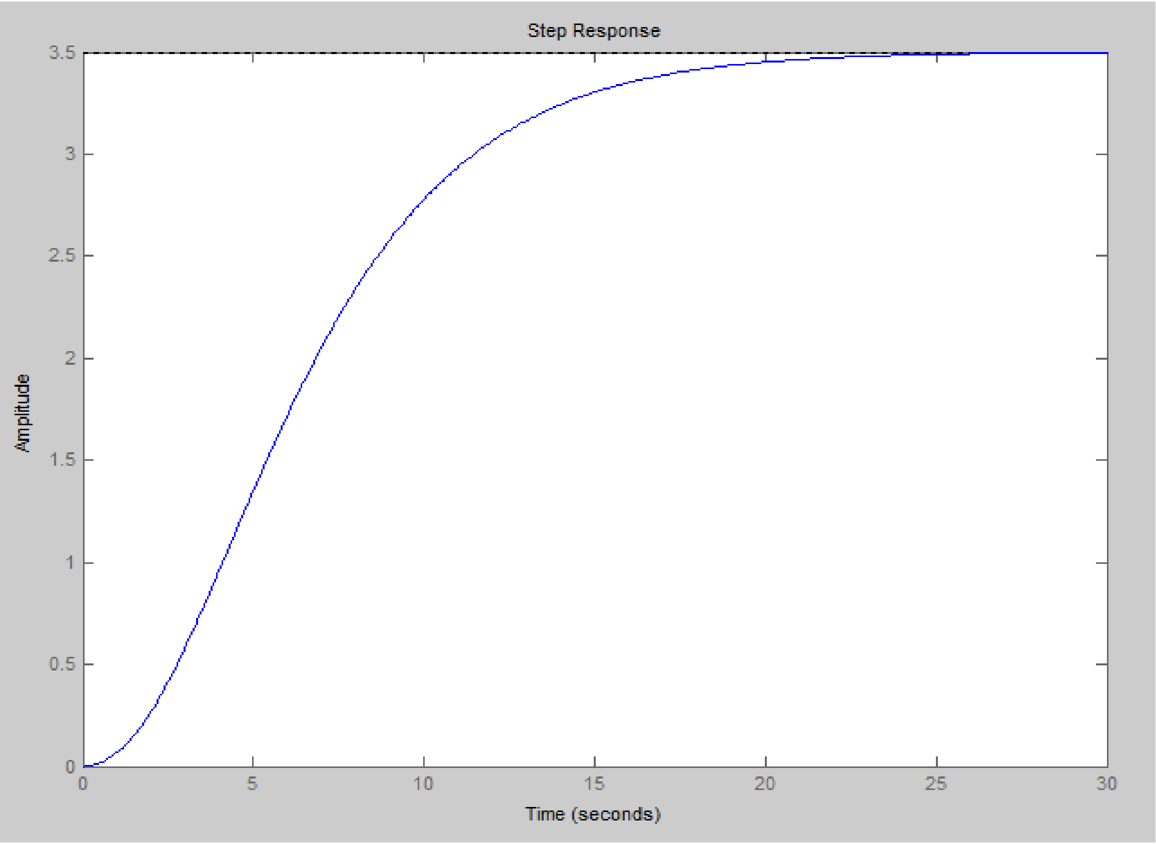

Fig. 4.20: Unit step response of internal model control based proportional integral derivative controller for a second order with second order disturbance with λ=3

The Simulink block diagram of internal model control based proportional integral derivative controller for the second order with second order disturbance with λ=6 is shown in Fig. 4.21

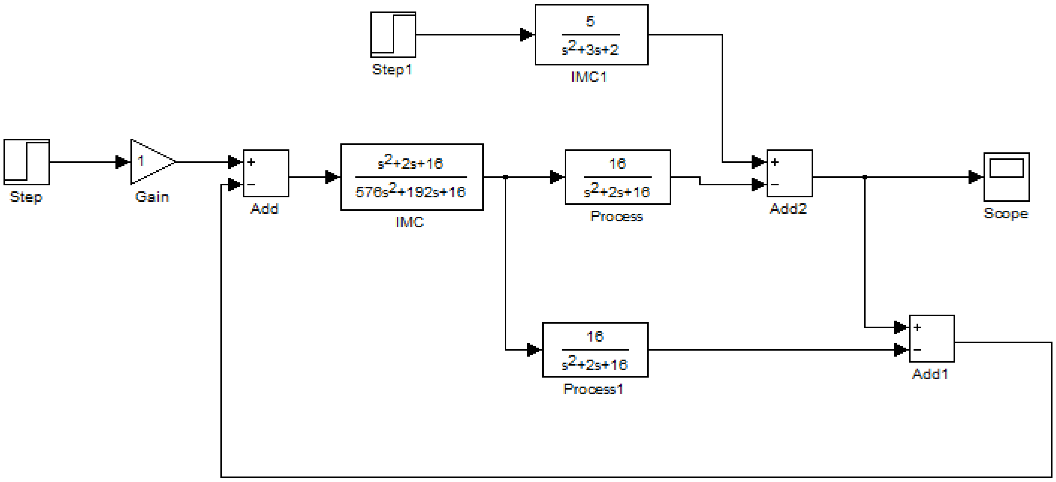

Fig. 4.21: Block diagram of internal model control based proportional integral derivative controller for the second order with second order disturbance with λ=6

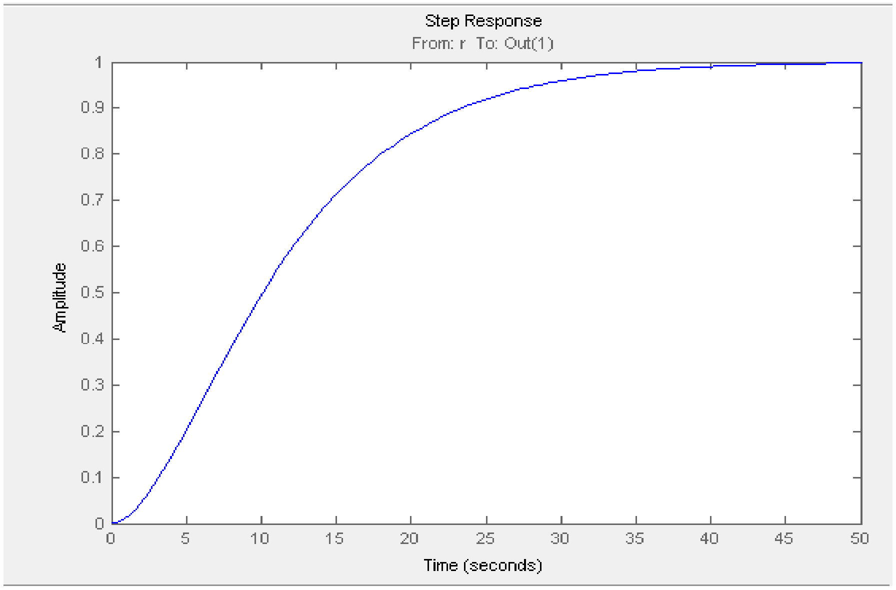

Fig. 4.22: Unit step response of internal model control based proportional integral derivative controller for a second order with second order disturbance with λ=6

4.2.7 Simulation of Internal Model Control Based Proportional Integral Derivative Design for a Second Order with Third Order Disturbance

The transfer function of an internal model control based proportional integral derivative controller for a second order with third order disturbance is given below. The transfer function is taken from the reference paper [34]. In it disturbance of third order is taken which is given below and the rest of the procedure to find out and the value of the parameters of proportional integral derivative controller is the same as mentioned above.

$$G_d = \frac{5}{s^3+6s^2+11s+6} \qquad 4.30$$

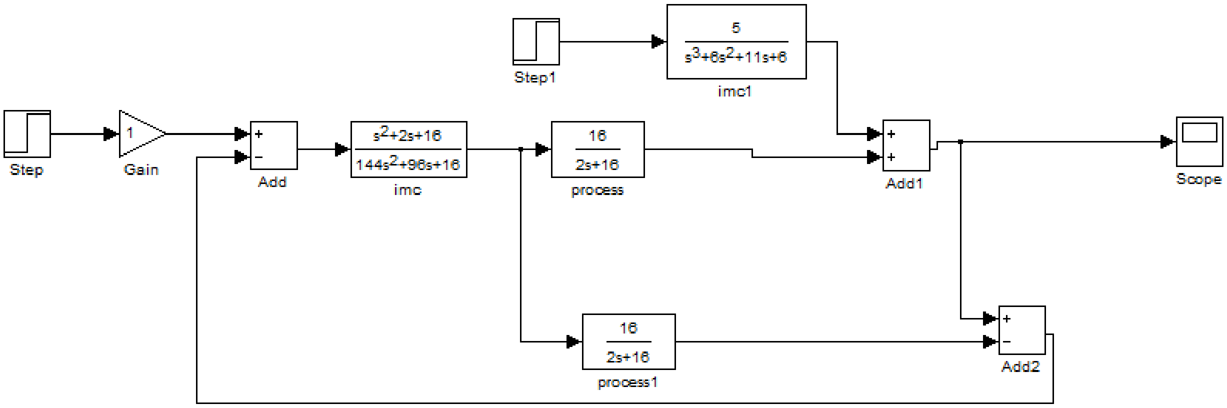

Fig. 4.23: Simulink block diagram of internal model control based proportional integral derivative controller for the second order with third order disturbance with λ=3

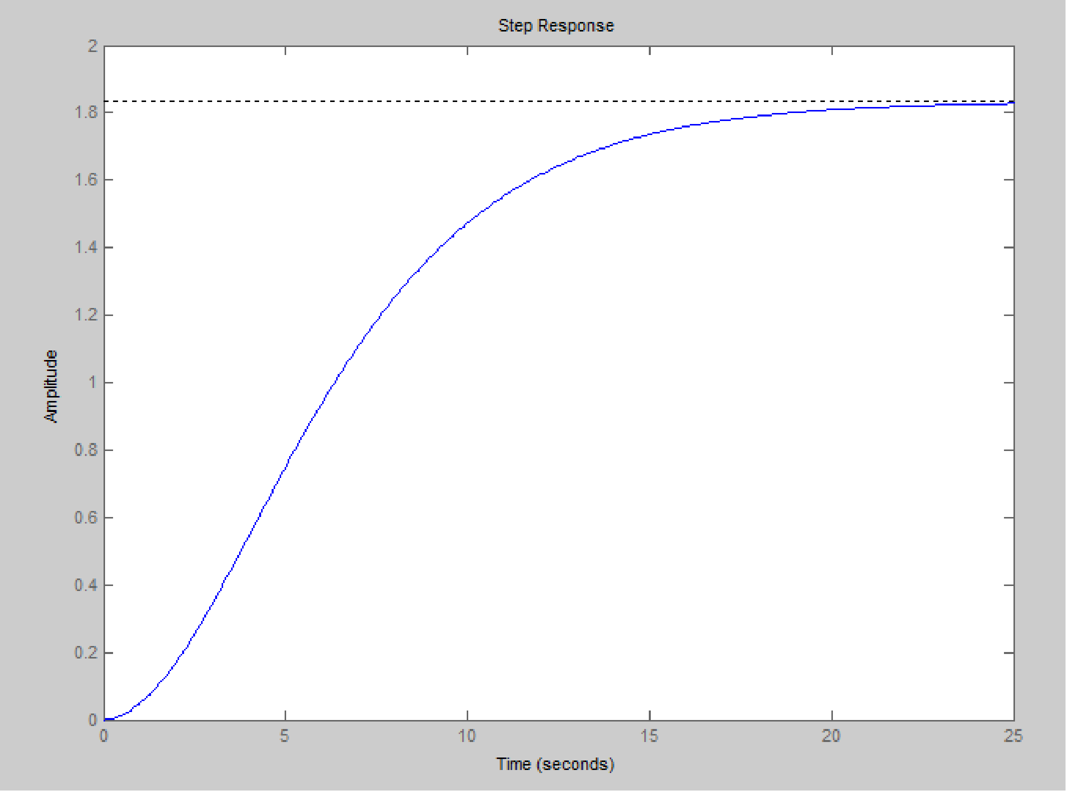

Fig. 24: The Unit step response of internal model control based proportional integral derivative controller for the second order with third order disturbance with λ=3

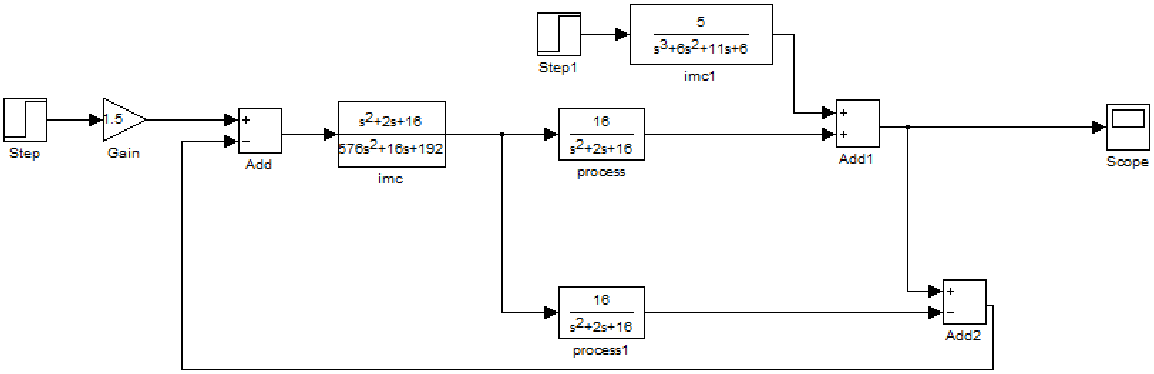

Fig. 4.25: Simulink block diagram of internal model control based proportional integral derivative controller for the second order with third order disturbance with λ=6

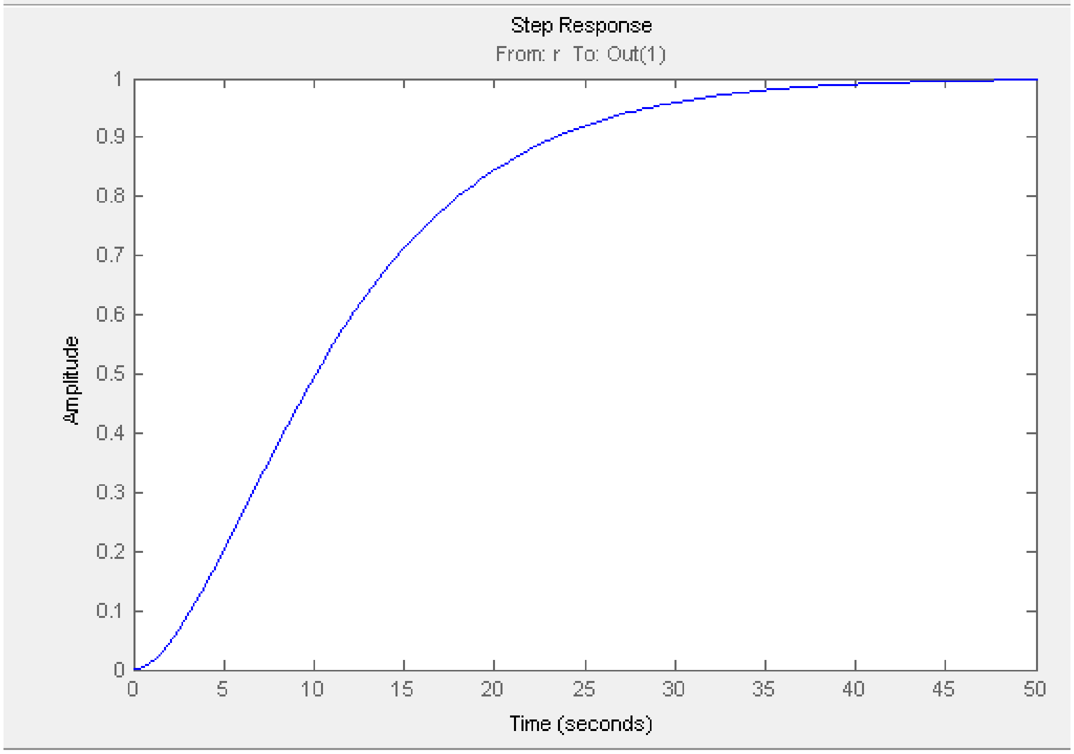

Fig. 4.26: Unit step response of internal model control based proportional integral derivative controller for the second order with third order disturbance with λ=6

Various tuning parameters of internal model control based proportional integral derivative design based on different orders of transfer functions obtained from above are shown in table 4.1.

Table 4.1: Various tuning parameters of internal model control based proportional integral derivative design based on different orders of transfer functions

Orders of Transfer functions	**Λ**	**K_c**	**τ_i**	**τ_d**
Ideal internal model control based proportional integral derivative	3	0.04	2	-
First order internal model control based proportional integral derivative	3	0.04	2	-
	6	0.02	2	-
Second order internal model control based proportional integral derivative	3	0.0416	2	0.5
	6	0.0208	2	0.5

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The internal model control provides a transparent frame work for control system design and tuning. The internal model control based proportional integral derivative controller design is simple and robust to handle the model uncertainties and disturbances and less sensitive to noise than proportional integral derivative controller for an actual process in industries. The internal model control based proportional integral derivative controllers design results in only one tuning parameter which is closed loop time constant λ internal model control filter factor. The internal model control based proportional integral derivative 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 internal model control based proportional integral derivative design procedure can be implemented in industrial processes using existing proportional integral derivative control equipment. the internal model control based proportional integral derivative controller design is used for open loop unstable processes because the internal model control suffers from internal stability.

And also various tuning parameters have been found based on the different orders of transfer functions. The standard internal model control filter from $f(s) = 1 / (\lambda s + 1)$ shows good set point tracking. Thus internal model control based proportional integral derivative controller is able to compensate for disturbances and model uncertainty while open loop control is not. Internal model control is also detuned to assure stability even if there is model uncertainty.

5.2 Future Scope

The internal model control based proportional integral derivative 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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