STRUCTURE AND TUNING INTERNAL MODEL CONTROL FOR INTEGRATING PROCESS

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ABSTRACT

The integrating process is a non-self-regulating process that its response increases or decrease gradually with time if changing in manipulated or disturbance variable. Usually, integrating process can be found in chemical process like exothermic reaction. In chemical industry that integrating process in reaction process, can cause the unexpected event in chemical plant, such as runaway reaction. The purposed of this study is to design and tuning IMC (Internal Model Control) controller for unstable process (integrating process). The internal model control is expected to overcome the dangerous situation. The standard IMC structure however could not handle the integrating process. The modification at Kaya structure is proposed. The modification is by eliminating (replacing) disturbance controller. The proposed IMC structure then simulated to 3 cases which are Integrating First-Order Plus Dead-Time (IFOPDT), Integrating Second-Order Plus Dead-Time (ISOPDT), and Integrating Third-Order Plus Dead-Time (ITOPDT). The tuning parameter of the proposed structure is determined by using Mp tuning method. The performance at the proposed IMC structure and tuning method are compared with one degree of freedom IMC (1DOF-IMC), Kaya structure units Mp-GM tuning, and IMC-based PID controller. The results show that the proposed structure and tuning method give the smallest IAE.

STRUKTUR DAN PENALAAN KAWALAN MODEL DALAMAN (IMC) UNTUK PROSES BERKAMIR

ABSTRAK

Proses berkamir adalah proses yang tidak boleh mengawal selia, peningkatan tindak balas atau pengurangkan secara beransur-ansur terhadap masa jika terdapat perubahan dalam pembolehubah dimanipulasikan atau gangguan. Biasanya, proses berkamir boleh didapati dalam proses kimia seperti tindak balas eksotermik. Dalam industri kimia yang mempunyai proses berkamir, dalam proses tindak balas, boleh menyebabkan peristiwa yang tidak dijangka dalam proses tersebut seperti reaksi yang tidak di jangka. Kajian ini adalah untuk merekabentuk struktur dan penalaan IMC (Model Kawalan Dalaman) pengawal untuk proses tidak stabil (proses berkamir). Model kawalan dalaman dijangka untuk mengatasi situasi berbahaya yang di nyatakan di atas. Struktur IMC yang biasa bagaimanapun tidak dapat mengendalikan proses berkamir. Pengubahsuaian pada struktur Kaya telah dicadangkan dalam kajian ini. Pengubahsuaian adalah dengan menghapuskan (menggantikan) pengawal gangguan. Struktur IMC menjalani proses simulasi dalam 3 kes (keadaan) iaitu IFOPDT, ISOPDT, dan ITOPDT. Parameter untuk penalaan ditentukan dengan menggunakan kaedah penalaan Mp. Prestasi pada struktur IMC yang dicadangkan dan kaedah penalaannya telah dibandingkan dengan struktur 1DOF-IMC yang biasa, struktur Kaya dengan penalaan Mp-GM, dan struktur PID yang berasaskan pengawalan IMC. Keputusan menunjukkan bahawa struktur yang dicadangan adalah bagus dan memberi nilai IAE terkecil.

TABLE OF CONTENT

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

d	Disturbance input
e	Error between measurement and model
E	Error between e and set point
G_c	Transfer function of controller
G_{c1}	Transfer function of set point controller
G_{c2}	Transfer function of disturbance rejection controller
G_d	Transfer function of disturbance
G_p	Transfer function of process
G_{pm}	Treansfer function of internal model
K	Gain of process
K_c	Proportional gain
r	Order of controller
s	Laplace domain
y	Measurement
y_{sp}	Set point
α	Lead constant of Gc2 controller
λ	Filter time constant
θ	Time delay
τ	Time constant of process
τ_D	Derivative time constant
τ_I	Integral time constant
ω	Frequency

LIST OF ABBREVIATIONS

1DOF-IMC	One- degree-of-freedom Internal Model Control (generally as IMC)
2DOF-IMC	Two-degree-of-freedom Internal Model Control
IFOPDT	Integral First Order plus Dead Time
ISOPDT	Integral Second Order plus Dead Time
ITOPDT	Integral Third Order plus Dead Time
GM	Gain Margin
IAE	Integral Absolute Error
IMC	Internal Model Control
Mp	Maximum peak (or resonant peak)
PID	Proportional Integral Derivative

CHAPTER 1

INTRODUCTION

1.1 Background of Proposed Study

Internal model control (IMC) is one of the controllers that very rapid in technology. The main idea of IMC is the algorithm use the model in the process directly. The algorithm based on the model of the process. The process with very precise model can control the process easily (Rice R. and Cooper D. J., 2002). However, there are several problems if the process is unstable such as integrating process. The integrating process is a non-self-regulated process that its parameters always change with time and its parameters change in an unpredictable style that cause by a manipulated or disturbance variable (Rice R. and Cooper D. J., 2002). When the process is unstable, IMC system are naturally unstable.

1.2 Problem Statement

The integrating process will response in the patterns of decrease gradually or increase gradually and a very unstable process. The reaction will runaway and do not get the right products. Also as a consequent of usage integrating process can cause the unexpected event in chemical plant. Thus, a one technique or model controls needs to be developed so as to stabilize the unstable process of integrating process.

1.3 Research Objectives

The objective of this study is to design and tuning IMC controller for unstable process (integrating process).

1.4 Research Questions

This study researches the best potential system to control the unstable process and how much can it contribute to the world chemical product demand.

The question is can standard IMC be implemented to unstable process? What the structure that can be used to control integrating process? Also how to get the parameter of IMC controller for unstable process? The question is answered in methodology part of this report.

1.5 Scope of Proposed Study

The scope of study includes the study of the effectiveness of internal model control in tuning the integrating process, particularly to make the control process much more effective and easier to industries. Use integrating process transfer functions of IFOPDT, ISOPDT, and ITOPDT (Kaya, 2004). The study also covers the use of software which is Matlab in control system and simulation process.

1.6 Expected Outcome

The study will produce method and procedure to control integrating process by using IMC principle. In Matlab software, the simulation part of controlling integrating process using IMC principle will be shown. The expectation is this study may help chemical industries in controlling integrating process and other process.

1.7 Significance of Proposed Study

IMC can be use in every chemical industry. The significant of the study is the commercialisation of the internal model control for chemical industries as well as less the complicated part in tuning of integrating process. Also, IMC can be applying on the entire plan with different characteristic.

1.8 Conclusion

This study is highly beneficial in chemical industries and will help to tackle the control problem of integrating process.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Self regulating process is a process that can self regulate from unsteady state to steady state condition when change the parameter or there is disturbance variables in the open loop for a certain time (Rice et. al, 2002). It is inversely proportional to non-self regulating process. The process for non-self regulating process cannot convert naturally from unsteady state to steady state.

An example of non-self regulating process that is widely used in literature is about tank that had pump installed at the discharge pipe of the tank. Feed entered from the feed pipeline into the tank. The manipulated variable for this case is the volume of the tank. The volume of tank would remain steady if the feed rate equal to discharge rate.

If the feed rate becoming slow and the discharge rate is faster compared to feed rate, the volume of tank will be lower compared to its steady state condition and finally drains empty.

Vice versa, the tank will fully load and overfilled if the inlet flow rate exceeds the outlet flow rate (Arbogast et. al, 2007). The feed will present outside the tank. It may be hazardous and dangerous to the workers. In industries, integrating process is a process that is hard to control and very dangerous if not being regulated. It would cause a disaster because of the unsteady state condition. So basically for such a dangerous process, tune controller in closed loop was strongly needed (Rice et. al, 2002).

2.2 Integrating Process Control

To control the integrating process, there are always challenges. First of all it is because of the variables of integrating process that were always drastically increased and sometimes drastically decreased by time. Another challenge was the tuning controller that is used for self regulating process that could not compete well with integrating process because of its wildness. The method to control integrating process can be divided into three main processes. Collect closed loop dynamic process data, fit the data with a simple linear model, and use the model parameters in correlations to obtain PID tuning parameter values (Rice et. al, 2002).

PID is short form that is combined from three words, proportional, integral, and derivative. PID is a controller that is widely used in industries and its performance was proven by the acceptance in control industries. But, PID controller is only best for self regulating process and the ability of the controller could not be proven in integrating process. In a research done by scientist and engineer, the number of tuning rules for PID controller is much more for stable overdamped processes as compared to integrating processes (Ahmad Ali et. al, 2010).

PID controller will produce noise when operated. Specifically, derivative action causes measurement noise to be amplified and reflected in the controller output signal (Rice et. al, 2002). This may cause problem and conflict in derivatives of the measurement for the slope in the process. The slope would be shown clearly in graph.

To control the noise and any error that occur to the controller and may affect the controller measurement system, derivative filter has to be used in the derivative equation of PID controller (Eriksson et. al, 2009). PID controller was not very effective with integrating process and need some help. Therefore, in a few literatures PID controller was combined with internal model control to get more accurate result. IMC method provides equal performance in set point tracking and superior filtering of excessive controller action when compared to the other methods (Rice et. al, 2002). Internal model-based control (IMC) has been shown to possess many advantages over PID control, particularly in the presence of significant process dead time (Chia Tien-Li et. al, 2008).

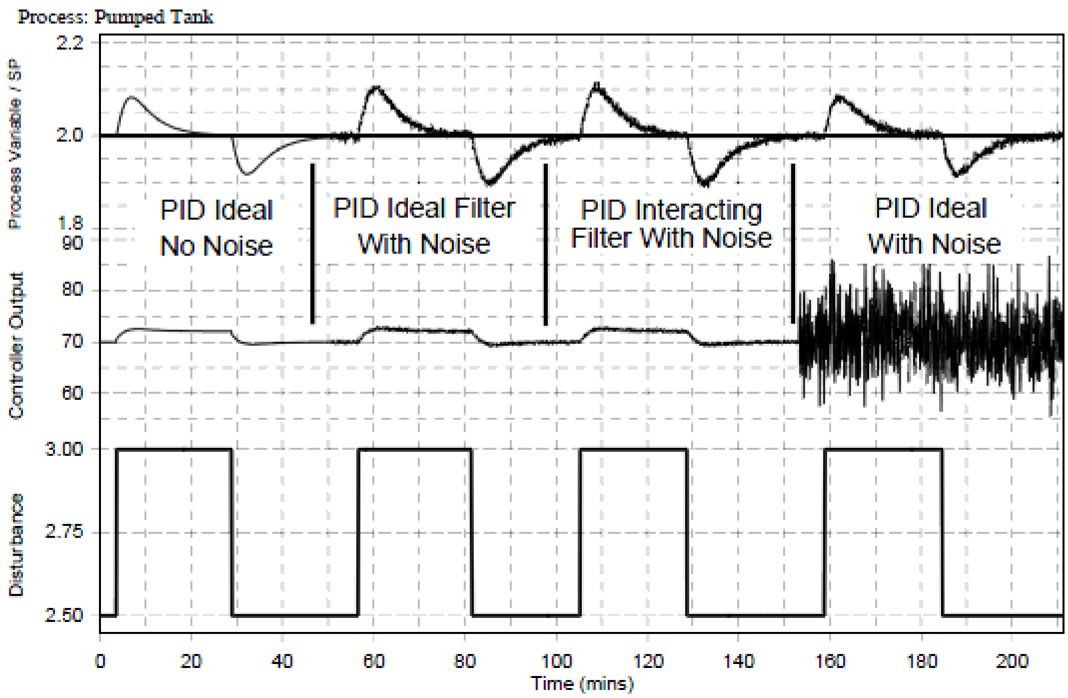

Figure 2.1: The graph showed the effect of noise in PID controller.

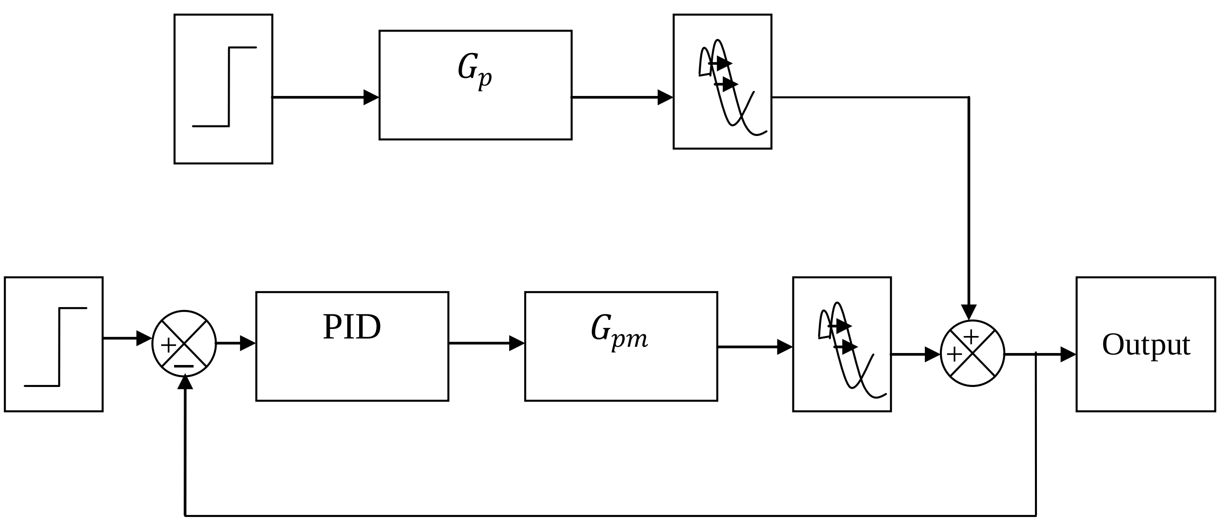

Figure 2.2: PID controller structure (Seborg et. al, 2011)

Figure 2.2 is based on Process Dynamics and Control book, third edition. To get the parameter of Proportional, Integral, and Derivative, a few calculations had to be made based on table 11.1 in the book. Standard PID controller equation:

$$G_c(s) = K_c(1 + \frac{1}{\tau_I s} + \tau_D s)$$

Figure 2.2 was the standard structure of PID controller which $K_c, \tau_I, and\ \tau_D$ was determined by using the table 11.1. The parameters calculations also depend on internal model of the process. There are 15 cases for 15 different transfer functions of internal models that give different equations to search for the $K_c, \tau_I, and\ \tau_D$ (Seborg et. al, 2011).

Table 2.1: IMC-based PID controller setting for $G_c(s)$ from M to O in Process Dynamics and Control book, 3rd edition

Case	**Model**	$\boldsymbol{K_c K}$	$\boldsymbol{\tau_I}$	$\boldsymbol{\tau_D}$
M	$\frac{Ke^{-\theta s}}{s}$	$\frac{2\tau_c + \theta}{(\tau_c + \theta)^2}$	$2\tau_c + \theta$	$-$
N	$\frac{Ke^{-\theta s}}{s}$	$\frac{2\tau_c + \theta}{(\tau_c + \frac{\theta}{2})^2}$	$2\tau_c + \theta$	$\frac{\tau_c\theta + \frac{\theta^2}{4}}{2\tau_c + \theta}$
O	$\frac{Ke^{-\theta s}}{s(\tau s + 1)}$	$\frac{2\tau_c + \tau + \theta}{(\tau_c + \theta)^2}$	$2\tau_c + \tau + \theta$	$\frac{(2\tau_c + \theta)\tau}{2\tau_c + \tau + \theta}$

As in the table above, there is IFOPDT model at case O. IFOPDT is a integrating transfer function which means case O can be used in finding the parameters (P, I, and D) to control integrating process. Based on that, the equation of $K_c, \tau_I, and\ \tau_D$ from the table was equal to:

$$K_c K = \frac{2\tau_c + \tau + \theta}{(\tau_c + \theta)^2} \quad , \quad \tau_I = 2\tau_c + \tau + \theta \quad , \quad \tau_D = \frac{(2\tau_c + \theta)\tau}{2\tau_c + \tau + \theta}$$

Where, based on Skogestad rule (Skogestad, 2003) , τ_c was equal to the value of θ from the model.

2.3 Internal Model Control (IMC) for Integrating Process

In IMC, process model is directly used in controller algorithm (Berber et. al, 1999). Then if the process model is stable, it will produce stable control system. However, if the process model is not stable such as integrating process, some modification is needed (Tao Liu et. al, 2011). On the other hand, when the model is not perfect, the closed-loop response of IMC control structure is much more complicated and can even be unstable if the filter is not detuned sufficiently (Brosilow et. al, 2001).

Several factors that make the model inaccurate are different operating conditions, for example, change in flow rate, temperature and or pressure. Therefore, the model uncertainty needs to be considered in designing the IMC controller. It is proven that internal model control have many advantage compared to PID controller. IMC was easier compared to PID. IMC make the process less complicated by only using first-order model. Specifically, the equation from the actual process will be converted to first-order model equation before using in internal model control (Brosilow et. al, 2001).

Implementation of IMC is simplified in a large class of industrial applications where the process dynamics can be adequately characterized by a simple first-order model requiring only estimates of process gain, lag time constant, and dead time for implementing the controller design (Chia Tien-Li et. al, 2008). For tuning, by using IMC it would be much easier and can be done by only changed the filter time constant. Decrease the time constant means to rapidly get the reaction response at closed-loop. As for increase it may cause slower closed-loop response but more stability can be gained.

IMC has the potential to achieve zero steady-state error for set point and process disturbance input. It is shown analytically and verified by computer simulation that this approach assures zero steady-state error for set point (SP) changes and process disturbance inputs (Chia Tien-Li et. al, 2008). Internal Model Control has been shown to be a powerful method for control system synthesis (Wen Tan et. al, 2003).