Decoupling Design of Model-Driven Control System for Better Sensitivities

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Abstract- **Proportional-Integral-Derivative (PID) controllers have survived changes in technology and they have been the most common way of using feedback in engineering systems. These are widely used in the industrial control system today because of its simple structure. However tuning of PID control systems is difficult because of its increased configuration parameters. Later for getting good performance KIMURA developed a model called MD-PID control systems about ten years ago. It is a cascaded model of main controller and PD control loop combining with the control process.**

In this paper after retrieving the design of TDOF PID controllers, we are cascading the MD-PID control to it with a new PD-feedback loop for determining better sensitivities. The proposed MD TDOF PID controllers are conducted by using Matlab/Simulink software. The designed MD TDOF PID controller is illustrated to own the properties of stabilizing the unstable processes, fast tracking to the change of set points and rejecting disturbance in the control system design. We introduced the structure and properties of the MD PID control system for decoupling.

Keywords-PID controllers, sensitivities, MD-PID controller, two degree of freedom, MIMO and decoupling.

I INTRODUCTION

PID controller is the most often used control system in industry. It is well known for its ability of correcting error in control systems, stabilizing process, controlling non-linear and time-variant systems. However, a PID controller is not always effective in producing desired system performance due to its simple structure and empirical tuning schemes [1]. A set of three parameters traditionally tuned by Ziegler–Nichols rules may not lead to a satisfactory system. The control processes that have long dead time, oscillatory output and unstable sub-process such as chemical plants require a higher-level architecture controller than one degree-of-freedom PID controller tuned by one set of three parameters [1]. Many control schemes such as predictive PID control scheme, dynamic matrix control (DMC-PID) control scheme are used to improve the performance of conventional PID in controlling the processes with long time delay.

In addition, the intelligent approaches such as fuzzy logic and neural networks offer new control strategies for the systems. The parameter optimization of PID by genetic algorithm is also used to design PID controllers .

As one of the advanced control algorithm, internal model control (IMC) has drawn more and more attention of researchers since it was proposed. IMC provides a simple yet effective framework for the analysis of control system, and has such advantages as regulating the parameters on-line conveniently, good robustness and tracking performance. Hence, many attempts have been made to exploit the IMC framework to design PID controllers. However, the parameter tuning of IMC-PID controller is limited by the tradeoff between tracking input signal and disturbance rejection performance. In addition, IMC-PID controller includes the model parameters in controller structure. Thus, the parameters of the controller should be re-tuned when the parameters of the system change or the system has serious uncertainties. To overcome the drawbacks of the conventional IMC-PID, the Two-Degree-of-Freedom PID controller tuned by two sets of three parameters is used to optimize the command tracking and disturbance rejection performance simultaneously and has become an interesting topic for many researchers recently. A Two-Degree-of-Freedom control scheme by the modified smith predictor (TDOF CS MSP) was proposed in for integrating and unstable delay processes.

A model driven control (MDC) concept was proposed by Kimura [1] as an alternative control system of IMC. MDC concept suggests using an ideal plant model as a block of a control system to compare the error of the actual plant against that of the ideal plant. A model driven PID control system developed by Masanori.It combines an MDC control system with a PD local feedback, an IMC, and a set point filter. In model driven Two-Degree of-Freedom PID (MD TDOF PID) to replace the IMC which has One-Degree-of-Freedom, with an IMC Q filter which has Two- Degrees-of-Freedom. The reason is that a MD TDOF PID control system owns better disturbance rejection properties by adding one more tuning parameter to MD PID control system. However, in the above-mentioned works, the values of parameters in main controller and set-point filter are set based on internal model control method. The drawback of these approaches is that the capability of MD TDOF PID cannot be fully exploited in improving the control system performance. There is a need for systematic method to tune the parameters in MD PID by optimizing the performance indices. Hence an effective tuning method of the parameters is needed in designing MD TDOF PID control system.

In this paper, the function of each block of the MD TDOF PID is analyzed. A systematic design procedure of MD TDOF PID is developed and a performance-based tuning method of MD TDOF PID controller parameters is proposed. Two performance decisive factors – variance control and variance tracking – are used to design the tuning method. The variance tracking is the ability for output to follow the input signal and the variance control consists in keeping the output of the system at a set point while recovering as quickly as possible from disturbances .

II MD TDOF PID CONTROL SYSTEM CONFIGURATION

MD TDOF PID control system can be divided functionally into three parts as shown in fig (1).where P(s), r, e, v, u, y, d and n are controlled process, set point signal, deviation signal, internal controller output, process input signal, process output signal, disturbance and noise.

$$y = P(s)(u+d)+n \qquad (1)$$

PD feedback compensator, main controller and set point filter, each of which plays a different role in the control system, shown in Figure.1. The main controller can be further decomposed into a gain block, a second order Q filter with tuning parameter λ, α and a first order model with time delay. PD feedback compensator is used to stabilize the plant(process)p(s) and make the transfer function of the process including the pd feedback itself f(s) to a first order system with time delay.

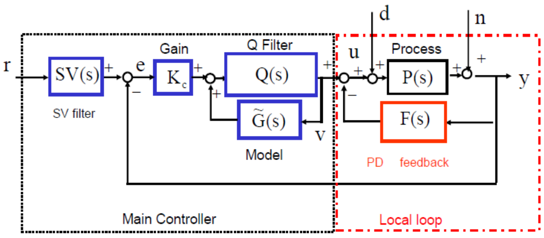

Fig. 1. A Model-Driven PID Control System

$$G(s) = \frac{P(s)}{1 + P(s)F(s)} \qquad (2)$$

$$G(s) \cong \frac{Ke^{-Ls}}{1 + Ts}$$

Where,

$$F(s) = \frac{Kf(1 + Tfs)}{(1 + kTfs)} \qquad (3)$$

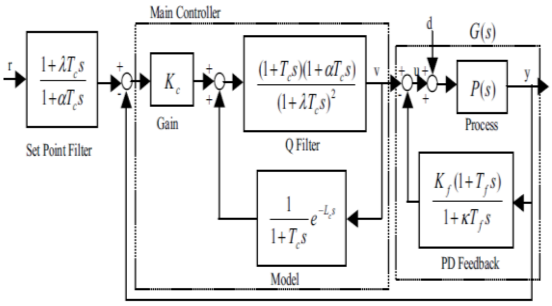

Fig2:Model Driven Two Degrees Of Freedom Pid Controllers

Main Controller Design:

The main controller consists of three blocks: gain block, Q filter block Q(s) and model block. The model block is the ideal model G(s) of the controlled process compensated by PD feedback.

Where Kc=1/k; Tc=T; Lc=L (4)

Since there is a pole at *s*=0 in the main controller composed of the *Q*(*s*) filter and the model, an integral mode is prepared automatically. After all the steady state offset of a control deviation is regulated to zero for a class of step disturbances and step references. Finally the output y can be expressed as in the case of the nominal case.

$$y = \frac{e^{-Ls}}{1+\lambda Ts}r + \frac{Ke^{-Ls}}{1+\lambda Ts}\left(1-\frac{(1+\lambda Ts)e^{-Ls}}{1+\lambda Ts}\right)d \qquad (5)$$

By using the second order Q filter,

$$Q(s) = \frac{(1 + T_c s)(1 + \alpha T_c s)}{(1 + \lambda T_c s)^2} \qquad (6)$$

and the set point filter,

$$= \frac{(1 + \alpha T_c s)}{(1 + \lambda T_c s)} \qquad (7)$$

Where λ=adjusting parameter of the response speed set point.

α=adjusting parameter of the regulation speed from disturbance without affecting the response speed from set point.

$$\alpha = 1 - (1 - \lambda)^2 \exp(-L_c/T_c) \qquad (8)$$

α, can be obtained by cancelling the lowest pole of the process.

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III. REDUCED MODEL

Because of well-designed PD local loop, the MD-PID control system can be applicable for not only long dead time processes, but also integral processes, oscillatory processes, small dead-time processes and even unstable processes.

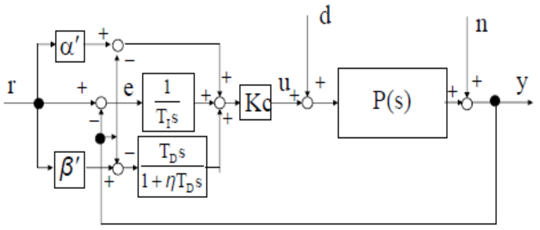


Fig.3.Reduced Model Of Md-Pid Controller

Figure 3 shows a block diagram of a TDOF PID control system should be designed. Where K_c, T_i , T_d and h are gain, integral time constant, derivative time constant and derivative gain in the TDOF PID control, respectively. And a′ and b′ are feed-forward gain in proportional portion and derivative portion concerning the reference signal, respectively. In order to convert a TDOF PID control system from the MD-PID control system, we applied a well-known Taylor expansion method.

The above reduced model is taken as the subsystem of each block.By comparing the three different values of α,the better sensitivities are obtained for control system.p1,p2,p3 are the first order delay systems with dead time.

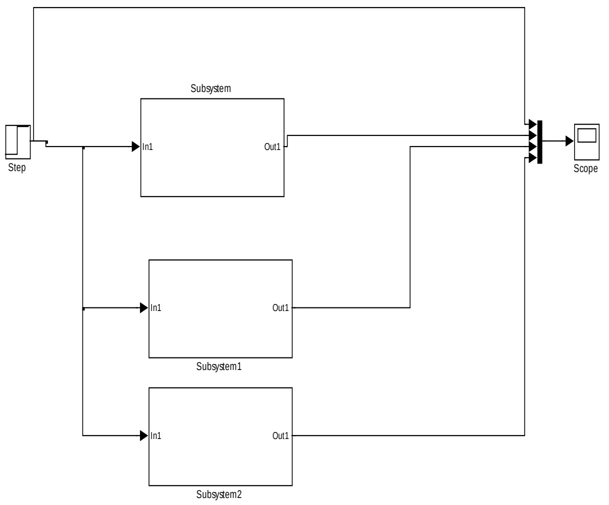


Fig 4.Simulink Equivalent Model Diagram

Internal subsystem model designed as shown in the figure 5.simulink model consists of three subsystems which is p1(s),p2(s),p3(s) connected with a single input step signal.

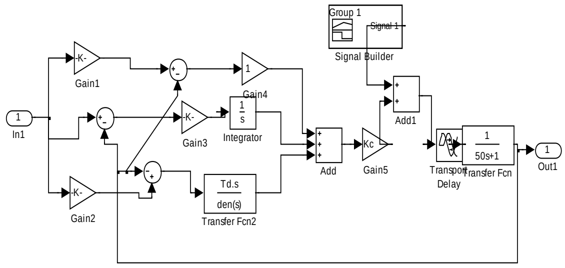
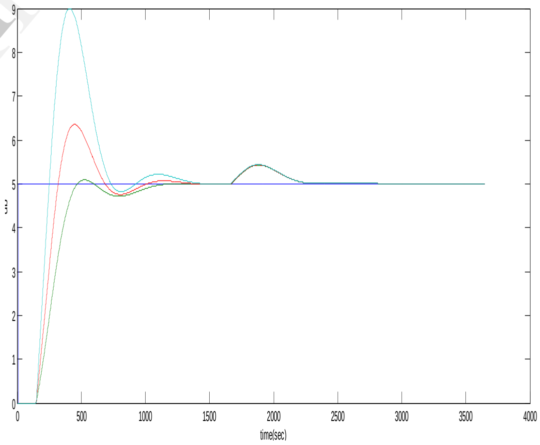


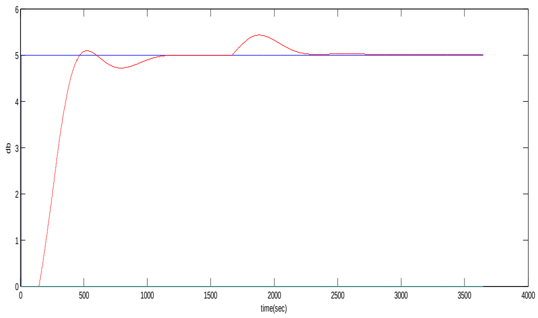
Fig.5.Internal Model Of Subsystem

	P_1	P_2	P_3
K_f	0.8	0.4	2.45
T_f	7.139	7.204	11.131
κ	0.1	0.1	0.1
K	0.556	2.5	0.69
T	20.33	34.64	9.296
L	21.41	21.85	6.111

Fig.6.Parameters Considered For P1,P2,P3



[a]



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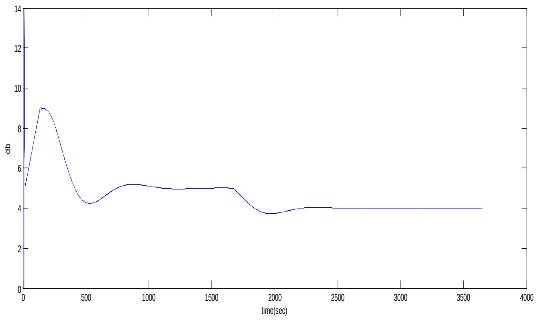

[c]

fig.7. [a].sensitivities of the MD PID controller with different α values, [b].gain response of the system and [c]. phase response of the system

IV. PRACTICAL INDUSTRIAL FIELD EXPERIMENTS:

As simulation results of MD PID control systems were shown in the former papers, some results of field experiments of MD PID control systems are introduced in this section.

Paper manufacturing plant:

Paper manufacturing company uses a great deal of water for all of paper making processes, water treatment process and boilers. A reservoir is used for providing water to all of the paper making processes at this site. To keep water level of the reservoir, river water is pumping up by using a variable speed inverter control pump and is sent to the reservoir at the 600 meters far from the pumping place. So the control process has integral mode, delay mode and dead time mode.

So the water level was oscillating with long period by using a conventional PID control at a conventional PI control phase as in Figure 6. The amount of fluctuation of water level is reduced to about 1 of 3 by applying the MD TDOFPID control. Finally the set-point (SV) was lowered, and energy-saving and healthy operation has also been attained.

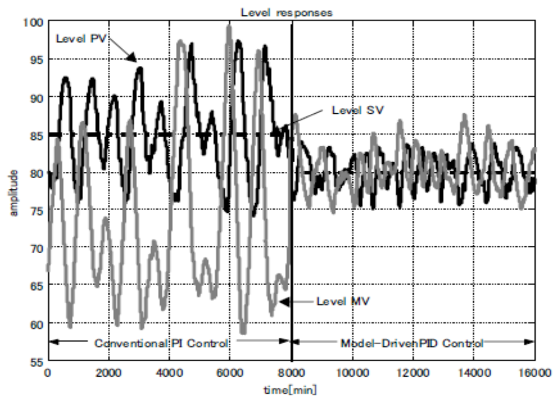

Fig.8. Comparison of water level control for reservoir using pid and mdpid control for paper manufacturing

V.DECOUPLING DESIGN OF MD PID CONTROL SYSTEM

Many applications of MD PID control system are existed in petro chemical plants and paper manufacturing plants. We attempted to increase the applications of MD PID control system to MIMO systems.

A decoupler K_d as a additional block, therefore K_d is designed to satisfy the equation[4].

$$\lim_{s\to 0} P(s)K_d = I \qquad (9)$$

therefore,

$$K_d = 1/P(0) \qquad (10)$$

both Q and the set point filters are designed from the diagonal elements of P(s) K_d in the design procedure.

Numerical Example:

Consider the MIMO system with two inputs and the two outputs of the process P(s).

$$P(s) = \begin{bmatrix} \frac{3.0e^{-20s}}{1+50s} & \frac{1.0e^{-25s}}{1+60s} \\ \frac{5.5e^{-18s}}{1+50s} & \frac{5.0e^{-12s}}{1+60s} \end{bmatrix} \qquad (11)$$

the decoupler K_d is as shown in,

$$K_d = \begin{bmatrix} 3.0 & 1.0 \\ 5.5 & 5.0 \end{bmatrix}^{-1} \qquad (12)$$

and decoupled models G_m are obtained by,

$$G_m = \begin{bmatrix} \frac{e^{-20s}}{1+50s} & - \\ - & \frac{e^{-12s}}{1+60s} \end{bmatrix} \qquad (13)$$

the below block diagram fig.9 shows the response curves of the MD decoupling PID control system and the conventional decoupling PID control designed by using model matching method by Kitamori for step disturbances.

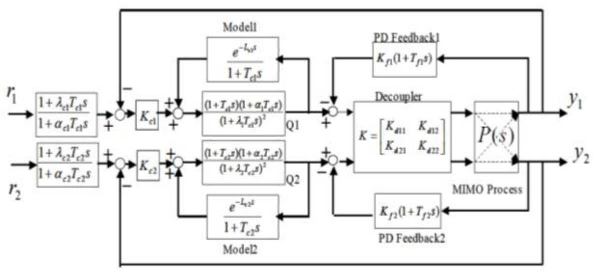

Fig.9 model driven decoupling pid control system for mimo controlled system.

The output responses of MD decoupling shows the sufficient good control inspite of using simple gain decoupler

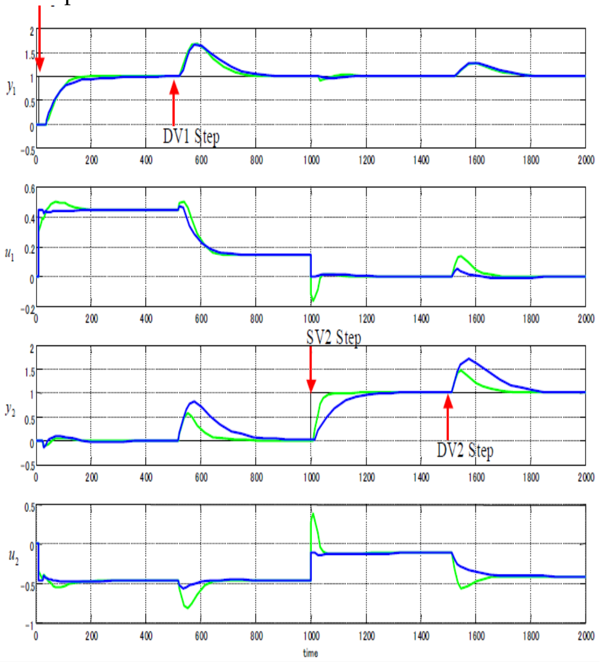

Fig.10 comparing responses of the MD decoupling and the conventional decoupling PID control system designed by model matching method.

VI.CONCLUSION

This paper extended a new PID control system, named as Model-Driven TDOF PID control system, which is combined with a local PD feedback, second order Q filter, a first order delay model with dead time and set-point filter. The MD TDOF PID control system has strong capability to stabilize by using the PD feedback and second order Q filter, to regulate quickly against disturbance and to track quickly to the change of set-point without overshoot. we also suggested applicability of MD PID control system to interacting MIMO system. Good performances are obtained in spite of only using single gain decoupler.

Through practical industrial field experiment, effectiveness of the MD PID control systems such as quick responses for both set-point tracking and disturbance regulating responses are shown.

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