APC2004

Model-Driven PID Control System, its properties and multivariable application

Takashi Shigemasa, Masanori Yukitomo,
Power and Industrial Systems Research and Development Center ,
Toshiba Corporation
Toshiba IT & Control Systems Corporation

Outline

- Introduction
- Model Driven PID Control System
  - structure and properties
- Multivariable Model Driven PID Control System
  - structure and simulations
- Conclusions

Introduction

PID control system: widely used as a basic control technology,

however, **is not always easy tuning and has control limitation for long dead-time processes**.

What is a simple, widely applicable process controller with easy to tune?

Based on the motief, we developed Model Driven PID Control System by extending the Model Driven control concept proposed by Kimura.

Firstly, Model Driven PID Control System, its structure, properties.

Secondary, the Model Driven PID Control System for multivariable processes on regulatory control level and simulation results.

Model Driven PID Control System

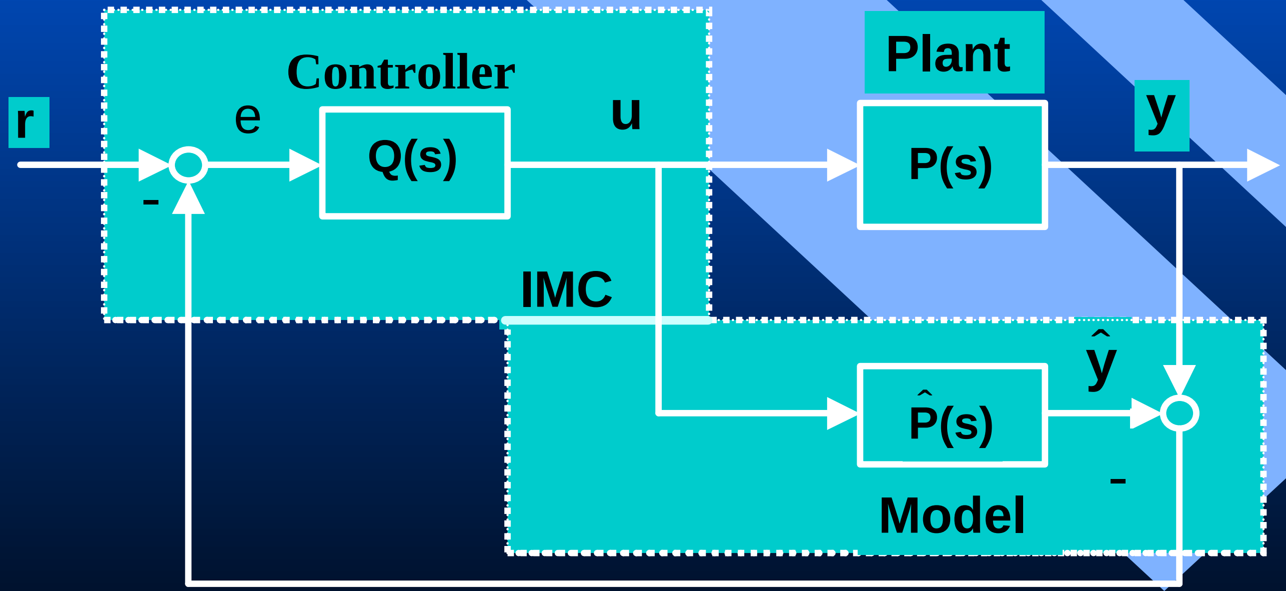
- Model Driven Control Concept
- Model Driven PID control system
- Structure and Properties

Model-Driven Control Concept

Definition: Kimura(CDC2000Sydney)

A control system architecture which uses a model of the plant as a principal component of Controller is called a model-driven control.

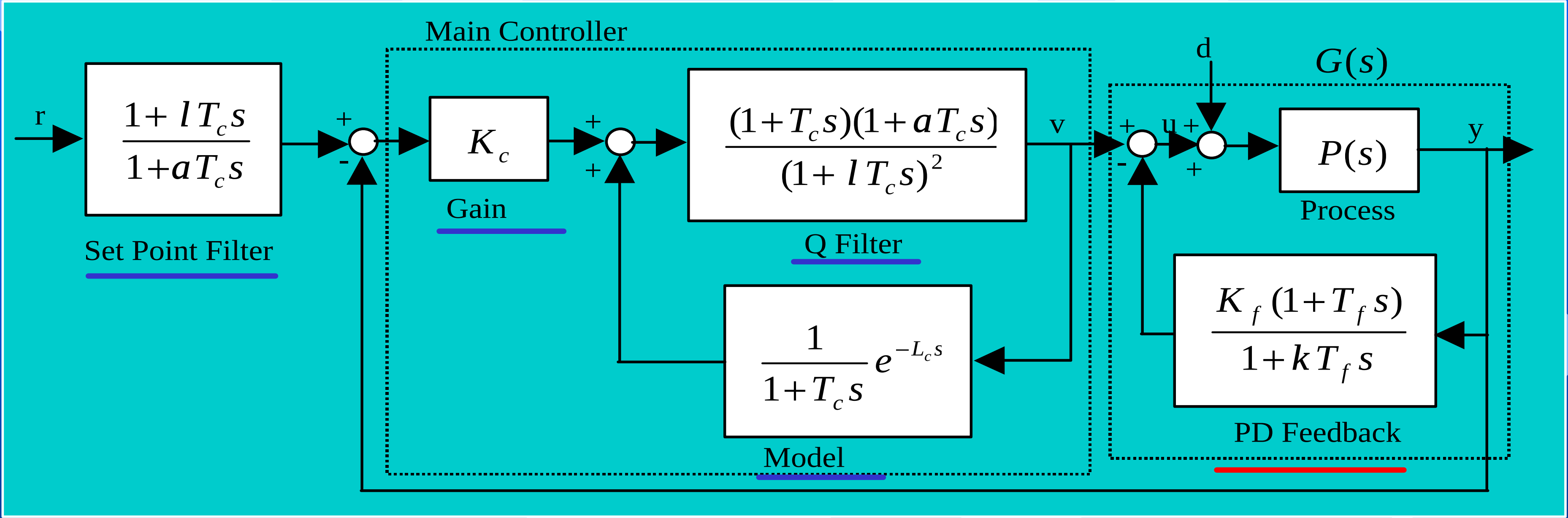
IMC Architecture Morari, Zafirou,1989



Features of MDC

- Simple Structure
- Easy Tuning
- Proven Stability and robustness iff P(s) is stable

Structure of Model Driven PID Control System

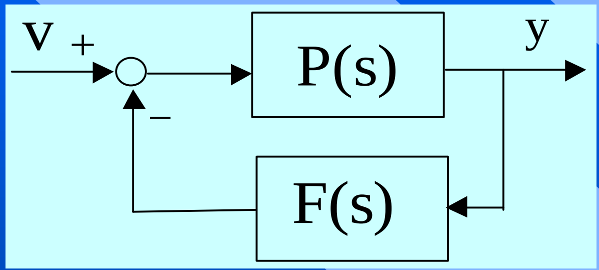


- PD Feedback
- Main control ;

  Gain , second order Q-filter and normalized first order delay model with dead-time for inner loop
- Set-point filter

Design steps

Step 1 PD Feedback F(s)



$$G(s) = [1 - P(s)F(s)]^{-1} P(s) \cong \frac{K\exp(-Ls)}{1+Ts}$$

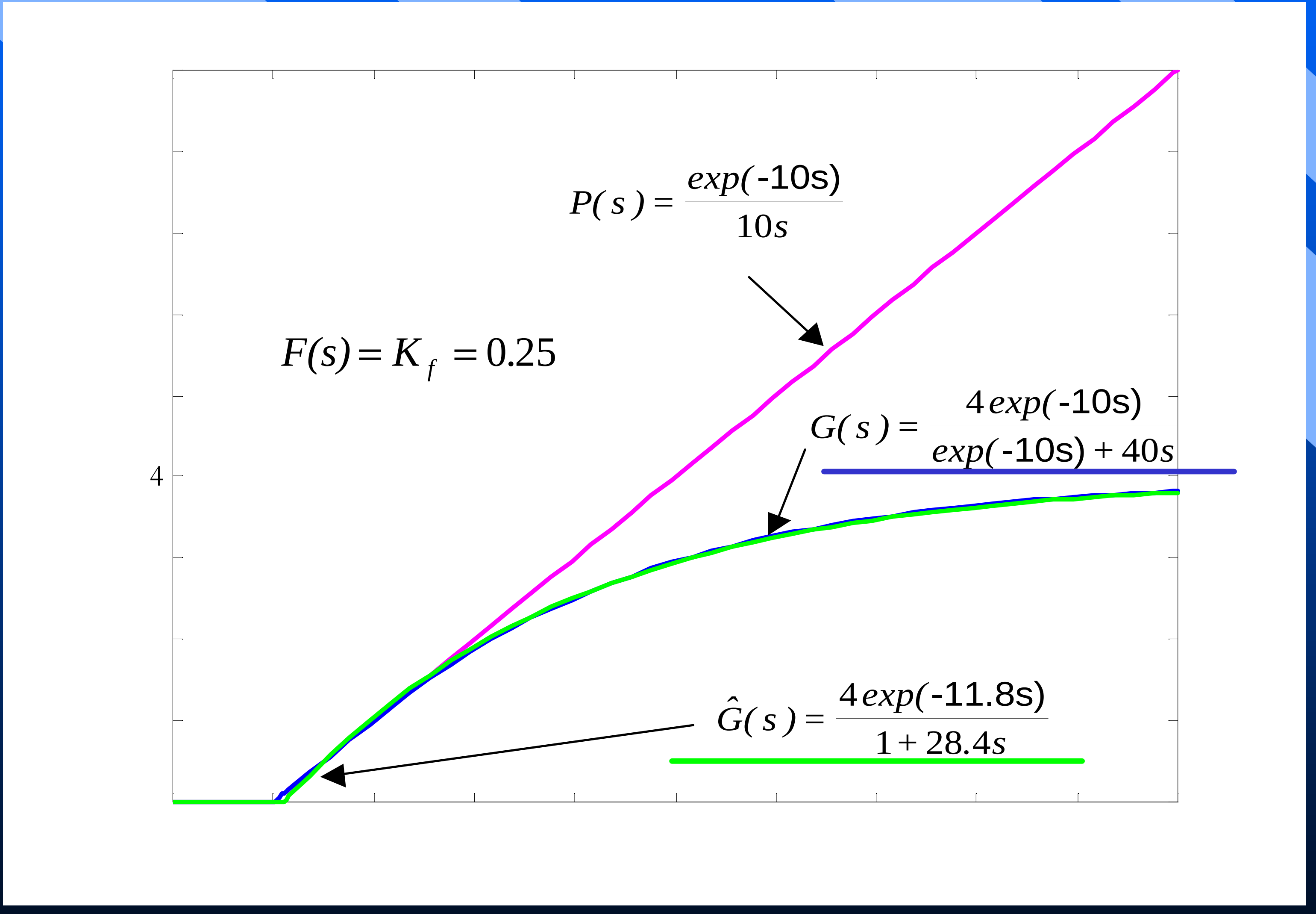
$$F(s) = \frac{K_f(1+T_f s)}{1+k\ T_f s}$$

Compensate inner loop dynamics G(s) to a first order system with dead time by using PD feedback F(s).

Design methods :partial model matching method,frequency region method,pole placement,<u>simulation</u>.

Wide applicability, for not only first order delay process with dead time but also integral process, oscillatory process and unstable process

Example: A integral process can be converted to a first order delay system with dead time



Design steps(continued)

Step 2:Main controller and set-point filter

1) Kc=1/K

2) Tc=T

3) Lc=L

Step 3:TDOF property by adjusting λ and α.

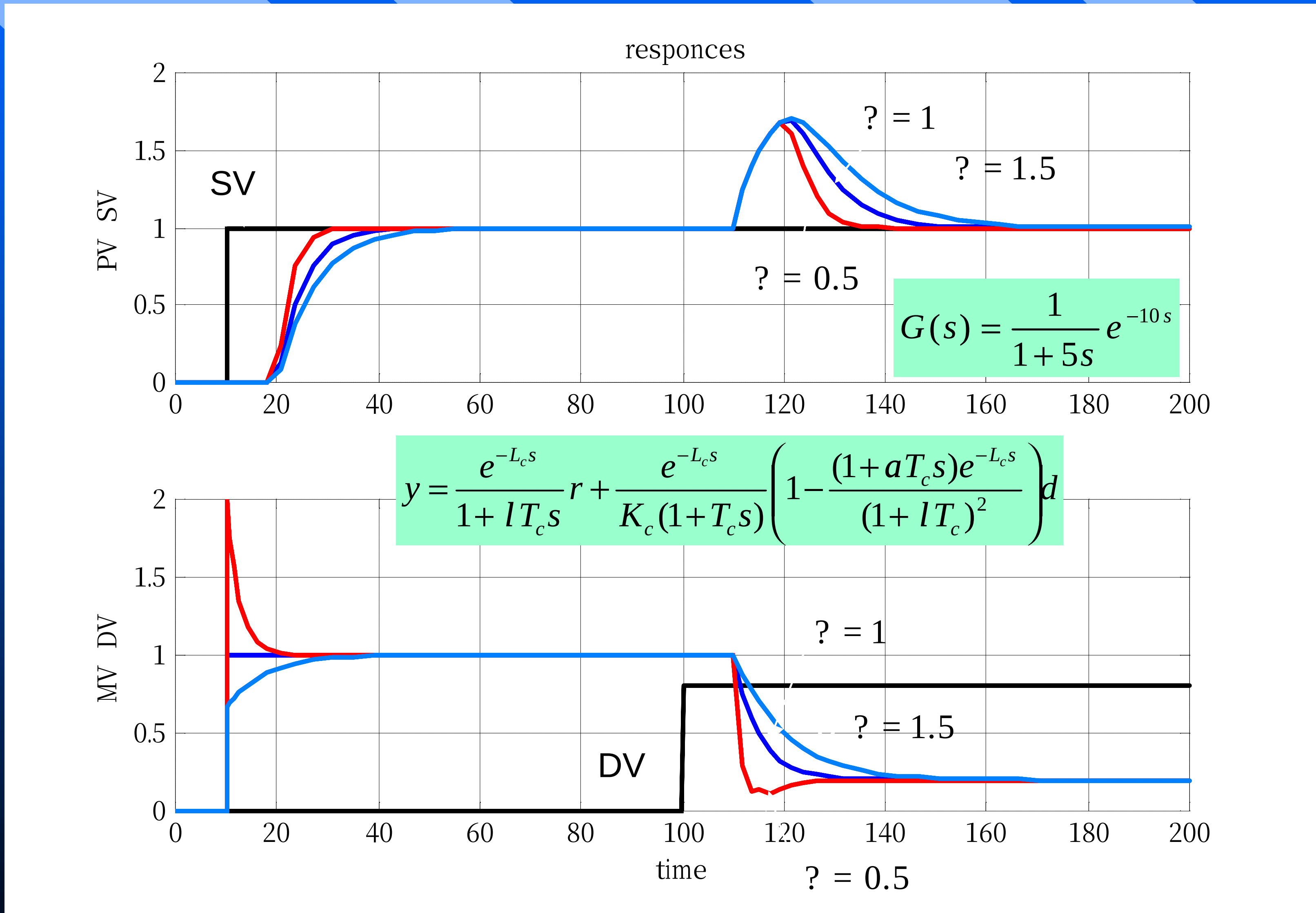
$$y = \frac{exp(-L_c s)}{1+\lambda T_c s} r + \frac{exp(-L_c s)}{K_c(1+T_c s)} [1 - \frac{(1+\alpha T_c s)(1+T_c s)}{(1+\lambda T_c s)^2}] d$$

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

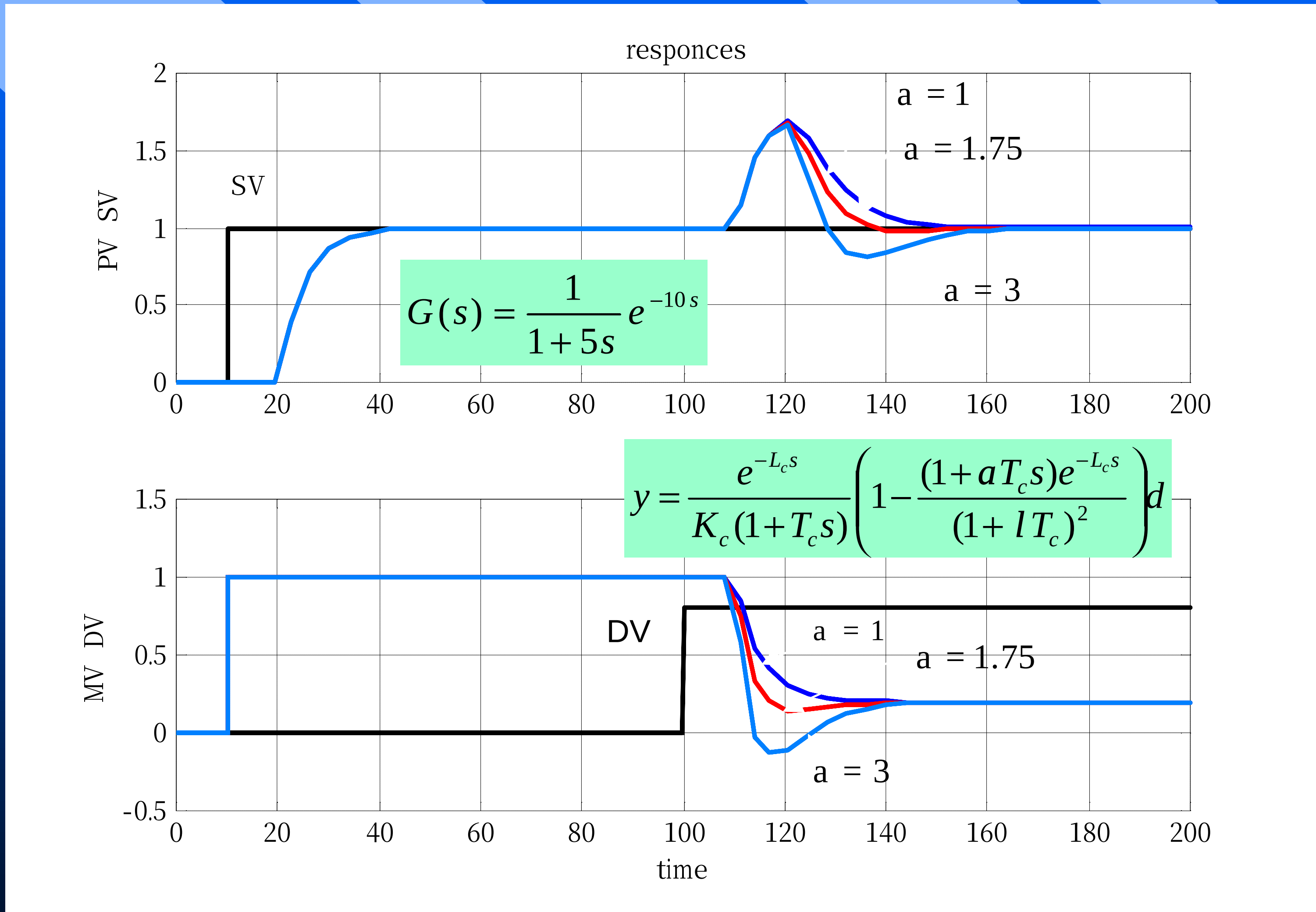
$$\frac{1+\lambda T_c s}{1+\alpha T_c s}$$

λ: response speed α:Disturbance regulation

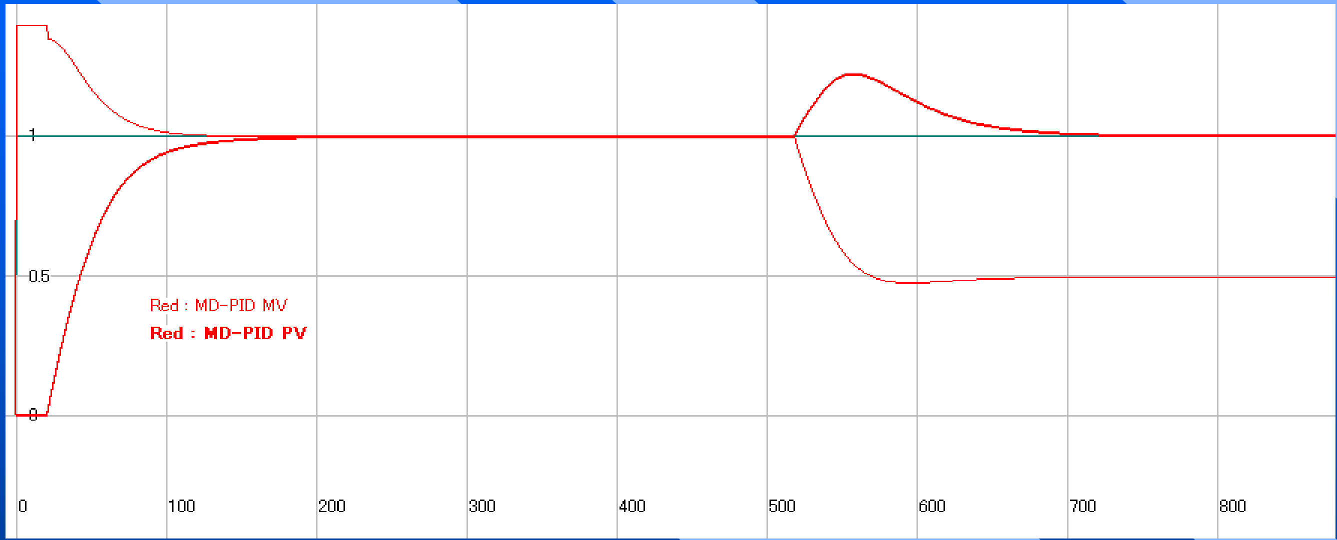
Adjustable response speed by λ

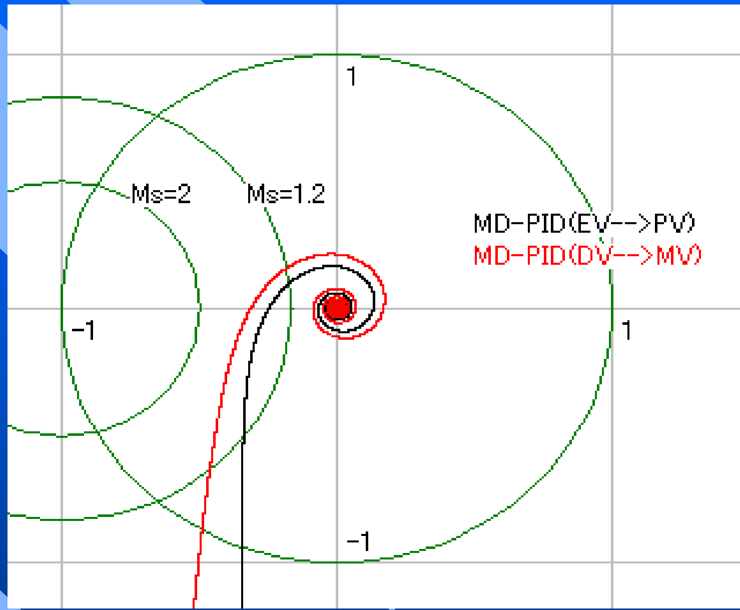


Adjustable Disturbance regulation speed by α



Robustness





Nyquist curves

$$P(s) = \frac{\exp(-20s)}{1+50s}$$

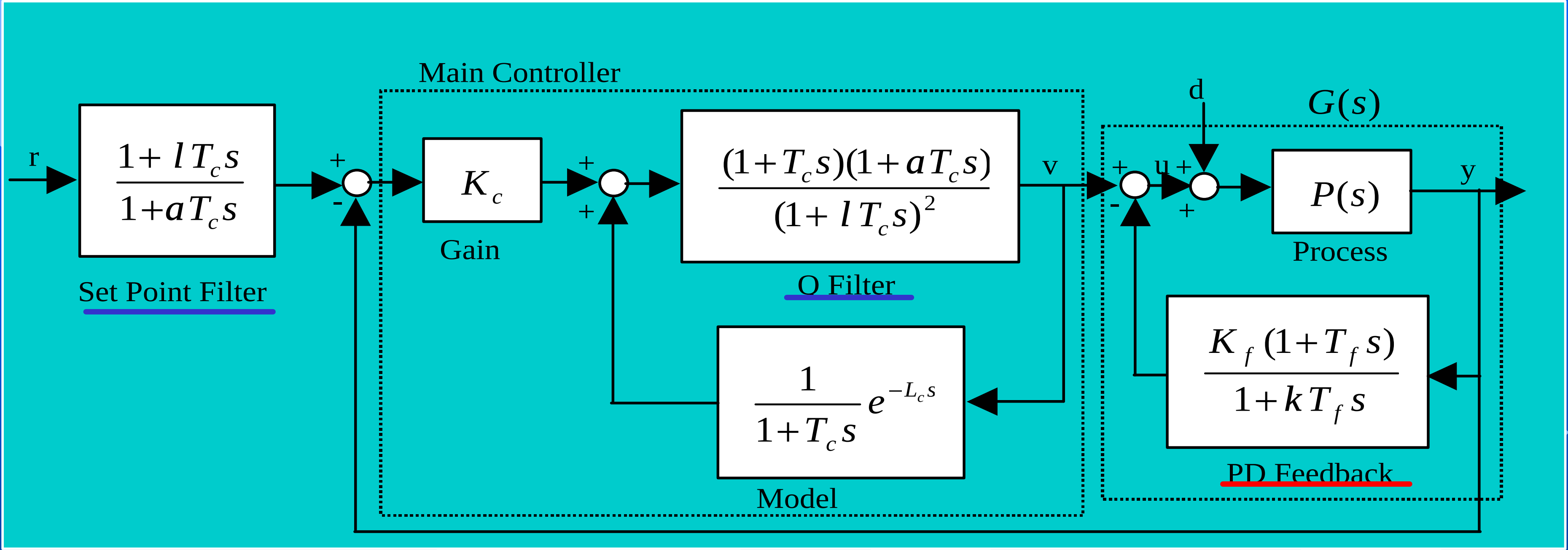
$$F(s) = 0.4$$

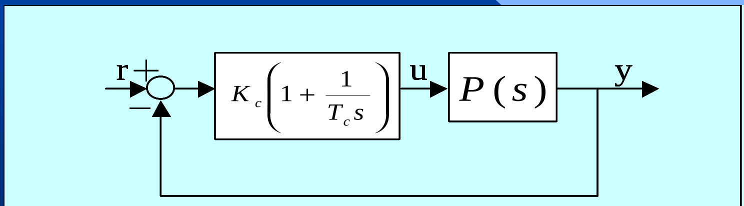
$$G(s) = \frac{0.714\exp(-21s)}{1+28.7s}$$

MD-PID(EV-->PV)
Gain Omega = 0.09
Gain Margin = 12.12dB
Phase Margin = 69.94deg

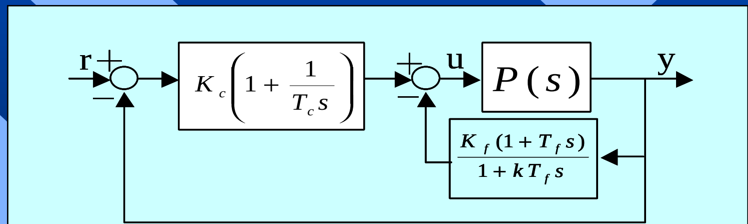
MD-PID(DV-->MV)
Gain Omega = 0.09
Gain Margin = 10.09dB
Phase Margin = 60.64deg

Upper compatibility

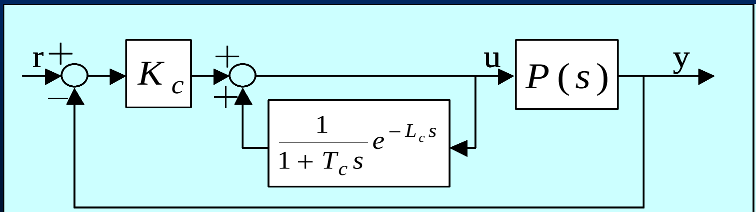




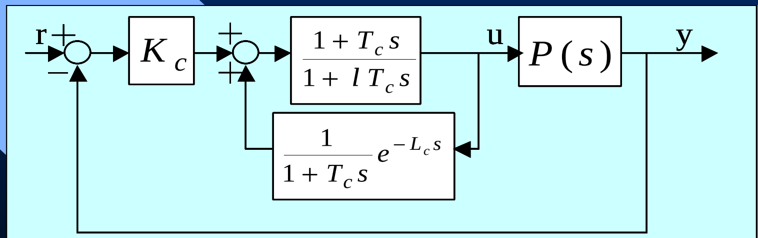
PI Control : $K_f = T_f = 0,\ l = a = 1,\ L_c = 0$



PI-PD Control : $l = a = 1,\ L_c = 0$



PID τ d Control : $K_f = T_f = 0,\ l = a = 1$



IMC : $K_f = T_f = 0, a = 1$

Summery of Properties

1. Wide Applicability PD feedback

$$G(s) \cong \frac{K\exp(-Ls)}{1+Ts} \qquad F(s) = \frac{K_f(1+T_f s)}{(1+?\,T_f s)}$$

2. Two degree of freedom characteristics

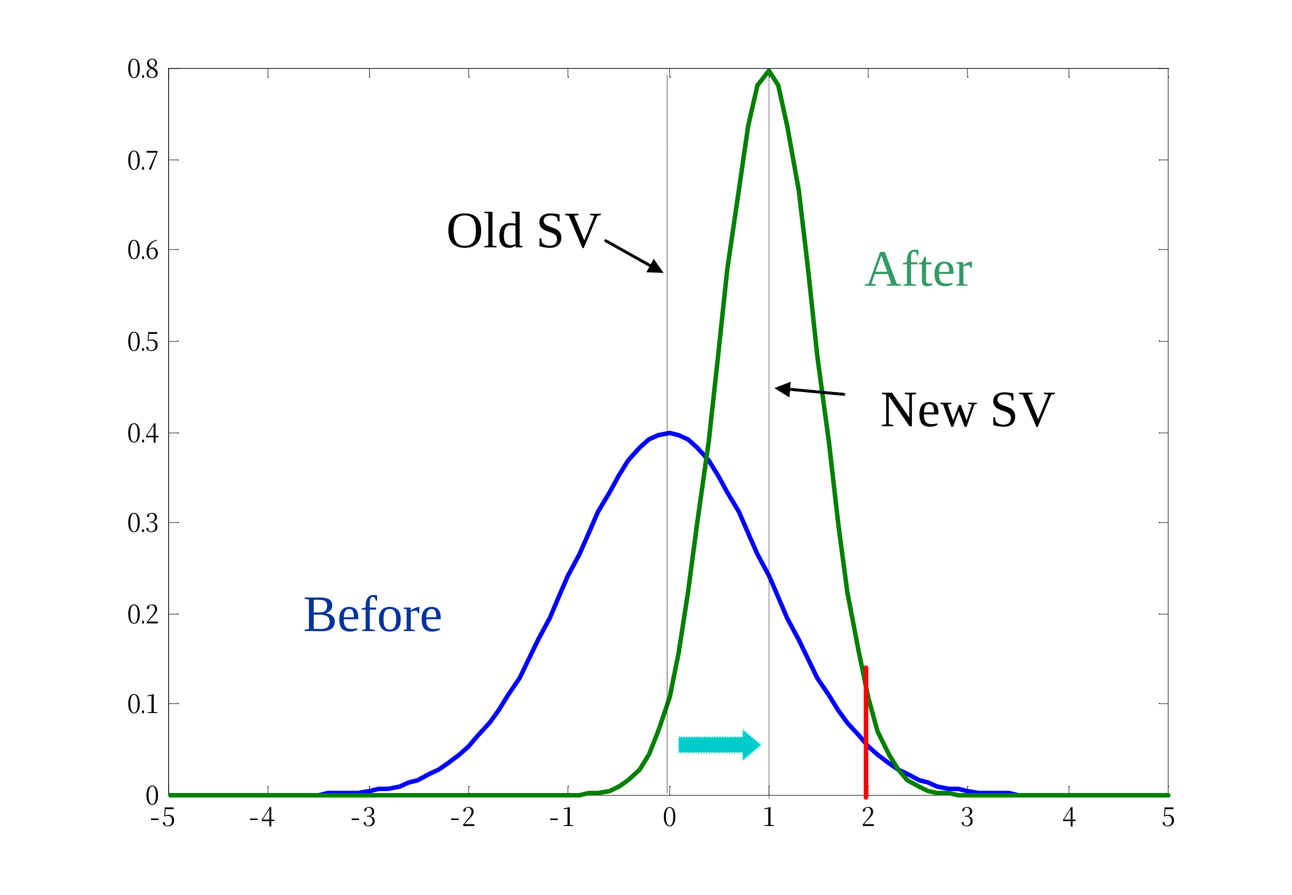
Kc=1/K Tc=T Lc=L

λ tuning;Response speed, α tuning:Disturbance regulation speed

3. Robustness can be examined by well-known nyquist chart

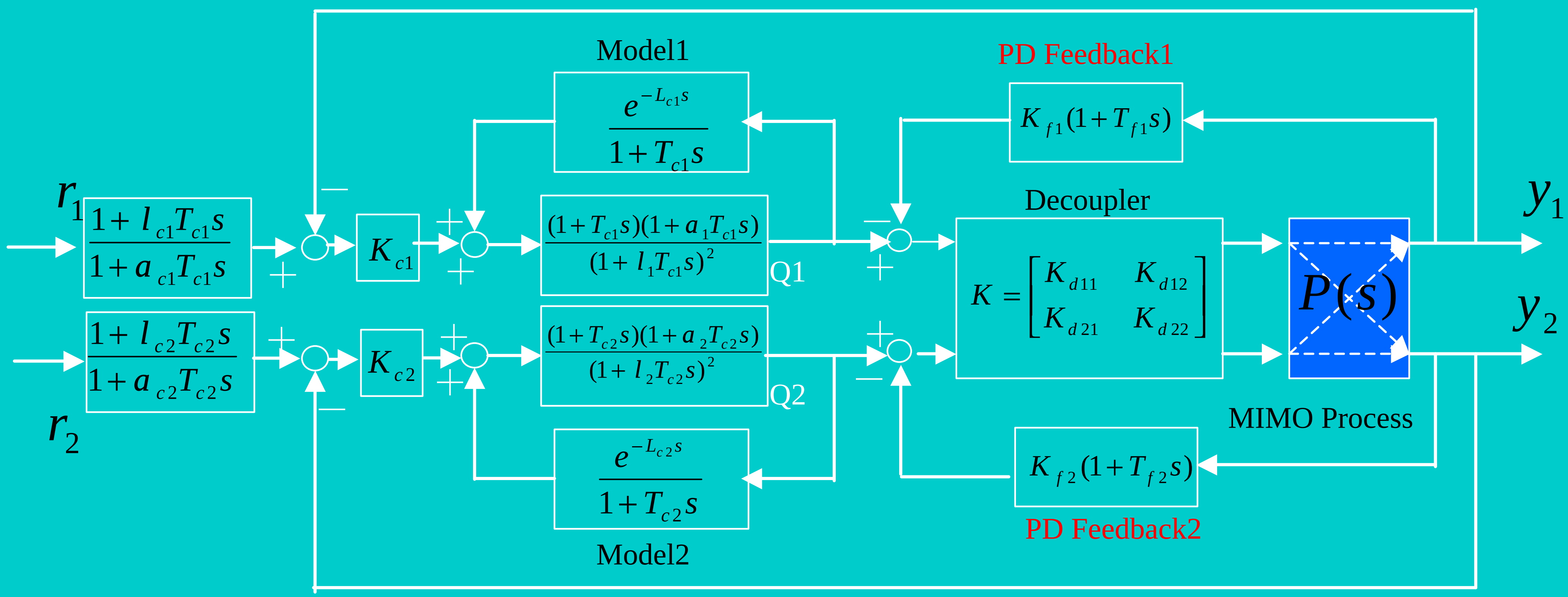
4. Upper compatibility from conventional PID control systems

Control performance - PV distribution -



Reported reduce operator's over-riding actions and fuel cost, obtain high quality of product though some field applications.

Multivariable Model Driven PID Control System



Design steps

1. Decoupler（K_{dec}）

$$P(s)=\begin{bmatrix} \frac{K_{11}}{1+T_{11}s}e^{-L11s} & \frac{K_{12}}{1+T_{12}s}e^{-L12s} \\ \frac{K_{21}}{1+T_{21}s}e^{-L21s} & \frac{K_{22}}{1+T_{22}s}e^{-L22s} \end{bmatrix} \Rightarrow K_{dec}=P(0)^{-1}=\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}^{-1}$$

the control process

A decoupler

2. Other MD control systems

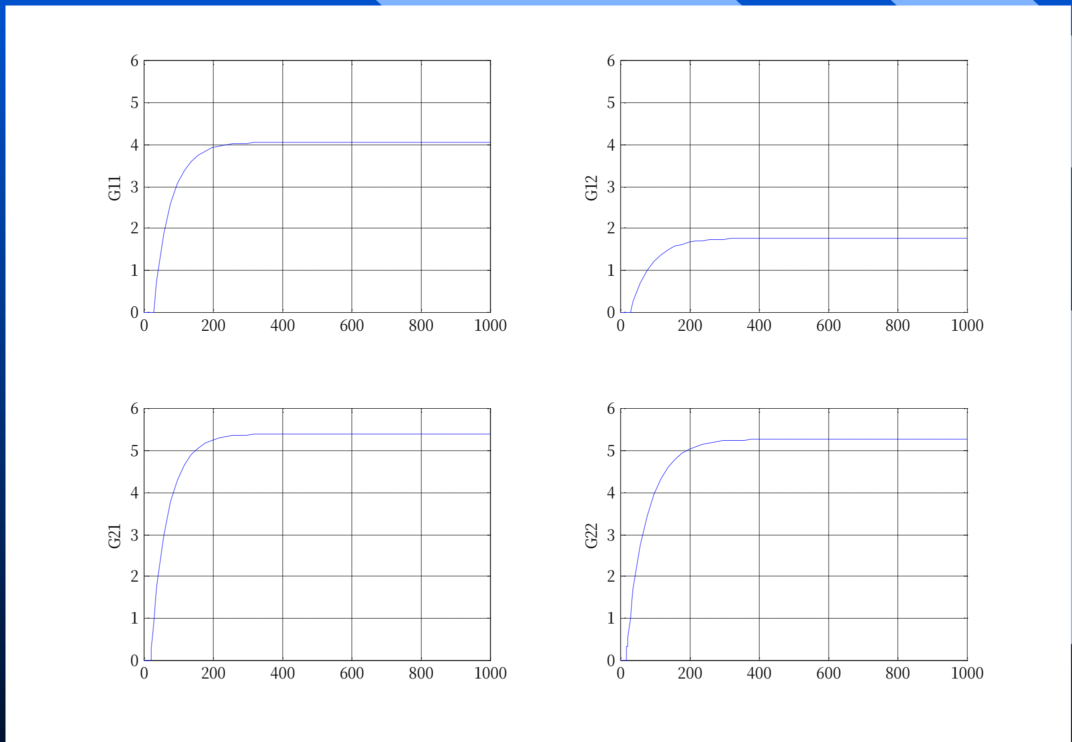
$$K_{dec}P(s)=\begin{bmatrix} \hat{P}_{11} & \hat{P}_{12} \\ \hat{P}_{21} & \hat{P}_{22} \end{bmatrix}$$

Designed for the diagonal element of $K_{dec}P(s)$

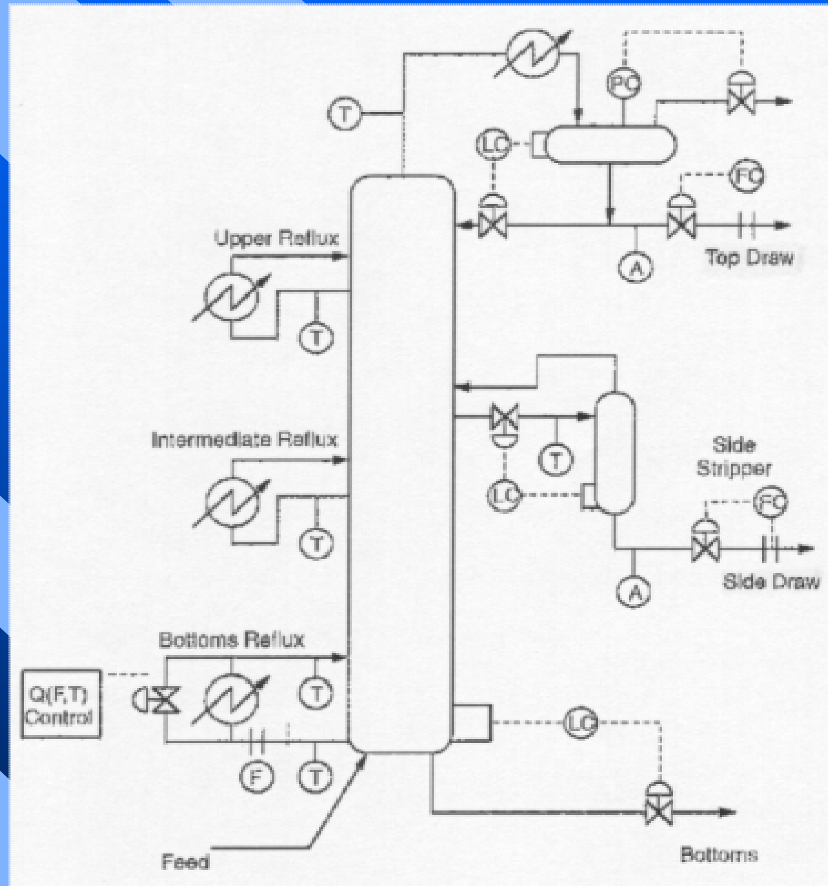
Simulation

Controlled object ： Shell heavy oil fractionator

$$P(s)=\begin{bmatrix}\dfrac{4.05}{1+50s}e^{-27s} & \dfrac{1.77}{1+60s}e^{-28s}\\ \dfrac{5.39}{1+50s}e^{-18s} & \dfrac{5.27}{1+60s}e^{-14s}\end{bmatrix}$$



Step responses



IEEE Control System Magazine
Shell heavy oil fractionator
By Daniel E. Rivera

Design results

1. Distributed MD PID Control

$$\text{Decoupler} = \begin{bmatrix} 0.4465 & -0.1500 \\ -0.4567 & 0.3431 \end{bmatrix}$$

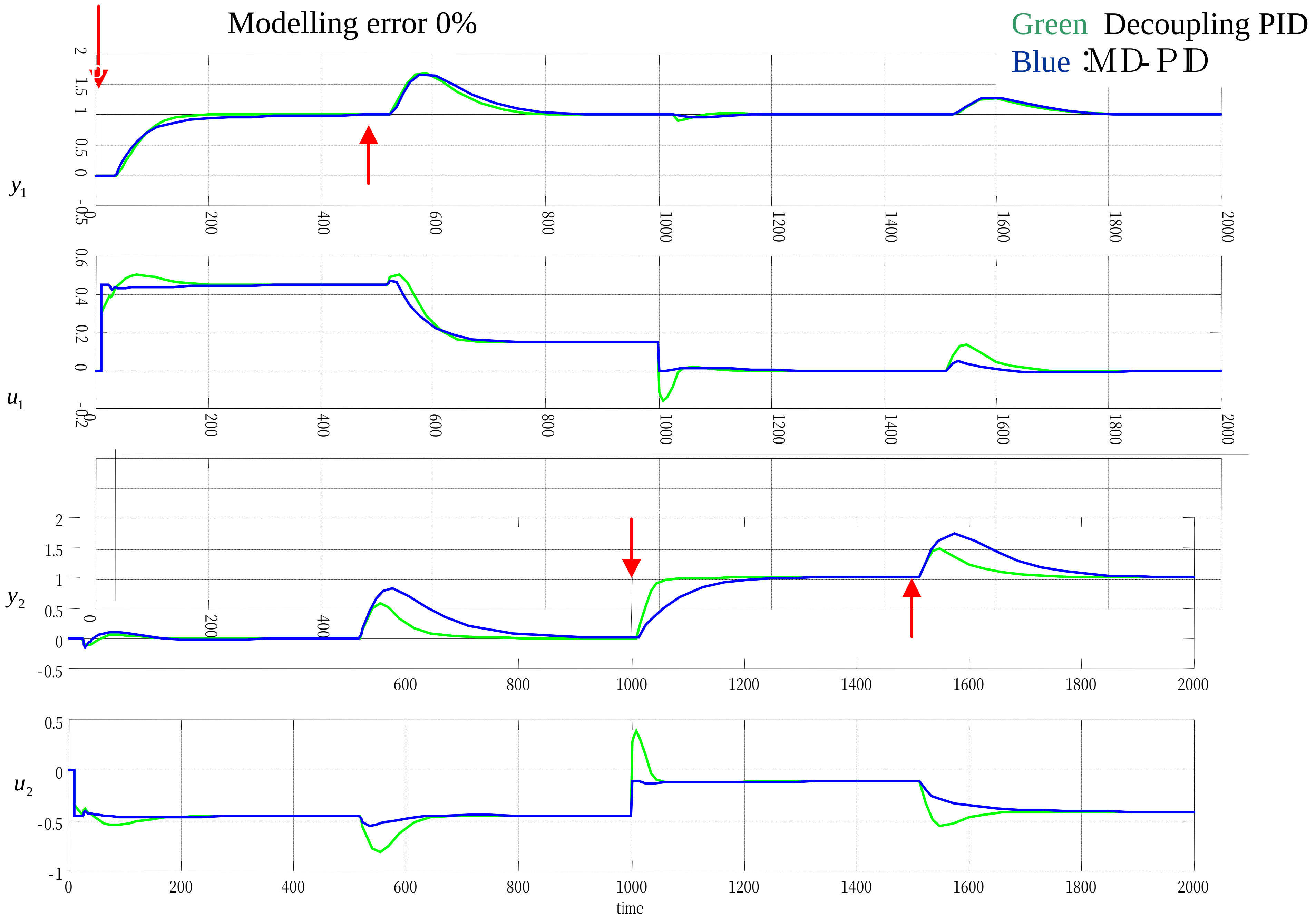
$$\text{model1} = \frac{1}{1+50s}e^{-27s}, \text{model2} = \frac{1}{1+60s}e^{-14s}$$

2. Decoupling PID Control

by Model-matching method by Kitamori

$$K_p = \begin{bmatrix} 0.2982 & -0.2618 \\ -0.3455 & 0.7372 \end{bmatrix}$$

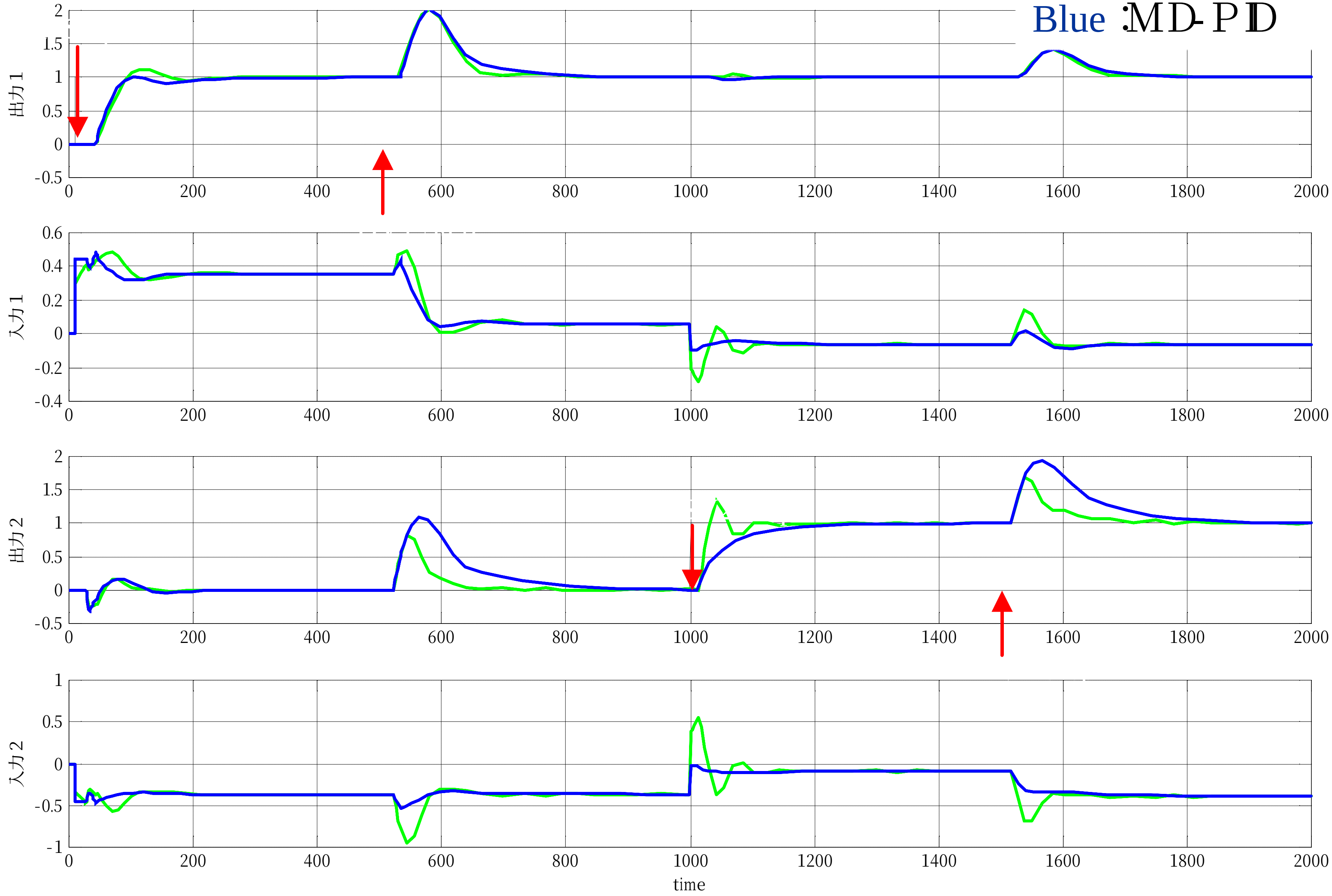
$$T_I = \begin{bmatrix} 45.1015 & 47.6909 \\ 51.1015 & 58.6909 \end{bmatrix}$$



Modelling error 0%
Green Decoupling PID
Blue :MD-PID
y1
u1
y2
u2
time

Modelling error 25%

Green Decoupling PID
Blue :MD-PID



Conclusions

★We discussed a Model Driven PID control system,its properties and a multivariable application.

★PD feedback give us wide applicability of controlled processes:

	Delay with dead time		Zero	Oscillation	Integral	Unstable
	Small L/T	Large L/T				
PID	●	△	△	△	△	△
MD-PID	●	○	○	○	○	○

★MD-PID control system shows Good control performances like a TDOF control system with easy tuning.

★ MD- PID control system has upper compatibility from conventional PI, IMC, PID τ d and PI-PD

★ Multivariable MD PID Control system shows useful results in spite of simple control structure.