ECET- 462

Application of Computers in Process Control

Purdue University, Calumet

[LABORATORY 8]

Tuning of a PID controller using Ziegler-Nichols Method

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LAB 8

Objective:

1) To demonstrate the use of PID controller using LabVIEW.
2) Finding the values of K_P and T_I and T_D using Ziegler Nichols Method for Tuning the PID controller

Software required: LabVIEW

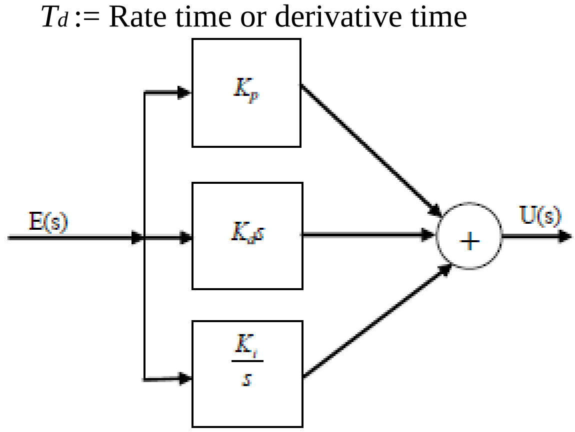
Background:

PID controllers are probably the most commonly used controller structures in industry. They do, however, present some challenges to control and instrumentation engineers in the aspect of tuning of the gains required for stability and good transient performance. There are several prescriptive rules used in PID tuning. An example is that proposed by Ziegler and Nichols in the 1940's and described in this note.

The PID controller encapsulates three of the most important controller structures in a single package. The parallel form of a PID controller has transfer function:

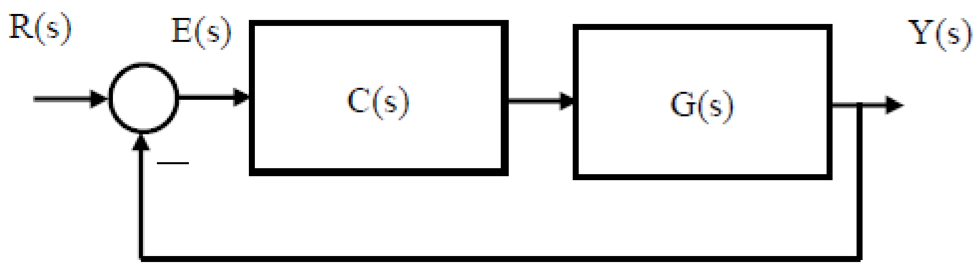
$$C(s) = K_P + \frac{K_I}{s} + K_d s$$
$$= K_P(1 + \frac{1}{T_I s} + T_d s)$$

where:
K_p := Proportional Gain
K_I := Integral Gain $\quad$ T_I := Reset Time $=K_p/K_i$
K_d :=Derivative gain $\quad$ T_d := Rate time or derivative time



Parallel Form of the PID Compensator

The proportional term in the controller generally helps in establishing system stability and improving the transient response while the derivative term is often used when it is necessary to improve the closed loop response speed even further. Conceptually the effect of the derivative term is to feed information on the rate of change of the measured variable into the controller action. The most important term in the controller is the integrator term that introduces a pole at $s = 0$ in the forward loop of the process. This makes the compensated open loop system (i.e. original system plus PID controller) a type 1 system at least; our knowledge of steady state errors tells us that such systems are required for perfect steady state setpoint tracking.



Ziegler-Nichols Tuning

In 1942 Ziegler and Nichols, both employees of Taylor Instruments, described simple mathematical procedures for tuning PID controllers. These procedures are now accepted as standard in control systems practice. Ziegler-Nichols formulae for specifying the controllers are based on plant step responses.

Steps to determine PID controller parameters:

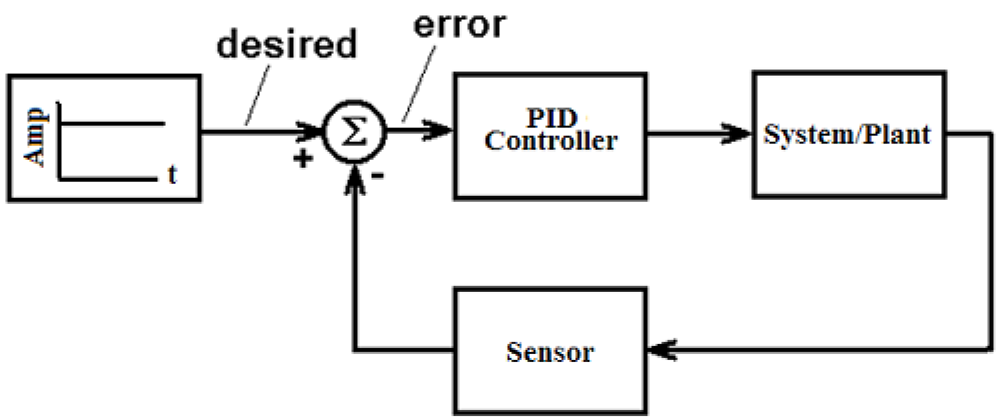
1. Reduce the integrator and derivative gains to 0.
2. Increase K_P from 0 to some critical value $K_P=K_c$ at which sustained oscillations occur
3. Note the value K_c and the corresponding period of sustained oscillation, T_c
4. The controller gains are now specified as follows:

PID Type	K_P	T_I	T_d
P	0.5Kc	Inf	0
PI	0.45Kc	Tc/1.2	0
PID	0.6Kc	Tc/2	Tc/8

Consider a process with transfer function:

$$G(s) = \frac{1}{(s+1)(s+3)(s+5)} = \frac{1}{s^3 + 9s^2 + 23s + 15}$$

Let us consider that the overall system has a unity feedback.



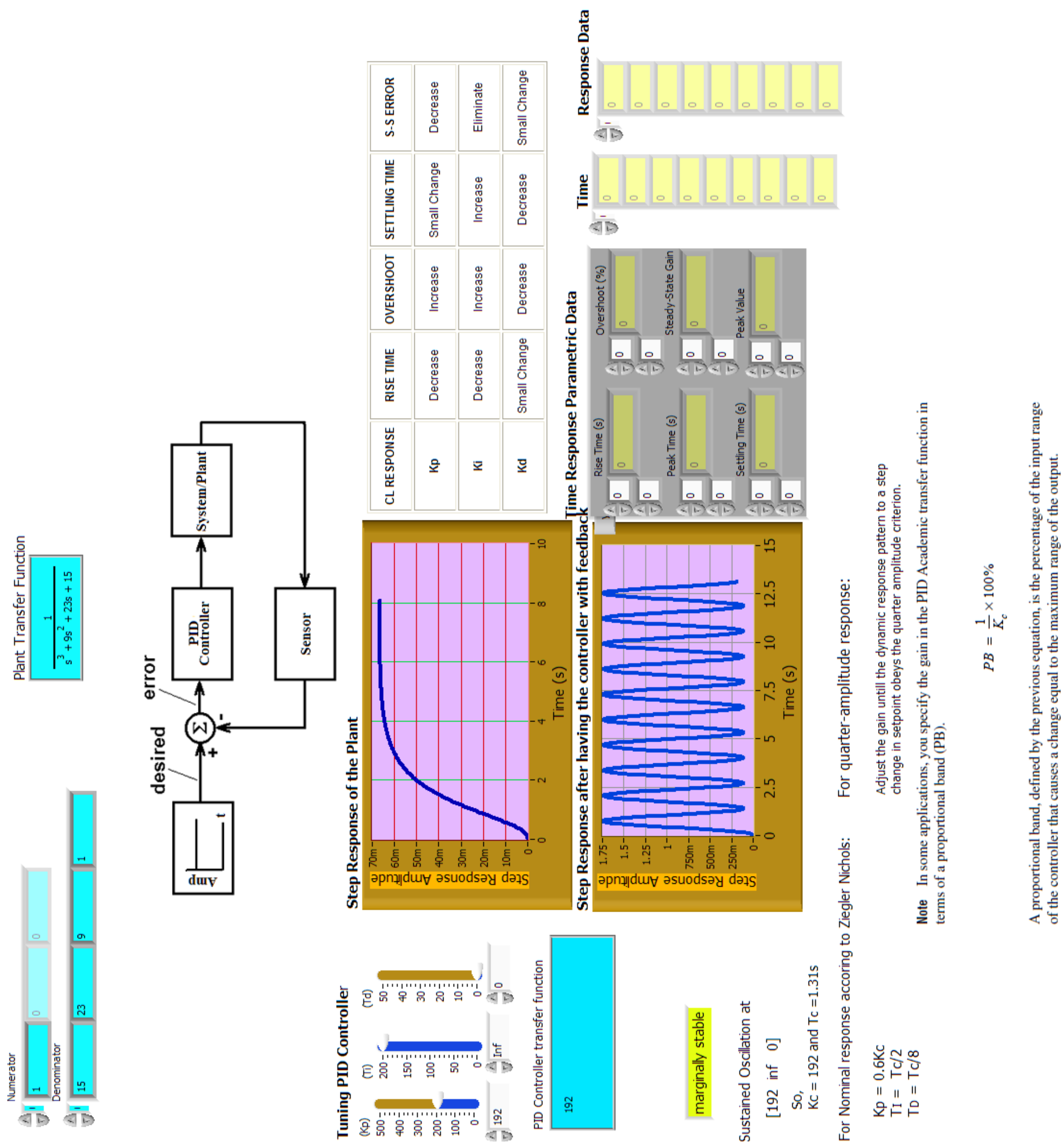
Changes in system's closed loop response because of the changes in PID parameters with respect to a step input can be best described using the following chart:

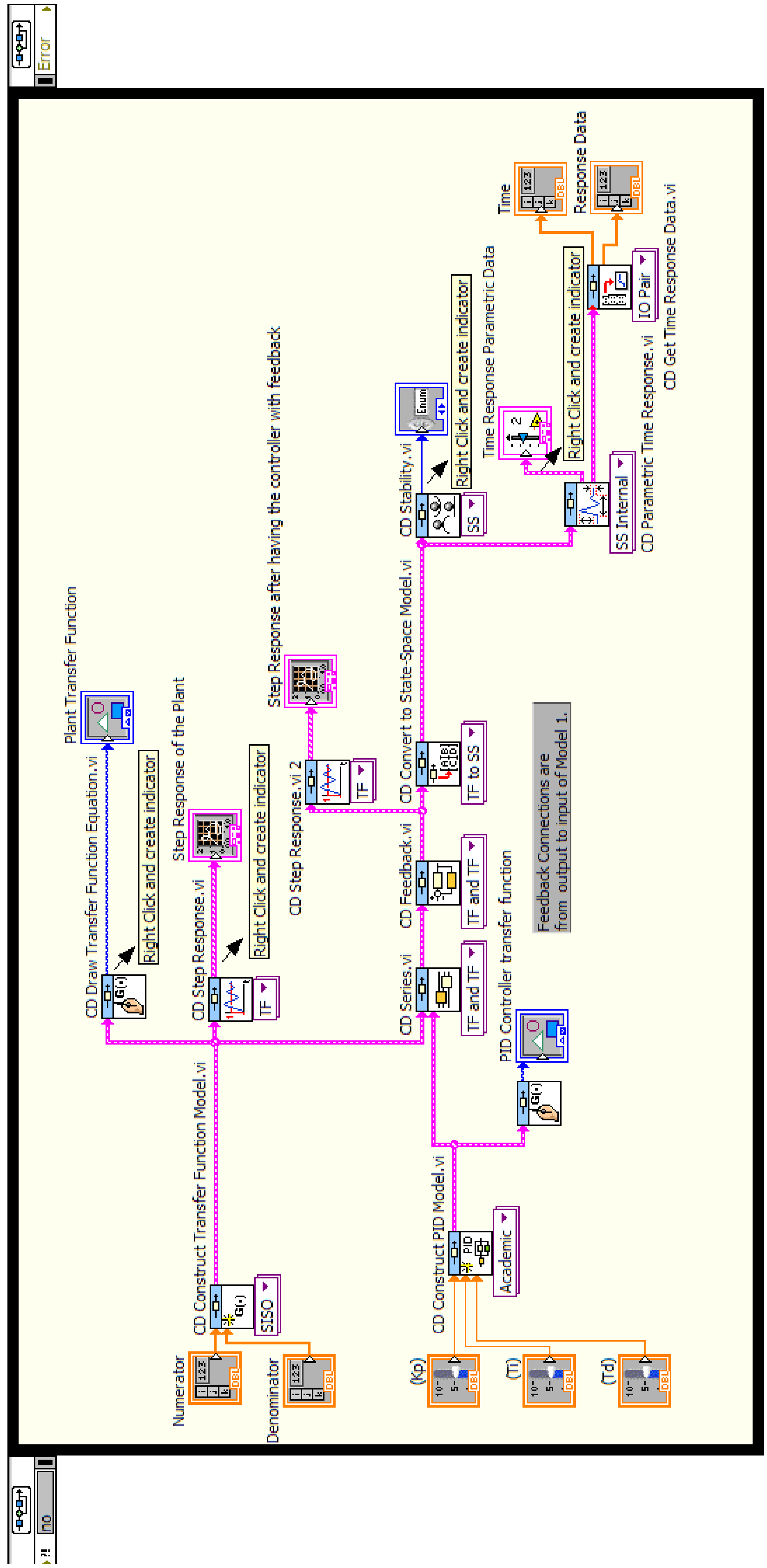
CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

In LabVIEW there are several PID controller modules. We shall use the Academic PID controller. The difference between different PID controllers is shown below:

PID Controller Form	Equation
PID Academic	$\frac{U(s)}{E(s)} = K_c\left(1 + \frac{1}{T_i s} + \frac{T_d s}{\alpha T_d s + 1}\right)$
PID Parallel	$\frac{U(s)}{E(s)} = K_c + \frac{K_i}{s} + \frac{K_d s}{\alpha K_d s + 1}$
PID Parallel Discrete	$D(z) = \frac{(2K_pT + K_iT^2 + 2K_d)z^2 + (K_iT^2 - 2K_pT - 4K_d)z + 2K_d}{2Tz(z-1)}$
PID Series	$\frac{U(s)}{E(s)} = K_c\left(1 + \frac{1}{T_i s}\right)\left(\frac{T_d s + 1}{\alpha T_d s + 1}\right)$

Program:


Numerator
1 0 0
Denominator
15 23 9 1
Plant Transfer Function
1 / s^3 + 9s^2 + 23s + 15
desired
error
Amp
t
PID Controller
System/Plant
Sensor
Tuning PID Controller
(Kp) (Ti) (Td)
192
Inf
0
PID Controller transfer function
192
marginally stable
Sustained Oscillation at
[192 inf 0]
So,
Kc = 192 and Tc =1.31s
Step Response of the Plant
Step Response Amplitude
Time (s)
Step Response after having the controller with feedback
CL RESPONSE | RISE TIME | OVERSHOOT | SETTLING TIME | S-S ERROR
Kp | Decrease | Increase | Small Change | Decrease
Ki | Decrease | Increase | Increase | Eliminate
Kd | Small Change | Decrease | Decrease | Small Change
Time Response Parametric Data
Rise Time (s)
Overshoot (%)
Peak Time (s)
Steady-State Gain
Settling Time (s)
Peak Value
Time
Response Data
For Nominal response accoring to Ziegler Nichols:
Kp = 0.6Kc
TI = Tc/2
TD = Tc/8
For quarter-amplitude response:
Adjust the gain untill the dynamic response pattern to a step change in setpoint obeys the quarter amplitude criterion.
Note In some applications, you specify the gain in the PID Academic transfer function in terms of a proportional band (PB).
PB = 1/Kc × 100%
A proportional band, defined by the previous equation, is the percentage of the input range of the controller that causes a change equal to the maximum range of the output.


Error
no
Plant Transfer Function
CD Draw Transfer Function Equation.vi
Right Click and create indicator
Step Response of the Plant
CD Step Response.vi
TF
Right Click and create indicator
Step Response after having the controller with feedback
CD Step Response.vi 2
TF
CD Construct Transfer Function Model.vi
SISO
Numerator
Denominator
CD Series.vi
TF and TF
CD Feedback.vi
TF and TF
CD Convert to State-Space Model.vi
TF to SS
CD Stability.vi
SS
Right Click and create indicator
Time Response Parametric Data
Right Click and create indicator
SS Internal
CD Parametric Time Response.vi
IO Pair
CD Get Time Response Data.vi
Time
Response Data
Feedback Connections are
from output to input of Model 1.
PID Controller transfer function
CD Construct PID Model.vi
Academic
(Kp)
(Ti)
(Td)

Conclusion:

1) Follow the steps describe above to tune the PID controller.
2) Find the values of K_P, T_I, $T_{D.}$
3) What is the effect of changing the PID controller parameters in the step response of the overall system?
4) Note the Time response parametric data after the controller is tuned.

Ref:

The Design of PID Controllers using Ziegler Nichols Tuning --Brian R Copeland; March, 2008