IMPLEMENTATION OF PID CONTROLLER IN CASCADE MODE FOR TWO TANK SYSTEM

by

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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Approved:

(Dr Manzoor Hussain)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Sharidatul Husna binti Hamidon

ABSTRACT

This report basically discusses the research done and basic understanding of the chosen topic, which is **Implementation of PID Controller in Cascade Mode For Two Tank System.** The objective of the project is to improve the efficiency of the process control on the Mobile Flowmeter Calibration Trainer through implementation of PID controller in cascade mode. Whereas in the existing system, the controller used to control the flow of the plant is working in single mode which is less efficient. This pilot plant is equipped with three different flowmeter which are Coriolis Flowmeter, Vortex Flowmeter and Orifice Flowmeter. The Coriolis Flowmeter is used as the master flowmeter and two others flowmeter can be connected in series with master flowmeter. In addition this project will also include the installation of two channel flat bed recorder on the pilot plant. This project will begin with numerous researches either by journal references or seeking internet information that accomplished based on the project title. In order to seek out for significant information, the next action to be taken is consulting certain problem regarding to the process control with expert technician. Several experiments will also be conducted as the introduction to have basic knowledge towards the plant. The scheduled experiments are Comparative Study of different Flowmeter and Flow Control and Controller Tuning. Then, fine tuning method for optimum controller technique and MATLAB simulation will be conducted. The performance of PID controller in single mode operation and cascade control will be compared. At the end of this project it is hope that the efficiency of process control for Mobile Flowmeter Calibration Trainer can be improved.

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LIST OF ABBREVIATIONS

MV	Manipulated Variable
CV	Controlled Variable
SP	Set point
Ti	Integral Time
Td	Derivative Time
PB	Proportional Band
P	Proportional Algorithm
PI	Proportional Integral Algorithm
PID	Proportional Integral Derivative Algorithm

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Control can be defined as maintaining the desired conditions in a physical system by adjusting selected variables in the system. Most basic control systems consist of a control loops as shown in Figure 1[5]. It has four main components which are [5]:

- A measurement of the state or condition of a process
- A controller calculating an action based on measured value against the set point value.
- An output signal resulting from controller calculation which used to manipulate the process action
- The process itself reacting to thus signal and changing its state or condition.

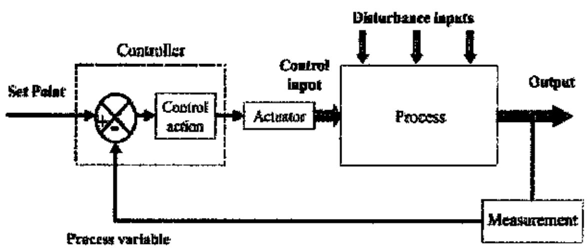


Figure 1: Element of the Process Control

Control is necessary for two reasons which are to maintain variable at desired value when disturbance occurs and to response to changes in the desired value of set point. In this case, the variable needs to be control in flow rate of liquid between pipelines interconnected of Mobile Flowmeter Calibration Traine

Mobile Flowmeter Calibration Trainer

The Mobile Flowmeter Calibration Trainer is designed and developed for the learning activity of liquid phase flow measurement, calibration and control. It is made up of a buffer tank, a precisely calibrated calibration tank, various instrumentation, process pumps and set of interconnected pipelines [1]. For the overall process description of the pilot plant, the liquid is foremost fulfilled the buffer tank before it is transferred to the calibration tank via the interconnected pipelines.

The flow of the liquid can be in reverse direction depending on the requirement of the activity. The measurement of the flow rate then will be displayed both on the flowmeters screen and respective flowrate indicator at the control panel.

Flow Measurement Techniques

In order to control the flow of the liquid, the flow measurement or flow rate of the liquid have to be considered. The liquid flow rate is determined inferentially on the liquid's velocity or the change in kinetic energy. The formula to calculate the flow rates are:

$$Q = V X A$$

Where:

Q= liquid flow through the pipe

V= average velocity of the flow

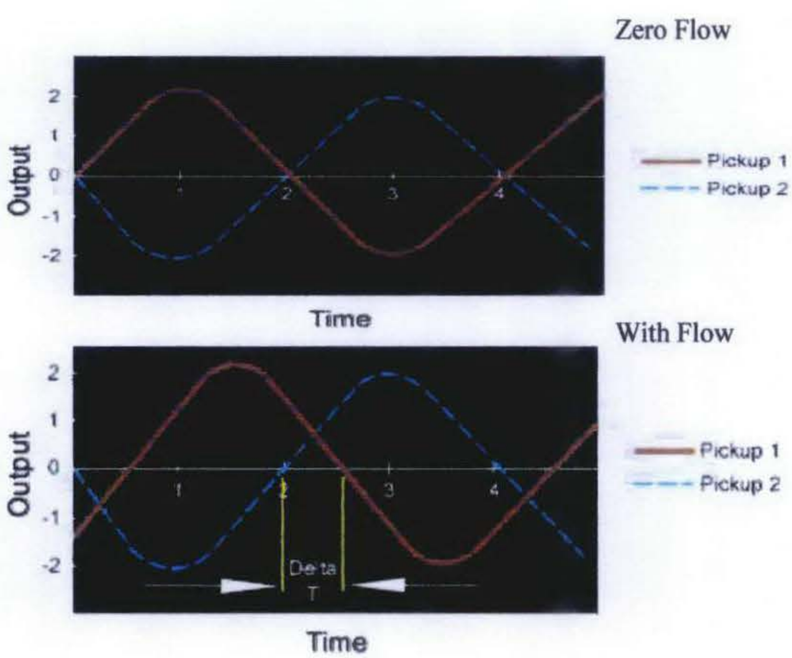
A= cross-sectional area of the pipe

This pilot plant is equipped with three types of flowmeters which are Coriolis Flowmeter, Vortex Flowmeter, and Orifice Flowmeter. A Coriolis Flowmeter used as master flowmeter. Two other flowmeters, namely a Vortex Flowmeter and an Orifice Flowmeter can be connected in series with the master flowmeter.

- Coriolis Flowmeter :

Figure 2: The Tube of Coriolis Flowmeter

- Operates on the principle of Coriolis force. With this principle, mass flowrate can be measured independent of changes in fluid density and temperature. This flowmeter is capable of measuring true liquid mass flow, volumetric flow and liquid density.[1]



- Vortex Flowmeter:

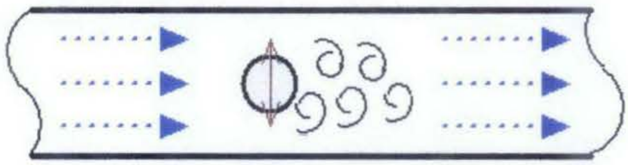


Figure 3: Vortex Flowmeter

- It operates on the principle of vortices created when a bluff body is present in the flow stream. It is a volumetric flowmeter whose flow measurement is dependent on the density of the flowing fluid.[1]

- Orifice Flowmeter:

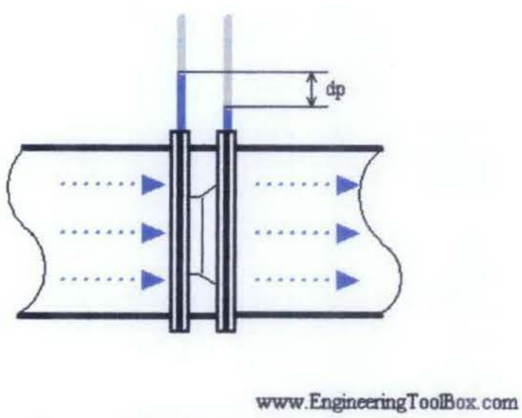


Figure 4: Orifice Flowmeter

- It operates on the principle of pressure drop due to an orifice plate in the flow stream. The difference in pressure between the upstream and downstream of the orifice plate is proportional to the square of volumetric flow across the orifice.[1]

1.2 Problem Statement

Mobile Flowmeter Calibration Trainer is a miniature plant and is designed for the teaching of liquid – phase flow measurement, calibration and control. The Konics Controller is used to control the flow and level of the liquid for the pilot plant. However, the parameters PB, Ti and Td are fixed by the provider. Therefore, to improve the efficiency of the process control Yokogawa Controller YS170 is installed. Furthermore, the controller is working on single mode of operation which is less efficient. Thus, both of the controllers will be arranged in cascade control with one PID controlling the set point of another.

1.3 OBJECTIVE AND SCOPE OF STUDY

1.3.1 Objective

The main objectives of this research are to improve the efficiency of the control flow process on the Mobile Flowmeter Calibration Trainer by replacing the existing controller with Yokogawa Controller YS 170. The additional objectives of this project are listed below:

- To enhance comprehension towards the principles and performance of different kind of flowmeters that commonly used in processing plant.
- To understand the performance of PID controller in single mode operation and cascade mode.
- To analyze the performance of PID Controller in single mode as well as understanding the concept of feedback control.
- To analyze the performance of PID Controller in cascade mode.

1.3.2 Scope of Study

The scope of study for this project is to improve the performance of PID controller in controlling the flow of liquid in two tank system of Mobile Flowmeter Calibration Trainer. Throughout this project the comparison between single mode operation and cascade control will be conducted. In view of the fact from previous project for single mode operation conclude that the PI Ziegler-Nichols Close loop controller shows the optimum performance in controlling the liquid flow rate. For cascade loop control tuning, the Trial and Error Method is going to be applied in order to determine the best performance.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview on PID Control

The PID controller has several important functions: it provides feedback, has the ability to eliminate steady state offsets through integral action and it also can anticipate the future through derivative action. The controllers are sufficient for many problems particularly when processes dynamic are benign and performance requirements are modest. This algorithm is for single loop systems, also known as single input- single output (SISO) which one have controlled and one manipulated variable.

The PID algorithm can be described as [1]:

$$u\ (t) = K\ (e(t) + 1/T_i \int e(\tau)\ d\tau + T_d\ d\,e(t)\ /\ dt)$$

Where u is the control variable and e is the control error $(e=y_{sp}-y)$. The control variable is a sum of three terms: the P-term which proportional to error, the I-term which proportional to integral of error and the D-term which proportional to the derivative of error. The controller parameters are proportional gain K, integral time T_i and derivative time T_d.

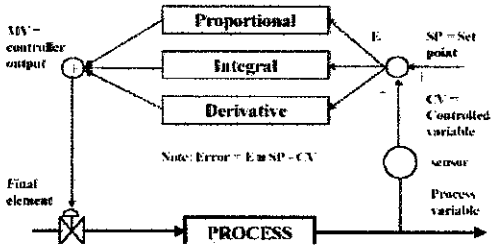


Figure 5: Overview Schematic of PID Control Loop [3]

2.1.1 Proportional Action

The first mode will make the control action the adjustment to the manipulated variable proportional to the error signal, because as the error increases the adjustment to the manipulated variable also increases. The equation for proportional mode is as [3]:

$$MV_p(t) = K_cE(t) + I_p$$

$$G_c(s) = MV_p(s)/E(s)$$

$$= K_c$$

Where

$MV_p(t)$ =Manipulated Variable
$E(t)$ = Error
K_c = Controller Gain
I_p = Constant of initialization
$G_c(s)$ = Controller

The controller gain K_c has units of (manipulated / controlled) variables, which is the inverse of the process gain K_p. The larger K_c the more the controller output will change for a given error. For instance, with a gain of 1 an error of 10% of scale will change the controller output by 10% of scale. The equation also include a constant term or bias, which is used during initialization of the algorithm I_p. During the initialization the value of the manipulated variable should remain unchanged, thus the initialization constant can be calculated at the time of initialization as [3]:

$$I_p = (MV_p(t) - K_cE(t))|_{t=0}$$

Where

$MV_p(t)$ =Manipulated Variable
$E(t)$ = Error
K_c = Controller Gain
I_p = Constant of initialization

This mode is simple, provides a rapid adjustment of the manipulated variable, does not provide zero offset although it reduces the error, speeds the dynamic response and can cause instability if tuned properly.

2.1.2 Integral Action

Since the proportional mode does not completely eliminate the effects of disturbance, this mode should be persistent in adjusting the manipulated variable until the magnitude of the error is reduced to zero for a step like input. The equations for integral mode are [3]:

$$MV_I(t) = K_c/T_I \int E(t')\, dt' + I_I$$

$$G_c(s) = MV_I(s)/E(s)$$

$$= K_c/T_I S$$

Where

$MV_I(t)$ =*Manipulated Variable* $E(t)$ = *Error*
K_c = *Controller Gain*
T_I = *Integral time*
I_I = *Constant of initialization*
$G_c(s)$ = *Controller*

The integral mode also has constant of initialization in the equation. This mode is simple, achieves zero offset, adjusts the manipulated variable in a slower manner than the proportional mode thus giving poor dynamic performance and can cause instability if tuned improperly.

2.1.3 Derivative Action

If the error is zero, both the proportional and integral modes give zero adjustment to the manipulated variable, however if consider the effect of disturbance on control variable at time equal to *t* when the disturbance just begins to affect the controlled variable. The error and integral error are nearly zero, but a substantial change in the manipulated variable would seem be appropriate because the rate of the controlled variable is large. This situation is addressed by the derivative mode [3]:

$$MV_d(t) = K_c T_d dE(t)/ d(t) + I_d$$

$$G_c(s) = MV_d(s)/E(s)$$

$$= K_c T_d s$$

Where

$MV_d(t)$ =*Manipulated Variable* $E(t)$ = *Error*
K_c = *Controller Gain*
T_d = *Integral time*
I_d = *Constant of initialization*
$G_c(s)$ = *Controller*

The final adjustable parameter is the derivative time T_d, which has units of time, and the mode gain has an initialization constant. Note that the proportional gain and derivative time are multiplied together to be consistent with the conventional PID algorithm. The derivative mode amplifies sudden changes in the controller input signal, causing potentially large variation in the controller output. This mode does not influence the final steady state value of error and provide rapid correction based on the rate of change of the control variable and also cause undesirable high-frequency variation in the manipulated variable.

2.1.4 When Is PID Control Sufficient?

PID control is sufficient for process where the dominant dynamics are of the second order. For such process there are no benefits gained by using a more complex controller. A typical case of derivative action improving the response is when the dynamics are characterized by time constants that differ in magnitude. Derivative action can then profitably be used to speed up the response. [2]

Derivative control is also beneficial when tight control of higher-order system is required. The higher-order dynamics would limit the amount of proportional gain for good control. With derivative action, improved damping is provided; hence a higher proportional gain can be used to speed up the transient response.

2.2 CASCADE CONTROL

Cascade control is one of method used to enhance single loop control performance. It can dramatically improve the control strategies, reducing both the maximum deviation and the integral of error for disturbance responses. Cascade control design considers the likely disturbances and tailors the control system to the disturbances that strongly degrades the performance. It used an additional "secondary" measured process input variable that has the important characteristic that indicates the occurrence of the key disturbance.

The important feature in the cascade structure is the way in which the controllers are connected. The output of the exit primary controller adjusts the set point of the secondary controller in the cascade structure; that is the secondary set point is equal to the primary controller output [3]. Thus, secondary control loop is essentially the manipulated variable for the primary controller.

A few important features of cascade structure should be emphasized. First, the secondary controller is much faster than the primary controller. The improvement results from the much shorter dead time in the secondary loop than in original single loop system. Second, the secondary controller with an integral mode remains in the design to ensure zero offset for all disturbance sources.

The two controllers in the cascade are referred to by various names. The three pairs of names in the most commonly used terminology are presented in Table 1.

Table 1: Pairs of cascade control terminology

Flow	**Level**
Primary	Secondary
Outer	Inner
Master	Slave

Figure 3 shows the structure of cascade control system which summarizes the flow information and can be used to evaluate important properties such as stability and frequency response [10].

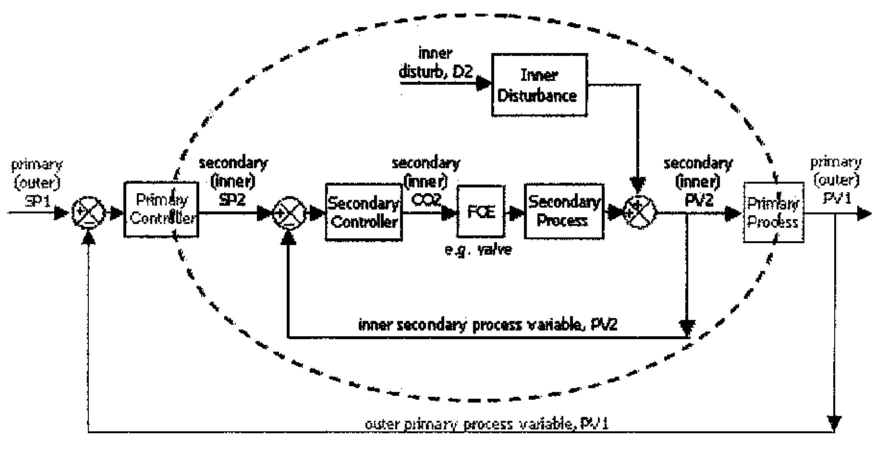


Figure 6: Block Diagram of Cascade Control

SP1 = outer primary set point

SP2 = inner secondary set point

CO2 = inner secondary controller output signal

PV2 = inner secondary measured process variable signal

D2 = inner disturbance variable

FCE = final control element such as a valve

2.3 YOKOGAWA CONTROLLER YS170

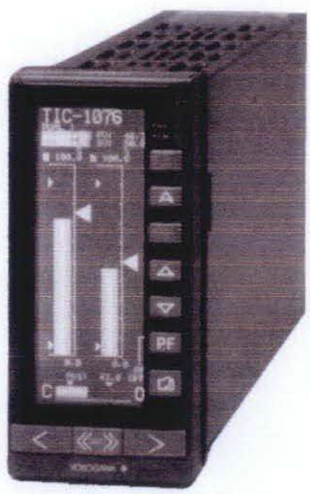


Figure 7: Yokogawa Controller Model YS 170

The YS170 is a programmable controller, whereby the analog and discrete inputs/outputs can be assigned regarding function. The program and inputs/output assignments must be completed prior to field connections.There are four modes available [4]:

i. User programmable mode
ii. User-selectable multifunction mode
    - Single loop mode
    - Cascade mode
    - Auto-selector mode

Controller mode

i. User programmable mode:

Combines control modules and computational modules by programming. In this mode, the user can choose either single control module, cascade control module or selector module. [4]

ii. Single Loop Mode:

A single controller with advanced control functions external cascade setpoint, ratio control, feedfoward and tracking. [4]

iii. Cascade Mode:

Two control modules connected in cascade. A single YS 170 controller can implement cascade loop. External cascade setpoint, ratio control and feedforward are provided. [4]

iv. Selector Mode:

Two controller modules are connected in parallel. A single YS 170 controller can implement an auto selector loop. External cascade setpoint, ratio control for each loop are provided. [4].

2.3.1 Electrical Connection

Figure 8: Front Panel Display for Yokogawa

The front panel of Yokogawa Controller include:

i. Remote setpoint
ii. Local setpoint and automatic
iii. Manual operation of output
iv. Increase setpoint
v. Decrease setpoint
vi. Programmable function key
vii. PAGE key
viii. Manual output keys

Figure 9: The yellow and red

The red lamp (FAIL) illuminates if a failure in the CPU or associated digital circuitry occurs. Additionally, a contact output dedicated to this FAIL function is available at the rear terminals. This solid state output can be connected to an annunciator or other device to notify operating personnel that the instrument is malfunctioning. The yellow lamp (ALM) is activated if a process alarm has been initiated. High, low, or deviation alarms cause the yellow LED to illuminate.

Below are the connections for each mode available on the Yokogawa Controller YS 170; single mode, cascade mode, autoselector mode and programmable mode.

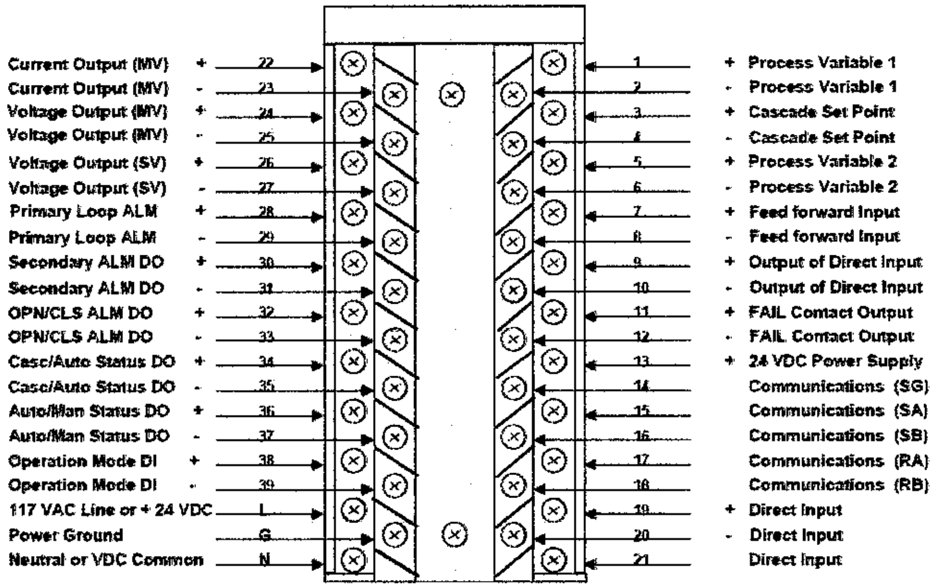


Figure 10: Electrical Connection of Controller for Single Mode

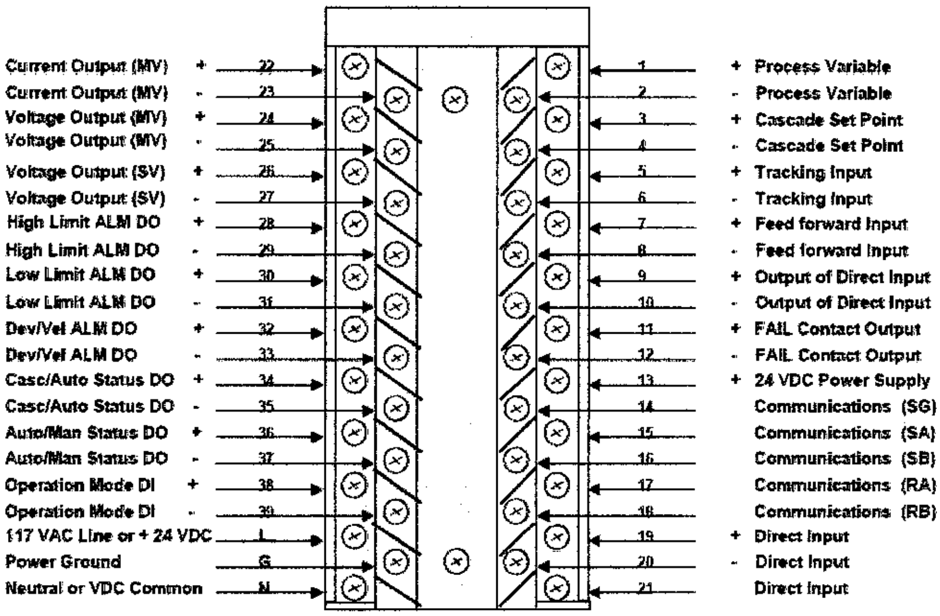


Figure 11: Electrical Connection of Controller for Cascade Mode

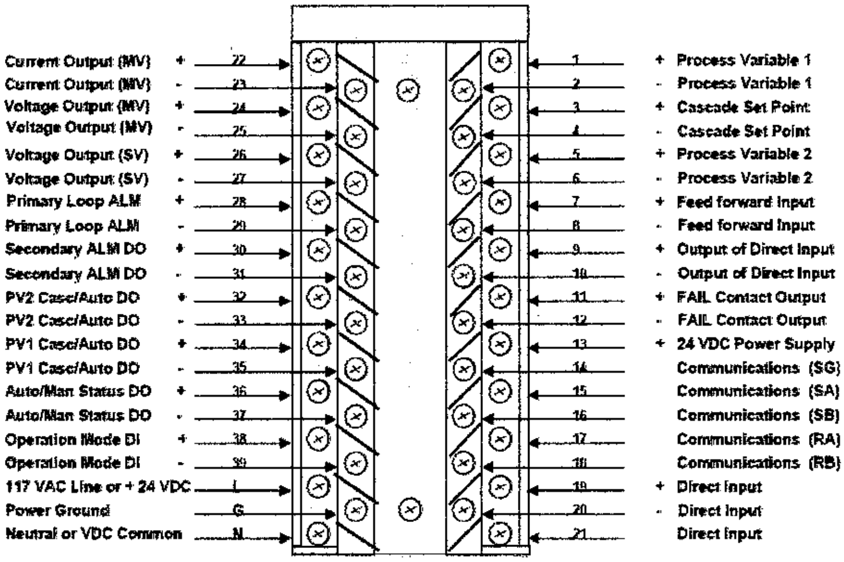


Figure 12: Electrical Connection of Controller for Autoselector Mode

2.4 CONTROLLER FINE TUNING

Controller tuning can be defined as the process of selecting the controller parameters to meet given performance specifications. This process involves the selection of the best value of Proportional Band (PB), Integral Time (Ti) and Derivative Time (Td). The most important objectives for tuning a controller are:

i. Minimization of the integral of the error:

The objective here is to keep the area enclosed by the two curves, the SP and PV trends; to a minimum [5].

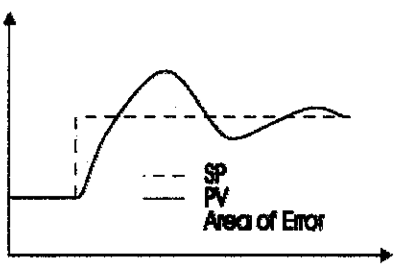


Figure 13: Integral on error

ii. **Minimization of the integral of the error squared:**

As shown in Figure 11, it is possible to have a small area of error but an unacceptable deviation of PV from SP for a start time. In such cases, special weight must be given to the magnitude of the deviation of PV from SP. Since the weight given is proportional to the magnitude of the deviation, the weight is multiplied by the error [5]. This gives error squared (error squared = error * weight). Many modern controllers with automatic and continuous tuning work on this basis.

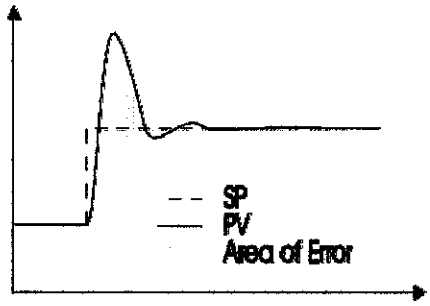


Figure14: Integral Of the Error Squared

iii. **Fast control:** In most cases, fast control is a principle requirement from an operational point of view. However, this is principally achieved by operating the controller with a high gain. This quite often results in instability, or prolonged settling times from the effects of process disturbances [5].

iv. **Minimum wear and tear of controlled equipment:** A valve or servo system for instance should not be moved unnecessarily frequently, fast or into extreme positions. In particular, the effects of noise, excessive process disturbances and unrealistically fast controls have to be considered here[5].

v. **No overshoot at start up:** The most critical time for overshoot is the time of start up of a system. If we control an open tank, we do not want the tank to overflow as a result of overshoot of the level [5].

Each parameters of PID controller has different effect when the parameters are manipulated. The table below shows the effect [7]:

Table 2: Effect of manipulating controller

Parameter	**Rise time**	**Overshoot**	**Settling time**
Kp	Decrease	Increase	Small Change
Ki	Decrease	Increase	Increase
Kd	Small Change	Decrease	Decrease

PID controllers may be tuned in a variety of ways, including trial and error method, Ziegler-Nichols tuning or Cohen –Coon. The Trial and Error method requires a closed loop system; it steps through the system from proportional to integral to derivative. This method is a divide and conquers approach; first it puts the system into a rough solution from which small tweaks are performed to perfect the response [6]. The Ziegler- Nichols requires determining the critical value of controller gain (Kp) that will produce a continuous oscillation of a control loop. This will occur when the total loop gain (K_{Loop}) is equal to one. The controller gain value (Kp) then becomes known as the ultimate gain (Ku). While Cohen – Coon method is more complex than Ziegler – Nichols. This method is more sensitive than the Ziegler-Nichols as it is limited to one type of open loop response [6].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

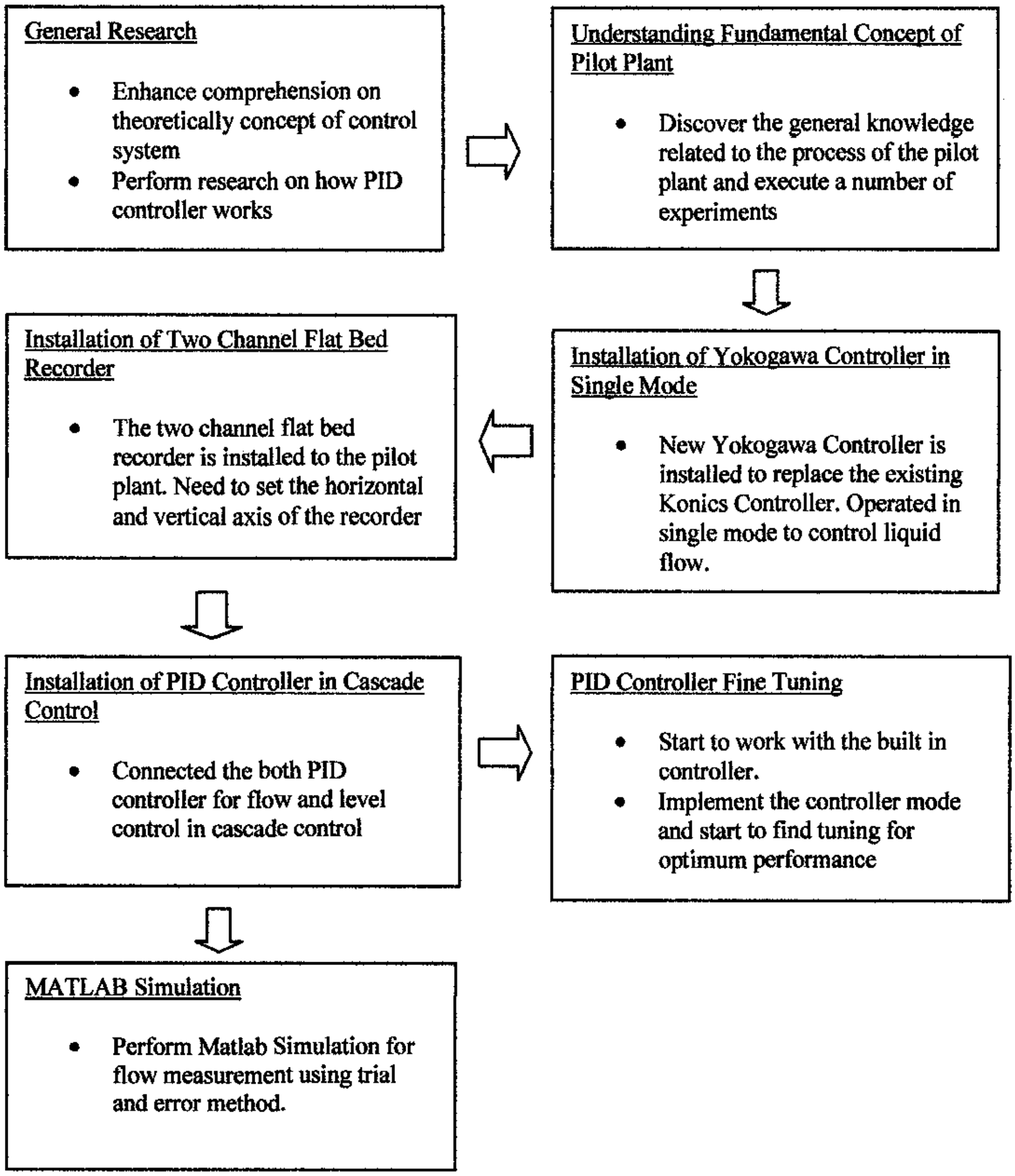


Figure 15: Flow Chart of Project

3.1.1 General Research.

The research will be performed either by journal references or seeking internet information that accomplished based on the project title. The research scope will be focus on process control system in plant and characteristics of PID algorithm. Besides, the methods for enhancing single- loop control performance will also be explored.

3.1.2 Understanding the Fundamental Concept of Pilot Plant.

In order to understand the fundamental concept of pilot plant several numbers of experiment will be execute to illustrate the application of theories. The experiments included are Comparative Study of different Flowmeter and Flow Control and Controller Tuning. Any problem regarding the process control will be consulted with expert technician.

3.1.3 Installation of Yokogawa Controller in Single Mode

Determine and implement the wiring connection for Yokogawa Controller to replace the existing Konics Controller. The controller is connected to the control valve and the process variable.

3.1.4 Installation of Two Channel Flat Bed Recorder

This two channel flat bed recorder is installed to the plant so that the result and data of the experiment or process can be saved. Two probes from the flat bed recorder are connected to set point and process variable terminal at the controller. The probes from flat bed recorder and the controller which both can accept 4mA to 20mA are connected directly.

3.1.5 Installation of Yokogawa Controller in Cascade Control

The Yokogawa Controller for flow control and level control is connected in cascade connection based on the manual. The controller is then configured to cascade mode. In /cascade mode the primary variable is level and the secondary variable is flow

3.1.6 PID Controller Fine Tuning

Select the controller mode and start to find tuning for optimum performance. Tuning a cascade control system involves two steps; first the secondary controller is tuned, then primary controller is tuned. The secondary must be tuned satisfactorily before primary can be tuned.

3.1.7 Matlab Simulation

Simulate the flow process control system into Matlab by using trial and error method. The parameter PB, Ti and Td are adjusted to find the best performance. The graph obtain from the plant is then compared the simulation in Matlab.

3.2 Single Loop Tuning Procedure Using Trial And Error Method

1. Set the control operation mode to the M mode, and closed the valve to 0%.
2. Set the integral time to 9999 seconds, the proportional band to a large value and set the derivative time to 0 second.
3. Start the pump 101 by push the button on the front panel.
4. At the Loop Panel, adjust the set point (SP) to 10 m^3/h.
5. Slowly increased the opening of the control valve to bring the Process Value (PV) almost equal to the set point.

6. Observe the Process Value from the Trend Panel and wait until it has stabilize to constant value.
7. Set the control operation mode to the Auto mode. And wait for PV to stabilize.
8. Decrease the value of proportional band (PB) from a large value to a small value (e.g 150% to 100% to 50%). Based on Rules of Thumb, the PB value for flow is between 50 to 500.
9. In this case, allow enough time to pass so that the conditions of control operation at each step can be observed. The value of PB is changed until a steady oscillation is obtained.
10. Introduce the integral time, Ti to the process so that the process can reach the zero offset.
11. Normally, decreasing the integral time steeply changes merely the time required to balance the condition to the set point and it does not change the operating condition much.
12. The value of PB and Ti is adjusted for several times to obtain the desired performance.
13. After the optimum performance is obtained, print out the graph.

3.3 Cascade Loop Tuning Procedure Using Trial And Error Method

3.3.1 Secondary Loop Tuning (Flow)

1. Set the control operation mode to the M mode, and closed the valve to 0%.
2. Set the integral time to 9999 seconds, the proportional band to a zero value and set the derivative time to 0 second.
3. Start the pump 101 by push the button on the front panel.
4. At the Loop Panel, adjust the set point (SP) to 10 m^3/h.
5. Slowly increased the opening of the control valve to bring the Process Value (PV) almost equal to the set point.

6. Observe the Process Value from the Trend Panel and wait until it has stabilize to constant value.
7. Set the control operation mode to the A mode. And wait for PV to stabilize.
8. The proportional component is now considered by increasing its value until a steady oscillation is obtained.
9. Scaling the current proportional value down by a factor of two will give the resulting proportional value and will dismiss the steady oscillations.
10. Next, the integral time is increased until steady oscillations are obtained. The present value of the integral coefficient is scaled up by a factor of three and applied to the integral as the final value.
11. Increased the derivative time until for a final time the oscillation are at the constant period and amplitude.

3.3.2 Primary Loop Tuning (Level)

1. Set the parameter for the secondary controller using tuning constant that obtained in secondary loop tuning.
2. Set the secondary controller to cascade mode by press on the 'C' button at Operating Mode Keys.
3. The set point of secondary controller should be equal to the Manipulated Variable (MV) of primary controller.
4. The value of PB, Ti and Td are adjusted again just like the procedure in secondary loop tuning to find the optimum performance.

3.3.3 Cascade Control System [9]

1. Ensure that the secondary controller is still set in Cascade Mode and the best performing controller tuning parameters keyed in.
2. Set the primary controller to Manual Mode. Key in the best tuning parameters obtained from primary loop tuning.
3. Set the M of primary controller manually to 10%.
4. Wait until the secondary controller is able to control its PV properly at its set point.
5. Adjust the set point of primary controller to 15 m^3/h. Then set the primary controller to Auto Mode. The two loops are mow in cascade control, with secondary controller receiving command from the primary controller.
6. Observe the primary loop curve from the Trend Panel and wait until it has reasonably stabilized at the set point.
7. Increased the set point to 20 m^3/h. Note the change to the set point of the secondary controller when the level is moving toward its set point.
8. Observe the PV curve from Trend Panel and determine the response characteristic of the process.

3.4 Tools and Equipment Required

Hardware:

- Mobile Flowmeter Calibration Trainer
- Yokogawa Single Station Controller
- Two Channel Flat Bed Recorder
- Alligator Clips
- Electrical tools(wires, power supply, etc)
- Multimeter

Software:

- Matlab 7.1 and Simulink

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 *Experiments on Mobile Flowmeter Calibration Trainer*

Major System Components

Mobile Flowmeter Calibration Trainer is designed and developed by Pc Automation Sdn Bhd for the learning activity of liquid phase flow measurement, calibration and control. The pilot plant is equipped with:

- Buffer Tank (VE 100)
- Calibration Tank (VE 200)
- Coriolis Flowmeter
- Vortex Flowmeter
- Orifice Assembly And D/P Flowmeter
- Flow Transmitter
- Level Switch
- Level Transmitter
- Pneumatic Control Valve
- PID Controller
- Level Indicator
- Temperature Indicator
- Flowrate Indicator Cum Totalizer
- Programmable Logic Controller(PLC)

Discussion on Functional Description

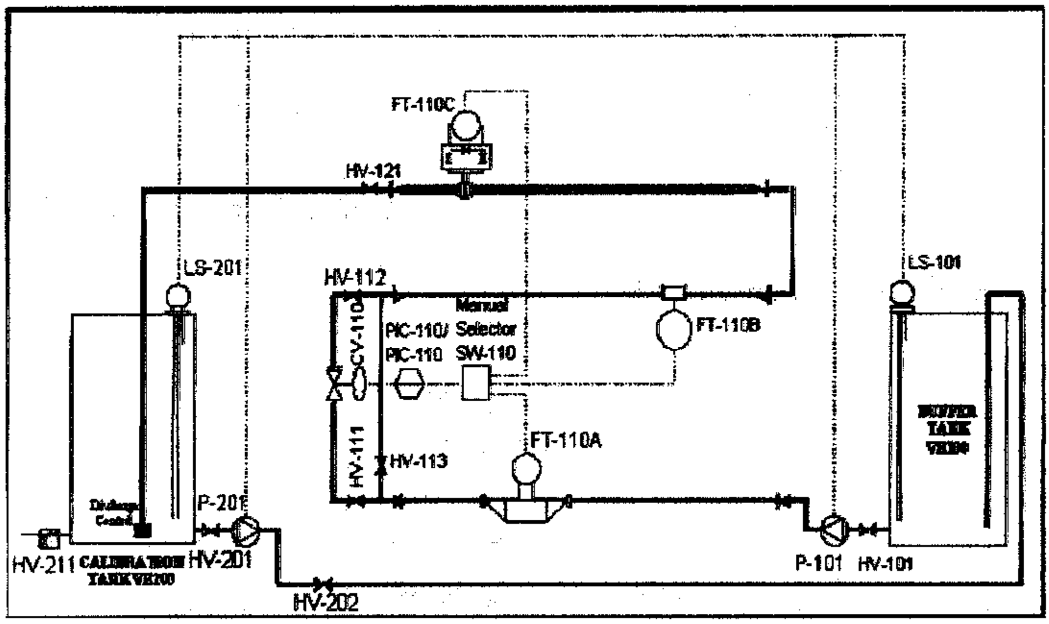


Figure 16: Overall Process Diagram of Pilot Plant

Liquid is pumped from the Buffer Tank (VE 100) through three different flowmeters and control valve. Ensure that the tank is full with water before any activity is conducted on Pilot Plant. The flow of the liquid can be pump from Buffer Tank to Calibration Tank or from Calibration Tank to Buffer Tank. Also make sure that piping for instrument air is connected to the pilot plant because the control valve is operated using compressed air. The controller only can control one of the flowmeter either coriolis flowmeter, vortex flowmeter or orifice flowmeter. To choose which controller is going to be used, tune the selector knob at front panel of Pilot Plant (A for Coriolis, B for Vortex and C for Orifice). The chosen flowmeter will display the current flow reading on the control panel.

In the tank there is a level sensor (LS 201, LS 101) which will measure the level of water transfer to the tank. Once the level of liquid reach to maximum level, the alarm will be activated. Push the Acknowledge button at the front panel and the stop the pump.

Procedure to Transfer liquid from Buffer Tank,VE 100 to Calibration Tank,VE 200.

1. Make sure that the tank VE 100 is filled with water.
2. Close the valve HV 202.
3. Open the valve HV 121. The opening of the valve can be between 0 to 100%.
   The larger the opening means that there is high flow of water into the tank.
4. Start pump P101 by push the button on the front panel.
5. The liquid then flow through the coriolis flowmeter, vortex flowmeter and orifice flowmeter.
6. The flowrate are display on the flowmeter itself and also at the front panel.

Procedure to Transfer liquid from Calibration Tank,VE 200 to Buffer Tank,VE 100.

1. Make sure that the VE 200 tank is filled with water.
2. Close the valve HV 121.
3. Open the valve HV 202.
4. Start pump P201 by push the button on the front panel.
5. The level transmitter inside the tank will give high alarm if the level of liquid transfer is exceeding the limit.

Comparative Study of Different Flowmeters

This experiment is carry out to observe the performance of all flowmeters attached to pilot plant which are Coriolis Flowmeter,Vortex Flowmeter and Orifice Flowmeter . It is also conducted to compare which controller is more accurate to be selected as reference flowmeter. Data and analysis of comparative studies of different flowmeter are discussed below.

Table 3: Flowrate of Three Different Flowmeter

MV%	L/Min Coriolis Flowmeter		L/Min Vortex Flowmeter		L/min Orifice Flowmeter		PV
	FIZ 110A	TOT 110A	FIZ110B	TOT110B	FIZ110C	TOT110C	
5	0	0	0	0	0	0	0
10	10.78	95.34	10.85	93.22	0	0	10.51
25	12.88	97.48	12.85	95.36	12.05	90.01	12.51
45	32.54	101.34	32.35	98.95	30.15	93.99	32.48
50	35.95	109.78	35.43	106.09	33.43	101.7	35.67
55	38.6	119.08	38.23	114.96	36.23	109.87	38.55
60	40.76	130.85	40.53	122.33	38.25	116.13	40.69
65	42.61	126.78	42.25	123.19	39.73	118.95	42.44
70	43.32	131.87	42.85	129.76	40.43	123.73	43.02
75	43.47	134.86	43.15	132.27	40.79	126.69	43.23
80	43.59	130.6	43.36	128.15	40.73	122.72	43.3

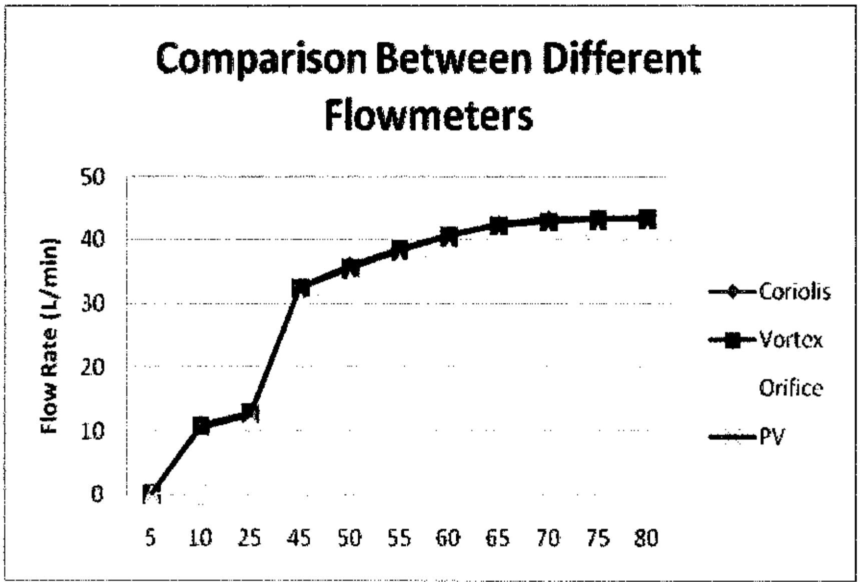


Figure 17: Graph of Comparison between Three Flowmeters

From the experiment, it can be found that reading for coriolis flowmeter and vortex flowmeter is slightly the same. While the reading of orifice flowmeter is lag compared to the others flowmeter due to the location of this flowmeter. When opening of the valve is less than 20 %, the orifice flowmeter cannot detect the flow movement inside the pipe from buffer tank to calibration tank.

The opening of the valve is the manipulated variable. FIZ 110A, FIZ110B and FIZ110C give the reading of the current flowrate correspond to the valve opening while TOT110A,TOT110B and TOT110C display the accumulation of liquid flowrate for the overall experiment. From the experiment also, we can observe that the flowrate is increasing as the percentage of valve opening increase.

The coriolis flowmeter show the best performance as the reference flowmeter. This flowmeter has been placed upstream of the control valve. This is common practice because the length of straight-run piping is needed upstream for reasonable accuracy[13].

Relationship between Flow and Level Measurement

This experiment is also conducted to see the relationship between level of liquid inside tank and the flowrate of liquid when the time is constant. The level of liquid in the tank is taken after every 3 minutes. The opening of the valve is the manipulated variable. Below are the result obtained.

Table 4: Relationship between Level and Flowrate

MV%	Level
45	21.39
50	23.39
55	25.11
60	26.43
65	27.13
70	28.24
75	28.77
80	28.79

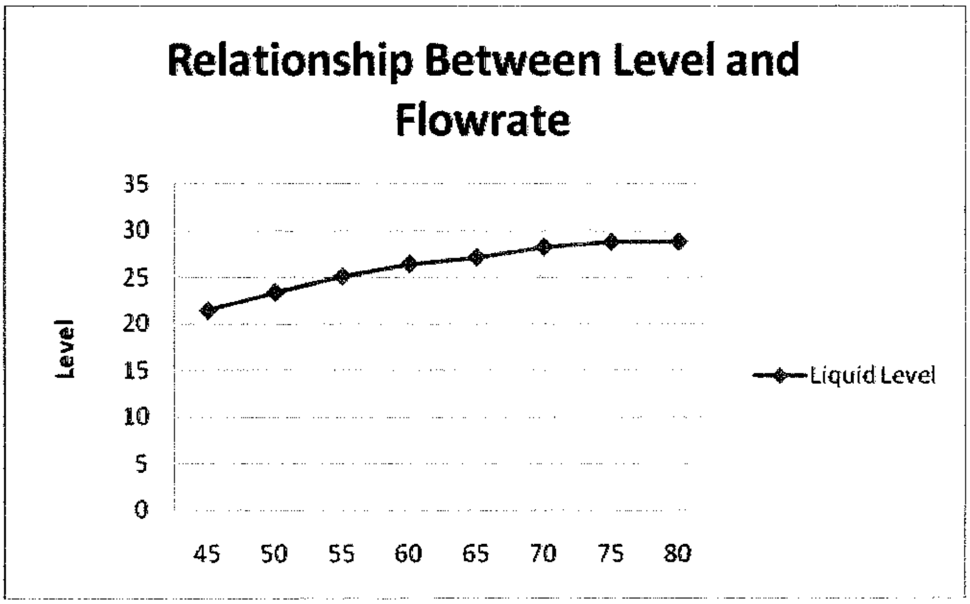


Figure 18: Graph of Relationship between Level and Flowrate

As shown in the graph, the level of liquid in the tank increase as the percentage opening of the valve is increase. Thus, the level of liquid inside the tank changed linearly corresponding to the changes of flowrate .Theoretically, when the valve opening is large it will allow higher quantity of water to flow in 3 minutes time.

4.1.2 Single Loop Mode

Basic Control Theory

Controlled systems are shown as a block with the appropriate input and output variables also with a sensor, controller and final control element such valve. (See Figure 13) Its response is described in terms of dependence of the output variable on the input variable.

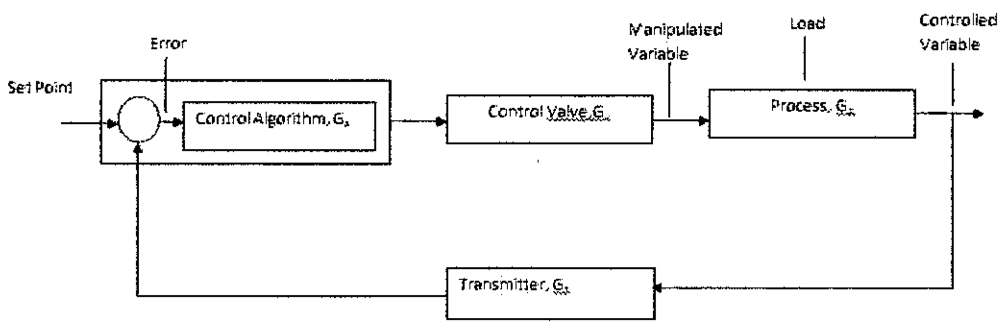


Figure19: Feedback Control Loop

In closed-loop control the task is to keep the controlled variable at the desired value or to follow the desired-value curve. This desired value is known as the reference variable. The controlled variable is first measured and an electrical signal is created to allow an independent closed-loop controller to control the variable. The measured value in the controller must then be compared with the desired value or the desired-value curve. The result of this comparison determines any action that needs to be taken.

In this study, the volumetric flow (the output variable) is to be maintained at the predetermined value of the reference variable. First a measurement is made and this measurement is converted into an electrical signal. This signal is passed to the controller and compared with the desired value. Comparison takes place by subtracting the measured value from the desired value. The result is the deviation.

The controller now passes a signal to the manipulating element dependent on the deviation. If there is a large negative deviation, which is the measured value of the volumetric flow is greater than the desired value (reference variable) the valve is closed further. If there is a large positive deviation, that is the measured value is smaller than the desired value, the valve is opened further.

Electrical Connection

In order to implement the new controller, first the existing connections need to be trace in order to establish new connection for Yokogawa Controller. As from the LCP Loop Drawing, it is found that Coriolis flow meter, (FT110A), Vortex flow meter (FT110B) and Orifice flowmeter (FT110C) are connected to their terminal block and then attached to FI-101A, FI-101B and FI-101C respectively. Another terminal on FT110A, FT110B and FT110C is also attached to Control Loop Selector Switch. From the Control Loop Selector Switch, they are connected to Konics Controller (KP 5500) terminal 8. This Konics Controller also connected to the control valve (CV110).

Therefore, to replace the Konics Controller with Yokogawa Controller YS170, the existing connections need to be terminated. The wire tagged as KP 5500-8 and KP 5500-9 is connected to Yokogawa Controller on terminal 1 and 2 (process variable 1 and 2). While the wire tagged as KP 5500-1 and KP 5500-2 is attached to terminal 22 and 23(manipulated variable) on the new controller. The new connection is as shown below:

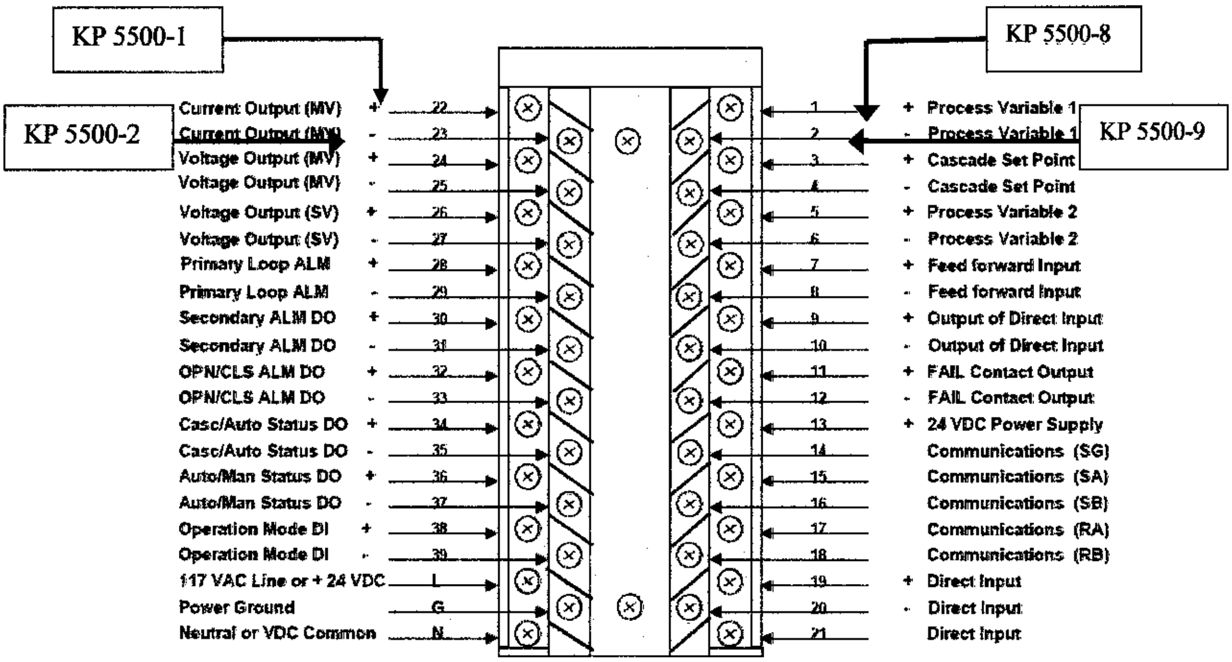


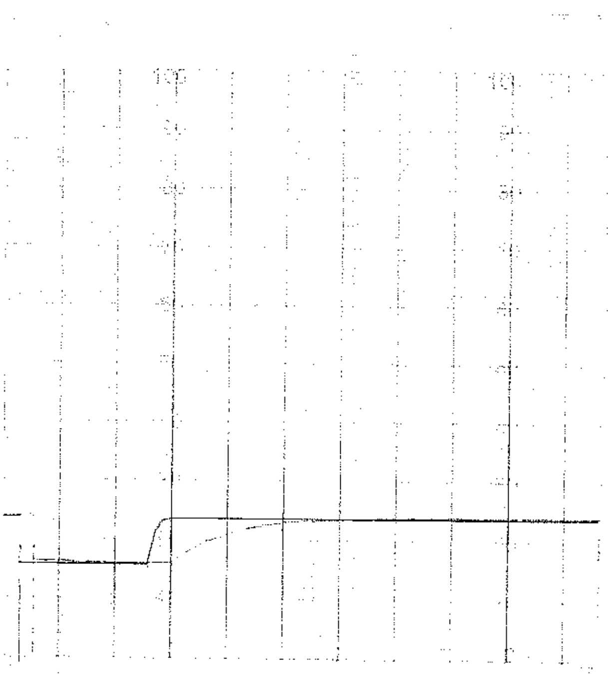
Figure 20: New Electrical Connection of Controller for Single Mode

After the installation has complete, the connection of new controller is tested. The Yokogawa Controller is turned on and Manipulated Value (MV) is manipulated to see its response on the control valve (CV110). The MV value is adjusted from 0% of opening to 100% opening. The connection is successful as the valve opening is corresponding to the percentage of MV.

Single Loop Fine Tuning

The single loop tuning for flow measurement is conducted using Trial and Error Method. Different value of Proportional Band, Integral Time and Derivative Time was keyed in to find the best performance.

First Trial



Valve and Pump Setting:

HV202 = 40%

HV112 = 60%

HV111 = 40%

HV121 = 100%

Controller Gain:

Propotional Band, PB

= 49.3%

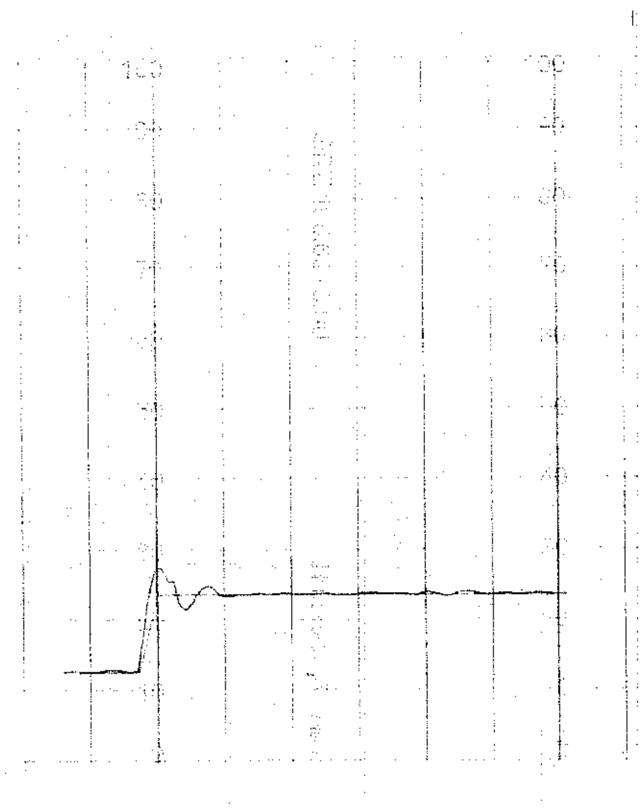
Integral Time,Ti = 5s

Figure 21: Process Curve for Flowrate in Single Mode

Observation:

This response reach the steady state value and it respond to the set point change. The process does not have overshoot. The rise time is about 11 seconds and the settling time is 16 seconds. Once it reaches the desired value, the process become stable and does not oscillate. The PV has fast response towards the change in MV.

Final Result



Valve and Pump Setting:

HV202 = 60%

HV112 = 50%

HV111 = 100%

HV121 = 90%

Controller Gain:

Propotional Band, PB

= 130.7%

Integral Time,Ti = 0.5s

Figure 22: Process Curve for Flowrate in Single Mode

Observation:

This response reach the steady state value and it respond to the set point change. The process does not have overshoot. The rise time is about 6 seconds and the settling time is 11 seconds. Once it reaches the desired value, the process become stable and does not oscillate. The PV has fast response towards the change in MV.

4.1.3 Cascade Mode

Basic Theory on Cascade Loop

The primary disadvantage to feedback only control is a disturbance must be felt by the output variable before there is a control system response. In cascade control multiple output measurements are used to improve the response of the most important primary output to a disturbance.

Consider the two tank system of the Mobile Flowmeter Calibration Trainer where there are three flowmeter attached to the pilot plant which will measure the flow rate of liquid as the liquid is transfer from buffer tank to calibration tank. The main objective is to vary the manipulated flow rate as little as possible, while satisfying the level constraints.

The liquid level in the tank is controlled by manipulating the valve position of the pipeline control valve. Clearly, the disturbances in flow rate of the liquid will end up changing the desired level of liquid.

The best way to compensate for disturbances directly affecting the liquid flow rate is to cascade the level controller to a flow controller of pipeline's pneumatic valve. The output of the level controller is the set point to the flow controller. The output of flow controller is the pressure to the control valve, which changes the valve position and therefore, the flow rate. Any change in the pipeline pressure will be 'felt' immediately by the flow measurement, allowing flow controller to take immediate correction. The block diagram is shown in Figure 23.

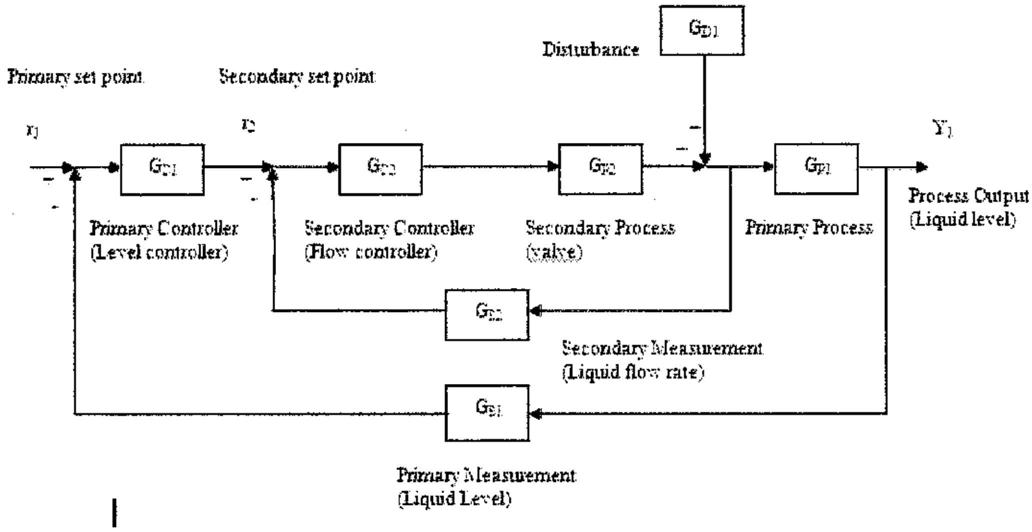


Figure 23: Cascade Control Block Diagram

In this strategy, the level controller is known as primary, or master controller, while flow controller is the secondary or slave controller. The dynamic of flow control loop are very fast, making the flow controller easy tune. The level controller is quite slower than flow controller, so the primary loop can be effectively tuned as if the flow controller response is instantaneous.

Rules of Thumb for Cascade Control

- Cascade control can be successfully used to reject secondary process disturbance when primary process has a much larger time constant while the secondary process has a small time constant.
- The most common cascade control loop involve flow controller as the inner loop. This is because this type of loop easily rejects disturbances in fluid stream pressure either upstream or downstream of the valve.
- The inner loop should be tune first before the outer loop is tuned.
- Cascade control can be easily combined with other forms of control such as feed -forward control.

Advantages using cascade control:

- Disturbances that affecting the secondary variable can be corrected by secondary controller before it influence primary variable
- The primary lag seen by the primary controller is reduced, resulting in increased speed response
- Allow secondary controller to handle non-linear valve and other final control element
- Large improvement in performance when secondary variable is much faster than primary variable

Electrical Connection

Electrical Connection for cascade mode was proceed after the completion of single loop mode. As discussed, cascade uses an additional measurement of a process variable to assist in control system where there are supposed to have secondary loop instead of having primary loop only. The selection of extra measurement, which is based on information about the most common disturbances and about the process dynamic responses, is critical to the success of the cascade controller.

The chosen primary variable is level control and secondary variable is flow control. The secondary controller set point is equal to the primary controller output. Thus, the secondary flow control loop is essentially the manipulated variable for the primary level control loop. Below are the setting of controller for cascade mode and the electrical connection on the controller.

However, the controller cannot function properly in cascade mode because the primary loop and secondary loop is not interconnected. Supposedly, the MV1 is equal to SP2, but when MV1 is adjusted SP2 does not follow the adjustment. Instead of, the MV2 follow the changes made in MV1. As the set point is changed, the controller does not response to control the process.

Table 5: Setting of Cascade Mode for Yokogawa

CONFIGURATION	DISP LAY	SELECTION
Configuration Panel 1	SET	ENBL
	CTL	CAS
Configuration Panel 2	CMOD1	CAS
Configuration Panel 3	DI1F	E-PMV,E-STC,E-O/C
	CSR1	ON
	CSW1	ON
Voltage Output/ Current Output	Connect JP1 to the J2 side Connect JP2 to the J4 side	

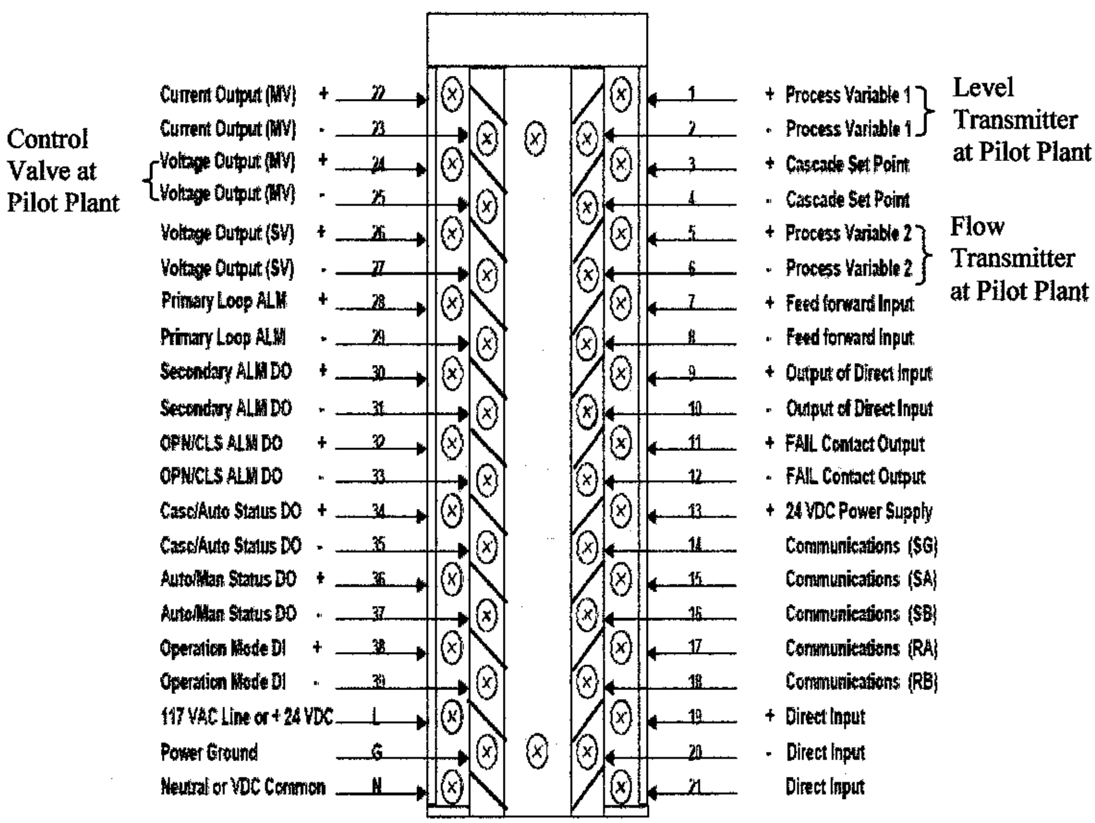


Figure 24: Electrical Connection of Controller for Cascade Mode

4.2 INSTALLATION OF TWO-CHANNEL FLAT BED RECORDER

Two-Channel Flat Bed Recorder is installed to the Mobile Flowmeter Calibration Trainer because this plat is not equipped with instruments that allow it to save and record the result obtains from the experiments. This Flat Bed Recorder is consists of two pens of red and blue colour, graph paper and usually drive by stepper motor.

Figure 25: Electrical Connection of Controller for Cascade Mode

The probes of flat bed recorder are connected to the process variable and set point terminal at Yokogawa Controller. Since both probes from flat bed recorder and the controller can accept 4mA to 20mA, so they are connected directly. Once the process start, the flat bed recorder can be turn on at anytime based on response wanted. The pens movement follow the process curve and change of the set point.

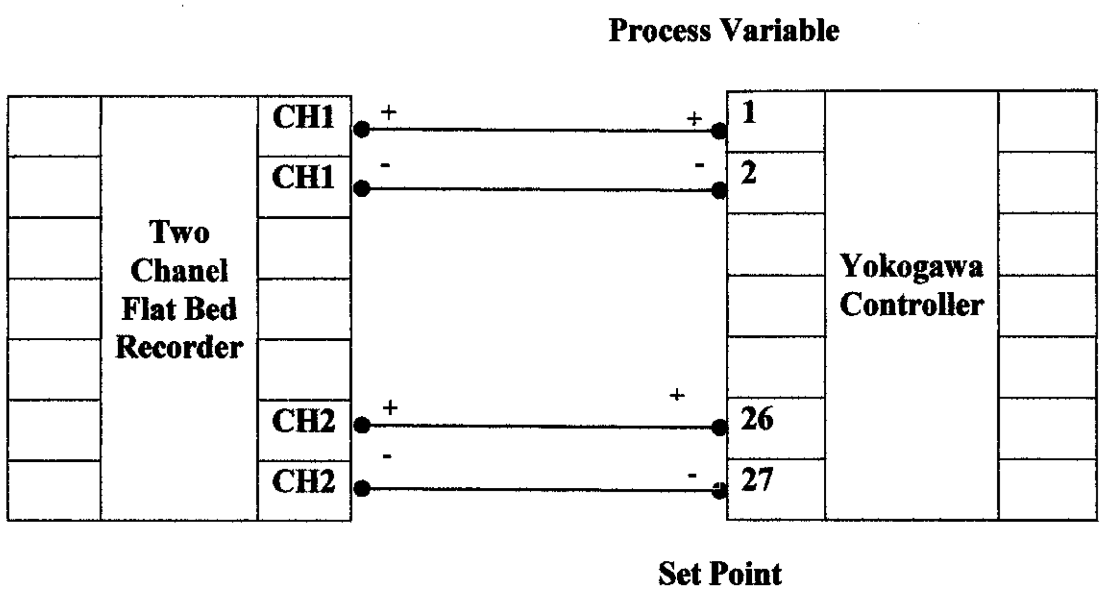


Figure 26: Wiring Connection of Two Channel Flat Bed Recorder

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The first objective to enhance the process control on Mobile Flowmeter Calibration Trainer by replacing the existing controller with Yokogawa Controller YS 170 is completed. The parameters of PB, Ti and Td of the existing controller, Konics Controller had been fixed by the provider. Thus, by installing the Yokogawa Controller YS170 the parameters can be adjusted to obtain better performance.

Second objective to have better understanding towards the principles and performance of three different flowmeters that attached to the pilot plant is completed by conducting several experiments. The experiment conducted is comparative study between flowmeters. Both flowmeters, Coriolis Mass Flowmeter and Vortex Flowmeter show good performance since they give reading correspond to the actual reading of process variable. Relationship between level and flow measurement had also been studied. It is found that as the opening of the valve increase, the level of liquid also increases.

The third objectives of this project which analyzing the performance of PID Controller in single mode as well as understanding the concept of feedback control is achieved. The controller PV's terminal is connected to flow transmitter at pilot plant and MV terminal is connected to pneumatic valve. By applying Trial and Error Method, PI mode shows the best performance in controlling the flow process with Proportional Band equal to 130.7% and integral time 0.5 second.

However, the last objective which is to analyze the performance of PID Controller is cascade mode is unable to be achieved. The problem arises due to hardware problem where the Yokogawa Controller cannot response to the set point of the process on the pilot plant. The primary loop and secondary loop are not interconnected.

In a conclusion, this study has given the author better understanding in process control technique especially in process industry involved flow control. Even though the performance of PID Controller in cascade mode cannot be accomplish, the author has gained better understanding on the cascade control principles.

5.2 Recommendations

Distributed Control System (DCS)

Connecting the pilot plant to the DCS will ease the simulation of process control and data recording. A DCS refers to a control system usually of a process or any kind of dynamic system, in which the controller elements are not central in location but are distributed throughout the system with each component sub-system controlled by one or more controllers. The entire system of controllers is connected by networks for communication and monitoring.

DCSs are connected to sensors and actuators and use set point control to control the flow of material through the plant. For this pilot plant which consist of flow transmitter, level transmitter and control valve, the flow measurements are transmitted to the controller, usually through the aid of a signal conditioning Input/output (I/O) device. When the measured variable reaches a certain point, the controller instructs a valve or actuation device to open or close until the fluidic flow process reaches the desired set point.

A server and or applications processor may be included in the system for extra computational, data collection, and reporting capability. Thus the data from the experiment can be saved and recorded for further reference.

Fuzzy Control System

Rather than using PID controller to control the performance of the pilot plant, fuzzy control system is also possible to be applied. Fuzzy control system is a control system based on fuzzy logic which is a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 0 and 1 (true and false).

Liquids variation

Throughout this project, the water is used as the liquid to conduct the experiment. Other type of liquid or chemical also can be used during the experiment in order to gain deep understanding of fluid flow and measurement principles.

REFERENCES

[1] User manual Book 1 of PcA SimExpert Mobile Pilot Plant SE231B-21(Flow Control and Calibration Process Unit)

[2] Karl Johan Astrom, 1995, PID Controllers: Theory, Design and Tuning

[3] Thomas E. Marlin, McMaster University, 2000, Process Control; Designing Process and Control System for Dynamic Performance

[4] User Manual Book Yokogawa Single Station Controller

[5] Srinivas Medida,IDC Engineering Pocket Guide, Volume 6, Industrial Automation

[6] Neil Kuyvenhoven, Calvin College, December 19, 2002, PID Tuning Method, an Automatic PID Tuning Study with MathCad

[7] Jinghua, Zhong,Purdue University, Spring 2006,PID Controller Tuning; A Short Tutorial,

[8] EXP 1: Simple PID flow (FIC-513-POS), Student Manual

[9] EXP 5: Cascade PID Temperature Control,(TIC-634 /FIC-631), Student Manual

[10] http://www.expertune.com

[11] Practical Process Control e-textbook
http://www.controlguru.com/pages/table.html

[12] http://en.wikipedia.org/wiki/PID_controller

[13] B. Wayne Bequette, Process Control:Modeling, Design and Simulation, January 2003

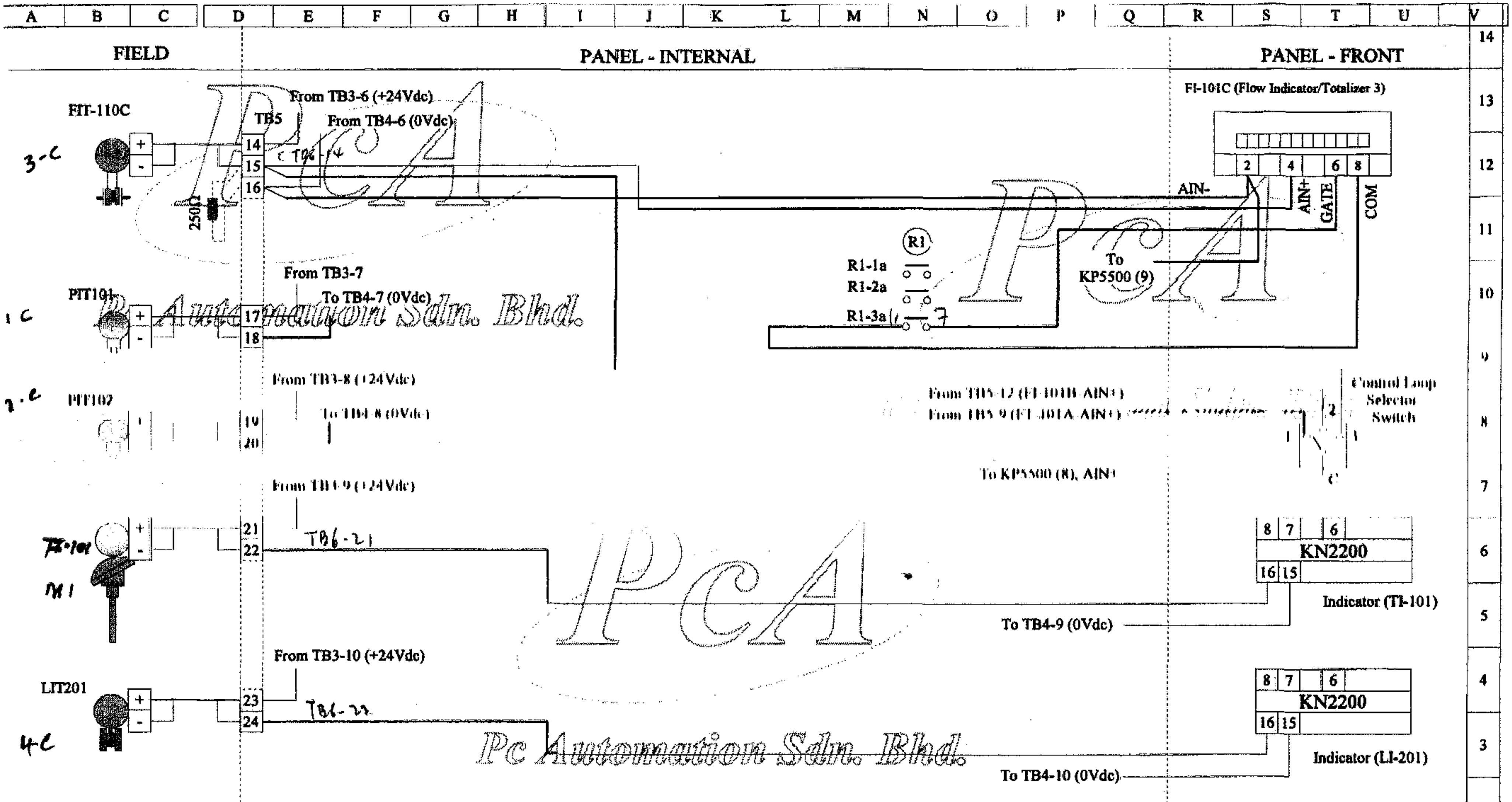
APPENDICES

APPENDIX A

MOBILE FLOWMETER CALIBRATION TRAINER

APPENDIX B

DRAWING FOR PILOT PLANT



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End User: Universiti Teknologi Petronas (UTP)

Proj: Mobile Flow Calibration Pilot Plant

Drw. Title: LCP - Loop Drawnig

Drw. No: Drawing No:

	By:	Date	Checked:
Designed:	LEE BOON TECK	2007 Aug. 28	
Drawn:	LEE BOON TECK	2007 Aug. 28	

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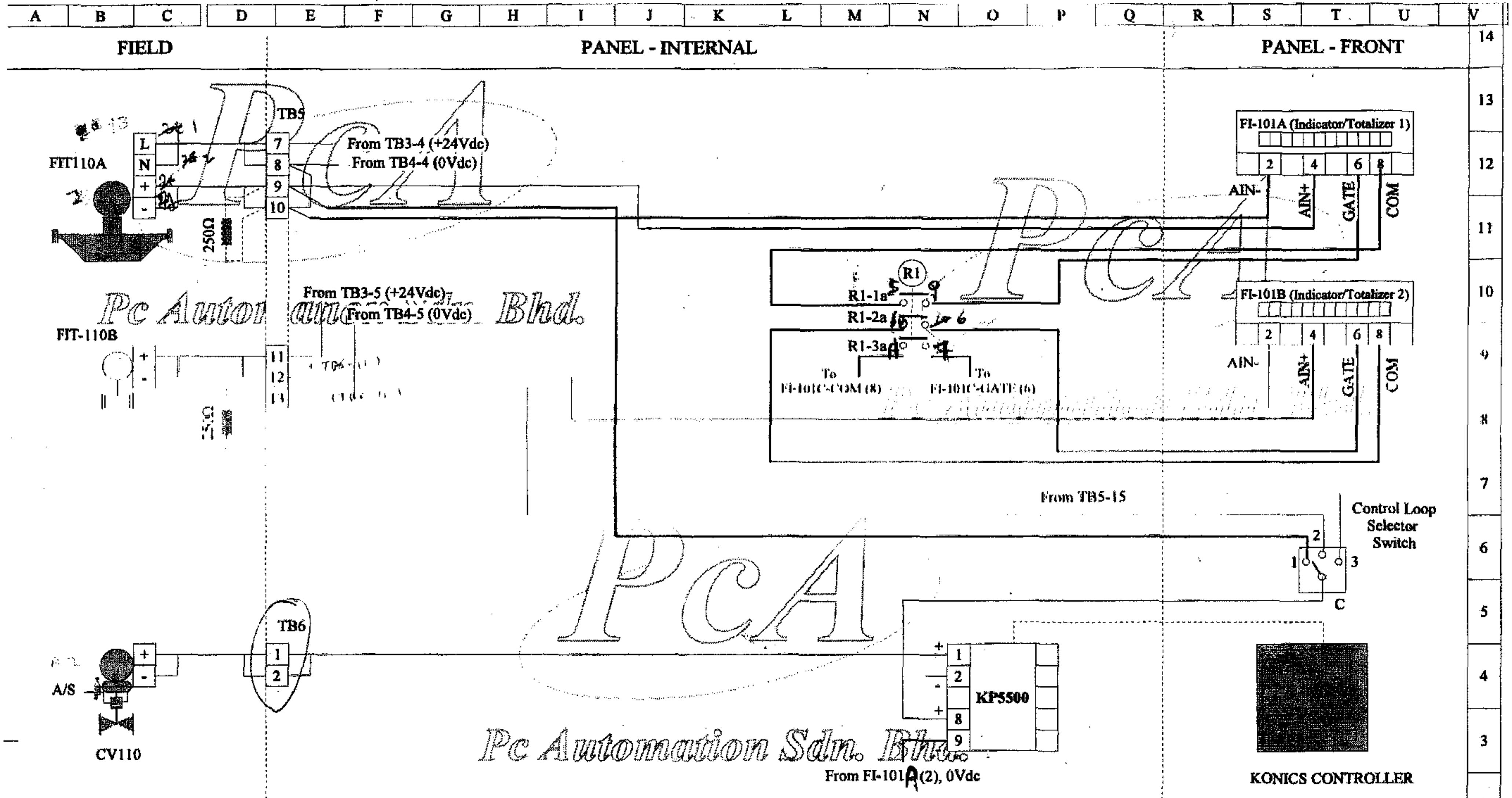
Page: 3 OF 3



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Client: Advance Altimas Sdn. Bhd.

End User: Universiti Teknologi Petronas (UTP)

Proj: Mobile Flow Calibration Pilot Plant

	By:	Date	Checked:
Designed:	LEE BOON TECK	2007 Aug. 28	
Drawn:	LEE BOON TECK	2007 Aug. 28	

Drw. Title: LCP - Loop Drawnig

Drw. No: Drawing No:

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