

Water level control system of the tank engineering essay



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The report provides an interim account of water level control system of a tank. The step-test experimental results for both (old and new) tanks and the method of calculating the water flow rate into the tank has been discussed. In addition, the techniques to work out the pump horsepower, motor power and the pump efficiency had been covered in this report. Future work on the laboratory experiment on proportional gain (P) and proportional plus integral gain (PI) testing and its relevance to industrial process and the approach to accomplish the set objectives of the project were discussed.

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NOMENCLATURE

P – Proportional

PI – Proportional Integral

PD – Positive displacement

PID – Proportional-Integral-Derivative

PWM – Pulse width modulation

Qo – Output

Qi – Input

INTRODUCTION

In years back level control has been a major issue in the industrial processes. The controlling of liquid level is essential in most industrial processes such as: food processing, nuclear power plants, water purification systems, industrial chemical processing, boilers etc. Although, most industrial problems such as: controlling the speed of motor, or fluid level in a tank, or temperature of the furnace are due to the installation of control process when the control concepts had not been properly understood (Dutton et al.,

1997). However, the ingenuity of control engineer can often overcome these challenges by producing a well-behaved piece of equipment.

Mostly, proportional-integral-derivative (PID) controllers are used for liquid level control in most applications and can be applied to many industrial processes and mechanical systems. PID controllers proven to be a perfect controller for simple and linear processes, but when it comes to controlling of non-linear and multivariable processes, the controller parameters have to be continuously adjusted (Bhuvaneshwari et al., 2008). In process control systems, nonlinearity is the rule rather than the exception. Most control loops such as pressure, temperature, composition, etc., are significantly nonlinear. This may be because of nonlinearity due to control valves, or on account of variations in process gain, time constant, and dead time, as discussed in (McMillan et al, 1994). Therefore, the study of control system has contributed to huge impact positively to our modern day development.

A plant can be controlled manually or automatically and the control system consists of a plant with its actuators, sensors and a controller. Manual controlling process of a plant cannot be as accurately enough compared to automatic control. An automatic controller is made up of device, electronic circuit, computer, or mechanical linkage etc. The interface between the plant and the controller requires actuators (control elements) to provide control action.

In instrumentation, detectors and sensors (measurement elements) are needed to provide information about the plant status to the controller (Golten and Verwer, 1991). However, the most important characteristic of a

plant is its stability, which indicates that a system can be control smoothly without undue oscillation or overcorrection. The behaviour and performance of a control system depends on the interaction of the entire element. The difference between the set-point and the actual value of the variable is called error. Another important characteristic of a control system is how quickly it can respond to an error and correct it. The smaller the error, the better it would be for the control system.

The basic types of process control are open loop and closed loop system.

+ The open loop system has no feedback because it has no sensor to sense the fluid level in the tank. While the closed loop system is characterised by a sensor and a feedback signal which carries information from the measurement device to the comparator. Typical actuators used in liquid level control systems include pumps, motorised valve, on-off valves, etc. In addition, level sensors such as displacement float, capacitance probe, pressure sensor (Bateson, 1999), etc., provide liquid level measurement for the purpose of feedback control.

In a closed loop feedback control system, the forward path transfer function is $G(s)$ representing the process or plant being controlled together with any controller dynamics. The feedback path transfer function, $H(s)$, represents the measurement system or transducer which provides the feedback signal (Golten and Verwer, 1991). The overall transfer function relating the controlled variable Q_o to the desired value or reference, Q_i is

Q_i

Qo

Figure 1: Closed loop block diagram

Hence, the procedure of deriving the equation above can be found in the appendix page.

In addition, the prime objective of feedback control systems is to minimise the differences between the output and the reference input since this represents the error. The control system should be quick as possible in reducing this error to zero (or to some reasonable low value) when there is either a disturbance or change in reference value (Golten and Verwer, 1991).

Feedback has similar advantages when applied to automatic control system, it has the ability of controlling a system that deals with unexpected disturbances that might occur within the system and adapt to changes in the plant. Therefore, with the advancement of electronics and its applications, the understanding of close loop control system increased rapidly, since feedback amplifier is essential (Healey, 1975). A simple control system is used to maintain a constant water level in a tank, example of such is toilet systems in various homes. The swinging arm attached to the input valve of the WC water tank allows water to flow into the tank until the float rises to a point that closes the valve. When the water level is low in the tank, the swinging arm moves downwards which allows more water to flow into the tank. This continues until the swinging arm returns to its initial state. This is a simple and effective level control system for water tank.

Another level of control system is a steam boiler where the level of the water in the boiler must be maintained between certain limits; otherwise, it may lead to serious damage to the boiler and building as well as cause hazard to the building occupants (Miller et al, 2004). Water gages serves as a means of measurement level in the boiler. In an engineering context, the addition of control systems must be justified in terms of their profitability, or environment safety. A control system must be effective and efficient, and remain so throughout the life of the plant (Dutton et al., 1997). The performance of a system is often expressed in terms of their parameters such as: speed of response, stability and steady-state error. A good speed of response may often be achieved at the expense of steady state error and stability (Premier, 2008)[1]. Stability is one of the most important characteristics in any system. For a system to be stable, the system components must be appropriately sized for the application and the system must be correctly adjusted (tuned).

The objectives of this project is to investigate the control of water level in non-linear water tank which is fed by a centrifugal pump and discharges to a sump tank through a valve. The tank is a V shaped tank which has a straight wall. The system inflow would be adjusted alongside with the control signal to the outlet valve and the outlet pump during the simulation.

Furthermore, the project task includes designing a proportional (P) only and proportional + integral (PI) controller for a specific operating point and implementing it as an analogue s-domain system. The objectives would be accomplished by examining the dynamics of the water tank, modelling it from first principles and by applying step tests to identify the system model <https://assignbuster.com/water-level-control-system-of-the-tank-engineering-essay/>

at various operating points. The diagram below shows the equipment used to carry out the experiment.

Figure 2: Water tank level control system

Figure 4: Block diagram of ' V' Shaped Tank system

AIM

To characterise a new V tank

Conduct identification and control experimentation

Comparing it with an existing replicate system

OBJECTIVE

Relating level control to industrial applications.

Understanding the dynamics of water tank, modelling it from first principle

Application of step-test to identify the system model at various operating points.

Designing a proportional + integral controller for specific operating point.

1. 1 EXPERIMENT COMPONENTS

In order to perform the laboratory experiment on process plant (V-tank), the experimental components used are: amplifier, sensor transducer, water tank, valve, and pump which are discussed below.

1. 1. 1 AMPLIFIER

The amplifier is a very important part of any control system. Basically, it is used to deliver an output signal which is larger, in a prescribed way, than the input signal. A good designed amplifier mostly requires that the input impedance should be large so that the source is not loaded, and the output impedance should be small so that the power element can be easily driven (Anand & Zmood, 1995)[2]. An amplifier could be referred to as the signal conditioner use in this experiment. An am

In pulse width modulation (PWM) the amplitude and repetition rate remain constant, and the width of the pulse is varied according to the modulation signal amplitude (Parr, 1996)[3]

Pulse Width Modulated (PWM) signals are increasingly being used to drive continuous actuators such as d. c. motor, hydraulic servos and a. c. motor. If the switching frequency of the PWM amplifier is sufficiently high in relation to the actuator time constants, then the signals will be average around the value (Olsson & Piani, 1992)[4]. The motor is driven by a Pulse Width Modulated (PWM) power amplifier, which supplies power to the motor proportional to a voltage signal from the controller.

Pulses are produces at regular intervals, the duration or width of the pulse being proportional to the size of the voltage at each of the times concerned (Bolton, 1991)[5]. The reason why pulse width modulation is used is that conventional power amplifiers would simply burn at high power levels. The advantage of switching is that the solid-state devices are not continuously loaded with high power and therefore their power dissipation is low. This fact

makes PWM amplifier very efficient. In PWM amplifier, the switching can be directly controlled from the digital output ports of a computer.

1. 1. 2 SENSOR

In virtually every engineering application, there is the need to measure some physical quantities, such as displacements, speeds, forces, pressures, temperatures, stresses, flows and so on. These measurements are performed using this physical device called sensors, which are capable of converting a physical quantity to a more readily manipulated electrical quantity (Onwubolu, 2005). A sensor could be referred to as transducer.

Although, there are different kinds of liquid level transducers which are used in variety of control applications with different function such as: float-type liquid level transducers, hydrostatic pressure liquid level transducers, capacitance probes, and so on. But with respect to this project, the pressure transducer will be the point of focus. The pressure transducer is used to measure the height (or head) level in the tank

For a sensor to function effectively there is a need for signal conditioner and a display system. This signal conditional obtains signal from the sensor and manipulates it into a condition which are suitable either for display, or control system usefulness. Hence, a display system shows the output readings from the signal conditional (Bolton, 1999)[6].

Since the dynamic and static characteristics of the sensor or measuring element affect the indication of the actual value of the output variable, then the sensor plays an important role in determining the overall performance of the control system. The sensor usually determines the transfer function in

the feedback path. If the time constants of a sensor are negligibly small compared with other time constants of the control system, the transfer function of the sensor simply becomes constant (Ogata, K., 1997).

In selecting a good transducer with respect to its performance and system measurement, certain criteria had to be fulfilled. The accuracy of the transducer to which it has been calibrated, its response to error within the system, its stability i. e. the ability of the transducer to give the same output reading when used to measure a constant input over a period of time, etc (Bolton, 2008)[7].

1. 1. 3 WATER TANK

Water tank is a

The tank characteristics are non linear depending on the operating point and are such that tank level surface is a function of the level.

Figure 5: Tank fluid level system

The objective of the controller in the level control process is to maintain a level set point at a given value and be able to accept new set point values dynamically and this level control system must be controlled by the proper controller. In considering the top section of the tank as shown in fig. 5 above, the flow-rate can be calculated using Bernoulli's equation. From Bernoulli's law the flow through a valve q (m^3s^{-1}) is related to the pressure head across the valve h (m) by the following equation, in which g is the acceleration due to gravity, C_d is the coefficient of discharge (m^2) (Dutton et al., 1997).

Modelling the Tank

The tank can be modelled from first principles with the provision of certain assumptions. For the sake of simplicity, it is possible to consider the top section of the tank with parallel sides and then extend this model to deal with the whole tank. The prismatic section of the tank can be considered to be a simple rectangular tank with an inflow Q and an outflow, Q_L as in Figure 2. By considering conservation of matter, we can say that the flow into the tank must be equal to the flow out plus the flow converted into a change in level.

but if then

1. 1. 4 VALVE

Control valves are commonly encountered elements in process plant and the equation that describes their flow behaviour are nonlinear. Other nonlinear effects may exist because of the valve characteristic and the equipment surrounding the valve. Control valves are used to regulate the flow rate of fluid in a system. The control of flow rate can be achieved by varying the size of the passage through which the fluid flows (Stenerson, 2004)[8]. The control valve modulates the flow of a fluid by introducing a variable area aperture into the pipeline. The volumetric flow rate, Q , of a particular liquid through a valve is proportional to the pressure drop across it, $\hat{h} \sqrt{P}$.

Thus, let k_v be the valve coefficient which is the function of the valve opening or lift, h . in order to avoid dimensionality, the lift, h is defined as a fractional lift, i. e. when h is 1 the control valve is fully open, and when the h is 0 the valve is shut.

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1. 1. 5 VANE PUMP

In selecting a pump for a specific task, there are certain factors that needs to be considered such as: the height at which the pump will be moving the liquid to, the speed that is required, and the pressure flow at the pump's outlet. A pump is a mechanical device that changes mechanical power into fluid power. Positive displacement (PD) pumps perform work by expanding and then compressing a cavity, space, or moveable boundary within the pump. In most cases, these pumps actually captured the liquid and transport it through the pump to the discharge nozzle (Bachus & Custodio, 2003)[9]. However, the flow through PD pump is mostly a function of the speed of the driver or motor. A D. C motor drives the pump at a constant speed in most cases so that the delivery would be constant, i. e. the flow Q is normally constant (Healey, 1975).

The pressure or head that a PD pump can generate is mostly a function of the thickness of the casing and strength of the associated accompanying parts (seals, hoses & gaskets). In addition, a PD pump has been designed to have some strict tolerance parts. This strict tolerance controls the flow, and pressure that these pumps can generate. The ability to pressurize the fluid to higher pressures will depend on the tolerance of the components within the pump. Hence, the closer the pump's tolerance, the higher the capabilities would be (Brumbach & Clade, 2003).[10]Furthermore, there are three types of positive displacement pumps in use nowadays which are: vane pump, gear pump and the piston pump. These kinds of pump had different similarities depending on their performance but based on this task it would be concentrated on vane pump.

Vane pump are used in hydraulic systems. When the rotor rotates the pump's vanes in a counter clockwise direction which caused the vanes to slide in and out of their slots within the pump housing, a large amount of fluid would be carried from the inlet to the outlet (Onwubolu, 2005)[11]. This results from the eccentricity of the centre of the rotor with respect to that of the housing.

Figure 3: Vane Pump

1. 1. 5. 1 PUMP TEST

In order to examine the pump's accuracy, a test was carried out on the pump. The pump was used to move water from one container to the other within a time limit. Using the laboratory scale machine, the empty container was measured to weighs 0. 585Kg. However, the pump was tested at different voltage supplied to the pump from 1v – 10v at every one minute and then measured the filled container to know the actual weight. The reading was measured in kilogram (kg) which was converted to litres per minute. The conversion was 1kg to 1litre at a constant time. The outcome of the pump testing experiment could be seen in the graph below.

Graph 1: Outcome of Pump Testing Graph

In addition, the pump testing results obtained from the graph above shows that the pump was not functioning perfectly. The inaccuracy of the pump's efficiency is as a result of imbalance modified vanes inside the pump. The actual dimension of the vane inside the pump was 8mm inner diameter, 52mm outside diameter and 22mm thickness. The out diameter of the vane was cut-down or modified to roughly about 40mm for the vane to rotate

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easily within the casing. Hence, the graph's shape should be linear and not the linear curve shape in graph 1. From this experiment, it was observed that at any increase in voltage supplied to the pump; there will be large amount of pressure increase from the flow outlet and vice versa.

Pump

Figure 4: Modified Vane Size

Figure 5: Actual Vane Size

2. LITERATURE REVIEW

Literature review

3. CONTROLLER

A controller is a device which monitors and influences the operational condition of a given dynamical system. In closed loop control system, a controller is used to compare the output of a system with the required condition and convert the error into a control action designed to reduce error. The error might be as a result of some changes in the conditions being controlled or because of changes in the set value. Most industrial controllers use electricity or pressurized fluid such as oil or air as power sources. Controllers may also be classified according to the kind of power employed in their operation, such as pneumatic controllers, hydraulic controllers, or electronic controllers. For this kind of controllers to be used for a particular task, it must be based on the nature of the plant and the operating conditions (Ogata, K., 1997)[12].

3. 1 P ONLY

With proportional control the change in the controller output from the set point value is proportional to the error (Bolton, 1991)[13]. This means that the correction of the control element such as valve will receive signal which depends on the size of the correction required.

Although, a system with a proportional control may have a steady state offset (or drop) in response to a constant reference input and may not be entirely capable of rejecting a constant disturbance (Mutambara, 1999). For higher order systems, large values of the proportional feedback gain will typically lead to instability. For most systems there is an upper limit on the proportional feedback gain in order to achieve a well damped stable response, and this limit may still have an unacceptable steady state error. Therefore, there is a limit on how much the errors can be reduced by using proportional feedback only. One of the ways to improve the steady state accuracy of the control system is to introduce integral control.

Set point

Error

Process variable

Amplifier

Actuator signal

Plant

3. 2 P+I CONTROLLER

The primary reason for integral control is to reduce or eliminate constant steady state errors within the plant or system. Several limitations of proportional control are resolved by integral control. The steady state response to this class of load disturbance is completely eliminated. Thus, as long as the system remains stable, the system output equals the desired output regardless of the value of K_P and its dynamic response (Mutambara, 1999)[14]. If the designer wishes to increase the dynamic speed of response with large integral gain, then the response of the system becomes very oscillatory. Hence, in order to avoid this oscillatory behaviour of the system then both proportional and integral control should be used at the same time.

Set point

Error

Process variable

Amplifier

Actuator signal

3. 3 PID CONTROLLER

Most industrial processes are controlled using proportional-integral-derivative (PID) controllers. The popularity of PID controllers can be attributed to their good performance in wide range of operating conditions and partly to their functional simplicity, which make it easy to operate (Dorf

and Bishop, 2005)[15]. PID controllers are so effective that its controlling ability are standard in processing industries such as petroleum, refining, etc.

In order to design a particular control loop system, the constants value of KP, KI and KD had to be adjusted to an acceptable performance.

Increasing KP and KI tends to reduce system errors but may not be capable of also producing adequate stability, while increasing KD tends to improve stability. The combination of the three control components in this system yields complete control over the system dynamics. The proportional-integral-derivation (PID) controller provides both an acceptable degree of error reduction and an acceptable stability and damping.

4. METHODOLOGY

4. 1 STEP-TEST EXPERIMENT

The first part of the laboratory experiment involves determining the theoretical model at various level (h) of the water tank which include the prismatic bottom of the tank, the V shaped section and the top parallel sides of the tank. The water level in the tank was measured by a pressure sensor which was calibrated in the instrumentation laboratory prior to the experiment which showed that the pressure transducer produced a voltage signal proportional to the head.

To start this experiment, the centrifugal pump was switched on and the Lab View step input programme was opened. The centrifugal pump was used to fill the water tank from a rectangular sump tank and also ensuring that there was enough water in the sump tank to perform the experiment. Although,

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the control valve was ensured to be fully open so that there would be continuous flow of water from the sump tank into the main tank as a result of constant running of the pump.

After warming up the pump for some time, the pump bias was then set on the Lab View program to 1.3 volts (constantly) where the water is just about to start dropping into the tank. Using one second sampling time, the step voltage was increased repeatedly by an additional 0.1 volts each time the head (h) settles from 0v - 0.1v, 0.1v - 0.2v, and so on. As a result of increases in voltage, the water level would be increased as well in the tank. Once the water level reached the top of the tank, in order to prevent the water from overflowing the step voltage was reduced back to zero volt (0v) which allows the water to be empty back into the sump tank from the main tank and data or result was collected from the PC.

4.2 P ONLY EXPERIMENT

In order to perform the P only experiment, the proportional gain has to be calculated to get the accurate value that would be input into the system. The proportional gain value can then be input into the LabVIEW package to run the experiment. The set point can be changed from one point to another to see how the plant would respond to the sudden changes to increase in set point

The second part of the experiment entailed the design of the P only controller and P + I controller.

As regards to the P only controller, once the values of the steady state gain and time constant were found from the initial step input experiment, the <https://assignbuster.com/water-level-control-system-of-the-tank-engineering-essay/>

next step was to design a P only controller which will give closed loop dynamics $1/3$ that of the open loop plant, which was then used to calculate the values of K_p at known head (h). Having calculated the K_p values, the pump was then switched on and allowed to warm up, also the Lab View P only controller programme was initiated. With the pump warmed up the K_p value was then entered into the P only controller programme alongside the same value for the pump bias and the sample time used in the previous experiment, i. e. 1. 28 volts and 1 seconds respectively. The P only controller programme was allowed to run and the results for the sensor output (volts), the error (e) and the control effort were recorded and retrieved.

4. 3 P+I EXPERIMENT

Finally to control the level of water in the tank and eliminate the steady state error the Proportional Integral Controller experiment was initiated, the h_f (design level to which the tank is to be controlled) was defined and further derivation resulted in two unknowns, K_p and T_I . The values for K_p and T_I were then calculated for, then input into the Proportional Integral Controller program and allowed to run with a sample time of 1 seconds. The results for the sensor output (volts), the error (e) and the controller output were recorded and retrieved.

5. RESULTS DISCUSSION & ANALYSIS

5. 1 SYSTEM TRANSFER FUNCTION

AMPLIFIER

WATER TANK

SENSOR

CONTROL VALVE

PUMP

PROPORTIONAL ONLY

PROPORTIONAL PLUS INTEGRAL

5. 2 SYSTEM MODELLING

5. 3 SYSTEM PERFORMANCE

5. 4. RESULT DISCUSSION

Graph 1: Step-test experiment of voltage against time.

Graph 2: Step-test experiment of voltage against time

6. CONCLUSION

FUTURE WORK

Filter design discussion: noise reducer

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