OUTCOME 2

PROCESS CONTROL SYSTEMS AND CONTROLLERS

2 Understand process control systems and controllers

Need for process control: quality; safety; consistency of product; optimum plant performance; human limitations; efficiency; cost; environmental

Process controller terminology: deviation; range; span; absolute deviation; control effect; set point; process variable; manipulated variable; measured variable; bumpless transfer; process variable tracking; direct and reverse acting; offset; on-off control; two step control; cycling; three-term control (proportional band, gain, proportional, proportional with integral, proportional with integral and derivative, proportional with derivative)

System terminology: distance velocity lags; transfer lags; multiple transfer lags; capacity; resistance; dead time; reaction rate; inherent regulation; open loop; closed loop; load; supply; static gain; dynamic gain; stability; loop gain

Tuning techniques: Zeigler-Nichols; continuous cycling; reaction curve; ¾ decay methods; tuning for no overshoot on start-up; tuning for some overshoot on start-up

Represent systems using: P and I diagrams; loop diagrams; wiring diagrams; constructing and using diagrams to appropriate standards

A full understanding of control can only be achieved through studies of system models and the mathematics behind it. If you want to study this you should study the tutorials at www.freestudy.co.uk/d227.htm

You will find excellent tutorials on this topic at http://www.spiraxsarco.com/resources
THE NEED FOR PROCESS CONTROL

Perhaps to understand the need for process control it would be a good idea to refresh our memories of what process control is about. **Processes** usually refer to the production of mass quantities of things such as oils, chemicals, power, food, aggregates and so on.

In order to control these mass production enterprises we need to measure and control many **process variables** such as temperature, pressure, flow rate, speed, density, position, viscosity, salinity, force, stress, strain, volume, mass, weight, quantity, level, depth, acidity, alkalinity, hardness, strength and so on. Industries such as these must pay due attention to the following.

**SAFETY**

Many of these processes involve dangerous materials (e.g. toxic and explosive substances) and dangerous conditions (e.g. high pressures and temperatures).

Historically, it has been found that using manual control at each stage of production leads to accidents and poor quality.

Safe operation of plant can only be done by operating within the specified parameters and this can only be done by accurate measurement and control of the process. In the event of unpredictable failures, the safe shut down of plant should be automatic.

**QUALITY**

The quality and consistency of the product requires that the properties of the product be maintained within the specified parameters. This again depends on the ability to measure the process variables accurately and control them.

**ENVIRONMENT**

We should never forget the effect of accidents on the environment from oil spills to the release of toxic chemicals. Neither should we ignore the result of the process itself on the environment from the emission of greenhouse gases to unwanted by-products.

**ECONOMICS**

In economic terms, the production of products at prices we can afford can only be achieved by mass production. Mass production in the past was an indication of poor quality but this is a thing of the past thanks to modern instrumentation and control systems. Clearly mass production reduces the labour costs. Modern systems are flexible thanks to computer technology, especially Programmable Logic Controllers. This enables a production process to be changed on command so that variants of a product can be made to order and so reduce the need for separate production lines.

**SELF ASSESSMENT EXERCISE No. 1**

Write a short dissertation on the benefits of automated control on the purchase costs, running costs and quality of mass produced motor vehicles.
GUIDE ANSWER TO SELF ASSESSMENT EXERCISE No.1

Those of us old enough to remember what cars were like before the 1980's remember that there were very few models and variants of the model to choose. The engine oil had to be changed from summer to winter because the viscosity index of the fuel was too poor to cope with the temperature change (look it up).

The engines wore out rapidly and the bodywork rusted away in a few short years. The spark plugs and cylinder head valves got covered in carbon deposits and so the cylinder head had to be removed at regular intervals to be 'de-coked'. The brake linings and the clutch plates wore away in no time at all and needed regular replacement. A new engine had to be "run in" – a process of letting the big end and main bearings wear themselves gradually into the best fit and likewise the pistons, gears and valves. Throughout the life of the engine and particularly during "running in" the oil had to be changed regularly to remove the wear particles and the carbon deposits leaking past the piston.

Why does a modern car perform so much better? Thanks to modern measurement and control we have fuels and oils that are made and blended to a high standard so that the viscosity is always correct and they keep the engine clean and even protect it.

We have brake and clutch materials that are made from better materials accurately mixed and manufactured using efficient controlled production methods.

The parts of the engine and bodywork are manufactured more accurately and more consistently so that they always fit. Valves, pistons, gears and so on are made and controlled to precise dimensions so that they work correctly right from the start.

The cost of a new car in the 1960's was more than one year's average salary and that was for a basic car with no radio and no heating. The cost of a modern car with many advanced features is much less than half a year's average salary. This has come about through the use of automation and control that brings down the cost of the raw materials and the cost of producing the vehicle. A modern production line enables variants of the model to be produced at will by changing the programme in the controller so we have a much wider choice of model.
PROCESS CONTROL TERMINOLOGY

In the following, we will look at the description of several controlled systems in order to familiarise you with the terminology used.

ON/OFF or TWO STEP TEMPERATURE CONTROL

CASE 1 – SIMPLE LEVEL CONTROL SYSTEM

A typical level system is illustrated (commonly found on automatic washing machines). The pressure switch is normally closed (N.C.) and when the level is low it is not activated so the CONTACTS close and the circuit is made. The solenoid valve which is normally closed is activated and opens to let in water. When the level rises above the high level position the switch activates and breaks the circuit so the flow stops. It is often possible to adjust the operating pressure to set the level so the controlled level is always above the switch. The pressure at which the contacts close is different to the pressure at which they open so the level will drop a small amount before the valve opens.

CASE 2 – TEMPERATURE CONTROL

A typical controller is shown with connections for both thermocouples (TC) and resistance thermometers (RT). The set temperature (SET POINT) may be adjusted and depending on the model, the actual and set values may be displayed. DEVIATION is the difference between the set point and the actual temperature. The ABSOLUTE DEVIATION is the deviation from the mean temperature. The range over which the temperature may be controlled is called the SPAN. The switched output may be normally open or normally closed and is used to switch on or off the heating element. The block diagram for this system is shown below.

Note that the signal path forms a CLOSED LOOP and all automatic systems are closed loop systems. The CONTROLLED VARIABLE is the temperature (θ₀ is used generally for output values). This is measured with the SENSOR. The voltage representing θ₀ is amplified. This is compared to a voltage created by the SET VALUE (θ₁ for input value) and the resulting error (θₑ) is used to make correcting action. The ERROR is processed by the CONTROLLER (in this case a switching action) and the resulting signal (electric power) is applied to the CONTROLLED ELEMENT (the heater). Because θₑ = θ₁ - θ₀ such systems use NEGATIVE FEEDBACK. Note the symbol used for a comparer (the element that produces the error). This might be a simple differential amplifier in an electronic system.

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TIME RESPONSE DIAGRAMS FOR ON/OFF SYSTEMS

The **TIME RESPONSE** of a simple **ON/OFF** thermostat is like this. The temperature rises until it is too hot and the thermostat switches off. The temperature then falls until the temperature is too cold and the thermostat switches on. The output temperature will **CYCLE** between an upper and lower limit and the frequency of the cycling depends on the difference between the temperatures at which switching on and off occurs. Clearly they can never be made the same. The temperature will be controlled within an **ERROR BAND**.

**CONTINUOUS CONTROL**

You will find excellent tutorials on valve control at:

**CASE 1 – TEMPERATURE CONTROL WITH STEAM HEATING**

A more sophisticated control system will use a **REGULATOR** or **PROCESS CONTROL UNIT (PCU)** containing features that will enable the temperature to be brought close to the right value. The example shown has a tank that is heated by steam flowing through a heating coil. The system uses a liquid expansion sensor connected directly to the control unit. The set point and the actual temperature are shown on the display and an air signal is supplied to the valve to open or close it. In this way the steam flow is increased or decreased until the temperature of the tank is correct.

The control unit (typical one shown) has many adjustments that are made by a skilled technician to obtain optimum performance. The sensor can often be connected directly to the regulator. In particular there is the control action which has up to three adjustments called **PROPORTIONAL, INTEGRAL** and **DIFFERENTIAL (PID)**. This will be explained later. The block diagram of this system is like this.
CASE 2 – PNEUMATIC - FLOW CONTROL EXAMPLE

Let's have a look at a flow control system next. The diagram illustrates a simplified system with many important features not shown.

To control the flow of a fluid, we must measure it and a popular method is with differential pressure flow meters (DP Meters) such as venturi meters, orifice meters and so on. These produce a differential pressure representing the flow rate. The differential pressure is connected to a pneumatic D.P. Cell. The D. P. cell will have controls for adjusting the zero point and the span.

The output of the D. P. cell connects to the controller. Inside the controller you can set the input value. You can also set the zero point, the span and the three constants for PID control (this is discussed later). The flow rate is compared to the set value by purely mechanical and pneumatic means and the output to the actuator will change until the flow rate and the set value are the same (ideally).

The actuator may be designed to be fully open at 0.2 bar and fully closed at 1 bar or it can be the other way round (DIRECT OR REVERSE ACTING). The controller can also be set to be direct or reverse to match the actuator.

The important point is STANDARDISATION. The standard shown here is 0.2 – 1 bar. The only thing not standard is the flow range so a technician would have to calibrate the d.p. cell to produce a standard signal to represent the actual flow rate span. Typically this would involve doing the following.

1. Close the isolating valves and open the equalising valve to make the differential pressure zero.
2. Adjust the zero point control on the D.P. cell to produce an output of 0.2 bar.
3. Close the equalising valve and open the isolators.
4. Set the flow to the maximum (control valve fully open).
5. Adjust the span control on the D.P. cell to give the standard maximum output of 1 bar.
6. Because adjusting the span affects the zero setting, repeat until the output pressure is 0.2 bar at zero flow and 1 bar at maximum flow.
7. A calibration of flow against output pressure should show a linear relationship.

The setting of the controller or regulator is discussed later. The system described here shows a valve that moves from open to close from the range 0.2 to 1 bar. Often a VALVE POSITIONER is used because this is not sufficient pressure to operate the valve.

Next let's see how we could use an entirely electric control system.
CASE 3 – ELECTRO/PNEUMATIC FLOW CONTROL

This is the same as the previous case with the exception that an electrical D. P. cell is used so that the control signal is a standard 4 -20 mA input and the output is also 4 – 20 mA. This is converted into a pneumatic pressure of 0.2 – 1 bar with a current to pressure converter (I/P).

The converter will be ready calibrated with the standard input and output and should need no further calibration. The d.p. cell will need to be calibrated to match the required span of flow rates.

VALVE POSITIONER

In some cases the actuator on the valve may require a higher operating pressure than 0.2 – 1 bar. In this case a VALVE POSITIONER is used. These are a complete regulated system. They are attached to the valve and operate from the standard signal pressure but supply a higher pressure to the actuator. There is mechanical feedback from the valve stem to the unit so that no matter what force is required to move the valve, the pressure will build up until the valve moves.

CASE 4 – ALL ELECTRIC SYSTEM - PUMP SPEED CONTROL

It is more efficient to control flow by adjusting the speed of a pump rather than throttling the fluid with a valve. This example shows in simple form the use of an electric/electronic control unit.

The 4 – 20 mA output from the d.p. cell is compared to the set value and a regulating signal of 4 – 20 mA is applied to the motor which has its own electronics for converting this into power. The result is the pump changes the flow until the difference between actual and set flow rate is zero (ideally).
SELF ASSESSMENT EXERCISE No.2

Draw the control circuit block diagram for the steam pressure regulation system described below.

High pressure steam is reduced in pressure by the reducing valve that basically throttles the steam. The opening of the valve is set by the positioner which receives its signal from the controller. The required pressure is set on the controller and compared with the pressure from the feedback line. Depending on whether the pressure is too high or too low, the controller puts out the signal to the positioner to open or close the valve to compensate.
DIGITAL SYSTEMS

Modern systems are increasingly **DIGITAL**. This simply means that all the signals in the previous examples are either converted into digital numbers or created as digital numbers. The controller becomes a computer in which the error is calculated and processed and then the result is applied to the control element. The diagram shows a basic digital system for controlling the speed of a motor.

![Diagram of a basic digital system for controlling the speed of a motor.]

The computer is most likely a **PROGRAMMABLE LOGIC CONTROLLER (PLC)**. The digital signal applied to the controlled element must be converted into power (pneumatic or electric) to operate the actuator. The processes will involve **ANALOGUE to DIGITAL CONVERSION (ADC)** and **DIGITAL to ANALOGUE (DAC)** conversion.

In a process industry it is probable that all the digital systems are controlled from a central control room and to do this everything is linked by a **FIELDBUS**. It is arranged as a hierarchy with a central computer at the top (probably in the control room) where an operator can monitor everything. The next layer will be the PLCs each controlling a process. The lowest level is the one containing all the process variables and signals to and from the sensors, actuators, lights, switches and so on.

![Typical Fieldbus arrangement diagram.]
SYSTEM RESPONSE

For any of the systems described, the controlled variable is $θ_0$ and the set point is $θ_i$. The error is $θ_e = θ_i - θ_0$ for a system using negative feedback. If the set point ($θ_i$) is changed or if a DISTURBANCE occurs to the controlled variable ($θ_0$), the system must bring the controlled variable back to the set point. The way that the controlled variable changes with time is called the SYSTEM RESPONSE and this is a plot of the input and output signals against time. In dynamic systems such as robots, the changes occur rapidly and time responses are measured in seconds or smaller. In process control the responses are slower and the responses are more likely to be measured in minutes.

CAUSES OF TIME DELAYS IN THE SYSTEM

INERTIA/INERTANCE/INDUCTANCE

These properties make it difficult to speed up and slow down and so makes things act out of phase with the correcting action. For example hitting the brakes on a car does not produce an instant stop because of the inertia. Putting your foot down on the accelerator does not produce an instant increase in speed because of the inertia. The same effect occurs with any pipe carrying a fluid so a change in flow might happen at one end but not at the other until a small time later. Inductance in electrical circuits delays the change in current but these are small in comparison.

ELASTICITY/COMPRESSIBILITY/CAPACITANCE

This is a property that delays things happening because it absorbs some of the input action. For example if you had a spring between your brake peddle and the lever you would have to press it further before sufficient force is transmitted to the lever. You get the same affect if air gets into your hydraulic lines because the air compresses and this would make a delay. In electronic systems capacitors affect the electrical signals the same way. The filling of tanks takes time (e.g. the level control previously) and this introduces time delays. The raising of pressure in a gas vessel takes time because of the compressibility of the gas. The raising of temperatures takes time because of the thermal capacity of the system (e.g. temperature control).

FRICTION/RESISTANCE

Friction reduces signal strength and resistance reduces electrical signal strength. This combined with the other effects has a dramatic affect on the time lags. For example pressurising a gas vessel through a partly closed valve takes longer than when the valve is fully open. When capacitive and resistive elements combine to delay a signal the lag is called the TRANSPORT LAG or TRANSFER LAG.

STEPS and RAMPS

If the set point is changed suddenly or a sudden disturbance occurs, the change resembles a step on the response diagram. If the changes occur at a constant rate, they resemble ramps on the diagrams (also known as velocity change). Other forms of changes can occur such as cyclic sinusoidal changes but these are more applicable to dynamic systems rather than process control. The diagrams do not show how the output responds to the changes.
Let's take a superficial look at how a level control system responds to a change.

The actual level \( \theta_o \) is sensed by the pressure transducer. The electrical output will be converted into a standard air pressure. This is sent to the control unit. The set value for the level is \( \theta_i \) and the error is \( \theta_e = \theta_i - \theta_o \). The error is present inside the controller in signal form and this results in a signal to the control valve and a flow rate into the tank \( \theta_p \). Any error results in the supply valve being opened or closed to increase the inflow and outflow.

Consider that the level is correct. In this case there will be no inflow. When liquid is drawn off, the level will drop and the valve will open to allow an inflow. It is impossible to maintain the correct level while liquid is flowing out of the tank because we need an error to keep the valve open. The level will only settle at the set point when there is no outflow and no inflow. In a system like this, we get an **OFFSET ERROR** as shown.

Clearly, if the level is to be made equal, we need the control valve to open more so that the inflow is larger than the outflow until the level is correct. Then we want the inflow and outflow to be equal. To achieve this we introduce a form of control called **AUTOMATIC RESET** or **INTEGRAL CONTROL**. This is built into the Process Control Unit. While an error exists, the output pressure from the PCU will grow with time and the valve will open more until the inflow exceeds the outflow for a while and then settle with equal inflow and outflow.

We are going to examine time delays and lags in the system. In this example, such delays might cause the system to **HUNT** or **CYCLE** because the levels **OVERSHOOT** and **UNDERSHOOT** and the correcting action gets out of time (phase) with the level. A major cause of this is too much **GAIN** and a fast **REACTION RATE**.
DEAD TIME

This is also called **DISTANCE - VELOCITY LAG.** Suppose the input is changed suddenly. Due to various affects, some time will pass before the output starts to change. This is the dead time. For example a long pneumatic control line and inertia and back lash in the actuator mechanism will produce a time delay before the actuator moves. The result is illustrated.

**PROCESS CONTROL UNITS (PCU)**

Now we should have a closer look at how to set the regulator for optimal performance. In particular we want to examine the PID controls, (Proportional, Integral and Derivative). This involves the setting of three values. On pneumatic controllers the settings are made by physically adjusting the mechanism. On electrical and digital controllers, it is done by setting the values with a key pad.

The mathematics behind this are too complex to give a full analysis here. You will find the topic fully covered in the tutorial at [www.freestudy.co.uk/control/t11.pdf](http://www.freestudy.co.uk/control/t11.pdf)

First consider the block diagram of the level control system previously discussed.

The PCU contains the signal summing device and the processing elements. It is this processing that we are now discussing. The principles apply to all closed loop systems with negative feedback. The error between the set value and the actual value of the process variable is $\theta_e$. This is processed by some means to provide an output signal to the controlling element $\theta_p$. We may think of the processing as three parallel processors as shown.
PROPORTIONAL

If we only have proportional control then \( \theta_p = k_p \theta_e \)

\( k_p \) is the proportional constant or GAIN that basically governs the amplification of the signal and so sets the magnitude and rate of response. Most PCUs have a control called the PROPORTIONAL BAND.

The proportional band is defined as \( P = 100/k_p \) so \( k_p = 100/\text{proportional band} \)

\( \theta_p = 100 \theta_e /P \)

The proportional band is usually the adjustment to be made from 0 to 100%

With proportional control only and typical transfer lags in the system, the output response to a STEP CHANGE will produce a change in the output. This is typically an exponential growth as shown.

The speed of response is often defined by a TIME CONSTANT ‘T’ or ‘\( \tau \)’. The mathematics would show us that for a simple system \( T \) is the time taken to reach 63.2% of the change. It takes a time of 4\( T \) to reach 99.9% of the change (near enough the time to get to the new value). \( T \) depends on the proportional constant so in theory reducing \( T \) makes the system change faster and this is one of the adjustments to be made on the regulator.

In the case of the temperature control system described earlier the temperature will rise to the correct value. In the case of the level control we would get OFF SET as described earlier. In order to prevent this we have INTEGRAL ACTION.

INTEGRAL

This is also called automatic offset and was described briefly earlier. A PCU with integral control action will increase or decrease the output in response to an error so long as the error is present. In affect it alters the set point to compensate for the offset. Mathematically, integral control is given by the equation:

\[
\theta_p = K \int \theta_e \, dt
\]

where \( K \) is the gain. It is never used on its own but is added to the proportional control term so in reality we have:

\[
\theta_p = k_p \theta_e + K \int \theta_e \, dt = k_p \theta_e + \frac{k_p}{T_i} \int \theta_e \, dt = k_p \left\{ \theta_e + \frac{1}{T_i} \int \theta_e \, dt \right\}
\]

The term \( T_i \) is called the integral time and this is the constant that must be adjusted on the PCU. We can see that so long as there is a positive error present \( \theta_p \) will increase with time and so long as there is a negative error present \( \theta_p \) will decrease with time. In this way \( \theta_p \) will change until \( \theta_e \) is zero. The overall gain is still \( k_p \) and this will affect the rate of change of the output.

DIFFERENTIAL

For differential control on its own we have the mathematical relationship

\[
\theta_p = k_p T_d \frac{d\theta_e}{dt}
\]

This tells us that the output of the PCU is directly proportional to the rate of change of the error. \( T_d \) is the differential time constant and this is the third item to be set on the PCU. The affect of this control action is to speed up the rate of response. When a step change occurs \( d\theta_e/dt \) is large at the start and \( \theta_p \) is greater. Near the end of the correction \( d\theta_e/dt \) is small and \( \theta_p \) is smaller. This means the error is corrected more quickly.
Normally all three control terms are available in the PCU and the technician must adjust $k_p$, $T_i$ and $T_d$ to get optimal response. In this case the output of the PCU is given by:

$$\theta_p = k_p \theta_e + k_i \left( \int \theta_e dt + k_p T_d \frac{d\theta_e}{dt} \right) = k_p \left( \theta_e + \frac{1}{T_i} \int \theta_e dt + T_d \frac{d\theta_e}{dt} \right)$$

If the settings are incorrect, especially for the differential term and the gain, the output may overshoot and undershoot causing the output to cycle above and below the set value. This must be avoided by TUNING the PCU. The following describes the affects of tuning the PID constants.

**ADJUSTING THE PROPORTIONAL BAND**

This produces the affects shown when a step change is made. If the P-band is too wide we have a small gain and a large offset may occur (Graph A) but the output does not cycle. Narrowing the P-band will increase the gain and reduce the offset (Graph C). This is the optimal condition with proportional control only. Reducing P further produces too much gain and the output will cycle about the set value (Graph B).

**ADJUSTING THE INTEGRAL ACTION**

If the integral time is small (too short) the output will overshoot and cycle about the set point (Graph A). If the integral time is too long, the output will cycle but in a decaying manner and settle after a long time period. (Graph B). When the adjustment is optimal, the output will overshoot slightly just once and then settle at the set point. (curve C)

**ADJUSTING THE DERIVATIVE ACTION**

If the derivative time is too big then overshoot will occur and the output will cycle (curve B). If the derivative time is too small the output will take too long to reach the set value (curve A). When the time is optimal, the output will settle in the shortest time with no overshoot (curve C).

**SUMMARY**

<table>
<thead>
<tr>
<th>Action</th>
<th>Stability</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase P</td>
<td>Increased</td>
<td>Slower</td>
</tr>
<tr>
<td>Increase $T_i$</td>
<td>Increased</td>
<td>Slower</td>
</tr>
<tr>
<td>Increase $T_d$</td>
<td>Decreased</td>
<td>Faster</td>
</tr>
</tbody>
</table>

**SETTING UP A PCU**

Each PCU has to be adjusted to match the characteristics of a particular system. The idea is to produce the fastest correction without offset error or cycling. There are several techniques for doing this. In order to optimise the performance of a system, the controller parameters need to be set. The late Zeigler and Nichols produced a practical guide for setting up three term controllers for plant systems dating back to the 1940’s. The following is still useful for that purpose.
CLOSED LOOP METHOD

In this method only proportional gain is used and \( k_p \) or P is adjusted until instability just occurs and the controlled variable (plant output) cycles. The system is then at the limit of instability. The gain and periodic time (time to complete one cycle) \( T_p \) are noted. \( k_p \) is then reduced to 0.6 (equivalent to increasing the proportional band by 1.7) of its value and the other two parameters are set so that:

\[
T_1 = \frac{T_p}{2} \quad T_d = \frac{T_p}{8}
\]

This will produce a response to a step change in the form of a decaying oscillation and the amplitude of the second cycle will be \( \frac{1}{4} \) of the initial amplitude as shown. This is accepted as a reasonable setting for most process plant systems.

These figures are different when there is no differential control (P + I) and when only P is used. The figures are given in the table below.

**PROCEDURE LIST**

1. Remove integral action on the controller by increasing the integral time (\( T_i \)) to its maximum.
2. Remove the derivative action by setting the derivation time (\( T_d \)) to 0.
3. Wait until the process reaches a stable condition.
4. Reduce the proportional band (increase gain) until the instability point is reached.
5. Measure the time for one period (\( T_p \)) and register the proportional band setting at this point.
6. Using this setting as the start point, calculate the appropriate controller settings according to the table below.

<table>
<thead>
<tr>
<th>Type of control used.</th>
<th>Prop. Band Setting</th>
<th>Integral Time ( T_i )</th>
<th>Derivative Time ( T_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P + I + D</td>
<td>x 1.7</td>
<td>( \frac{T_p}{2} )</td>
<td>( \frac{T_p}{8} )</td>
</tr>
<tr>
<td>P + I</td>
<td>x 2.2</td>
<td>( \frac{T_p}{1.2} )</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>x 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OPEN LOOP METHOD

In this method the feedback path is disconnected usually by switching to manual in the PCU. A step change is made to the set point and the output is monitored. A typical plant process produces an open loop response as shown.

\( \tau \) is the **EFFECTIVE DEAD TIME** or time delay due to the transfer lags. \( T \) is the time constant of the system. \( H_1 \) is the input step and \( H_2 \) the resultant output step in the steady state. The steady state gain is \( H_1 / H_2 \).

The settings for the controller are then adjusted as follows.

\[
k_p = 1.2 \frac{T H_1}{\tau H_2} \quad T_1 = 2 \tau \quad T_d = 0.5 \tau
\]
BUMPLESS TRANSFER

Sometimes it is necessary to remove the automatic control and most PCUs have a switch for manual control. When this is done the feedback $\theta_o$ becomes zero and the error would suddenly change. The system would try to respond to this step change. To avoid this, the value of $\theta_o$ is locked when switching to manual control. In a digital system this would involve storing and holding the digital value of $\theta_o$ in a register and performing the numerical comparison with this value instead of the live value.

SELF-TUNING CONTROLLERS

Modern systems and sub-systems especially digital systems, provide the ability for automatic or self tuning of the PID parameters. The self-tune controller switches to on/off control for a certain period of time. During this period it analyses the results of its responses, and calculates and sets its own P I D parameters. The modern controller can now operate what is termed an adaptive function, which not only sets the required initial P I D terms, but monitors and re-sets these terms if necessary, according to changes in the process during normal running conditions. Such controllers are readily available and relatively inexpensive. Their use is becoming increasingly widespread, even for relatively unsophisticated control tasks.

SELF ASSESSMENT EXERCISE No. 3

1. A plant process is controlled by a PID controller. In a closed loop test using only proportional gain, the limit of stability was found to occur with a gain of 4.5 and the periodic time was 80 s. Calculate the proportional, integral and differential constants required so that a ¼ decay is obtained in response to a step change.

\[
(k_p = 2.7, \quad T_i = 40 \, \text{s} \quad \text{and} \quad T_d = 10 \, \text{s})
\]

2. The three term controller in a plant process is to be adjusted for optimal performance using the Zeigler Nichols open loop method. The proportional gain was set to give a steady state step change equal to the input change. The time delay was 24 seconds and the time constant was 50 seconds. Calculate the proportional, integral and differential constants required.

\[
(k_p = 2.5, \quad T_i = 48 \, \text{s} \quad \text{and} \quad T_d = 12 \, \text{s})
\]