Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 16: Instrumentation and Control Systems

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 3

Control Concepts

3.1 System Concepts

It's important that engineers are aware of some of the concepts involved in real-world control, digital simulations require a lot of assumptions for effective computation.

3.1.1 Distance/Velocity Lag

Distance/velocity lag is the delay involved between the input and the output. For example, the boiler in a house may be switched on, with the thermostat regulated to a given value, however, the boiler is not switched on and the temperature of the house and the water immediately turns to the temperature set by the thermostat, it needs to warm up. Fig.3.1 shows the temperature reading of the temperature compared to the value set by the thermostat and demonstrating the distance/velocity lag.

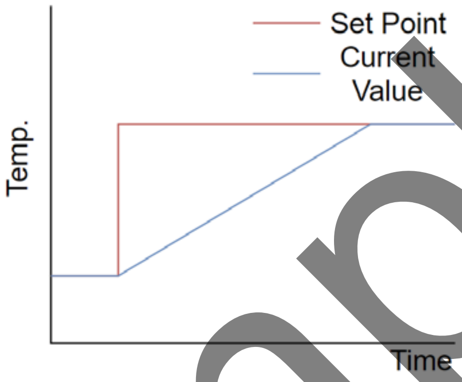

Fig.3.1: Distance/velocity lag example

3.1.2 Capacity

Capacity can be considered the limit of a system, or how much of a physical quantity the system can hold. Such as the amount of fluid a container can hold, how much weight a machine can operate with, or the amount of charge a capacitor can hold. Adding to a system already at capacity can cause several problems, whether it is mechanical failure, electronic failure, loss of product, hazardous spillage, or, in the case of pressurised systems, explosions.

3.1.3 Resistance

Resistance occurs in all forms of motion. No system is 100% efficient, and we must consider any and all resistances that will limit the output of the system. By not accounting for resistance in calculations, accuracy is lost. Sometimes it is too difficult to account for all resistive forces, and sometimes it is possible to overlook small resistances, but these small resistances add up. Most engineering systems will incorporate a "safety factor" a multiplier employed to ensure that any small resistances overlooked are more than compensated for.

3.1.4 Gain

The gain is given as the ratio of the input to the output, when considering the gain of the system it is important to consider both the static and dynamic gain.

Static Gain – The static gain is the gain of the system when it is stable. If the input remains constant, and the system is stable, then the output will begin to revert to its steady state.

Dynamic Gain – Dynamic gain is the gain of the system as it is adapting to a variation in the input. Unlike the static gain, the dynamic gain will not be a constant value and will be a function dependent on time. The dynamic gain is not solely restricted to stable systems, but also unstable systems.

3.1.5 Stability

Stability is whether or not the system can be controlled by the control system in place. Let's consider a power plant, a schematic of a typical power plant system is shown in Fig.3.2.

- Pipe pressure at every stage
- Temperatures at every stage
- Air flow into the combustion chamber of the boiler
- Rotational speed of the turbine shaft
- Pressures at every stage of the pipe

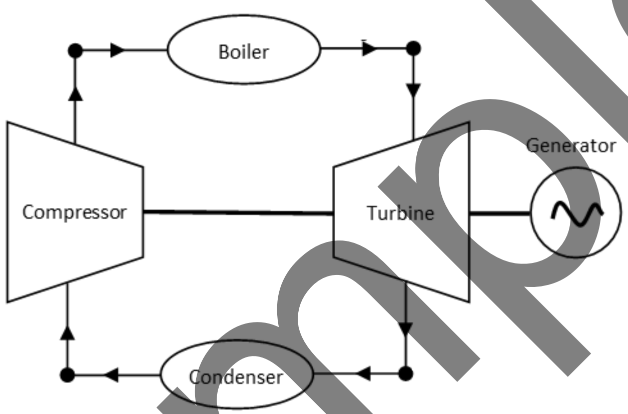

Fig.3.2: A basic power cycle

Theory

Let's say it's the middle of the night, and everyone has gone to sleep, and electricity demand is incredibly low; this will drop the resisting electromechanical torque produced by the generator, and as a result, the generator will speed up and produce a higher voltage, which lowers the current even more and will become unstable. The increase in voltage will also ripple through to the grid and damage most household electronics.

What if it is the world cup final? During half time electricity consumption is at one of its peaks in the UK, as everyone goes to put the kettle on. The huge demand will increase the electromechanical torque from the generator, slowing it down. This in turn will drop the voltage, which further increases the current demand and slows it down even further.

The stability of this system is related to the mechanical input power, and the electrical power output that can be produced by the generator. The variable δ is with regards to the asynchronous motor, and it is considered the difference between the electrical stator speed and the rotor's mechanical speed.

Need AES Notes to finish this

3.2 Feedback Systems

The systems can be considered either open loop or closed loop, which has been discussed in Workbook 2. But engineers also need to consider more about the different type of feedback that a system can have.

3.2.1 Positive Feedback

Positive feedback control systems use the set point and current value of the system and add them together since the feedback is "in phase" with the input and compatible. The effect of positive feedback is to increase the system's overall gain as opposed to a system without feedback.

We can use an Operational-Amplifier (Op-Amp) to create a simple positive feedback system, shown in Fig.3.3 below. When the input V_{in} is positive, then the feedback from the Op-Amp will begin to add to V_{in} and the overall gain will increase, as V_{out} will also increase.

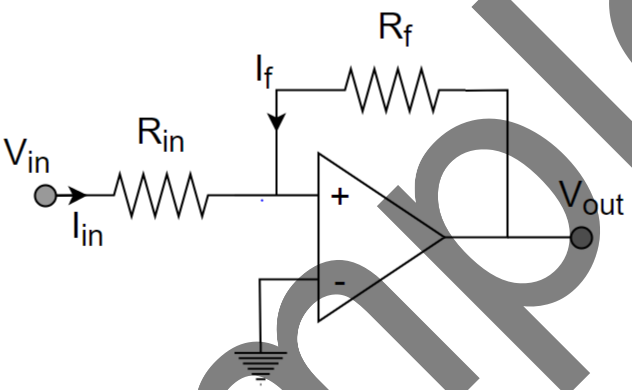

Fig.3.3: Op-Amp positive feedback system

Gain will increase as long as V_{in} is positive, when V_{in} becomes negative, the gain will begin to decline. The simplest way to think about a positive feedback system is "less is less, and more is more".

3.2.2 Negative Feedback

Negative feedback control is accomplished by feeding some of the output voltage back into the inverting input terminal of the Op-Amp. An Op-Amp negative feedback system is shown below in Fig.3.4, one thing to notice is that the V_{in} is now connected to the inverter of Op-Amp.

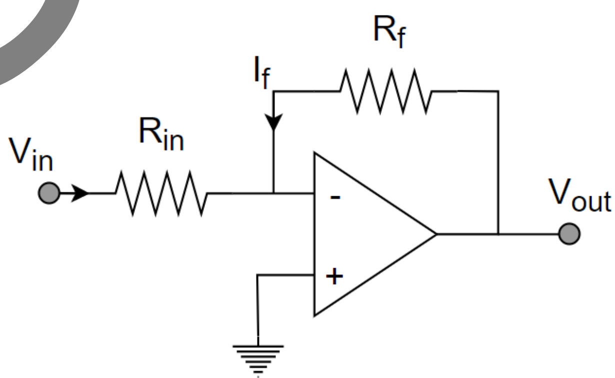

Fig.3.4: Op-Amp negative feedback system

3.3 System Tuning

It is rare that the control algorithm will work perfectly first time, most tuning simply comes down to trial and error, which is why simulations are so useful in the design process. The ability to simulate a range of conditions in seconds for a process that could take days is a huge advantage in keeping up with deadlines.

3.3.1 Different PID Systems

Workbook 2 mentioned that there are three different types of PID controllers, there is the Interactive algorithm, Noninteractive algorithm and Parallel algorithm, which was discussed in Workbook 2. Each system has its own version of tuning and optimisation.

Interactive Algorithm – One of the oldest PID control algorithms, this algorithm is still found in many controllers today and was used in the original pneumatic and electronic control systems. The block diagram of the interactive algorithm is shown in Fig.3.6 below.

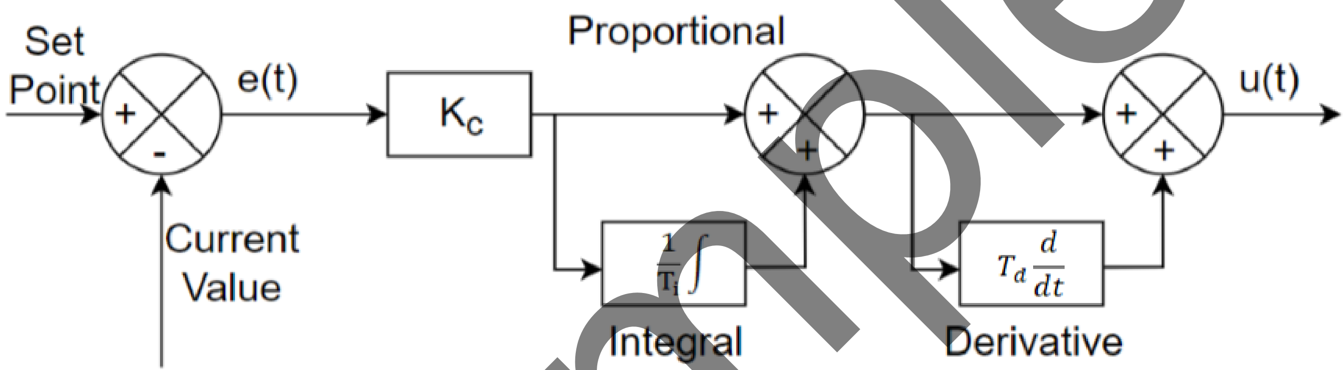

Fig.3.6: Interactive algorithm block diagram

The governing equation of the controller's output is shown in Eq.3……, where K_c is the controller gain T_i is the integral reset rate (measured in integral gains in repeats per minute) and T_d is the derivative constant.

$$u(t) = K_c\left[e(t) + \frac{1}{T_i}\int e(t)dt\right] \cdot \left[1 + T_d\frac{de(t)}{dt}\right] \qquad \text{(Eq.3……)}$$

Noninteractive Algorithm – The noninteractive algorithm calculates the derivative and integral values in parallel, shown in Fig.3.7 below.

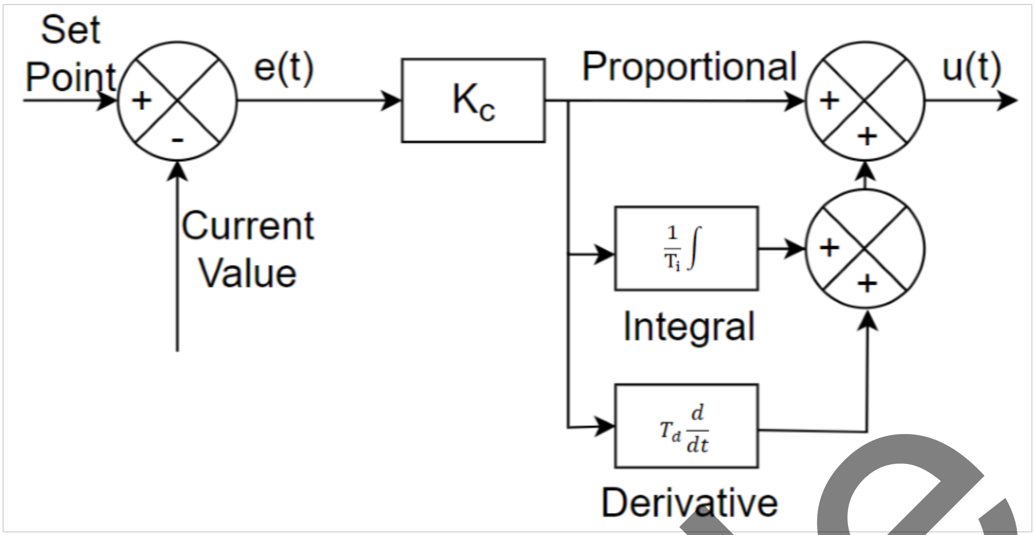

Fig.3.7: Noninteractive algorithm block diagram

The equation for the noninteractive algorithm is given as Eq.3……, if T_d is zero, and the system is just a PI controller, then the noninteractive algorithm is the same as the interactive.

$$u(t) = K_c \left[e(t) + \frac{1}{T_i}\int e(t)dt + T_d \frac{de(t)}{dt}\right] \qquad \text{(Eq.3…….)}$$

Parallel Algorithm – The parallel algorithm has already been discussed in Workbook 2, the block diagram of the system is shown in Fig.3.8.

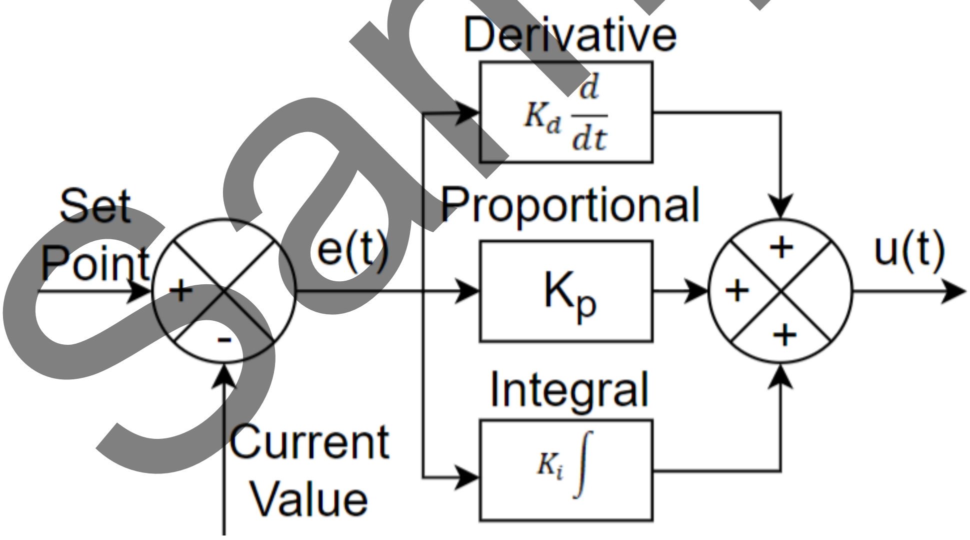

Fig.3.8: Parallel algorithm block diagram

The output of the parallel PID system, as discussed in Workbook 2, is shown in Eq.3……, where K_p, K_i and K_d are the gains for the proportional, integral and derivative calculations, respectively.

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \qquad \text{(Eq.3………)}$$

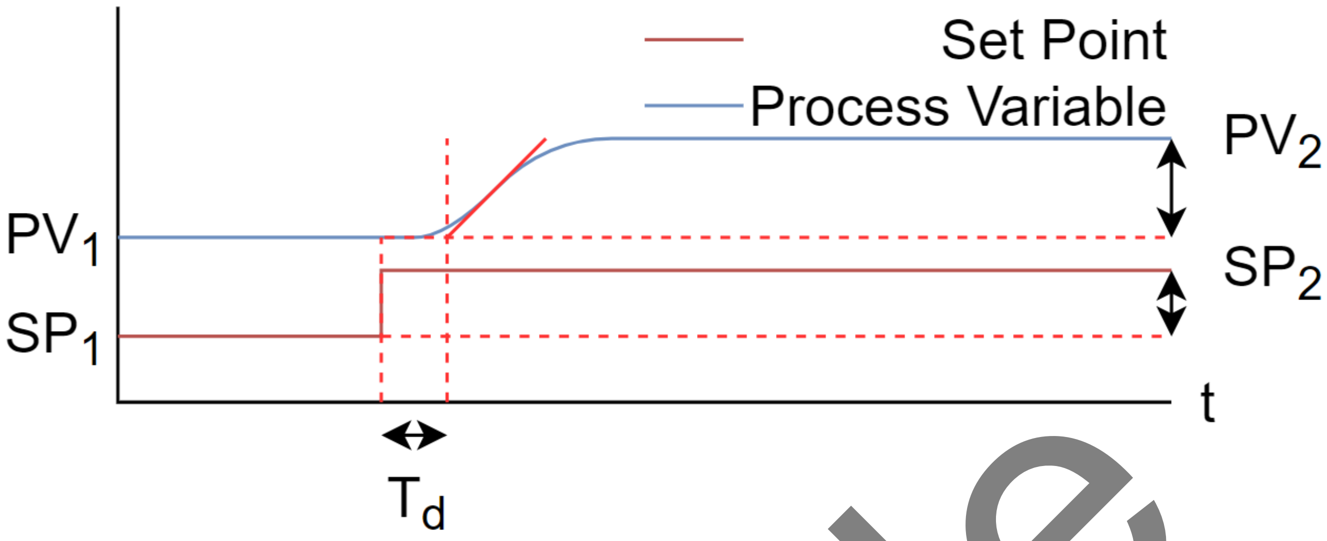

Fig.3.10: Calculating the "dead time" of the system

6. Using the same tangent from Step 5, find the point when it reaches the same value as 0.63 of the change in the process variable (Eq.3……)

$$y = PV_1 + 0.63(PV_2 - PV_1) \qquad \text{(Eq.3……)}$$

7. Mark the time that the process variable reaches this point, and the difference in time between this point and the end of the dead time is given as the process time constant τ
8. G_p, t_d and τ are then used to calculate the values for K_c, T_i and T_d

Table.3.1: The equations for calculating the controller constants

	K_c	T_i	T_d
P	$\frac{\tau}{t_d G_p}$	–	–
PI	$\frac{0.9\tau}{t_d G_p}$	$\frac{0.3}{t_d}$	–
PID	$\frac{1.2\tau}{t_d G_p}$	$\frac{0.5}{t_d}$	$0.5t_d$

The numbers should not be taken as a definite answer, and the system should be rigorously checked with these numbers before accepting them.

3.3.3 Ziegler-Nichols Closed Loop Tuning

This method is used for closed loop systems. The first step of this tuning method is predominantly trial and error, and it is important that the trial and error portion is carefully done, to ensure that the system retains an element of stability to it.

1. Set T_i and T_d as zero, set K_c as a very low value.

	K_c	T_i	T_d
P	$\frac{1.03}{2G_p}\left(\frac{\tau}{t_d}+0.34\right)$	–	–
PI	$\frac{0.9}{2G_p}\left(\frac{\tau}{t_d}+0.092\right)$	$3.33t_d\frac{\tau+0.092t_d}{\tau+2.22t_d}$	–
PD	$\frac{1.24}{2G_p}\left(\frac{\tau}{t_d}+0.129\right)$	–	$0.27t_d\frac{\tau-0.324t_d}{\tau+0.129t_d}$
PID	$\frac{1.35}{2G_p}\left(\frac{\tau}{t_d}+0.185\right)$	$2.5t_d\frac{\tau+0.185t_d}{\tau+0.611t_d}$	$0.37t_d\frac{\tau}{\tau+0.185t_d}$

Once again, these values should be tested to ensure that they produce a stable waveform.

3.3.5 Lambda Tuning

Lambda rules are, once again, very similar to the Ziegler-Nichols open loop method, in the sense that the calculations for the controller settings revolve around G_p, t_d and τ. Steps 1-7 are the same as the Ziegler-Nichols open loop method. But now a new constant τ_{cl} is selected, this is the closed loop time constant, and this is selected by the engineer. Typically, the value for a very stable control loop is $\tau_{cl} = 3\tau$. The PID controller parameters are then calculated using Table 3.4.

Table.3.4: Lambda controller parameter equations

	K_c	T_i	T_d
PI	$\frac{\tau}{G_p(\tau_{cl}+t_d)}$	τ	–

The advantages of lambda tuning include the fact that they are much less sensitive to any errors when determining the process dead time. Another advantage is that the process variable will not overshoot the setpoint after a disturbance or set point change. However, if the system has a long time constant, then the controller will have a long integral time, which makes the recovery from disturbances very slow.

3.3.6 Overshoot Tuning

Overshoot tuning is for parallel controllers and is completely trial and error. There needs to be a specification for the overshoot, and a maximum allowed value for it to ensure it is stable. A flow chart for overshoot tuning is shown in Fig.3.12.