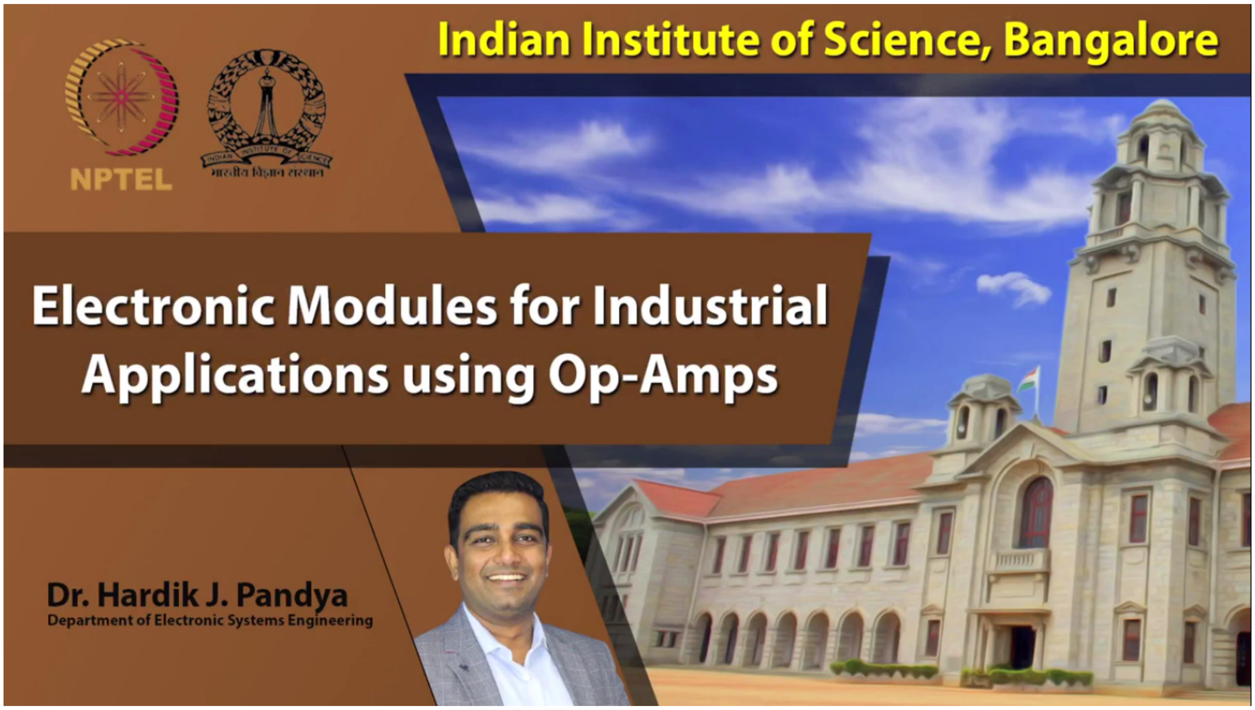
Indian Institute of Science

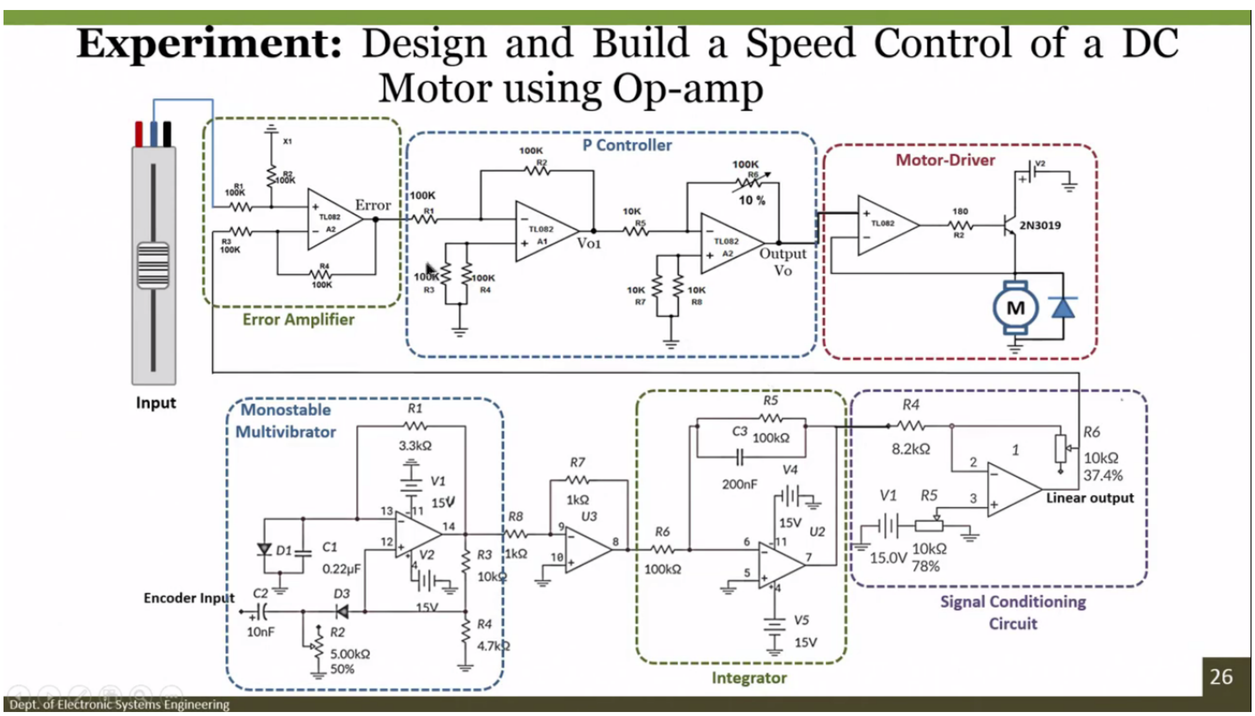
भारतीय विज्ञान संस्थान

NPTEL

National Programme on Technology Enhanced Learning




Welcome to the module. In last module we have seen the working of the different sub-systems that are involved in order to control the speed of a DC motor. We have also seen the simulation of each and every sub-system whether it has been meeting our requirements or not. Then we have also seen experimentally how individual sub-systems are working where in order to match with the requirement of the other sub-system either that individual sub-system is meeting or not.



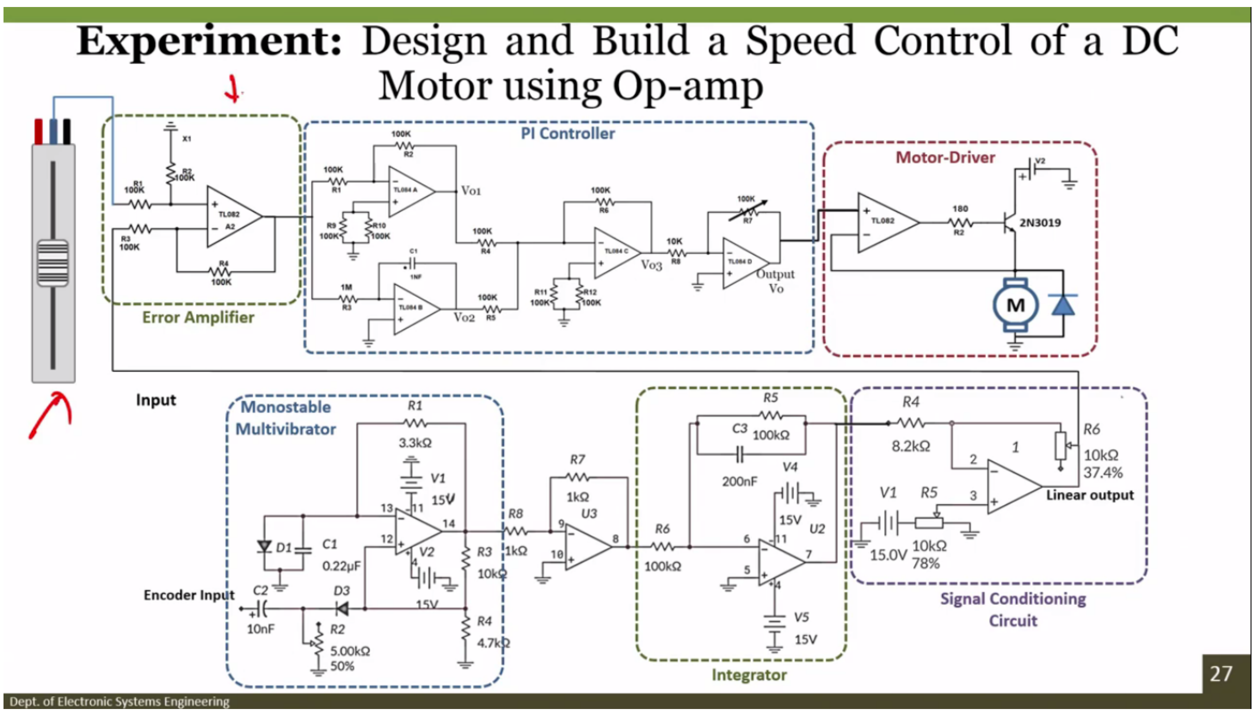
Now in today's module we are interfacing each and every system which will be the complete signal condition circuit for your DC motor. In order to control the speed of our DC motor. Now we will see an experiment on interfacing. Experimentally as it is very – as it contains so many different sub-systems it is difficult to create the system in a simulation and to visualize it. So what we do is that we use the compute system on a break board some part will be on break board, some part will be the other board which we have already designed for PPI [00:01:43] controllers. What we do is that by using a pot we will create a set point. This is the input which is nothing but a set point. By using the rotary pot we will create a set point and the input, the output of the pot will be directly connected to the input of an error amplifier but generally speaking the design board has another operational amplifier here which is nothing but buffer amplifier or voltage follower. The voltage follower is connected between the output of potential meter to the input of error amplifier. The reason is that since the output we are getting from the set point is being provided by using a potential meter resistive device network and at the input of an error amplifier again it is connected to the another resistive device network, there are chances of having loading the input.

So in order to not have a proper –in order to avoid loading effect instead of directly connecting it through connecting the output of a potential meter to the input of an error amplifier we use a voltage follower acute. But in this case I have not showed you but in reality we have design and voltage follower circuit in the board and we have connected error amplifier to this. Then another input of the error amplifier if you see it is connected from the output of signal conditioning circuit. The second stage of signal conditioning circuit.

Now the output of this either we can connect it to P controller, or PI controller, or PAD controller such that by varying the gains we can change the gain of P controller, P gain and that will be given as an input to the motor driver circuit. But since it is gain controller if the gain is really high there is a chances of getting an output greater than 5 volts. But our motor as per the specifications of the motor, the motor, the maximum rated voltage is 6 volts. And we have designed our signal conditioning circuit to operate from zero to 5 volts. If it is operating at 6 volts the RMP of the motor will be higher again the chosen resistance R1 and C1 may not match with respect to that value.

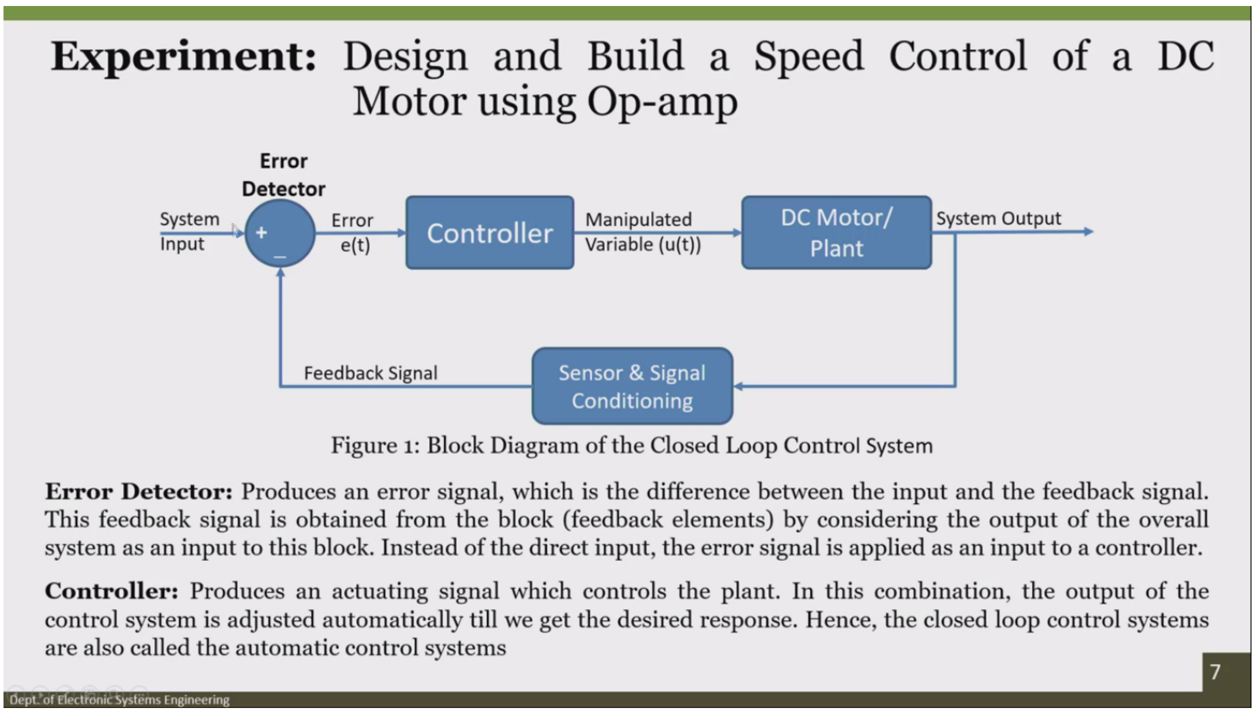
So some pulses may miss. So because of that reason we have restricted our operating voltage to 0 to 5 volts. But since the output voltage of the controller which is nothing but a manipulated variable entirely depends upon the error signal that we have and the gain that we set. If the error is higher and the gain is also higher there is a chances of getting output voltage greater than 5 volts. So in order to not to damage the circuit we have in practical we have given Zener diode of 5.1 volt connected with this point. So that even if the P controller output voltage is higher than 5 volt, because of the Zener diode it provides the input voltage to the motor, driver circuit to be only of 5 volt. So the motor will be operating at a very high voltage.

So it acts as one is safety. Other one is – yeah it acts as safety. Then the output of this is given to the motor driver circuit where we have already seen the working as well as real time demonstration of how exactly it makes the motor to work everything, analysis as well as simulation. And based upon the input voltage that we have it here the motor RPM automatically changes and it is linearly dependent. So in order to see at what RPM it is rotating whether it is rotating at the same RPM as set by the user we have used an encoder which is a digital encoder which provides the pulses and these encoder output is connected to a mono stable multi vibrator at this point. Since we have not show any encoder here I have not given any connection but in practice there is an encoder which is nothing but a sensor in our case use the digital pulses and it is connected to the encoder even that we have seen that. Then this is our mono stable multi vibrator, inverting amplifier, and this is integrated circuit which makes the linear output. Then the signal condition circuit to match the output of integrated circuit to the input mapping factor, user input mapping factor. So the mapping factor is approximately 1 volt per 20 RPM. So if user set the input to be of 5 volts which means that he is making the motor to rotate at 5 into 20 approximately 100 RPM. So it depends upon the what is the voltage set by using potential meter RPM of a motor it will always maintain control the RPM of a motor to be as per the user requirement but since the motor is a second order system and we have so many restrictions that motor should not go more than 5 volts and everything and initially when the input voltage is 5 but the motor initial condition is zero the error that is given to the P controller will be almost 5 volts, error will be always – this particular value will be 5 and if the gain is somewhere around 2 there are chances of going the output voltage to 10 volts. So in order to not to damage so we are restricting to Zener diode circuit. So such cases and when the gain is really smaller there are chances of getting an offset error. This is called offset error.




Of course this can be avoided by using PI controller where the same set point error amplifier instead of P controller we used PI controller here. Then this is our motor driver and mono stable multi vibrator, integrated and signal conditioning circuit. What is changes is along with proportional we also have integrating term. I hope by now you understand the importance of having an integrated circuit and how exactly the PI controller eliminates the effect due to the offset voltage, offset error as well as very fast response.

Now we will see the working of this model. So if you look into this complete board, so this is – this part is completely the signal conditioning circuit as well as driver circuit for our motor. So this is our motor. If you see here this is the DC micro-geared DC motor with attached encoder. So the RPM of this DC motor is 155. So it has at the back side if you observe it has encoders connected to this. Now if you see the pin configurations of this DC motor the top one is the motor input, the bottom which is connected to the red wire M2 which indicates with an M2 is your other terminal of the motor input. So whereas the second pin is a ground. The second pin here is the ground and the C1, C2 are nothing but the outputs from the encoder. So in order to understand whether the motor is rotating in clockwise direction or anti-clockwise direction by observing the phase shifter between the C1 and C2 we can estimate the rotation of the motor and the RPM will be determined based upon how many number of pulses the encoder is giving per minute. The fifth terminal is VCC which is nothing but the power to the encoder. So basically the max input voltage given to the encoder is 5 volts. And the motor will be the maximum voltage that is required for the motor to operate is of somewhere around 6 volts.




So now the design signal conditioning circuit will be used within a range of zero to 5 volts. When we look into our slide so recalling our complete closer loop control system so the input which has to be given which is nothing but the set point to the system will be given by using this potential meter we can provide the set point required for the complete system and whereas the next block in that closer loop system if you observe which is nothing but an error director so this particular block which is implemented using TL072 this particular block act as an error amplifier. So error amplifier basically which measures the difference between the set point and the output from the encoder or sensor. So the output from the error amplifier which is nothing but an error has been given to different controllers here. So this board has four different controllers. So the first one is on/off controller. The second one is P controller. The third one is PI controller and the fourth one is PAD controller. So it depends upon which controller to be used for our application by using this particular max similar to that of max but mechanically by connecting the jumpers from the output of an error to different bug connectors here will decide what type of controller this particular closer loop system is using. And similarly at the outside if you see we also have the similar kind of connection where it depends upon which controller that the system is using from the output of this connecting it to the input of the motor driver. So why do we require a motor driver, if you recall, the motor always requires little higher current and our operational amplifier cannot provide the enough current to drive the motor. So hence by making use of the output from the operational amplifier as a triggering input to the driver circuit the current will be drawn from the power supply but the triggering input will be given from our controller. So as a result the required voltage will be given to the motor from the input of based on the input of the controller but the current will be taken from the power supply.

So as we have already seen the working as well as the theoretical understanding of driver circuit that complete circuit has been implemented using at this particular place. So if you see this is the transistor which we are using TN3019 which is MPN transistor and this is our 56 ohm resistor which is connected in series with in between the ammeter of the transistor to the input of a motor such that it will allow not – it will not allow higher current to pass through the motor. Similarly here if you see this is a TL072 again we are using TL072 in negative feedback amplification mode basically an inverting mode so that any voltage that is being applied to the input of a positive terminal will be generated across the output of motor. As a result whatever the output the controller is giving the same output will be across the motor but the current required to drive the motor will be taken from this transistor and the output of this – the output of the operational amplifier is connected to the base of transistor by using the another resistor here which is 180 ohms to 220 ohms. The only idea of having this resistor is to limit the current flow through the transistor. Then this part if you observe this part we have another TL074 which has – which is nothing but a quad operational amplifier. In that quad operational amplifier this side we are implementing mono stable multi vibrator. If you recall the importance of a mono stable multi vibrator what we have discussed in the previous module. So you understood that the importance of having a mono stable multi vibrator such that it can convert the encoder pulsing output to the analog output voltage. So in order to get an analog output voltage the mono stable multi vibrator which is being designed based upon the output of encoder is connected to the inverting amplifier so this is the place where we have implemented the inverting amplifier. Then the output of inverting amplifier has been connected to the integrator so that the integrator will help us to give a constant output voltage. So whenever there is a change in the RPM the encoder will give more number of pulses as a result the encoder will give us negative slope signal, negative slope output signal. But we have given a set point it is scale factor of 1 volt per 30 RPM. So if you want to make the motor to rotate at 30 RPM the input to be provided is of 1 volt but the output that we are getting after interfacing this signal conditioning will be somewhere around with a negative slope but we require increasing positive slope. So as we have already seen the circuit that we have used in order to convert this negative slope to positive slope with respect to the – with the same parameters of gain as well as an offset that complete idea has been implemented at this particular side.

So if you recall, if you see the circuit that we have used it is completed a differential amplifier circuit where as the RF so the RF resistor which is a feedback resistor is used to tune the gain such that in order to match the scaling factor of the input as well as the output of the encoder. This particular resistor acts as an R1 resistor to adjust the offset in order to meet the requirements of the input signal, mapping factor of the input signal.

So now so what we have done is the output error so this is the part where we are giving an input to the controller which is nothing but set point and to understand what voltage we have given which corresponds to the RPM that is required for the motor to rotate we are using a [00:18:01] to understand the voltage applied at the input of set point by using this particular approach. Then the output of an error is connected to the P controller so the error has to input one from the set point which is internally connected, other one from the sensor as well as a signal conditioning circuit by using this wire it has been connected to this. Whereas the output from the P controller, sorry, the output from the error has been connected to the input to the P controller as well as the output from the P controller has given an input to the driver circuit by using this wire.

Now we will see the working of P controller in order to maintain, in order to control the RPM of the DC motor using by looking into the signals from the [00:19:01]. So let me switch on. So now we will see by providing different output, input voltage as a set point to the system how exactly the motor is rotating. So what we have done is that the first channel it has been connected to the output of the potential meter whereas the second channel which is blue in this case, it is connected to the output of encoder as well as the signal conditioning circuit. So since the digital pulse has been converted into an analog output voltage by using the proper signal conditioning circuit there. So we can directly interface and we can see the input as well as an output responses at this point. So yellow represents my input, whereas the blue represents, sky blue represents the output.

So let me change the input. The scale is two right. Let me change the scale to 1 volt both the cases. So this particular line represents zero so what I will be doing is that I will increase the voltage to somewhere around 5 volts, sorry, right now I will go with 3 volts. So the yellow line if you see it is nothing but the input whereas the sky blue line represents the output, encoder output. So now if you see since we are using a P controller and the order of the system is second order system and since the gains that you have used is of already at higher level we can see because of not enough gains it can be noticed that there exit some offset error between the set point as well as the output voltage. How can we reduce? If you want to further reduce it we have to increase the gain of operational amplifier in the P controller but since the board is already fixed, it has been set to a maximum gain we don't have an option of changing but we can design the same P controller with very varying the gain with increased resistance value which can go upto further gain and we can notice it.

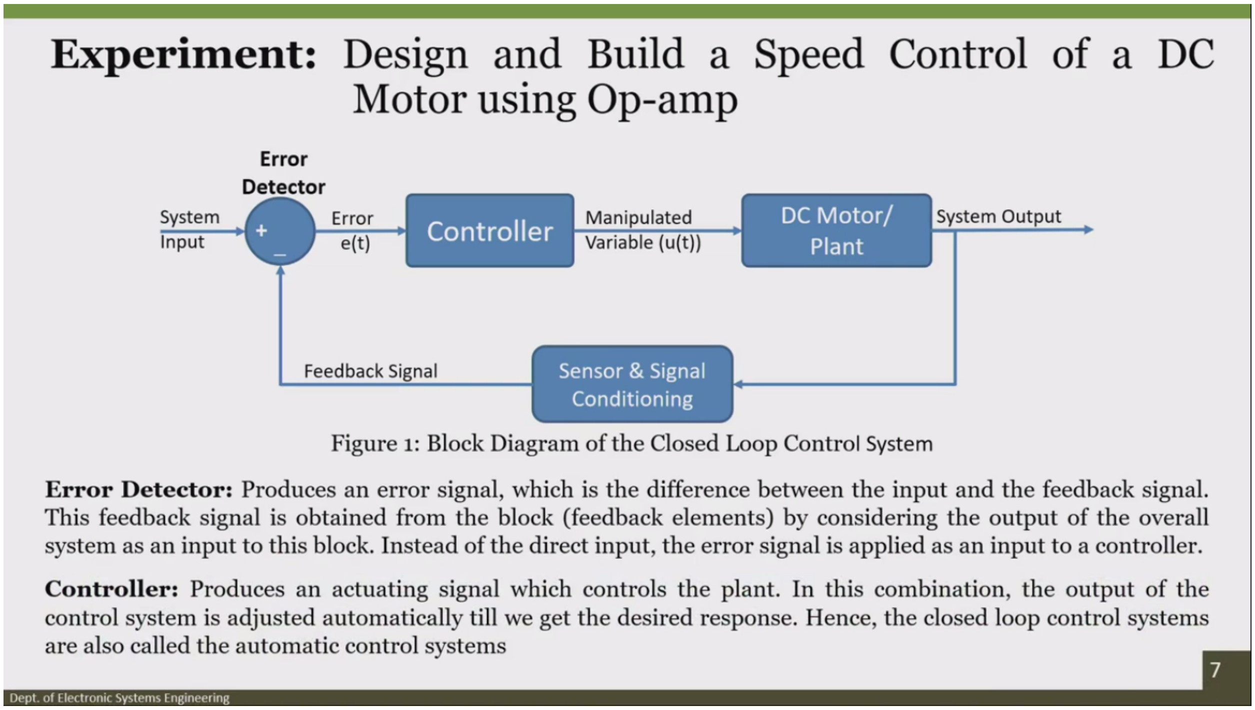


Figure 1: Block Diagram of the Closed Loop Control System

So right now it is at 3. So then I will change it to 5 so as we are working with the P controller we can see that it is nothing but a proportional controller. So when we change, when the error is immediately changing proportionally the input voltage given at the input voltage across the motor will also proportionally changing. So because of that suddenly we can see there is a change in the speed of motor but there exist an offset. So one way to avoid this offset is either by going with PI controller or PID controller but what happens, what if I go directly by using a P controller changing the gain? The problem is that when you go with the higher gain of P controller at initial stage there are chances of providing higher voltage in order to make the motor to rotate to the required RPM but because of that the current run as well as the voltage applied across the motor will be higher resulting the damage of the system.

So since to protect the motor from higher voltages the output of controller is connected with Zener diode of voltage 5.2 volts. So even though the controller provides an output voltage higher than 5 volts but the Zener diode can regulate and provide the maximum input of the DC motor to 5 volts. The reason is that this DC motor can only operate at a voltage of maximum of 6 volts above which there are – it will damage. So because of that reason we have used the Zener diode across the output of a controller which is being connected as an input to the driver circuit of a DC motor. So as a result even if you further increase the gain of P controller you cannot reach to the set point. So let me change to lower value so somewhere around 2 volts. And see whether it can be operated at 2 volts or not. Now here if you see so the yellow line suddenly decrease to 2 volts still the output of the motor is following the input which means that it is properly following, it is properly controlling but it has some offset error. So we will see how exactly this offset error can be eliminated by using PI controller.

Now what I will do is that the output of P controller I will connecting the output of error to a PI controller. Similarly, the output of the PI controller will be given as an input to the driver circuit. So I have given input to 3 volts now if you observe the encoder, the motor is rotating very slowly and it is trying to reach the set point. So here we can see the motor so which is rotating slowly and it has started increasing the RPM of the motor. So slowly, slowly increasing. And at one particular time after reaching the time it maintains the output of RPM as an input set point.

Now the time take by the motor to reach to the set point entirely depends upon the integrating factor or the proportionality as well as integral constant that we have given by using the resistor in our PI controller. So if you want to further decrease the time taken for the motor to reach to the set point what we can do is that either we can change the gain in I controller such that it takes very less time in order to reach to set point. However, because of that the initial voltage as well as current drawn by the motor will be higher again we should always have to tune the controller parameters such that the voltage applied as well as current flowing through the motor should not damage the motor. So here we can see slowly increase, increase after somewhere around 10 seconds the output is following the input but with minimum error when compared to that of the P controller.

Now it's almost saturated. So even the motor is also rotating with the same RPM as the set point that we have considered. So what is the set point we have given? It is of 3 volts. 3 volts corresponds to somewhere around 90 RPM because we have given a scaling factor as 30 RPM 1 volt per 30 RPM. So 1 volt corresponds to 30 RPM. Since it is of 3 volts it is of 90 RPM. So now the motor is rotating at a speed of 90 RPM. Let me increase to 5 volts and see whether the motor can go 50 RPM or not but since it is a PI controller again it require some time in order to reach the motor to 5 volts which is nothing but 150 RPM. So we can see that at this point I have changed my input from 3 volts to 5 volts, then the motor started rotating at higher RPM. You can notice the motor. You can hear the noise too. Started rotating at higher RPM, slowly, slowly increasing. Since it is very difficult to understand whether the motor is rotating at low RPM or higher RPM the output of the encoder has been connected to [00:28:12] so here we can observe the motor has started increasing increasing. So how do we understand by looking into the encoder pulses.

So in this case as we have seen about the maximum resistance values that we can go with the PI controller because of the use of resistance in PI controller board we cannot further raise the resistance value otherwise we can even go with little higher gains integral gains in order to decrease this time taken for the output to go the set point. But even though, even the values are smaller we can understand how exactly the integrator controller is working. The concept remains same but the tuning parameters which is required to make – to achieve the very fast response we have limitation in the tuning parameter because of the resistor but after ten seconds it can be clearly observed that if you see the output the output and input are almost the same which means that now the motor is rotating it at 150 RPM. Even when I suddenly decrease the RPM because of that time constant which is because of the integral parameter, integral time constant it takes ten seconds even to decrease the RPM from the current RPM to the set RPM. So let me decrease. I decreased to somewhere around 2 volts. So slowly slowly started decreasing it but it will not – it cannot suddenly happen because this is not a P controller. It is a PI controller. It has an intelligence. It has to calculate area under the curve which is nothing but the error in this case in order to provide the proper manipulated variable to the plant. But here if you see started decreasing, started decreasing, started decreasing but after sometime because of due to the gains that we have set there after 10 seconds in this case it reached to the set point again.

So after almost ten seconds here we can see that still the output and the input are having the same magnitude which means that the error is almost equal to zero. But this fluctuations when you see the output you can see some fluctuations this is because of the integrator output. If you further increase the resistance of the capacitor that we used in the integrator still we can decrease those fluctuations. But however, it is clearly understood that the motor right now it is controlling based upon the set point given by using a potential meter in this case.

With this we will close this module. Thank you.