Op-Amp Practical Applications: Design, Simulation and Implementation

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Lecture – 29
Experiment on Temeperature Controlled Circuit using Op-Amp as ON-OFF Controller and Proportional Controller

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Experiment: To Design and Build a Temperature Controlled Circuit using op-amp as ON-OFF Controller and Proportional Controller

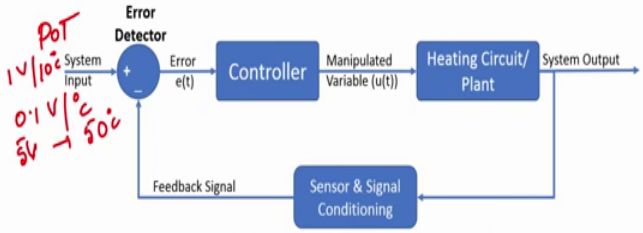

Figure 1: Block Diagram of the Closed Loop Control System

Error Detector: Produces an error signal, which is the difference between the input and the feedback signal. This feedback signal is obtained from the block (feedback elements) by considering the output of the overall system as an input to this block. Instead of the direct input, the error signal is applied as an input to a controller.

Controller: Produces an actuating signal which controls the plant. In this combination, the output of the control system is adjusted automatically till we get the desired response. Hence, the closed loop control systems are also called the automatic control systems

Now, we will see the experiment right. So, if you recall so, we have applied a system input at this point. So, if you recall the explanation in the board we are using a pot as a system input, and the sensorvity that we have selected that is nothing but our the factor at which the input volt the relation between the input voltage. And, the temperature is somewhere around 1 volt per 10 degree centigrade; so, which means that 0.1 volt per degree centigrade.

So, that means, if I apply 5 volts as an input to the system so, that is corresponds to 50 degree centigrade, ok. So, what we do? What we will do now is that, we will apply 5 volts using potentiometer at this point.

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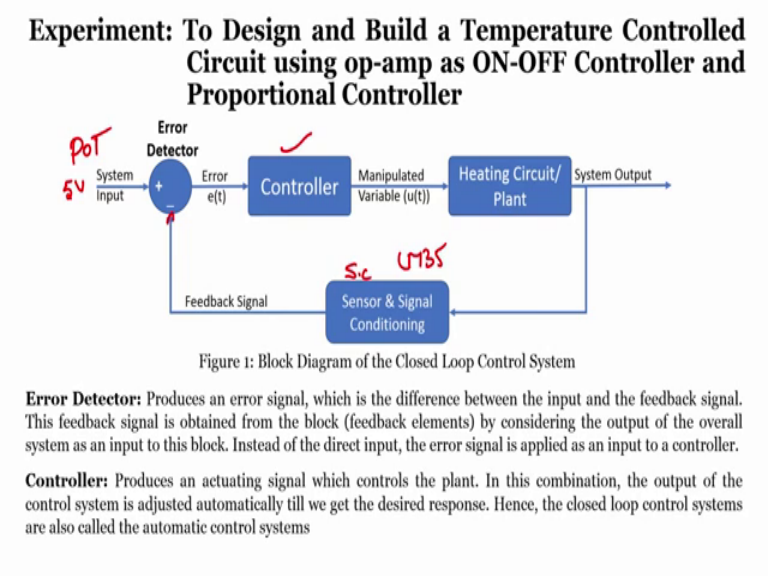

And as you have already seen we have constructed a signal conditioning circuit for the sensor, and the sensor was stick on the stick onto the plant. The plant in this case is a transistor, on top of a transistor we stick that a temperature sensor. The temperature sensor that we are using is LM 35. Isn't it?

So, since this the factor was different, the input factor on the output factor of sensor output is different, we are using a signal conditioning circuit, and that signal conditioning circuit we have connected externally. So, the output of this is again connected to the board. So, at this particular point it will be connected. So, depends upon what type of a controller that we are using whether P, PI or on off controller, the working of the complete symbol change. So, if you look into the circuit board here. So, this is the part when we look into the board.

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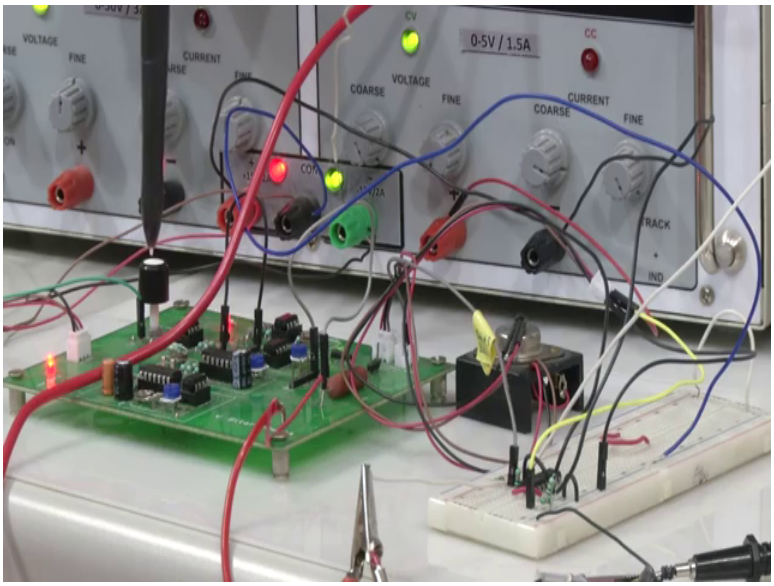

So, this is a part so, this part by varying the knob we can see what input voltage that we are applying; which means that the corresponding set temperature value, the corresponding set temperature. And this is our transistor on top of it there is a LM 35 sensor.

So, this particular breadboard is a signal conditioning circuit for the sensor. And the output is connected to the sensor part, sensor point. So, right now when you observe on the multimeter when we see the complete multimeter, the right now it is showing as the input voltage. This multimeter is connected to the output of the part; which means at the input we have connected to 2.2 volts.

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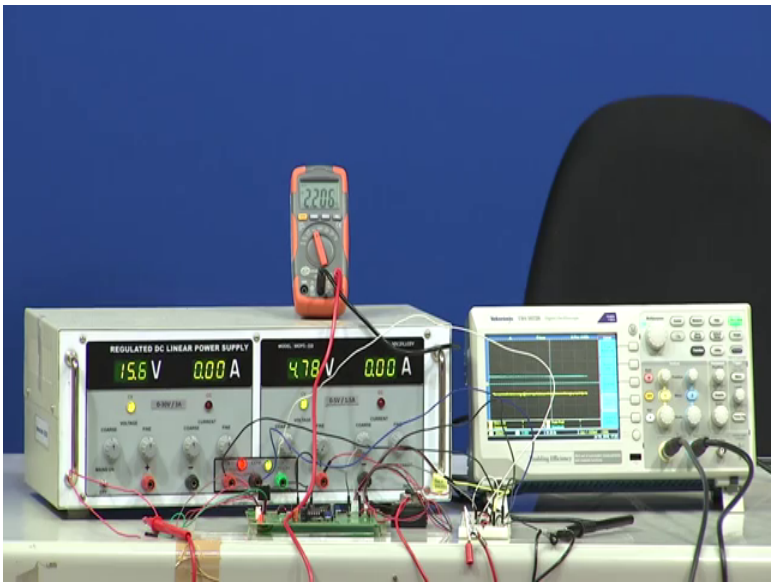

Meaning, I am asking that temperature to be maintain on the plan to be of 22 degree centigrade. Now is it possible to maintain 22 degree centigrade, right now if I see we do not have any other air controlling system or cooling system in our place. So, that is a reason beyond our room temperature it cannot go below.

If we have external AC or some other cooling system which can accordingly change the temperature value, even the output can maintain, the output can maintain as 22 degree centigrade. So, since we can only heat in this case, what I am doing is, I am putting the temperature to be 5 volts; so, which means that I am expecting the temperature on top of a transistor to be of 5 volts.

So, what I did it? I am changing to 5 volts, right. So, this is right now at 5 volts, now this is set point. So, what is the actual temperature on the sensor? If you want to see the actual temperature on the sensor when we look into the CRO, here we can see. So, the right now temperature is 0.51 1 see here. It is slowly increasing right, and this particular line. This line is 5 volts, because the one particular margin the one block is corresponds to the 5 volts that we have set here. The channel if I see, the blue one is 5 volts. And the yellow color is nothing but output from the controller.

So, the board is right now connected to on off controller, right. So, that means, that the output of the error is connected to the controller input, and the output of the controller is again connected to this controller means since on off controller is connected to the

heating circuit. So, if you recall, what we have discussed in our on off controller and the simulation, we have seen that when the input voltage or when our temperature value, if you recall what we have seen, right?

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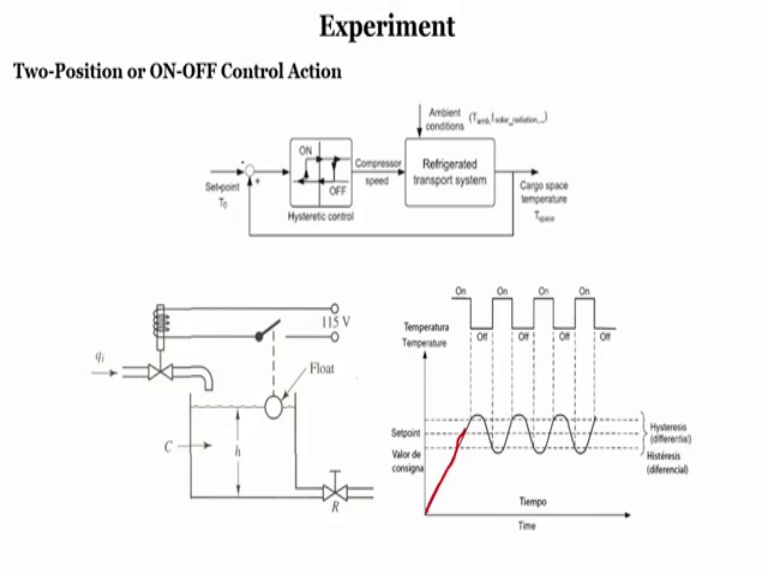

So, if the input signal is greater than one particular threshold the state will change, and it will keep on fluctuate right. That we have already observed even in our simulation too right, by using say by using multi sim. Now even if you observe that the set point here, the set point here that we set was as we have calculated in our theory session right, by using those resistors, by using those spots, we have considered few set points.

And now since the input temperature is of 50 degree centigrade; that means, the 5 volts we have applied as an input system; whenever the temperature is greater than 50 degree, and that is higher threshold value, it is making the on of controller to go to the off state, we can see clearly right. And when the temperature is below the second set point somewhere it is very close to 50 degree centigrade, in this case 5 volts; if I want to talking with respect to the voltage is below 4-point like below 5 volt somewhere around the 4.9 some value, whatever the resistor that we are choose based upon that.

Again the on off controller is switching on; that means, it is allowing the transistor to start heating it. So, that means, it is clearly seeing that the on off controller is keep on switching on and off on and off of my plant. So, based upon on and off, how much time it is on, and how much time it is off. And depends upon the convention external

parameters the switching on and off everything will depends right. So, as a result it is trying to maintain the temperature on the plant to be around 50 degrees, it is not very close to 50 degrees, around 50 degrees; that around entirely depends upon, what is a gains? What is thresholds that we have set on off controller and external parameters too right.

So, right now it is at 50, why do not we change it to some other value, right? So, when we look into multimeter right now it is at 5 volts. What I will do is that, I will change to somewhere around 60 degree, meaning 6 volts. Now see whether it will be switching on or of how exactly it is. So, what I will do is that, I will slowly increase the pot. So, right now it is an off condition, and I am asking to be at 60 so, that is why it is switching on, right. I have set it to 60 so, till it goes to 60, it is updating the CRO is updating.

So, we can see here so, it has reached to somewhere around 60, that is why a the on of control it is a off, and again when the value is slightly higher than. So, what I can do is that, to make it visible I will increase the time division to 2 volts. So, previously the sorry not time division, I mean the amplitude division, right now a previously it was it somewhere around 5 volts one block right now one block is 2 volts; here we can observe here 2 volts. So, here we can clearly see, and that the since the value 6. So, 2, 4, 6 the third line, here we can see this particular third line is 6 volts right.

So, when we see the output, output is slowly increasing and decreasing. So, when our it is increased more than 60; that means, this particular dotted line, this particular dotted line, we can see switching off the on off controller, when it is below that particular dotted line it is again starting it, you can clearly see that. So, that means, one thing is clear that the one of controller is not maintaining exactly at the 50 degrees or the exactly at the set point. That is what even we have seen in theoretical. So, as long as if your plant can with samples on in off on off and on, there will not be of any problem and it is very easy to implement.

Now, we can also see so, we have observed with the changing higher value. So, suppose say right now the temperature is it is somewhere around 60 degree centigrade. So, if I want to understand if I put you know I need a thermometer; say right now LM 35 sensor is also temperature can be sensor, or we can even experience the heat by touching the transistor to. So, right now it is a 60, what if I suddenly change the input voltage to 10

degree. So, since it is a 60; whereas, the set point what I am I am decreasing it to 10 degree, then we can see on off controller should be off for certain duration; that duration entirely depends upon the convection to till it reaches to 10 degree, right.

Since we do not have an external cooling system available here, we cannot see the on off controller in on condition at all. So, what I will do is that, I will make it as 10 degree when I look into the multimeter. So, when we look into the multimeter, when I look into the multiple meter, I am changing I am decreasing the voltage value. So, decreasing value to somewhere around 1 volt. So, 1 volt meaning I am expecting the temperature on top of the transistor to be 10 degree, right 1 volt meaning 10 degree.

So, if I observe, now due to external convection the trans the temperature on the transistor it starts slowly decreasing, it started slowly decreasing, slowly decreasing. And since we do not powering it on, the reason is that the error value the threshold value is higher than the temperature value, because the set point value is very smaller in this case and the temperature on top of with transistor is very higher; that is a reason the on off controller is still in it switch off condition, we can observe that. On off condition simply in switch of condition.

So, due to external convection so, in order to heat it very fast, in order to cool it very fast what we can also do is it, we can blow some air. So, we can see some sudden drop in temperature value, because we are externally convicting, we are externally blowing somewhere so that heat will be convicted. Slowly cools down, slowly cools the and even we can touch on top of the transistor so that it conduct. So, no matter whatever may be the possibilities it has to maintain. So, let me change it to somewhere around 30 degree; so, 30 degrees more than more than room temperature value.

So, whenever the temperature value is greater than 30 degree it will switch off, and if it is lower than the 30 degree, again it will switch on, right somewhere around 31 degree. We can see so, right now the temperature value is somewhere around 244.5; that means 45 degree. Still it is cooling down so, I am externally blowing air. So, it started cooling so, if I want to switch it on the temperature value should be below 31 degree centigrade. So, that means that so, somewhere around this point, somewhere in between these 2 boxes. If this value is between these 2 boxes that is 3. So, why it is taking time? Because it has to naturally cool it.

So, since it is taking too much of time what I will do is that, I will keep it as 35; so, 3.5 value. So, right now it is at somewhere around the 30 38, since the thermal gradient is very smaller, it takes too much of time to cool it down to. Now, we can see the temperature value has become lower than the 35 set point then the controller started, switching on. So, since it is switched on for particular duration, that it has powered the system, and how much amount of energy is given to the system inter depends upon what is the gain that we have set. So, since it was powered for small duration, that was enough to heat it to such a higher value. So, that is why it was it will be off for a particular duration. It will be off for longer duration, because the thermal gradient at this stage is very, very smaller.

So, depends upon what is the set point that we have using, depends upon what is the gain that we have set on off controller, the complete pulse like complete frequency of the pulse entirely depends upon those parameters in this case. So, basically it depends upon the threshold set that we set for on off controllers. So, right now the temperature is somewhere around 36, 37, 38. I will simply blow some air right. So, because of that the temperature has become lower, again on off controller started the yellow color line we can see; that is an output from the controller right.

So, this a way we can easily understand the working of on off controller, how the controller will, you know, goes from one state to another state depends upon the thresholds that we have set, and depends upon the set point depends upon the out temperature on top of the transistor. Now we will see the demonstration of P-controller. So, as if you recall, if we recall our complete circuit board, we made a jumper connections right we made a jumper connections.

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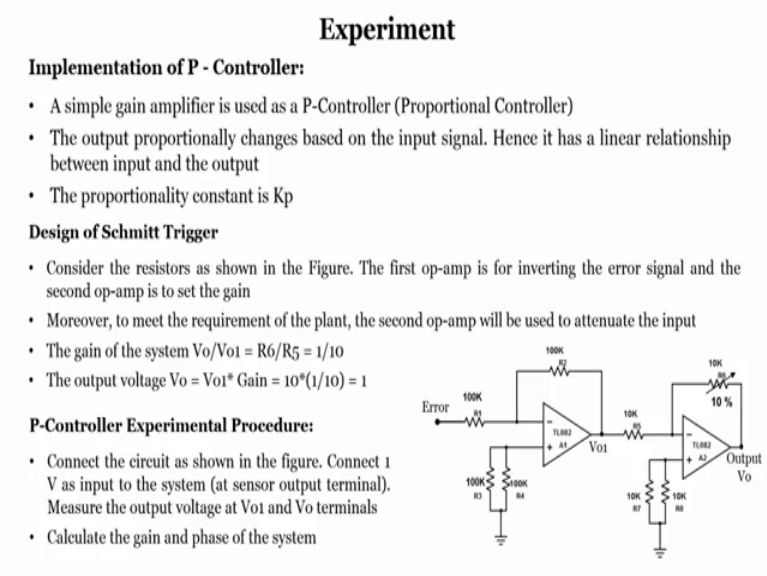

And if you change the input jumper from on off controller when I look into the circuit board, if a change is jumper connections from on off controller to P-controller, right. So, simply changing simply changing the jumper connections from on off controller to P-controller, because we have created one for on off other one is P other one is PI as well as PID controllers 2.

So now right now the controller that we are using is P-controller. So, when I look into the multimeter, the set point that we have using is 3.6 something, right. So, what I will do is that so, the error value is very smaller, I will change the set point to somewhere around 5 degree so, easy to understand. So, for sorry 50 degree which means that 5 volts.

So, the right now the temperature is somewhere around 36 something. And the set point is 5 volts 50 degree. So, since there is an error so, if you see the controller output that is yellow color. The error was too much because of the error was too much it is pumping higher amount of energy. Because of that higher amount of energy, the temperature started increasing, because of increasing temperature there are also linearly decreasing linearly decreasing.

So, since the error value is linearly decreasing, the energy that is pumping into the system is also smaller, and because of your natural convention, say it is also getting it cold. So, since it is 5 degree. So, the value is 2 one amplitude is 2 4 and this is 5. So, in

order to understand what I will use it I will create a cursor. I will create a cursor and keep it at 5 degree 5 volts. So, cursor to I will select cursor 2 and I will keep it at 5 volts, right.

So, this line this straight line. So, other than that I will what I will do is that rather than creating cursor to I will go with the cursor one which will be yellow in color, sorry, that is also blue. Or I will take source as channel one, and I will change this 2 5 volts cursor one somewhere around here, right. So, that is the 5 volts or I will switch off the cursor that is not so, not a problem ok.

So, this particular complete line this is a cursor value. So, since both are in same color it is difficult to identify. So, that is right now it is at set point somewhere around 5 volts. If you see that, right the temperature is completely maintaining. Now if I blow some air externally using some external system or something. So, what happened the temperature will cool down, as a result the error value will also be little higher. So, because the error is higher, the proportionally the input voltage that is being applied to the plan will also be higher, as a result the current flowing through the plan will be higher starts it is heating, we can also observe that. So, we can see the temperature because of blowing air the temperature is decreased the error values started increasing it.

Since the error value started increasing as a result write the voltage applying to the system is higher. But finally, if you observe again it starts maintaining, maintaining to 5 volts. So, the difference between the previous circuit on off controller, and the pre controller is that the P-controller can maintain the temperature. But on off controller it cannot maintain, it will try to you know settle within the range that we have specified, written by switching on and off. So, if that particular range is ok, we can either go with a very a simple controller on off controller. Or if you have to maintain completely we have to go with some other controls like PRPI or PRI controllers, right.

Also the right stem of the complete system, the right stem of the system depends upon what is the P gain in that we are using. Smaller the gain higher the a smaller the P gain smaller higher the response simmer, I can say it takes longer duration to reach to the set point. If higher the gain, it takes a lesser time to reach to the set point. If I want to understand that what I will do is that, I have to increase a gain it has to cool down then it has to I have to start the experiment after cooling down to room temperature, and then we have to see what is a response time right time of the system.

So, based upon the different gains we can also identify the corresponding change in the response based upon the change in the P-controller gain, right. So, it is since it is it takes some time, I hope this is for us. So now, what I will do is that I will change the temperature to somewhere around 60 degree. So, that means, 6 volt supply right. We can see 6 volts in the sense, it has to reach to this particular point, this line right.

So, the temperature started slowly increasing, you can see. Now it has reached to almost close to 60, somewhere around 59. We can see why this particular controller output has increased and decreased, because since there was some error between the set point and the actual output voltage, because suddenly I have change the input from 50 degrees to set point value from 50 to 60. As a result, the error change was higher somewhere around 10 degree. That because of that error, since we have applied some gain, it will be multiplied with a gain factor of that value, right gain factor into the error value that corresponding controller output is nothing but this value. This is this particular voltage will be given as an input to the plant.

So, as a result, when the error is too much high very high input was applied to the system causing the temperature to reach to the set point as a result the error value will be slowed or will be smaller. So, here we can see the error slowly decrease slowly decreased. So, it happens when the input voltage is reaching to our set point right. So, no matter what so, one thing it is clear that when we observe our on off controller as well as a P-controller, P-controller can maintain, but on off controller always switches from in order to maintain the temperature it will always switch on and off, ok.

So now we will see the working of a P-controller. It is each to understand about what type of controller that we are what type of controller that we are using here. So, when it is an on off controller, you can observe the output of on off controller to be a square wave; that is the reason it will always either in positive saturation or negative saturation. But whereas, in case of on off controller P-controller, we can see depends upon the error value, the output of the controller is proportionate to that of your error. So, if the error is higher the output is higher. If the error is smaller, the output of the proportional controller is smaller. That is why it is called proportionate, proportional controller, entirely depends upon that error. Now, we will see the working of PI controller.

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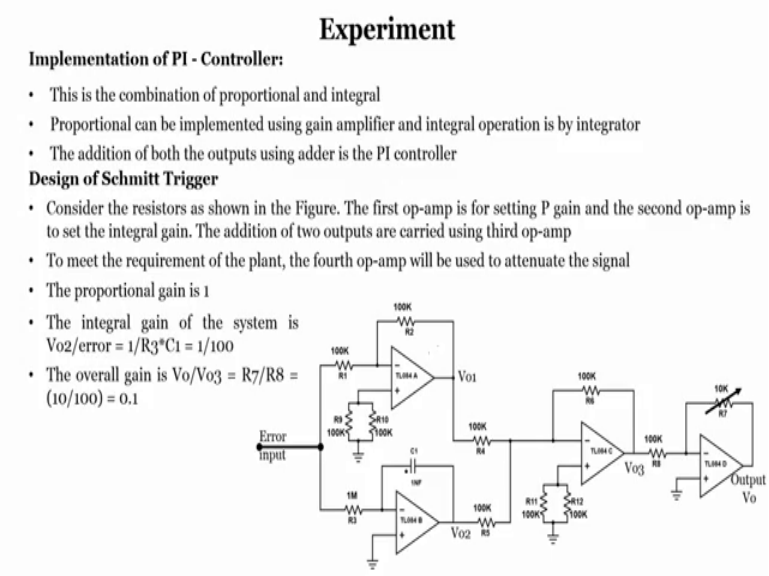

So, this is what the circuit that we have used even in the board. So, what we do is that, so, since we have completely designed the board, design the board it is only simply just replacing the wire from P-controller to PI controller. So, what I will do is that I will change the input from PI 2; that means, the error value is connected to PI. So, similarly the output is also connecting it to the PI controller. So, since right now it is at completely at 50 60 degree centigrade. So, it is very hard to understand how exactly the PI control works. What will is that, we will make it we will let it cool it down. So, that is why I am putting the set point to somewhere around 100 milli, when I look into the multi meter, you are setting it to somewhere around 100 milli. Let it cool down then will start our experiment again.

Now, it has cooled down too, since we have kept the set point to somewhere around very low temperature value somewhere around 111.9 milli volt. So, that means, approximately 0 degree centigrade, and since room temperature cannot go beyond certain temperature value, right because we do not have external cooling system, right. So, the temperature on top of the transistor is also equal to the room temperature at present.

Now, in order to understand the demonstration how exactly the PI controller works, what we do is that, we will change the set point to somewhere around same 5 volts which is nothing but 50 degree. And, we can observe how exactly the PI controller output is

changing, as a controller output is changing as well as the change in the output temperature took.

So, just let me refresh the screen, then I am putting the temperature the set point to be 5 degree; when I look into the multimeter we can understand, what temperature value that we are setting it now. So, 4.22 and this is 5 volts right. Now we can see depends upon the what is a gain that we have used, right and depends upon what is the current a temperature value, the value started increasing, error value right, you can clearly see that, ok.

So, previously it was in negative, this was completely negative. And it started increasing, increasing, increasing. So, and the a what is are you know the rise time, how fast it has to reach to the set point, entirely depends upon what is the gain that we have set. So, if I change the P gain as well as I gain in a PI controller, even the time taken to reach to the set point will be it will be very fast, will be smaller value itself. If the gain is smaller, as a result since a gain will be smaller, it takes a little longer duration in order to reach to the set point.

Now, this particular line is 5 volts right 2 4 and this is 5 volts right now. So, it is almost reach to the set point right, we can see it started it reach it to the set point and we can also observe what is a controller value. Now, the difference between a P-controller and PI controller raise, here we are adding some intelligence by using integrator. So, integrator when I simply change the temperature value from 50 degree to 40 degree, it will not suddenly change, it is not a proportionate action.

So, it depends upon cumulative of errors, cumulation of my previous errors right. If even though if the temperature is you know some a for example, if the error is maintaining it always 10 degree, the error will be keep on you know in case of for example, like say, the set point is somewhere around 40 degree. As well as the output is somewhere around 30 degree.

So, if you observe there is an error of 10 degree, if it is a proportional controller, as long as there is a 10-degree error, proportionality the output will always be at the same value, no matter what. But in case of an integrator it is not like that.

Now, at this particular time instant, if the error is 10 degree, it will provide some particular output voltage. Now even after some x 1-time duration, are t 1-time duration, if the error remains the same, the input voltage or the output of the controller will not be the same value it will be higher than the previous value. That depends upon how much duration that was that error was maintaining at the same value right. And depends upon what is a gain that we have said. That is why it is like addition of your previous error, it is does not depend not only on your present error value, it depends upon your previous errors too. That is why integration is nothing but area and the curve under the curve.

So, at this particular time duration how much area is under the curve is nothing but your integrator. So, that is the reason, even though if the error value is a constant, the output will not the proportional controller output will never be a constant will we keep on increasing or decreasing depends upon whether you are in a posture error side or a negative error side.

Now, we can clearly see that, no matter what it depends upon the I gains and P gains that we have set in a P-controller, but it has reached to the set point. Now even the same thing what we have observed with the P-controller and PI control almost the same. It is maintaining constant temperature. But when I compared with the on off controller, on off control is not like that. On off control is completely like on off, on off switching; that means, the controller output will be always in a pulsating mode, right.

Whereas in case of P-controller as well as PI controller depends upon your set point, right depends upon the actual temperature value; it automatically changes their controller output. Once it reaches set point some minimum amount; that means, the system is completely on, but the input voltage or input power apply to the system is very smaller amount right. But the difference between the P-controller and PI controller is that, the P-controller the major problem the P-controller is that if we are going with a higher order systems apart from 0 order system, if we are going with a first order or a second order system basically with second order, even though if we reach to that one particular value of control gain of P gain, right.

Even if we keep on increasing the gain of P-controller, there will always have an offset. Offset is nothing but the error between your set point to the actual output. Even if you keep on increase P gain, that offset will remains constant right. So, in order to eliminate

the effect is due to the offset, this generally seen in higher order system somewhere around first order and second order system basically and more than first order system.

If your system is if you are observing such an offset, even though if you keep on increasing a P gain, if that offset was really negligible change in the offset error, one way to eliminate at offset is by using I controller. So, the combination of P and I what it does is that, it not only eliminates is offset created by the P-controller or offset that was not eliminated by using a P-controller, the time taken to reach to the set point will be really faster; within less duration it can go to set point. But the problem is that, in order to reach to within a less duration, initial the pump in current in this case, the pump in current or the pump in power will be really higher.

If your system unable to withstand such a higher power, there are chances of damaging a system 2; so, one way to avoid is you have to observe whether what are the gain that we have set is within the operating range of your plant. If it is not an operating range, that subjects are that sudden increase of current completely damages system. So, but if you require such a faster output, faster setting time, but it is providing you over shoot, one way to eliminate that overshoot is by using addition of AD control. So, the combination of P I and D not only eliminates an offset, it also decreases the overshoot. And it will not have any influence on your (Refer Time: 36:10) metal right.

So, but what happens you know as long as you are adding one more term into the system the complexity of the system will be little higher, right. So, in this particular case 3, we are only seeing about on off P and PI controller, I hope this is clear to you went to go with the P, went to go with on off, went to go with PI and went to go with PID. So now, now right now it is a continuously maintaining at 50 degree centigrade, now let me change the temperature value to 50 right. Sorry, 50 I will change the temperature value to 60 degree; that means, I have to a play input voltage of 6 volts, so applied input voltage of 6 volts. We can see depends upon the gain that we have set, even though the voltage was the difference was only 10 degree, see the sudden change in the controller gain, right.

Now, 60 in the sense, this particular dotted line right; now we will see how long it takes to reach the dot dot dot the dotted line entirely depends upon the gains kp and ki gains in this case, right. It is almost reach within less duration itself, right. Reached that means, it

is already settled, now what I will do is that, I will keep it that 30 degree, and let me see whether it is you know cooling on one. We do not have any external cooling by the way, naturally it has to cool down. So, if I clearly observe here, since the error is very, very higher and the error value is negative error right, if you observe that the output has gone to negative.

So, when we recall our the plant working, when you apply negative voltage, there will not be any you know transis of current into the transistor, as a result it will not heat. Because that means, the transistor will be completely in off state basically, right. So, that is why even though the error is higher, the negative the output of the controller is going to negative negative value, but it will not have any influence on the plant because, it has a naturally cool down. So, till it is it reaches to 30 degree right, it has naturally cool down, once it reaches to 30 degree again it starts maintaining the temperature of 30.

So, to understand what I do it, rather I am going 30 I will go with the 40. So, it takes a lesser duration compared to that, yeah 4 volts. So, right now it is at 50 degree, I will blow some air. So, 40 in the sense, it has to reach to this particular dotted line, the below dotted line. So, right now it is somewhere around 42. So, it is almost close to 40 degree. Now, if I see if it would have been a proportional action, it would not have been in a negative direction. It will be in either 0 or in positive; small positive, because it is already close to 40 degrees centigrade. But in this case this since it is a PI, it not only depends upon the present error, it also depends upon the previous error right.

So, since the error accumulation was too higher because of negative, it was not you know it is not going to 0 state 0 voltage at all. So, it takes some duration to go to the proportional controller output to go to the 0 volts, and then slow sorry it is for proportional integrator, slowly to 0 volts, then slightly increase in input voltage, right. So, that entirely depends upon the previous errors too, not only the present error previous error. So, it is naturally converting. Now, it is in actually speaking it is an off condition. It is also it 40 d slightly decreased, the temperature value is slightly decreased.

But even then the system was not it turned on, because it is below 0 degrees. This is 0 volts, below 0 volts, the value is still right. If it is a proportional action, right it is it should be somewhere around close to higher than the 0 volts. So, the output temperature value is somewhere around 39 degree. So, we can clearly see it is slowly decreasing so,

its started now. So, if I see the controller output, it was somewhere close to 0 volt increasing. Now the temperature is 38.5. So, started the temperature controller if you see the PI controller, it has slightly increased, the output voltage of the controller.

So now, that means, now the temperature you know it started increasing. So, if you see, since it is not a great amount to start heating it. So, even though it is maintaining a 38.5, after some duration you can see the values keep on increasing. So, if you observe from here, there was no from here if you see there was no change, but even then the values started increasing, increasing, increasing. And, it will linearly increase as long as if your error was not changing; that is the beauty of our PI controller in this case. That is because of our accumulation of your previous error right.

Now, if you see the current temperature now it has gone to 40 degree. Now, it will be maintained at that particular value. So, I hope this is clear. So, this away we can understand the difference between on off controller, P-controller and PI controller. And how to, went to go with a P-controller, when to go with on off controller and when to go with the PI controller. So, how exactly the controllers works depends upon what type of control action that you are using, how exactly it works, that completely you know demonstration we have seen now.

Thank you.