Circuits for Analog System Design

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Lecture No. # 10
Proportional Temperature Controller Design

In today's lecture we will discuss about how to design a proportional controller because in the previous lecture we discussed about how to design a on off temperature controller and we had used LM 336; that is I C sensor we had used for temperature sensing. Today we use thermocouple as a temperature sensor and then design a proportional controller instead of on off temperature controller.

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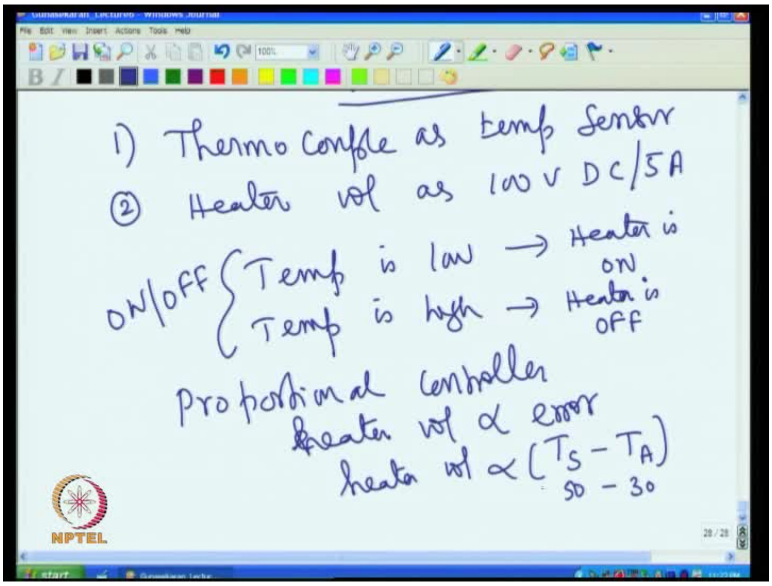

So, today's topic will be proportional temperature controller (No Audio From: 00:50 to 01:02). So, we use thermocouple as a temperature sensor (No Audio From: 01:07 to 01:16). Now, in this case we take second point is the heater voltage because heater voltage as 100 volt is required; we will see for various heater voltage how to design. But first we take heater requires assume 100 volt d c and then it needs assumes say 5 ampere current. And, then thermocouple, we use as a temperature sensor will make a proportional temperature controller.

Because if, now if you see on off temperature controller, there the controller was working basically; temperature is low means if temperature is low, low means, lower than set temperature then heater is on. If temperature is higher, that is higher than the set temperature; temperature is high, then heater is off. This what we had seen that is with high and low with respect to set temperature. For example, if I set 50 degree if the temperature lower than 50 then heater is on, if the temperature is higher than 50 then heater is off. We also had so on there is a small region, where in you will have a hysteresis that is the on on at one temperature, one off at two different temperature that we had seen in the previous class.

But if you have this kind of on off controller, essentially you know this is on off controller. You cannot get very good temperatures everytime because once once it is on at set if I am setting at 50 degree, once heater is on at 50 degree; then immediately it cannot go, so we had to give a some hysteresis. That is you know if you switch on at 50 degree and then it will switch off only at 51 degree. Similarly, we will again it will come out only at 49 degree and this is the must to avoid too much of on off action; particularly if we are using a relay. Even if you are not using a relay, this will be going on off on off and even if there is no relay also, you will have this temperature is (( )) this automatically coming from the system. So, if you want high accuracy in temperature control, we have to go for proportional controller.

In proportional controller, what we do is in proportional proportional controller we will make such a way the error voltage, that heater voltage; actually, heater voltage is proportional to the error. In the sense, whatever the heater voltage are applying that actually, the error is here nothing but difference between set value, that is temperature is set temperature something and actual temperature something. So, heater voltage is always proportional to this. That is if I set say 50 degree and actual temperature is 40 degree, then difference is 10 degree; then corresponding to that heater voltage will be there. Suppose, difference is more; suppose if this is 50 and if this is 30 degree then difference is more, now heater voltage will be more. If the error is more heater voltage will be more, if the error is 0 heater voltage obviously will be 0.

So, the heater voltage is no more on or off; it is actually the heater voltage will be somewhere between on and off. That is if you have under volt, under voltage as the heater voltage, depending upon the error you will have the heater voltage; it can be anywhere from 0 to 100 volt. So, the heater voltage is basically proportional to the difference between the set temperature and the actual temperature. So, that is the basis of proportional controller.

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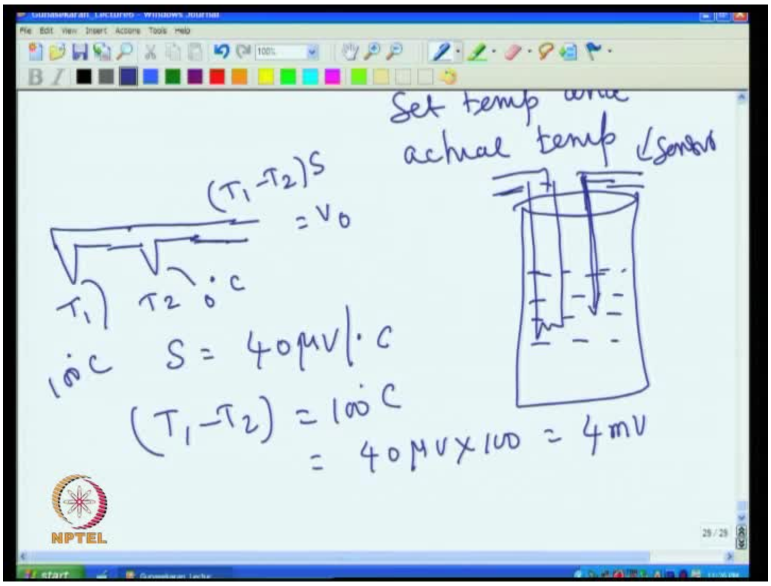

So, we had generate a heater voltage; that is proportional to difference between difference between set temperature and set temperature and actual temperature. So, obviously if we have to design, then I should have a actual temperature of the system should be known and then what is the set temperature that should be known. And, then you have to find the difference. So, let us take the same example in this case assume that I have one oven here; that I want to maintain this temperature. Then, what I do is I will assume that I have a here a heater is there and also put the sensor here. The sensor in this case is thermocouple; I will show you how to make this thermocouple; so you have the two ends are coming here. So, this is acting as a sensor and then this is the heater voltage heater.

Now, what I do is I take the sensor which is the thermocouple. So, thermocouple basically gives me, you know if I take two junction thermocouple; then temperature difference between this junction say T 1 and T 2. So, you will get a voltage T1 minus T

2, is the temperature difference between the these two junctions into the sensitivity is the output voltage. So, most of the thermocouples if we see sensitivity is 40 microvolt per degree c; most of them will be in this range. Some of them we have 10 micro volt also there, some of them we have 59 millivolt above, 59 micro volt is there. But you know we take average value which is around 40 micro volt for; you will see most of the thermocouples give 40 micro volt. For example, chromel alumel thermocouple gives you 40 micro volt because a thermocouple basically means two different metals gives you, forms a junction and the difference between the two junction gives you the output voltage.

So, for example, if this is at 100 degree c, if I keep this at 0 degree c then difference between this actually comes, 100 degree c. Then, that gives me 40 micro volt into 100 that is equal to 4 millivolt it will come; these two ends. So, the the temperature difference is high you will get more voltage; that is how the thermocouple actually senses the temperature. And, in fact this is the only device that actually today gives you electrical output for a temperature; in fact this is a good sensor not only to measure temperature it can also be used to convert heat energy into electricity, electrical energy. Because and in fact this is the only device that you have for this only the basic lies based on this one only even other device is also generate electricity based on convert electricity; produced electricity from thermal energy. It is the very useful device; this has been extensible used in army to generate electricity not only to measure temperature. But here we concentrate more on how to use this to measure temperature and this case we use this to measure temperature and then also to control the temperature.

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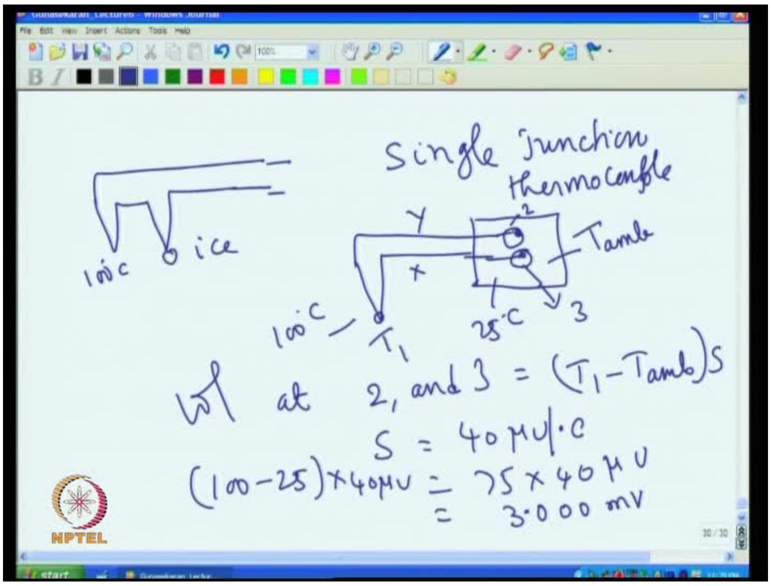

So, what only one disadvantage in this thermocouple is we have to gap; for example if I want to measure the temperature, then I have to keep one junction at fixed temperature say ice and another temperature where I want to measure is 100 degree c. Then, I will get difference between these two junctions producing a electrical output. But then to keep this junction at a fixed temperature is a problem. So, in industry normally they do not prefer this two junction thermocouple; they use only one single junction. So, you have a single junction; so, basically you try to use single junction thermocouple. Other way around, actually it is only (( )) single junction thermocouple. The second junction is formed indirectly; like for example, if I terminate this single junction in copper then this is one metal x and the another metal y wire. So, this x and this copper forming one junction here, y and copper forming a second junction and x and y forming a third junction.

Basically, we have 1 junction, 2 junction, 3 junctions are there; but then the end result of this is like this. If these two junctions, 2 and 3 are at the same temperature assume that it is a room temperature, so I have to put a big block in the room and terminated these two wires in this block with of course small insulation here. So, insulation also essentially at the same temperature of this big block. Then, the temperature produced is T 1 and if this is say ambient T ambient, then the voltage available between 2 and 3 voltage at 2 and 3 is actually T 1 minus T ambient into sensitivity. Where in this case s, we have taken as 40 micro volt per degree c.

So, for example, if invariably you know the ambient say assume is 25 degree c and if this is say 100 degree c; then you will get 100 minus 25. It produce the voltage only for 75 degree difference that is into 40 micro voltage sensitivity. So, that is 75 into 40 micro volt; that is micro volt. So, that comes you will get 3 millivolt 3 millivolt as a output voltage; so it it gives you corresponding to 75 degree only. So, of course, there is no issue because you are now eliminated to one junction and now we yet have only one junction and then you are terminated in the room temperature; so, ice is no more required. But the problem is that if the ambient temperature changes, suppose if the room temperature changes, then you will have problem because we are terminated at room temperature.

Suppose, the room temperature goes to 50 degree, then the same 100 degree at T 1 will give you, for example this temperature is continuously 100 but this are changed from 25 to 50 degree; because room temperature are changed. Then, this will give you only 50 into 40 micro volt that will be only 2 millivolt. The same 100 degree, see now gives only 2 millivolt; earlier when the room temperature was 25 degree c, the same 100 degree had given you 3 millivolt. So, if you have to be successful in using this, then we have to compensate this ambient temperature change; because when ambient ambient temperature changes, the output generated by the thermocouple also changes actually. So, one or two provide ambient ambeint temperature compensation, if we are using a single junction thermocouple.

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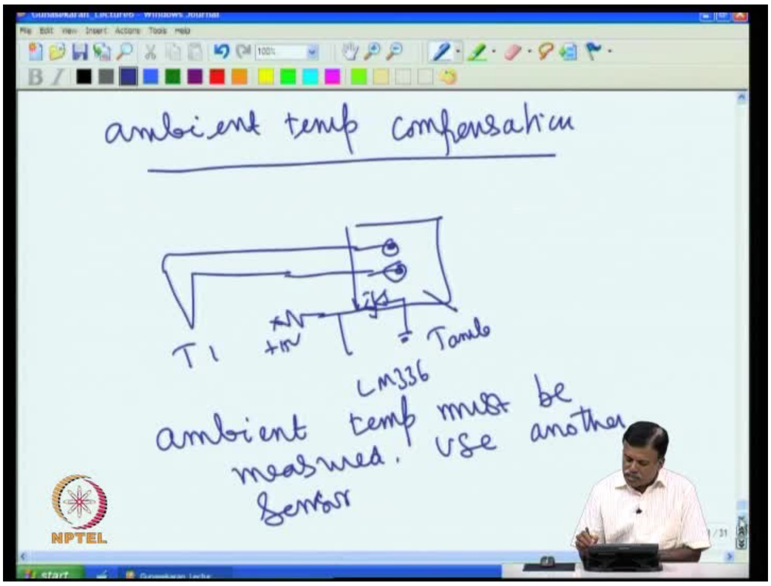

So, that we call generally it is called in industry circle ambient temperature compensation. So, what is done in this case is that you take the junction, keep it wherever the temperature to measure say T. And, then the thermocouple is terminated in a block, isothermal block say copper with of course insulation, so that it cannot get shorted. So, this is at T ambient, then what to you do is you measure this temperature using another sensor so it can be like our I C sensor which actually for example I give plus 15 volt here. Then, earlier we have discussed LM 335, so I can use; for example, LM 336 or LM 336 can be used to measure the temperature of this block. If I know the temperature of this block, then there is no problem because I know T ambient; then I can find out from this output voltage what is the temperature of this. So, all that known is ambient temperature must be measured (No Audio From: 14:11 to 14:21)

So, use another sensor; so if I measure the the temperature of this block, that is ambient temperature means the the block is assumed to be in ambient temperature and we are measuring the temperature of this block. So, we have to measure the ambient temperature of this block and then once you measure the ambient temperature of this, then you can find out the actual temperature by subtracting this.

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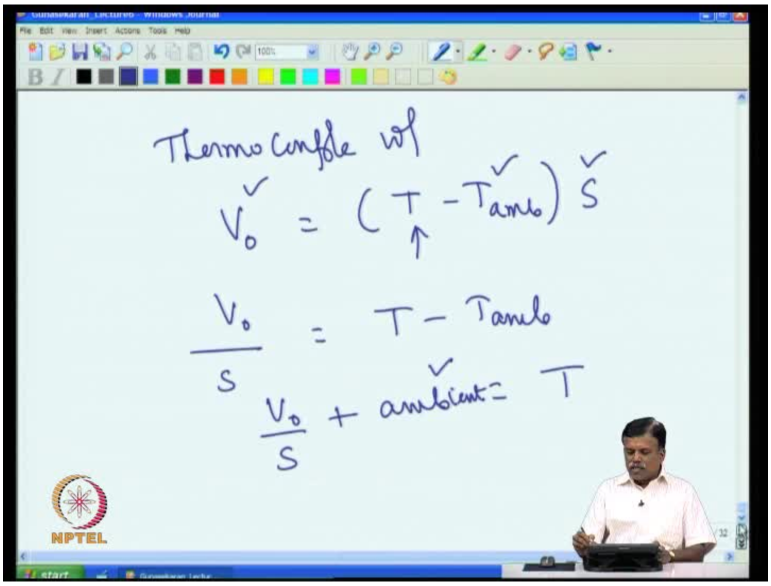

So, what is normally done is the measure the thermocouple voltage; thermocouple voltage is actually nothing but T minus T ambient into S. So, that is voltage, so voltage output. So, we know voltage output here and we know ambient temperature, we know since S, so T can be calculated; this is how this is done. So, normally what is done is the output voltage divided by the sensitivity gives you the T minus T ambient. And, T ambient is known, so V 0 by S plus ambient add that gives me actual temperature of this (( )) actual temperature to be measured. So, what is done is we measure ambient temperature separately, we add with output voltage that is given by the thermocouple; of course, considering the sensitivity. Then, you will get the actual temperature; so this is what it is to be done.

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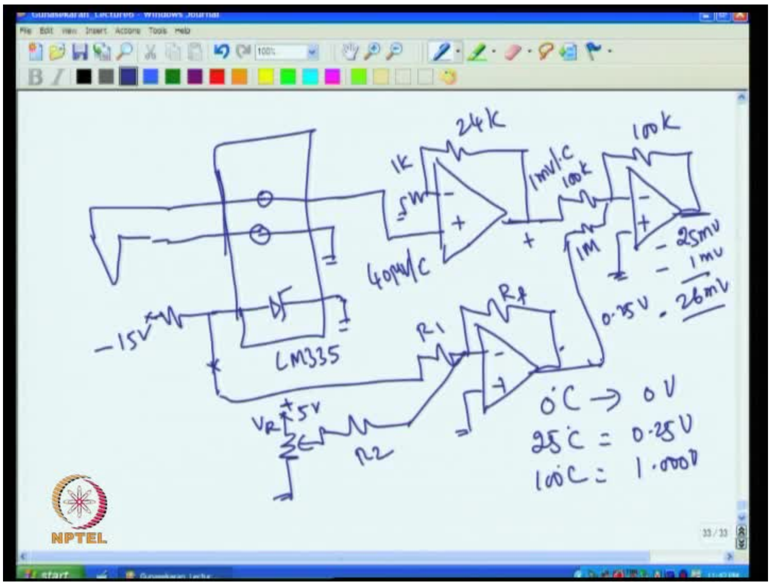

So, what normally we done is you take the thermocouple single junction you take, then take it and terminate it in a block; isothermal block take it here, of course it is isolated the normally you ground this, take the other other input, you get it amplified. For example, I have enough say 24 k just for academic purpose I take gain of 25 here. If I put 24 k and 1 k then I will get at the output because this sensitivity here is 40 micro volt per degree c, so 1 degree change here will give me 40 micro volt change here 40 micro volt change here and 40 micro volt amplified by 25 will give you 1 millivolt. So, you will get 1 millivolt change for every 1 degree change at the output of this. But only thing is that the actual to know the actual temperature we have to, if we know the actual temperature what we have do is we have to add, measure this ambient temperature. So, I put one more sensor here, in this same block I will touch this; mechanically I keep it but there is no electrical conduct to the block. So, I keep this one say plus 15 or LM 336, 335; sorry it is a temperature sensor not 336, LM 335 is a temperature sensor.

We know that at this point you will get temperature corresponding to this block. So, at 0 degree c it gives you 2.73 volt, 100 degree c it gives you 3.73 volt which we have discussed earlier. So, this voltage must be suitably altered and added to this to get the actual temperature. So, we have to do that now, because this gives you 10 millivolt per degree c; where as at this point we get only 1 millivolt per degree c. And, the second problem is this is not giving at 0 degree c 0 volt, it gives you 2.73 volt if the temperature of this block is 0 degree c. So, normally what is done is we subtract out that 2.73, so we can have this. (No Audio From: 18:39 to 18:49)

So, we have we reference here say 5 volt reference will be there, I can have this arrangement to. So, if this is plus the subtraction it has a minus; so I add the the minus voltage we had so (( )) earlier, how to desire on R 1 and R 2 and all. So that I can get here 0 volt at 0 degree c, that can be achieved. And, then at 1 degree c, I will get 10 mill volt; this we have discussed earlier in our in the previous earlier discussion, how to measure the temperature using LM 335? So, I can do this and get output voltage corresponding to temperature here.

Now, only thing is this gives me at this point 10 millivolt per degree c. Now, the temperature goes up that plus voltage is going up; so if the plus voltage goes up this will go minus. Because more the temperature and you you will get more the voltage; of course, it will keep going in the minus side. Because 100 degree c I will get minus 1 volt, at 0 degree c I will get 0 volt, at 25 degree c I will get minus 250 millivolt. So, that is good because we of course, we want to add this and this, so we can this and this be a same polarity. And, then this 10 millivolt supposed to be made into 1 millivolt and to be (( )).

Now, there are two ways of doing this, I can also make it; for example, I can remove this plus 15 here. I put here minus 15, then I reverse this this chap this LM 335 only but I reverse connected; so that now I will get minus 2.73 at 0 degree c. Then, that minus 2.73 will come at 0 degree c; that will give me plus so when temperature goes up this will go up, more minus that will make it more plus. So, now what happens? Only thing is this is to be reversed; so I will make this as plus 5 volt, this and this should be opposite. So, I put plus here and here I minus, so both are subtracting and become 0. So, at 0 degree c it is 2 minus 2.73; I for example, I put plus 2.73 then I will get 0. When 100 degree c it will go to 3.73 minus 3.73; that will be complex one here, because this is kept only 2.73.

So, essentially you know you will get, essentially you will get now here 0 degree c, you will get 0 volt. Then, at 25 degree c you will get 0.25 volt, at 100 degree c for example, you will get 1 volt; that is what happens, that can be adjusted here. Now, we have to add the this two to get the temperature in permission, that we can do with one summing amplifier. So, what we can do is I can take this, I can submit up; of course, this will reverse I think, does not matter. We can reverse it again if we require; so I take this, then this voltage and this voltage are add at up.

So, this gives me 1 millivolt per degree c, this gives me 10 millivolt per degree c; because the sensitivity is 10 millivolt and we are not scaled much 1 is to 1, so you will get 10 millivolt. So, if I put all the resistors equal, then this will dominate because we want to add ambient temperature with thermocouple junction (( )). That mean, if this is 1 millivolt this also should be 1 millivolt per degree c, but this what we are getting is 10 millivolt; that is not difficult to solve. What we can do is we can scale this one; for example, if I have 100 k here I put 100 k here and I want this have a less contribution so I can have 1 (( )) here or I can have a 10 k 10 k and 100 k here. So, the ratio now what will happen is that, this and this are added; so you will have 1 millivolt change will come as 1 millivolt here.

For example, at 1 degree c this will give me 1 millivolt and then if the ambient temperature is 25 degree c then this will give me 0.25 volt; 0.25 will give me 25 millivolt at this point. Of course, this is plus so this will come minus and then this is also plus so 1 millivolt will come as 1 millivolt here; that is also minus, minus 1 millivolt. So, I will get 26 millivolt here, minus 26 millivolt. Assume this is at room temperature 25 degree c, then I will get 0.25 volt here; that 0.25 will come as 25 millivolt here, because this is 10 is to 1.

So, you will get 250 millivolt here come as 25 millivolt here. Then, if the if this is giving you 40 micro volt, then this will come as one mill volt; that 1 millivolt will come as 1 millivolt, so you will get 26 millivolt representing the temperature is 26 degree. Because if this is giving you 40 micro volt here and if this is 25 if this is 25 degree, then only this is at 26 degree; then difference is 1 degree it would have given 40 micro volt. So, that 26 degree junction temperature correctly appears at this output. So, this is how the ambient temperature compensation is done and you get at this point, voltage corresponding to the temperature including the junction temperature. So, the you will get at this point voltage corresponding to the temperature. And, this ambient temperature compensation is a must because now a days in industry no one uses dual junction thermocouple; everyone uses only single junction thermocouple. They always give ambient temperature as the compensation in this manner.

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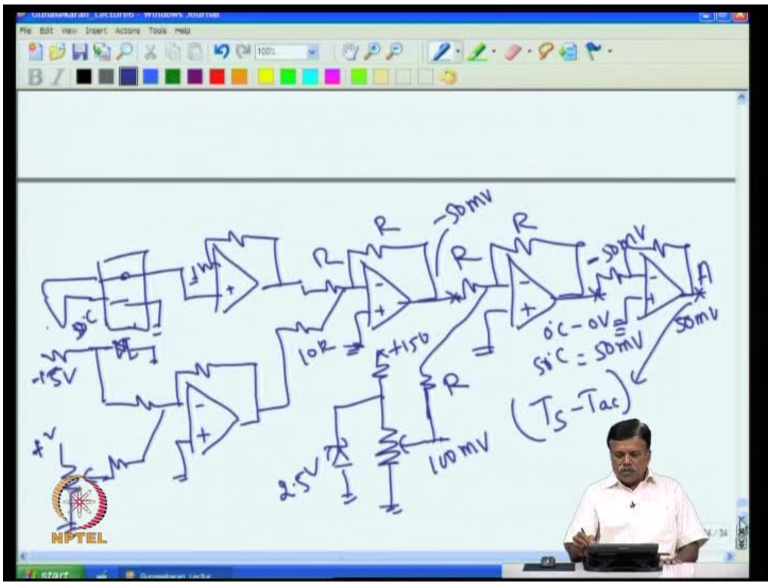

So, now what we have done is we have now got output voltage corresponding to temperature. Now, this we have to use it for controlling the temperature. So, now if I see this the whole circuit that it looks like this, if I draw now. For example, I take this, then I put the block for terminate the junction; then I put the amplifier here to amplify the thermocouple voltage. Then, we use measure the temperature of this block by putting a (No Audio From: 26:00 to 26:06) minus 15 volt, then we take this; then we have put the ambient temperature compensation circuit. What we have done was that we we go back and see our this thing; I retain the same circuit that would be better. So, I will put the another reference voltage that is plus and then same as what we have discussed earlier.

And, these two are added up (No Audio From: 26:56 to 27:04) to get you the temperature; of course, this is going minus side. If we want make it plus, we can invert it or even we can invert it but I think we will not do that. We can simply invert it to get it such that you will get positive voltage, that would be easier for discussion; but nothing wrong in negative voltage, we can work with negative logic also. But for beginner it confuses, so I made it such that the gain is here 1 and here you have R and R, we added

10 R; so at this point you will get voltage corresponding to temperature. So, that means at 0 degree c, you will get 0 volt; if it is at 50 degree then you will get 50 millivolt. So, every 1 degree you will get 1 millivolt output. Now, this should be used to control the temperature of the oven. So, to control the temperature of the oven, whatever do is I have to produce the error voltage; that is what the meaning of the lecture we are started. So, we have to now get the error voltage; error voltage means the actual temperature that is given at this point minus the set temperature.

So, to control then I had to have a set temperature and find the difference between this. So, we can set the temperature by using a zener voltage; for example, if I have a reference in or here say 5 volt zener or 2.5 volt zener available, I can have this. And, then say plus 15 volt available, I bias the zener and put the potential meter across the zener; so across this, you know across the across this you will have 2.5 volt. So, I use this potential meter to derive whatever voltage that I need. So, this is now acting as a set value and this is acting as the actual temperature. So, I have to find the difference between this and this; so, that I can do it in a different ways.

For example, I can I can add a difference amplifier so or I can even have summing amplifier this polarity and this polarity are opposite. If this is plus and if I give here minus, then if I do the summing at the inverting input then I will get minus. So, I can do one thing, we know here I am getting already this, this is minus. So, if I have plus here, I can submit at this point; so normally what is done is you keep this one for example here. So, if we see say at 50 degree c, we as we said this gives me minus 50 millivolt. Suppose, I want to stabilize the temperature at 50 degree, then I give here also say plus plus 50 millivolt. Assume, this is also R, so if this is if I say this plus 50 millivolt and if the actual temperature also 50 degree, then this will give me minus 50 millivolt. So, this is plus minus and the ratios are equal; so, I will get 0 volt. They said difference that the error will become 0, that is because our set value and the actual temperature are one and the same.

So, if I if the temperature is 50 50 degree c assume this is at 50 degree c. so, this is at say 50 degree c, then I know that I will get here minus 50 millivolt. Then, if I want to say temperature to be raised to 100 degree c, assume that I put this junction in a oven whose temperature to be measured; then I want to keep the oven at 100 degree c. That means, I will keep this junction in the oven and I want take the oven to 100 degree c, then what happens? If the oven is at 50 degree c, I know I will get minus 50; then what I will set? I will set this one to 100 millivolt, I will set this one to 100 mill volt.

So, the oven is now at 50 degree c; so I will get minus 50, this is 100. So, net result would be that you know, you have plus here more; so you will get minus 50 millivolt here, you will get a minus 50 volt. So, if I increase this as long as this is higher, then you will get a more and more minus here. So, if the then if the heater is on, assume that heater is on then if this temperature if this temperature goes up; then this minus also will go up. Then, as more and more minus comes this will also come down; when the temperature becomes 100 here, this will become minus 100 and this is plus 100 then this again will become 0. So, this obviously we are now what we have done is we have generated error voltage; of course, error is minus, so we do not want normally minus logic. So, we can also make it plus logic by inverting it; that can be done. So, we want we can do that or even we can invert previous stage and do that. I think we need not go back and we can simply invert it to get plus logic, so I can have this.

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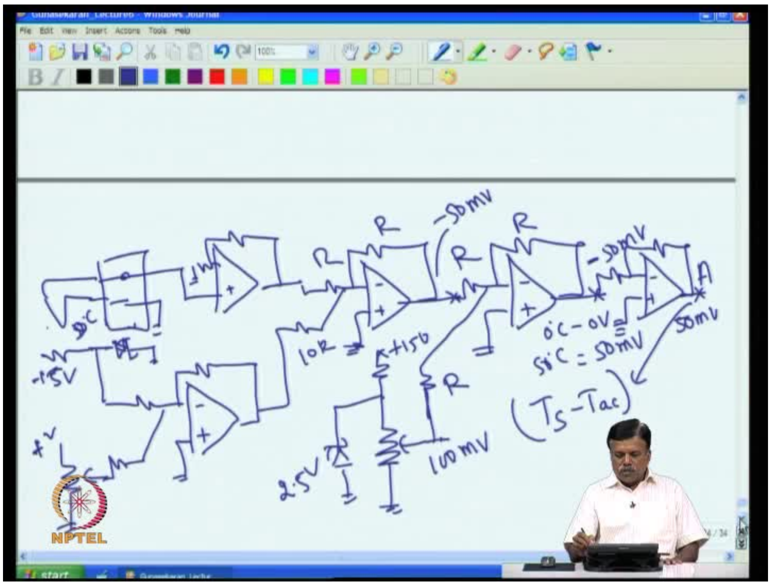

So, all that now comes is that I will get here; if the temperature difference is 50, suppose if this is 100. If the actual temperature is suppose, if a set temperature is the set temperature is 100 and actual temperature is 50; then I will get plus 50 millivolt here. So, here you will get error 50 millivolt for example here. So, this point gives me error voltage; so this voltage is nothing but T set minus T actual. Every one milli one degree difference it gives you 1 millivolt. If the temperature if this temperature is higher, output will be high. if if the if this temperature is higher output will be minus. So, for example, morning and we come on switch on the oven, oven will be at 25 degree c. So, this will be at 25 degree c and if we are set 100 degree say 100 millivolt here, then the difference is 75; so, you will get 75 mill volt at this point in the morning. So, this would obviously drive a heater then only heater will heat up and go.

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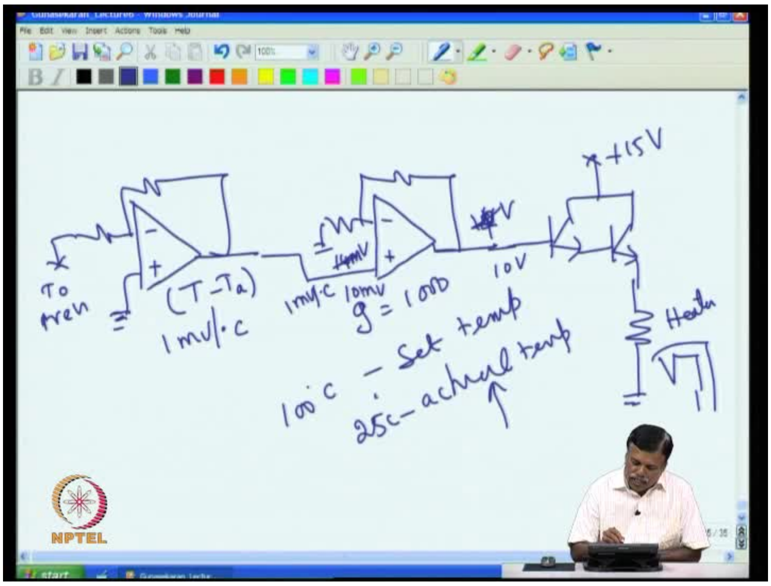

So, what we do is this output what we had taken here, so I name it as A, this output I should use it to drive the heater to to complete the temperature controller circuit. So, what I do is the next, I will take this output. So, I will draw from that stage, so that inverter stage what we are drawn at the end. So, that is coming from the previous stage, so you have to previous stage what are connected there; it goes there and you will get here error voltage, that is this gives me T minus T ambient. If a 1 millivolt per degree c is the sensitivity at this point, because every 1 millivolt difference will give me every 1 degree c will give me 1 millivolt difference at this point.

Now, I have to proceed to the next stage that is I have to now I got a error voltage. Now, I have to produce heater voltage proportional to this error. So, how will you do that? Now, what I do is I amplify this to get the error voltage; so I can connect this and put a gain. Suppose, if I give gain is equal to 1000, then every 1 degree difference gives me 1 millivolt here. So, every 1 degree difference will give me 1 volt at this point or even I can have; say for example if it is 1000, 10000 gain; so, normally we do not give single stage 10000 gain. We will discuss about this more about this later; if you want we can give 100 gain one stage, another 100 gain in another stage, that will make totally ten thousand gain.

So, at this point of time we assume that we had given 10000 gain in one single stage which is normally you should not do. You should give only lower gain only in any single stage; I will explain the reasons little later. So, if you take this is 10000 gain then 1 milli 1 degree difference will give me 1 millivolt here; that will give me 10 volt at this point. This I should give it to the heater, we set heater is the 100 volt has to be driven. Now, for example, I can give it to heater like this and I want heater as 5 ampere current. So, I put a Darlington pair and then I give for example, here 100 volt and then I put the heater here. These heater using the oven and then there only the thermocouple is kept that what we are seen in the previous figure, the thermocouple is actually physically kept here to sense the temperature of the oven.

Now, if 1 degree difference is there you get 10 volt and you will get; if the 10 volt is present here you will get 9.4 volt at this point. And, then another point 6 less here, that will give you 8.8 volt at this point; 8.8 volt will be applied to the heater. We always have to lose this 1.2 volt but the problem is, we know that the output of the op amp will not go beyond 15 volt. Because if I operating with 15 volt supply, I can expect only around 13.5 volt to 14 volt maximum not more than that. So, another 1.2 goes here so you will get only around 13 volt; so but heater needs 100 volt. So, with this arrangement it is not possible to get 100 volt, if the heaters of a requirement is less than 15 volt then this works all right. So, we will see first with this how it works; then we change over to 100 volt, it will see how to make 500 volt. So, assume that this is only 15 volt and a heater needs only 15 volt, in that case this circuit this temperature controller works fine.

Now, if you see if the set temperature is 100 degree c and the morning if you come and switch on and if it is at room temperature that is at 25 degree c is the set actual temperature, this is set temperature, 25 degree c is the actual temperature. Then, difference is 75, I know that I will get 75 millivolt here and 75 millivolt multiply by 10000 will give you 750 volt and 750 volt cannot come what is available is only 15; so 15 volt comes here. And, here 13.8 comes and heater heats up. And, then once heater heats up then actual temperature will be keep rising and this actually you want actual temperature goes up.

Then, voltage at this point voltage at this point will keep decreasing because original temperature difference was 75; so, you got 75 millivolt. If the temperature difference is 10 degree that is if the after sometime the heater got heater was after sometime the heater is on for some time; then the temperature of the oven goes up and then the difference between the set temperature and actual temperature comes down. And, if the set difference is only 10 degree then this becomes the 10 millivolt; then 10 millivolt actually correspond to here 100 volt (( )). When the difference comes 1 degree, then it comes 10 volt; when the difference comes 0.5 degree here, then you will get 0.5 millivolt and that will make this one to go 5 volts.

That means, now that means as the temperature as the heater heats up, temperature is raising and this voltage comes down then this voltage also comes down. So, it will be if you give I gain then for example, in this case the how heater voltage cannot go more than 15. Then, once it comes to 1.5 millivolt that is once the temperature difference is 1.5; this becomes 1.5 millivolt and these had come to 15. The temperature difference is less than 1.5 degree then the difference will be less than 1.5 millivolt and this also will come out of saturation. That is this also come below 15; that means this is operating in the linear region and this also will be operating in the linear region. So, that means if the that means heater will be heater voltage is coming down; that means once the temperature raises, then at very close range then this voltage are come down and this voltage also come down and heating also comes down. Well, at some point you know the whatever heat that generated by the heater will be equal to the heat that is going out, at that point it will stabilize; that is idea of this proportional controller.

So, proportional controller to work we have to make sure the gain is not very high; because if the gain is very high it can easily become on off controller. For example, if I put a gain of 1000 then for to get 15 volt you need 15 millivolt difference here; because 15 millivolt into 1000 will give me 15 volt. That means, the heater will get into linear region that is from fully on region we start coming out and delivering less and less heat as this voltage raising up. But then the gain is 1000, then if at 14 millivolt; then that 14 degree error only, this because 14 volt. Then, heating come down little bit then further with the temperature goes up then this will come down to say 10 millivolt, then this comes close to 10 volt, then this comes to 10 volt.

Now, heating further come down because now we are coupling 10 volt minus 1.2, that is 8.8 only. Now, if that heat is still higher to maintain this at 100 degree c, then this will still go up. This will come down because the temperature will go up and the difference will come down and this will come to say 8 millivolt. If this difference come to 8 millivolt, then this will go to 8 volt; then this also will come down. So, as that temperature rises, this is coming down; you know this voltage is coming down and the heater voltage is also comes down and it produce the less heat. So, then the temperature rise at one point, what will happen; the heat coming here will be equal to heat going out. Because as the temperature rises, the amount of heat that is the amount of voltage coming here and the amount of heat generated comes down. And, net result is at one point the amount of heat going out to be equal to the amount of heat generated and the the controller will stabilize at that temperature.

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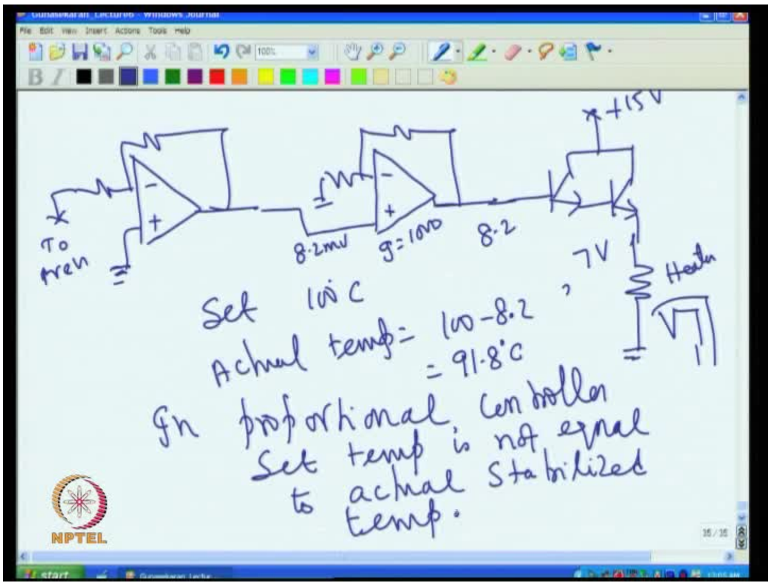

That means, if you see very closely if I set 100 degree, 100 degree if the set temperature is 100 degree; so if I take this you know the set temperature is 100 degree. Then, to maintain the assume that to maintain the oven at 100 degree c, the heater needs say 7 volt. The 7 volt here calls for 7 volt here calls for 8.2 volt here; 8.2 volt if you give only I get 7 volt. To get 8.2 volt if the gain is 1000 here, if the gain is given 1000 then I need

8.2 millivolt here. That means, 8.2 millivolt will become 8.2 volt and that will become 7 volt. Assume that 7 volt is what is required to keep the oven at 100 degree c; then once it comes to 8.2 millivolt this will become 7 volt and then if temperature is not going to raise any more and this will remain 8.2, this will remain 8.2, this remain 8.2, this remain 8.2 and then this is at 7 volt.

But mind you, you have a difference of 8.2 8.2 millivolt here. That means, the actual temperature is not 100, the actual temperature will be 100 minus 8.2; that will be 91.8 degree only. That, means if I set 100 degree c then over ruled stabilizer 91.8 degree c, that will give a difference of 8.2 millivolt. That difference between this actual temperature and set temperature will be 8.2; that means actual temperature is 91.8, set temperature is 100, the difference is 8.2. That 8.2 will come here, that will come as 8.2 volt here because the gain is 1000 and you will get 7 volt here. And, we assume with 7 volt is what is required to maintain around 100 degree c.

So, this system will stop here that means the even though I have set that 100 degree c, but system will not go to 100 degree c; it will stay away 100 only. Because if the error is 0 that is it if the set temperature equal to actual temperature, error become 0 and this become 0 and this become 0; no heating will take place. And, without heating it cannot give the system at high temperature. So, you need always some heating voltage; that means always some error is required. That means if there is error means the set temperature and actual temperature are different. So, proportional controller this is one of main drawback. That is if we want 100 degree c, then if we set 100 degree c system not going to stabilize 100 degree c; it going to stabilize little less than 100 degree c. That difference only drives the heater and this is one of the drawback of the proportional controller.

Now, one way of solving this problem is that if I want 100 degree c, you set little more than 100 degree c; say you set 108 degree, then it will come and stabilize at 100 degree that can be done. But then that problem is not so simple; this error voltage what we have, it creates another issue in proportional controller, that is much more serious then what we are discussed so far. That is what we have discussed the difference, that is error by itself is not a serious problem; the secondary effect of the error is the problem. So, the point that we should we noted at the point is in proportional controller in proportional controller the set temperature set temperature is set temperature is not equal to is not equal to actual stabilized temperature (No Audio From: 47:15 to 47:25) actual stabilize.

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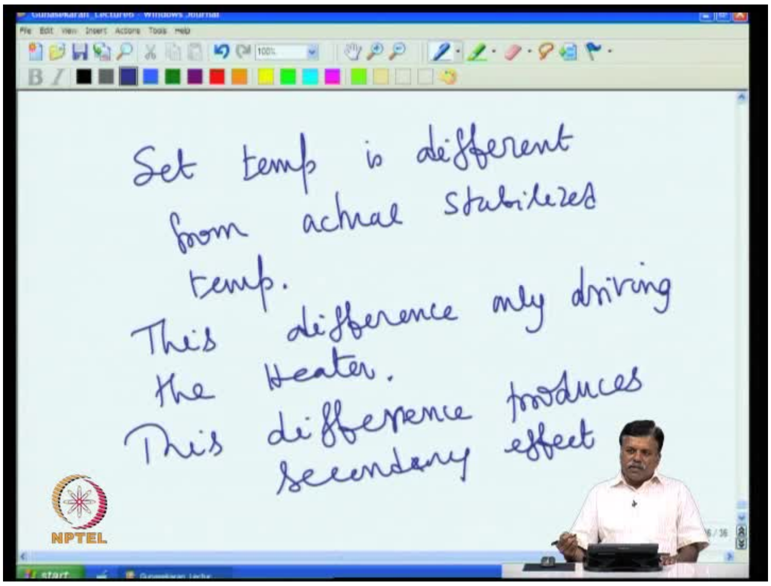

So, set temperature and the actual stabilized temperature are different. Set temperature is different from actual actual stabilized temperature. This this difference only this difference only driving the heater (No Audio From: 47:57 to 48:03) this difference only driving the heater. This is a very important point that we have to remember in proportional controller and this difference produce the secondary effect, this difference this this difference produce the secondary effect. What is this secondary effect? (NO Audio From: 48:26 to 48:35) And, this is a very serious issue because of this only we got PID temperature controller and so on. Because if the, see proportional controller is much better than on off controller; because on off controller you know heater voltage switched on or off.

Whereas, in proportional controller the heater is neither are fully on nor fully off; it is in the linear range. But the error only drives the heater voltage, the net result is we are not getting what temperature that we wanted. If we want 100 degree c then the oven going to stabilize till away from the set value of 100 degree c. Of course, you may say that in a increase the gain then the error will come down. For example, instead of 1000 gain I put here 10000 gain, then to get same 8.2 volt I need only 0.8 millivolt here. For example if I the oven need 7 volt to stabilize 100 degree c, then I need 8.2 volt here. To get 8.2 volt, I need only 0.8 0.8 millivolt; if the gain is 10000. So, I can increase the gain to make the oven go very close to the set value. For then if I keep if I increase the gain then soon you will find that even very small difference makes this fellow to go high and full 15 volts are coming here; that means it will become on off controller.

So, if you go for high gain then system move towards on off controller and then you will find that similar to on off controller the temperature also will be going up and down. So, increase the gain is not the solution to make the temperature to come close to the set value. Now, if it is set you know the set value is not equal to actual, where the temperature stabilize. Then, what is the secondary effect? The secondary effect is like this. See, the heater now we are assumed that heater needs 7 volt, so I will explain with another figure what is the secondary effect.

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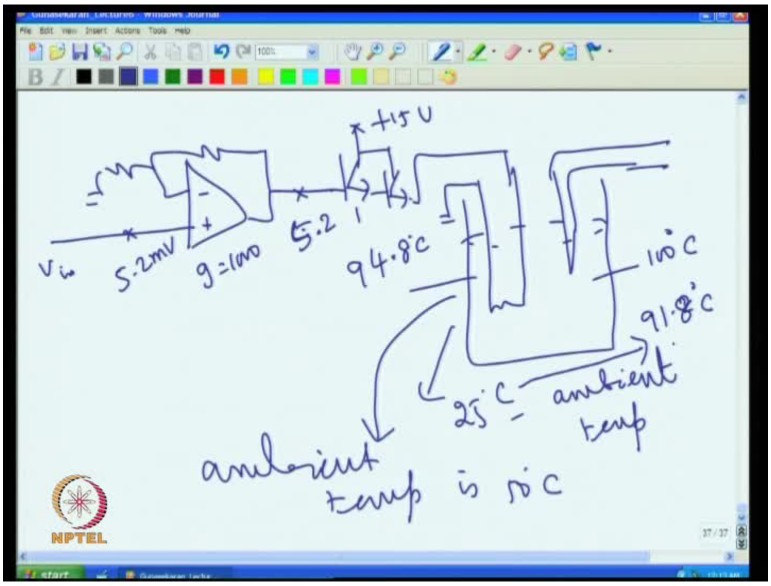

See, we had taken the I draw only the heater part and the flask part. So, you have the heater voltage here and the heater was driven through a Darlington pair and heater voltage was given to this. And, you have here plus 15 volt and then this is the final from output that was given to this and this is the gain stage. We have assumed that you have a gain of 1000, this is the v input come from the error voltage. So, if I want you know here if I want 8 volt, then I need the gain is 1000, I need 8 millivolt here.

Now, assume that the ambient temperature is 25 degree c. This wherever thermocouple is kept and we want to maintain this at 100 degree c. So, I I was set to 100 degree c, the ambient is 25 degree c is the ambient. Now, at when ambient is 25 degree c, then the system comes 8 volt here and then this fellow stabilizes at 91.2 2 degree c and because it cannot go to (( )) I had set to 100 degree c. But it does not go to 100 degree c, it goes only to 91.2 degree c, because if it trying to go more than 91.2 then this error will come down. Then, the heater voltage you know this goes try to go more than the 91.2, this error will come down and this voltage will also come down and the heater will not able to maintain 91.5 degree with the voltage and heater comes down.

So, the now it has stabilized at 91.2 but we want an 100 degree c and this is situation at 25 degree c ambient. Suppose, the ambient temperature goes up up to 50 degree c, see the ambient temperature goes up to temperature is 50 degree c, if it goes 50 degree c; then the oven what will happen? The oven will radiate only less heat, because oven is a 100 degree c; the ambient till here it was 25, now it had gone to 50 degree. That means, now less heat will come out from the oven and then the temperature will trying to go up. Then, once the temperature trying to go up then this voltage will come down, the error will come down and this will also reduce. But then since the less heat only going out from the system and it also needs only less heat only to the system, because heat going out heat should be equal to heat coming at the point only the system will stabilize.

Since, the ambient temperature gone high and only the less heat is going out, now this needs only less heat. That means, now it does not require 8 volt, it needs assume it needs only 4 volt. It needs assume this needs only 4 volt that mean at this point it will come to 5.2; that means 5.2 means this will come to 4. And, at 4 volt is enough to make that heat generated by this equal to heat going out.

So, what will happen is to get 5 point two I need only 5 millivolt difference here. So, I do not need 8 millivolt; so I need only 5.2 millivolt. So, now what happens when ambient temperature gone to 50 degree eventually what happen this will come to 5.2 millivolt, this will become 5.2 and the 4 volt is enough to maintain this. So, what will happen? This temperature will not be now 91.2, this temperature will be 94.8 degree; that means the ambient temperature increased 50 degree this had gone to this 94.8 degree c. The ambient temperature was 25 degree c, so oven was 91.2 degree, 91.8 degree c. That means we are not changing the setting of the temperature, we are kept only 100 degree setting. When the room temperature is 25 degree c, this are stabilized at 91.8 degree. When the room temperature went up to 50 degree c, it now went and stabilize at 94.8

degree c. It looks as if the oven temperature is changing with ambient; even though we are not changing the setting.

So, it is like this. You know if I have a proportional controller, if I set this at 100 degree c and come and see in the morning and morning you know room temperature is 25 degree c. You will see that you know the oven is stabilized at 91.8 degree c, then I leave it; I do not change any setting but then I come in the noon when room temperature gone up say to 50 degree. Then, I will come and see at that time it would stabilize at 94.8 degree c; that means without doing anything it look as if the, it looks as if the controller is stabilizing at different times at different temperature, even though temperature setting is not changed.

This is happening because you know the heat coming in has to be heat going out at that part of the stabilizes. Since, heat going out is changing correspondingly, you know the amount of voltage required also changing. That amount of voltage generated by the error voltage, so the error voltage also changing. So, this is one of the drawback of the proportional controller. So, one have to be one if the temperature have to be constant throughout the day, then only choice is you increase the gain; you know do not keep low gain, you go for high gain. But high gain will make it, this temperature going up and down.

If you keep at low temperature, then from morning to evening if you watch the temperature of this, that will be changing slowly. So, this is a serious problem and this was recognized by the practicing engineers in industry first. Because after all this temperature controller and this theory theory controller all are actually generated not by the academic people. There are generated by the practicing engineers who who had done through trial and error method generated the whole lot of theory for on off controller, proportional controller, theory controller and so on.

Later academic people added too much of mathematics into there and they also complicated I would say in a certain way. Actually, the proportional controller, theory controller simpler things inverted by the practicing engineers for a real world applications. So, proportional controller is very good compared to on off temperature controller to get good stability. But then the set temperature, that is actual temperature continuously changes according to the ambient temperature; this is a serious drawback.

So, this issues addressable for practicing engineers and then they developed the so called PID temperature, Proportional Integral Differential temperature controller.

In fact, the first step is proportional integral temperature controller. So, the made the added integral action to solve this problem; that is, when ambient temperature changes the temperature of the oven changing. That problem was solved by adding a integral action to this. So, how that problem is solved, this we will see in our next lecture. Because it is a very interesting topic, how the PID controller evolved and how it is working. One if one try to understand reviewing the mathematics, it would be good. So, I would try to explain everything without introducing any mathematics, it is better to understand that way before getting into mathematics. In fact, I am not going to touch the mathematics at all in this. Thank you.