INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

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Topic Lecture – 10
Introduction to Automatic Control(Contd.)

Good afternoon so having seen that so now we have to take care of these and design and controller appropriately. Now let us look at performance so what is the first requirement of performance.

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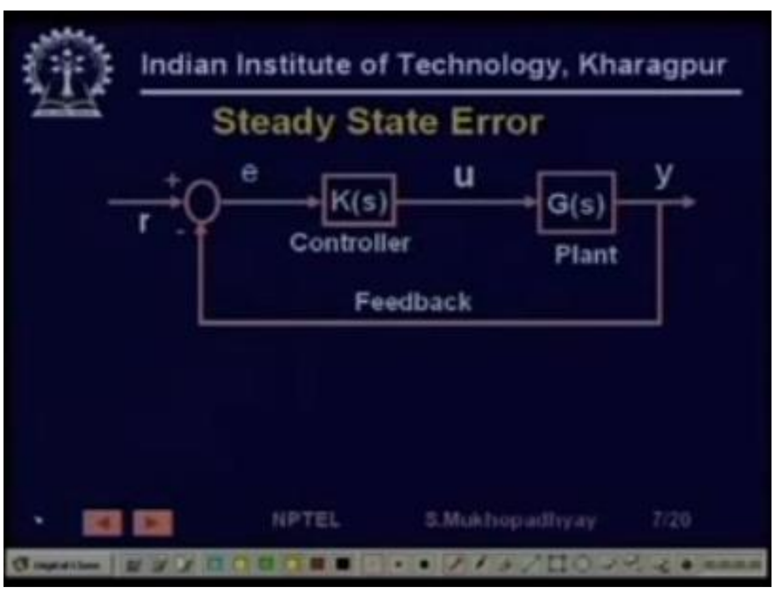

The first requirement of performance is that performance can be divided into two types in control one is called steady-state performance and other is called transient performance, in general steady-state performance is much more important than transient performance simply because of the fact that that performance holds over a much longer interval generally in industrial automation the set point change is somewhat infrequently.

For example if you take a power station boiler then it set point over a day will typically be changed 7, 8, 9 times maybe less. So when you will have load coming in the morning it set point will be changed when lighting load in the evening will start going down after let us say 10 o'clock or 11o'clock load will fall at that time you have to reduce the set point. So there are infrequent set point changes.

And in between these set points are generally maintained this happens for a lot of process equipment. So if you have performance regulations which are persisting during that phase when this is when the set point is held then that is generally considered much more serious than errors that can occur when the set point is changing or immediately after that time for a short duration. So we would first like to ensure steady state performance.

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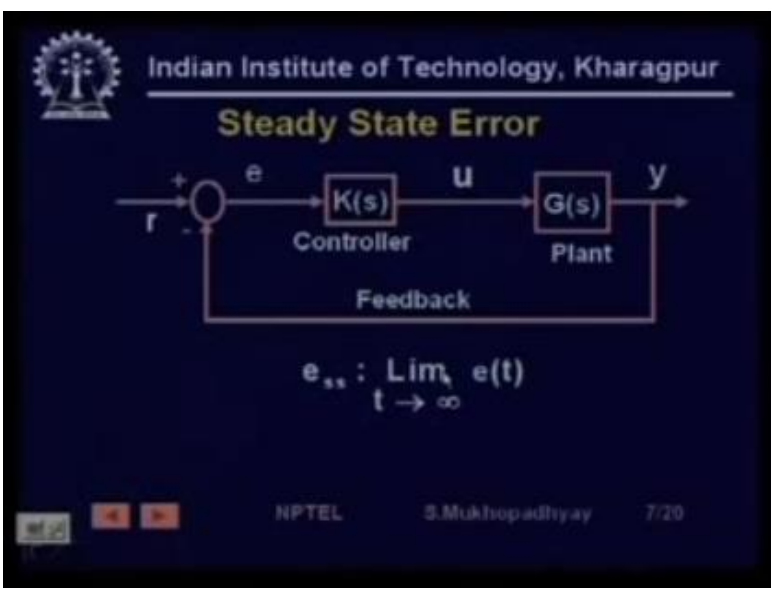

And the major consideration for that is steady state error that is we want that r should be equal to Y at least in the steady state obviously if r suddenly changes y cannot suddenly change. So y will have to y will take some time to come to the level of r but once it comes we want that this error will be 0, we want 0 steady state error these our wish. So solve obtain that right so for that so we want that this is the steady state error that is limit of T can be typically we take a unit step response.

If the reference input suddenly changes then how is as time passes does the error go to 0 that is limit of T can be infinity e(t).

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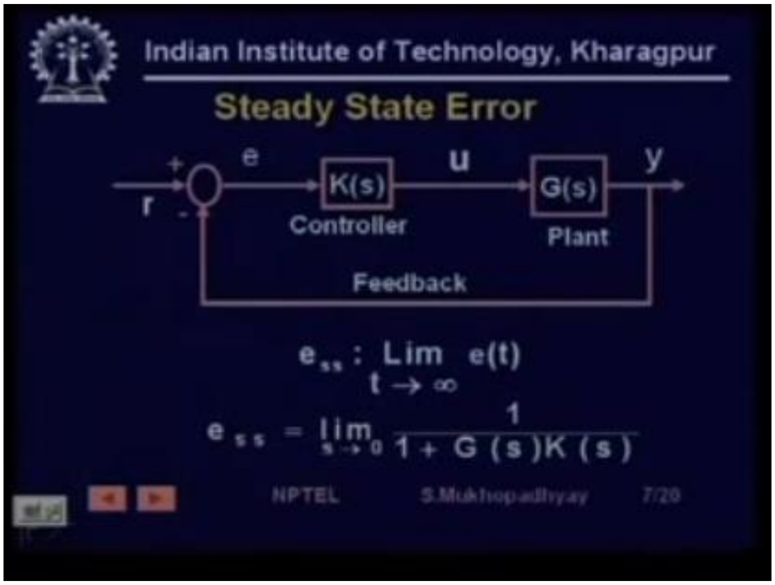

We can also express it in frequency domain form which says that which is the final value theorem of Laplace transforms and which comes down to the fact that e steady state is limit of s tending to zero 1/ G(S) K(S) right. So this is the steady state error and we have to ensure one of the prime requirements is to ensure by control that this goes to zero. So how do we do that, so we have to control for 0 states instead let us take simplest case of proportional control.

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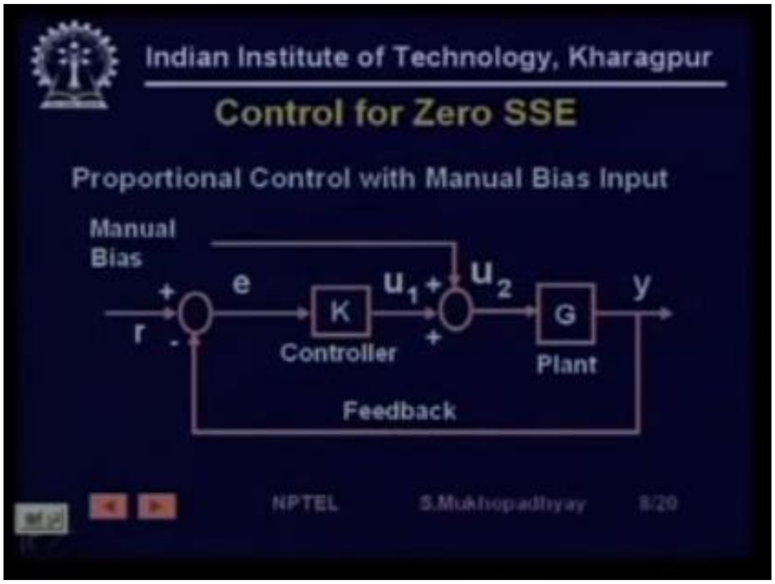

The problem of proportional control is that if you want to proportional control is just you have a simple gain and if you get an error of 1 volt you generate a maybe an output of 100 volts if you get a 2 volts you generate output of 12. So just simple multiplication.

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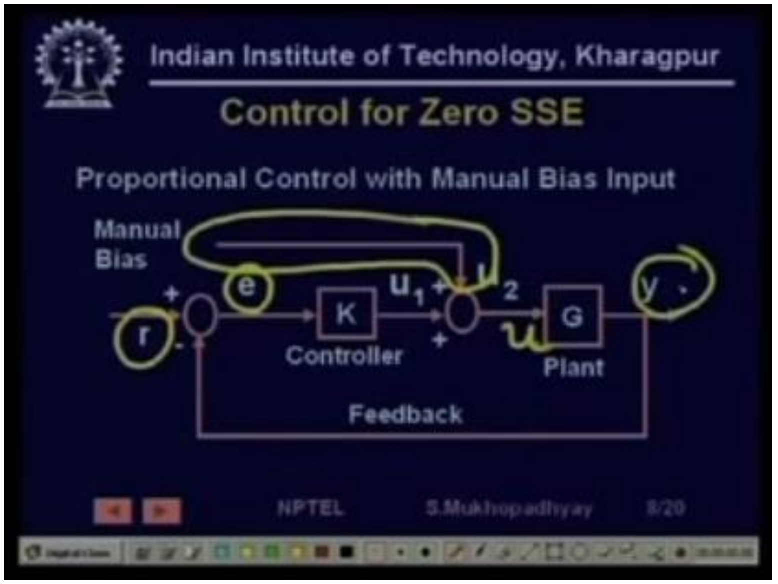

Now obviously we want to be what we want we want that this R be equal to Y, so we want to r is a certain values. So we want to maintain a certain value of y now naturally in it happens so happens that for maintaining a particular value of y we need a particular value of u, so for the time being assume that this is not there. So now how are we going to get this U, if you want to maintain this U.

Then we have to maintain a particular value of E, so unless we have a certain amount of steady state error we cannot generate U and therefore which you cannot generate Y so we cannot make steady at 0 ever, using proportional control that is what it turns out to be. So what happens is that the there are two things that could happen.

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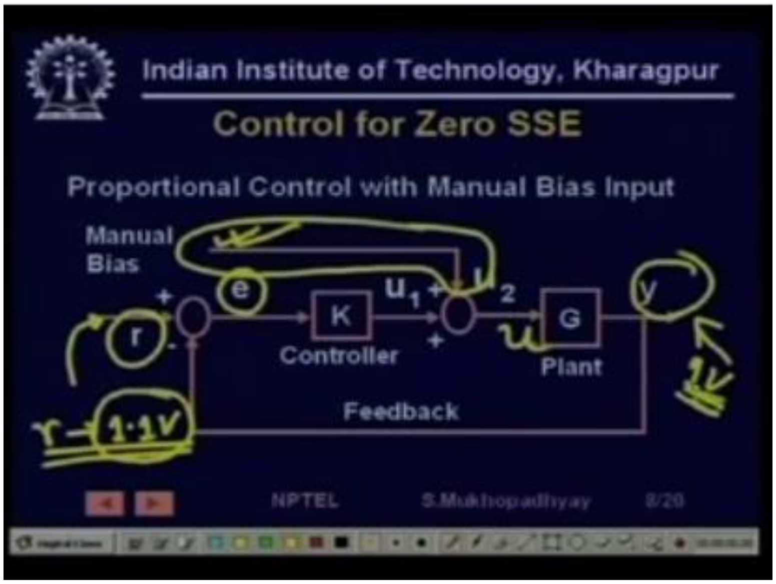

Either you could artificially increase this r that is if you want let us say an R of really one that the that the output stays at 1 volt you give an R of maybe 1.1 volt, just what volt you have to give that if you calculate but so you artificially increase 1.1volts so that here you get 1 volt which is a real output you want, right. Or what you could do is apart from what the controller is doing you can give a you can give what is known as this manual bias that is you apply some additional input, right directly to the plant.

So you do one of these two things in that case you can maintain whatever output you want but what is the problem, the main problem is that who is going to give this input how do we know by how much for example if we give 1.1 volt for 1 volt how do we know let us say if you want an output of 3 volts what output we have to give, by how much so naturally it should not require a manual you know manipulation. It should be done automatically right.

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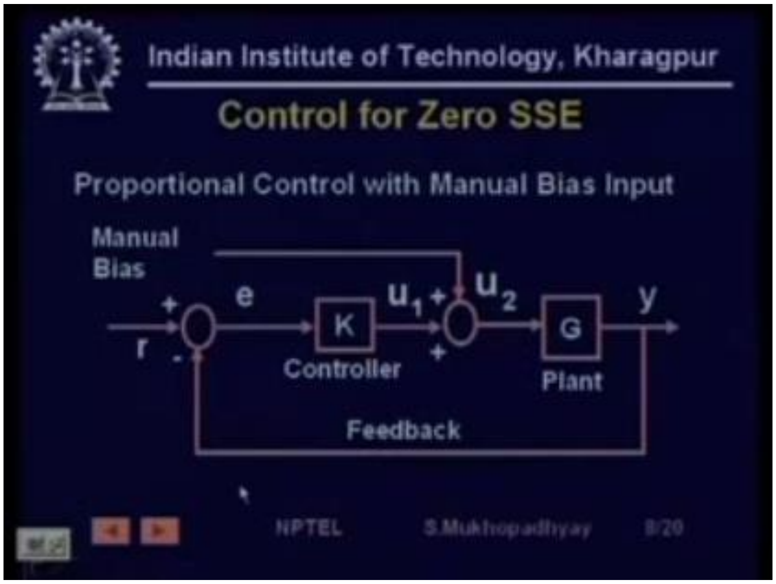

So that brings us to the question that how can we automatically generate this bias input without any manual intervention.

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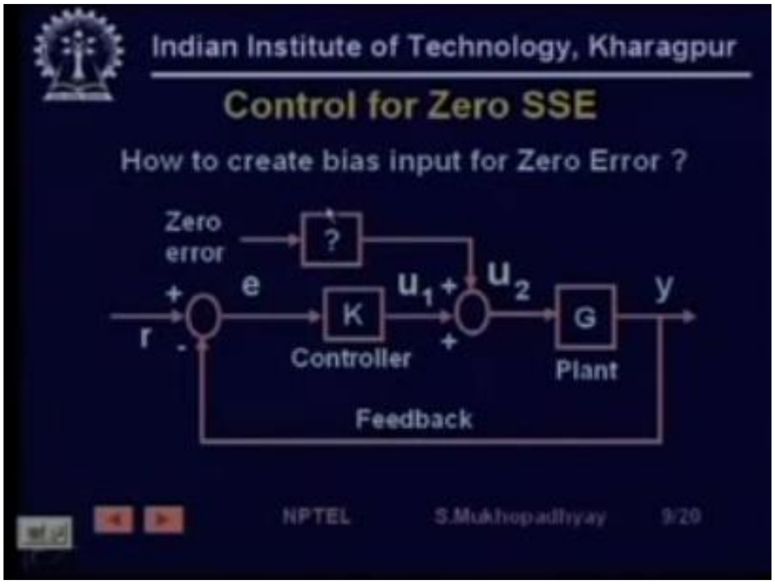

So the question is that how do we how to create bias in put for 0 error, right. So that is the situation described here what should be this.

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So we see we that what is the device which for 0 error gives and gives an output, so that device is actually an integrator so somewhere in the loop there should be an integrator then even if the error is 0 we will be able to give a finite output.

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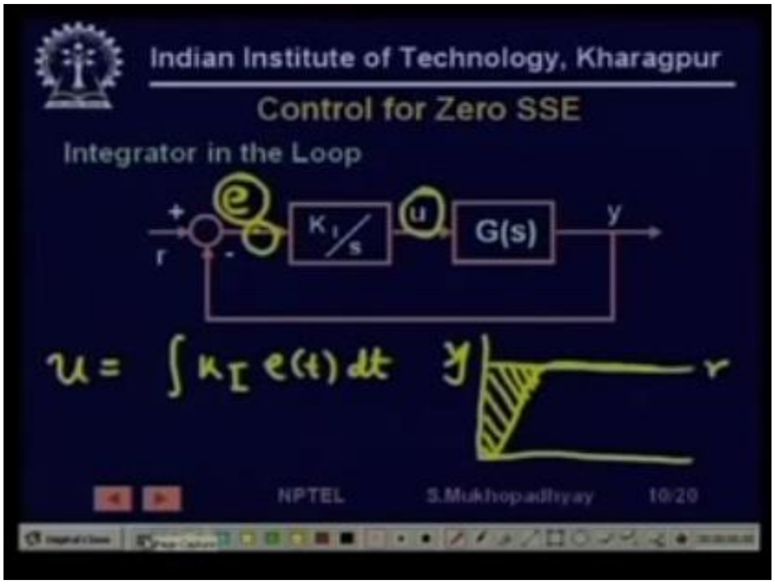

So there are actually two cases in which an integrator is required, so the first case is this one so if you have an integrator he imagined that we have written ki / Si in Laplace domain notation which means that this is actually an integrator that is U is equal to ∫ Ki e(t) d(t) so this is the integrator, so this is equal to u. So now you see that even if after sometime this at this point if you even if we get e.

E goes to 0 so for example suppose the error goes to 0 this is this is y this level is r this is the level so here error is going to 0 but what will be the value of the integral what will be the output of this block, the output of this block is going to be the area under the curve because this is the error this is y and this is r so r – y is this vertical distance, so this is the area, right. So this area even if the error remains 0 this area remains finite.

So you can generate a finite U even when the error is 0, but keep generating so having an integrator helps.

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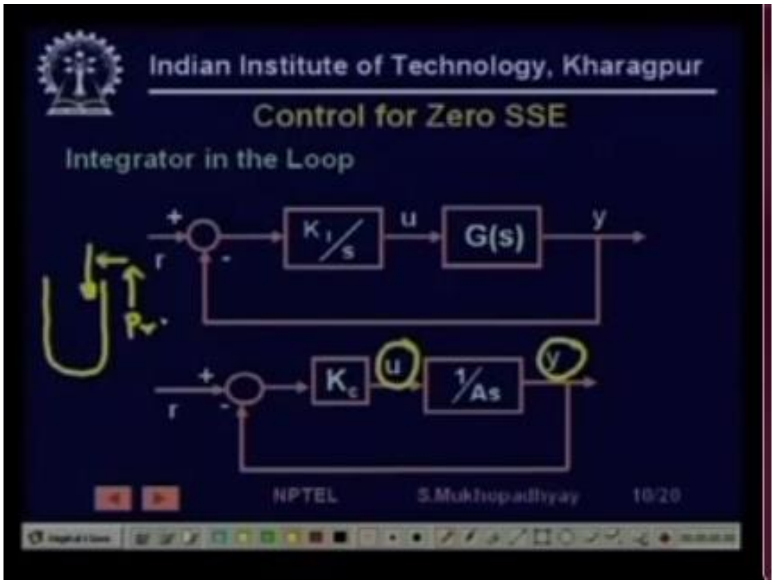

There is another case in which you can have an you can have an integrator that is the integrator is actually part of the plant itself which means that to be able to sustain an output the plant may not need an input all the time, so the plant itself is an integrator what is the typical example of this a typical example of this is a tank so suppose you have a cistern you know like we have in our toilets.

So you can have a flow in and the this flow in is actually this flow is actually proportional to the level actually there is a if you might have noticed if you have looked into the cistern that there is a there is a ball cock floating ball so when the when there is no water then the ball cock is hanging like this and water flowing, so as water rises so the ball cock goes up and at a certain level the valve through which the water is flowing will actually close.

So at that level it will be maintained so you see now so this tank is a plant which this tank is a plant.

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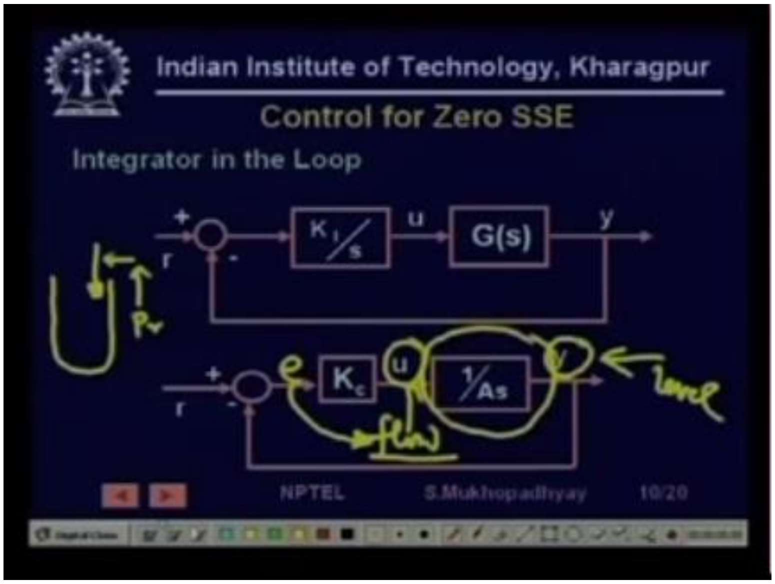

Which is which has an integrator with respect to flow because the level is nothing but an integral of flow, so at some point to be able to maintain a level this is a level it does not need any flow so the flow can go to zero, so still so we are having a simple proportional controller so the error going to zero flow goes to zero but she level is maintained so this is a another situation where you can say have 0 steady state error.

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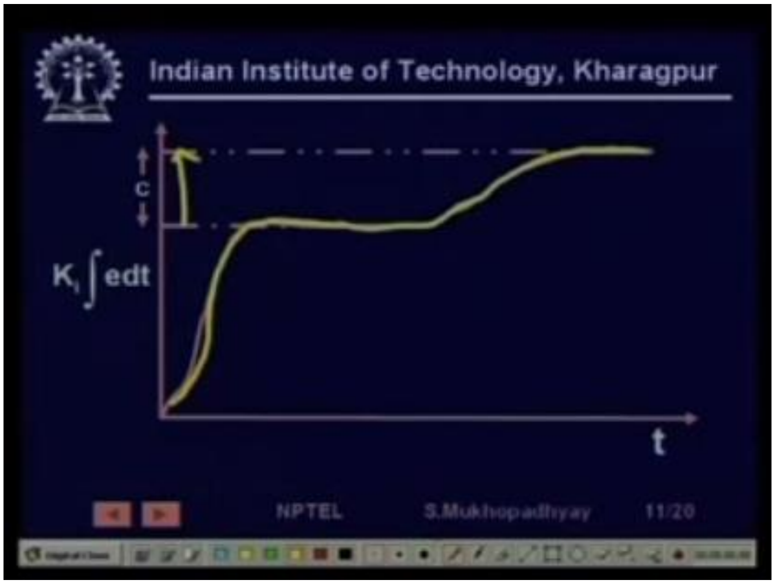

Now so exactly this is what happens so now we see if you if you put the integrator what happens is very interesting so what happens is that this bias input which were previously coming now comes automatically that is the integral output which I was talking about now increases still it can then it goes to zero and then if you if you change the set point again from here to here again some error will be created.

And again integrated will generate it just enough output such that it can be it can be sustained without the error, so you see that the integrator is actually the integrator actually works as.

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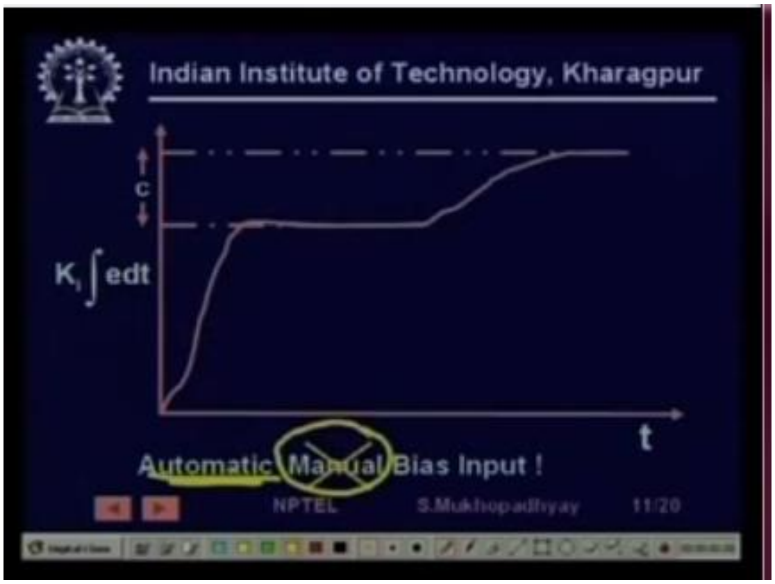

The integrator actually works as a very interesting thing it actually gives a bias input but which is not manual, so the bias info integrator I is actually exactly like the like that like the bias input but it generates it automatically you do not have to give it annual you do not have to give it manual and it will adjust itself depending on if you depending on the set point so the integrator will automatically build up and give enough additional input such that at zero error it can be sustained.

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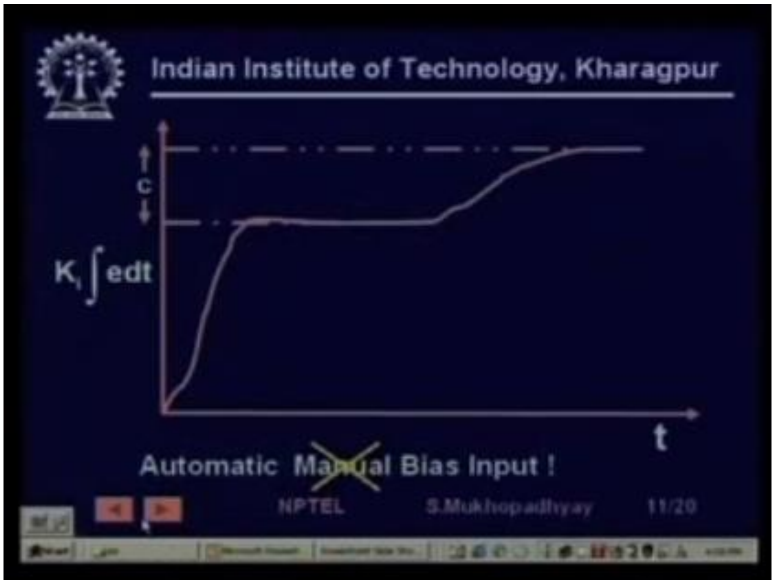

So that is the principle by which 0 steady state error is obtained.

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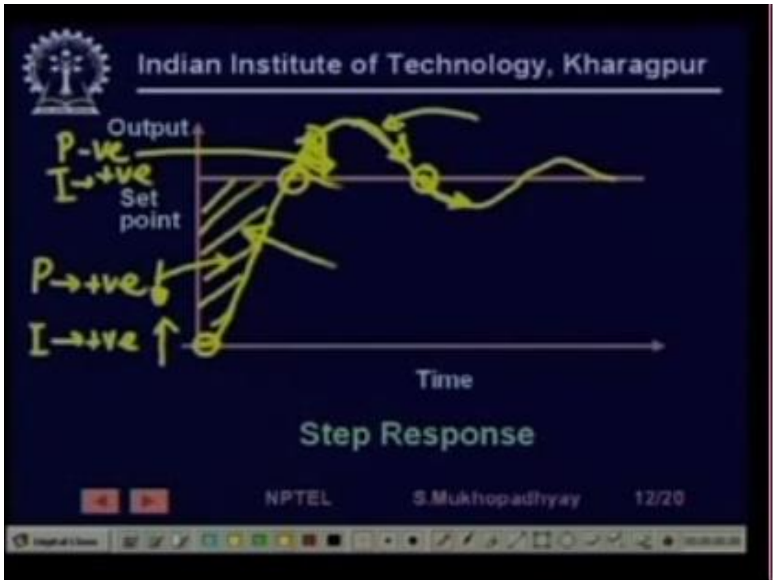

Now only thing is that now this has certain there are certain drawbacks too for example let us see that if you give a step response if we give a step response then how does it how does it work how does the loop work, so you see that suppose the process starts from here, okay. So the process starts from here it starts so as you have given so here there is a lot of error so the proportional controller now generates a positive input.

Which drives the plant so the plant goes up and typical we are likely to get a step response like this, so what happens during this phase during this phase during this phase you have proportional is positive error is positive so output is positive but since the error is decreasing so the output is going down so it is positive but going down that is the output of the proportional controller, what does the integral controller do?

Integral controller is also positive because it is integrating positive error and it is increasing because the because the area as it is going with time this area is continuously increasing, so it is positive and going up increasing, right. So what happens at this point error is 0, so the proportional controller output is 0 but because the integral controller output s still positive so the plant continues on this journey in this path, right.

Now at when it is here let us say when it is here the proportional controller around this point P is negative P is negative but I is still positive because of the fact that there is already a large positive integral accumulated here so here integral is negative this part of the integral is negative but still there is a large positive integral so it so that overall net output is maybe still positive so it continues on this journey.

But eventually the this integral value also reduces and the proportional controller value also becomes enough- so the overall input turns negative and the plan turns to move, now again the same thing happens here once it crosses this line now that now again it will it will oscillate so you see that typically because of integral control they are tends to be an oscillation so that tends to be a high overshoot.

And an oscillation so this is a drawback of typical control that is to gain steady state error to gain to gain 0 steady state error this is the price that you are paying that in your transient response you are likely to get some.

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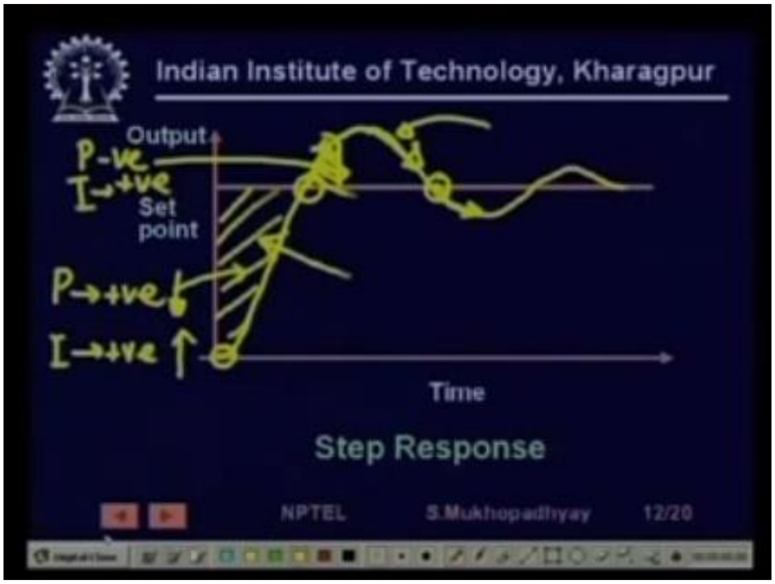

Overshoot so.

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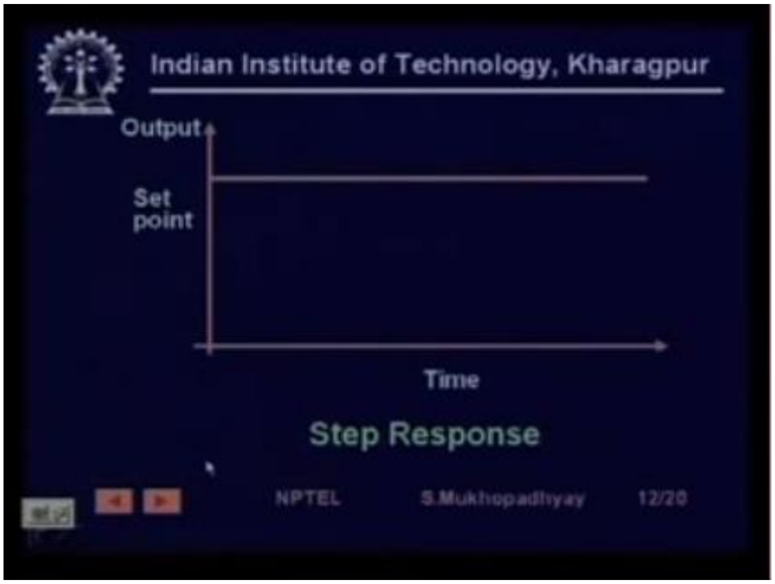

That is the picture for the step response.

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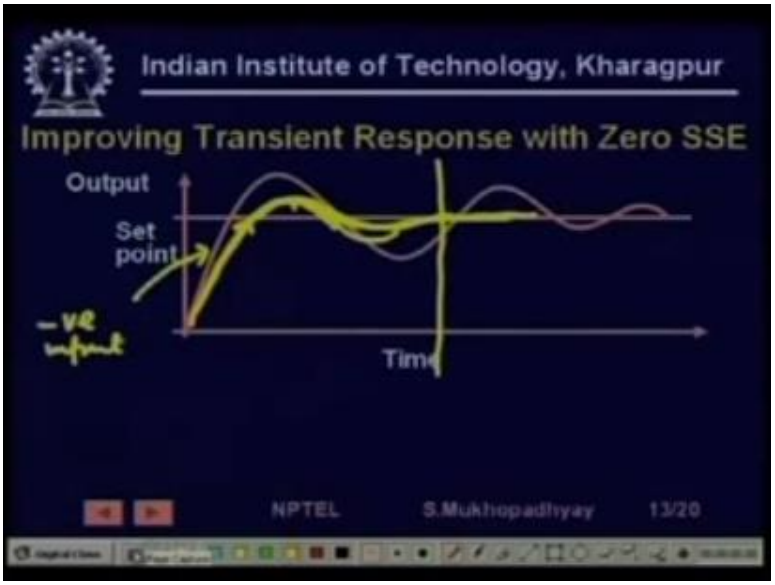

So we want to improve transient response without sacrificing the steady state, level so if you want to do that then what we have to do is that around this point only here we have to we have to be able to keep breaking you know we have to keep breaking and around this point so that we can quickly turn so what happens is that here now we have to you have to slow down so slowing down means during this phase we have to create more negative input.

Which will grow towards this point as it comes closer it should this negative input or increase similarly around this point this negative input should also this negative input should also keep increasing so that it quickly turns and then actually it will settle very fast so you see it will not oscillate if you we want that it does not oscillate so many times but rather follows this yellow car maybe does a small overshoot and then immediately settles down.

This is the kind of curve that we want, so now it turns out that this kind of curve we can obtain if we add.

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A derivative term together right, so we want to reduce rise time what is rise time we want to reduce rise time is we want to reduce this time we want to typically speaking we want to reduce overshoot that is this height and we want to also reduce settling time there is total time but taken for you to come to a steady state, so we want to reduce that all these now getting all this is somewhat difficult and that is why you need to have a you need to have a non-trivial tuning exercise. To you know come to a compromise between these we could.

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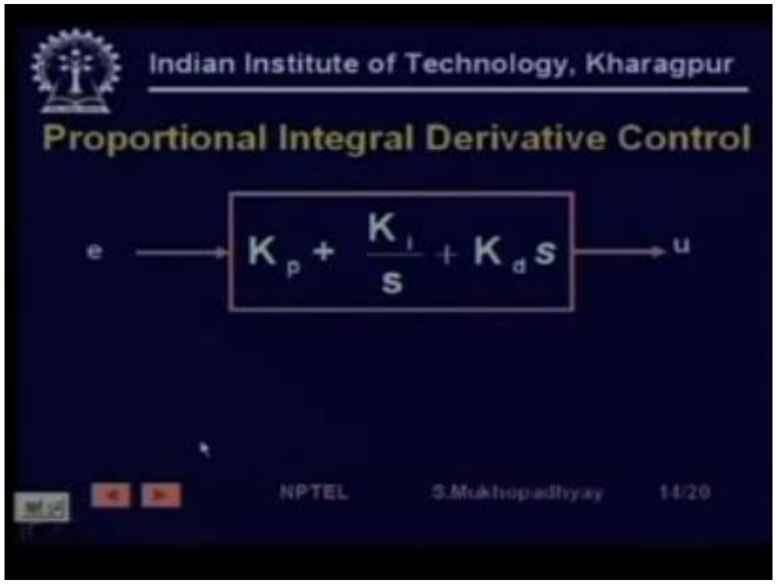

Typically what we do is it turns out that these things can be achieved we have already discussed proportional and integral controller and we have also seen that adding a derivative will you know try to break so that it does not go towards much overshoot.

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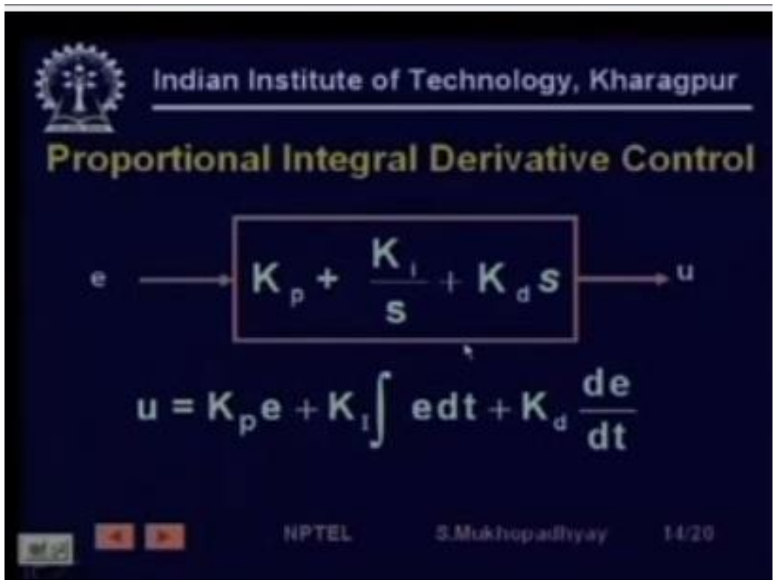

So we need a we need a proportional controller because if you do not have a proportional controller then there will be tend to be too much too much of oscillation we need an integral controller to have 0 steady state error and we need to have a derivative controller to have low overshoot and fast settling time and we need to tune this gains Kp, ki and Kd nicely so that we get a good transient response without sacrificing on the 0 steady state error.

One thing interesting to see is that this so we now calculate input like this, now interestingly that you see that in the steady state in the steady state the total of e0 so therefore this term is 0 so the proportional controller is 0 and since he is not also changing so there is a de/dt is also 0 so that is also gone so we only have the whole output coming from the integral part. So the 0 steady state error concept that you have studied for the integral control holds.

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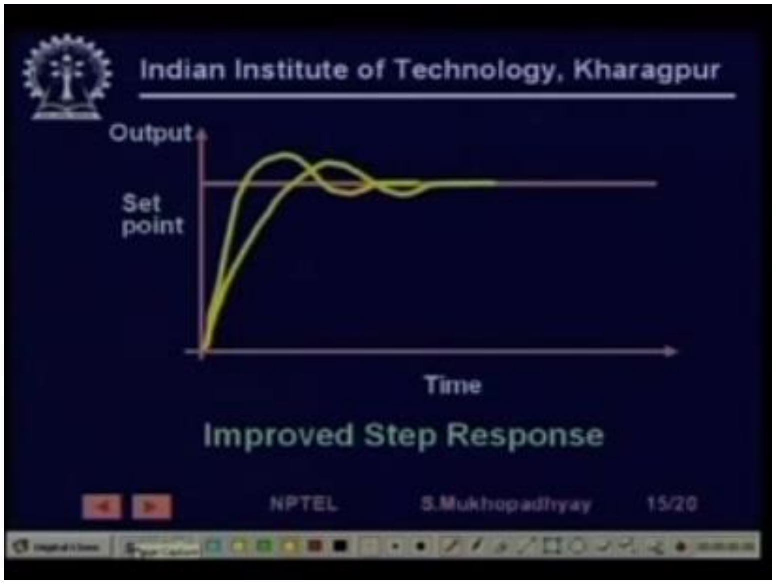

So as I said that we need we are we are looking for a step response like this would be a very good step response and we if you can make it even sharper even better but generally if we want to make it sharper then if we can make it like this even better so this is a good step response that we would like to achieve.

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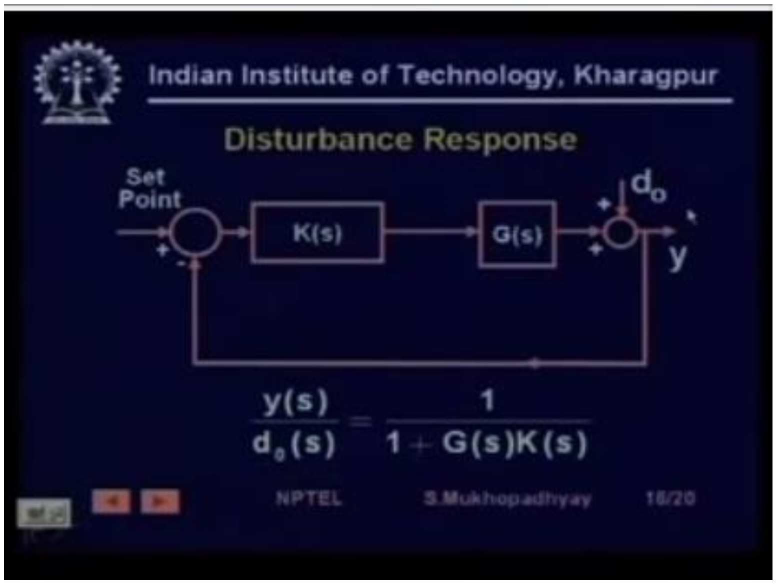

So now come to the point of disturbance rejection, so what is the disturbance response the disturbance so let us talk about there are there are there are several types of disturbances and you can do the same kind of analysis but the most predominant disturbance which occurs generally is the load disturbance in a process, occur due to various reasons property variations of materials, variations in power sources, voltages variations in pressure sources all sorts of things.

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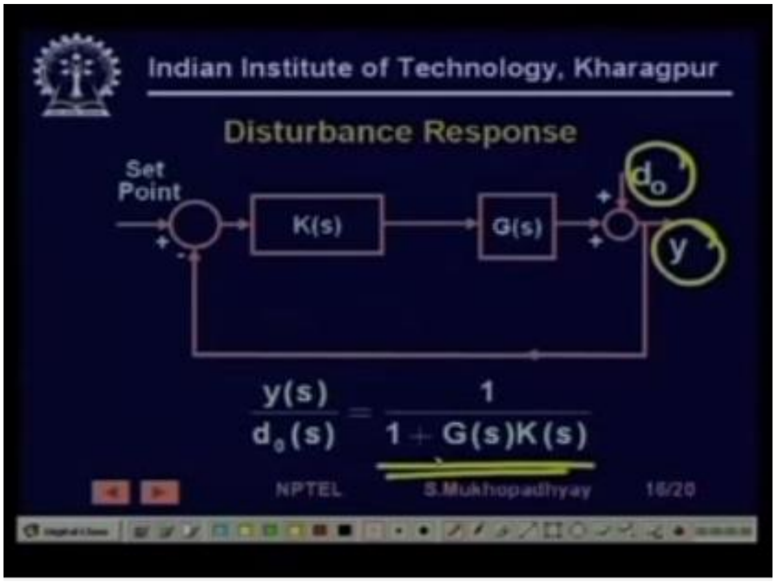

So it turns out that the transfer function we want to reduce the effect of the we want to reduce the effect of d0 on y so what is the transfer function between y and d0 that turns out to be this so now again we see that if you have so you know it is not possible to exactly neutralize all kinds of disturbances but let us say one of the major kinds of disturbance is step disturbance again that is disturbances we change once or twice and then stay on okay.

So if you have step disturbances then you can again see that.

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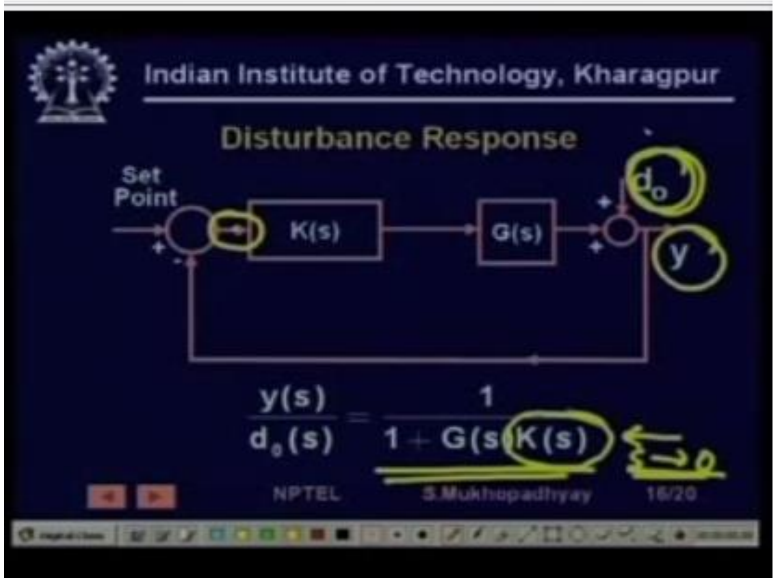

If you have an if you have an integral then this term will actually go very high as a tends to 0, so the effect of so for the same reason exactly similar transfer function is coming so the same reason why e goes to 0 with integral control if you put integral control even the effect of step disturbances will also go away because the integral value will rise and it will provide the additional torque to actually take care of the disturbance.

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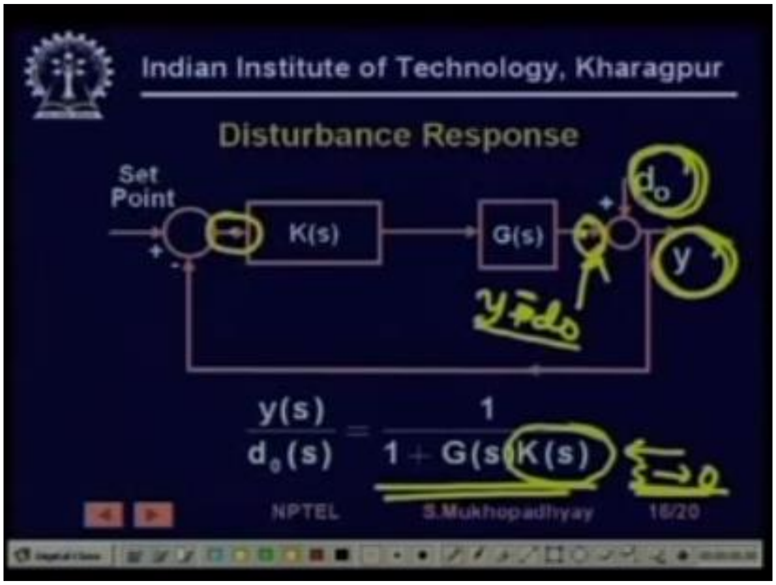

So it will produce an integral will rise and it will here it will instead of producing y it will automatically produce an output y + d 0 or other y - d 0 so that after plus d0 you will get the desired value of y, so this is going to happen so integral control is one of the major ways of reducing disturbance response.

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So this is these are now let us look at some other issues for example this we have to we have to actually remember these things they are very practical issues and we possibly did not learn about these in our in our earlier control scores when we treated things rather ideally but we must remember here that some other non ideal exits.

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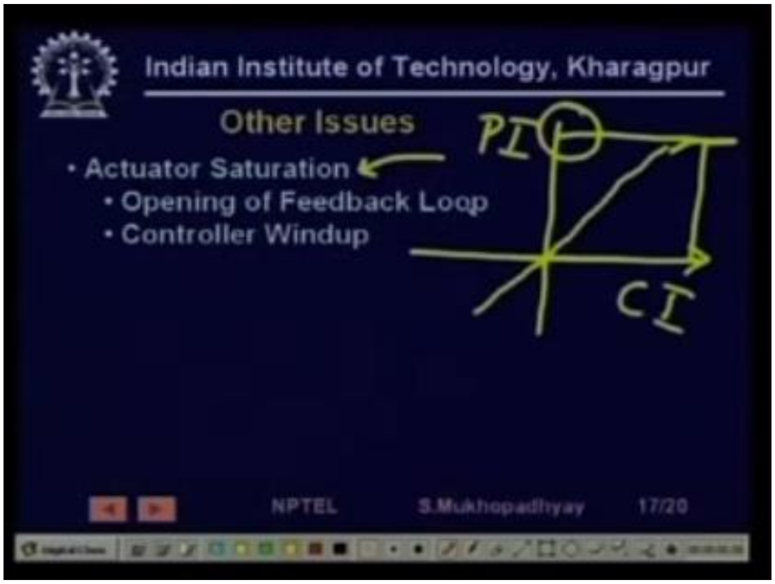

For example, there can be very often there can be actuated saturation that is the characteristic of the is the control input CI and this is the plant input PI so this is the actuator characteristic, so as you increase the control input the actuator will also proportionally include the plant input but only up to a certain point after which it will saturate, so if you give more and more control input it will not give you proportionally high planting.

So that should as typically will saturated, now when the actuator saturates effectively the feedback loop is opened because the effect of the error no longer transmits to the output or rather the plant input so the input does not change in response to the error but is held constant that is the case of an open loop operation, so your control is gone.

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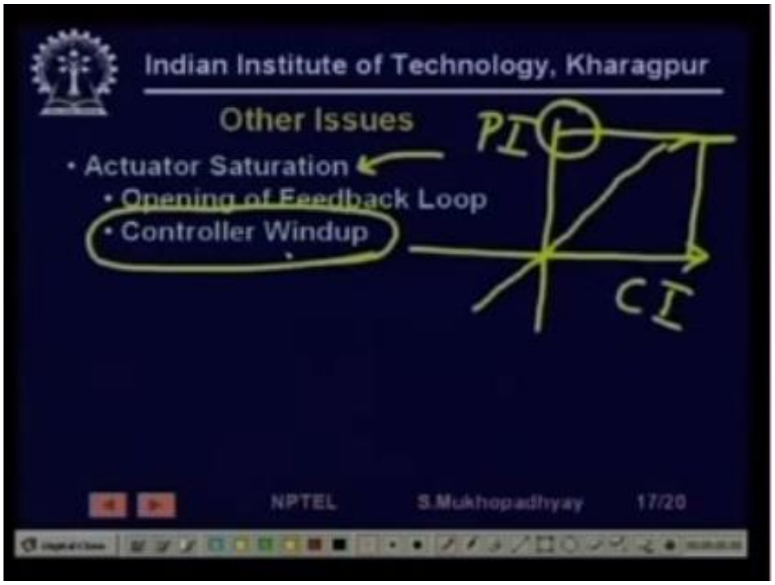

And not only that these sometimes as we shall see later that the kinetic that says persistently actuator saturation persistent actuator saturation has very bad effects on controllers especially with because of the fact that controllers have memory so this is a particular phenomenon which occurs in PID controllers and we are going to take a look at it in great detail in the next lecture.

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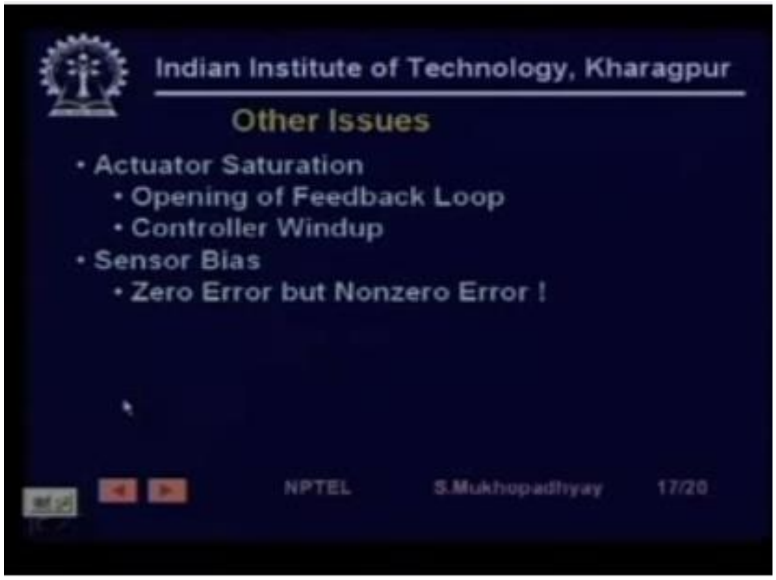

So next issue that we should look at is sensor bias so you know remember that if you have a sensor bias sensor has errors then sensors are the eyes of the controller so whatever the sensor sees that the controller simply works on that so if you have bias you will think that is the controller will produce an input.

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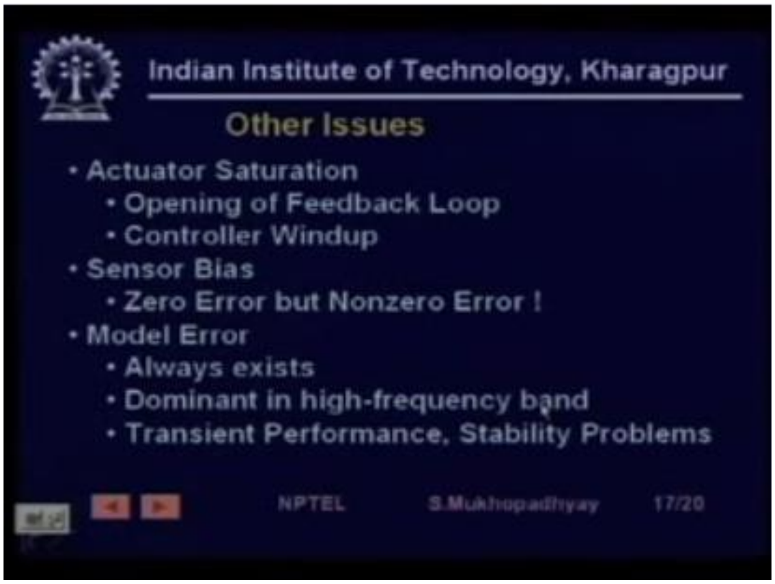

Which will have zero error but actually there will be non zero error so that is you so you have zero error but you have non zero error similarly we have to remember that that you always have actually you design controllers based on some models but it always turns out that these models are actually inaccurate so you are always going to have model errors and this model errors are typically dominant in the high frequency band.

And now remember that if you have inaccuracy in the high frequency band it is the error in the hive actually typically instability occurs in the high frequency band not in the DC band low frequency band so if you have modeling error in the high frequency band then such modeling inaccuracies can also lead to stability problems, so we have to remember these things.

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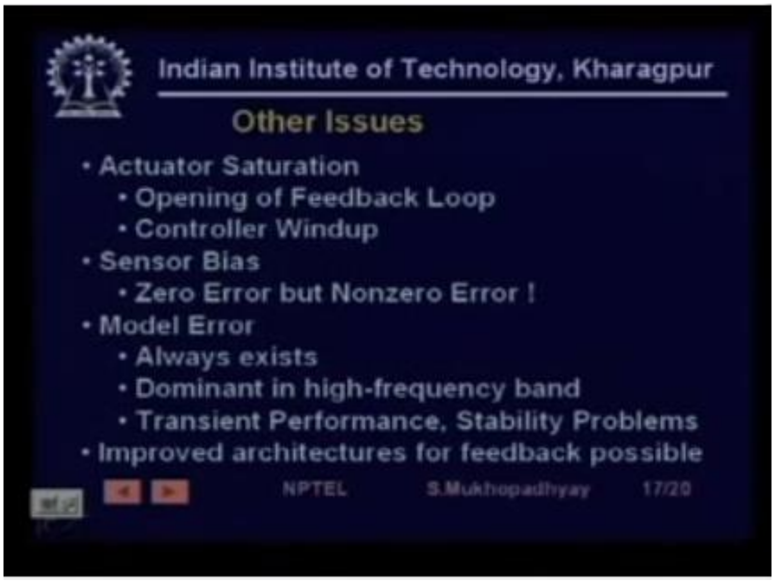

So to take care of these things various kinds of other architectures are possible then what we have that is the loop structure what feedback will use how we will use the controllers and we will see some of them for example feed-forward configuration cascade configuration we will see all of them, so they are possible.

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Finally while we are going towards the conclusion let me mention some of my pet facts about control in colloquial terms, so I say that what you feedback is what you control what you so the controller exactly tries to maintain the feedback so if you feedback s erroneous then your control is erroneous, if you are sitting in the middle of the room and if you have put your temperature sensor at the at the roof of the room then you are controlling the temperature at the roof of the room not in the of the room right .

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Then when you what you cannot actuate you cannot control so you may be giving whatever in output from the controller you may be using a fancy algorithm but if you cannot actuate it then you are not controlling it well.

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If you can if you can measure or estimate the disturbances then you can compensate them so one of the I mean there are many advanced algorithm switcher which precise you try to do that stability is basically stability is not enough stability is barely basic performance you must ensure stability and then ensure performance but while you ensure performance if you as you try to go more and more drive more and more and improve performance eventually instability results.

So instability is actually comes it actually decides the generally decides the maximum performance that you can achieve.

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And models are always approximate most systems are actually nonlinear but that does not mean that we can work with approximate.

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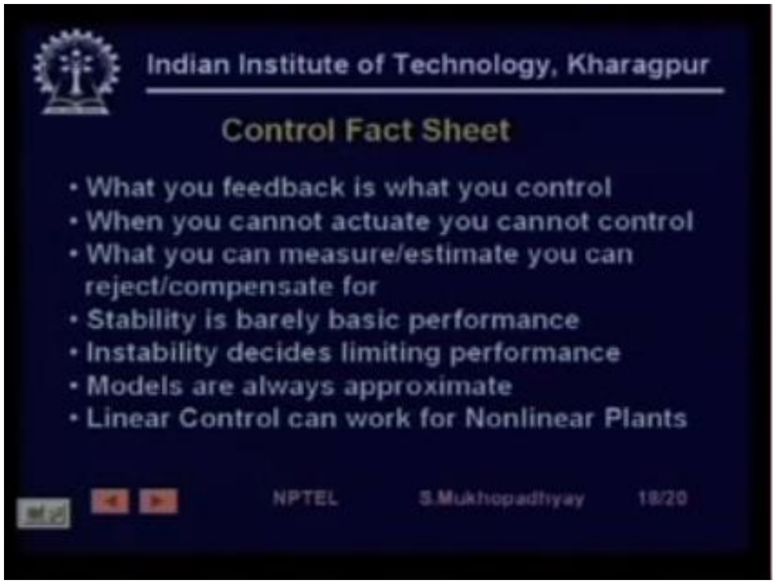

So linear control can work very well for non linear plans but sometimes nonlinear control may be working better but 95% of industrial controllers are linear.

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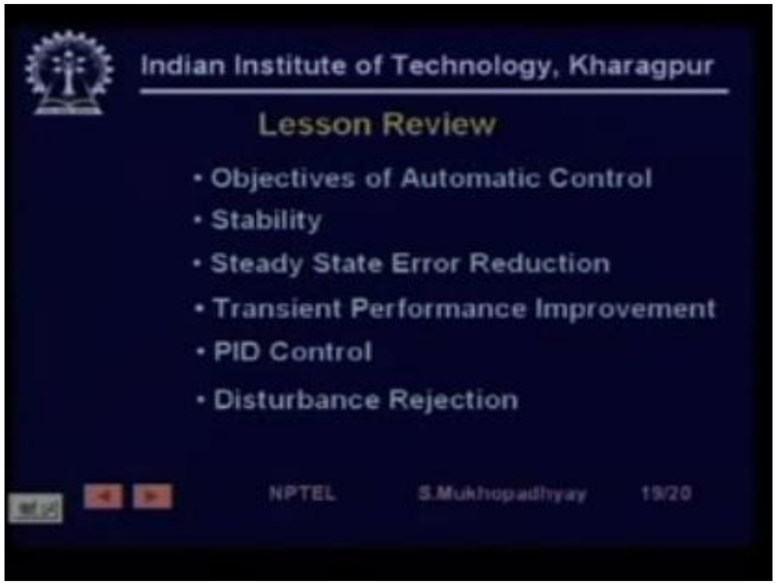

So we have come to the end of the lesson and let us review quickly so we looked at the objectives of automatic control maintain stability follow set point this term reject disturbance, if we looked at stability and found the causes of stability in because of instability in the process loop we looked at steady state error and the ways of reducing it and we also looked at the ways of reducing transient performance keeping the steady state error at zero.

So we saw that the PID control is a very effective waves and simple and effective way of doing that and eventually we say we saw that PID control can also do some amount of very common disturbance rejections.

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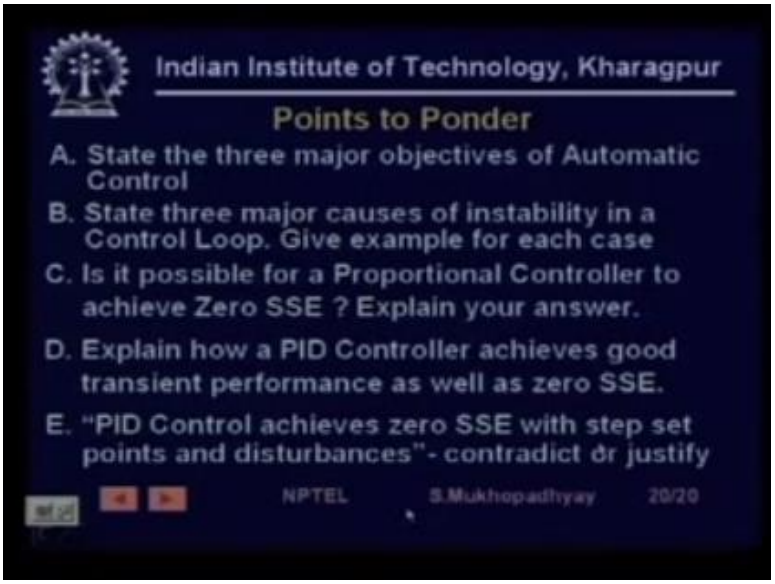

So that is the end of the lesson let us here are some points for you to ponder, first is that state the three major objectives of automatic control which I have just now said, state three major cause of instability in a control loop and give this is tricky try it given example for each case practical example and is it possible for a proportional controller to achieve zero steady-state error I have already explained an example.

You try to explain it in your own language and explain how a PID controller can achieve good transient performance as well as zero steady state response and finally justify or contradict the statement that PID control achieve zero steady-state error with step set points and disturbances, thank you very much we will see the next lecture.