INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and
Control

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Topic Lecture – 18
Time Delay Systems and
Inverse Response System
(Contd.)

Now having said this let us come to the second part of our lecture which is on inverse response processes right so what are inverse response processes with let us first defined typically inverse response processes occur when the output.

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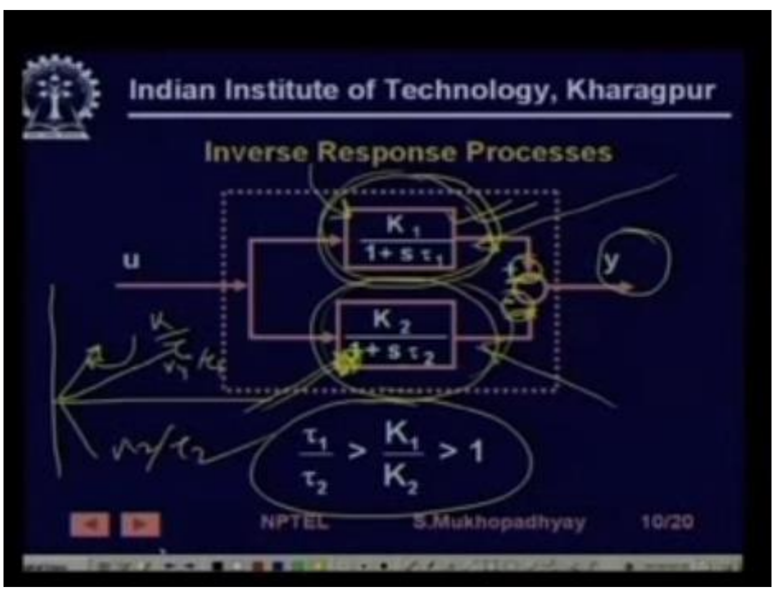

Is actually produced by two effects so this is one effect which produces the output and this is another effect that produces output they together produce the effect overall effect of the output and it turns out that one of them is opposing the other so you see one is plus another is minus the second fact is that in the short timescale that is over time scale in the initial phases this one dominates and in the long term this one dominates so when you have such a situation then obviously in the short term you will get an effect which will come according to this one and in the long term you will get an effect which will come according to this one and they are opposing.

So the thing is that you why it is called an inverse response process because the response to an input initially you see in an opposite fashion and finally you seen a in another fashion so if you design a controller for this process then for the initial time scales this is going to be the response of this will actually confuse the controller this is and might cause in stability and other thing this is the main problem for example in this case why is the why is it supposed to be dominated by this initially and dominated by this later on opposing things are is clear because it there is plus and there is a minus.

But how do you know that that initially this one will dominate and initially that one will dominate for example the effect of this branch is to produce a negative output and the effect of this branch is to produce a positive output now we can we know that if you have a K_2 / K_1 plus s τ_2 then towards the initial phases then towards the initial phases the response increases like a straight line whose slope is given by K/ τ so in during initial response this block will produce a slope which will be - K_2/ τ_2 and this block will produce a slope which is K_1 / τ_1 and this is K_2 τ. So since according to this condition K_2 / τ_2 is greater than K_1 /τ_1 so therefore initially the response now we can go to the next slide so what is going to happen is that.

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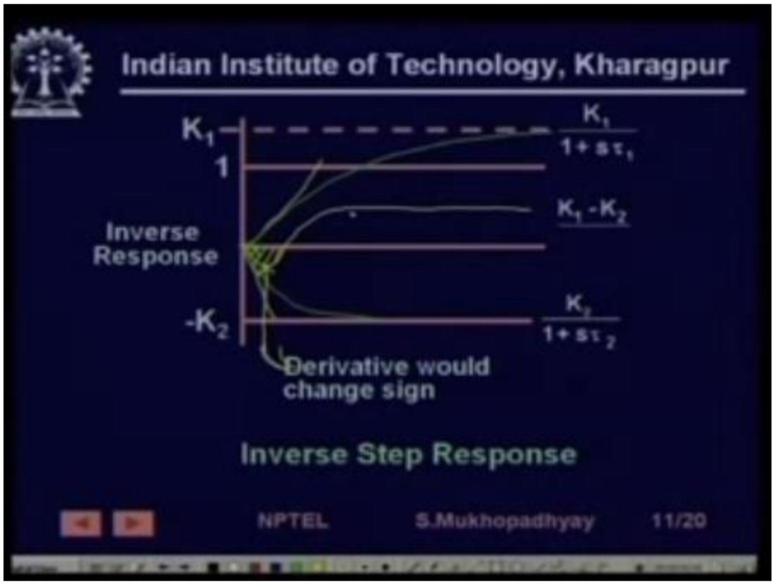

What is going to happen so imagine that let us consider this the step response of that process so I have given a unit step so the response due to the K_2 block will start is very difficult to understand where to put it so the response due to K_2 block will start along this way and the response due to the K_1 block we will start along this way with this slope so the net result will be that the overall response will initially start going negative and then it will change sign and then it will settle at a level which is given by K_1 -K_2 because those are the initial because the response due to the K_2 block will actually level this will be the response while the response due to the K_1 block is going to be like this.

So eventually and this is the overall response so see that the system will though it is through a positive unit step has been given initially the system will show for this time the system will show an inverse response it will go in the opposite direction and finally settle down in the positive direction this is what is called an inverse response one thing we must note that the derivative of the response this changes sign much earlier it changes sign much earlier than they actually the response changes sign.

This is a fact which is to be noted which has some b array so now having seen the kind of responses that we expect let us at least see one example of why it happens at all so let this is this is a very classic example of a what is this kind of process in verses response processor sometimes also called non minimum phase systems and this is a classic boiler drum level control is one of the very classic examples.

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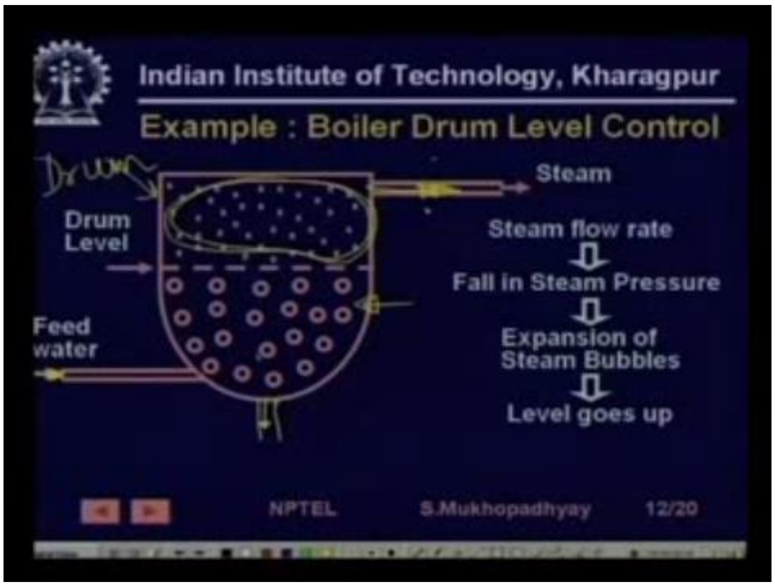

Of an inverse response process you know boiler drum means that ball boilers if you go to a power station then what happens is that the boilers have tubes in them and in those tubes water is water vaporizes so the water steam mixture actually goes and actually what happens is the water flows from a tank on the boiler which is called the drum so let us get the picture. So actually the this is this is the container on one hand the feed water increases in fact there is there is another outlet of this which is not shown here that outlet is here.

And the it is through this that the water flows into the boiler tubes so the water goes into the boiler tubes and returns also returns right so when it returns it has lot of steam so water returns this is the return and this is the boiler drum level so this thing is called the boiler drum it is basically a dunk which is a big horizontal drank situated right on top very high above typically a power station boiler is about three stories high and the drum is on top of that if you want to see it you have to go up a number of stairs.

So what happens is that without going into much details of boilers let us what happens is that the water enters here there are lots of bubbles steam bubbles which actually come to the surface being lighter they come to the surface and then the break and then they form a steam part in the boiler which eventually goes out and finally goes to the super heater and then enters the turbine for power generation.

Now imagine so in the steady-state what happens is that the mass if the boiler drum level has to be maintained then the mass of feed water that that you are the mass of water that is entering the system and the steam that is leaving the system must be matching so what happens now imagine that the power station operator wants to increase the power so you will do what so for increased power you need to supply increase theme to the turbine so the steam flow rate will be changed so when the steam flow rate is changed immediately what happens immediately what happens see what should happen in the in the steady state what should happen in the steady state what should happen is that the sea that is also shown here that.

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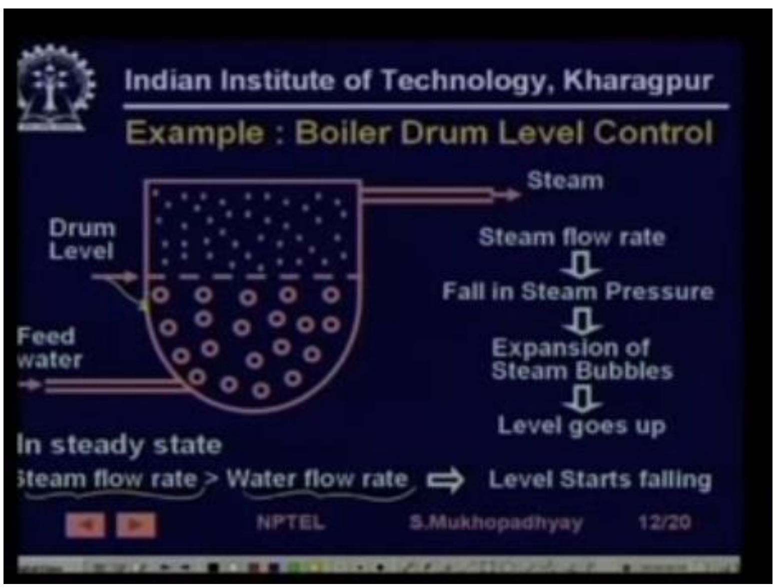

That in the steady state steam flow rate is increased so steam flow rate is actually greater than water flow rate so there is a material imbalance so eventually this drum level finally should start falling because more less material is entering and more material is leaving the system this is going to happen in the steady state but what happens in the short range what happens is that immediately when the steam flow rate is increased there is a reduction in pressure the pressure falls.

Now you see that what this the crux of the matter is that this level is here there are bubbles these are steam bubbles so the volume occupied by the steam bubbles actually depend on the pressure which is applied on the surface so the moment this pressure will be released these bubbles will expand so the expansion of steam bubbles which will mean that this volume will rise volume will go up.

So you see that here you see a non minimum phase response that is in the long range the volume will should start falling but in the short range what will happen is that it will go up this is non-minimum phase behavior this is shown in various other cases in aerospace plants also such a thing is shown but anyway so now what this causes so let us look at the thing a little analytically also.

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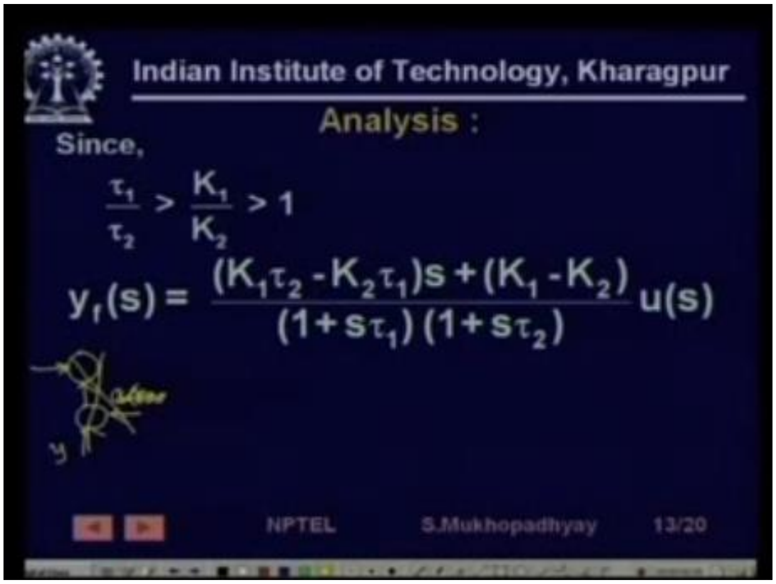

So you see that if you just see the feedback transfer function and do up little analysis we will find that the y feedback was the point where we were adding that Smith predictor output so this was y and this was that G(1-e) to the power this is not that one this is this was yeah so basically this says that simply this is nothing I sorry we are not yet considering feedback at all so this is nothing but the open-loop output for example let us go back a little bit let us go back a little bit.

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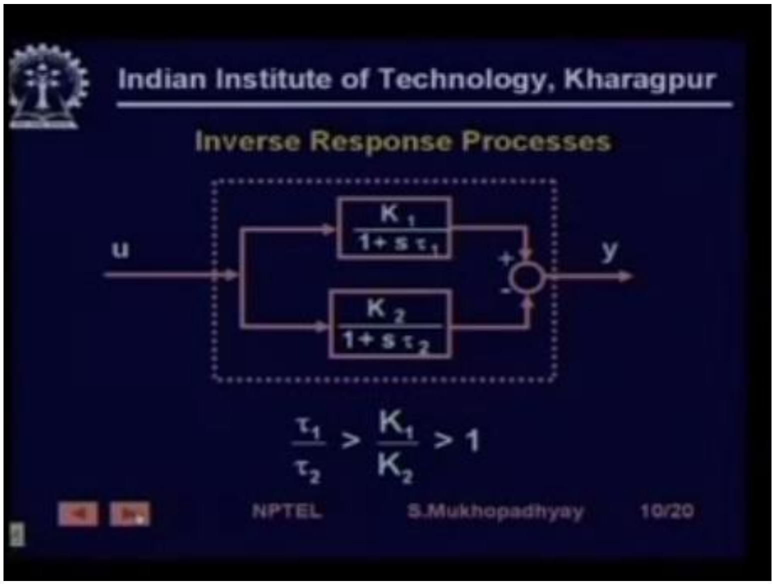

So this is nothing but the response to this one so the response to simply if you calculate y it will come out to be that expression right.

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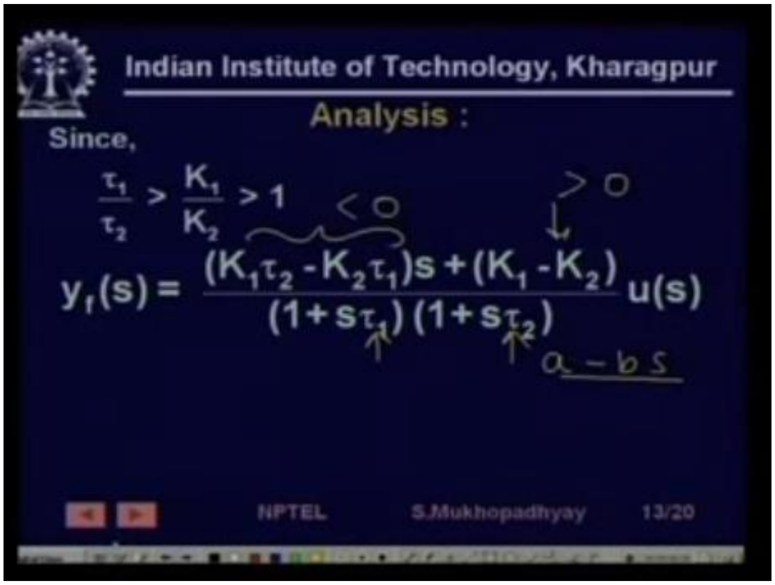

So correct so this is simply the open-loop transfer function now what we found that you see $K_2\tau_1$ is actually greater than $K_1\tau_2$ from this expression so therefore this is actually a negative quantity less than zero and this is a positive quantity greater than zero because K_1/K_2 is greater than one so what happens is that we have a fact so we have a we have terms like you know a - bs which means that it has a zero the poles are this will give the poles and this will give the zero of the transfer function. That there is a what is known as a right half plane 0.

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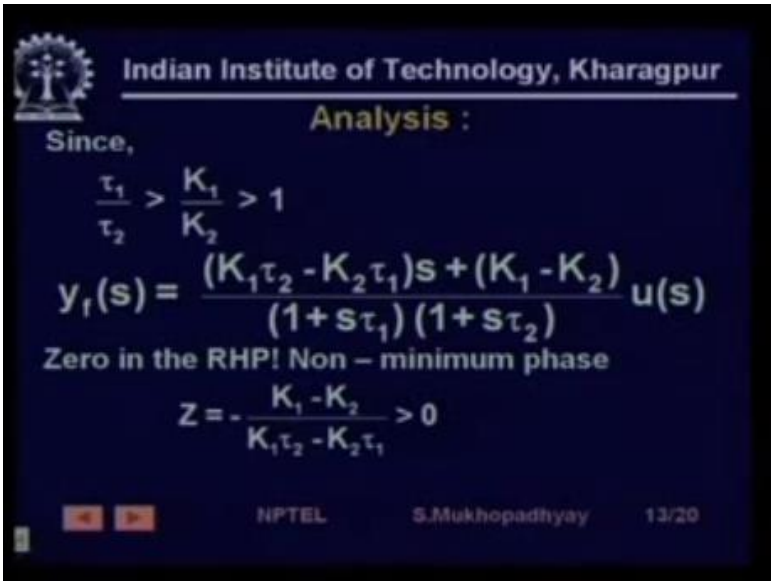

So the real part of the 0 is in the right half plane and such the transfer functions are called non minimum phase for a different reason the which is not concerned we are not concerned with that so we will not try to explain that and that zero location is given by this $-k_1/k_1$-k2/k_1 τ2-k_2 k_2 τ_1 k so that is the location of the zero now the question is that the it is this opposing effect which is causing this inverse response and which is also causing the 0.

So the question is that how can we remove this non minimum phase behavior why we should remove it that we will also see but this non minimum phase B we can at least understand at this point of time that the controller is going to get confused because the controller has been designed for the final response which should move in a certain way initially the response is going to move in a different way so the controller will tend to give a different kind of I mean controllable will get confused in driving the plant.

So now the question is that so perhaps we should remove this non minimum phase zero and somehow put a minimum phase zero now how to do that this is not for example we know that if we have.

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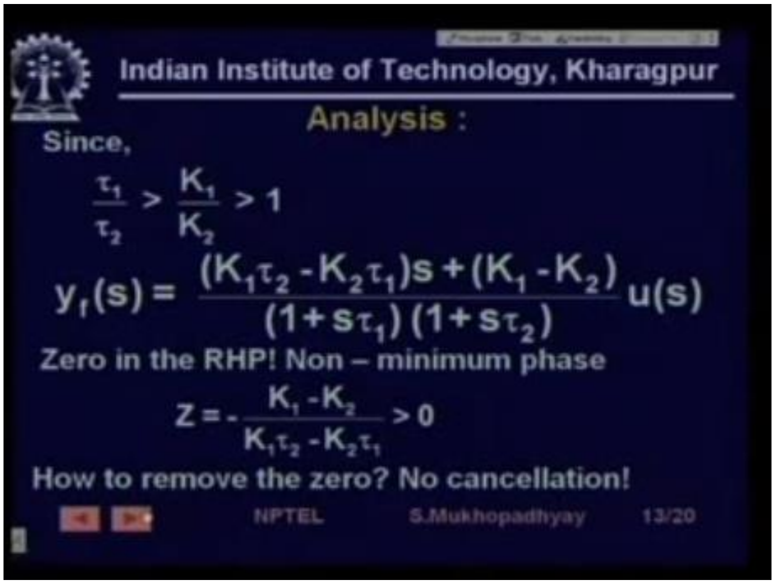

You know with the kind of transfer function that we have considered till now so far generally also in first level control courses they always have the poles choose color so the poles can be in the even there in if they are left half plane then stable if they are in the right half plane unstable and we buy feedback we have seen using a controller we can bring it from right half plane to left half plane but what do we do about zeros one very standard way of changing zero suppose our transfer function has s + a / s + b that is which as the left half plane 0 and we want to change it to we have to make it to s+ c / s + d.

So then what do we do so we first we can always multiply it by s +c/s + a so where this is we are talking about zeros so let this b only so if you want to change the 0 we can always multiply it so that this and this will get cancelled and we will get this but this is not possible when you have a right half plane 0 because if it is s- a/ s +b then you cannot multiply it by s + c /s - a and say that this is cancelled and it will give me give you this because this transfer function is unstable.

So what is what this is going to cause is it will cause and if you try to do it like this it will cause what is known as internal in stability so what happens is that internally some signal will go unstable although it may not affect the output.

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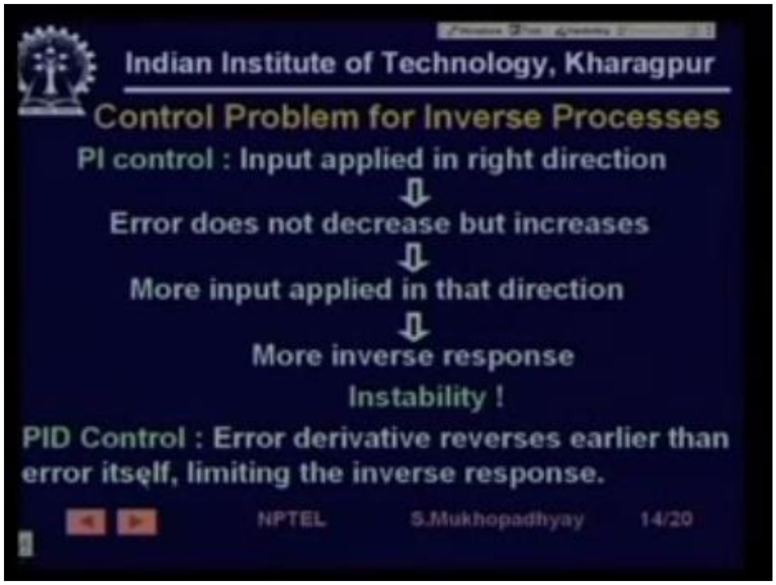

So we cannot cancel the zero you see so what we must do is so what do we do so this is another case where we are saying so actually now we come to the control problem what happens in the let us say for example if you have a PI controller then the PI controller will apply some input in the right direction it will change this see the set point coming from coming but the error does not decrease because the error goes in the opposite because the response goes in the opposite direction so the error does not increase it does not decrease but it increases.

So what is the PI controller do it applied more input things that it is not going so let me apply more input so the more the input is applied the more inverse response will come and this might lead to an instable seat and an unstable situation on the other hand if you have a PID controller PID controller also not only sees the error as integrals also since the rate now as we have seen that the rate will reverse quicker so the PID controller has is likely to give slightly better response because it will try to reverse give correct inputs much faster because of the derivative reversing.

This is just a ester side but let us see first how we can we can we can compensate for this inverse response.

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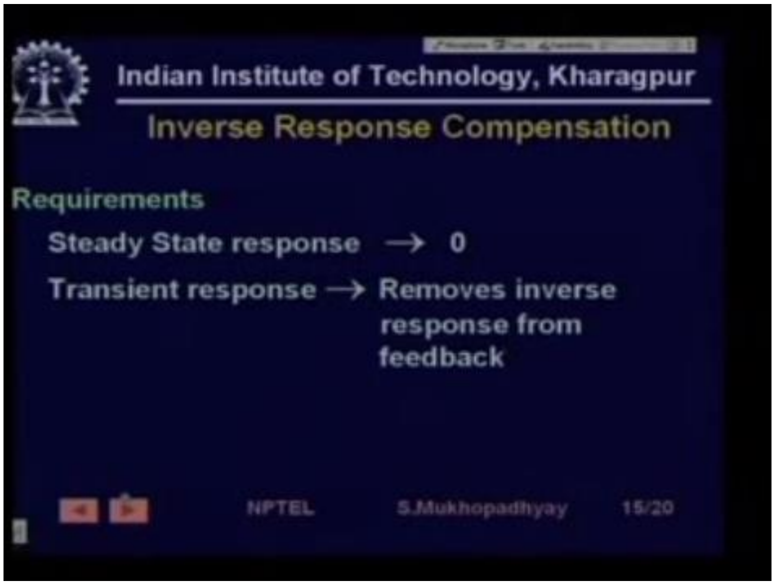

So first what is the requirement the requirement is that in the steady state my response should be alright so this whatever compare I want to do its effect in the steady state should be should not be there but in the transient response actually what it should do is this inverse response it should not allow to be feedback to the controller which is confusing the controller this is the main thing so it should remove the inverse response from the feedback in the initial parts. Now how to do that.

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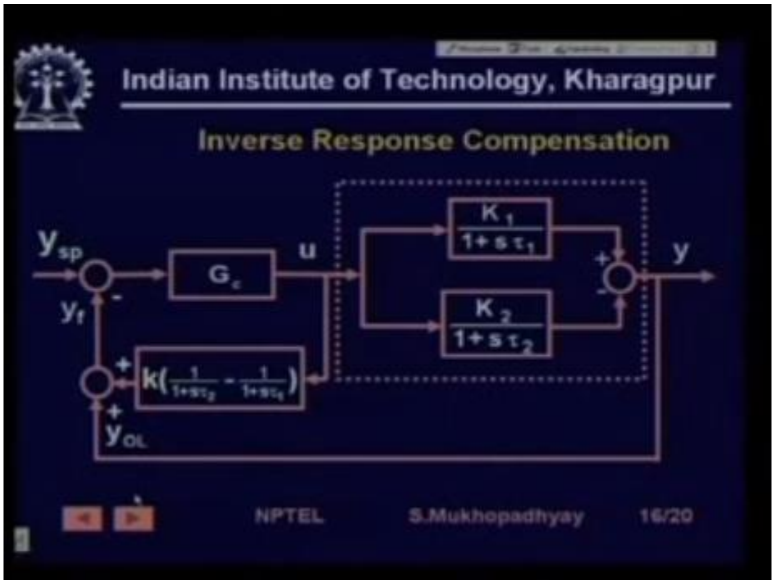

So to do that we have this so you see again just like Smith predictor we are again adding another term here so this select this so again adding another term here now what is the effect of this term the effect of this term in the steady state in the steady state the effect of this term you can verify is 0 because 1 / 1 + s τ_2 and 1 / 1+ s τ_1 set s_0 this the steady gain of this is this is 0 then the steady state no effect but in the transient what happens so now the plant is seeing this feedback rather than open loop response feedback. I am now modifying the view of the plant so what happens is.

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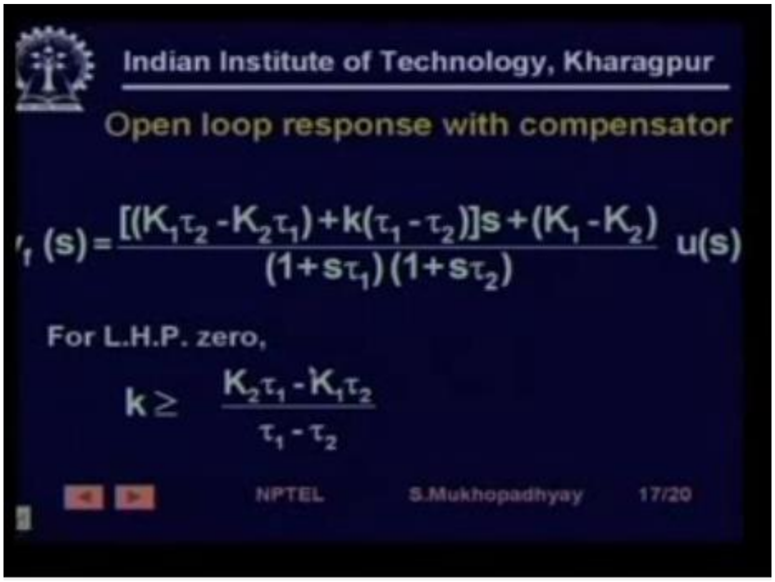

Now the feedback term if you calculate then you will get it as K1 τ_2 –k_2 τ_1 +K x τ_1- τ_2 so this is this term has been added now previously it will only this and it was negative so if you want to shift the zero then what we have to do is what we have to do is we have to add this K in such a manner that k is greater than equal to these then what will happen is that this 0 will become left half than 0 and the non minimum phase response will not be shown to the controller.

So the controller will not see the non minimum phase response and will not get confused so this is the this is the approach which is taken for non minimum phase systems.

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So this is the way that we are now coming to the end of the lecture and we have to quickly review the lesson so first we so are the sources of time delays and their effects on stability and then we saw a way of controlling by Smith predictor controls we did exactly the same thing for inverse response we saw inverse response how it arises in a process and its problems and finally we saw a way of inverse response compensation.

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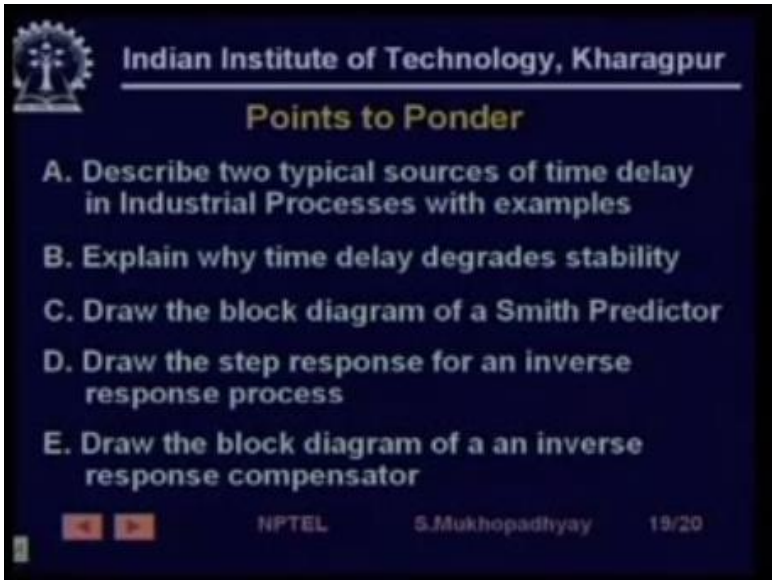

To end the course to end the lecture that we have as usual some points to ponder so you can describe two typical sources of time delay in example industrial processes you give your example explain why time delay degrade stability try to understand it draw the block diagram of a Smith predictor this you should be able to do without after this lesson the step response for an inverse response process and finally the block diagram of an inverse response compensator.

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So that is all for today thank you very much.