Industrial Automation and Control
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Lecture - 15
A. Predictive Control of Time Delay Systems
B. Control of Inverse Response Systems

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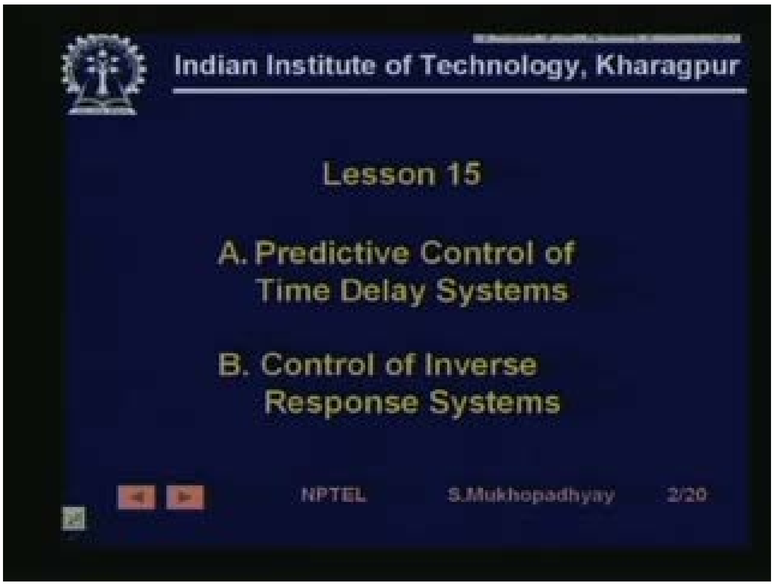

Very good morning to you. Today we are going to look at lesson number 15 of this course which is on, which is on two topics. A - Predictive control of time delay systems and control of inverse response systems. So, we are going to look at two typical kinds of processes, which I would rather say two special kinds of processes which arise in the industry in various contexts. And we are going to see special configurations for controlling these processes.

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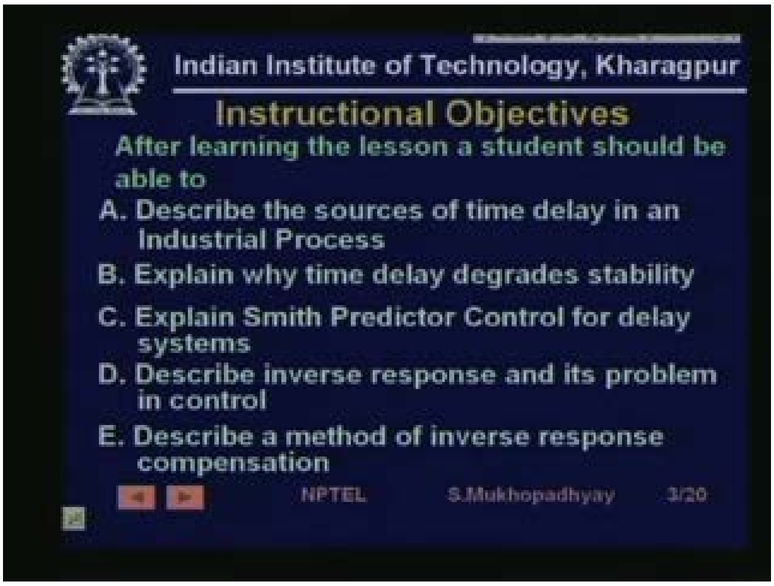

So, as is our practice we will first look at the instructional objectives for this course which are number one, first of all we need to understand how time delays arise in industrial processes and then we need to understand why what is the effect of this delay and why it generally degrades stability and creates problems. And finally, in the context of time delay we have to understand, we have to look at least one way of one effective way of controlling it and see what it involves.

Similarly, for inverse response processes we have to first of all know what is inverse response and how it arises and at least an example and what kind of problems it cause in control and then see one method again of inverse response compensation. So, this what we are setting out to learn today. So, let us first look at the causes of time delay.

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The main cause of time delay is transportation lag. This is the most common and prevalent type of cause for time delay, because in the industry material has to be transferred from place to place in the course of operation and material transfer, flow of liquids, movements these things take time. So, there is this is the, this is called what is known as transportation lag and is causes you know the majority of the cases where time delay is seen especially in process control, chemical process control. The majority of cases is due to this transportation lag.

So, this transportation lag can cause a delay either in a process because things have to be transported from one end to the other. For example, suppose you have a distillation column. So, if you want have composition control, and if you give an input let us say either at the either increase the let us say the reboiler heat input. Then the effect of that input has to, has to travel that is the, which will lead to a temperature change in the material. Then that has to physically travel up and down, that is the vapor has to travel up and the liquid has to travel down to finally, effect composition. So, this essentially involves a delay.

Similarly, in the case of an actuator, you know actuators typically let us say again, let us, let us take the case of temperature control. Temperature is controlled by sending steam, heated steam around jackets of reactors let us say one way. So, if you give an input that is if you increase the steam flow rate by giving a command in a valve, then that increased steam flow rate must that steam must travel and fill the jacket for the transfer to actually take place, right.

So therefore, this transportation lag causes delays both in the process and in the actuator. Similarly, apart from transportation lag there are situations where delays are caused also in the sensors. For example, sometimes you have you know especially in composition control sometimes you have instruments analysis instruments called analyzers in the loop. So, they will give you various properties of liquids percentage of a, of a particular ingredient of the composition. I mean something like a gas chromatograph and these instruments by their very nature they sometimes involve delays.

So, sensors can also involve delays there are, there is another class of cases where you know sometimes sensors for example, now a days in the industry a lot of camera based sensors are used. Now, camera based sensors involve lot of computing that is image processing related computation to give the result. So, sometimes these computations involve a certain kind of delay, right. In the typical factory context, it is, it is often not significant these kind of delay. But in other especially for electromechanical context, where you need to control at a high speed sometimes these delay could prove non trivial.

The third very interesting case where something where a delay may be caused is because there is a human in the loop. You know apart from coming little aside from industrial example one of the classic examples of a human in the loop control system is a car. So, car has a driver, who is the controller. So, he gets his feedback from his eyes and he reacts by giving control inputs to the car. For example, if he sees that the brake lights of the car ahead lights up, he sees this and jams the break.

So, because of inherent human reactions, this sometimes involves a certain amount of time called the driver reaction time. And in fact, this is what in transportation engineering, this is a factor which will which will eventually decide what can be available or safe velocities of cars and safe distances that they must maintain at that velocity. So, humans in the loop can sometimes also cause delays. Now, what are the effects of time delay?

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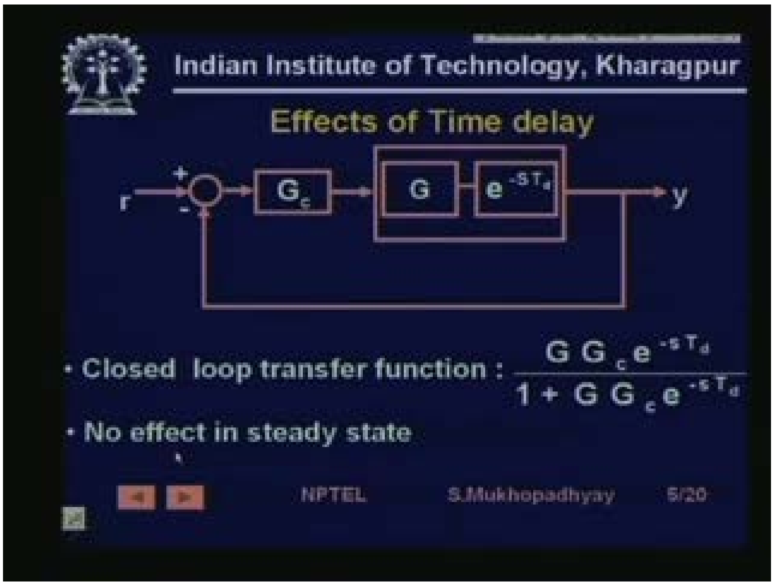

Let me tell you that I mean how time delays cause problems. For example, I will tell you, I will share with you one example of mine. Have you seen, you must have seen some modern bathrooms where there is a, where there is a there is running hot and cold water supply. So, usually typically you cannot at least I have not seen a bathroom where you can set the temperature of the mixed water, what is generally provided is a hot water, is a hot water tap whose knob you can turn and a cold water tap. Now, suppose that you want to take a shower and you want that a water at a, at a certain temperature. So, what are you going to do? You are going to setup a control loop, how?

You are going to, you will probably I mean the safe way of doing things is to turn on the cold water to the maximum and then put your hand in the shower and feel the temperature and then adjust the hot water. In fact, this is what I was doing one day and after sometime I realized. So, I put my hand in the cold water, it was, it was too cold for me. So, I started turning the hot water tap. So, I was turning and then suddenly I found that the water is too hot and then I started turning back and suddenly I found that the water is too cold.

After I was doing this unmindfully and after two three cycles, I took notice of this fact that what is happening. Why I am not able to set a particular temperature, but rather always either exceeding on the positive side or on the negative side. And then it suddenly donned on me that wow here is the, this is the case, typical case of an, of an oscillating process control loop and why was it happening? Why was the loop oscillating?

The loop was oscillating because there was a delay between my turning the knob and the, and the water actually coming on to my hand because it had to travel through a pipe. So, here there is a, there is a, there is a transportation lag. There was no lag in the sensor because compared to that delay, the delay in feeling the temperature was negligible. But coupled with the fact that my controller gain was very high, you know typical taps which you have in the bathroom are quick opening kind of valves so that you can by a small turn of the knob you can increase the flow rate very fast.

And then I was also impatient in the morning, I have go to somewhere. So, I was very quickly moving the knob. So, my controller gain was very high and there was a delay in the loop. So, in effect what resulted was an unstable process loop which was continuously oscillating. So, this is exactly what tends to happen in a process loop if the controller gains are high that it will tend to oscillate.

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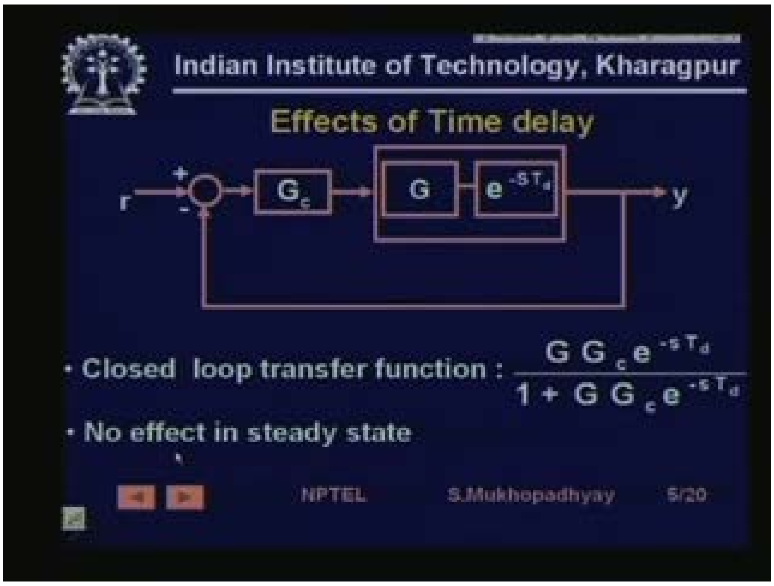

So, now let us, let us analyze this phenomenon little more technically. So, here you have this is, this is the standard process control loop where you have, where you have this is, this is the controller, this is the controller and this is the plant. And this is the delay that I am talking about and this is the normal process control loop. So, what happen let us look at what is the, what is the closed loop transfer functions, right, close this and so what is the closed loop transfer function.

So, the closed loop transfer function is very obvious that is G G c e, e to the power minus s T d divided by this is the delay. So, let us, let us try to look at this transfer function and understand what is happening. First of all, we notice first thing let us notice that in the steady state how can you get the D C or steady state transfer function just by setting. In most cases not all cases. But in most cases you can get the steady state behavior by setting s is equal to 0. So, if we set s is equal to 0 irrespective of the time delay this transfer function will become G G c by 1 plus G G c.

So, the steady state transfer function is not effected by delay, right. So, this is the message that in steady state delay has no effect. But as we have just seen that it has an effect, it does had a have an effect in the transient state that is when set points are changed or when disturbances occur. It is going to have an adverse effect and it is during these times that the process must may start to oscillate, right. So, let us try to that is what we want to study try to understand. So, let us look at this same transfer function in a slightly different way.

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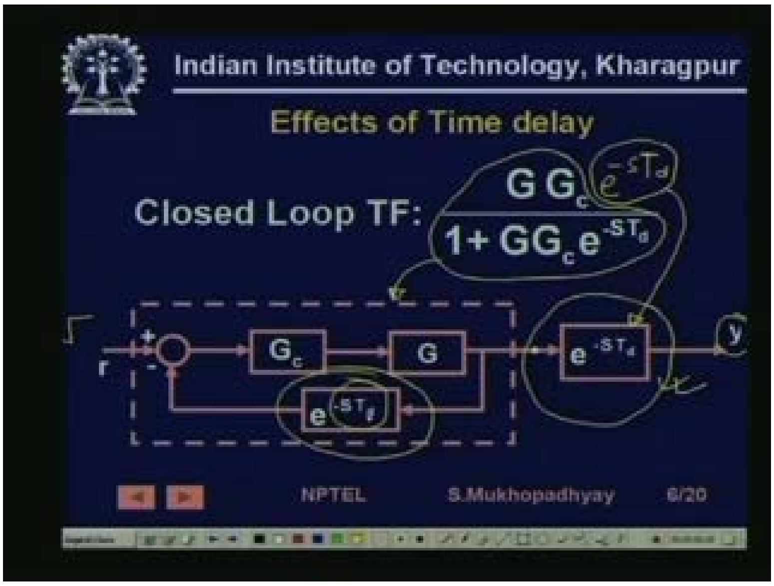

So, the same transfer function I have now I am now, I am now looking at the loop in a different way, this was the transfer function. Initially, our transfer function was G G c e to the power minus s T d. So, now this e to the power minus s T d if I take outside then this part of the transfer function can be represented by this block.

So, you see that so now, this closed loop transfer function we can represent in a block diagrammatic form in this manner. That there is a delay, which is going to be caused in the response, if you give a step input there is no way that the output will start moving immediately. There is no way that the, that this output will start moving immediately and we cannot do anything about it. It is the inherent characteristic of the plant.

On the other hand, now this plant apart from the delay how is this plant different from the delay free plant with which we can do ordinary feedback control. So, firstly, it is, it is different in the way that there is a delay caused in the output. Now, a delay is a delay which cannot be avoided, but nevertheless this delay is not going to cause any problem in stability. Simply, the response will be delayed by an amount T d which cannot be helped. But it is this delay which is going to cause problem in the stability because it is going to add to the loop phase, right. This is minus s T d. So, it is going to add loop phase lag and it is this that is going to cause the problem.

Now, you see that how does it cause the problem. So, to understand that let us first notice that in the delay free process this would have been a direct term. So, in the in the delayed process we are going to add additional loop phase delay without adding anything to the loop gain because the magnitude of this operator is always 1, only there is a phase lag.

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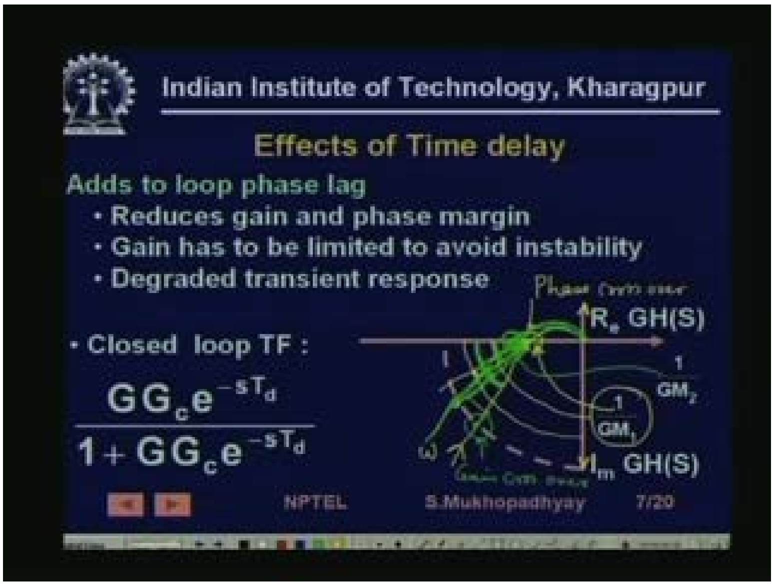

So, having noticed that let us… So, this adds to loop phase lag. And therefore, here is a comment which we will see in greater detail that it reduces gain and phase margin. So, how does it, how does it reduce gain and phase margin? We will see that. It also says that the, that the gain has to be limited to avoid instability. Obviously, if your gain margin is reduced then the allowable level of gain becomes lower.

So, you must use the lower gain. Now, whenever we know that whenever we use a lower gain, the problem that comes is that you have degraded transient response. In some cases for example, if you if you are using proportional controller and if you uses, use a smaller gain then you are going to get it greater steady state error because in the steady state delay has no effect.

But if because of the stability reasons, one has to use lesser value of K. Then that lesser value of K is going to cause just, cause a greater steady state error which is a, which is a degradation in performance. So, this is the major problem of time delay, but before that let us see how this gain margin and phase margin is reduced. Imagine that the, that the original plant not original plant that the, that the plant suppose the transfer function G G c has a or other the transfer function has a nyquist plot like this.

So, in this direction as we know omega is increasing, this is the increasing frequency direction these are the 2 axis. This is the, this is the real axis real rather this is the imaginary axis and this is the real G H S axis. So, this is generally what is called the phase cross over frequency. So, and it is, it is this is, if the gain here is G M then the gain margin is 1 by G M 1. So, this is that of the loop without delay. Now, if you have a loop with delay then what happens? What happens is that, at every, at every frequency now and magnitude will remain same and the phase lag and there will be a phase lag added. So, if you add constant magnitude loci and suppose at this frequency. So, phase lag will be proportional to frequency.

So, suppose at this frequency this much of phase lag is added. So, at this frequency which is higher some other phase lag will be added. This phase lag will be added, here this phase lag is added. Here more phase lag will be added. So, in other words now the plant will follow a different trajectory. So, it will follow a trajectory like this. So, now let me put a different color. So, that we can understand this phenomenon. We have to put a let us put a green color. So, now the new plant with delay flows through the green line. So, it has, it has got shifted because of the delay.

So, now what happens? So, now, you are now the phase margin has reduced previously what was the phase margin? This was the phase margin that is the phase at the this is called the gain cross over frequency. So, the phase margin was this angle. Now, the phase margin is reduced and it is this angle. So, it is this angle now. Similarly, the gain has increased. So, now, the gain margin is reduced. So, this is if G M 2 is the gain then 1 by G M 2 is the gain margin. So, that has reduced. So, this is how the system is gradually coming closer and closer to instability.

And therefore, the maximum gain that you can use for the plant which is represented by the yellow line, the plant which is represented by the yellow line this yellow line and the plant which is represented by green line you can use a lower gain, right. So, this is what happens. This is why gain has to be lowered to avoid stability and that in turn causes problems in the response. So, this is the point that I was trying to make. So, having said that let us go back to our discussion.

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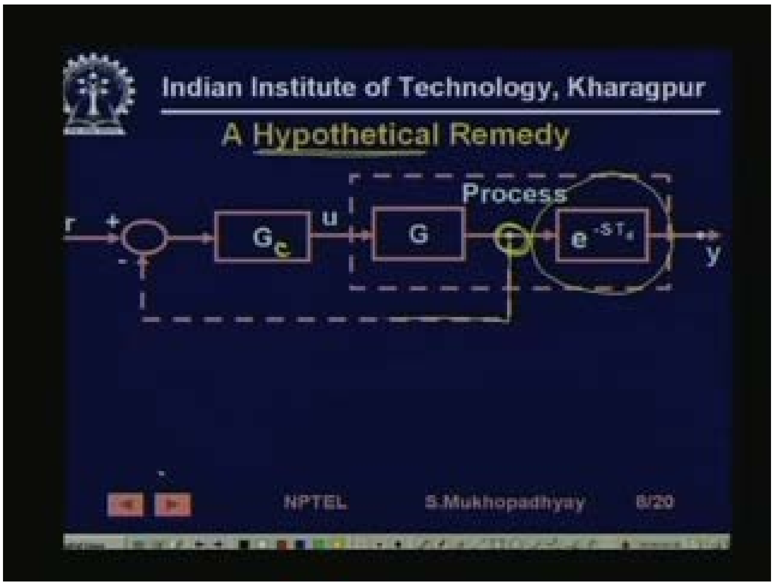

So, now what is that width that we want, what was, what is the, so let me present a hypothetical remedy. That is, it would have been very nice, it would have been very nice if this delay is any way, this delay is any way not possible to remove as such. But if somehow we could take the feedback of the process from this point then at least the stability part of it would have been like a this is, this is G C by the way.

Then at least the stability part of it, from the stability point of view the effect of delay I could neutralize. Apart from the fact that in the response there will be a delay that is generally not of too much concern in industrial process control because they are generally I mean whatever response you want it will come a little later. That is not so much of a problem, but what is the problem is the change in the feedback loop.

So, somehow if I could take a feedback from there, but I cannot take a feedback from there because it is within the, because this point is inside the process and it is not measurable. In fact, it is an, it is an intrinsic part of process, right. So, since this point is not measurable that is why this solution is hypothetical because we cannot take a feedback, actual feedback. But here comes the, here comes the...

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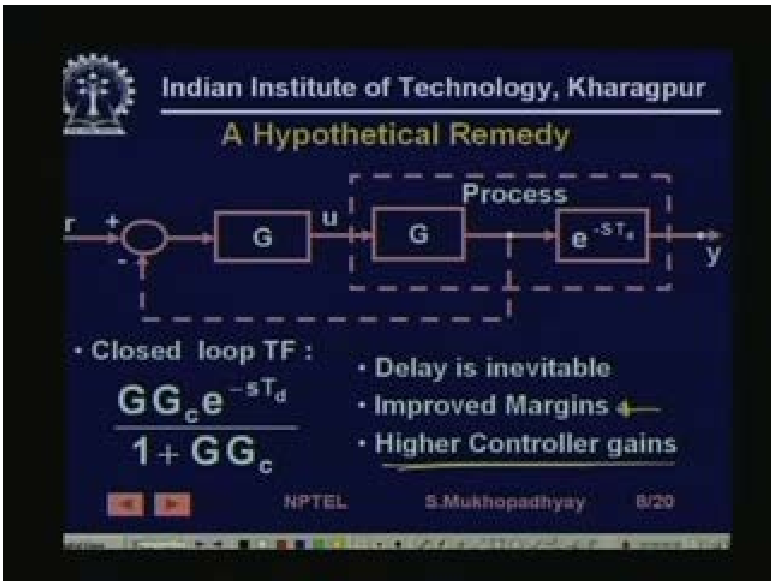

So, now if we could do it then I could have much more improved margin, I could have improved margins like the, like my, like my old case. So, my margins remains would not have would not degrade. And therefore, I can use higher controller gains. And therefore, my responses would be like the I can use higher controller gains. So, that I can improve transient response without worrying about the additional stability constraint imposed by the delay. So, that is the problem. So, then how am I going to do this?

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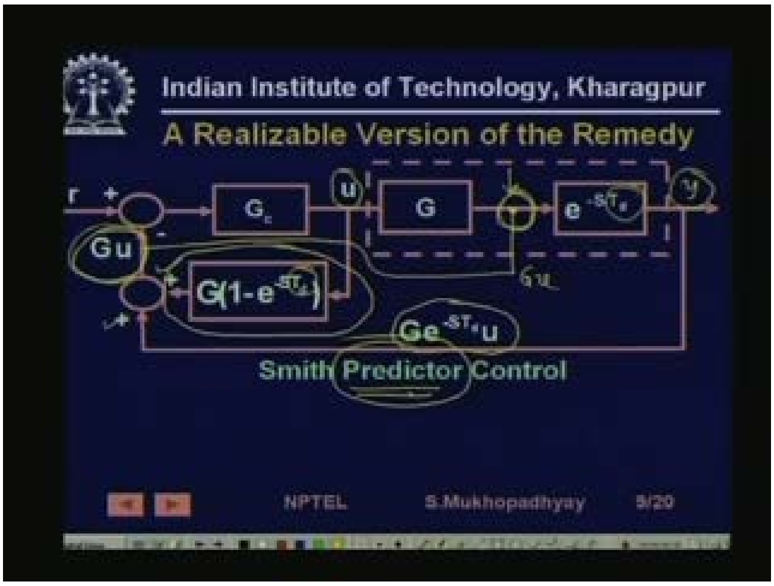

So, to do this, let me put a so called realizable version of the remedy. So, now what I am going to do is this. So, you see I am giving the original feedback, which I was giving normal feedback and apart from that I am giving an additional feedback. So, what is this, what is this? Typically speaking in the ideal setting y is equal to G into e to the power minus s T d into u, correct.

So, this is G into the e to the power minus s T d into u. And on the other hand now you see that if this is a big if, but if I knew G and T d very accurately then there is no reason why I cannot simulate this transfer function and then feed it by u c. u I have because it is coming out of the controller. So, I already have it controller is in my machine only.

And if I knew the model. So, about getting u there is no problem, but about getting if I knew G and if I knew this T d, these are questions how well you can get them, but suppose for the time being that you have it. Then we could put it here and then you see if I, if I add this and this what do I get. I get G u. So, as if. So, what is G u? G u is the signal here. This is G u. So, by adding this term I am creating a situation as if I am able to make a virtual feedback here that is what I wanted, right.

So, if I do that then I will able to use my, use the kind of gains that I can use for the system without delay. So, this is the basic principle of Smith predictor control. So, what I am trying to do why is it called a predictor? Why is it called a, why this term prediction? Because I am trying to in effect, I am trying predict the output. Why? Because this is y, this is the output, and what is this? This is nothing but a future output which will appear here in the measurable form after time T d.

So, since I am. So, I am trying to recreate that. So, in other words I am trying to predict the output and then give it feedback. That is why it is called the Smith predictor control. Now, there are of course, several questions as to how you can do it? So, the first question is that you require to be able to do it, you require this to be known accurately and more importantly you require this to be known accurately.

You see it is rather it is not. So, simple to estimate time delays, because time delays are often confused with time constants in the response. They actually generates similar kinds of responses, it is very difficult to differentiate between time delay and time constant. But time delays and time constants differ in a very tangible way what is that way. That for time constant for example, suppose you have a transfer function called K by 1 plus s tau.

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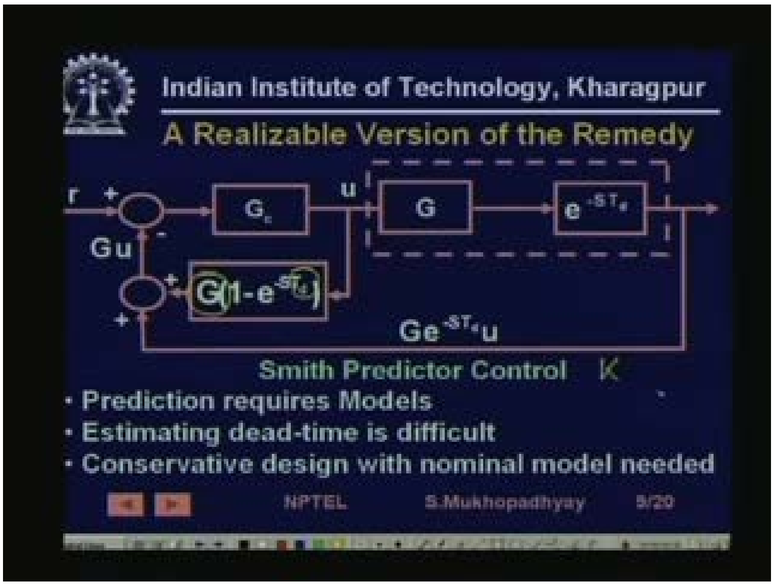

This is a, this tau is a time constant. So, as far as the phase response is concerned, let us take a, let us take a white page now will it come?

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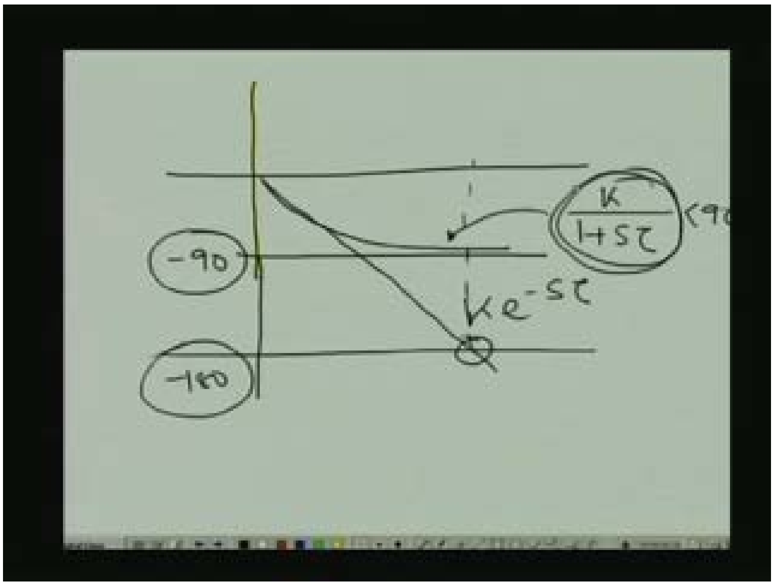

So, this K by 1 plus s tau. Let me choose a different color pen because the background is now white, let me chose black. So, the phase of K by 1 plus s tau is is going to be limited to minus 90. So, it cannot increase beyond minus 90. This is for K by 1 plus s tau. On the other hand, K e to the power minus s tau will have a phase, which is increasing linearly with frequency. So, there is no bound so this means so for example, this system phase will is always less than 90, but this system phase will is at some frequency it is going to cross, at some frequency it is going to cross the minus 180 point which is the critical point for stability.

So, the question is that. So, there is always this phase lag the phase lag of the process with a delay is always going to cross 180. But the question is what is the gain at that point. So, to ensure stability you have to keep the gain low at that point. That is why you have a limit on the gain. While in this case, in this case you do not have any limit on the gain. So, what happens? So, you see that I am in a time constants and time delays are slightly different and time delays are potentially more risky, but distinguishing them from time constants may not always be so simple.

So, therefore, estimating get time is difficult. And therefore, we must have a conservative design that is if we think that the, if we should always design a controller K for a worst case delay because if the delay is if we design for a best case delay and if the delay is more then we might land up with instability, right. So, this is another problem that as such we have to limit the gain and because of the fact that we cannot estimate the delay accurately in many cases in our design we would, we would estimate it conservatively and we will further limit the gain because of lack of knowledge.

There may be another case also. There may be cases where the, where the delay will be varying you see the delay is caused by what? Delay is caused by transportation lag. So, basically it is the time required for the material to flow at a given flow or given distance. Now, this flow given distance how much time is required, that is the time delay. Obviously, depends on the flow rate. Now, the flow rate depends on what? Flow rate depends generally on the operating condition of the plant, right. So, if a, if a reactor is producing is producing something at let say 50 percent volume then the flow rate will be half of generally speaking it will be half of, if it is working at 100 percent load.

So, the so the time delay will reduce. So now, depending on various operating conditions the time delay in a process can even vary not only the first of all it may be it may be difficult to assess. Secondly, it may also vary. So, if you are going to design a single controller for all operating points then further you have to always take, make a design which is which will hold good for the worst delay. So, which means that for the, for the best case delay we are going to get you may get very poor response. So, actually these are the, these are the problems of time delay systems which is somewhat over come. Now, how are these things, how are these things over come here.

So, here also you have to do a, here also if this G and this just a moment. So, here also if this G, I am sorry. If this G and this T d are, this has to be selected as black. So, if this G and this T d are not properly known then the compensation that I am talking about will not take place. It will take place only partial. So, here also we have to make a conservative design, but at least the situation is better.

There is one more point, very interesting point which I, which I wanted to mention. That is the question is that if we want to calculate G u then and we are saying that we need G we are assuming that we know G accurately. So, if you want calculate G u and give feedback and if have u and we know G. So, then why do we need this feedback at all? Why do you need this? Why cannot we just take u and multiply it by G and then give a feedback? That is most simple. But what do we get at get then? Then we get what is known as we get what is known as open loop control. There is no feedback. What are the problems of open loop control?

That any error in G will directly affect the output y. Any disturbance here will not get corrected. The biggest advantage of feedback control is that it gives you performance irrespective of generally irrespective, of course you have to know certain things, but small modeling errors do not effect performance. That is the single reason for which feedback control is used and if you take this feedback away actually this is not in presence of modeling error this is not G to the power minus s T d.

So, if you want to have the benefit of a delay correction according to a model and then also keep your control performance sensitive to modeling errors as well as disturbances then you must feedback measurement. So, you cannot just multiply it by G and send because then you are going to be blind to actual reality if there is a disturbance that will not be affected here. So, it is for this reason that although under ideal condition it actually turns out to be G u, but in real conditions it will not turn out to be G u and it will that is your control loop will not become blind to things such as disturbance things, such as modeling errors delta G here, right.

So, it is for this reason that you must keep the feedback and it is for that reason that we have added this term other than taking G u. So, these things must be these are some you know some fundamentals principles which was be realized in control. Now, having said this let us come to the second, the second part of our lecture, which is on inverse response processes, right. So, what are inverse response processes?

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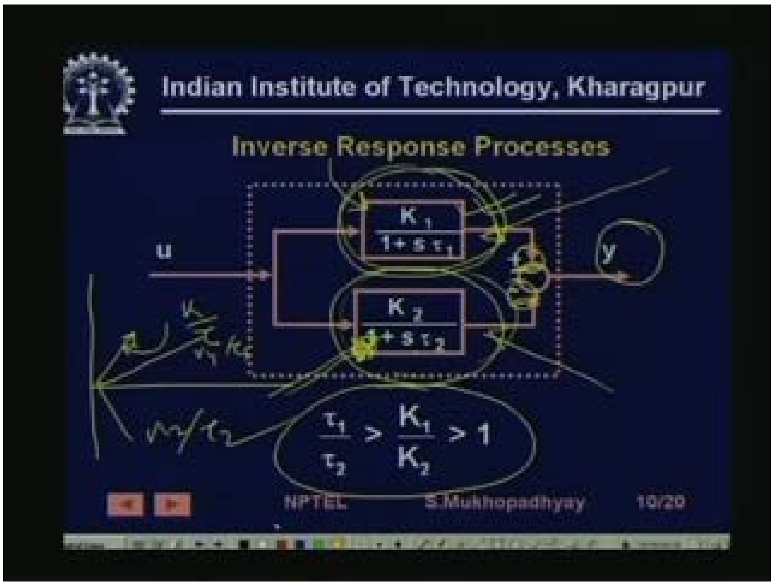

Let us first, let us first define it. Typically, inverse response processes occur when the output, the output is actually produced by two effects. So, this is one effect which produces the output and this is another effect that produces output.

They together produce the effect overall effect on the output and it turnouts that one of them, one of them is opposing the other. So, you see one is plus another is minus. The second fact is that in the short time scale that is over time scale in the, in the initial phases this one dominates and in the long turn this one dominates. So, when you have such a situation then obviously, in the short turn 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 see in a, in another fashion. So, if you design a controller for this process then for the initial times scales this is going to be the response of this will actually confuse the controller. This is and might causing stability and other things, this is the main problem.

For example, in this case, why is the 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 a plus and there is minus. But how do you know 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 by 1 plus s tau 2 then towards initial phases, then towards the initial phases the response increases like a straight line whose slope is given by K by tau. So, in during initial response this block will produce a slope which will be minus K 2 by tau 2. And this block will, this block will produce a slope which is K 1 by tau 1 and this is K 2 by tau 2. So, since according to this condition K 2 by tau 2 is greater than K 1 by tau 1. So, therefore, initially the response now we can go to the next slide. So, what is going to happen is that, what is going to happen?

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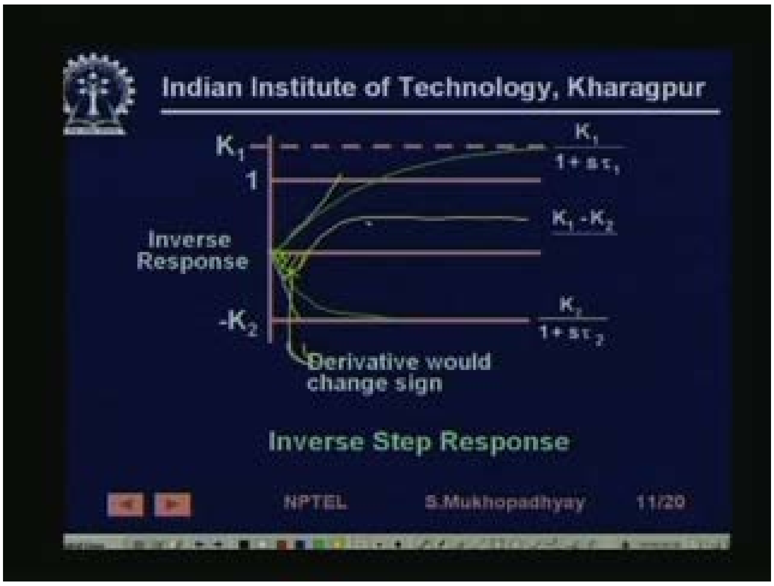

So, imagine that, let us consider this the step response of that process. So, I am given a unit step. So, the response due to the K 2 block will start, is very difficult to understand we have to put it. So, the response due to K 2 block will start along this way and the response due to the K 1 block will start along this way with this loop.

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 minus 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 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 the actually the response changes sign, this the fact which is to be noted which has some bearing.

So, now having seen the kind of response that we expect let us at least see one example of why it happens at all. So, let us this is, this is a very classic example of a what is this kind of process inverse response processes are sometimes also called non minimum phase systems.

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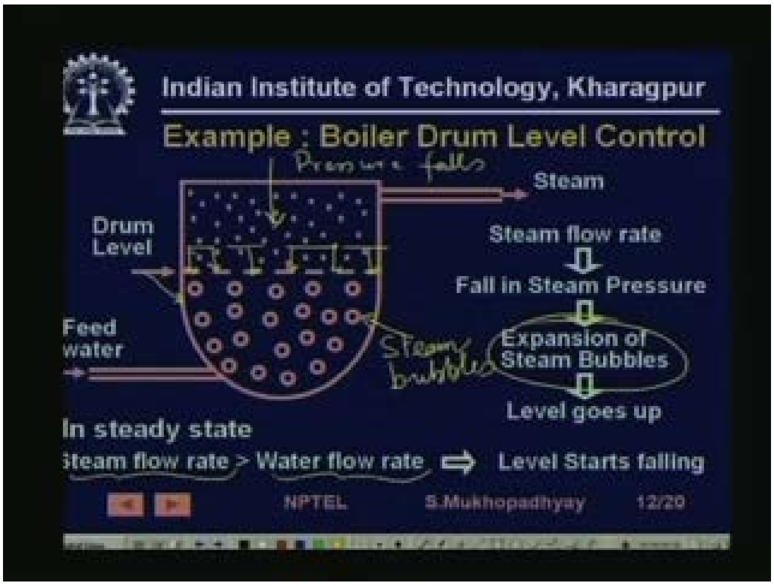

And this is a classic boiler drum level control is one of the very classic examples of an inverse response process. You know boiler drum means that boilers if you go to the power station then what happens is that the boiler have tubes in them and in those tubes water is, water vaporizes. So, the water 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 in to 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, this the return.

And this the boiler drum level. So, this thing is called the boiler drum, it is basically a tank which is as big horizontal tank situated right on top very high above. I mean typically a power station boiler is about 3 storeys high and the drum is on top of that if you want see it you have go up a number of stairs.

So, what happens is that without going into much details of boilers let us see what happens is that water enters. Here there are lots of bubbles, steam bubbles which actually come to the surface being lighter they come to surface and then they break and then they from 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 you are the mass of water that is entering the system and the steam that is living the system must be matching. So, what happens now imagine that the power station operator wants to increase the power. So, he will do you what. So, for increased power you need to supply increased steam 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 see that is also shown here 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 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? In the short range, what happens is that immediately when this steam flow rate is increased there is a reduction in pressure, the pressure falls. Now, you see that 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, this is 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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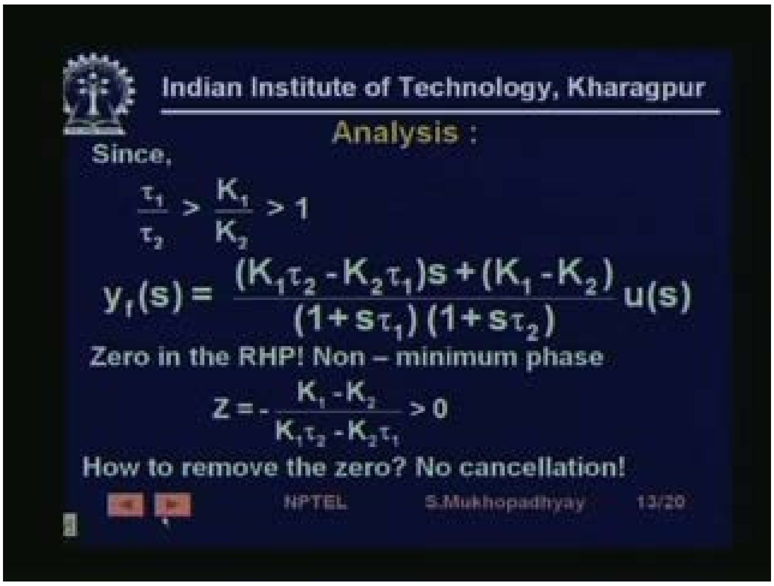

So, you see that, if you see just see the feedback transfer function and do a little analysis we will find that the y feedback, feedback was the point where we were adding that Smith predictor output. So, this was y and this was that G into 1 minus e to power, oh this is not that one, this is. This was yeah. So basically, this says that simply this is, this is nothing. Sorry, we are not yet considering feedback at all. So, this is nothing, but the open loop output. For example, let us, let us go back a little bit, let us go back a little bit. So, this is nothing, but the response to the this one. So, the response to, simply if you calculate y it will come out to be that expression, right. 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 0 and this is a positive quantity greater than 0 because K 1 by K 2 is greater than 1. So, what happens is that we have a fact. So, we have a we have terms like you know a minus b s, which means that it has a 0, the poles are the, these are this will give the poles and this term will give the 0 of the transfer function that there is a what is known as a right half plane 0.

So, the real part of the 0 is in the right half plane and such transfers 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 0 location is given by this minus K 1 by K 1 minus K 2 by K 1 tau 2 minus K 2 tau 1. So, that is the location of the 0. 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 we can, 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 controller will get confused in driving the plant.

So, now the question is that. So, perhaps we should remove this non minimum phase 0 and somehow put a minimum phase 0. Now, how to do that? This is not. For example, we know that, if we have you know 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. Let me choose color.

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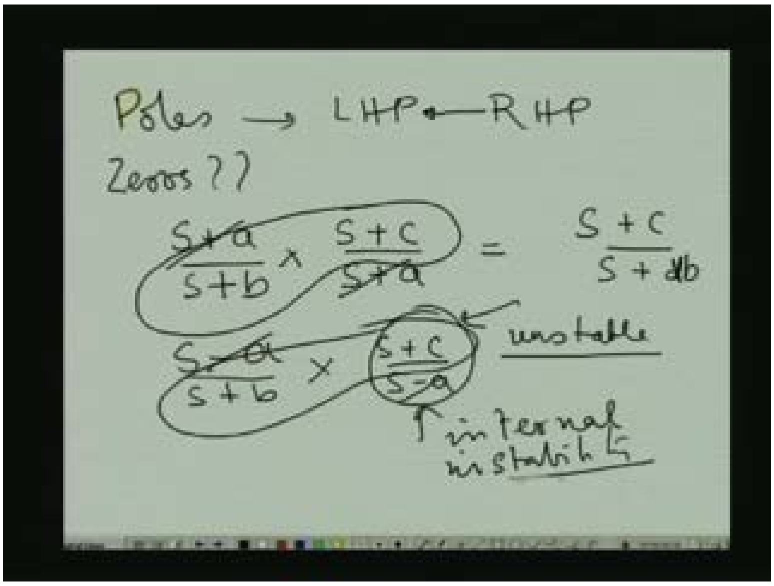

So, the poles can be in the, in the if they are in the left half plane then stable, if there in the right half plane unstable and we by feedback we have seen using a controller we can bring it from right half plane to left half plane. But what do we do about 0s, one very standard way of changing 0s.

Suppose our transfer function has S plus a by S plus b that it has left half plane 0. And we want to change it to, we have to make it to S plus c by S plus d. So, then what do we do? So, we first we can always multiply it by S plus c by S plus a. Suppose, this is we are talking about zeros. So, let this is b only.

So, if you want to change the 0 we can always multiply it. So, that this and this will get canceled and will get this. But this is not possible when you have right half plane 0 because if it is S minus a by S plus b then you cannot multiply it by S plus c by S minus a, and say that this is canceled and it will give me, give you this because this transfer function is unstable. So, what is, what is this going to cause is it will cause and if you, if you try to do it like this it will cause what is known as internal instability. So, what happens is that internally some signal will go unstable although it may not affect the output.

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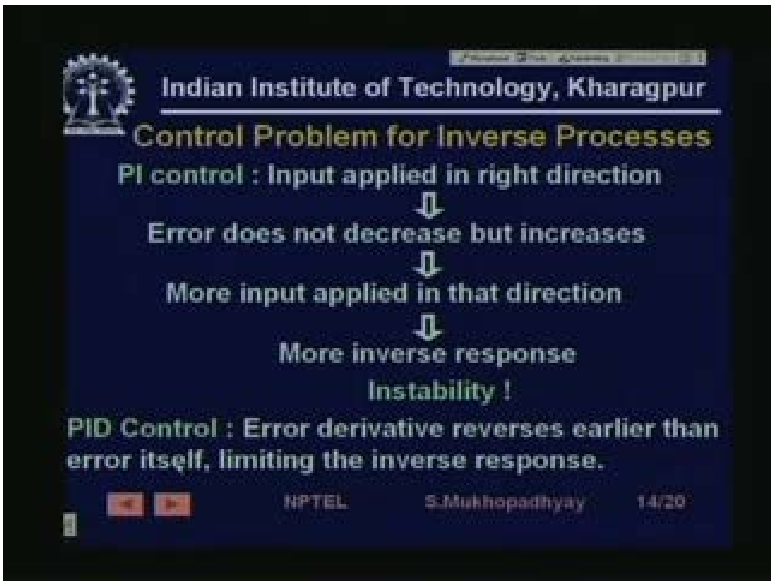

So, we cannot cancel the 0 you see so what we must do is… So, what do we do? So, this is, this is another case where we were saying. So, actually now we come to the control problem. What happens in the, let us say for example, if you have a P I controller then the P I controller will apply some input in the right direction and it will change the single 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, does not decrease, but it increases. So, what does the P I controller do? It applied more input, it things that oh it is not going. So, let me apply more input. So, the more the input is applied the more you, more inverse response will come and this might lead to an unstable situation. On the other hand if you have a P I D controller, P I D controller also not only since the error as integral, it also since the rate.

Now, as you have seen that the rate will reverse quicker. So, the P I D controller has is likely to give slightly better response because it will, it will try to reverse give correct inputs much faster because of the derivative reversing. This is just a, just a sight. But let us see first how we can compensate for this inverse response.

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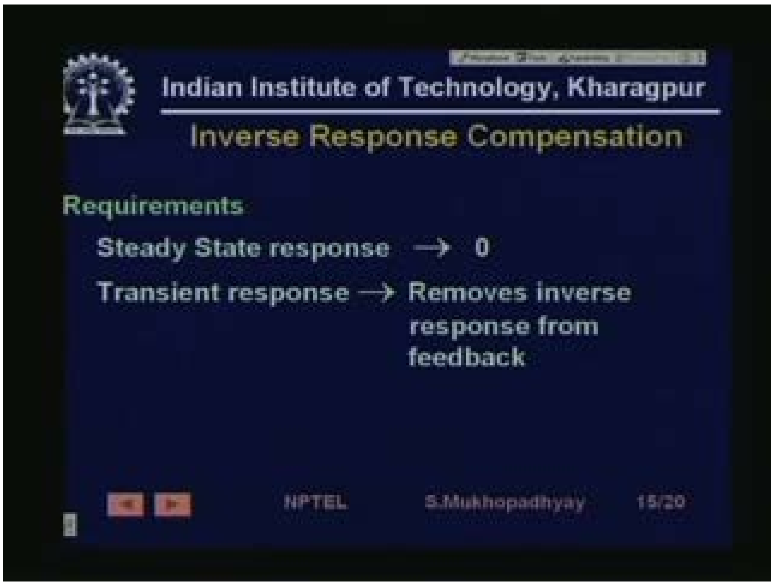

So, first what is the requirement. The requirement is that in the steady state my response should be all right. So, the whatever compensation I want do its effect in the steady state should be, should not be there. But in the transient response actually what it should do is, this inverse response it should not allow to be fed back 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 do you do that?

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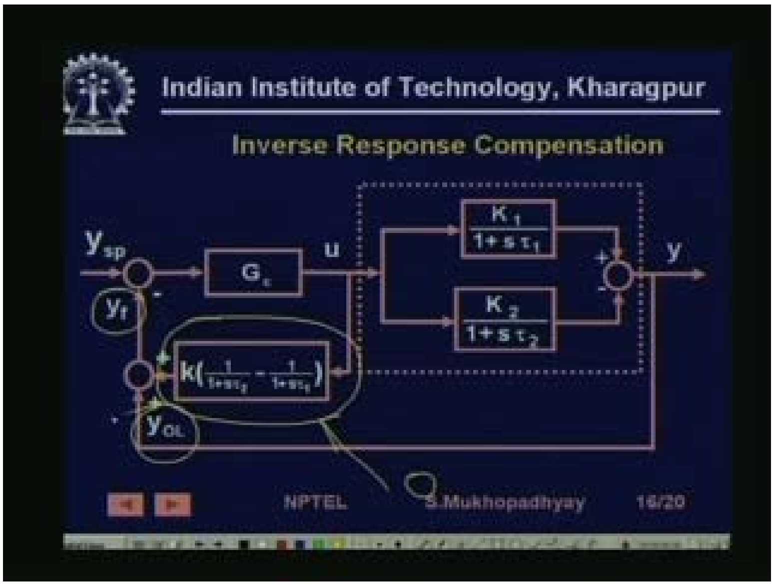

So, to do that we have this. So, you see again just like, just like Smith predicator we are again adding another term here. So, this you select this. So, again adding another term here. Now, what is effect of this term. The effect of this term in the steady state, in the steady state the effect of this term you can verify is 0 because 1 by 1 plus s tau 2 and 1 by 1 plus s tau 1 set s to 0.

This the steady state gain of 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, I am now I am now modifying the view of plant. So, what happens is…

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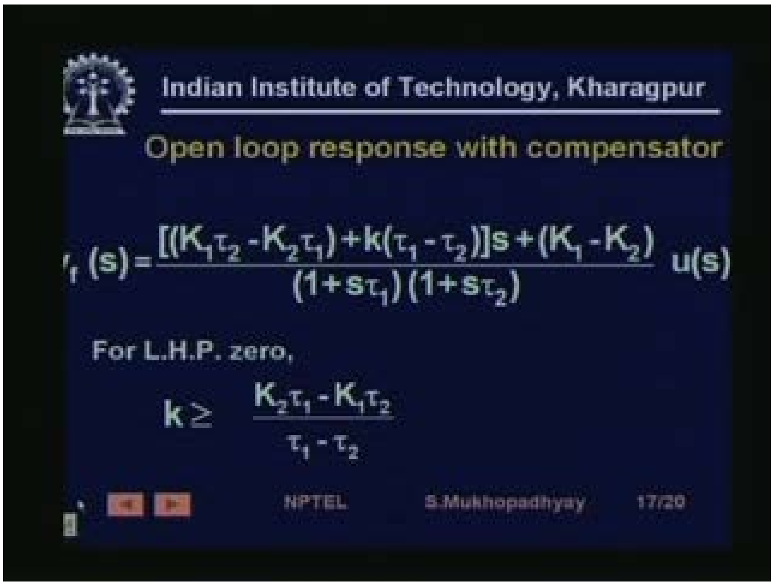

Now, the feedback term if you calculate then you will get it as K 1 tau 2 minus K 2 tau 1 plus K into tau 1 minus tau 2. So, this is, this term has been added now previously it was only this and it was negative. So, if you want to shift the 0 then what we have to do is, what we have to do is we have to add this K in a such manner that K is greater than equal to this. Then, what will happen is that this 0 will become left half plane 0 and the non minimum phase response will not be shown to the controller.

So, the controller, the controller will not receive 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. So, this is the way that we are now coming to the end of the lecture and we have to quickly review the lesson.

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So, first we saw 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 is we have as usual some points to ponder so you can describe two typical sources of time delay in example industrial process. You give your example. Explain why time delay degrades 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. So, that is all for today.

Thank you very much.