Industrial Automation and Control
Prof. S. Mukhopadhyay
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 14
Feed Forward Control Ratio Control

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Good afternoon, and welcome to the fourteenth lesson of this course. Today we are going to look at, feed forward control and ratio control.

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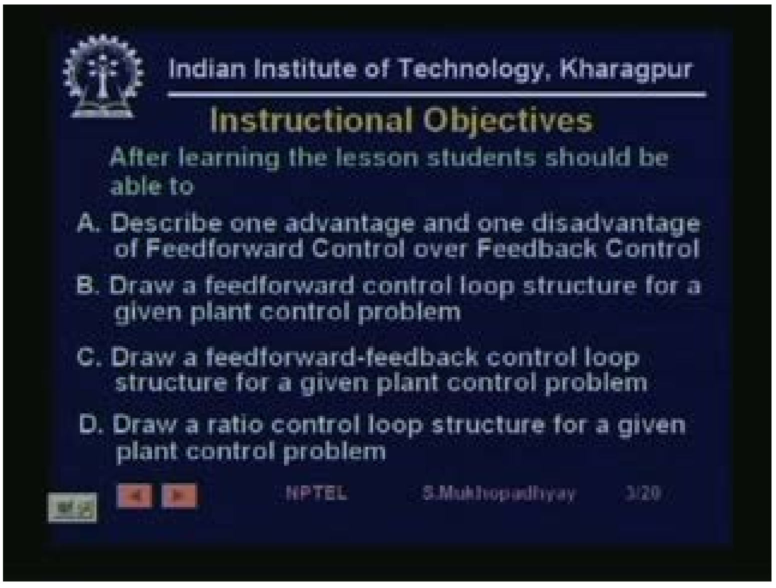

So, far we have looked always looked at the classical control structure, but today we will look at some other control structures, which you which are fundamentally different in principle. So, before we do that we have to take a look at the instructional objectives.

So, after learning the lesson the students should be able to describe one advantage and one disadvantage of feed forward control over feedback control. There are some there is a fundamental disadvantage of feedback control. So, which is an there is a, there is a fundamental disadvantage of a feedback control which is overcome by this feed forward structure. And on the other hand the feed forward structure also suffers from a disadvantage which is overcome by feedback controls.

So, we will comparatively assess these two, and we should be able to draw given a control problem we should be able to draw the a feed forward control loop structure. And as I have just now said that feed forward control has some advantage it also has some disadvantage. So, for best results one should use both the feed forward control and the feedback control in a control configuration.

So, we will see how to draw such loops and finally, we will take a look at a particular kind of control problem which is very common in various thermal. And chemical processes is called ratio control, which is very similar to this feedback feed forward configuration. So, that is these are our instructional objectives.

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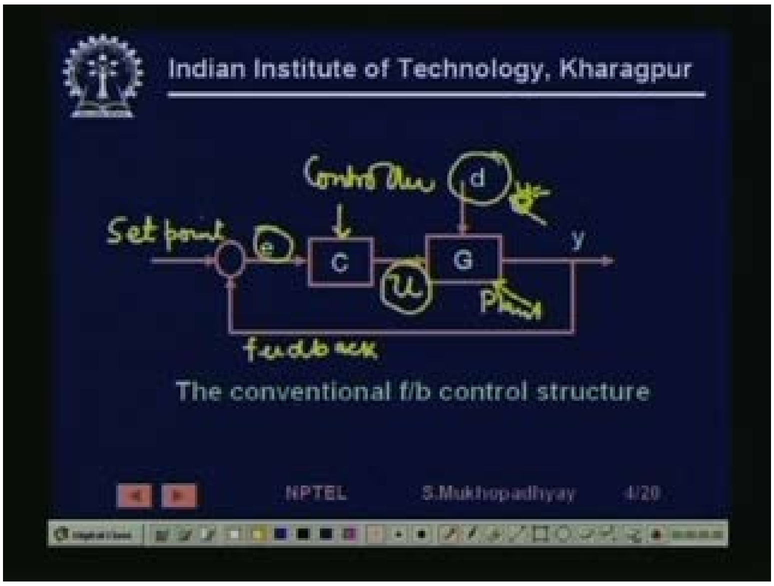

So, having seen that let us look at the conventional feedback control structure. So, as we have seen here this is the well known structure where you have the set point here. So, this the set point, and this is the feedback, and here you have the error. This is your controller, this is the control input u, which goes to the plant this is the plant now, and which produces the output.

As we have discussed before also that the plant has several sources of disturbances, other factor which are beyond our control also affect the output it is not only u, which affect the output. But there are other factors which also affect the output and which are beyond our control typically such factors we call a disturbance.

So, now we have also seen for example, we have seen that using feedback control structure we have sometimes want it to take care of disturbances and we have seen that it is possible. It is possible to take care of disturbances also in the feedback control structure, but only in a in the steady state case. Generally, the feedback control structure does not, does not is not very efficient in handling in neutralizing disturbance is very fast and this is the fundamental disadvantage of feedback control for which a feed forward is generally used.

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So, the main drawback of feedback control is that the control action starts immediately for set point change, but not for a change in the load disturbance. So, it immediately response to any change in set point, but not, so for a change in the disturbance, will see how. Therefore, why is it so? Because of the fact that the, if you see the feedback loop let us see the feedback loop, back again to appreciate this. I am sorry we are going back, you are not going back you should have gone back.

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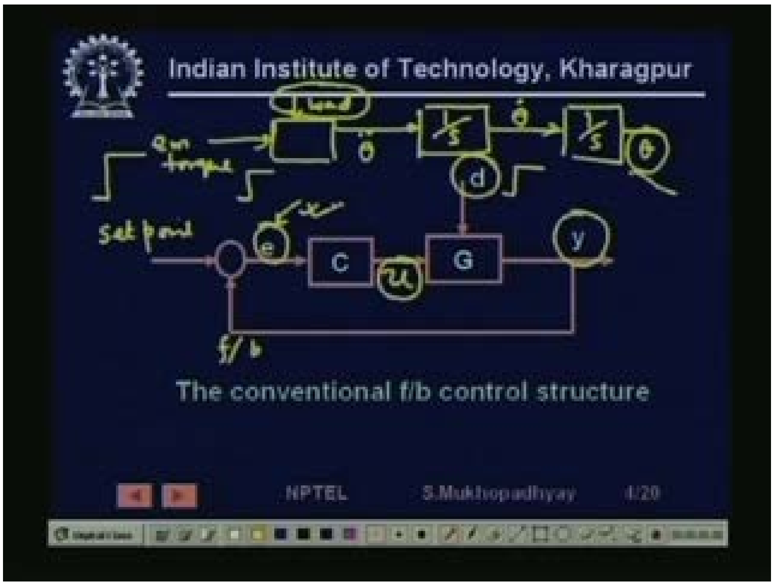

So, let us look at the conventional feedback control structure that we have studied all that time now, here we have this is a set point I am sorry. So, this is the set point, and this is the feedback, and this is the error, this is the control input u, this is the output y, and this is the disturbance d we have seen all these. Now, it so happens that that when does a when does a feedback controller work it works essentially based on the error.

So, if the error changes and by the amount the error will change the control input will change according. So, now let us see that if there is a sudden change in the set point then immediately there is corresponding sudden change in the error. So, immediately the input starts changing immediately in response to the set point, right?

So, the feedback controller is fast at responding to set point changes, but what happens when there is change in the disturbance level. For example, suppose we are trying to maintain the position let say the angular position of a motor, which could be related to other positions by gearing etcetera. So, if you see the structure then what happens is that that, there is an electromagnetic torque which is a control input there is a load torque which is the disturbance, so load this creates an acceleration.

So, you get creates actually theta double dot. This goes through one level of integration and gives you theta dot, this goes to another level of integration and gives you theta. So, you see that the, that the disturbance enters here and goes through two integration to finally, produce a change in the output.

So, since these are integrator these are slow devices. So, even if there is a set step change in the disturbance there will not be a step change in the output, but the rather the output will start slowly decreasing So, it will, so the speed if the, if the load torque is suddenly increases then there will be a slowly fall of theta. Now, the feedback controller can only respond to the error. So, if there is a slow change in y then the change in error will also be slow.

So, the feedback controller will not immediately try to raise its input because a disturbance is because the disturbance level has raised. But it will changes input slowly which means that the speed will fall to a good extend and then, slowly the feedback control action will come in to play and then, the input will rise and then, the speed error will be corrected. It, so for a, so the speed error will actually persist for a long amount of time this is a fundamental drawback of feedback control and it is this drawback that feed forward tries to address.

So, we have the drawback of feedback control that the control action starts immediately for set point change, but not for changes in load disturbance. Therefore, in processes where you have a large time constants or delays such that a disturbance takes a long time to finally, show its face in the output your corrective action is going to be delayed. So, regulation will be ineffective, because large errors may persist for long amounts of time.

So, that is the problem, what are examples typical example is torque disturbance in speed or position control. That is the one that we have does just discussed, second one is for example, control of temperature. For example, coolant pump pressure, the coolant pump pressure, coolant will pump pressure change will affect coolant flow. Coolant flow will from the change in coolant flow to the fall in temperature to the rise in temperature is involved the thermal capacity of the let us say of the, of the vessel whether it is a reactor may be it is a reactor.

So, even if the coolant pump flow suddenly falls for the temperature to fall it takes a lot of time. So, the, so there a, so the corrective action to the, to the coolant flow does not take place if it is done using a using the feedback control structure. So, we have feed forward control.

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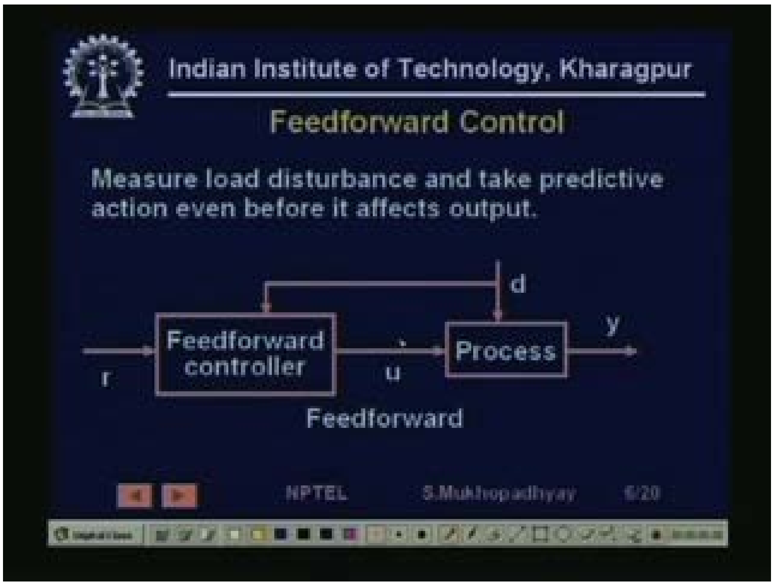

Now, let us see that first in it is pure form, what is feed forward? So, the basic principal is that you measure the load disturbance change. So, in feedback control the load disturbance change is not measured, what is measured is the process output, but since the disturbance takes times to affect the output. So, in the feed forward control our approach is to, is to measure the load disturbance itself. So, this may or may not be possible if it is not possible then you can apply feed forward. So, this also shows restrict the applicability of feed forward to situations where disturbances can be measured, and disturbances can be measured in many situations.

So, it, so if you can measure the load disturbance then you can take predictive action even before it affects the output. So, that errors are not really generated. So, here what you have is that you have a process, you have a feed forward controller, and you measure the disturbance and you feed it back to the feed forward controller.

So, the feed forward controller at the reference are both used in the feed. So, the feed forward controller utilizes the value of the reference as well as the value of the disturbance to compute the input. Now, if you see it carefully, you will realize that it is a form of open loop control there is no there is no feedback from the output, but rather the two inputs are sensed and a control action is provided.

So, what is happening? So, naturally your compensation is not really based on the final result that you that you desire, in the sense that you must know that if there is a disturbance change, there how much disturbance change is to be compensated by how much input, this must be known before hand. Because suppose this relationship suppose you know that if you have a 10 percent change in the disturbance you need to apply a 5 percent change in the input.

Now, suppose that 5 percent becomes actually 6 percent then what will happen is that you have over compensated this and the and the output will not be maintained, but you have no way of knowing this because you are not taking a feedback from the output. So, essentially the effectiveness of the feed forward control would depend crucially on knowing accurately how the how the set point affects the output and how the disturbance affects the output.

In other words, for feed forward control to be accurately to produce accurate results you must know the process models very accurately. And if you and the modeling error will directly show in the control error, this is not the case in feedback and it is the greatest advantage for which feedback control is used everywhere. That feedback control does not depend to any significant extend on the model it does depend on the models, but since you are actually checking the output. So, you do not really need a very accurate description of the process model this is a fundamental difference fundamental advantage of feedback control and a, and a fundamental disadvantage of feed forward control.

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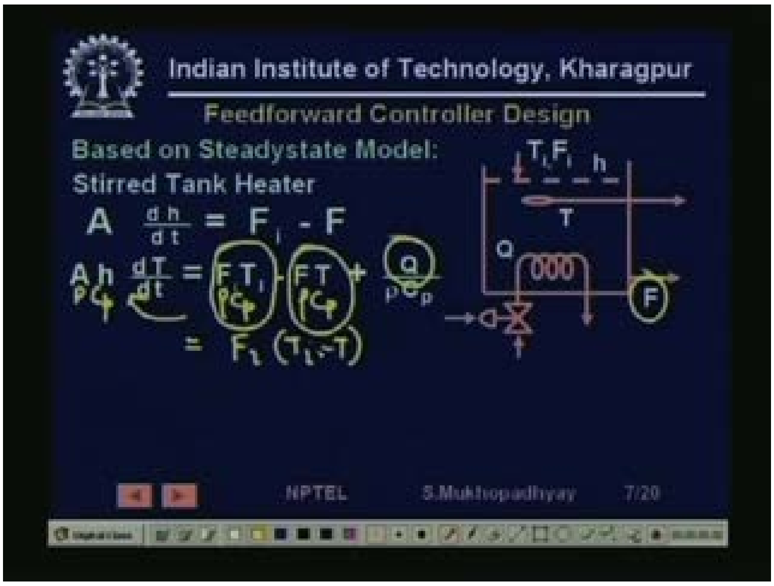

So, now having recognized this let us understand, let us see how we can design feed forward controller. Now, as we said that design of the feed forward controller would require a model now, models are difficult to obtain, but even with those difficulties steady state models are actually easier to obtain. So, therefore, let us first see that how based on a steady state model we can design a feed forward controller.

Obviously, that controller may not give us very good transients response to the disturbance, but as a first step we should see how to design a feed forward controller based on a steady state model. So, here is a process where, we are having a tank there is some there is some fluid which is flowing in and the fluid inlet fluid has some temperature T i, and there is an outlet flow F and there is temperature T which we want to maintain. And how we are maintaining it? We are maintaining it by changing this steam valve flow rather steam valve position, and we are for simplicity, we have just to we are adjust model that by changing this u, we can actually change the heat input to the process.

So, then what are the, what are the process model equations? The process model equations you have two models. One is mass balance, which says that the A is the cross section of the tank and h is height. So, dh dt is there is the volumetric accumulation of accumulation rate of the tank, it says that must be equal to the inlet flow rate minus the outlet flow rate that is simple.

The second equation is the energy balance. So, if you multiply this rho C p this side, you will, you will find that the inlet enthalpy is F i into rho C p F i into T i. We can understand this that, if you multiply, you will get a rho, you will get a rho C p here, you will get a rho C p here, you will get a rho C p here. So, rho C p F i T i is the input enthalpy of the incoming fluid this is the output enthalpy of the outgoing fluid.

So, whatever is remaining this is the in additional heat input through this coil. So, this net this is the net sum of the input minus output that will go towards increasing the temperature of the process that is very standard. Now, let us first assume for simplicity that F i and F are same actually. F i and F will to be there may be another control loop which if you want to maintain the level then, they may be another control loop which will, which will control F may be using a pump to match F i. If we, if you want to keep the level constant let us assume that such a loop exist and somehow has been designed. So, once is once you have done that we have F i equal to F. So, this equation the first term becomes F i into T i minus T, because F i is equal to F. So, under this situation let us see, that, so under this situation, let us see.

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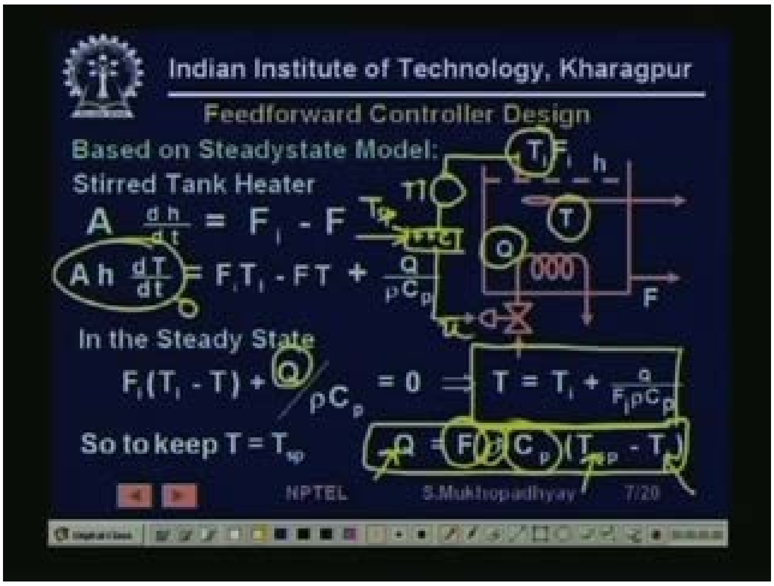

So, suppose now we want that the, that the temperature should be constant exactly constant. What is the disturbance here? The disturbance here is the for example, we could assume if we assume that F i and F are constant. So, that is all that could also be a disturbance, but it does not change. So, that disturbance change we are not considering, but there can be a disturbance change in T i that is inlet fluid which is flowing in can it is temperature can vary.

So, if its temperature varies, what you have to do is that? We have to correspondingly change the temperature Q the heat input Q. So, that this T is maintained this is this is our control problem and now, if we do have if we did a feedback control then if there is temperature change then that would have to effect T first.

And therefore, the T will change when the, we assume when the whole mass of the liquid will change. So, lot of time will take place before T can change because this has to mix through the through the volume. Rather than that we are assuming that if we sense this T i. Suppose, we put a temperature sensor temperature transmitter and put a controller and feed it back, here we give the set point. So, we are sensing the disturbance and this is my feed forward controller and I am applying this input here.

So, if that be, so then what should be what should be my control law for Q such that the temperature such that the left hand side of this equation will be 0. So, which means that, the temperature will not increase. So, in such a case what will happen is that,, so we have the right hand side equal to 0 which means that T is equal to this relationship now I want T should be equal to T set point.

So, to keep T equal to T set point this is my controller. So, this is my final feed forward control law which takes the set point input, takes the disturbance input, takes the model of the process which involves all these coefficients and produces an output which goes to the plant as input. So, this is my, so you see that if I make any error in let us say the value of rho see the value of density of liquid then, immediately the value of Q will be more and the temperature will not match T sp right? So, this is a, this is our problem, however, we have designed we have able to design a feed forward controller based on a steady state model.

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So, let us have see some remarks about the controller first that the controller is non-linear because, you have you have F T all these things can get multiplied together. So, there is no guarantee that is going to be linear. But that does not make in a difference to us we can always make non-linear calculations in a process. It needs an accurate process model as I have said, if you make errors in any of the coefficients you are going to get an error in control.

And see that the steady state, so what happens is that, if you have step input in T i there will be a step change in Q, but a step change in Q may not affect the may not exactly match the response of the temperature in the tank. As a that is there may be some transient that is from instant to instant it will not be able to match the it will not able to match the temperature.

For that, for do, so if you want to really have matching even at the transient level then you should design feed forward controller based on dynamic models which is even difficult, but that price you are paying because you can use a simpler process model. So, for transient response shaping we need a dynamic feed forward control for which we need a we need a accurate dynamic model. So, let us see a simple example simple extension of this problem how we can design a dynamic model.

So, we are going to look at feed forward controller design based on a dynamic model. So, again the same process again the same equations. Now,, so obviously, if you take, if you take Laplace transform then, you will get a model like this, here this should be rho. This is wrongly typed, this should be rho, this is tau the time constant this is also tau this is the time constant of the process. This time constant of the process generally depends on what? It depends on the volume of the process for example, if this is V and if the inlet flow rate F i then the time constant will be dependent on V by F I, right?

So, this is the time constant which is a dynamic parameter of the process this is not a, this is what makes the model dynamic. So, now we have a, we have a dynamic model of a system given by this just like old times. So, now if you want to max that is if you want to make if you want to make T sp S that is T set point S, S means that dynamically I want to match the time function of the set point to the time function of the actual temperature.

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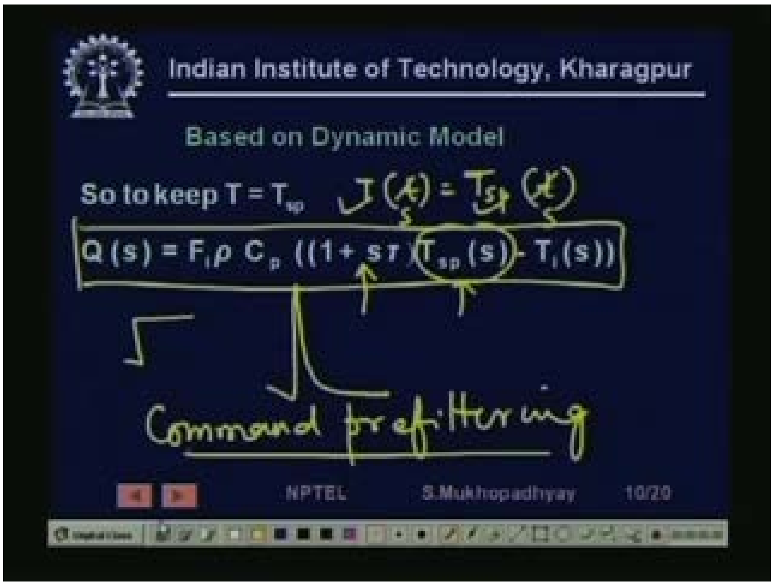

So, if we have, if we want to keep T is equal to T sp, T is equal to T sp means we want to now make T t is equal to Tsp t, that is every time instant not the final values every time instant we want to keep T t equal to T sp t. Then, obviously, if we consider them in the Laplace transform domain then t s will be equal to Tsps.

So, now we can in the previous equation when we had t s in the left hand side if you put T sp S there and then solve for Q s you will get this equation which is now my new dynamic feed forward control law. Very interesting to see that you are, so you see that the set point change now is multiplied by 1 by 1 plus s tau what is it means? It means that if you give a set point change in if you give a set point change suddenly then what will happen is that it will require a tremendously high input.

So, actually this controller is not very easily realizable and you cannot give such command changes, that is such command changes is to be able to mathematically it is ok. You can always equate, but this equation tells you that if there is a set point change and if you want the temperature to exactly follow the set point change then, you have to give an impulse input to the process which is clearly not possible. There will be, there will be saturations of actuator and the response will not be realized. But for slower varying set point changes, these things can be done. In fact, that is why sometimes what you do is called what you do is called command pre filtering, that is you actually put a pre filter before applying the set point to the process.

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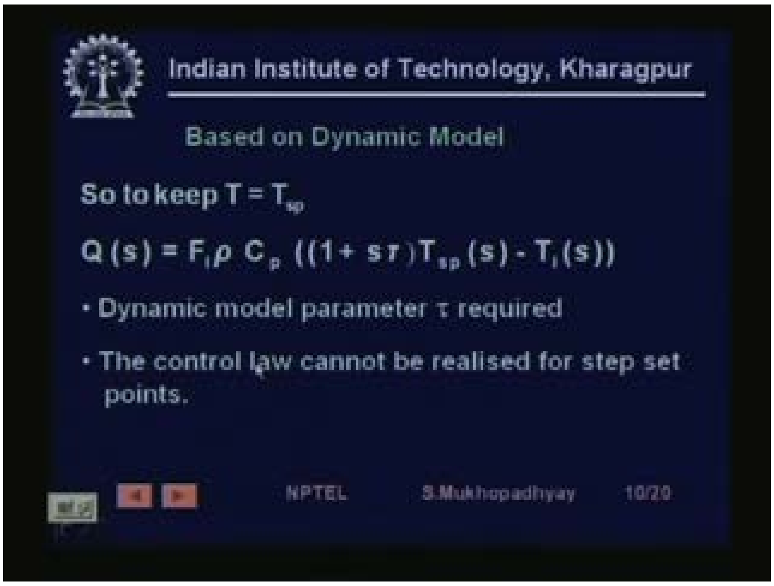

So that, even if so this is available observation that for in designing this law you need the dynamic parameter tau, you need the dynamic parameter tau. And this control law cannot be realized for step set points.

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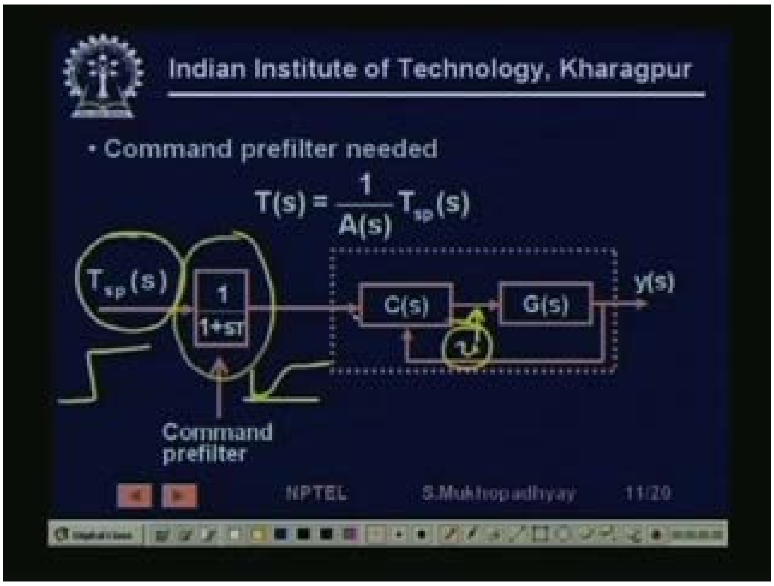

So, if we have step like set points therefore, we often put what is known as a command pre filter by in which what we what we do is that, we do not allow the operator to give the set point directly to the plant, but we put a filter in front. So, that even if it gives the set point the actual set point which will go to the plant will rise slowly. So, in such a case this control input saturation, u saturation will not take place and you can still control it. So, this is the, this is the way, this a very simple example of how a feed forward controller can be designed.

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So, now, let us look at the drawbacks of feed forward control that is the control is heavily dependent on model accuracy. So, what do we do? So, we have we want to actually have the best of both words, that is we want a quick responding controller to step and disturbance changes, but we do not want that our control law should be crucially dependent on the model accuracy. And if the model is little bit inaccurate immediately will get error in the control performance. So, what we have to do is that we have to mix and match, we have to mix feed forward with feedback to be able to get the best of both words. So, let us see how to do that. So, let us look at this problem.

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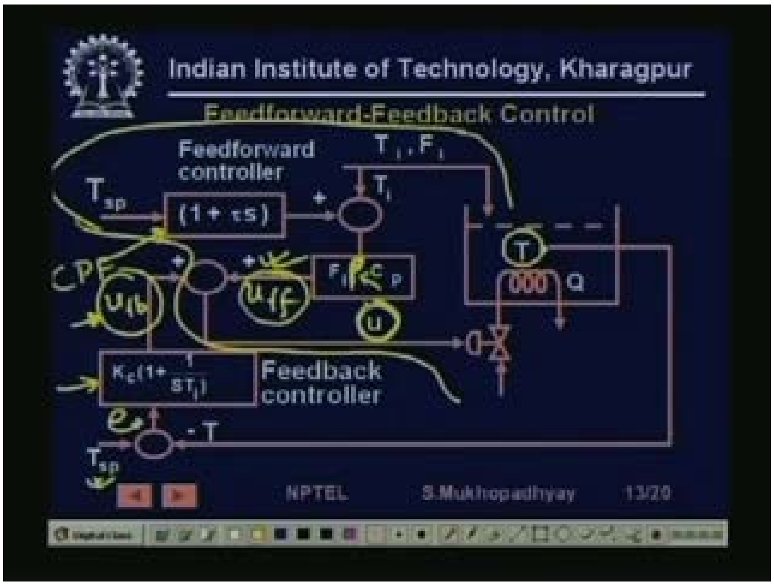

So, what is happening here, first let us, it is the same process. So, we have the feed forward controller. So, we have a T set point which is coming through a command pre filter command pre filter and T i they are going through this F i this should be this should be rho C p and then we are getting u right?

But now along with that we are also adding another loop. So, this part is the usual feed forward that we have seen this part where, we are measuring the disturbance giving the set point and according to our old calculated law we are giving the control input, but now the control input actually consist of two components. One part comes from feed forward, the other part comes from feedback.

So, now we are measuring the T also, and feeding it back comparing it with the set point generating error here and then feeding through a pi control. So, this is my u feedback.

And this is my u feed forward which together give u. So, what is happening is that suppose there is a modeling error in rho. So, the, so the rho is may be slightly less. So, what will happen is that the control input due to feed forward only feed forward, the, so the control input due only due to feed forward will now be little less.

So, if it is a little less then what will happen is that is that some control error will now built. So, that control error will now be sensed by the feedback part and that will provide additional input. So, if due to modeling error this fall short either becomes more or larger than required, then the corresponding compensating correction will be given by the feedback input and then the overall input will be just the right one.

So, what will happen is that you will get lot of speed in the sense that most of the most of the input which will come from feed forward will come quickly. Only a little input will not come because of the model inaccuracies that little input will be provided by this by the by the feedback. So, even if that little input comes slowly much of the correction will come very fast. So, you will get very good response and also in the steady state you will get no error because of the feedback corrections right?

So, you got the best of both worlds. So, this is the basic idea of combining feedback with feed forward and this is the reason why feedback is always combine with feed forward pure feed forward is nearly never applied there anywhere.

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So, now we are making some commends first you says that the stability characteristic depends only on the feedback loop, obviously, because a feed forward loop does not it is a kind of open loop. So, there is no stability question here, but the control energy comes mostly from the feed forward, because you want most of the corrections to come fast.

So, the, so you adjust the gains of the feed forward such that maximum part of u that is required for that change in the set point or the or the disturbance especially is coming from feed forward. So, most of the energy is coming from the feed forward and only the control error in feed forward is corrected by feedback controls. So, the control input which is coming from feedback is actually low in value, it that is why sometimes it is called a feedback trim. So, now let us see we will. So, this is this is one way of adding feedback with feed forward which is which is like a like an additive connection, additive connection you first apply feed forward something is remaining. So, you give a feed fact term and add it with the input.

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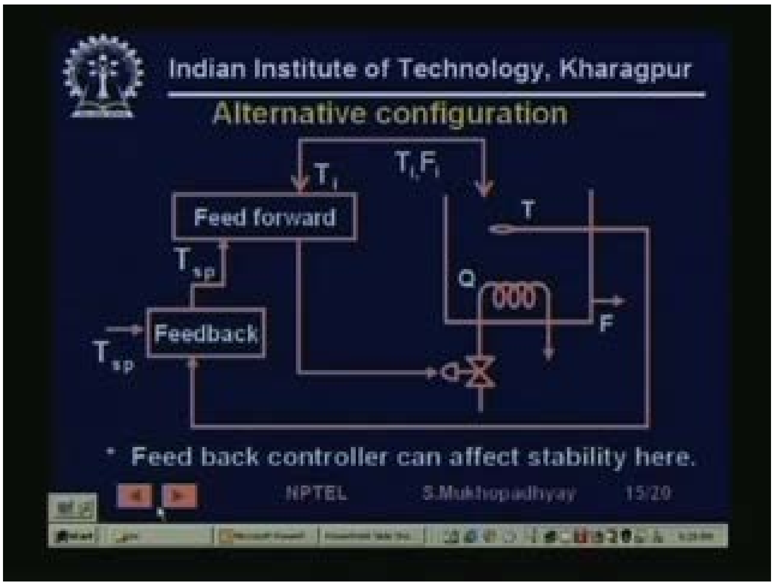

On the other hand, we could also connect these in a slightly different way for example, here what are we doing, here we have the usual feed forward. Again we are again we are measuring the disturbance this is the feed forward controller and we are giving u here standard again the same situation.

Only now this set point we are not providing directly, previously we were providing the set point directly do the feed forward controller. Now, the set point is being provided by the feedback control. So, what will happen is that suppose, the feedback control actually the now the feedback controller provides a set point to the feed forward controller.

So, if again due to feed forward action this input is not proper then this then there will be there will be some discrepancy between T and T set point. So, if there is a discrepancy between T and T set point immediately there will be some error and due to that error the equivalent set point which is being provided to the feed forward controller that will be the raised.

So, the feedback controller will continuously just like an operator as if there is an operator which actually looks at the feed forward control performance and gradually changes the set point till the temperature is just right. So, that is what is being done here the feedback controller looks at the temperature and because depending on the error it keeps on raising or reducing the set point to the feed forward which keeps its control input accordingly.

So, these are two different configurations in which a feed forward controller can be combined with feedback controller and here also the feedback controller can affect stability anyway. We are not examining the stability question very in depth, but obviously, the feedback controller can affect stability because it can happen if the, if the loop becomes unstable then this, then the equivalent T set point can actually oscillate. And then the whole loop will oscillates obviously, naturally such a thing can happen although we are not examining it in detail here. Questions like stability are difficult to not so easy to analyze, now we look at another control. Which is like which has both a feedback and a, and a feed forward flavor it is very, it is a very common control configuration which is used in especially in chemical processes.

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So, it is a special feedback feed forward control loop configuration which is widely used for maintaining composition control, fuel air ratio in burners, for example let us say if you have a if you have a any kind of burner let us say a boiler. So, boiler has a furnace see you have to produce flame, for producing flame you need two things, you need the fuel and you need the air, but they must be provided in such a ratio such that complete combustion takes place.

So, if you, so if you do not have if you do not have enough fuel then you are going to you will probably not generate enough heat, on the other hand if you do not have enough air then the fuel will not be completely burnt and you will produce pollutant like carbon monoxide into the atmosphere.

So, for complete combustion it is very important to maintain fuel air ratios right similarly, in distillation column reflux ratio is very a important thing which decides product quality. So, there are various situations where two materials must be must be brought together in some reactor or some chamber in precise volumetric flow ratios right? It is in this situation that you apply ratio control, there are two typical configurations in which ratio control is used.

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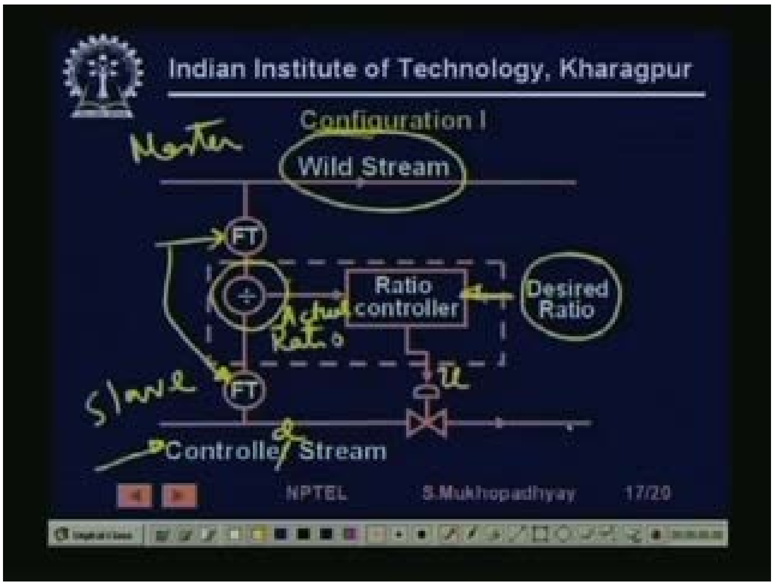

So, the first one is configuration 1, let us see that. So, you see in ratio control we have two streams the first one we call the wild stream. So, we do not directly control that stream, that stream is controlled by other considerations may be from production volumes, but, so it is like it is like a master stream which changes independently because of some operator change etcetera.

And this is the slave stream, or the controlled this is not controller, this is controlled stream. So, basic I will tell you our idea is that if the wild stream changes we must we must change this stream in such a manner that the ratio of the volumetric flow rate in the wild stream and the volumetric flow rate in the control stream are maintained as constant, right? This is our objective.

So, obviously, it to be able to reach that we have to measure these streams. So, we are putting two flow transmittance. So, they actually measure the volumetric flow rates. So, here we are dividing them to get the ratio. So, this is the actual ratio, and this is the desired ratio. So, and this is the ratio controller. So, this is another input this is another input and this ratio controller gives this input on the valve, so that the control stream is changed increase or decrease such that this ratio will keep changing.

So, you see that in this way you can maintain the ratio, there is another way by which you can do you could do it. For example, in this configuration what you doing is, see you are this time you are actually providing is, providing the set point from the wild stream.

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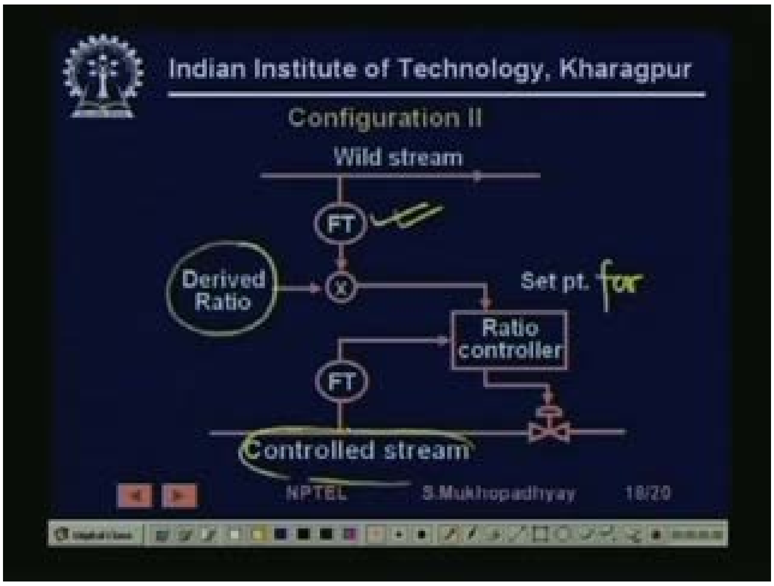

So, you are saying that you measure the flow rate in the wild stream, if you multiply by the derived ratio what will get? You will get that at this flow rate of the wild stream how much of the controlled stream material should come. So, in that sense it is a set point for controls for the flow rate of the controlled stream. So, using this you are providing a set point and then it is an, then it is an usual feedback control. So, this is, so you could do it in actually in either manner and get the ratio. So, this brings us to the end of this lecture, and we have to, let us review this lesson.

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So, we first of all looked at a fundament disadvantage of feedback control in the sense that it cannot respond immediately to changes in disturbance and slow to that. So, that happens because, sometimes the disturbance takes long time to effect the output and a feedback controller by its essential control configuration can respond only to changes in output, and has no way of knowing what disturbances are occurred. That causes errors to be that is errors must be formed to be corrected, in a feedback control errors must be form to be corrected. And if they form slowly then it takes then the errors exist for long periods of time.

So, if we want to get good response our one way of doing that, is to there are there are many situations where we can measure the disturbances. So, if we can measure the disturbances then, for the example we have seen that if the inlet temperature the, if the temperature of the inlet flow rate is a disturbance then it can be easily measured. So, in situations where we can measure the disturbance we should be able to change our control action immediately in responsive to disturbance changes even before they have actually cost, so we should neutralize the disturbance before it can produce an effect at the output.

So, it is from that desired that we have feedback feed forward control and this is the basic advantage of feed forward control and, but we have also seen that this it has a, it has a big disadvantage that we need to have the models accurately. And therefore, feed forward control cannot be used in isolation, it must be used along with a feedback trim.

Then we have seen the design a feed forward controllers both based on a steady state model as well as a dynamic model, I mean a very simple dynamic model. And we have seen that if we want to may design a feed forward controller based on dynamic models, and we expect the real match the that is the process output will from point to point will match the set point. Then say for sudden kinds of set point changes we may get, I mean unreasonable output inputs to the plant may be demanded which is not possible to be given.

So, therefore, from that point of view in such cases we have to apply what is known as command pre filter to the feed forward before the set point can be applied to the feed forward controller. Then, we have seen that how we have seen that basically for that reason that models in practice especially dynamic models cannot be obtained very accurately. It is, it is nearly always very difficult to get dynamic models accurately.

Therefore, we must combine a feedback controller along with the feed forward controller.

So, that the control error due to the model inaccuracies will be connected corrected in the feedback loops slowly, but eventually they will be corrected. So, you will get lot of disturbance correcting action very fast and whatever errors will remain they will eventually also be corrected. So, this is what we saw, and then we saw a ratio control configuration which is a mixed feed forward feedback configuration in the sense that, the disturbance to the plant you can say that the wild stream we are sensing and at the same time we are creating a feedback.

So, that we can control the, so the control stream is being controlled in a feedback configuration, set point is coming from the wild stream which can be which may or may not be in our hand. So, if is not our hand then it then it is like it is like a disturbance. So, it that is why it is a mix feedback feed forward structure.

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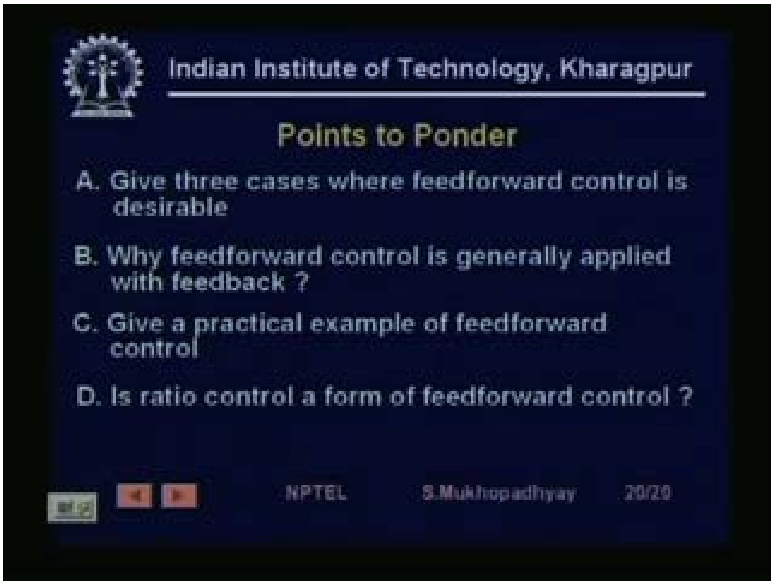

Finally, we come to some points to ponder, that is which are the cases where feed forward control is desirable. So, cases where the disturbance will take lot of time to affect the output disturbance can be measured there are those are the cases. And why feedback feed forward control is generally applied with feedback, this also you will find an answer in this stage we have said it may be, in this like lesson we have talked about it many times. And give a practical example of feed forward control, feed forward control is applied in again in many situations in motion control. Let us say, in rolling mills, in obviously, in temperature controlled problems as we have already seen. So, try to find out some example some one example of your own and see how the feed forward control is applied there.

And finally, is ratio control a form of feed forward control or is it a form of feedback control or is it a mixture? So, ponder over it, it could be called a feed forward control because it is sensing the disturbance, when at the same time there is there is also a feedback loop. So, justify whether it is a pure feed forward or for feedback or what sort of a structure it is. So, that is all for today. Thank you very much, we will meet in the next lesson again.

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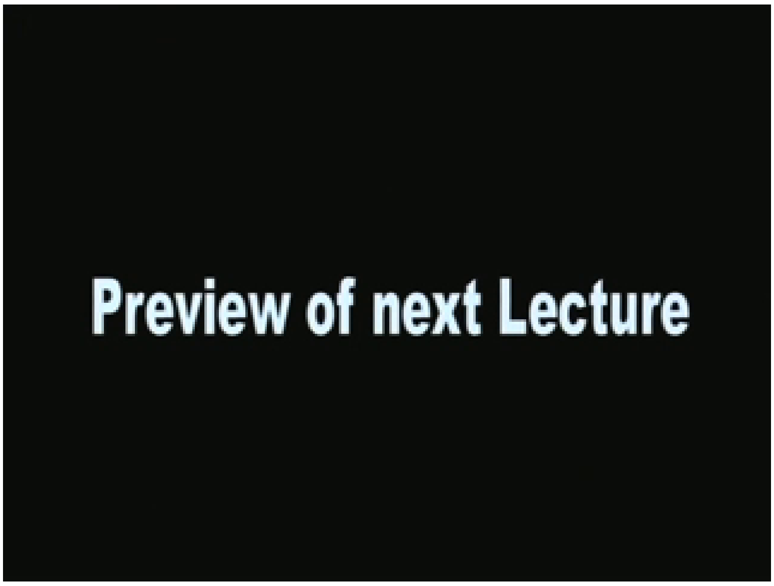

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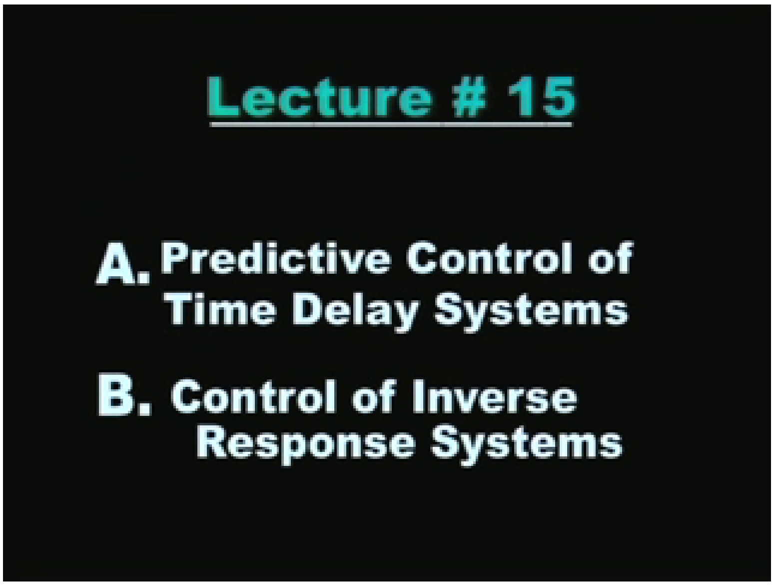

A very good morning to you. Today we are going to look at lesson number 15 of this course, which is on two topics. A, predictive control of time delay systems, and control of inverse response systems. So, we are going to look at two typical kinds of processes which I would rather say two special kinds of processes, which arise in the industry in various context and we are going to see special configurations for controlling these processes. So, as is our practice we will first look at the instructional objectives for this course which are:

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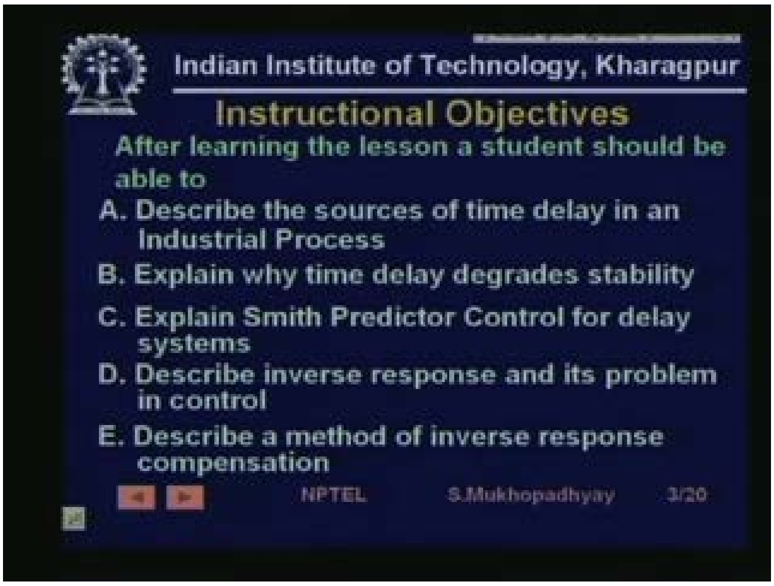

Number one first of all, we need to understand how time delay arise in industrial processes, and then we need to understand why what is the effect of this delay, and why it generally degrades stability and creates problems. And finally, in the context of time delay we have to understand we have to look 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 causes 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 codes 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 the 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 we have a distillation column.

So, if you want to have composition control, and if you give an input let us say either at the either increase the let 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 the delay.

Similarly, in the case of an actuator, you know actuators typically let us say again let us take the case of temperature control, temperature is control by sending steam you have degraded transient response in some cases for example, if you are using a proportional controller. And if you use as use a smaller gain then you are going to get in greater steady state error, because in the steady state delay has no effect. But if because of stability reasons you one has to use a lesser value of k, then that lesser value of k is going to cause thus cause a greater steady state error which is a which is a degradation in performance.

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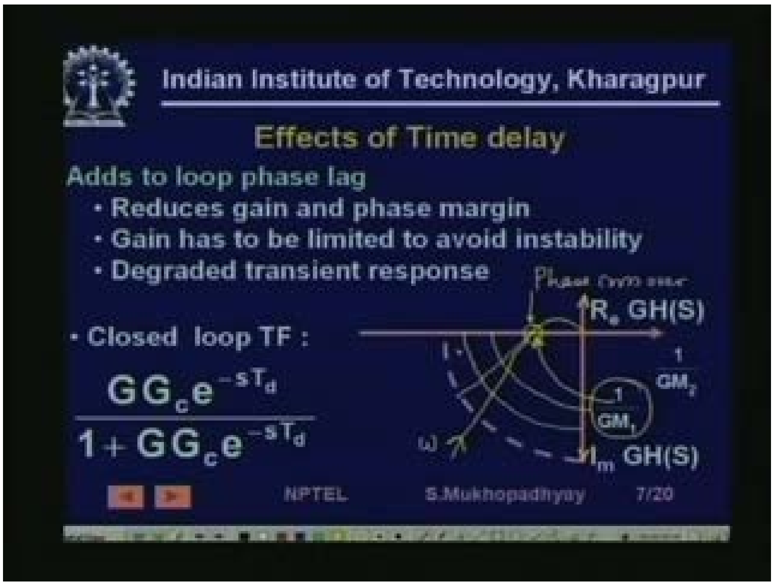

So, this is the major problem of time delay, but before that let us see how this gain margin and phase margin is reduced. Imagine that the original plant or not original plant that the plant suppose the transfer function GG c has a or rather the transfer function has an Nyquist plot like this. So, in this direction as we know omega is increasing. So, this is the increasing frequency direction, these are the two axis this is the real axis real rather this is the imaginary axis, and this is the real GHS axis. So, this is generally what is called the phase cross over frequency. So, and it is this is if the gain here is GM then the gain margin is 1 by GM 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 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 low side 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.

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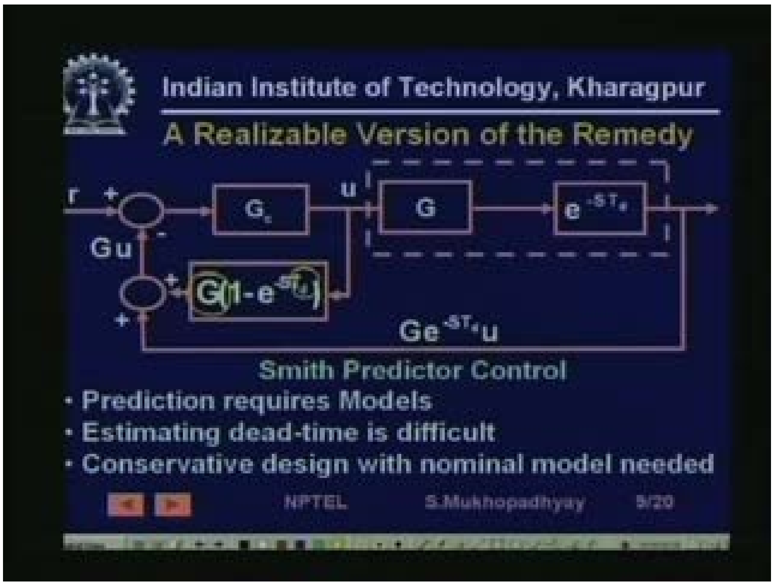

So, trying to in effect, I am trying to predict the output, why? Because, this is y this is the output and what is this? This is nothing but, a future output which will appear here in the measurable form after time T d. So, since I am so I am trying to recreate that. So, in other words I am trying to 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 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,, 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 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 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. So, that is all for today.

Thank you very much.