INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

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Topic Lecture – 15
Feed forward control
Ratio control

Good afternoon and welcome to the 14thlesson of these codes today we are going to look at.

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Feed forward control and ratio control so far we have looked always looked at the classical control structure

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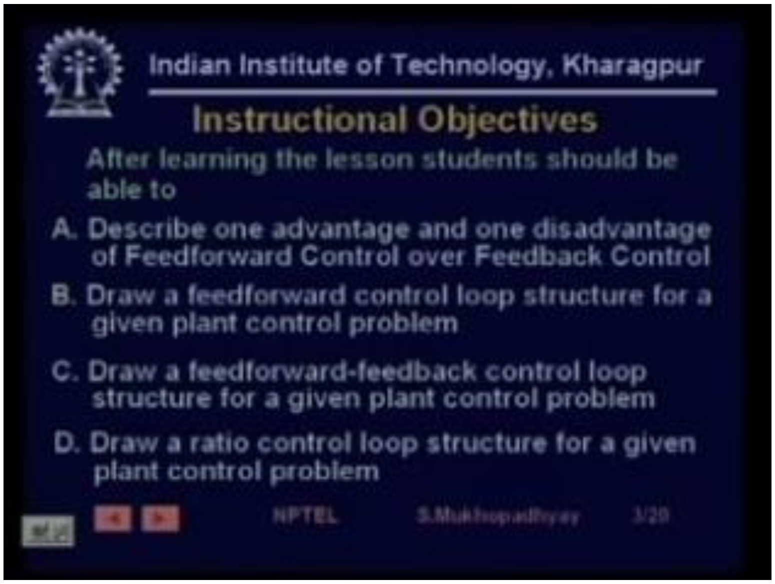

But today we will look at some other control structures which you which are fundamentally different in principle before we do that we have to take a look at the instructional objectives, so after learning the lesson the students should be able to describe one advantage and one disadvantage of feed forward control over feedback control there are some there is a fundamental disadvantage of feedback control so which is an this is 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 disadvantage which is overcome by feedback control.

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 it is called ratio control which is very similar to this feedback feed-forward configuration. So that’s these are our instructional objectives.

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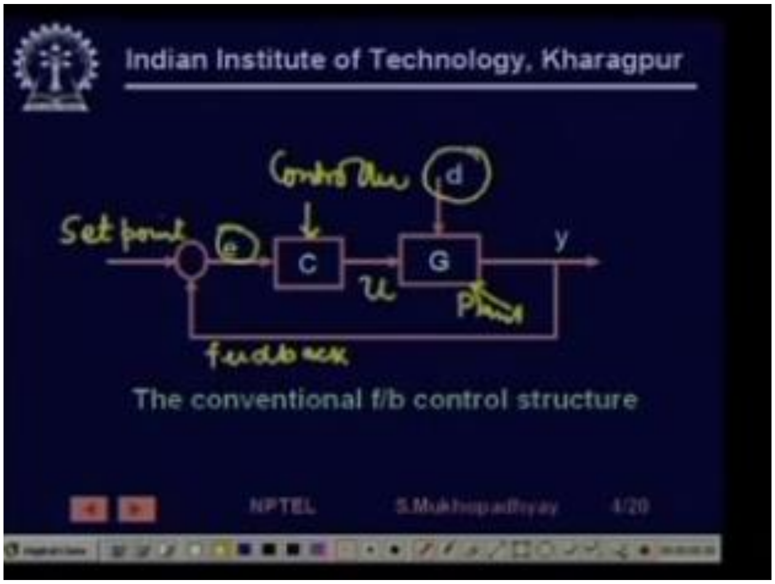

So having seen that let us look at the conventional feedback control structure, so as we have seen here this is the well-known structure where you have the set point here so this is the set point and this is the feedback and here you have the error this is your controller this is the control input you which goes to the plant this is the plant now and which produces the output now, as we have discussed before also that the plant has several sources of disturbances other factors which are beyond our control also affect the output it is not only you 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 structures we have sometimes wanted 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 disturbances very fast and this is the fundamental disadvantage of feedback control for which a feed-forward is generally used so, how yep!.

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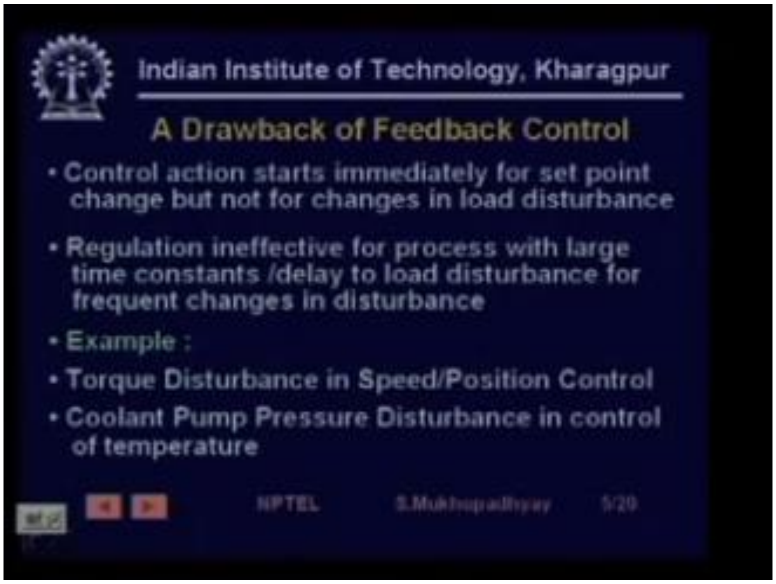

The main drawback of feedback controls that the control action starts immediately for set point change but not for a change in the load disturbance so it immediately responds to stew any change in set point but not so for a change in the disturbance we will see how, therefore why is it so because of the fact that the if you see the feedback loop.

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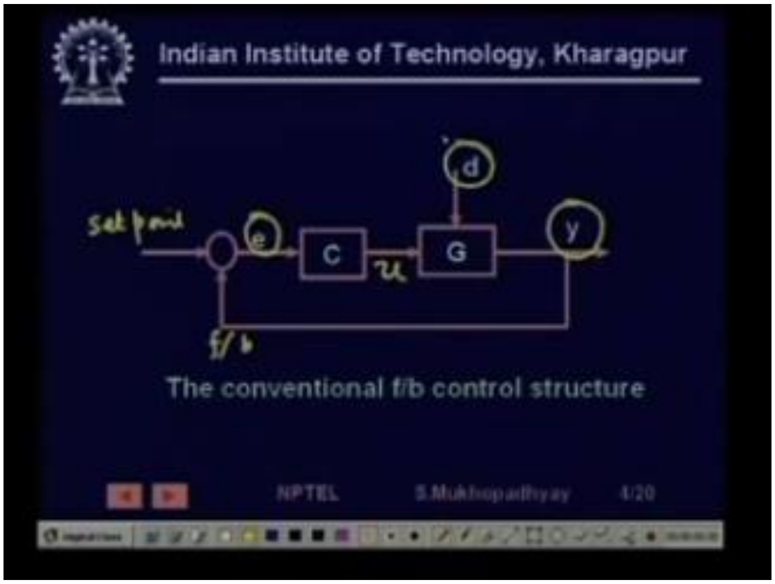

Let us see the feedback loop back again to appreciate this ,I am sorry we are we are going back we are not going back we should have gone back so let us look at the conventional feedback control structure that we have studied all the time now here we have this this is the set point I am sorry Yeah so this is the set point and this is the feedback and this is the error this is the control input you this is the output Y and this is the disturbance we have seen all these now it so happens that that when does the when does the feedback controller work it was 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 a 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 a change in the disturbance level for example suppose we are trying to maintain the position let us 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 the control input there is a load torque which is the disturbance.

So load this creates an acceleration so you it creates actually theta double dot this goes through one level of integration and gives u theta dot this goes to another level of integration and gives theta. So you see either that the disturbance enters here and goes through two integrations to finally produce a change in the output so since these are integrators 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 they 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 slow 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 our disturbance is because the disturbance level has raised but it will change input slowly which means that the speed will fall to a good extent and then slowly the feedback control action will come into play and then the input will rise and then the speed error will be corrected so far up 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.

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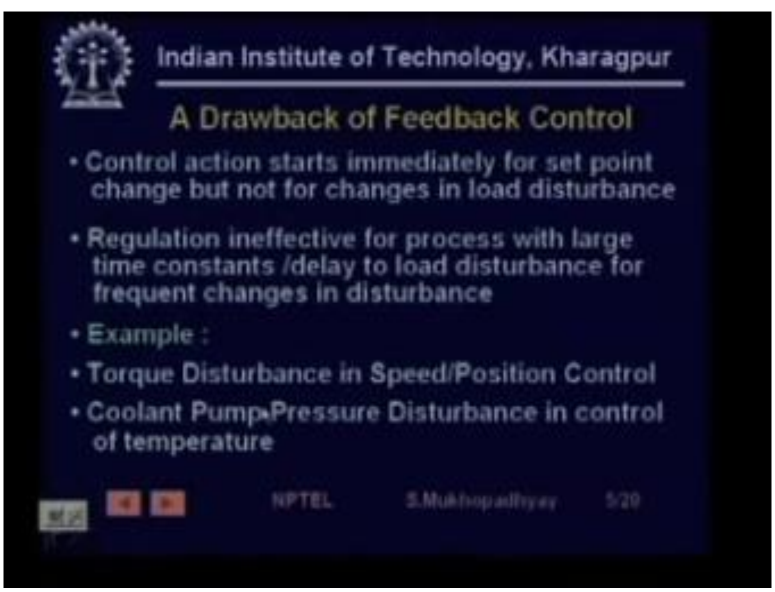

That the control action starts immediately for set point change but not for changes in load disturbance therefore in processes where you have large time constants or delays such that a disturbance takes a long time to finally show its face in the output your corrective action is going to be delayed so 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 talk disturbance in speed or position control that is the one that we have thus 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 falling temperature to the rising temperature is involves the thermal capacity of the let us say of the of the vessel whether it is a reactor maybe 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 is so the corrective action to the to the coolant flow does not take place if it is you done using a using the feedback control structure so we have feed forward control now.

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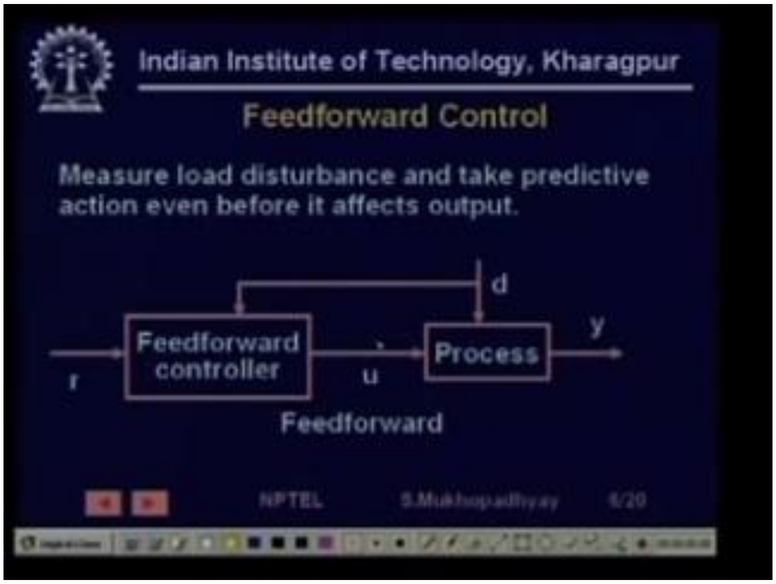

Let us see that first in since pure form what is feed forward control so the basic principle is that you measure the load disturbance change so in feedback control the load disturbance change is is not measured what is measured is the process output but since the disturbance takes time to affect the 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 cannot apply feed forward, so this also shows restricts the applicability of feed forward to two situations where disturbances can be measured and disturbances can be measured in many many situations 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 and 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 desire that you desire in the sense that you must know that if there is disturbance change their, how much disturbance change is to be compensated by how much input this must be known beforehand because suppose this relationship suppose you know that if you have a ten percent change in the disturbance you need to apply a five percent change in the input now suppose that five percent becomes actually six percent then what will happen is that you have overcompensated 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 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 extent 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 fundamental disadvantage of feed forward control.

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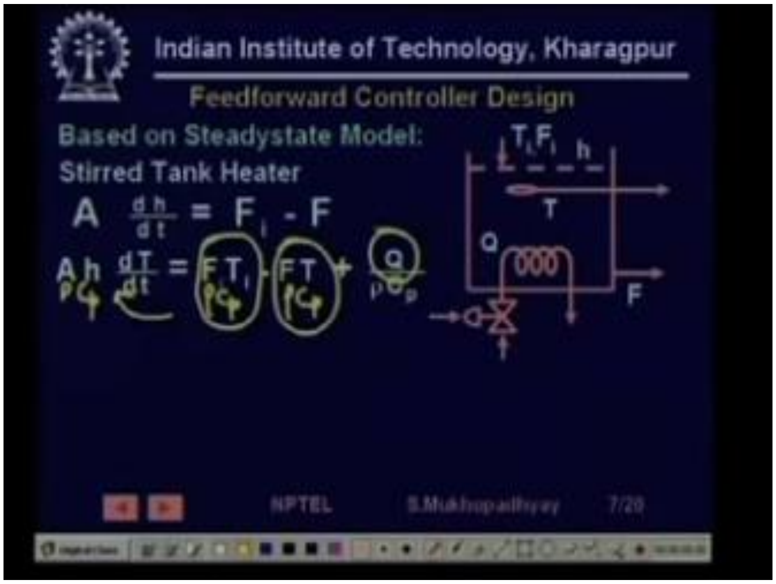

So now having recognized this let us understand just let us see how we can design feed forward controllers now as we have said that that design of a feed forward controller would require a model now models are difficult to obtain but even with those difficulties steady-state models are actually easier 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 that controller may not give us very good transient response to the disturbance but as a first step we should see how to design a feed forward controller based on a steady state models.

Here is a process where we are having 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 a 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 two we have just model that by changing this you we can actually change the heat input to the process.

So then what are the 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 the height so dH dT t is that is the volumetric accumulation of accumulation rate of the tank it says that that 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 row CP this side you will you will find that the inlet enthalpy is Fi into rows CP fi into TI we can understand this that if you multiply you will get a row CP here so Rho CP fi TI is the input enthalpy of the incoming fluid this is the output enthalpy of the outgoing fluid so whatever is remaining this is the 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 fi and fr same actually fi and F will have to be there may be another control loop which if you want to maintain the level then there may be another control loop which will control f maybe using a pump to match a Phi if you want to keep the level constant let us assume that such a loop exists and somehow has been designed so once we have done that we have fi equal to F so this equation the first term becomes fi into TI minus t because fi is equal to f so another situation.

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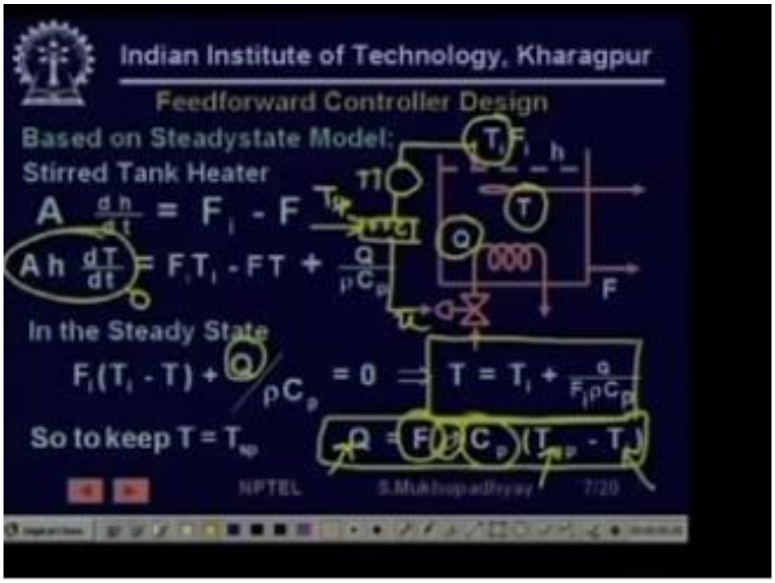

Let us see that so another situation let us see so suppose now we want that the temperature should be constant exactly constant what is the disturbance here the disturbance here is the for example we could assume if we assume that Fi in and Fi constant so that that is that could also be a disturbance but it does not change so that the seven change we are not considering but there can be a disturbance change in TI that is the inlet fluid which is flowing in can this temperature can vary.

So if its temperature vary is what we have to do is that we have to correspondingly change the temperature q the heat input queue so that this D is maintained this is this is our control problem and now if we do a feedback control then if there is a temperature change then then that would have to affect 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 TI 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 you okay 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 zero 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 zero 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 an input so this is my so you see that if I make any error in let us say the value of Rho so the value of density of the liquid then immediately the value of Q will be more and the temperature will not match TSP right so this is a this is our problem however we have designed we have been able to design a feed forward controller based on a steady state model so let us have see some remarks about the controller.

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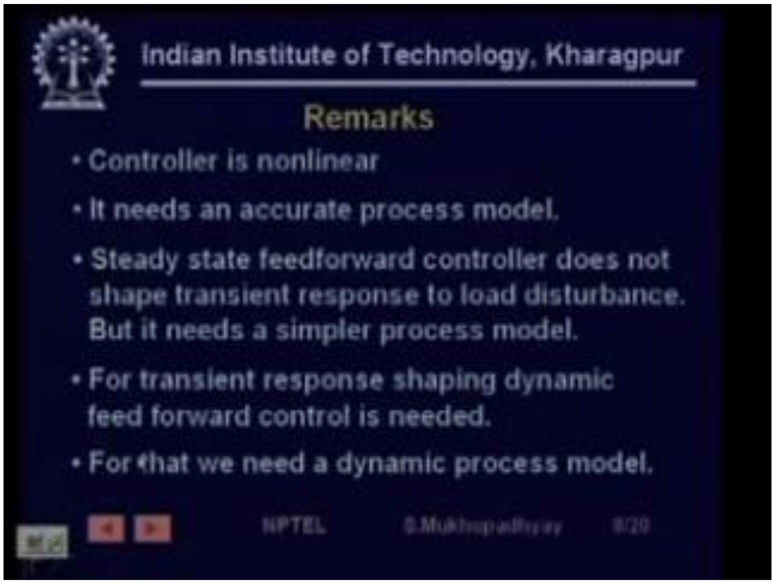

First that the controller's need is non-linear because you have you have F T all these things can get multiplied together so there is no guarantee that is going to be linear but that does not make any difference to us we can always make nonlinear calculations in a process it needs an accurate process 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 field so what happens is that if you if you have a step input in TI 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 truck that is there may be some transient that is from instant to instant it will not be able to match the it will not be able to match.

The temperature for that for do so if you want to really have truck 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 an 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,

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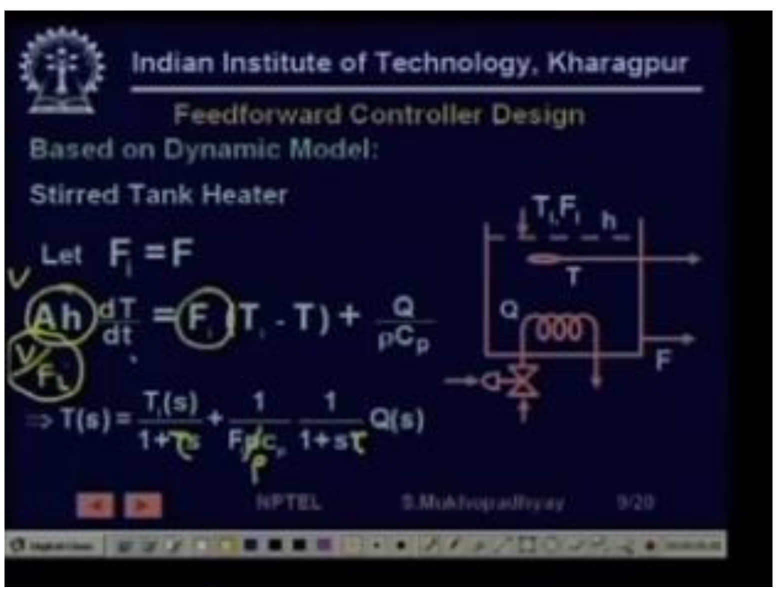

Feed forward controller design based on a dynamic model so again the same process again the same equations now so obviously if you take if you take Laplace transform then you will get a model like this here this should be Rho this is wrongly typed this should be Rho this is tau the time constant this 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 a H if this is V and if the inlet flow rate fi then the time constant will be dependent on V by Fi, 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 we have a dynamic model of the system given by this just like old times so now if you want to match that is if you want to make if you want to make TSPS that is T set point s, s means that, that dynamically I want to match the time function of the set point to the time function of the actual temperatures.

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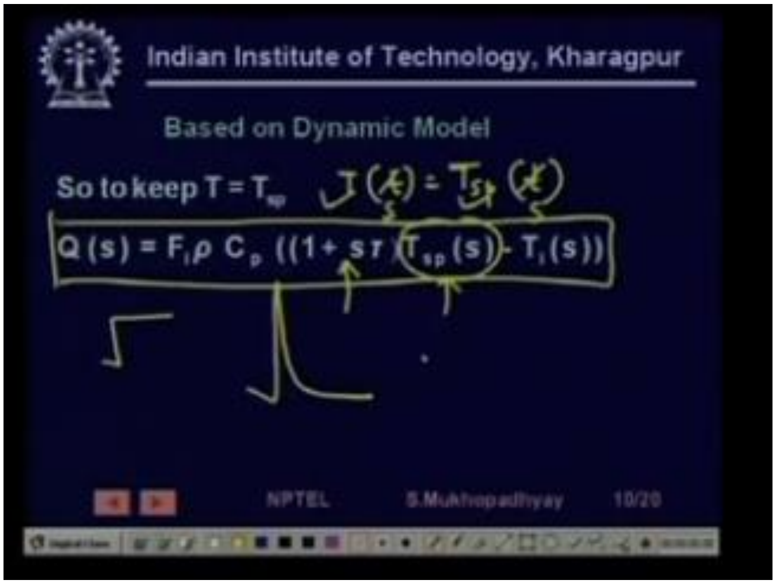

So if we have if we want to keep T is equal to TSP, T is equal to AC means we want to now make T,T is equal to T SP, T that is every time instant not the final values every time instant we want to keep T equal to TSPT then obviously if we consider them in the Laplace transform domain then TS will be equal to TSPS so now we can in the previous equation where we had TS in the left-hand side if you put TSPS there and then solve for QS 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 one by one plus s tau what does it mean? 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 to be able to mathematically it's okay 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 actuators 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 so that ,

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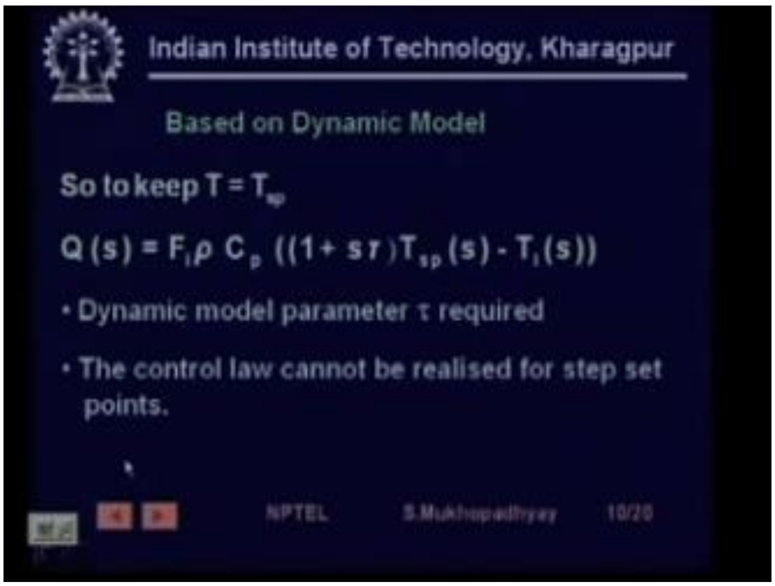

So that even if so yeah this is another observation that for in in designing this law you need the dynamic parameter tau you need the dynamic parameter tau and this control law cannot be realized for steps set points.

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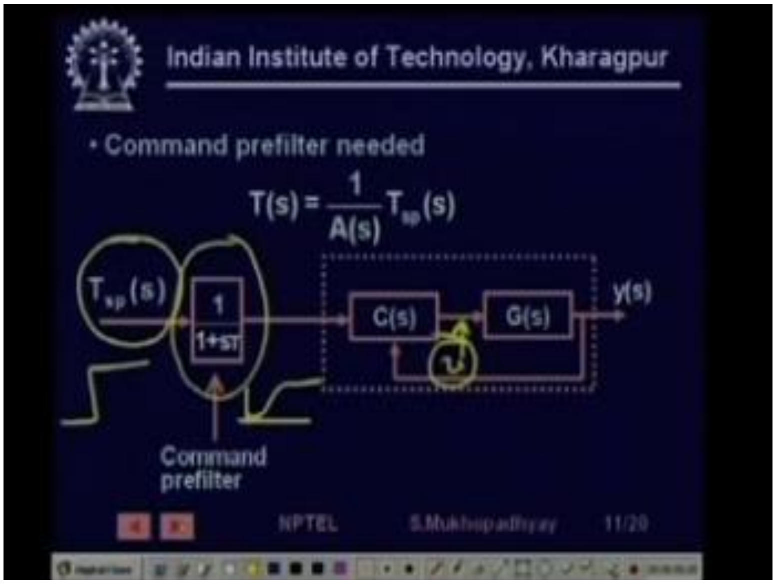

So if we have step like set points therefore we often put what is known as a command pre-filter by in which what we what we do is that we don't not allow the operator to give the set point directly to the plan but we put a filter in front, so that even if he gets give the set point the actual set point 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 is a very simple example of how a feed forward controller can be designed, so now let us look at the drawbacks of feed forward control.

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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 worlds that is we want a quick responding controller to step and disturbance changes but we do not want that that our control law should be crucially dependent on the model accuracy and if the model is little bit inaccurate immediately we will get error in the control performance so what we have to do is that you have to mix and match we have to mix feed forward with feedback to be able to get the best of both worlds so let us see how to do that.

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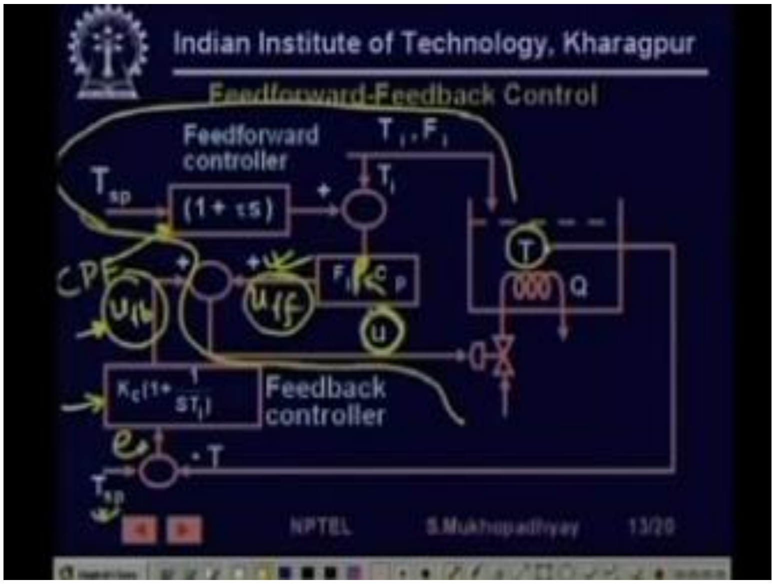

So let us look at this problem so what is happening here first let us it is the same process okay so we have the feed forward controller so we have a T set point which is coming through a command pre-filter command pre-filter and Ti they are going through this Fi this should be this should be Rho CP and then we are getting you 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 consists 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 controller so this is my U feedback and this is my U feed forward which together give you, so what is happening is that suppose there is modeling error in row so the row is maybe slightly less so what will happen is that the control input do to feed forward only feed forward the so the control input you only do two feet forward will now be a little less so if it is a little less then what will happen is that is that some control error will now build.

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 false 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 body but 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 combined with feed-forward pure feed-forward is nearly never applied in anywhere.

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So now we are making some comments first thing we says that the stability characteristic depends only on the feedback loop obviously because the 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 control.

So the control input which is coming from feedback is actually low in value that is why sometimes it is called feedback trim okay 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 correction you first apply feed forward something is remaining so you give a feedback term and add it with the input.

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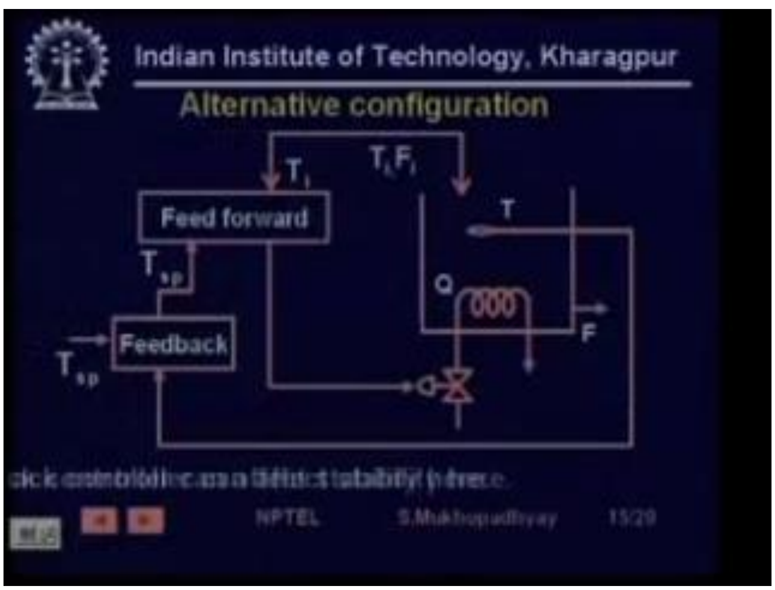

On the other hand we could also connect this in a slightly different way for example here what are we doing here we have the usual feed-forward again we are again we are measuring the disturbance this is a feed forward controller and we are giving you here standard again the same situation only now the set point we are not providing directly previously we are providing the set point directly to the feed forward controller now the set point is being provided by the feedback control.

So what will happen is that suppose the feedback on actually this now the feedback controller provides a set point to the feed forward control so if again due to feed forward action this input is not proper then this then there will be there will become discrepancy between T and T set point so if there is a discrepancy between T&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 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 gives its control input accordingly so these are two different configurations in which a feed for 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 if 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 says 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.