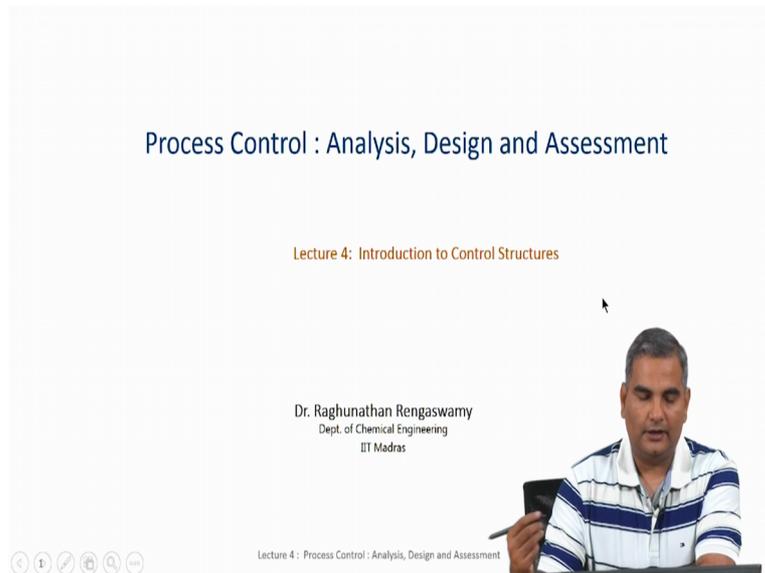**Process Control -Design, Analysis and Assessment**
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Introductory Concepts

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We will continue with our 4th lecture in the course on Process control: analysis, design and assessment. In this lecture I will introduce you to control structures, what to control structures mean? And how does one implement these control structures?

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So we will start with some "Control System" terminology which we have talked about quite a bit, so this would add as something that you can took a look at to remember while we go through this lecture. We already discussed that a control variable is a variable that needs to be maintained at it's decide value. Set point is a value that you want the control variable to take. Manipulated variable is the input variable that you are manipulating, so that the control variable takes the decide value.

Disturbance variables are input or exogenous variables that are outside the control of the system over which we have no control. So you cannot change those variables, what you need to do is, you need to control your Control variable at its Set point even when you have these disturbances acting and Error signal is the difference between the actual control variable value and the Set point.

So whatever you want a control variable to take and how far away from it are you is what is given by the error signal? And as we said before in previous lectures the control variable, let's assume it is at a Set point. Now you would need to change the control variable from its current position either because you have disturbances which change the control variable from its value and you want to bring it back to a Set point.

Or you want to change the Set point and the control variable follows the new Set point. So we talked about these and decide one of them is called Regulatory control and other one is called the Servo control.

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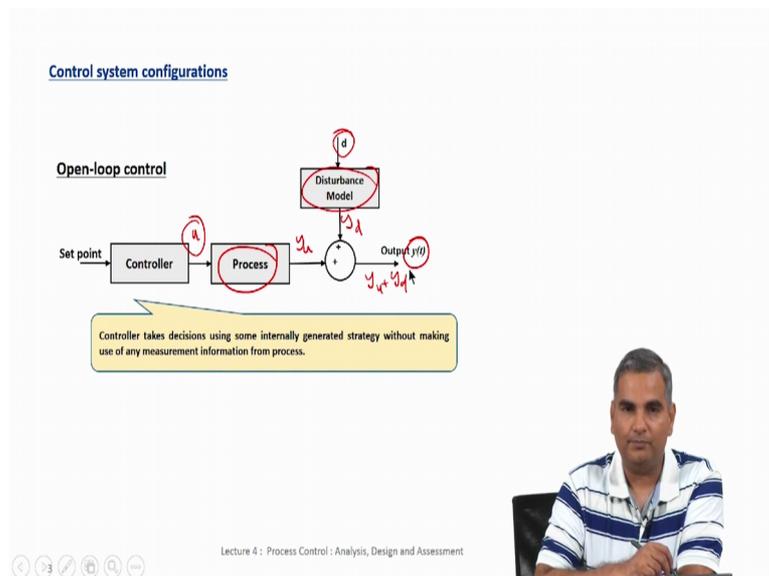
So the simplest idea for controller is the following. So I have a process whenever I draw a block like this basically this controller is giving the manipulated variable value into the process and then the output from just the changes in the manipulated variable is given by this. So we can say y u and this disturbance model is another place where the control variable changes.

So the output of this is y d and because we think about these systems as linear systems the total output change because of disturbance and u going to be y u plus y d which is what you will observe as y. You cannot usually directly split this y into these 2 components but mathematically this is what this means. So if we talk about simple open loop control basically what you are saying here is you give a Set point to the controller and then it basically decides that this is a manipulated variable value I'm going to keep and then wait till the output reaches a certain value.

So if we have a notion of a model of the process then you might say that if I keep this manipulated variable value at this level then I'm likely to reach this value for the output and that is a basis for my controller. And as we discussed before this open loop controller is unlikely to work very well. Simply because the models are not perfect, if you have perfect models, if you know the disturbance exactly and you have a perfect disturbance model and you have perfect process model.

Then it is possible that we can just do this controlling open loop very simply say what should u value be given the exact disturbance value and exact models, so that y takes a Set point value, okay. But this is unrealistic in real-life situations.

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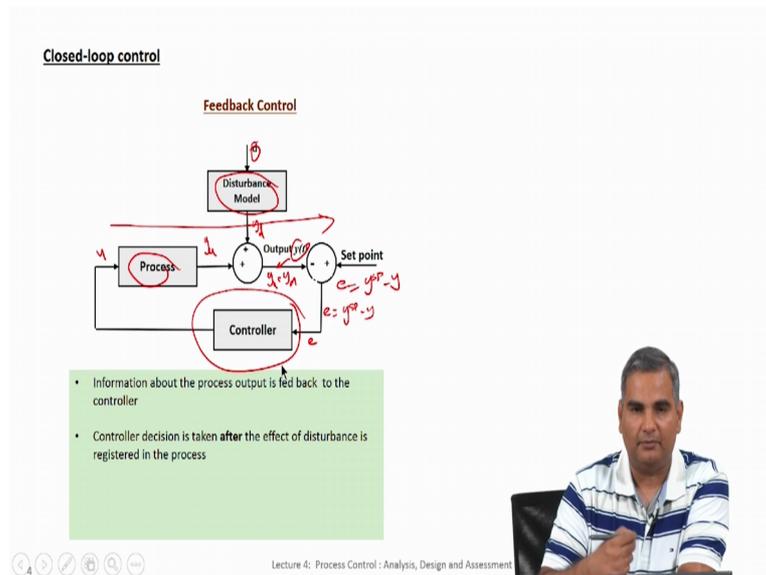
So to overcome the problem of cases where the disturbances are not measured, so that you cannot really know what the disturbance is, that is affecting the process and cases where you have mismatch between the model and the actual process and which is going to be the case most of the time. We still want to be able to control; in fact that our control variable goes to the Set point, so how do we do this is an interesting question?

Here is where the notion of feedback control comes in, so this concept is the most important concept in all of this course, so what is this feedback? Okay, so if you take this again, so if you start from here and go in this direction first. So we will worry about how we will get this u value, how we close the loop later?

First let's say okay this is the u, this is what the controller is saying the manipulated variable value should be and as before this is the effect of that on y and this is the effect of disturbance on y and I have yu plus yd which is actual output that we measured. And what we really want is this output that we measured y to be at a Set point value. Now if it is at its Set point value we don't want to do anything.

But if it is not at a Set point value what we do is, we generate an error term. So this error term is y Set point minus y. Remember when you talked about the circle and then we talked about these block diagrams I said you have to look at the circle and then say if it's plus and a plus

the 2 inputs are added as output and in this case you see that y Set point is plus y is a minus, so this error equal to y Set point minus y is what goes through this connection.

So the controller then basically uses this error to make a judgment about what is u should be. Now notice the difference between the open loop control and closed loop control. In the open loop control this information was not back on, so we had to rely only on the process model. So we couldn't do anything else. However in this case since we send back the error the controller is a pretty good idea whether the objective of control has been achieved or not.

So for example if this error is zero that basically means y and y Set point are the same, so y equal to y Set point. So the controller could say, look this error is zero so everything is fine and handy I don't have to do much, right? However if error is not zero that means there is a mismatch between the Set point and the output, so that should trigger the controller to act and the way the controller acts is by changing the u value.

So that this y u changes and then this loop keeps going on and this controller should ideally stop acting only when the error goes to 0, so this is the feedback control loop. And the ring that we are feeding back here is the error. This is a very very important idea in process control and this is a notion of closed loop control. In this case we will see later that whether we measure disturbance or not.

Whether we have an exact model for a process, we have an exact model for the disturbance or not. Just this notion of feedback control can get the output value to its Set point in many cases, so that's actually a remarkable idea where just a feedback control satisfies lot of the requirement of control even in the phase of process model mismatch and even in cases where we really do not know what are the disturbances that are acting on the process.

So this concept is what we are going to focus on in this course quite a bit. So we are going to look at how we model the process and this model will depend on what is the process that we are modeling. And we are also going to look at how do we come up with the equations for the controller, so how do we define this controller? Notice that the model equations are actually based on the physical process, right?

So if it's an aero plane the model equations are going to beat different, if it's a reactor the model equations are going to be different but those model equations are basically there to mimic the process. However controller is basically independent of this in some sense. So I

have to give a mathematical formula for the controller where the error is the input and the controller decides what the manipulated variable will be.

So this also underlines the fact that while the PAD control that we are going to see later is a fixed set of equations. It's been applied across all kinds of disciplines PAD controllers have 3 prevalent in mechanical engineering systems, chemical engineering systems, aeronautical Systems and so on. So there is some notion of universality to these controller equations and we will see why that is as we go through this course.

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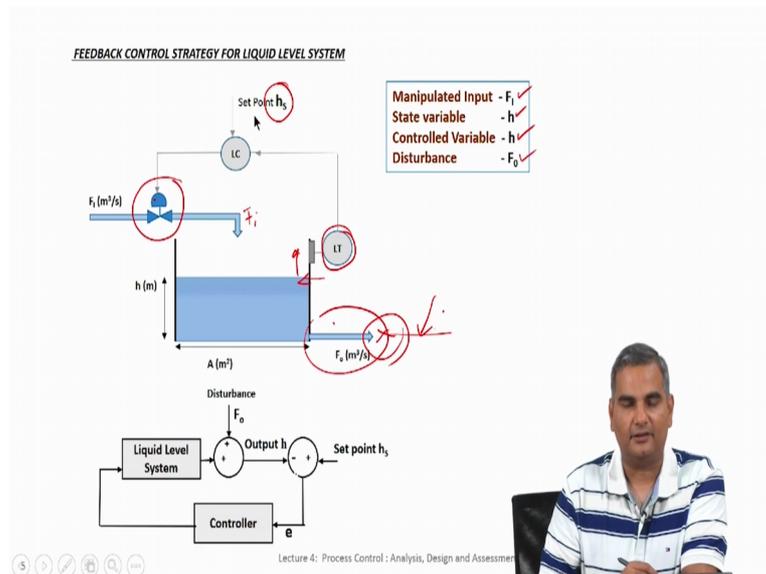
So let's take this liquid level system and then try and understand the feedback control strategy if we were to use for this liquid level. So in this case we have flow coming in, let's say we have a flow going out and we have height, okay. So now in this picture you will notice that we have put in our control valve here at the inlet. So that basically means that we should be able to manipulate the flow of the liquid that goes into the tank.

LT stands for level transmitter basically this is a sense that measures the level in the tank and this information goes into level controller. The level controller also needs the Set point for the height. So this is the actual measurement of the height this is a Set point and the error between this and this is used by this level controller to go and manipulated is valve, so that the flow rate is change.

Notice that there is no control valve here, so that basically means that depending on the height the flow out is going to vary. Now the same problem one could have chosen to put a control valve not here but here. In which case the manipulated variable would be Fnot

because by manipulating the position of the stem in the controller you can manipulate the flow going out of the tank.

And in such a case if there is no control valve here then this inlet flow will become a disturbance. So if this flow is coming from some other tank or some other system whatever are the natural fluctuations in this inlet flow will be accounted as disturbances and this will be the manipulated variable. So for the same problem I just wanted to illustrate that you could think about several different control structures.

And what to choose and how to implement are things that we will learn as we go through this course. So the manipulated variables in this particular example is Fi, the State variable is h, we also want to control this State variable h and if you have let's say further down there are some system here, let's say further down there are pressure fluctuations then the flow across this pipe would change depending on how the pressure fluctuations are there.

So you could also think of this as a disturbance variable for this problem or if this is just a system then this is the output variable, so it depends on how this is connected to the other system. So for example if that say there is another control valve, just a value here and then the pressure changes here would change the flow here because of pressure difference across the valve will change and that will create changes in F not and so on.

However if this is just a system then we could say F not is just a function of height and then say this is the only manipulated variable. So in this case what will happen is, supposing you want to maintain the height at this level. Now if the height increases the level transmitter will figure out the height is more than what it should be. So it will go here and check the Set point and then say the height is more than what the Set point should be.

So that basically means I have to reduce the inlet flow rate and so on. So this is how this feedback control will be done. So the feedback really comes from measuring the actual control variable and checking it against the Set point.
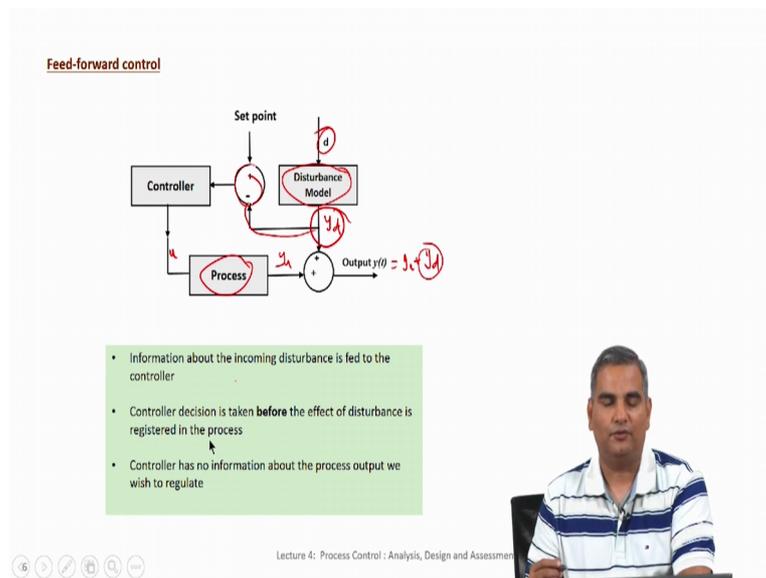
Now there is another type of control which is what is called the Feed-forward controller. So in this case look at this diagram right here. So as before I have u from the controller coming into the process and then I have output y u and then I have let's say disturbance, so y d, so this output is y u plus yd as we have been saying in all these lectures. Now supposing you were to actually measure the disturbance.

So that basically means you know even before this really happen is that because this disturbance is measured you know, it's going to have this effect on the output. So you could use this information to our controller and then say because this disturbance is going to hit the process soon, how do I change this u, so that I still maintain my output value at the Set point. So this is called Feed-forward control where we anticipate based on disturbance measurements what the changes are likely to be.

And we feed that information to a controller which changes the manipulated variable value. See the difference between this and the feedback control. In the feedback control the fact that a disturbance has hit the process is only inferred when the control variable changes its value, right? So once a control variable changes its value you know a disturbance has set and that is compared with a Set point and that error is used to manipulate the u to get the process to make sure that the output is at its Set point.

However in this case you're not using a feedback error but you're using a Feed-forward measurement of disturbance to say change the manipulated variable value in this way, so that

I'm able to control my output at its Set point, so this is Feed-forward control. Now similarly if you know that you want a Set point change then you could use that information to again manipulate and get a new u, so that the output goes to a Set point.

Here the problem is for Feed-forward controller to work well your measurement of, your disturbance in the accurate. The disturbance model should be accurate; process should be accurate and so on. And of course in more sophisticated system you could actually integrate both Feed-forward and feedback control together and then you can have an integrated Feed-forward feedback controller.

Which if you have the disturbance measurements and so on which will be very effective and you can imagine why? Because since you are anticipating the changes that are going to occur in yd based on the disturbance measurement you can automatically change u and whatever does not get fixed by the Feed-forward controller because of either poor measurement of disturbance or poor models those can be fixed by the feedback error this control. So abomination a Feed-forward and feedback can give you very very effective controller.

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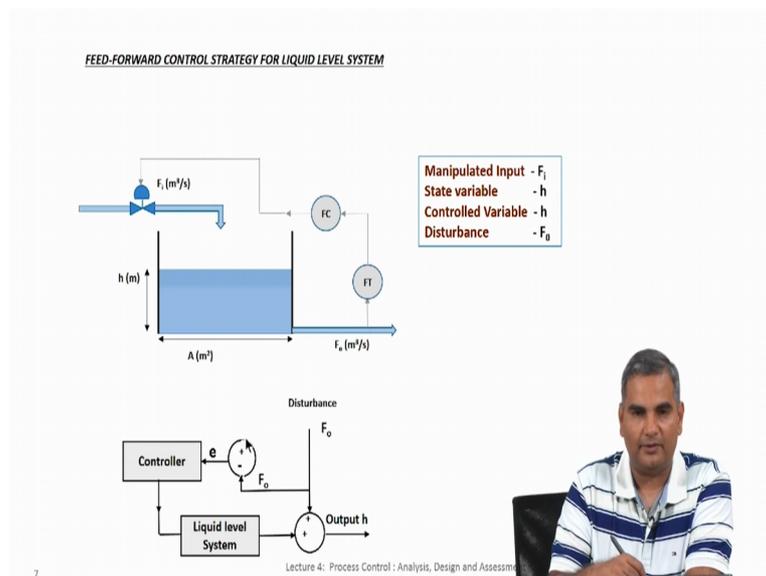
So here is an example of the Feed-forward control, so for example if you were to keep, if this is fixed at a particular flow rate, so you know this is not changing. If I have a flow out and then I am measuring the flow out and because of fluctuations downstream, let's say this flow out changes then you know the minute the flow, let's say the flow decreases you know that this site was at its steady-state because Fi and Fo were the same.

Now if Fo decreases that means there is a mismatch between what comes and what goes out, there is more coming in and less going out. So automatically you know the height increase, so what you can do is, you can measure this and then go and then set Fo to the F not in which case you can say immediately as soon as I have this changing I'm going to manipulated my variable here, so that the height is maintain properly. So this is a Feed-forward control strategy.

Now in the same example if you also add height measurement and then add error based manipulated and of the valve also then that would be a combine Feed-forward feedback control strategy which would take into account mistakes that are made in this F not flow change automatically because you would assume that the F not has changed by certain amount and then change effect correspondingly.

However the height would not remain constant that might be because this F not measurement itself is wrong. So those kinds of errors you can fix using a feedback control strategy.

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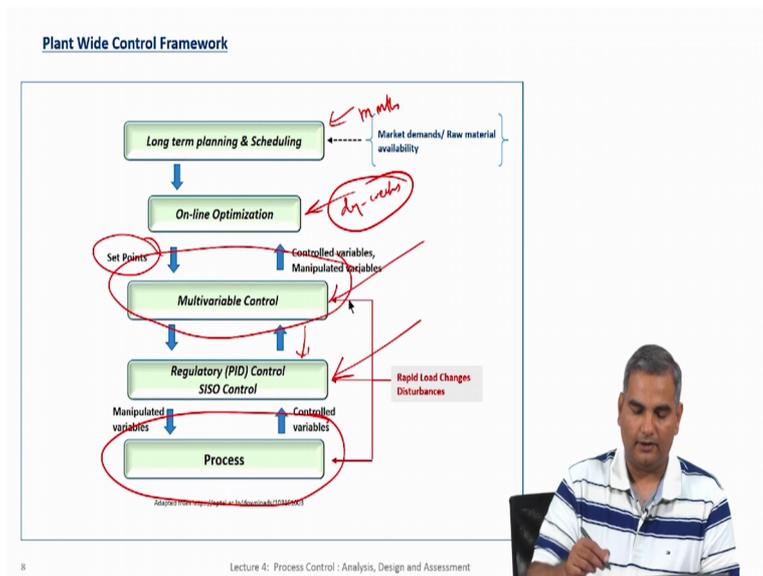
So these are some basic control structures, we will look at much more control structures in terms of cascade control, ratio control, and so on as we go forward but I hope that you have a reasonable idea of what is the notion of feedback control, why is feedback control important? And then notion of feedback control, when can it work? And the fact that if you combine both we can actually have very effective controller and so on.

In terms of connecting these 2 the overall control framework from as we talked about you will have really in real life, you have this multivariable control problems where you have to

manipulated the multiple inputs to control multiple outputs and as mentioned before, so those are broken down into several SISO control problems which is what is implemented in the process, okay.

And beyond this if you want even higher level view of plant wide control framework. The set points for this control variable is could come from an online optimization where you are looking at several factors, environmental factors that are affecting the profitability of the process and then using that information to figure out what are the Set point that you want to use for your control variables.

And this itself could have information from long-term planning and scheduling, so this is more at the level of planning for a let's say months and then this online optimization could be in the level of days to weeks. So these kinds of computations could tell you what are the Set point that you want for your many control variables and then those get passed on to the SISO control variables.

And then this whole set of multiple SISO control loop work in tandem to control the process so that it is very profitable. So this is overall picture of you know plant wide control and as I said before we are going to first focus on this my here we are going to look at the notion of PAD control, different control structures and so on then you're going to look at multivariable control itself and then the 3rd aspect is going to be controller performance assessment.

So if you want to think about the Essentials of process control, so you have to understand the control objectives, how do you mathematically describe a system in terms of its process dynamics we have to think about how to configure your controllers and what kind of control Law you should use? And there is also this aspect of hardware and software which becomes important when you actually implement these controllers in real processes.

We are not going to spend much time here in terms of hardware aspects of control and there is also this whole notion of instrumentation. So how do you put in the actuators, the controllers, the pumps and so on? And what measurements to take, how do you choose what sensor you need to choose and so on. So that is also something that we are not going to spend much time on this course.

So this for course will focus more on the control objectives, mathematical description, control configuration, control law in the SISO case and then extended it to MIMO case and then look at assessment of controller performance and so on. So with this I will and my 4th lecture and I will see you in my 5th lecture soon, thanks.