Chemical Process Control
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Lecture – 21
Block Diagram Representation

Hello students. Welcome to the second module of this course, and in this module, we will be focussing on process control. In the first module in the last three weeks, we looked at different ways we present process dynamics, and the whole objective of that exercise was to understand how processes behave. Now in this module in the next few lectures, we will look at how do we use this information about the behavior of a process to manipulate the behaviour to make sure, to ensure that our system behaves the way we want.

So that will be the focus of this module on process control. So for this first lecture, the objectives of this first lecture will be to develop block diagram representation for our systems, especially when we have a control system placed on top of a physical system. And then we will derive closed-loop transfer functions.

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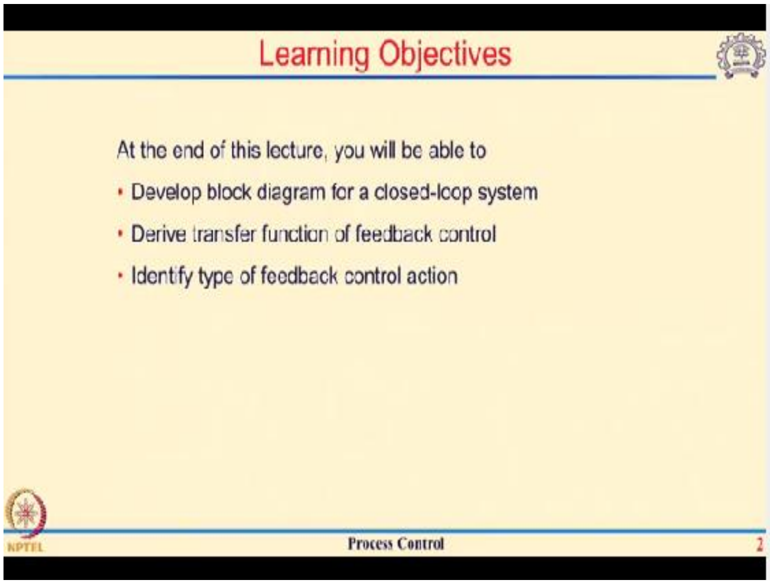

And lastly, we will look at the different types of feedback controllers which we have. So earlier in the first week, I had given you some glimpses about what a feedback control is. So feedback control is a way of controlling a process where we measure the control variable and use that information or use that feedback from the system to manipulate the manipulated variable. And we had seen that there are few advantages and disadvantages of having a feedback control.

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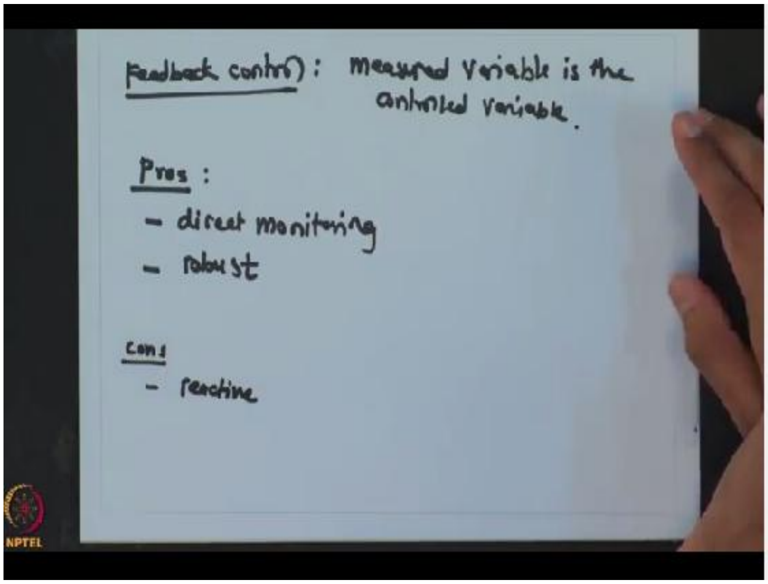

So in feedback control, the measured variable is the controlled variable, and because of that, the advantage is, it gives you direct monitoring. And this control strategy is also very robust. You do not need to know all the disturbances which are affecting the process. And because of that feedback control is one of the most commonly used control systems especially at a regulatory level and that is why in this module on process control, we will be heavily focussing on the feedback control part.

In addition to that, there are some cons as well, as it is reactive, it will take action only when the disturbance has affected the system. And we will see how that effect can be minimized by effectively designing this feedback control strategy. Now when I say feedback control is one of the most commonly used control strategy in industry, the actual correct way of saying that statement will be it is one of most commonly used control strategy by man as well as nature.

There are lots of examples in nature which follow feedback strategy. For the next few minutes, I will give you some examples where feedback control has been implemented by nature or man in the domain outside of our chemical engineering. A human body is a very good example where there are lots of feedback controls loops which are present.

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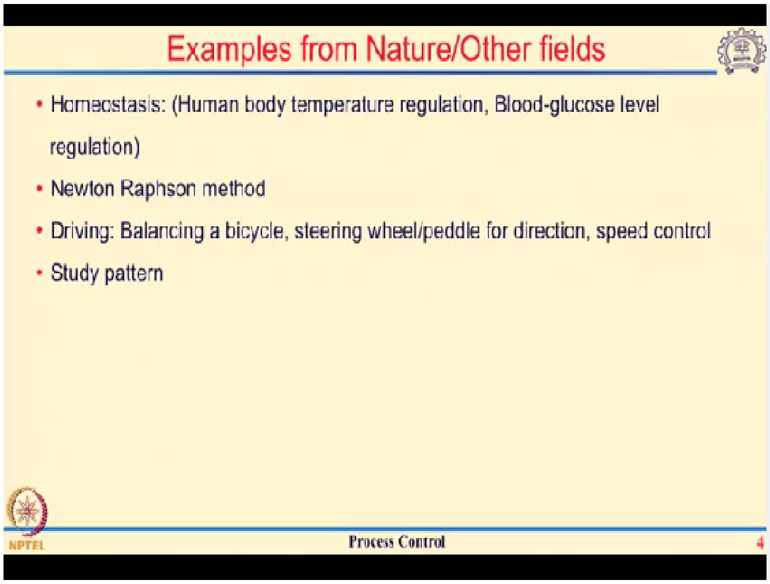

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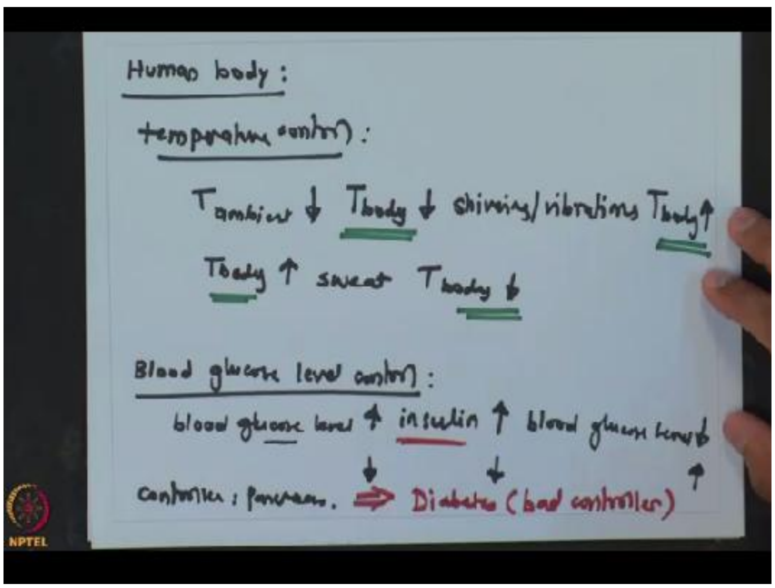

So if I take an example, so let us take temperature control. Now the human body maintains roughly 100 Fahrenheit or 98.3 Fahrenheit or 37 degree Celsius temperature irrespective of whatever are the external factors which are affecting the human body. The outside temperature is very cold, and because of that, the human body temperature tends to go down. So in that case, so let us say the temperature or ambient temperature falls.

Because of that body temperature tends to fall. In that case, the body's internal mechanism is such that we will shiver and when we shiver, there is vibration inside the body, and as you know, vibrations cause an increase in energy or increase in temperature and because of the shivering or let us say vibrations, that effect will be the body temperature will increase. So you can see that the decrease in the body temperature has caused, triggered a feedback action in terms of shivering which eventually, which helps us to increase the body temperature.

The same thing is true when the opposite case happens. Let us say you exercise or run quite a bit, then your body temperature increases. In that case, what do you do? You sweat. Because of sweating, there is phase change, and it is going to take the internal energy inside the body to cause that liquid to go out of your body, and because of that the energy, internal energy of the body decreases and this result in the reduction in body temperature.

So again you can see that an increase in body temperature causes some feedback action inside the body which resulted in the reduction in the temperature. So human body temperature regulation is an excellent example of feedback control.

The other case again very common is blood glucose level control. So whenever we eat carbohydrate, it gets converted into glucose and then the blood glucose level goes up. So whenever blood glucose level goes up, our pancreas would secrete a hormone known as insulin. So the secretion of insulin increases and that helps you bring this, digest this glucose and then because of that, the blood glucose level goes down. Now whenever you do fasting, that time the blood glucose level drops. Because of that the insulin level will also, the secretion of insulin will drop, and it will help you increase the blood glucose level to the desired value.

So the blood glucose control inside our body is also an example of feedback control, and the controller here is our human body or pancreas. Whenever this controller is not functioning properly, you get diabetes which means your blood glucose level cannot be maintained within the desired level because of different sorts of problems. Essentially the idea is, the rate at which insulin is produced in the body is not adequate to control the blood glucose level.

Another commonly used example of feedback control by man is while we are driving.

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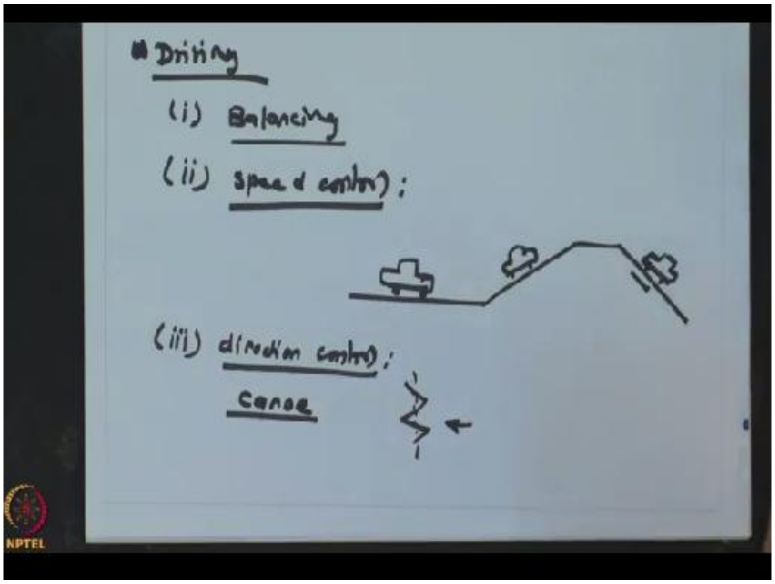

So whenever we are driving, one of the cases let us say we are driving a bicycle. Then balancing, it's also an example of feedback control. So what do we do? Let us say we are driving a bicycle. It is going steadily. It is balanced. Then no action is taken. As soon as let us say you go over a pebble, and then you get inclined towards one of the direction. What is natural tendency? That you shift all your weight to the other side so that the center of gravity again shifts back to the center, and then you can maintain the balance.

So when you are trying to balance, again it is a feedback control where you try to maintain a position of the center of gravity. The other thing where you use feedback control is in terms of speed control. So if you are going uphill, then you have to provide more energy into your car to maintain the same amount of speed. So let us say you are going at the same accelerator paddle and you hit uphill road.

So let us say your car is going like this and you are putting the same amount of acceleration. So you are putting, you have depressed the accelerator to the same amount, and then the speed gets maintained because the road is flat. Now let us say when you hit an uphill part. Now the same amount of acceleration is not going to give you the same speed. So to maintain the speed, what do you do? You press the accelerator more. So because of that, your car is able to maintain the speed on the uphill part as well. Now let us say, you are going downhill. In that case, you will have to release the accelerator because the gravity will naturally provide you some additional force and so the amount of force which you have to provide to your car reduces and so by changing this accelerator paddle, you try to maintain the speed within your desired value.

So again speed control when you do that is also part of a feedback control. And lastly, direction control. Whenever you are trying to control the direction, there is a steering wheel, and if your car is trying to move towards one direction, then you will obviously move the steering wheel to the opposite direction to make sure that your car tries to go into the straight line. This can be explained more; this can be visualized to a greater extent when you are trying to give direction to a canoe.

So whenever you are paddling a canoe, in that time if your paddles are not synchronized, it will try to go into a zigzag form and because of that, you will always try to maintain it to go in the straight line path. And the direction of the current may move your canoe into one or the other direction, and you always try to counter that by paddling on the correct side. So direction control again is based on the feedback depending on whether you are swerving away from your direction, you will take some control action.

So all these examples are of feedback control which is in general used. So as my point was, feedback control is a very commonly used strategy to control any process, and the same applies to our chemical engineering processes as well. So it is one of the very commonly used control strategies. So let us again try to revisit how, whenever we want to implement feedback control or any system, how do we go about and we will take an example of our surge tank.

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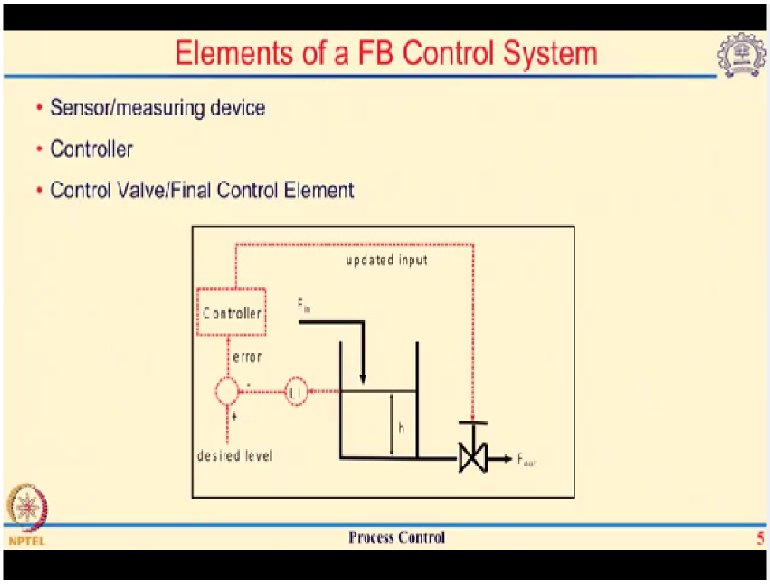

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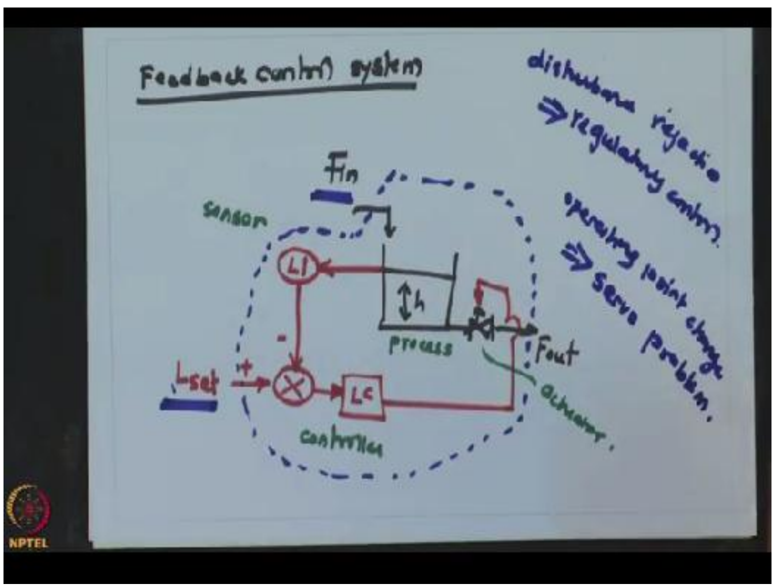

This is our surge tank where some flow comes in which is our typically a disturbance which is considered as a disturbance, and you try to manipulate this outlet valve so as to maintain the level inside this tank. So when we talk about the feedback control system, the first step of that is to measure the controlled variable. So the first thing will be to measure the level, we will call it as a level indicator.

So it will just take the current value of the level and convert it into some sort of electrical signal which will be able to drive the controller. So the next thing is, that current value of the level gets compared with the desired value. We will call it as Lset, and then we take the error of that signal.

Because we are interested in what is the difference between the desired value and the current value.

So that difference is then fed to the controller. So let us call it as a level controller. So it is going to add on this error and then accordingly it will, it is going to generate some sort of a signal, an electrical signal which will correspond to how much this valve should be opened. And then that signal will go to the valve and accordingly it will take action depending on the whatever is the controller signal whether to open the valve or close the valve.

And then the Fout will change. When Fout changes, that will have some effect on the height, and again this whole process will get repeated. So in terms of a feedback control system, along with the process, you have these additional blocks. So this is your process. On top of that, you have a sensor. You have a controller, and you have the valve, this is known as the actuator. So the feedback control system has these three additional components on top of this process.

And in general, if you see how this entire process is going to interact, what we can draw a boundary that, the way we are going to interact with this system is that some disturbance may occur into the system and then the control system should be able to reject that disturbance. The other way we are going to interact with the system is through this desired value.

So if there is some change in the process and if we want to operate this tank at a different level, even though there is no disturbance, we will change the set point, and the control system's objective is to move the system from this current height to the new height of new L_{set}. So this will be the two types of ways we will be interacting with this feedback control system. Whenever we look at the objective of disturbance rejection, we had called it as regulatory control.

Whenever the set point changes or operating point changes, that type of control problem, we call it as a servo problem. So we will look at how does the feedback control system behave when it is a regulatory problem or whether it is a servo problem. So in the next step, we will try to represent a process into its block diagram and then we will look at how do we formulate the transfer function for this combined feedback control system when we are talking about a regulatory problem or a servo problem.

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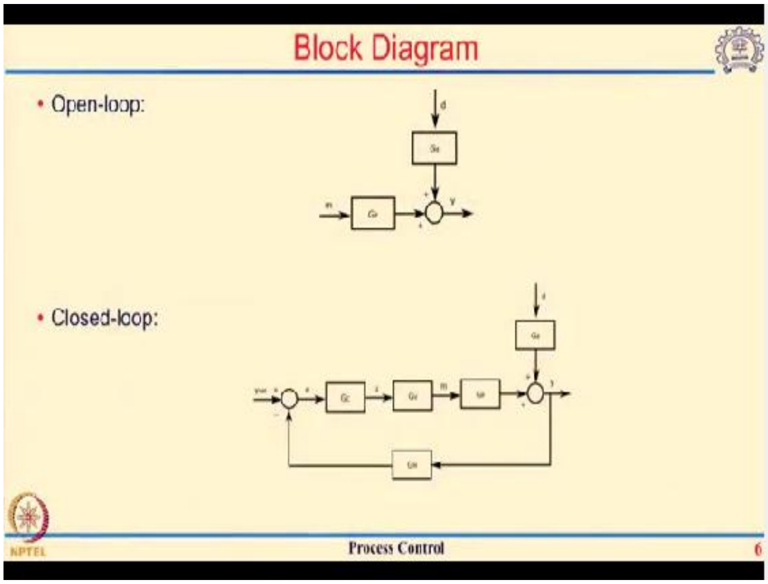

So let us start with the block diagram representation of the system.

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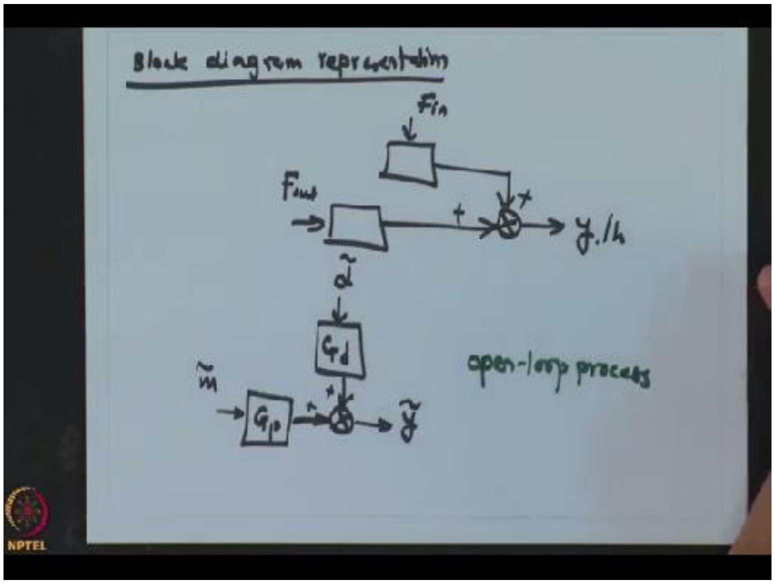

Even though we will take this liquid surge tank as an example, this block diagram can be drawn for any processes, and we will try to draw the general form of a block diagram. So if we look at this original process of the liquid surge tank, we know that there are two inputs into this process. One is F_{in}, and the other input is F_{out}. Both of these are going to affect the output of this process which is the height.

So we have two transfer functions. One is the transfer function from F_{in} to the output. Let us say in this case is height. And the other transfer function is between F_{out} and y and the actual output will be the addition of these 2, the effect of F_{in} and effect of F_{out}. So in general, the way I can write this block diagram is there is some transfer function for a disturbance. So if there is a disturbance, it will have some effect on the output.

And there is a manipulated variable. Let us call that particular transfer function as G_p and manipulated variable is m. So any system which has one disturbance input and one manipulated input will have two transfer functions, one for transfer function between output and disturbance and the other between manipulated input and output. And then the net output will be the sum of these two.

And again by default, we are considering the deviation variables in each of these cases. And this is the case when there is no controller which is placed, and we also called this arrangement an open-loop process. The response in the absence of a controller, we will be terming it as open loop response. So this is the basic process which has a disturbance and a manipulated input. Now we will try to expand this diagram and try to derive a block diagram for a feedback control system.

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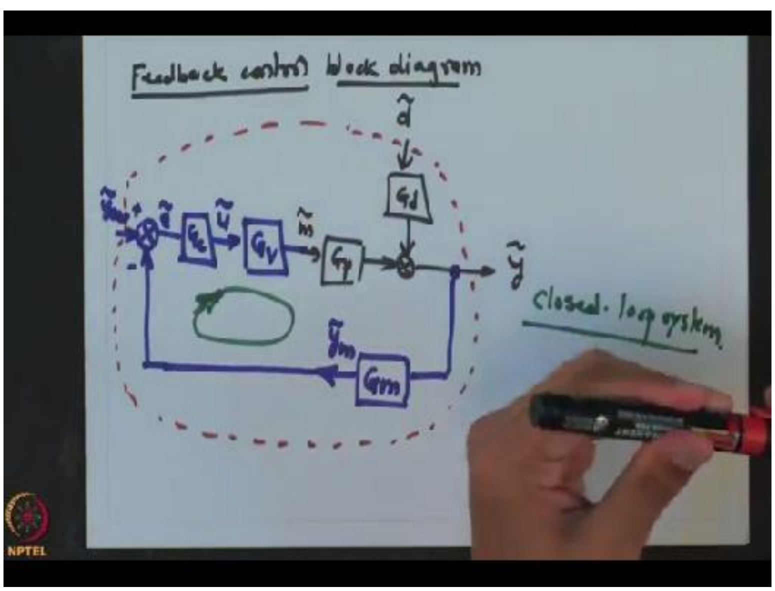

So our basic process remains the same. So you have a transfer function Gd between disturbance and output. And we have one more transfer function G_p between the manipulated variable and the output. Now on top of that, we will have the control system. So let us draw. So the first thing of the feedback control system is that we want to measure the value of the control variable. So we will have a measurement block, and the corresponding transfer function is say G_m.

What we get is the measurement value which ideally you want to be representative of the actual control variable value and this measurement, then gets compared. This will get compared with the desired value. So let us say this is y_{set}. So we will compare it with the desired value, and then the difference of that is called as the error signal, and that error signal goes to the controller. So the second block was the controller.

It will take some action, and it will give you whatever is the output of the controller, we will represent it as u. And then that output drives the actuator which was the control valve which is $G_{v,}$ and the output of G_v will be the manipulated variable. So this way the feedback control system will have these additional elements which we had just considered, and then this final form has a closed loop.

So you can see that if you trace down in this direction, the information flows this way and then gets circulated back. So there is a closed loop here, and whenever we have a feedback control or any control in general, we call it as a closed loop system. So whenever the controller is on or whenever the control loop is placed, we will call it as a closed loop system and you can see that that loop has this particular direction.

And in terms of our earlier representation, you can again see that this block diagram represents the installation of the feedback system so that you can have some changes in the disturbance. Whenever we are trying to reject the disturbance, the controller will take action. And then you may have some objective when you want to change the desired value, a set point value.

Now accordingly you want the output to change in response to that. So you can have a servo problem when these two variables are in play, or you may have a regulatory control when these two variables are in play. So now we will try to derive the transfer function for this particular closed-loop system.

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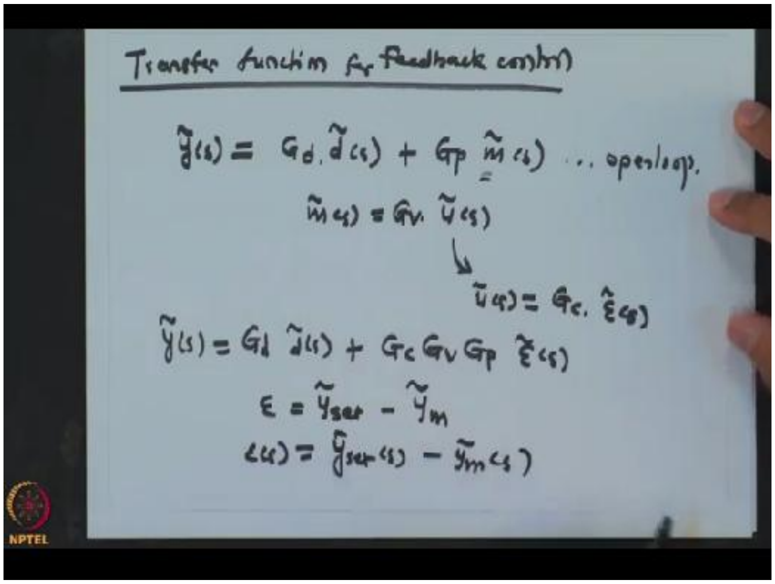

So for that let us start with the output block. So we can write that this $y(s)$ as the sum of 2 parts. One is the contribution from the disturbance, and the other is the contribution from the manipulated part. So it will be equal to,

$\tilde{y}(s)$= G_d**the Laplace of disturbance* + G_p**the Laplace of manipulated variable.*

$$\tilde{y}(s) = G_d\tilde{d}(s) + G_p\tilde{m}(s)$$

So this is the same as the open loop when there is no controller. And now when we start about the feedback control, we will start representing or adding additional things into this module. So we can write that this $m(s)$ is the output of the actuator. So we will be representing $m(s)$ as $G_v*u(s)$ and then this us is the output of the controller. So,

$$u(s)=G_c*\varepsilon(s).$$

By substituting these 2, what you are, we are going to get,

$$y(s)=G_d*d(s)+G_cG_vG_p*\varepsilon(s).$$

Now ε is the difference between the set value and the measured value. So $\varepsilon(s) = y_{set}(s)-y_m(s)$.

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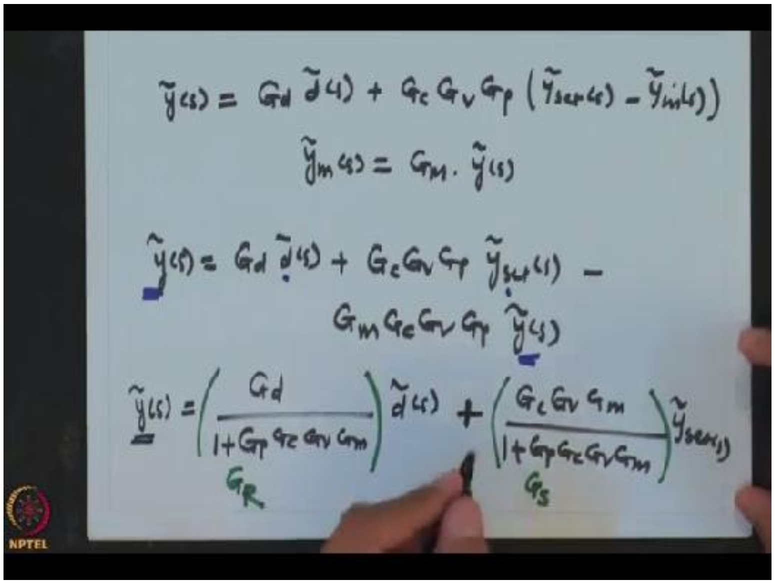

So let us now substitute that and what we get is,

$$y(s) = G_d\, d(s)+G_cG_vG_p\, [y_{set}\, (s)-y_m(s)].$$

And then lastly we can say $y_m(s)$ is the output of the measurement or sensor. So it is equal to $G_m*y(s)$. So we get,

$$y(s) = G_d\, d(s) + G_cG_vG_p\, [y_{set}\, (s)-G_mG_cG_vG_p*y(s)].$$

So what we have is there are 2 terms in y(s). This is the disturbance term and this is the set point term. So if we move this $y(s)$ term on the other side, then we can write,

$$y(s)=[G_d/(1+G_pG_cG_vG_m)]*d(s)+[G_cG_vG_m/(1+G_pG_cG_vG_m)]*y_{set}\, (s).$$

So this equation tells us that how the output is going to change in the presence of this feedback controller when a disturbance is affecting the process or a set point change is made. So this is the transfer function which will represent the effect of disturbance. We will call it as a regulatory transfer function or G_R and this is the transfer function which will tell us the effect between the set point change and the output. So it represents the servo problem. So we will represent it as G_S. So these are the transfer functions for the feedback controller whenever we are working it as a regulatory controller or a servo controller. In reality, both these actions will be happening together and then whatever is the output, will be the effect of changes in disturbance as well as the changes in the set point. So we will take a short break here and when we come back, we will look at different types of simple feedback controllers. Thank you.