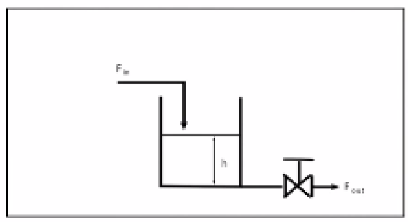
Chemical Process Control
Prof. Sujit S. Jogwar
Department of Chemical Engineering
Indian Institute of Technology-Bombay

Lecture - 03
Common Control Strategies

Consider the liquid surge tank given below. We will now try to look at what are the different strategies in which we can control the level inside this tank when there is some disturbance in the inlet flow rate.

Liquid Surge Tank



Variable	Description
Controlled variable	Height (h)
Manipulated variable	Outlet flow (F_{out})
Disturbance variable	Inlet flow (F_{in})
Set point	Desired tank height

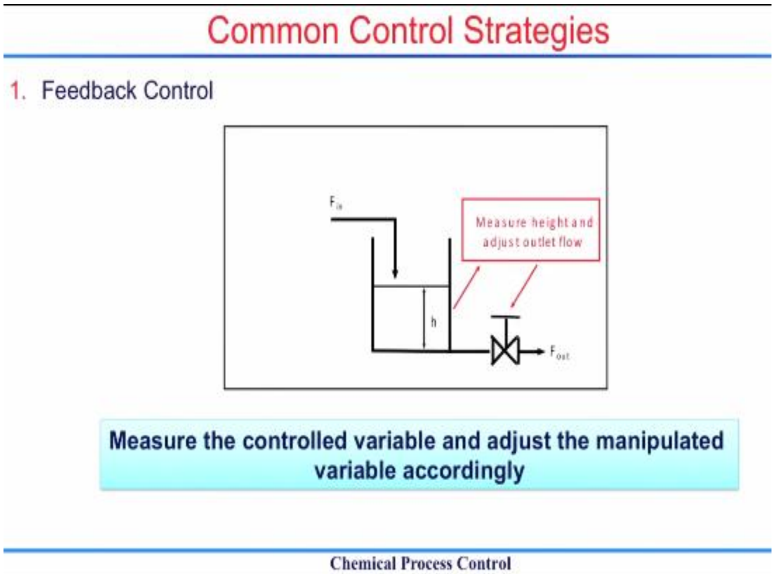
Chemical Process Control

1. Feedback Control

One way to control the level inside this tank is to measure height inside the tank. If the height inside the tank is above the desired value then we will increase the outlet flow rate such that the level inside the tank starts to go down and vice versa. If h value is less than the desired value then we want to hold liquid inside the tank. So we will reduce the value of F_{out}.

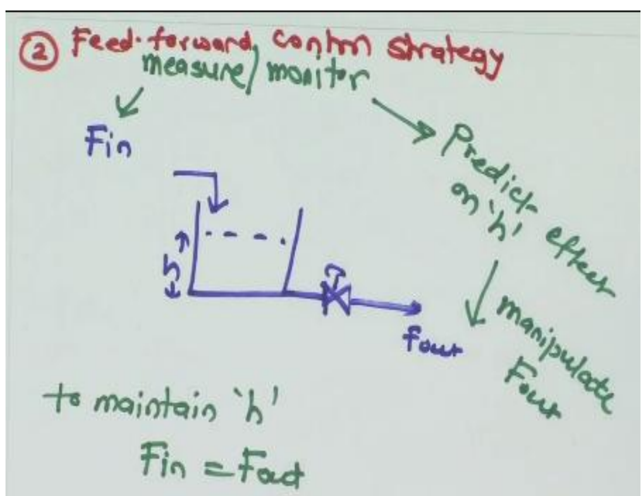
$$h > h_{desired} \quad F_{out} \uparrow$$

$$h < h_{desired} \quad F_{out} \downarrow$$



This particular control strategy, measures the value of the controlled variable, instantaneous value of the controlled variable and accordingly it changes the manipulated variable. This type of control strategy is known as a feedback control strategy. Because we are taking feedback from the system. So we are trying to learn from where the system is at currently. We are taking some feedback from the system and depending on what the system requires, we are taking an action. Now, try to think of is this the only way in which I can control this level or there are some other ways. So as it turns out, there are other ways of maintaining the height. So we will try to look at the second way.

(Refer Slide Time: 03:00)

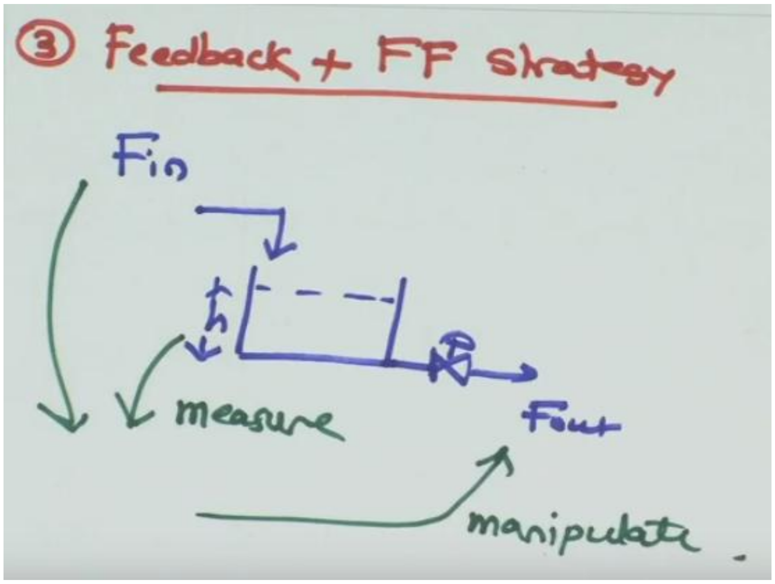


2. Feed-forward control

The other way to control this height is by knowing the fact, that in order to maintain the level, so to maintain level what we need is, the inlet flow rate should be equal to the outlet flow rate. So this particular control strategy, what it does is, it will measure or it will monitor the value of the inlet flow rate and then accordingly it will predict effect on the height and in order to negate that effect it will manipulate the outlet flow rate. So let us say if there was 5% increase in the inlet flow rate, it will be measured by this particular controller and accordingly in order to maintain the height it will try to bump up the outlet flow rate again by 5% so that Fin will be equal to F_{out} and the height or the level inside the tank will remain constant. So in that case there is no need to measure the height inside the tank.

All you are doing is, measure the disturbance variable, predict its effect on the controlled variable and based on that you take a control action such that the effect of that disturbance get nullified. So this type of control system, where you predict the effect of the disturbance and try to take an action before the system reacts to that disturbance is known as a feed-forward control strategy. So now again try to think is there any other way I can control or maintain height inside this tank?

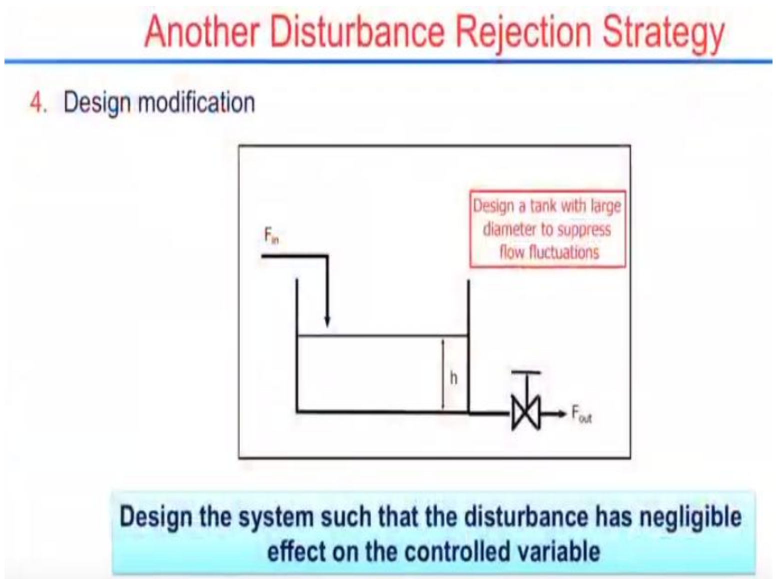
3. Feedback + Feed-forward strategy



Now the third strategy can be a combination of the two which is known as the feedback plus feed-forward strategy. So in this strategy what you do is, you measure the controlled variable as well as the disturbance and based on this combined information you take an action to manipulate the outlet flow rate. So it is as the name suggests, a combination of feedback and feed-forward control strategy wherein you measure the disturbance variable as well as controlled variable and take an action accordingly.

4. Design modification

Now do you think there is any other way of maintaining height inside this tank? As it turns out there is a fourth way which is not actually a control strategy but it is a design strategy by which you can make sure or maintain the height inside this tank.



While selecting a tank, you select a tank which has much bigger cross-sectional area so that even if there is a 5% change in inlet flow rate, the change in the height is very small.

$$\frac{dh}{dt} = \frac{1}{A}\frac{dV}{dt}$$

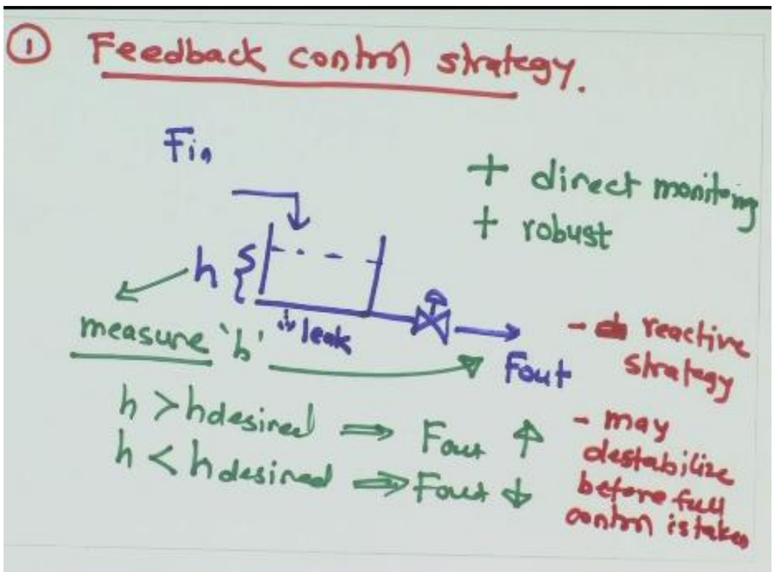
When you say $\frac{dh}{dt}$, it is actually $\frac{1}{A}$ times $\frac{dV}{dt}$,which is change in volume. So F_{in} change is going to affect the change in volume, but I can always select a very large area such that this $\frac{dh}{dt}$ is very small and the height of the tank would not change much from its desired value.

We will see later that it is not a controlled strategy, it is just a design modification which can be done so that you maintain the height inside the tank. So this particular strategy will be to design the system such that the disturbance has very less effect on the controlled variable.

Comparison of control strategies

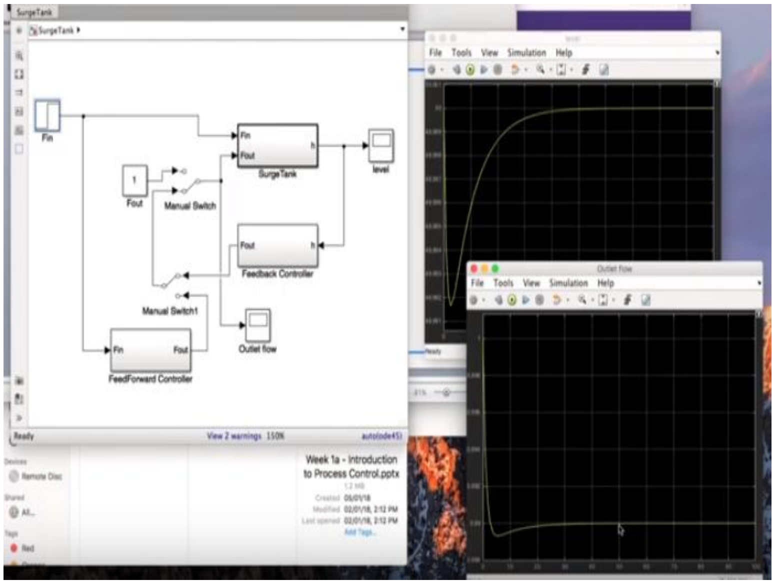
We have seen these three different control strategies as well as one design modification all of which can give you disturbance rejection for this case. Let us now go through all these four strategies and try to find out what are their advantages or limitations and then we will try to answer the question which among these is the best control strategy. So let us start with the feedback control strategy.

(Refer Slide Time: 09:43)



So we said that in the feedback control strategy we measure the controlled variable and take an action based on the feedback coming from the system. The main advantage of a feedback control strategy is that you have a **direct monitoring** of the controlled variable. So you will always have the value of the controlled variable and you would know whether it is getting controlled or not. The second advantage of a feedback control strategy is that it is **robust**. So let me explain that again by going through the simulation.

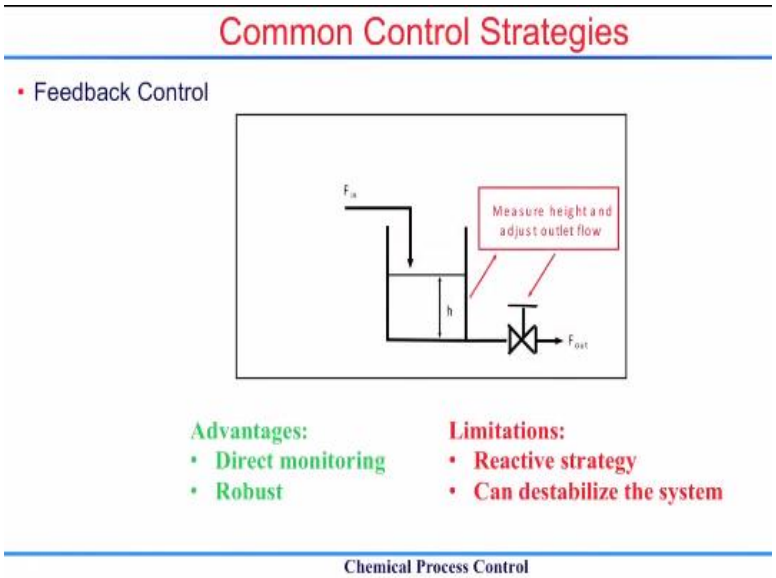
(Refer Slide Time: 10:43)



We have the surge tank and we said that there is one inlet and one outlet. There is no control over the inlet and the outlet can be manipulated to maintain the height. Now let us say if there is a small leak inside this tank. In that case will the feedback control strategy be able to control the tank? Consider the leakage to be 1% of the feed flow rate and there is no disturbance coming from the inlet flow rate. So inlet flow rate remains at value of 1. The only disturbance is that there is some leak inside the tank. And we have a feedback control system in place.

You can see that the feedback control system is able to maintain the height inside this tank to the desired value. This is done by reducing the outlet flow rate such that the total of outlet flow rate plus the leak flow rate which is not measured is maintained to be equal to the inlet flow rate. So that way you do not need to know if there are any additional variables which are going to affect the system. The feedback control system is robust enough that all you need to know is there is a control variable and there is an effect or what is the effect of manipulated variable on the controlled variable. As long as that much information is available this feedback control strategy is able to handle the system irrespective of any unknown disturbances which are going to affect the system. So now let us look at what are the limitations of the feedback control strategy.

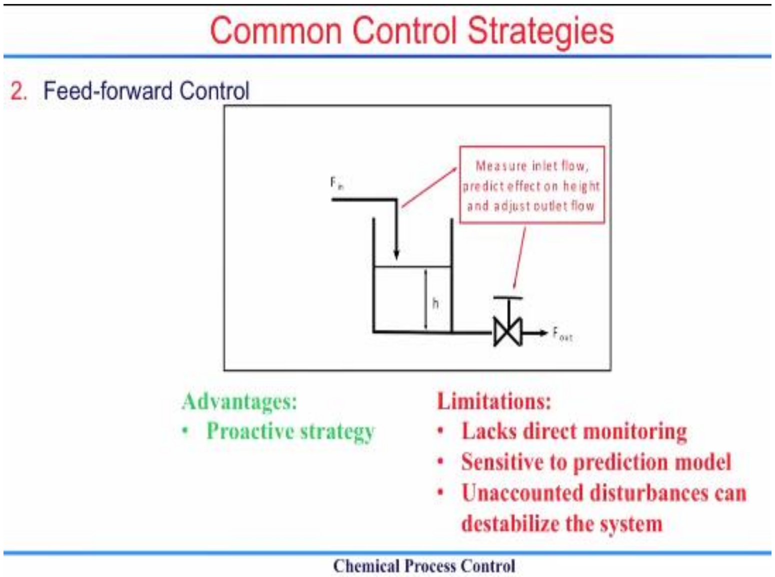
(Refer Slide Time: 13:09)



The primary limitation is that, it is a reactive **control strategy**. The feedback control strategy, will always work on the system only when the disturbance has affected the system. Only when height has changed from its desired value, the feedback control strategy will start working. Now for this particular example this may not be critical if the height goes to 51% or 52% and then comes back to the desired value of 50%. But in case the tank was almost close to full and the disturbance occurs in that case you may not have that much window where the height of the tank goes above the desired value.

Let us take an example of a reactor and the temperature of that reactor may be very close to the stability limit in terms of the catalyst used in that reaction or in terms of any side reactions which may be occurring. In that case you do not want the temperature to even slightly go above the desired value. But in such a case the feedback control strategy would still be activated only if the disturbance has shown some effect on the system. So in a way it is always reactive system and as I said based on these examples this reaction or this disturbance may destabilize the system before full action is taken. So that is, if the operating point is very close to the stability limit and the disturbance tends to move it towards the stability limit for some amount of time it may destabilize the system and depending on whether the system can return back or not this may be detrimental

(Refer Slide Time: 15:31)



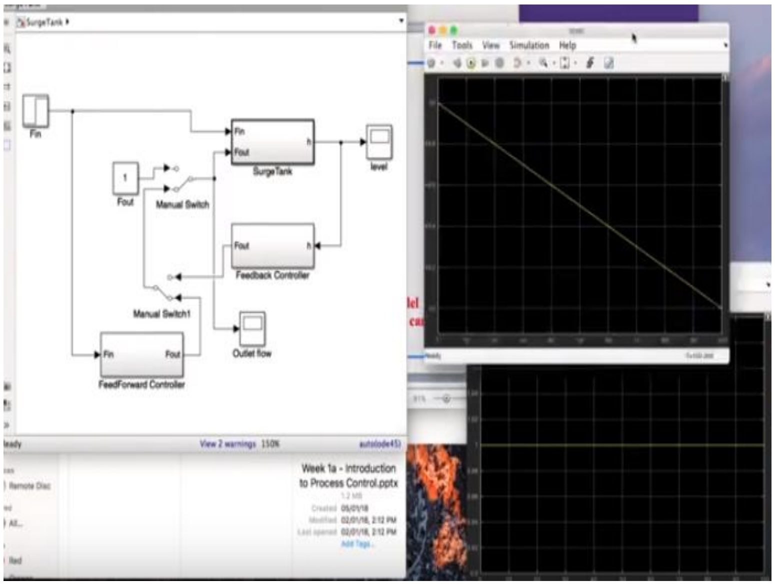
So the primary advantage of a feed-forward strategy is that it is a **proactive strategy**. So in a way it takes care of the limitation of the feedback control strategy. If there was some disturbance, even before that disturbance affects the controlled variable you are taking an action. So in this case even if the tank level was almost close to completely full let us say above 90%, as soon as the disturbance was detected the outlet flow rate would had been maintained close to equal to the outlet and then accordingly the height of the tank would not had changed from its desired value. So it is a proactive control strategy.

Considering the limitations, the first and foremost is, it **lacks direct monitoring**. So in this case all you are riding on the fact is I am measuring the disturbance and then accordingly taking action and I am assuming that the controlled variable remains at its desired value. So it all depends on how much, how good my prediction is of the effect of the disturbance on the controlled variable. If my prediction model is off, then all I am trying to control is a fictitious value of the controlled variable, whereas the actual controlled variable may be away from its desired value. But we are not measuring the controlled variable and so we would not know that the controlled variable is not at its desired value. Riding on the same fact, it is also **not robust** and it is **very sensitive to the prediction model**. In this case the prediction model was that as long as I maintain $F_{in} = F_{out}$ my height inside the tank is going to be regulated.

For the case of feed-forward control strategy if there was a small leak inside this tank then even if I maintain $F_{in} = F_{out}$ my height inside the tank will keep on reducing. We can appreciate that through the simulation.

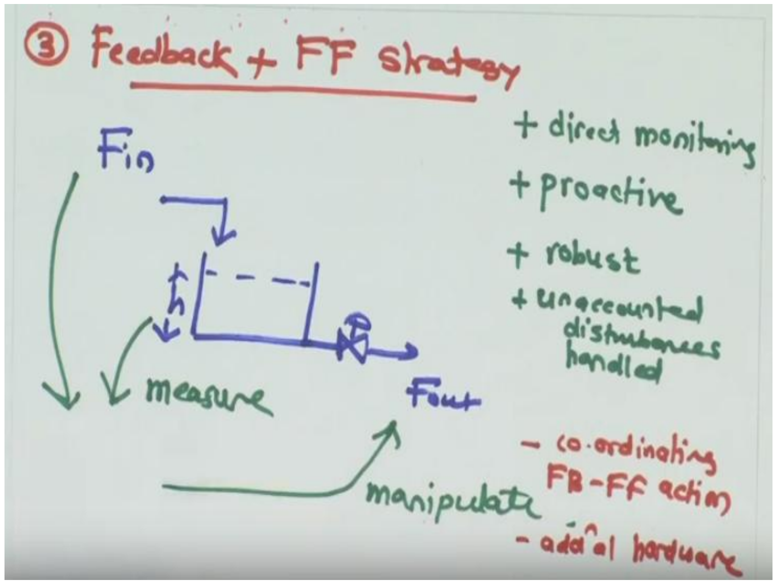
For the same system instead of a feedback controller, let us say I control it using a feed-forward controller which is just going to say that my F_{out} should be equal to F_{in}.

(Refer Slide Time: 19:04)



So if I apply that for the leak case, what you will realize is that, even though my outlet is equal to the inlet, my height inside the tank keeps on reducing because there is no way this prediction model is going to know that there is a leak inside the system. So the disadvantage of a feed-forward control strategy is that you need to know all the disturbances which are going to affect the system. If even a single disturbance is not detected then it has the tendency to destabilize the system. So it is **sensitive to prediction error** and **unaccounted disturbance** can destabilize. So these are the advantages and disadvantages of a feed-forward control strategy. If these feedback and feed-forward strategies were combined, you add up the advantages of both these strategies and try to get rid of the limitations.

(Refer Slide Time: 20:29)



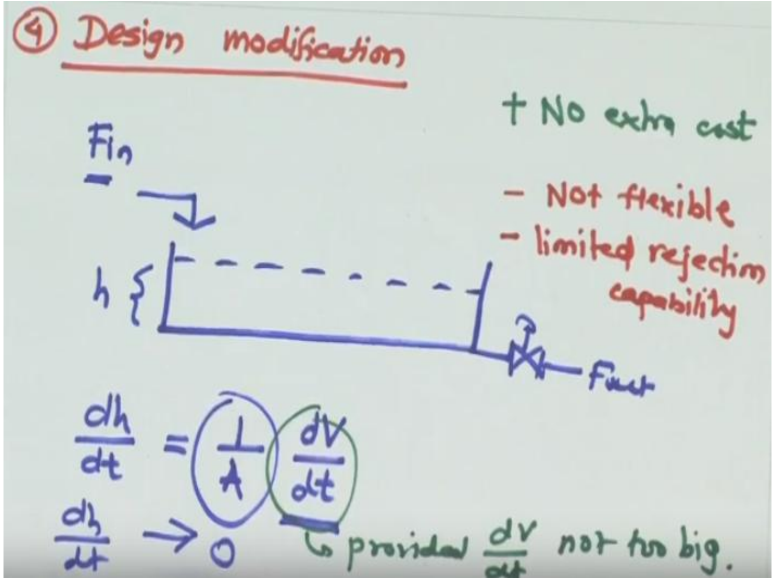
So the advantage of feedback plus feed-forward strategy is that it provides you **direct monitoring**. It can be **proactive**. It can also be **robust**. It can also work in the presence of unaccounted disturbances. So you may start thinking that this is the best control strategy and this maybe the most popular way in which chemical processes are controlled. As it turns out this is not the best method and there are limitations of these as well.

The main limitation is that, there are two players, the disturbance as well as the controlled variable. They are trying to manipulate or they are going to fight for this outlet flow rate and in case the disturbance wants the F_{out} to move in one particular direction whereas the controlled variable wants it to be moved in the other direction then there is a fight between these two control actions and it is very difficult to obtain the correct value of F_{out}. So coordinating feedback and feed-forward action is one of the main limitation of this particular control strategy.
When the feedback is telling one thing and the feed-forward action is telling the other way round then the system cannot take a correct decision and therefore coordinating or whom should you listen to first, whether feedback or feed-forward, that becomes a very critical decision in terms of effectiveness of this particular control strategy. There is also a limitation that you require **additional hardware**. In the typical feed-forward or feedback strategy there is only one measurement and one control action. In this case, there are two measurements which have to be measured. So for every control loop, there will be an additional cost of two instruments rather

than one instrument. But this is generally a secondary limitation. The major limitation is always **maintaining coordination between these two control actions**.

Now while we are at it we will also try to look at what are the advantages and disadvantages of this design methodology modification which does not require any, which is not really a control strategy.

(Refer Slide Time: 23:56)



The main advantage is that there is **no extra cost**. So all the cost is in the design and while operating the process you do not require any cost to control the system. There is no need for any instrument. But the disadvantage is that, **it is not flexible**. So after some time if I want my level to remain at 55% rather than 50% this particular strategy will not be able to do that automatically. So it is not flexible enough.

It can only be designed to operate at a particular value and it will not allow you a freedom to move from that and there is also limited rejection capability. I said that, this *dh/dt* will be small if I select a very large area but I did not tell you the remaining part of the story which is provided the change in the volume is not too big. So if the volume change is too large, then even having a large area would not be sufficient to maintain height at a desired value.

So that way, this design modification we just considered it as one of the option, but it is not effective or optimal option by which you can do regulation of the disturbance. To summarize, all these control strategies have their own advantages and disadvantages and there is no clear cut advantage of one methodology over the other.

Based on experience it turns out that feedback control strategy being very robust and requiring less or the minimum instrumentation is typically a preferred choice of control strategy. Only the extreme cases where your operating point is very close to the stability limit or the safety limit where you cannot allow any reactive action to be taken those cases we would have a feed-forward control strategy and sometimes even feedback plus feed forward control strategy. Thank you.