INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

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Topic Lecture – 09
Introduction to Automatic Control

Good afternoon and welcome to lesson 11 of the course on industrial automation and control.

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So far we have learnt about sensors, but before learning about actuators I thought that will be more useful to learn about automatic controls. Mainly because of the fact that several actuators are actually closed loop control systems themselves. So it is useful to learn about automatic controls before learning about actuators. S we'll start with automatic controls and go on for that with that for a few lectures and then eventually come back to actuators so here we go.

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This lecture is on introduction to automatic control, so we are going to discuss some basic concepts and finally look at the basic structure of a controller called the PID controller which is almost it is said that 90-95% of all industrial continuous controllers are PID controllers. So we are going to have a look at that why that structure of the controller is so useful. So that is the purpose of our lecture.

So let us see that in greater detail, so as we usually do let us look at the instructional objectives of this lesson.

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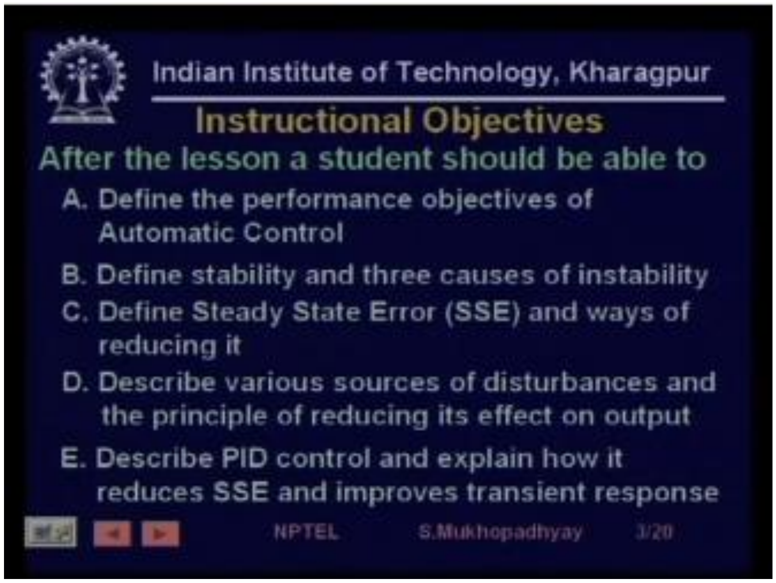

So after this lesson one should be able to define the performance objectives of automatic control what basically automatic control wants to do, he or she should be able to define what is basically, basically describe what is stability and three causes of instability which are very typical in a process in an industrial process control loop, should be able to define a very important performance indicator called the steady-state error and basic strategies or philosophies of reducing steady-state error.

And while doing it and of course, the other objective of automatic control is how to get rid of the disturbance cells or rather how to tackle the disturbances in the sense that how to reduce the effects of the disturbances on the output. And all these as we shall see will need to naturally lead to a kind of control structure which is known as PID control. So this is what we wish to learn today. So let us go ahead.

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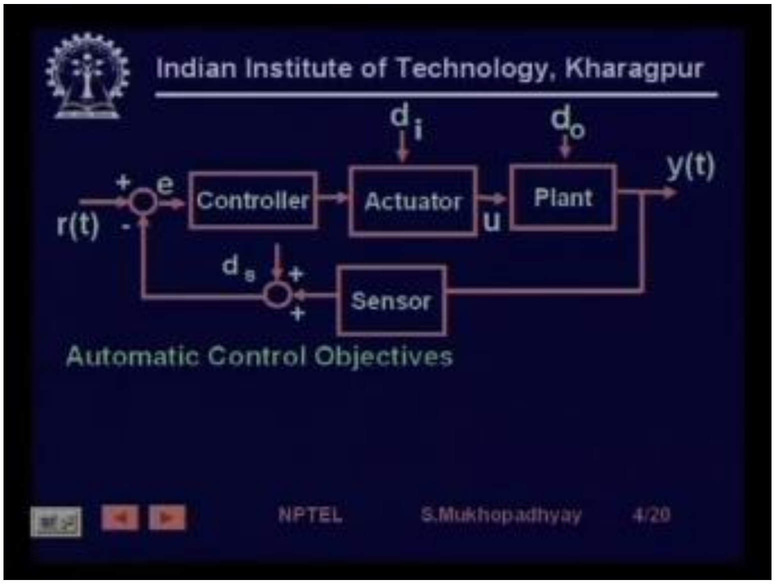

Let us first look at the automatic control objectives what does an automatic control loop basically does. So here is an automatic control loop well known to us because we have most of us have already had a course on automatic controls.

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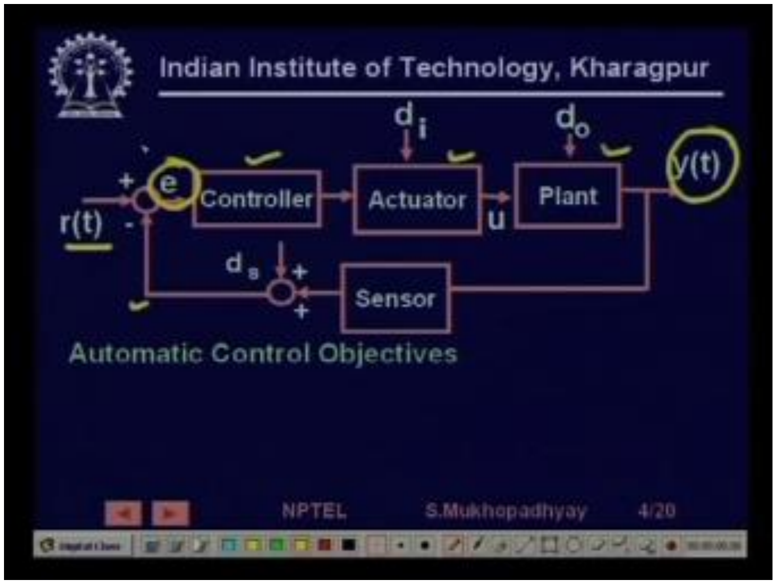

So here is the set point, here is the set point just a moment let me select my pen. So here is the set point and this is the controller, this is the actuator which as we have discussed which increases the control energy and finally gives input to the plant. This is the plant itself, this is the output which we want to control and this is the feedback through the sensor. This is the what is known as the error.

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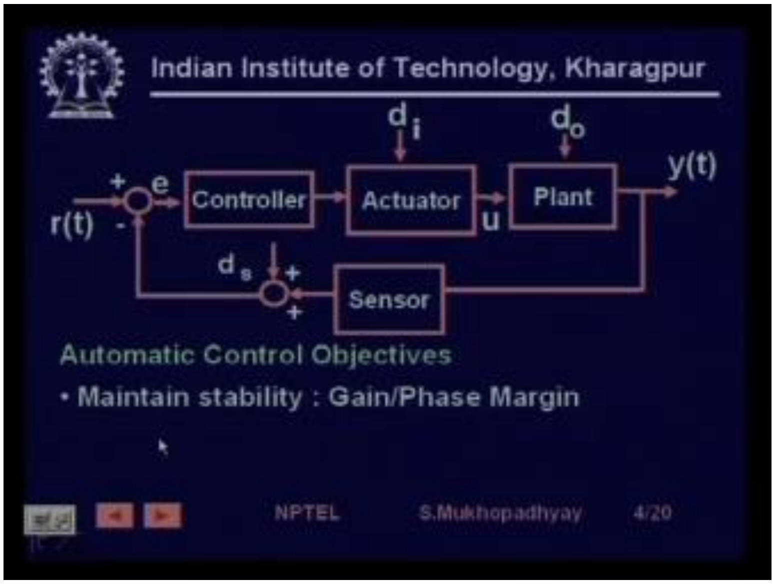

So what is the objective of automatic control, the objective of automatic control is firstly to maintain stability. What does it mean? It means that if you want to hold a particular, hold the output at a particular level we should be able to hold it. It is not that the output will run away or is not that the output will oscillate. So we want that quantities reach certain values and stay there that is roughly called stability.

In this course we are not going to have a very mathematical look anyway, so that is the basic idea of stability. So we want that signals in the loop should be stable, it is not that they should be continuously moving around.

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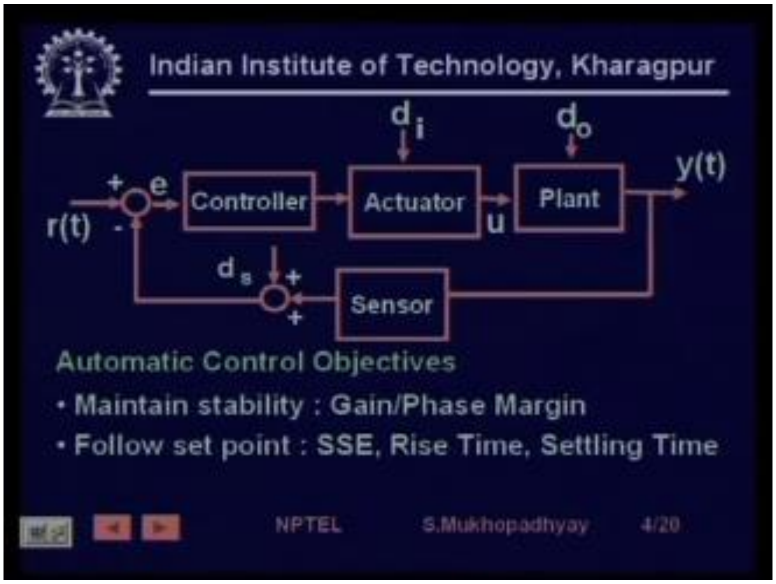

That is a very important objective of automatic control. Especially for processes which are inherently unstable this is a very important objective without this we cannot run the process at all. The next is to once you we can ensure that we can hold the outputs at a certain level wherever we want to, we want the output to follow the set points that is we want that the output will follow the set point.

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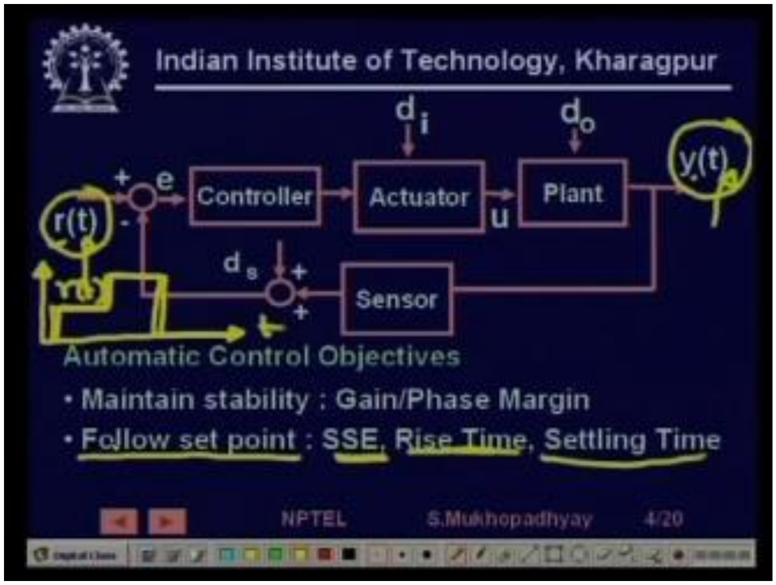

Now the set point is as we have noted it is a function of time and this output is also a function of time. So we would like that this function of time resembles this function of time as closely as possible. So how do we express this closeness, we express it in terms of typically this set point generally very often our step functions of time that is they change over time like this. So this is a typical, this is our T and this is T.

So they take step jobs again are held so we are typically talking of this kind of step response, this kind of set points. So we with respect to this kind of set points to express the degree of accuracy with which why can be close to our we express various quantities like the steady state error, rise time, settling time, etc, we will have a more detailed look at these. So basic, so this is a second basic important point follow the set point.

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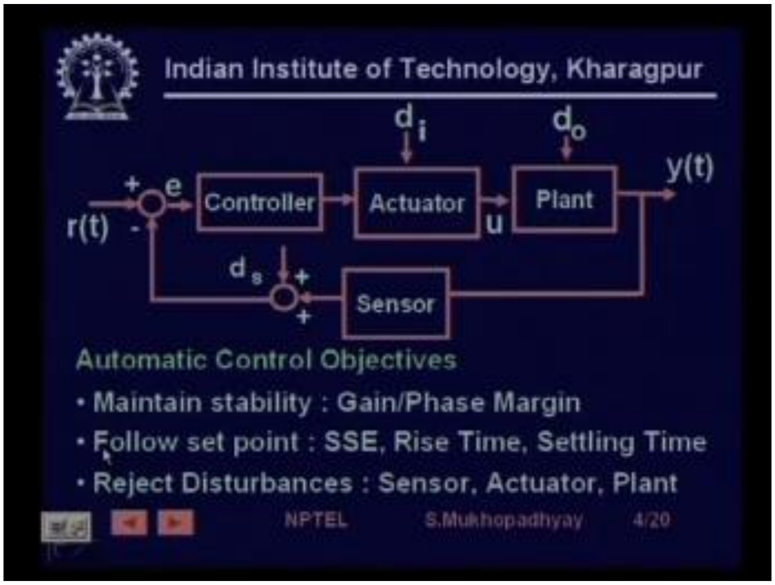

The next important point is of course, to reject disturbances that is even if the output once comes close to R there are several external signals which are working on this process.

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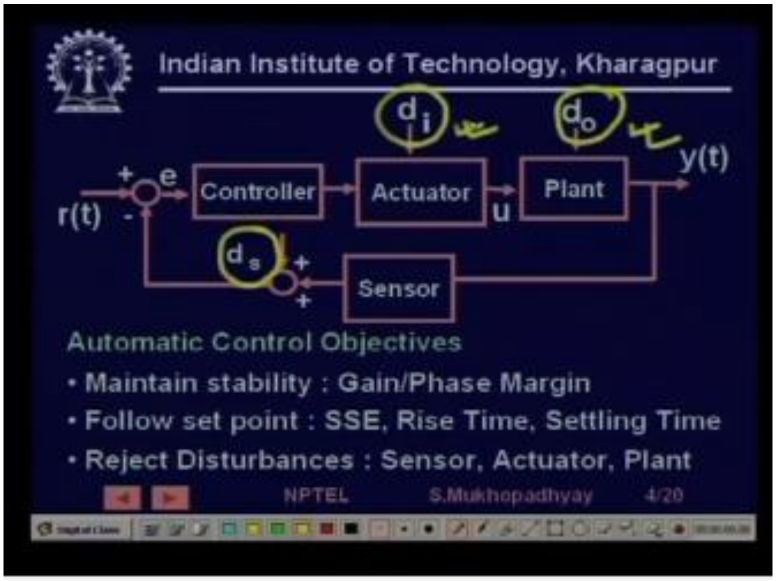

Which are not in our control, so there are output disturbances or load disturbances which occur very often, there are, there could be input disturbances from the actuator for example, we shall see that if you have a hydraulic actuator then one of the main things that happens in the see the actuator is basically an amplifier. It amplifies power, so anything which amplifiers power usually has a power source.

So for example, the hydraulic actuator has an oil pressure source. Now if the pressure of the oil changes that would be an input disturbance to the actuator.

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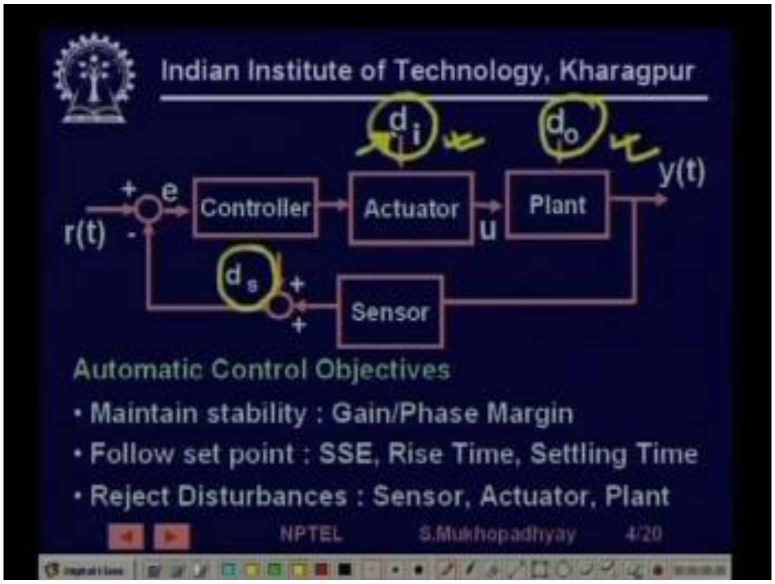

Similarly if you take manufacturing then what happens is that, for example, suppose you are taking rolling. So in rolling what you want to do is you want to control the speed of the rolls and the gap of the rolls. Now the, now when a metal bar comes and the here are the roles rotating so when it comes and grips the role immediately there is a tremendous torque demand which comes on this.

So that comes that torque depends on a lot of factors for example, one of the important things on which it depends is the temperature of the bar which is biting into the rules. So such things are called load disturbances.

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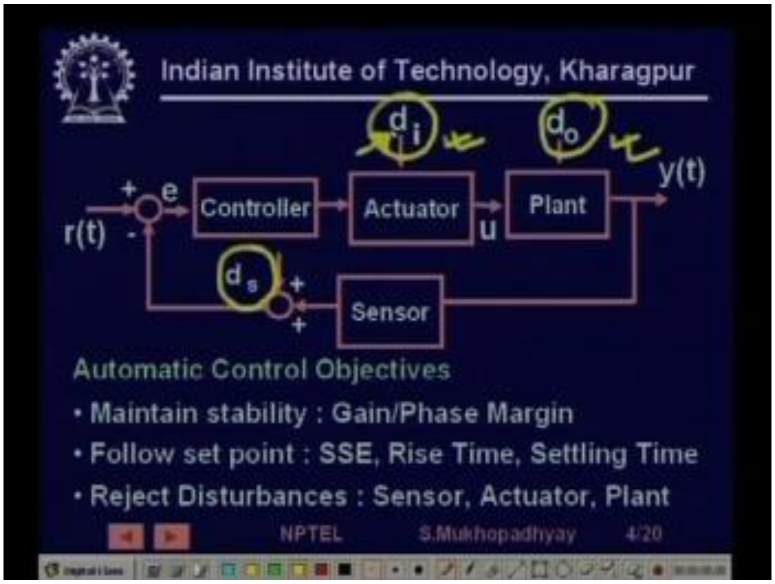

Similarly anything we want to sense we are going to have various kinds of measurement, noise, bias right. So electromagnetic noise, electrostatic noise, so they are the feedback disturbances. So there are various kinds of disturbances which are acting on the loop all the time which tend to move this output away from R, so the job of the controller is to every time it moves away from R the job of the controller is to generate suitable input such that it comes back to R.

So thereby rejecting disturbances so that is the other prime objective of automatic controls. So maintain stability, follow set point, and reject disturbance, these are the three major objectives of automatic control. So having said seen that let us look at the sea in some detail the concept of stability.

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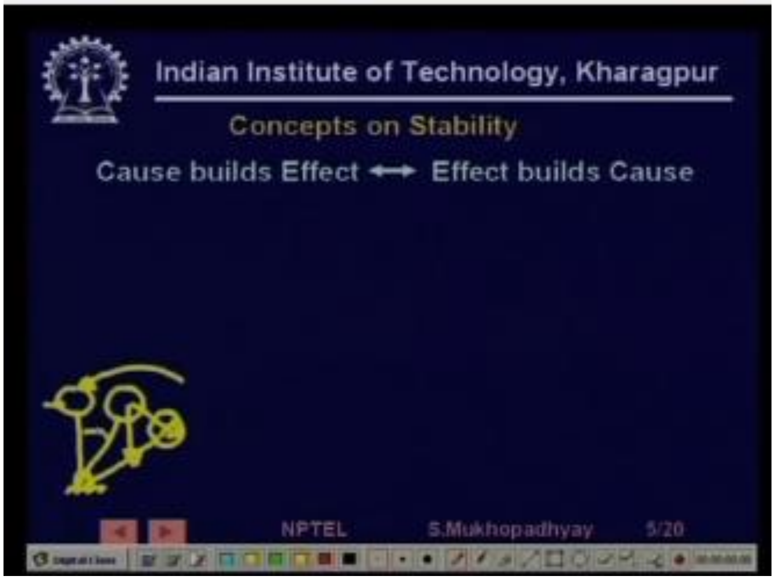

So let us make some common sense on this concept of stability so first is that cause, when do you have instability, we have instability when cause builds effect and effect builds calls right. So for example, suppose there is an typical case, let me give you a simple example, suppose you have an inverted pendulum, the pendulum which is held here on a hinge right. So if the pendulum is vertical it is suppose just maintaining its position.

Now if you, if there is if you given a little push, if you give it a little push let us say this side then the pendulum will come to this position. So here is a cause which produced an effect of an angle. Now due to this effect now the gravity force which was acting vertically down now it has a component this way. So now due to this component this pendulum will move further and will come to this position.

So you see that here is a cause which build that effect, that effect generated a further torque so it is generated further cause we generated further effect and therefore, this is not a stable position, this is an unstable position right. So this is the basic phenomenon of stability and this phenomenon demonstrates itself in various ways in case of flows, temperatures, motion, displacements every variable right.

So this is the basic concept of stability. So what is the next point, then what is the unstable response I mean how do you, how they are typically characterized. For example, take the case of there are two typical demonstrations of an unstable response for example, in open loop if the plant is not a operated in open loop then the output saturates to a stable operating point, what is the typical example.

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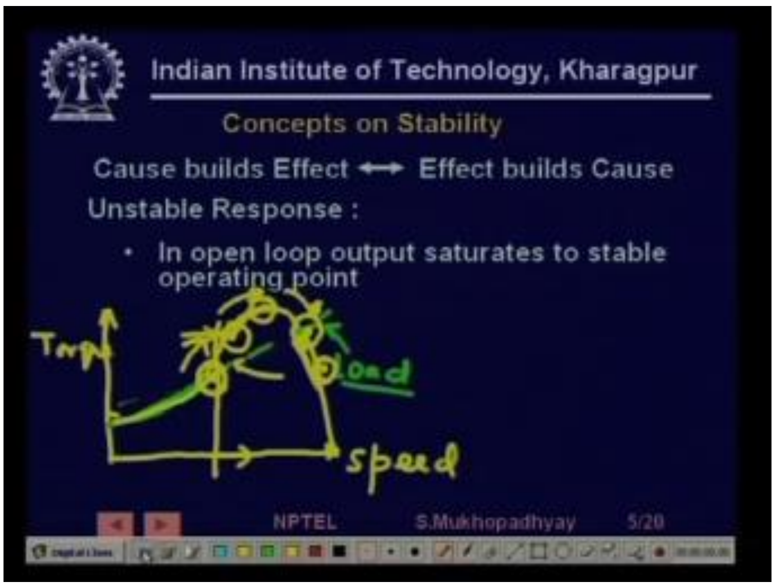

So typical example is suppose we have say, we have the case of an induction motor torque speed guard okay. So this side is speed and this side is torque as electrical engineers we have studied this. So the torque speed curve typically looks like this right, and let us say that a load characteristic, a load characteristic looks like this. So as the speed increases the load torque demand also increases.

So now if this load which is this is the load torque speed characteristic. So now if the suppose that we connect the motor to this load and then switch on the motor what is going to happen, say initially in this case of course there is a, the motor will not start because of the fact that this torque is larger. So actually what we show, we have to do is that we have we will assume that the torque will come here right.

The pen oh, I see I have to touch it here again it is in mode, I have to touch it to the pencil and then I have touch it to the color correct. So suppose the load characteristic goes like this and the motor characteristic rather than that right, suppose the motor was motor characteristic is through this path, motor characteristic is this. So now if you consider this operating point then suppose here the motor torque and the load torque are same.

So it is a stable operating point motor is generating enough torque which the load demands, but if the speed here is slightly changed let us say this way and if the motor goes to this position then what happens now is that the generated torque which is this one is more than the load torque which is given by the green curve. So now you have extra torque so now this extra torque will do what it will increase the speed of the motor.

So now the motor will go to this point where it has further extra torque then it will come to, finally it will eventually set to settled at this point, so you see at this point again the motor torque generated torque is actually equal to the load torque, but at this point now if you, if something increases the speed and it comes to this point my dot is getting shifted. Now what happens is that if the motor shift from this point to this point immediately what will happen is that the generated torque will actually fall below the load torque requirement.

So the motor will tend to go back to its old operating point so actually this is the difference between a stable and an unstable open-loop operating point that in an unstable point if you move it away from it, it tends to move farther away from it, and finally settle to a stable operating point this is what the motor is doing. On the other hand if you from the stable operating point if it moves away it is going to come back to that operating point. It will not move away right, so this is what is going to happen this is what I mean.

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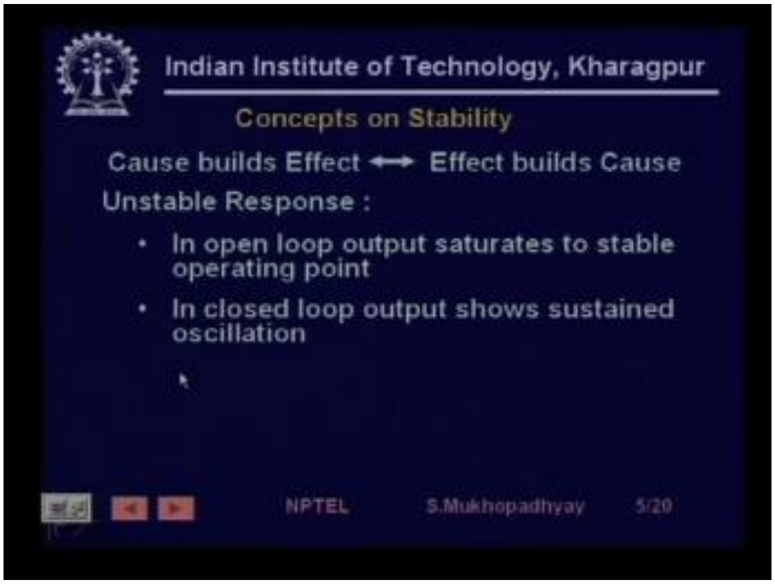

Now what happens is that but this tendency but you can always or if you use a controller one of the jobs of the controller is to operate a plan around unstable operating loop points, that is why control is used in many, many cases for example, in process control, in aircrafts, and also in motor.

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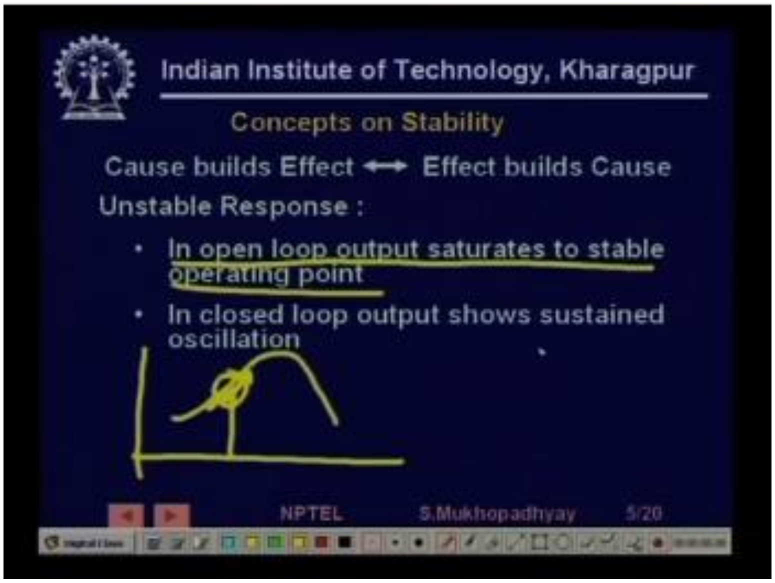

So what this will do is actually that giving taking the old example now if the toad speed curve is around this point then here if it is operating then now the control, now if it tends to move it will tend to move away, but now the controller will actually what the controller will do is that is the controller will control, then let us say the motor terminal voltage and it will actually reduce the torque so that it come, so it comes back.

Again when it comes back it will have a tendency to move this way and then it is a tendency to move this way. So again the controller will move it up, so under control this tendency of the open-loop to actually saturate to a stable operating point is actually prevented by the controller so every time from an unstable loop it will tend to go to the stable point but the controller will push it back then we tend to go to the other operating point and then the controller will again push it back.

So this is what happens, so the plant tends to run away and the controller keeps pushing it back, so you have an oscillating response.

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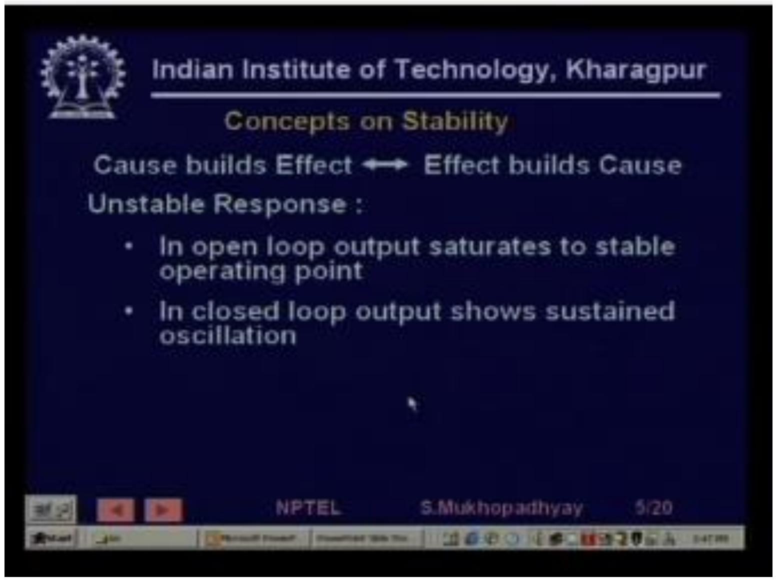

So usually this is typically what happens when in an, in case of an unstable response that the closed-loop output shows sustained oscillation. So that is also kind of, so instability. So this is typically what you find when you have in your operate of plant either open loop or closed loop.

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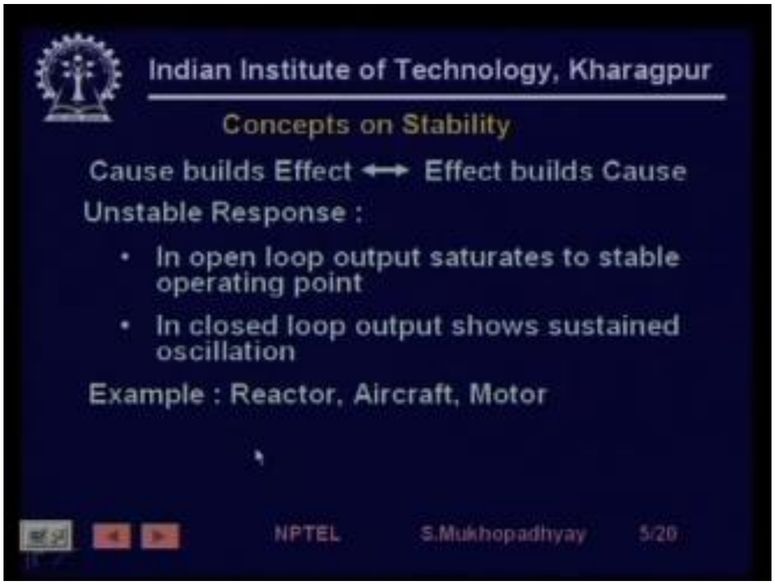

So and you can draw examples from exothermic reactors where temperatures tend to run away, aircraft where aircrafts are often very often unstable, or you can have motors like the example that I have given. So but so whatever saying is that you can still operate a plant around an unstable operating point using negative feedback, basically that is what your feedback control achieves.

It operates the plant in around the step in unstable point, the point which is unstable according to its open loop characteristic it can operate it there stably with feedback.

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However, it turns out that sometimes feedback can turn positive because of various factors like phase lags. So it is when feedback turns positive immediately at that time we start having oscillations and other symptoms of instability. So this is what qualitatively speaking, this is what typically happens. So now let us look at three major causes of instability in feedback loops, how does it occur in a feedback loop.

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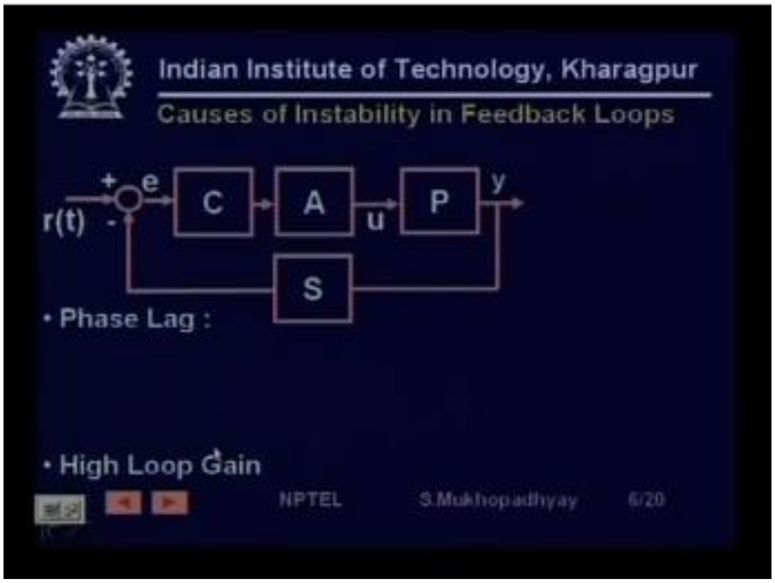

So what are the causes of feedback in this instability in this loop, there are two causes as we know that stability instead or rather instability is caused by two things firstly that the phase total phase lag around this loop must be less than 180˚ because otherwise if it reaches 180˚ then at that point negative feedback becomes positive feedback right. The second point is that but just having 180˚ phase shift is not enough, we should have enough loop gain.

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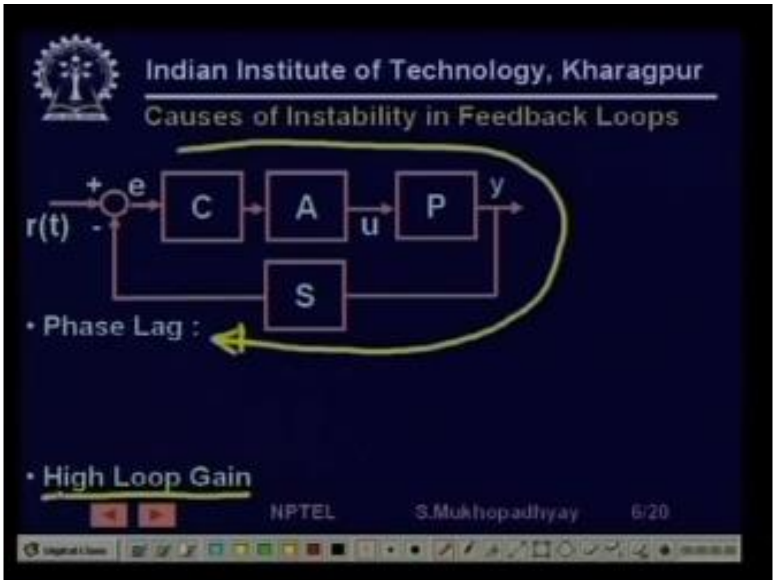

That is the cause must finally increase the effect and the effect should also increase the cause for that what you need is that you have a high enough loop gain. So these are the two major reasons one is that the phase lag should be less than 180 more than 180 or 180 at that frequency actually oscillation starts and the gain at that frequency should be high.

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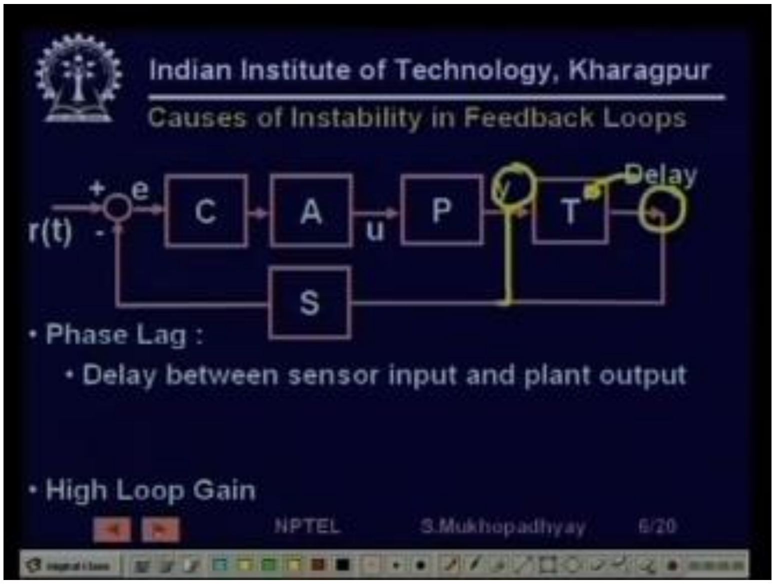

So now what are the causes, how can phase lag increase. So phase lag can increase in many ways for example if the delay between the sensor input and the plant output exists. For example, you see previously you see that we were taking the output from here, but for some reason if you take an output from such that there is a time delay between this signal which is the output you want to control and this signal which is the signal you are feeding back, so there is a delay of let us say T seconds then in that case that delay can easily generate instability. And this is one of the prime causes of instability so that is something.

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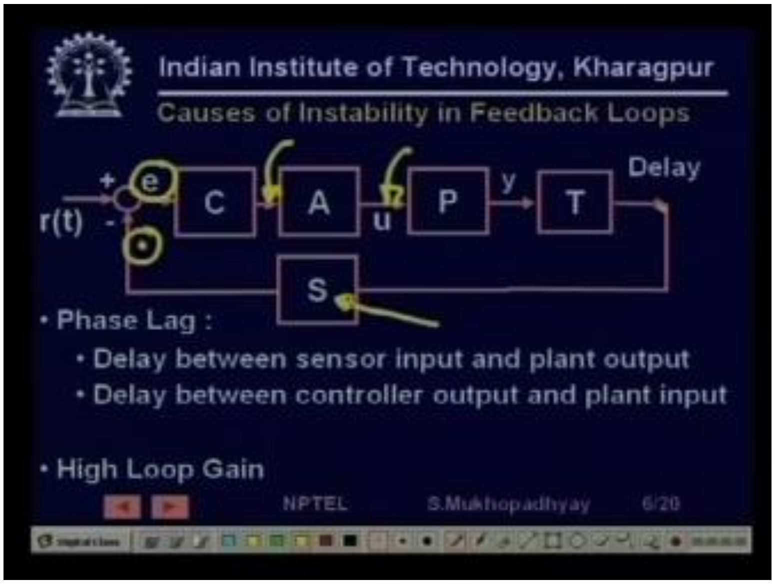

Next is oh, just a moment yeah, so what is the, similarly there could be delays between controller outputs and plant inputs right. So very often happens so there could be a delay, there could be a similar delay block at this point. Then there are also the, there is an overall delay basically what every time we have to see that what is the delay or phase lag between this point and this point that is the loop phase delay.

So it could be here, it could be here, even it could be here, it could be at any point or it could be even in the sensor, you know sometimes automatic controls processes even sensors like you have things like, you know online analyzers where there could be a considerable delay that is this delay actually occurs in the sensor.

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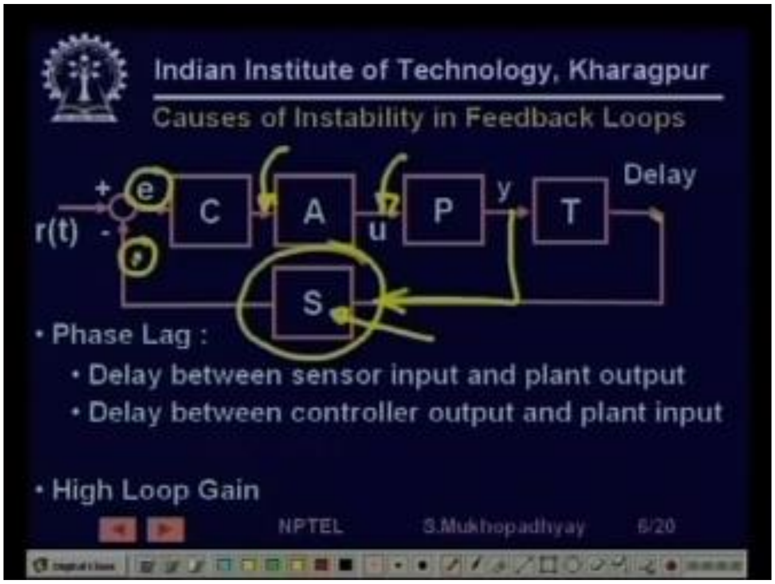

It is not in sensing the input directly from here it is fed but this unit causes a time delay that is also possible. So anywhere around this loop if you have delay it is a potential cause of instability.

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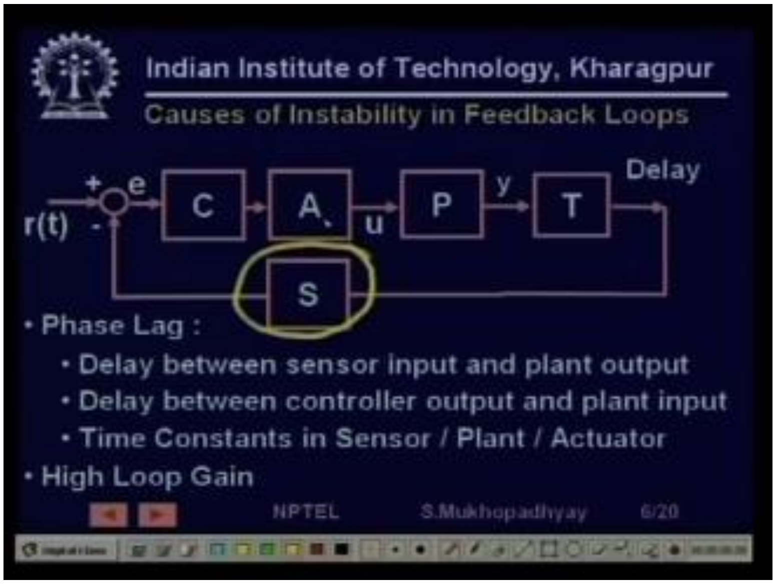

Next is and apart from delay you could have various kinds of time constants in this process. For example, you could have time constants in actually time constants always exists for example, the sensor we often take it as a unity feedback, but it is never exactly unity feedback it has its own time constants also because of the fact that the sensor is actually generally placed in a housing against jacket so such things cause time constants.

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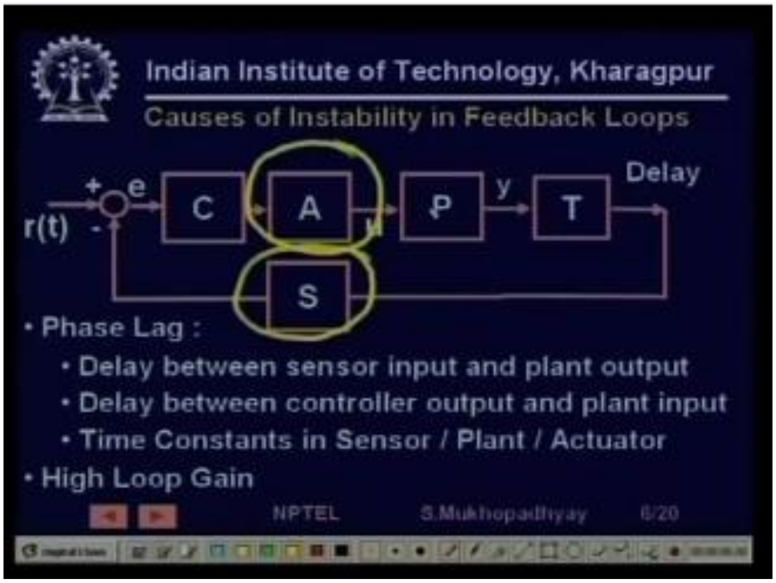

Similarly an actuator though we sometimes in our idealized view we sometimes think that the controller output directly goes to the plant, but it actually does not go to the plant it goes through a power amplification in the actuator which induces its own delay, there could be delays in, there are always delays in the plant.

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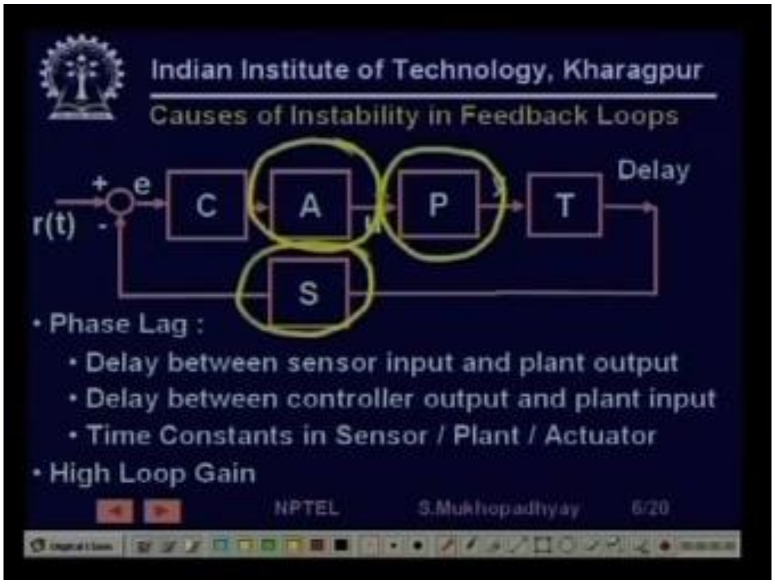

So these time constants and delays also calls instabilities.

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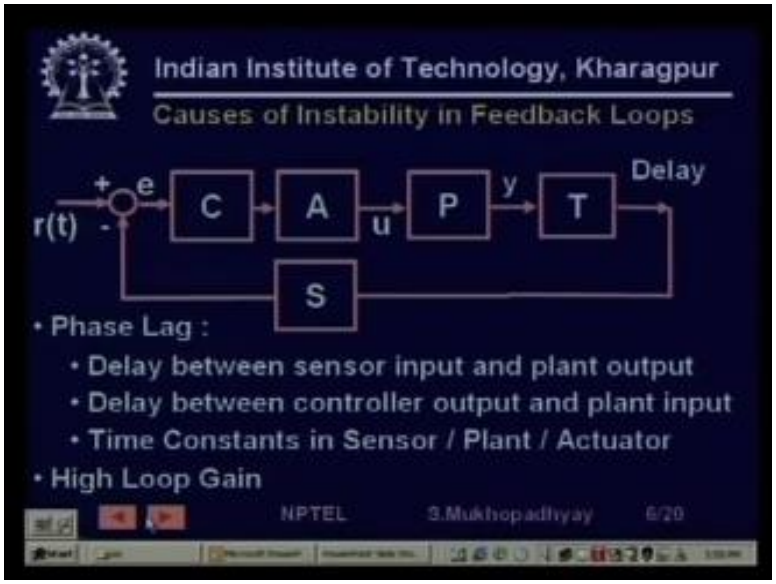

So these are the major causes of instability in a process loop.