Industrial Automation and Control

Prof. S. Mukhopadhyay
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 11
Introduction to Automatic Control

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Ready good afternoon and welcome to lesson 11 of the course on industrial automation and control. So, far we have learnt about sensors, but before learning about actuators I thought that, it 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.

We will start with automatic controls and go on, for that with that for a few lectures, and then eventually come back to actuators. Here, we go this lecture is on introduction to automatic controls. 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,9095 percent of all industrial continuous are PID controllers. We are going to have a look at that, why that, why that structure of the controller is so useful. That is the purpose of our lecture. Let us see that in greater detail. As we usually do, let us look at the instructional objectives of these lessons.

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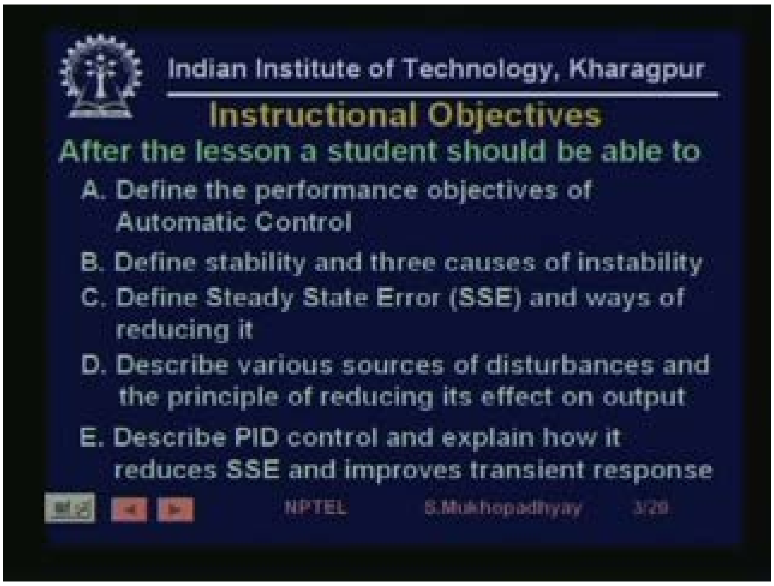

So, after these lessons, one should be able to define the performance objectives of automatic control, what basically automatic control wants to do? He or she should be able to define? what is basically describe, what is stability and 3 causes of instability, which are very typical in process in the in an, in an industrial process control loop should be able to define a very important performance indicator called 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 disturbances or rather, how to tackle the disturbance in the, in the sense that how to reduce the effects of the disturbances on the output. And all these, as we shall see will lead to a naturally lead to a kind of control structure which is known as PID control. This is what we wish to learn today. Let us go ahead.

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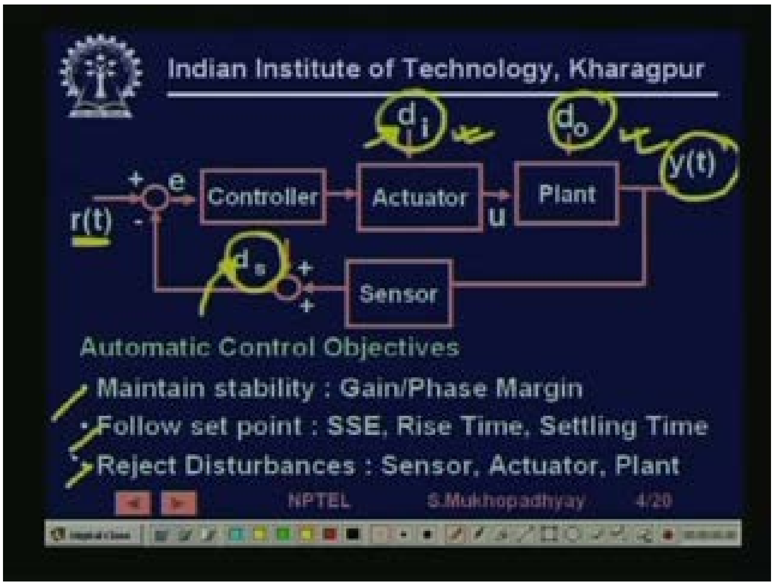

Let us first look at the automatic control objectives, what does an automatic control loop basically does? Here is an automatic control loop. Well known to us, because we have most of us have already had a course on automatic control. Here is the set point; here is the set point just a moment. Let me select my pen, here is the set point and this is the controller, this is the actuator which as we have as 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 what is known as the error, what is the objective of automatic control? The objective of automatic control is, firstly to maintain stability, what is 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 is not, that the output will run away or is not that the output will oscillate; 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.

That is the, that is the basic idea of stability. We want that signals in the loop should be stable is not that, they should be continuously moving around 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 the run the process at all.

The next is to, once you we can ensure that, we can hold the output at certain level wherever we want to, we want to the output to follow the set points. That is, that is we want that the output will follow the set point. Now, the set point is as we have noted it is a function of time and this output is also a function of time. We would like that, this function of time resembles this function of time as closely as possible, how do we express this closeness? We express it in terms of typically this set point, generally very often are step functions of time, that is the change over time like this. This is a typical this is r t and this is t.

They take step jumps again are held, we are typically talking of this kind of step responses, this kind of set points, we with respect to this kind of set points to express the degree of accuracy, with which y can, y can be close to r, we express various quantities like the steady state error, rise time, settling time etcetera will, we will have a more detail look at these basic.

This is second basic important point follow the set point. The next important point is of course, to reject disturbances that is even if we, even if the output once comes close to r, there are several external signals which are, which are working on this process, which are not in our control.

There are, 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 we have a hydraulic actuator, then one of the main things that happen in the, see the actuator is basically an amplifier it amplifies power.

Anything, which amplifies power usually have the power source. For example, the hydraulic actuator has a, has a, has an oil pressure source. Now, if the pressure of the oil changes that would be, that would be an input disturbance to the actuator. Similarly, if you, if you take manufacturing then what happens is? For example, suppose you are taking rolling, in rolling what you want to do is, you want to control these speed of the rolls and the, and the gap of the rolls.

Now, the now when a, when a metal bar comes and they here are the rolls rotating, when it comes and grips the roll immediately, there is a, there is a, there is a tremendous Torque demand, which comes on this. So, that comes that torque demand depends on lot of factors. For example, one of the important things on which it depends is the temperature of the bar which is, which is biting into the rolls, such things are called load disturbances.

Similarly, anything we want to sense we are going to have various kinds of measurement noise bias right. Electromagnetic noise, electrostatic noise, they are the feedback disturbances. There are various kinds of disturbances, which are acting on the loop all the time, which tend to move this output away from r.

The job of the controller is to, is to every time it moves away from r, the job of the controller is to, is to generate suitable input whether it comes back to r. There by, rejecting disturbances, that is the other prime objective of automatic controls, maintain stability follow set point and reject disturbance. These are the three major objectives of automatic control, having said seen that, let us look at the, see in some detail the concepts of stability. So, let us make some commonsense on this concept of stability.

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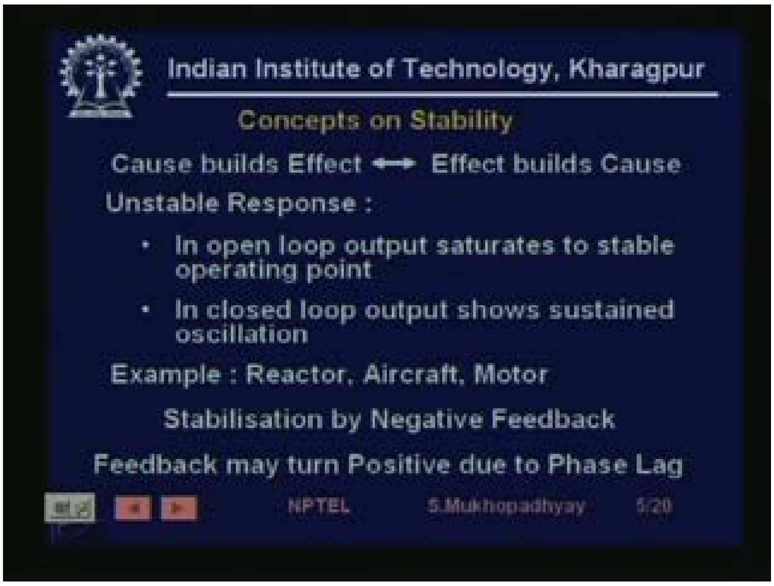

The first is, that when do we have instability, we have instability, when cause builds effect and effect builds cause right. For example, suppose there is a, suppose there is an, there is an typical case. Let me give you an simple example.

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Suppose we have an inverted pendulum, a pendulum, which is held here on a hinge right if the pendulum is vertical, it is suppose just maintaining its position. Now, if you if there is if you give it a little push, if you give it a little push. Let us say this side then pendulum will come to this position. Here is a cause, which produces an effect of an angle. Due to this effect, now the gravity force which will 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, you see that here is a cause, which builds the effect, that effect generated a further torque. So, it, so it generated, further cause which generated further effect and therefore, this is a not a stable position, this an unstable position right.

So, this is the, so this is the. So, this is the basic phenomenon of stability, and this phenomenon demonstrate itself in various ways, in case of flows temperatures motion displacement every variable right. This is the basic concept of stability. So, what is the next point, then what is the unstable response, how do how the typically characterized. For example take the case of, there are two typical demonstration of an, of an unstable response.

For example, in open loop, if the plant is not operated in open loop, then the output saturates to a, to a stable operating point ahead, what is, what is a typical example? Typical example is, suppose we have seen, we have the case of an Induction motor torque speed gut, this side is speed and this side is torque as Electrical engineers we have studied this.

So the, so the, so the torque speed curve typically looks like this right, and let us say that a load characteristic a, load characteristic looks like this. As the speed increases, the load torque demand also increases. Now, if this load which is, which is this is, this is the load torque speed characteristic. Now, if the, if the, suppose we connect the motor to a, to this load and then switch on the motor what is going to happen? Say see initially in this case of course, there is a the motor will not start, because of the fact that this torque is larger, what we show we have to do is, that we have to, we will assume that the torque will come here right the open, I see I have to touch it here, and here it is in the eraser mode touch it to the pens and then have to touch to the color correct.

Suppose a load characteristic goes like this, and the motor characteristic rather than that right, suppose the motor was motor characteristic is through this parts motor characteristic is this. Now, if you consider this operating point, then suppose, if here the motor torque and the load torque are same. So, it is a, 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 know is that, the generated torque, which is, this one is more than the load torque, which is given by the green curve.

Now, we have extra torque, now this extra torque will do what it will, it will increases the speed of the motor. 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 points. You see, at this point again the motor torque generated torque is actually equal to the load torque, in this point, now if you if something increases, the speed and it is comes to this point my dot is getting is shifted.

Now, what happen since, that if the motor shift from this point to this point immediately, what will happen is that, there generated torque will actually fall below the load torque requirement. So, the motor will tend to go back to its old operating point. Actually, this is the, this is the difference between stable and an unstable open loop operating point. That in an, in an unstable point, if you move it away from it tends to move further 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, if it moves away it is, it is going to come back to that operating point. It will not move away right, this is what is going to happen, this is what I need. Now, what happens is that, but this tendency, what you can always of if you, if you choose use the controller one of, the one of the jobs of the controller is to, operate a plan around unstable operating loop points, that is, that is why control is used in many cases.

For example, in process control in aircraft and also in motor what the, what the, what this will do, is actually that giving taking the old example. Now, if the torque speed curve is around this point, then here if it is operating then the now the control. Now, if it tends to move, it will tend move away, but now the controller will actually what the controller will do is, that is that the controller will control the.

Let us say, the motor terminal voltage and it will actually reduce the torque. So, that it comes whether it comes back. Again ever it comes back it will have a tendency to move this way and, then it will have a tendency to move this way. So, again the control will move it up. So, under control this the, this tendency of the, of this tendency of the open loop to actually saturate to a stable operating point, is actually prevented by the controller.

So, say every times of an unstable loop, it will tend to go to the stable point, but the controller will push it back , then there will tend to go to the other operating point and then the controller will again push it back, this is what happens. So, plant tends to run away and the controller keeps pushing it back. So, you have an oscillating response.

Usually this is typically what happens, when in an in case of an unstable response that, in that the close loop output shows sustained oscillation, that is also a kind of instability. This is typically, what you find when you have, when you operate a plant in either open loop or close loop. And you can draw examples from exothermic reactors, where temperature tend to a runaway aircraft, where aircraft are often very often unstable or you can have motors, like the example that I have given, but what I have said is that, you can still operate a plant around an unstable operating point using a negative feedback. Basically, that is what you feedback control achieves it operates the plant in around the in unstable point.

I mean the points which are the unstable, according to its open loop characteristic it can operate it, there stably with feedback. However, it turns out that sometimes feedback can turn positive because of various factors like phase lag , it is when feedback turns positive immediately at that time we start having oscillations, and other symptoms of instability 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 an, in a feedback loop?

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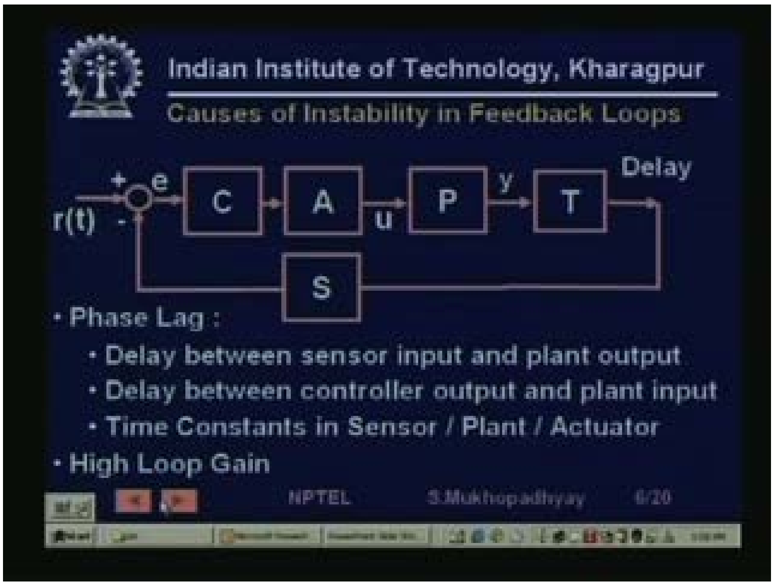

So, what are the causes of feedback in this instability in this loop? There are two causes as we now that stability or rather instability is caused by two things. Firstly, that the, firstly, that the phase total phase lag around this loop must be less than one 80 degree because, otherwise if it is, if it reaches 180 degree, then at that point negative feedback becomes positive feedback right.

The second point is a, but just having 180 degree phase shift is not enough; we should have enough loop gained. That is the cause must finally, increase the effect and the, 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, more than 180 or 180 at that frequency actually oscillation starts, and the gain at that frequency should be high. So, now what are the causes? How can phase lag increase? So, phase like an increase in many ways. For example, if the delay between the sensors input and the plant output exists.

For example, you see previously you see that we were taking the output from here, but for somebody is in, 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 it, which is a signal you are feeding back .So, there is a, there is a, there is a delay of.

Let us say, T seconds then in that case that delay can easily here at instability, and this is one of the prime causes of instability. So, that is something next is just a moment, what is the similarly there could be delays between controller output and plant inputs right? So, very often happens, there could be a delay, there could be a similar delay block at this point.

Then, there also the there is an overall delay basically, what every time you have to see that? What is the, 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 now sometimes, automatic controls processors even sensors like have are, I mean you have, I mean things like you, now online analyzers, where there could be a considerable delay. That is, this delay actually occurs in the sensor it is not in sensing the input, the 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. Next is an apart from delay you could have various kinds of time constant sin this process. For example, you could have time constants, in actually time constant always exists. For example, the sensor the often take it as a unity feedback, but it is never exactly unity feedback.

It has its own time constant also because of the fact that, the sensor is the actually generally placed in a placed in housing again jackets. So, such things cause time constant. Similarly, and actuator though we sometimes in our idealized view. We sometimes think that the controller output directly goes to the plant, but it is actually does not go to the plant, it goes through the power amplification in the actuator, which induces its own delay.

There could be delays; in there are always delays in the plant. So, these time constants and delays also cause instabilities. These are the major causes of instability in a process loop, having seen that. So, now we have to take care of these and designer controller appropriate. Now, let us a look at performance, what is the first requirement of performance?

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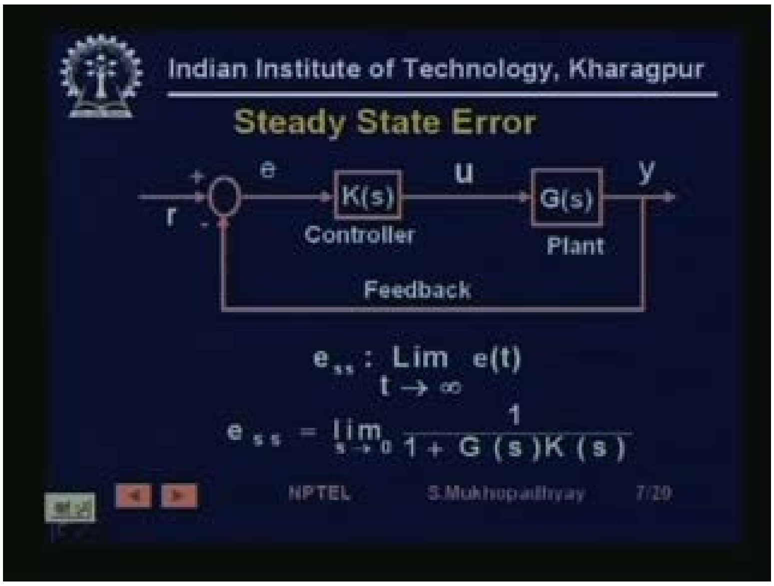

The first requirement of performance is that, performance can be divided into two types in control. One is called steady state performance and other intransient performance. In general, steady state performance is much more important than transient performance, simply because of the fact that, performance holds over a much longer interval. Generally in industrial automation, the set point changes somewhat infrequent. For example, if you take power station boiler there is set point over a day, will typically be change 789 times may be, may be less. So, when you will have load coming in the morning, it set point will be change when lighting load in the evening will start going down after.

Let us say, 10 o'clock or 11 o'clock load will fall and that time, we have to reduce the set point. So, there are infrequent set point changes and in between this, the set points are generally maintained this happens for a lot of process equipment. If, you have performance degradation, which are persisting during that phase when the set point is held, then that is generally considered much more serious than error, that can occur when the set point is changing or immediately after that time for a, short duration.

So, we would first like to ensure steady state performance and the major consideration for that is steady state error. That is, we want that r should be equal to y at least in the steady state; obviously, if r suddenly changes y cannot suddenly change. So, y will have to it, y will take some time to come to the level of r, but once it comes we want that this error will be 0, we want 0 steady state error this is our wish. So, how to obtain that right, for that we want that this is the steady state error, that is the limit oft and typically we take unit step response.

So, if there reference input suddenly changes, then how is as time passes does the error go to 0, that is limit of t tending to infinity e t. We can also express it in frequency domain form which says that, which uses the final value theorem of Laplace transform, and which comes downs to the fact that a, e steady state is limit of s standing to 0 1 by G s K s right. This is the steady state error and we have to ensure one of the prime requirements is to ensure by control that this goes to 0. So, how do we do that? So, we have to control for 0 state. Let us take the simplest case of proportional control.

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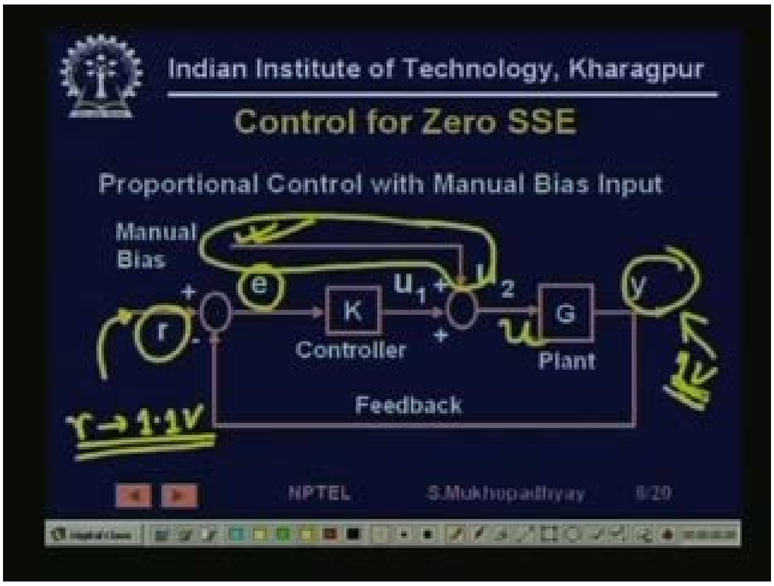

The problem of proportional control is that , if you want to proportional is just, you have a simple gain and if you get an error of one volts, you generate a may be an output of hundred volts, if you get another 2 volts you generate output of 200 volts.

So, just simple multiplication now; obviously, we want to, we what do, we want, we want that, this r be equal to y, we want to r is a certain value. We want to maintain a certain value of y. Now, naturally in it happens. So, happens that for maintaining a particular value of y, you need a particular value of u. For the time being, assume that this is not there, now how are we going to get this u, if you, if you want to maintain this, you then we have to maintain a particular value of e.

So, unless we have a certain amount of steady state error, we cannot generate u and the therefore, which cannot generate y. We cannot take steady state error 0 ever using proportional control, that is what it turns out to be, what happens is that the there are two things, that could happen either you could artificially increase this r that is, if you want. Let us say and r of really want that the, that the output stage at one volt you given r of may be 1.1 volt. Just, what volts we have to give that have to calculate, but you artificially increase 1.1 volt.

So, that here you get one volt, which is a real output you want right, or what you could do is apart from, what the controller is doing you can give a, you can give what is known as is manual bias, that is you apply some additional input right directly to the plant. So, you do one of these two things, in that cases you can maintain whatever output you want, but what is the problem? The main problem is that, who is going to give this input. How do you know by how much? For example, if we give 1.1 volt for 1 volt, how do we know? Let us say, if we want one output of 3 volts, what output we have to give by how much. So, naturally it should not require a manual. You now manipulation, it should be done automatically right that brings as to the question.

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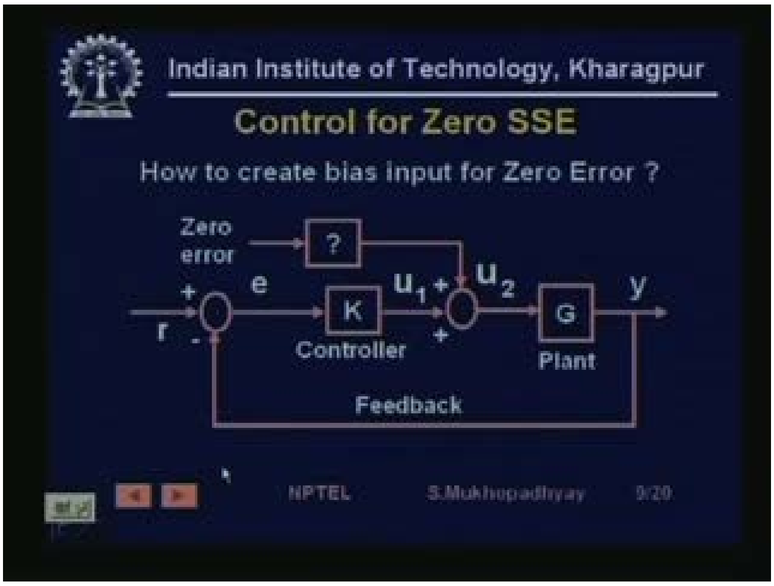

That how can we automatically generate this bias input without any manual intervention. So, the question is that, how do we how to create bias input for 0 error right? That is the situation described, here what should be this.

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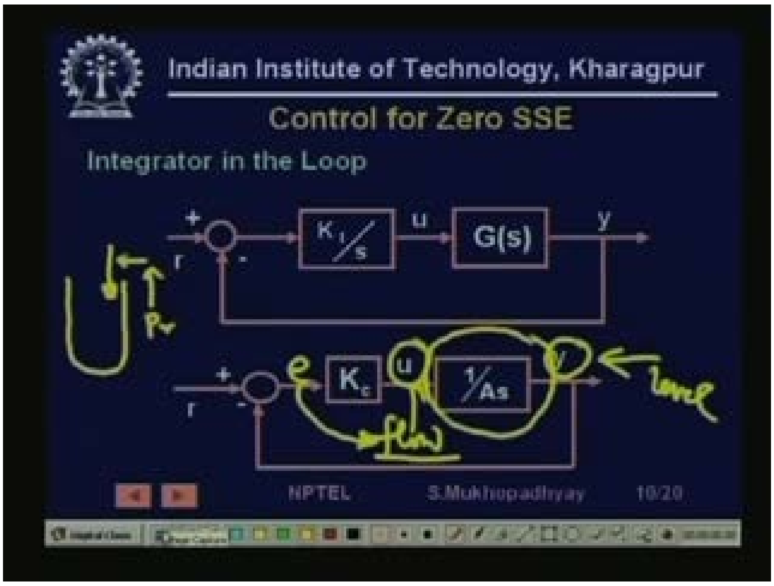

So, we see, we see that what is the device, which for 0 error gives a, gives an output that device is actually an integrated, somewhere in the loop there should be an integrated, then even if the error is 0, we will be able to give a finite output. There are actually two cases, in which integrators require, the first case is this one, if you have an integrated, imagine that we have written K I by s in Laplace domain notation, which means that this is actually in an integrated.

That is, u is equal to integral K I e t d t. So, this is the integrator, this is equal to u. Now, you see that even if, after sometime this at this point, if even if we get e goes to 0. For example, suppose the error goes to 0, this is, this is, this is y, this level is r, this is the level. So, here error is going to 0, but what will be the value of the integral, what will be the output of this block, the output of this block is going to be the area under the curve, because this is the error.

This is y and this is r. So, r minus y is this vertical distance, this is the area right, this area even if, the error remains 0 this area remains finite, you can generate a finite U even when the error is 0, you can keep generating, how an integrated helps. There is another case, in which you can have an, you can have an integrated that is, the integrator is actually part of a plant itself, which means that to be able to sustain an output, the plant may not need an input all the time. The plant itself is an integrated, what is a typical example of this? A typical example of this is a tank.

Suppose, you have a system, you now like we have in our toilets you can have a flow in and the, this flow in is actually this flow is actually proportional to the level actually there is a, if you might have noticed if you look into the system. That, there is a, there is a ball cock floating ball, when the when there is no water then the ball cock is hanging like this, and water flowing, as water rises.

So, the ball cock goes up and at the certain level, the valve through which the water is flowing will actually close. At that level it will be maintains, you see now this tank is a plant which tank is a plant which is, which has an integrator with respect to flow because the level is nothing but an integral of flow, at some point to be able to maintain a level, this is a level it does not need any flow. The flow can go to 0 still, we are having a simple proportional controller. The error going to 0, flow goes to 0, but still level is maintain this is an, this is another situation, when we can have 0 steady state error.

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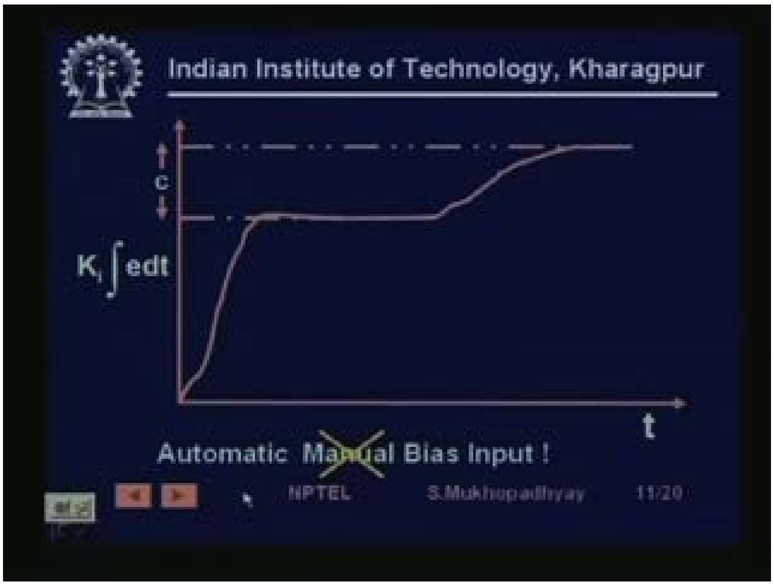

Now, so exactly this what happen, now if we see if we put the integrator, what happens is there interesting, what happens is that, this bias input, which was previously coming now comes automatically. That is the integral output, which I was talking about now increases still it can then it goes to 0. And then if you, if you change the set point again from here to here, again some error will be created and little again integrate. And we will generate just enough output, such that it can be a it can be sustained without the error.

See that integrator is actually, the integrator actually works as, the integrator actually works has a very interesting thing. It actually gives of bias input, but which is not manual, the bias in to the integrator raise actually, exactly like them like the, like the bias input, but it generates it automatically. You do not have to give it, you do not have to give it manually and it will adjust itself depending on, if you depending on set point. So, the integrator will automatically build up and give enough additional input, such that at 0 error it can be sustained, that is the, that is principal by which 0 steady state error is obtained.

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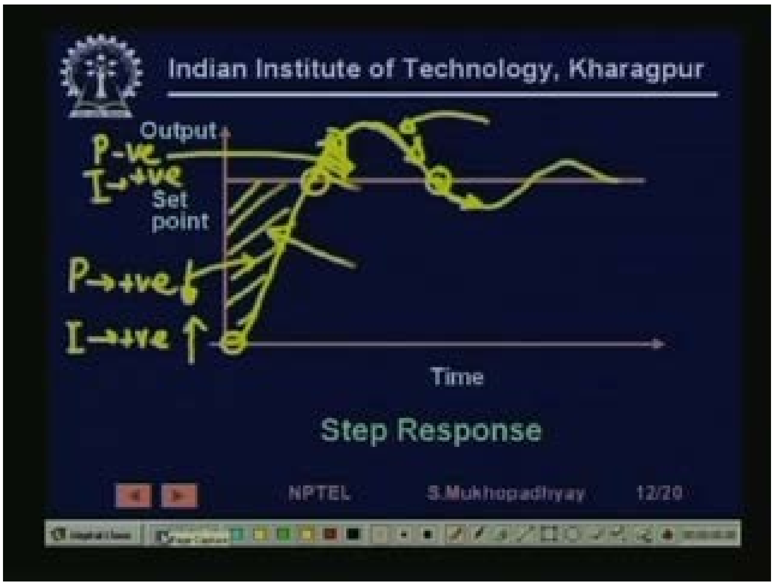

Now, only thing is that now this has certain there are, there are draw backs too. For example, let us see that if we, if we give a step response, if we give a step response then how does it, how does it work? How does it loop work? So, you see that suppose the process starts from here, the process starts from here and starts, as we are have given, there is a lot of error.

The proportional controller now generates the positive input, which drives the plant the plant goes up and typical we are likely to get a step response like this, what happens during this phase, during this phase, during this phase you have proportional is positive error is positive. So, output is positive, but since a error is decreasing, the output is going down, it is positive, but going down that is the output of the proportional controller, what does the integral controller do? A integral controller is also positive because, it is integrating positive error and it is increasing, because the, because the area as it is going with time, this area is continuously increasing, it is positive and going up increasing right, what happens at this point, at this point at this point error is 0.

So, the proportional controller output is 0, but because the integral controller output is still positive, the plant continues on this journey in this parts right. Now, at when it is here, let us say, when it is here the proportional controller around this point P is, P is negative, but I is still positive because of the fact that, there is already of large positive integral accumulated here.

Here, integral is negative, this part of the integral is negative, but still there is a large positive integral. So, the overall net output is may be still positive, it continues on this journey, but eventually the integral value also reduces and the proportional controller value also becomes enough negative. So, the overall input turns negative and the plant tends to move.

Now, again the same thing happens here, once it crosses this line now the now again it will, it will oscillate. So, you see that typically because of integral control they are tends to be an oscillation. There tends to be a high over shoot and an oscillation, this is a drawback of integral control that is to gain steady state error to gain to gain 0 steady state error. This is a price that you are paying that in your transient response; you are likely to get some over shoot. So, that is the picture for the step response.

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So, we want to improve transient response without sacrificing the steady state error, if you want to do that. Then, what you have do is that around this point only here you have to, you have to, you have to, you have to keep breaking.

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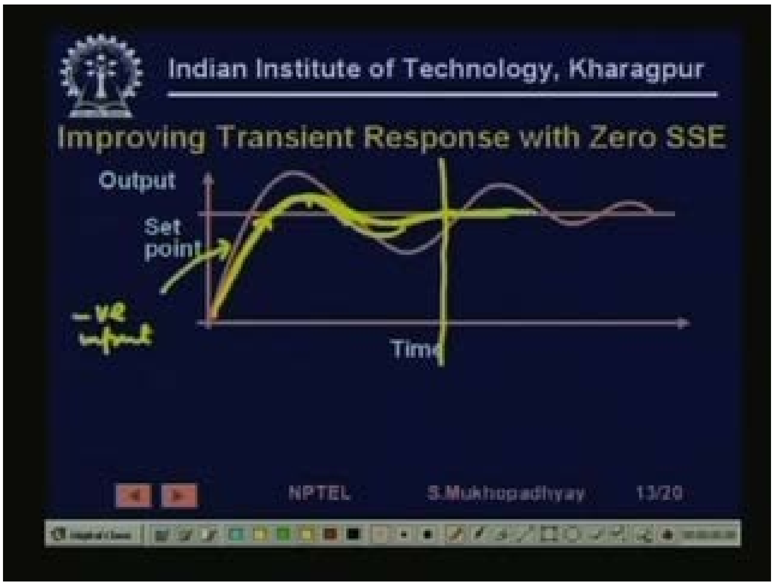

You know, you have to keep breaking and around this point that we can quickly turn, what happens is that, here now you have to, you have to slow down. So, slowing down means during this phase, you have to create more negative input, which will grow towards this point, as it comes closer it should this negative inputs are increase.

Similarly, around this point this negative input should also this negative input should also keep increasing. So, that it quickly turned then and then actually it will settle very fast, you see it will not oscillate, if you we want that does not oscillate. So, many times, but rather follows this yellow curve may be does are small over shoot, and then immediately settles down, this is the kind of curve that we want.

So, now it turns out that this kind of curve, we can obtain if we add a derivative turn to error right. We want to reduce rise time what is rise time, we want to reduce rise time we want to reduce this time. We want to typically speaking we want to reduce overshoot that is this height, and we want to also reduce settling time that is the total time by taken for it to come to statics. So, we want to reduce that all these now, getting all these is somewhat difficult, and that is why you need to have a, we need to have a nontrivial tuning exercise to. You now come to a compromise between these a typically.

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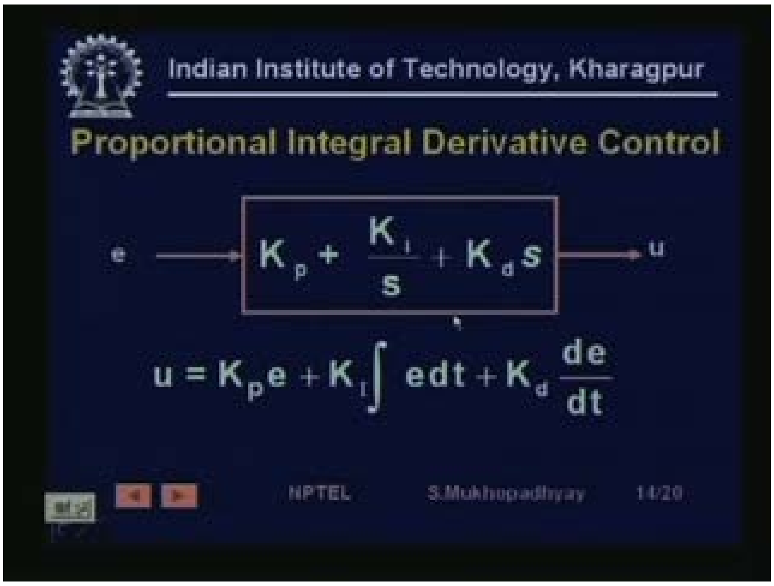

What we do is it turns out that these things can be achieved, we already discuss proportional and integral controller and we have also seen that adding a derivative will you now try to break. So, that it does not go towards much overshoot.

So, we need a, we need a proportional controller because, if we do not have proportional controller, then there will be tend to be too much of oscillation. We need a integral controller to have 0 steady state error, and we need to have derivative controller to have low overshoot and fast settling time and we need to tunes this gains K p K i and K d nicely. That we, we get a good transient response without sacrificing on the 0 steady state error.

One thing interesting to see is that this we now calculate input like this. Now, interesting the you see that in the steady state, in the steady state the total e 0 is. So, therefore, this time is 0, the proportional control is 0. And since e is not also changing, there is a d t is also 0, that is also gone. So, we only have the whole output coming from the integral part. So, the 0 steady state error concept that we have studied for the integral control holds now, as a as I said that, we need we are.

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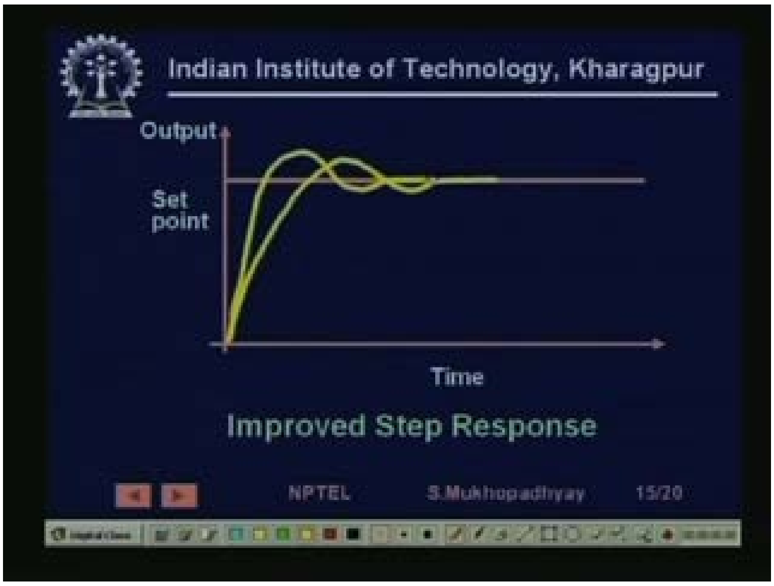

We are looking for a step response like this. This will be a very good step response and we if, we can make it even sharper even better, but generally if we want to make it sharper, then if we can make it like this even better. So, this is the good step response that you would like to achieve.

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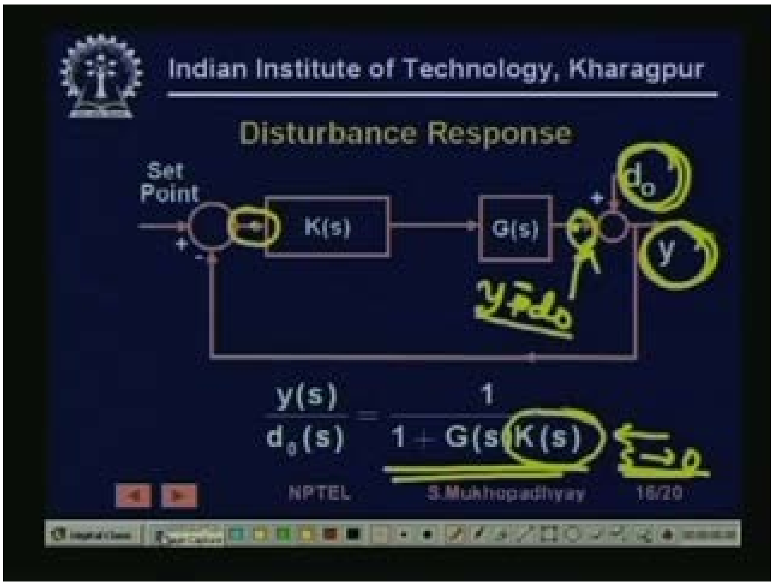

Now, come to the point of disturbance rejection. So, what is the disturbance response? The disturbance, we let us talk about there are, there are, there are several times of disturbances and we can do the same kind of analysis. But the most predominant disturbances, which occur generally is the load disturbance in a process, occur with various reasons property variations of materials, variation seen in a power sources, voltages variation seen pressure sources all source of things. So, it turns out that the starts the function, we want to reduce the effect of the, we want to reduce the effect of d 0 and y, what is the transfer function between y and d 0 that turns out to be this?

Now, again we see that if you have, you know it is not possible to exactly neutralize all kinds of disturbances, but let us say one of the major kinds of disturbance is step disturbance, again that disturbances we change once or twice and then stay on. If, we have step disturbances, then you can again see that and if you have, and if we have an integral, then this term will actually go very high as s tends to 0, the effect of. So, for the same reason exactly similar transfer function is coming. So, the same reason why e goes to 0 with integral control?

If, you put integral control, even the effect of step disturbances will also go away, because the integral value will rise, and it will provide the additional torque to actually care of the disturbance. It will produce an, it integral will rise and it will here, it will instead of producing y. It will automatically produce an output y plus d 0, or otherwise minus d 0. So, that after plus d 0 you will get the desired value of y, this is going to happen. Integral control is one of the major ways of reducing disturbance response.

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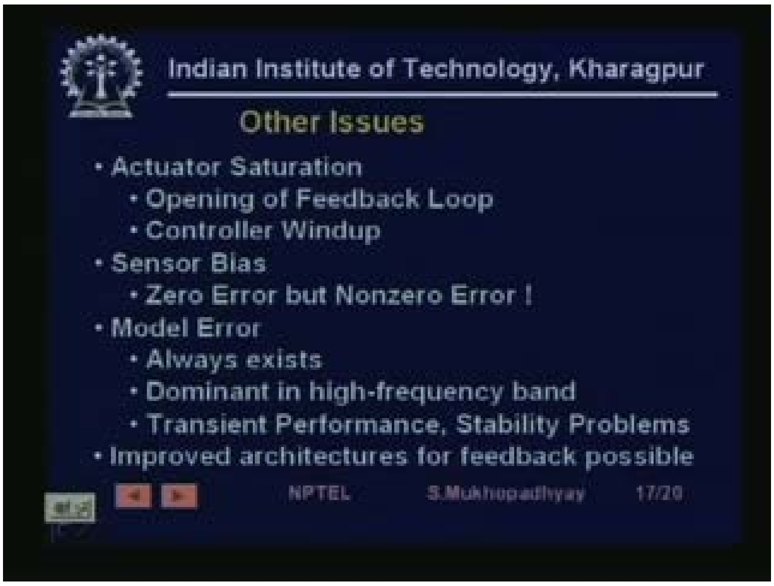

Integral control is one of the major ways of reducing disturbance response. So, this is a, now let us look some other issues. For example, if we have to, we have to actually remember these things because there are very practical issues. And we possibly did not learn about this in our, in our earlier control course, where we treated things rather ideally, but we must remember here that, some other non-idealness is exists.

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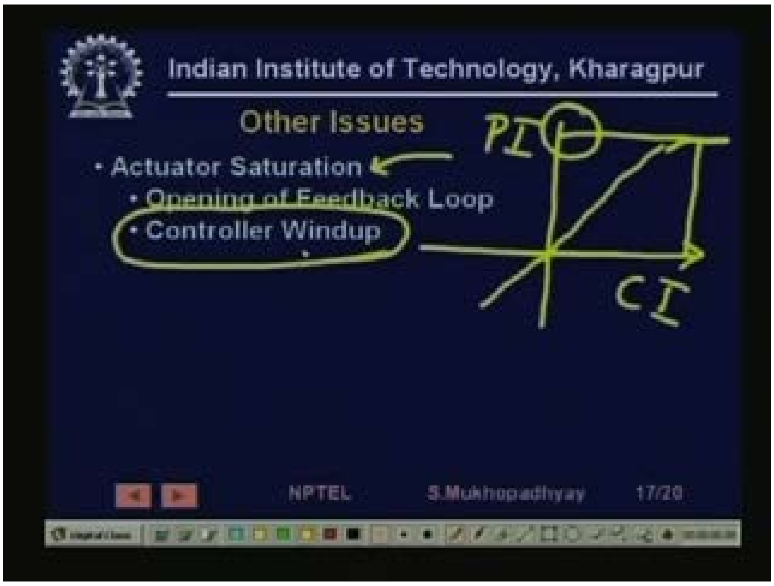

For example, there can be very often there can be actuator saturation, that is the characteristic of the this is the control input C I, and this is the plant input P I. This is the actuator characteristic. So, as you increase the control input, the actuator will also proportionally include the plant input, but only up to a certain input, after which it will saturate. If, you give more and more control input, it will not give you proportionally high plant in to the actuators typically will saturate.

Now, when the actuator saturates effectively the feedback loop is opened, because the effect of the error no longer transmits to the output or rather the plant input. So, input does not change in response to the error, but is held constant that is the case of an open loop operation.

So, your control is gone and not only that the sometimes as, we shall see later that the, that the, that persistently actuator saturation persistently. Actuator saturation has very bad effects on controller especially; with because of the fact that controller have memory, this is the particular phenomenon, which occurs in PID controller and we are going to take a look at it in great detail in the next lecture.

Next issue that we should look at is sensor bias; you know remember that if you have a sensor bias sensor has errors, and then sensors are the eyes of the controller. So, whatever sensor sees that, the controller simply works on that, if we have bias you will think, that is the controller will produce an input, which will have 0 error, but actually there will be none 0 error, that is. So, you say you have a 0 error, but you have none 0.

Similarly, we have to remember that you always have, actually you design controllers based on some models, but it always turns out that this models are actually inaccurate. So, you are always going to have model errors, and this model errors are typically dominant in the, in the high frequency band. And now remember that, if you have in accuracy in the, in the high frequency bandit is the, it is the error in the high actually typically instability occurs in the high frequency band not in the d c band lower frequency band.

So, if we have modeling error in the high frequency band , then such modeling inaccuracy is can also lead to instability problems, we have to remember these things to take care of these things. Various kinds of other architectures are possible than, what we have that is the loop structure, what feedback will you use, how will you use the controller and we will some of them. For example, feed forward configuration cascade configuration will see all of them. So, they are possible.

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Finally, while we are moving towards the conclusion, let me mention some of my pet facts about control in colloquial terms. I say that what you feedback is? What you control what you? So, the controller exactly tries to maintain the feedback, feedback is erroneous, then your any control is erroneous. If you are sitting in the middle of the room, and if you have put your temperature sensor at the, at the roof of the room, then you are controlling the temperature at the roof of the room, not in the middle of the room right. Then, when you what you cannot actuate you cannot control.

So, you may be giving whatever in output from the controller, it may be using a fancy algorithm, but if we cannot actuated then you are not controlling that, if you can, if you can measure or estimate the disturbances. Then you can compensate them, one of the I mean there a many advance algorithms, which a precisely trying to do that.

Stability is basically, satiability is not enough stability is barely basic performance ,you must ensure stability and then ensure performance, but while you ensure performance if you as, you try to go more and more drive, more and more an improve performance eventually instability results.

So, see instability is actually comes is actually decides the generally decide the maximum performance, that you can achieve and models are always approximate most systems are actually non-linear, but that does not mean that, we can work with approximate. Linear control can work very well for non-linear plants, but some time non-linear control may be working better, but 95 percent of industrial controllers are linear.

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So, we have come to the end of the lesson and let us review quickly. We look at the objectives of automatic control maintain stability, follow set point reject disturbance. If, we look at stability, and found the causes of stability in causes of instability in process look, we looked at steady state error and the ways of reducing it, and we also looked at the ways of reducing transient performance, keeping the steady state error 0. So, we saw that the PID control is a very effective and simple, and effective way of doing that, and eventually we say. We saw that PID control can also do some amount of very common disturbance rejections.

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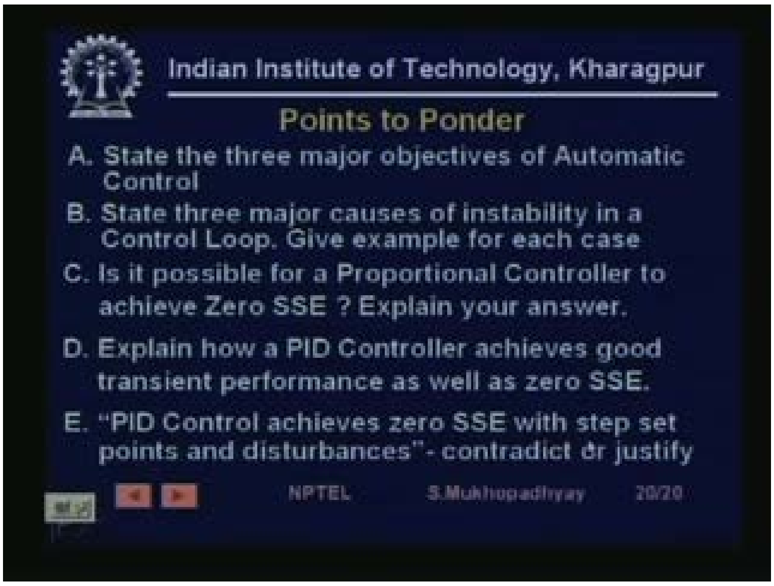

So, let us the end of the lesson. Let us here are some points for you to ponder. First is that state the 3 major objectives of automatic control, which have just now said state 3 major causes of instability in a control loop, and give this is tricky try it give an example for each case practical example. And is it possible for proportional controller to achieve 0 steady state error.

I have, already explained an example. You try to explain it in your own language, explain, how a PID controller can achieve good transient performance as well as 0 steady state response. And finally, justify or contradict the state may in the PID control achieve 0 steady state error ,with step set point and disturbances. Thank you very much will see in the next lecture.

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Good morning and welcome to lesson 12 of this course on PID Control. So, as usual before starting the course, we will review the instructional objectives.

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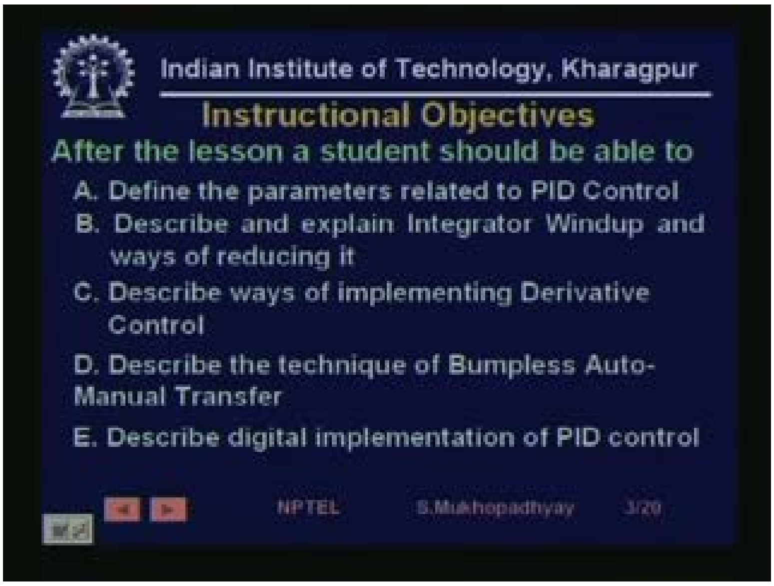

And these are. Firstly, that we will be related, we will be learn how to define the related parameters of PID control in an industrial context. Secondly, we will describe and explain in detail about a phenomenon, which may times occurs with PID control known as integrator windup, and the ways of reducing that.

We will describe various ways of implementing the derivative control part, we will also describe the one technique of you know bump less auto-manual transfer, that is when the control is transferred from auto to manual or manual to auto how. So that, it can happen without any short to the process and finally, we will describe digital implementations of PID control. So, in other words we are going to look at various practical aspects of PID control today. Let us begin with the PID equation.

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This is the PID equation, which we have seen in the last lesson. Also where K p is the proportional gain or sometimes, we this is not proportional band as written, but it is an it is proportional gain we will, but we will, but a very similar parameter called proportional band is also used in the context of PID controllers. We will see soon, how that is related to the proportional gain, next is the parameter T i, the parameter T i, here which is called the reset time, and expressed in a peculiar sounding unit called minutes per repeat.

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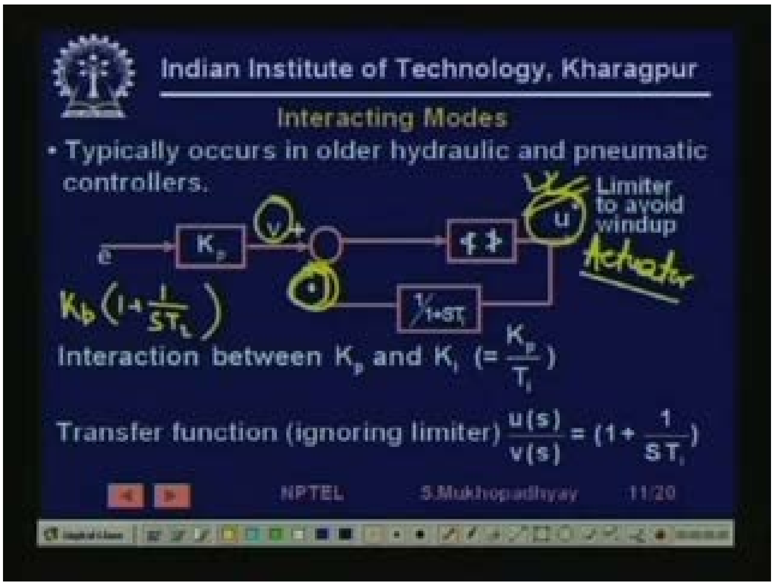

This is another way, by which an anti reset windup scheme can be implemented, typically in hydraulic and pneumatic controllers. Now, we will look at a phenomenon another problem, which occurs typically with integral control and that happens, when you have you know auto manual transfer.

Now, let me first explain this terms. There are, there are, there are many most processes, will also allow the operator to give input that is, if we, if we wants in then certain situations you can bypass the automatic controller. And rather using, some using some input device like a, like a potentiometer or a knob or a switch, you can given manual input to the plan. And you can slowly build it up, and then at may be some purpose right.

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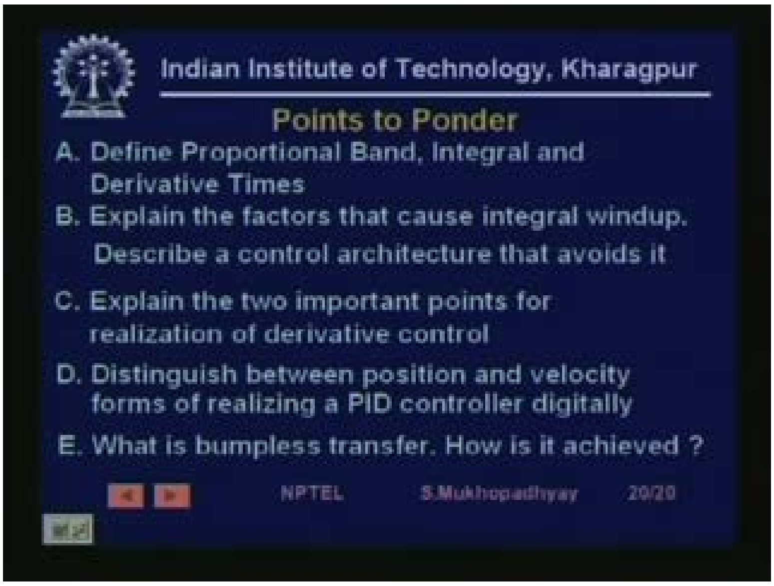

So, you might like to right yourself the definition of proportional bands integral derivative times. It is, you would like to explain the factors that cause integral windup. So, integral windup is basically cause by, basically cause by two factors, what are those factors? And we have discussed in this lecture too control architecture, which will avoid integral windup, how to avoid that.

Then, we have seen that while you are implementing derivative control, you have to take care of two points such that, you do not add unnecessary disturbances and shorts to the plant, what are they? And finally you have seen that a PID controller may be realize in what is known as a position form and velocity form. So, you need to think how to distinguish between them, when which one is required, and also what is bumpless transfer, and how it is achieved, the answers to the questions are exist in many text books, and also within the within this lecture.

Thank you very much.