Industrial Automation and Control
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Lecture - 16
Special Control Structures
Cascade Control
Override Control
Selective control
Spilt Range Control

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Good afternoon. This is our last lesson on process control. Today we will look at some special control structures, special in the sense that, so far whatever controls we have studied PID control, smith predictive control, everywhere the we had sensed 1 particular process variable, which we wanted to control, that is the output and we feed it back. And you also use only 1 actuator, and today we will see that in some cases, situations arise where we can use more than 1 sensor in a process or there are sometimes more than 1 actuator also.

So, we will take a brief look today at those kind of control structures, and we will also see what kind of advantages can be derived by these. So, that is the objective. In particular, we will study cascade control, which is a very popular control strategy, we will study something which is known as override control, selective control and spilt range control. These are very standard terminologies in, found in process control books. So, we will take a look at that right. So, before we do that, let us first see the instructional objectives.

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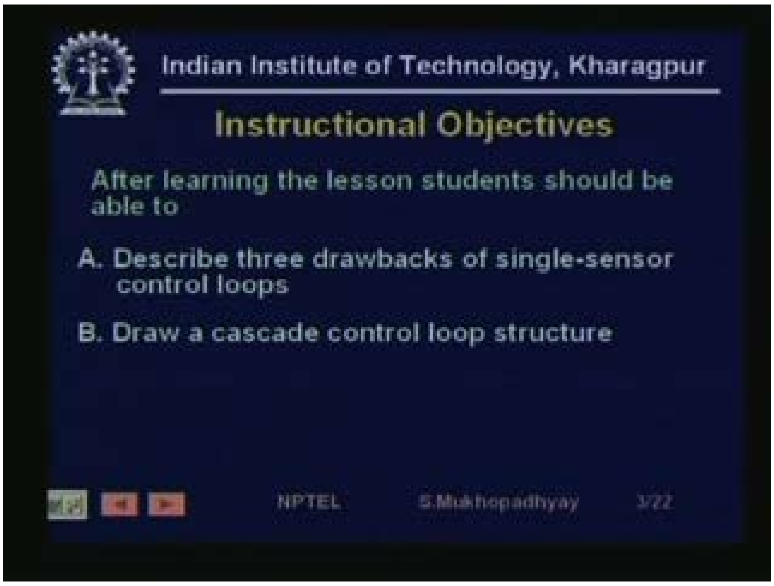

So, today after learning this lesson, the student should be able to describe some drawbacks of single loop control, and based on some of these drawbacks we can see that cascade control will address some of these drawbacks. And therefore, we will learn cascade control and we should be able to draw a cascade control loop and demonstrate the advantages of the structure over a single sensor feedback loop and conventional.

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Additionally we will also be able to understand what are, what are selective and override controls and similarly for split range controls. So, this, so the basic idea is to familiarize ourselves with these kind of control loops and understand their advantages. So, first we will take a look at the problems of single sensor control loops. Sometimes it happens that, you know the basic idea of a control loop is to correct or adjust the control input to take care of the disturbances, basically they are and it and a standard control loop does it by computing a control law based on the error. So, how quickly the control loop will be adjusted in response to a disturbance, depends on how quickly the error will be found. So, for example, we have found that in our, in our, in our single sensor control loop for example, in our let us take the standard control loop.

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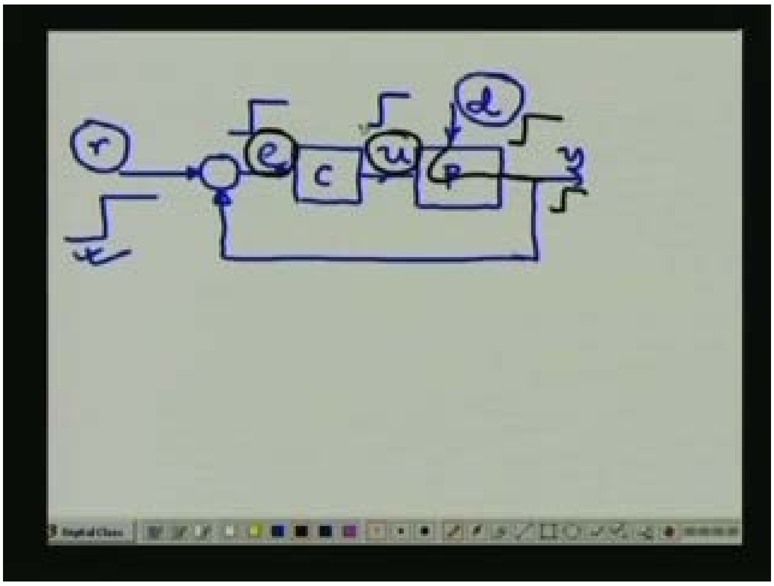

So, you have the reference coming here, and here you have the controller C, and the plant P, and this is the output, and there is a feedback. So, you see that there may be disturbances acting on the plant at various points, right. So, these are disturbances D, this is the set point R, and this is the output Y.

So, the controller basically calculates this U which is the control input to either take care of, to if, to take care of basically variations in either r or d. So, if r is changing that it needs to adjust U, so that Y becomes close to r. So, now you see that this controller does well because any change in r, if r changes from this level to this level let us say then immediately the error will also jump from this level to this level. So, the change in error E is almost instantaneous corresponding to the change in r.

So, the controller also response with an instantaneous change in U, and the output gets adjusted as quickly as possible. But that does not happen, when there is a change in disturbance level because this, the, even if you have a, let us use a different color of the pen. So, even if you have a disturbance d changing here, the effect of this disturbance to come on the output take some time because the disturbance has to enter through the plant and then travel to the output. So, for so during that time, the error E remains unchanged and the controller does not obviously, adjust its input. So, this is a, this is the problem of single loop control.

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So, having understood this, we can realize this that high lag between error disturbance and output can sometimes occur depending on where the disturbance is appearing. The next point is that now, we know that if there is high lag then our phase margin is low, that is a system loop transfer function has a lot of phase lag, so therefore, we need to keep our gains lower to maintain stability. Now, if we have to keep our gains lower naturally, we will get poor transient response. So, we are not driving the plant hard because of stability requirements, right. So, this is a problem which arises in single loop control sometimes.

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Secondly, this is, this is the problem which will address. We will see how it can be addressed by using cascade control and very commonly addressed. Now, there are some other situations skills controls. For example, in some cases, we have to control the a variable which exists over a distributed specially distributed region. For example, suppose we want to control the temperature in this room in which I am sitting so obviously, this room is a, is a big place where, I mean, I mean how do you control the temperature in a room typically in air conditioning, you provide cold air.

Now, how much cold air you will provide depends on what temperature you want in the room, but how do you give feedback. Obviously, using temperature sensors, but a temperature sensor will suppose it is a suppose it is an RTD. Typically, in air conditioning temperature, the sense using resistance temperature detectors. So, where will you put the resistance temperature detector will you put it on the ceiling or will you put it on the floor if it is on the floor which corner of the floor or would you put it in the center.

So, remember that you will be controlling the temperature at exactly the point where the, where the sensor is put. Even if the temperatures at the other places are slightly different, the controller has no way of knowing that because the sensor is controllers I. So, therefore, whenever we are having a sensors, we should understand that we are controlling the controlled value at that sensor location. So, if you want to maintain some uniform control over regions, sometimes we need to put more than 1 sensor and incorporate them in a control loop. So, this is a requirement in many cases.

So, therefore, multiple sensors at different locations are needed to control the overall process average. So, you want to control the average temperature of the room. So, you have to put 3, 4 sensors at 3, 4 different locations. Or sometimes we want to control extreme values, you know because sometimes the output at various places may not be the same and if it goes too high it may cause damage or if it goes to low it may cause damage.

So, sometimes you may, you may likely choose average values sometimes we may like to choose extremal values, that is maximal or minimal values, and for these purpose we need to put multiple sensors. There are also some cases, where systems are actually operated in different modes, that is when it is in, suppose the set point is very low then you want to operate a system in 1 mode, if it is very high you want to operate it in another mode, typically happens because processers are non-linear.

For example if we want to in, if you go to western countries then you will find that part of the air the temperature becomes warm. So, you need air conditioning or you need cooling, and part of the time when it becomes, when it I mean in winter you have to heat the room. Now, you see cooling and heating cannot be done using the same equipment.
So, you essentially for controlling the same process variable that is the room temperature, you need two different sets of equipment or actuators. And you need to have a control loop which will, which will incorporate these 2 actuators and actuate anyone of them depending on the set temperature that you want, that is whether the set temperature is less than ambient or is it more than ambient. So, in such situations, certain changes to the loop structure has to be made and we are going to study that. So, let us first look at cascade control, so we are first going to look at the at a at a motivation for cascade control.

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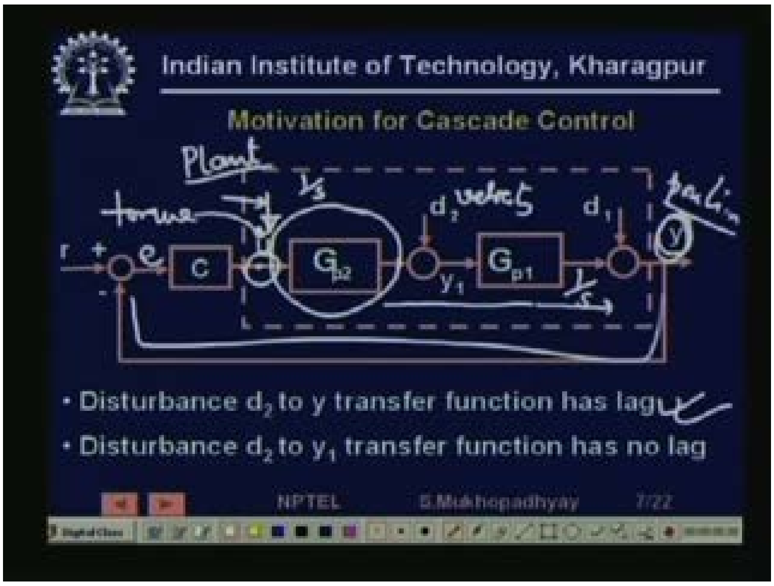

So, here we have a, imagine a process right, so here we have a process. So, this is our plant. We are just imagining that the plant is actually consisting of 2 different subsystems. Presently, we see examples, we will, we will see examples very shortly. There are, there are, there are many cases for example, cooling of reactors is a, is a very typical case where the relationship between the input, you know typically reactors are cool using, coolant liquids which flow through jackets of the reactor. So, the reactor has some space in its valve and you circulate coolant through that space, so that you can cool the temperature of the reactor. This happens for exothermic reactor where the reaction itself produces heat.

So, the input is the steam flow rate, and the output is the, is the temperature of the reactor which you want to control. So, between, so how does this steam flow rate translate into a temperature? So, there are various stages for example, first if you put, not steam flow rate coolant and flow rate. So, first the coolant flow rate will establish a temperature in the jacket then because there will be temperature difference between the jacket and the reactor interior. So, there will be heat transfer and heat will come from the reactor to the jacket and therefore, the temperature will if will fall. So, there are basically 2 different mechanisms, 1 is from flow to establishment of temperature in the jacket, and from jacket to affecting the, that is from the jacket between the jacket and the reactor heat transfer mechanism. So, they are, so such things happen and you have for example, in a motor, in motor suppose you want to control a position. So, you give, what you give, you give, you change the electrical voltage at the terminal of the motor.

So, the voltage suppose, it is a DC motor, so basically you change the armature current, if you change the armature current then what you change is torque. So, basically the input that you are giving is torque. Now, and the, so here you have a torque, and here you have position suppose, a position control application. So, between and, so from torque is directly position to acceleration, just divide by momentum inertia you will get acceleration, so that is constant. But between acceleration and velocity there is 1 integration.

So, this could be integration 1 by S and here you have velocity. Again between velocity and position, you have another integration. So, this is another 1 by S, and you get and you get position. So, you see that the between input torque and output position, you have 2 difference subsystems in this case in the case of motor it is an integral.

So, this is a very typical situation. Now, in this situation, there can be you know, there can be disturbances everywhere for example, there can be load disturbances. So, and where does the load disturbance come? The load disturbance can come in, come in various places, it can, in this case, in this case of the motor it can come, it can come at the at the, at the input itself, because total electromagnetic torque minus float torque will give you the net torque.

So, if a load disturbance comes here, this must travels through this whole process and then it will affect the output and then it will be feedback and then there will be error. So, takes lot for delay, this is the reason why, so what happens is that, if you have so much of phase lag then what is and sometimes what can happen is that you see the stability margins are lower, so disturbance d 2 to y transfer function has lag and the. But it, so happens that this intermediate variable y 1 is immediately affected by d 2 in this case. Or even if the disturbance acting here, the transfer function between the disturbance here and the measurement and the, and the, and the variable y 1 has much less lag than the transfer function than the lag between this disturbance and this output.

So, now this is, this is an observation. So, here is an intermediate variable which we are not using may be, it could be measured may be, could be measured very simply. For example, in the case of the cooling reactor suppose, we could measure the jacket temperature, why not? That involves simply putting a, putting a temperature sensor. Similarly, most position control loops have speed feedback.

So, putting so measuring the sharp speed requires simply putting some kind of tachometer or speed encoder they are not very difficult to measure. The advantage is that now we have another measurement. So, you see that, so the question is that, if we could measure some intermediate variable y 1 then feeding it back does it give any advantage?

Actually, it gives plenty of advantage, you can give significant improvement in response to disturbance also improvement in transient response to step, to set point changes because the controller gain can be significantly enhanced. So, that is achieved by cascade control so how? Let us see that.

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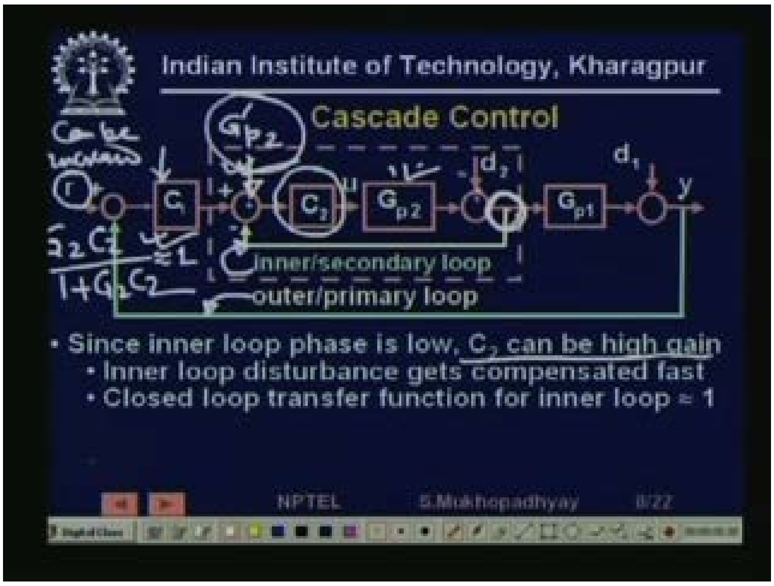

So, we look at cascade control, so now what to, what are we doing? So, let us look at this. First of all, suppose we have decided that there is some intermediate variable, there is some intermediate variable y 1, which I am going to measure, and I am going to feed it back. So, you see that now the y feedback loop, this is the outer or primary loop which is a standard loop. In addition to that, inside the loop we have put another loop, which we call the inner or the secondary loop. Now, what is the, what is the function on the secondary loop, there are several interesting function.

Firstly, if you look at it from the primary loop point of view, so now, previously it was in the loop there was C 1, GP 2, and GP 1. Now, we, you have in place of GP 2, you have GP dashed 2 which is the closed loop transfer function of this inner loop. Previously you had only this GP 2. So, what is the difference between G dash P 2 and GP 2. Firstly, G dash P 2 has much less phase, much less phase lag that is, that is always true because of the fact that, closed loop systems have much less phase lag than open loop systems.

So, this has much less phase lag, which means that the, if you look at it from an outer loop point of view, this C 1, G dashed P 2, GP 1 combination, the overall phase lag has now reduced. So, if it is reduced, then the value of C 1, which can be increased the, this value of that, the gains of the controller can be increased, right. So, C 2 can right now, which means that overall transient response will have, will increase because now r, any set point change in r will be acted upon much faster by C 1 because it is, it is higher gains. So, that is very good advantage.

So, which means that, we must design this loop such that, this G dash P 2 has significantly lower phase. So, when can we do that? So, when does a closed loop system have low phase? When C 2 is high you see, closed loop transfer function is what. It is G 2 C 2, G 2 C 2 by 1 plus G 2 C 2, is the closed loop transfer function of the inner loop. So, if C 2 is can be made high then this becomes almost equal to 1. So, the phase loop, phase lag reduces to 0.

So, we should be able to use a high C 2, but can we use a high C 2? Yes, we can because as far as this loop is concerned this loop phase lag is only GP 2. Previously, the outer loop we are, we are having problem because the phase lags of GP 2 and GP 1 were actually adding up. But now in the inner loop, we have only the phase lag of GP 2 to take care of for example, as for as our motor control is concerned, GP 2 has maximum has around 90 degree phase lag.

So, if something has a 90 degree phase lag, it is first order process then we can theoretically speaking, we can use very high gains of C 2. And if we use very high gains of C 2 then this closed loop transfer function will be almost equal to 1. So, it is indeed possible to have, for C 2 to have, to have. So, since inner loop phase is low, much lower it may be, it is often possible that C 2 can be very high gain and then the outer loop phase is also reduced significantly and therefore, C 1 can be of high gain, so that is, that is the point.

Second thing is that, previously we were thinking that, this response of d 2 travels to y much slower, so taking care of d 2 takes time. Now, what happens is that, the effect of d

2 or even the effect of let us say, if we have some disturbance here like in the case of motor, the time it takes from here to here is much lower than that from here to here. Similarly, from here to here is from d 2 to here is immediate, and since this loop has very high gain, so therefore, this the effect of disturbance either here or here, gets very quickly corrected in the inner loop itself and it does not travel to the outer loop.

So, we have been able to contain the disturbance within the inner loop and we are not, we are, we are, we are able to stop it from spilling over to the outer loop. So, effects of inner loop disturbances are neutralized very fast in the inner loop. These are very significant advantages, and as we said here, so the outer loop phase is low, so C 1 can be high gain and better transient response for the overall system.

So, you see that, you have several advantages, you have better stability margins, you have, you can contain inner loop disturbances within the inner loop and they will not affect the output, they will get corrected in the inner loop. And thirdly speaking your overall transient response will improve because you can use higher gains in the outer loop right. And all these you are getting at the expense of an additional measurement number 1, and number 2 a slightly more complicated control law. So, these are often very low prices to pay for a better control of the process therefore, they are very widely used.

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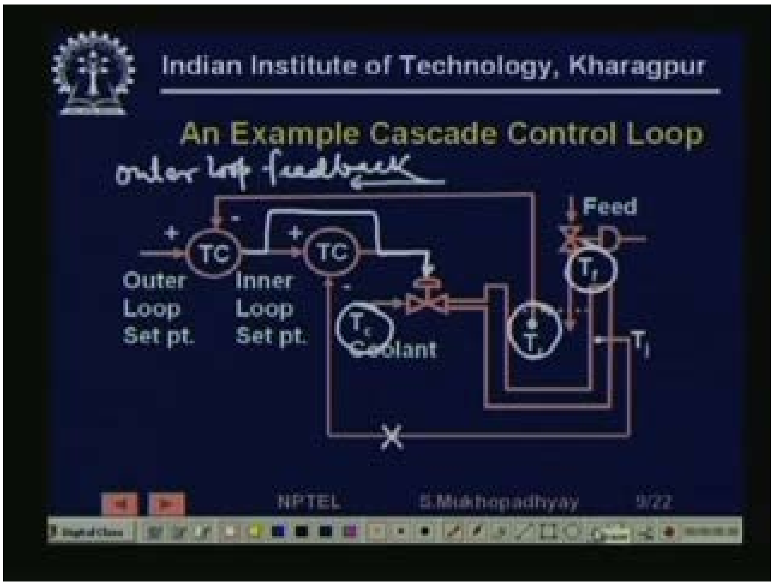

We will look at the example, practical example, so what we are having here is that we are having, we want to control this is a, this is a kind of exothermic reactor, so we want control the temperature of this reactor, this is what we want to control. So, obviously, we are giving a feedback here, this is the outer loop. So, this is the, this is the outer loop feedback or primary loop feedback. Initially let us assume that, this is not there, so you see we could, we could, we could actually do with this. And actually use in our single loop control, we could remove these parts, this feedback is not there we could use that, and we can have a normal control loop.

So, what are the disturbances? The disturbances are, there could be several disturbances for example, there could be a feed temperature T f, which will cause temperature of T r to temperature of the reactor to change. This is the disturbance, which will get quickly affect T r. There could this, there could also be a disturbance in the coolant temperature, the coolant itself we are controlling the flow rate of the coolant. But the temperature with the coolant is not known, probably that is not in our hand.

So, the temperature of the coolant itself could act as a disturbance and this will take a lot of time to travel to T r because first of all this has to change, this temperature coolant will have to change the temperature of the whole jacket, that itself is a heat transfer and mixing process. Once that jacket temperature is changed then through another heat transfer process, the reactor temperature will change and then only feedback will go and then only the flow rate will get affected. So, now instead of that, if we use instead of that, if we use, so now, we are going to use the, use of cascade control loop. So, we have made another measurement, one moment please, I want to take care of the eraser, I got it.

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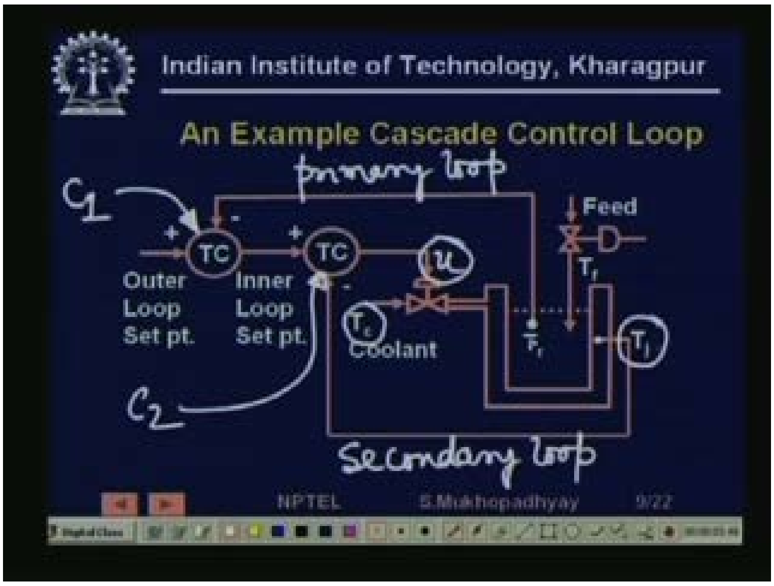

So, what we have is instead of that we have a, we have a, we have a cascade control loop where we are now incorporating this traditional measurement called the jacket temperature, and we are feeding it back right. So, this is our, this is my secondary loop or inner loop and this is my primary loop. So, now what I am doing is, I am giving, so the, so the primary loop feedback is there, there is error, it is coming to the first controller. So, this is my C 1, and this is another temperature controller which control the jacket temperature that is my C 2 and finally, this is U. Now, what happens is that, if there is a coolant temperature change then that will affect T j much faster and it will get feedback. And therefore, the flow rate will automatically get changed very quickly, even before there it can start affecting the reactor temperature.

So, this is the, so here is a, here in fact, I mean, I mean such temperature control loops in chemical processes are almost without exception, they are, they are cascaded. Just like in motor position control loops, you always have a kind of a velocity feedback, it is very rare when you do not have cascade control.

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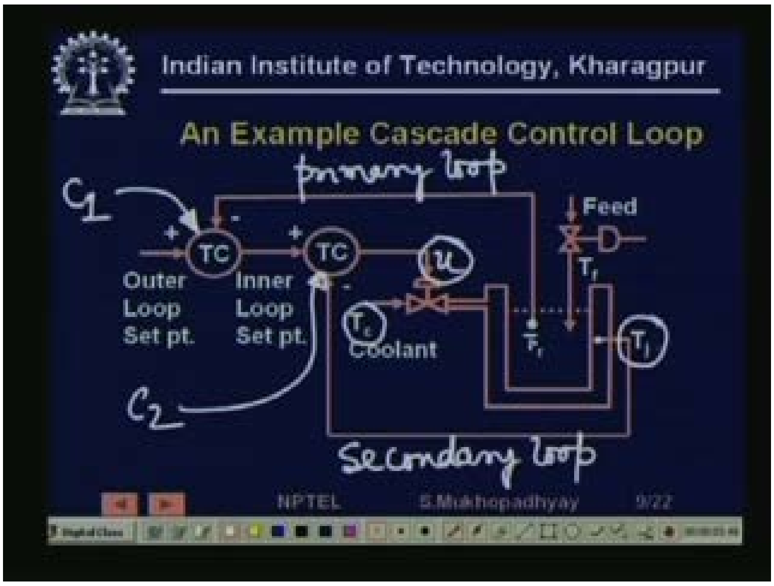

So, we come to the, so this is a, this is, this is the, this is I am trying to model that situation basically, so it shows how things are, so delta F c, which is a change in the flow of the coolant first. So, that, excuse me, so this just shows that, this delta FC affects this delta T j through the jacket. Similarly, this delta T c, in fact, actually these affects are this flow and temperature, these affects actually multiplicative, so I have considered their increment, so that they become additive.

So, this shows that, this delta T c also affects delta T j and then the once delta T j established then between delta T j and delta T r, there is the rector heat transfer dynamics. And similarly the feed temperature change also affects the reacted dynamic. So, this is one disturbance d 1, this is the other disturbance d 2, and we are giving a feedback around this jacket and again another feedback around the reactor. So, basically this is explaining that thing.

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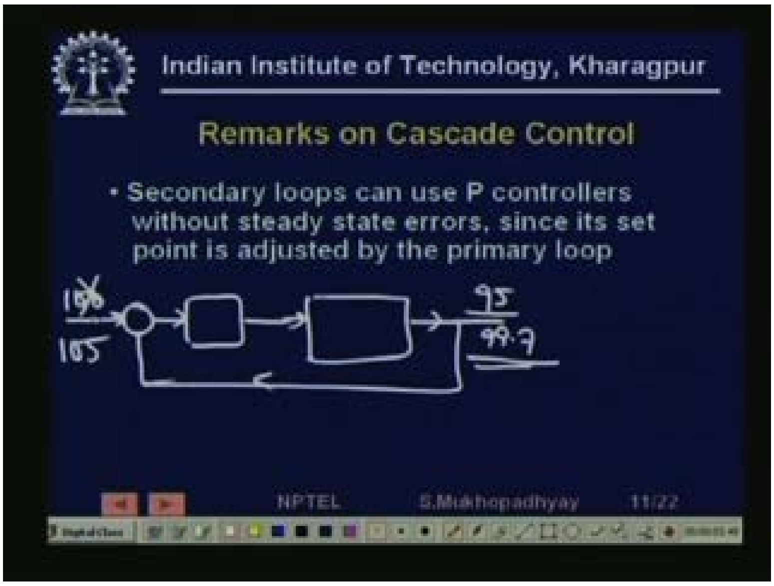

Then, so this have you understood cascade control which see some remarks that important remarks is that firstly, secondary loops can use P controllers, why? We know that, we know that P controllers can result in steady state errors.

So, but it, so happens that for example, firstly, the secondary loop output is a not real output. So, even if there is a, there is a steady state error, we are not going to, we are not interested as I mean for say, to control that output. Secondly, we have, we have already seen that, if there is a, if there is a steady state error what is the, what is the way of one way of going around? It is by increasing the set point.

So, suppose in a control loop if you give 100, there is some steady state error because there is some proportional controller, and here you get say 95, you know that you get a steady state error in this loop. Then one way of getting around this problem is that, you rather than giving 100 you give 105, if you give 105 you will, you will probably get something very close 99.7 or 8 or something you will get. So, the, so the technique is that you adjust the set point. Now, for the inner loop who adjust the set point? The set point is adjusted by the outer loop.

So, interestingly the, if there is a steady state error then what will happen is that the outer loop will slowly adjust the set point to the inner loop and this steady state error will vanish, so therefore, you can use P controllers. The second typically flow control loops are often secondary loops, and there is also a significant advantage because this flow control devices called valves are sometimes very significantly non-linear. So, something which is non-linear means what, see all the time we are, we have various non-linear systems and we are looking at them, we are, we are trying to analyze them using linear control theory.

So, which means that, we are using you know, they are incremental characteristic that is we are taking local loops and then we are considering a local slopes in their characteristic and we are considering them as a gains. So, the valve incremental gain changes considerably depending on in which region of flow you are operating. So, now and remember that you have lag, so you want to keep the overall process gain lower. So, and this process gain keeps varying, because the valve gain keeps varying. So, what you I mean, how do you design a controller?

So, to design a controller, you will have to keep the, you will have to keep the, you have to make a conservative estimate of the controller gain. So, that even for the highest valve gain, it will not go unstable right. But what happens here is that since, the valve is in the inner loop, so the inner loop controller, imagine what is the job of closed loop control? See, the job of closed loop control is such that, even if there is a variation in the process gain, the closed loop transfer function is not affected.

So, the closed loops of the valve variations are actually taken care of in the inner loop, and in the outer loop you can design a, so the inner loop characteristic closed loop characteristic is varies much less, because of valve gain variations and you can, you are able to make a much better estimate of the controller gain. So, this is the advantage, this is another advantage of cascade control.

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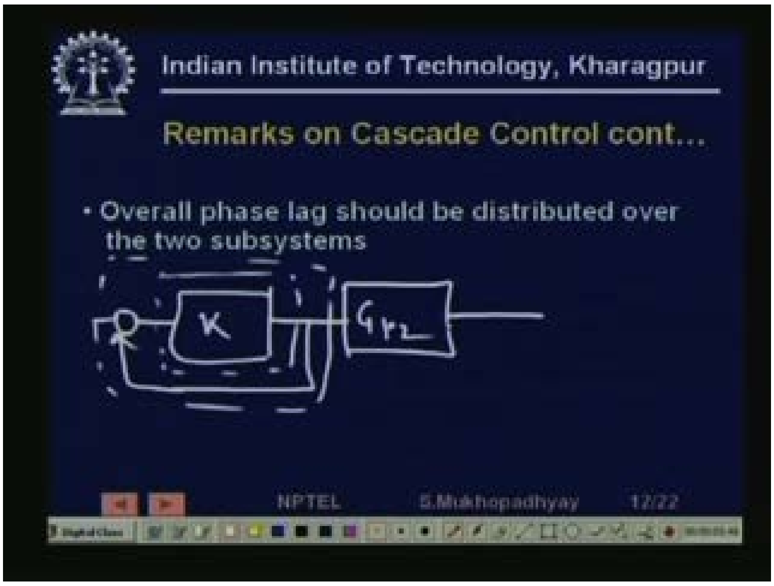

But for cascade control to be effective, we must remember that, this if overall phase lag must all, must be well distributed over this GP 1 and GP 2 because suppose that GP 1 is a constant K, there is no phase lag and all the phase lag is in GP 2. Then, what happens then what is the, what is the idea of giving a feedback here? See, then the feedback of the open loop plant, loop gain of the open loop plant and loop gain of the closed loop phase are same because both are constants. So, therefore, the problem of loop phase still remains, and the whole problem will come in the outer loop, so it is becoming like the old case.

Similarly, if you put, if you put similarly, if you put this one as K, if you put this one as K, and this one as GP 1, and put all the phase lag here then the problem will be to decide the inner loop. So, the inner loop controller will now have the same stability problems as the overall process. So, the in such situations, cascade control does not work well, or in other words this, so what do you do? So, you have to choose a variable, so the variable that we choose to feedback in cascade control should be very judiciously chosen. It should be chosen such that, it divides the plant into two sub processes of balanced phases right then the cascade control loop will actually work well.

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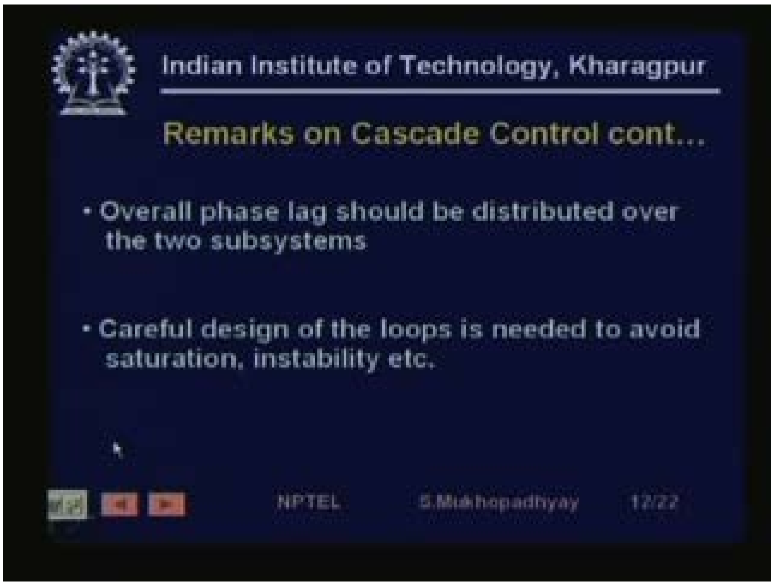

So, and well there are several other issues which we are not going to consider here, but there may be for example, there may be issues of saturation of actuators, there will be issues of you know frequency d tuning of the inner loop and the outer loop. That is, when the overall gain will peak at some frequency in the closed loop, in the in the inner loop and some other frequency in the outer loop, so such as they are, they are more complicated issues of design and we need not look at them at this stage.

So, this is cascade control, very common and give significant performance in improvements over very affordable cost in most cases and therefore, widely used. Now, we look at some other control structures namely, selective, override and spilt range control. So, first start with selective control.

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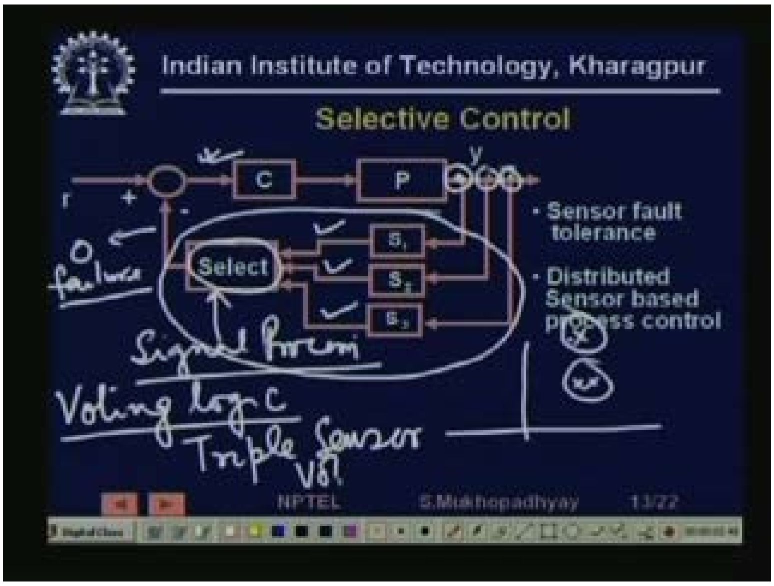

So, as we, as we said that, what we are doing here is that, we are , what are we doing, the loop is standard the only change comes here. So, what we have shown here is that, the same sensor the, actually we have shown that as if the same sensor values are being, the same process values are being said, but actually that is not so. This means that, the same process for example, room temperature are being sensed by three different sensors, which are three different locations.

So, therefore, although they are being tapped from here, so these signals are not identical, but they are, they are, they will be similar. And then here we have some I mean, selection or basically signal processing scheme. So, we can, so what signal, what signal processing scheme we will apply, depends on what we want to achieve. So, for example, if you want to achieve an overall temperature of this room, so then we should and some sort of an average then we should take the, take an average value.

This process should not select, but rather take average. If we want to know, if we want to ensure that in no corner of the room the temperature will be more than 25 degree centigrade then we should take the highest temperature of these three, and try to control that. So, temperature at every point of the room will be more than the set temperature or will be less than the set temperature.

So, in case of room cooling that is the case, so in that case, we can, we can choose the maximum value right. There are even other applications for example, sometimes you know, there are very catastrophic effects can occur in, occur in feedback control loops, if one of the sensor is feed. So, you can imagine that, if there was a single sensor feedback and if the sensor failed, some wire torn or something got burnt out, or some electronic circuit problem.

Immediately suppose, that this signal goes to 0 due to failure then what will happen? This will, the controller will have no way of knowing it, and it will simply see an error and therefore, it will try to drive the process unnecessarily, but that driving will not, will not improve this valve because it is due to a failure, it is not sensing anymore. So, in such cases, industrial accidents may result, equipment may get damaged.

So, what people often do is that they take S 1 S 2, they will put three sensors suppose, to sense same variable and then they will put a voting logic that is, if all three of the sensors are working, are normal they have not failed then their readings are going to be very close. If any one of the sensor readings goes significantly away. So, two of the sensor readings are here, while the third one is here means, that the third one could be faulty.

So, in which case the third ones value will not be used in control, so it will be cut out and only the average of the these two will be used. This is called triple sensor voting, triple sensor voting, and often applied in various you know critical control loops. So, by doing this, you can achieve certain degree of sensor fault tolerance. So, in such situations you can use sensor selective control. There are, there are even other situations where basically, where you can do medium filtering that is you can select outliers, when if suddenly one sensor gets big piece of noise then if you choose always the middle value, then you can reject noise better, so you can, it can also use for doing various kinds of filtering. So, selection of feedback for either minimal maximum values, or mean values, or median or mode values, so depending on various applications, you could choose. This is selective control. Very common sense approach, but can sometimes give you significant protection from things like failures. Coming to override control.

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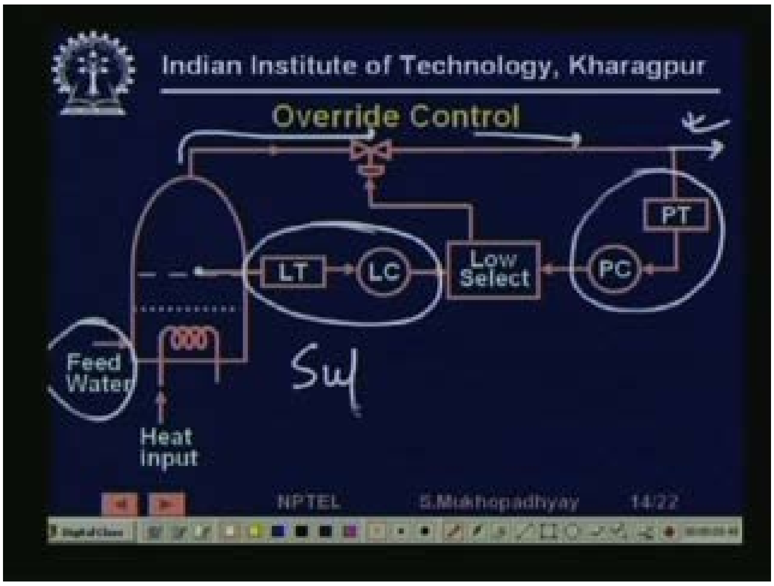

In override control, what we are, we are, I say, I mean the same system could be operated based on two, based on two different you know, modes or philosophies. So, they are, so basically it is something like an if and else logic that, if as long as this is happening operate the system in this way, but if that happens operate it that way.

So, essentially this control loop is a sort of a supervisory structure, which switches between in this case, it will, it will switch between two sensors to drive the same actuator and which sensor it will be used depend on, which mode it wants to operate the system in. So, typical example as of common sensor example, here you have something like boiler, where you, we are getting feed water and you are having heat input, so you are producing let us say steam.

So, what happens is that, you are, you are you are producing steam, you have water and, so there is a water level and steam is going out and being used for some purpose. May be for may be, it is a, it is the steam plant for the, for another, for the whole factory where several, where steam is required for several other purposes for heating of certain things. So, what you want is that, you want neither the, you do not want the, this level to fall to too low levels. So, if falls to very low levels then immediately the, it is the level loop which should get preference.

On the other hand, if this, if the, if this, if the pressure, the pressure of the steam should not beyond certain limit because then that may cause leaks, that may cause accidents. So, if the pressure goes up to a over a certain limit then the pressure control mechanism should take precedence. So, you are having two different control loops and which one will take precedence in a, in a given situation that depends on the state of two variables.
So, that happens, that is happening because it is, it is like a, it is like a protective scheme essentially because the controls will be actually, so you know coordinates because how much of steam will be finally, drawn here that is also not in, not in the within the purview of this controller. Similarly, how much of feed water that is going to be feed in and that is not also within the purview of this controller.

So, what happens is that, if this level is, if this level is falls too low then what will happen is that, the judicious strategy will be to close this valve, so that steam is not going out. So, that will, that will raise, that will, what will, what will cause is that the, that the level will rise, so we are, will not draw steam from here. And similarly if the pressure goes too high then also we should close the valve because otherwise it will, so the pressure will be, will be controlled.

So, in a depending on these two modes, so closing the valve means a lower input, opening valve means higher input. So, whichever one needs to close the valve, that one will be used. So, this is, so one, in one situation one control strategy will override over the other, so that is why it is called an override control. So, very simple and essentially these are, this is a supervisory control I should say because you are, because this is more like you know, supervising the, supervising the process, and changing the, changing the configuration of the process. So, coming back to the next one, the last one, that is spilt range control.

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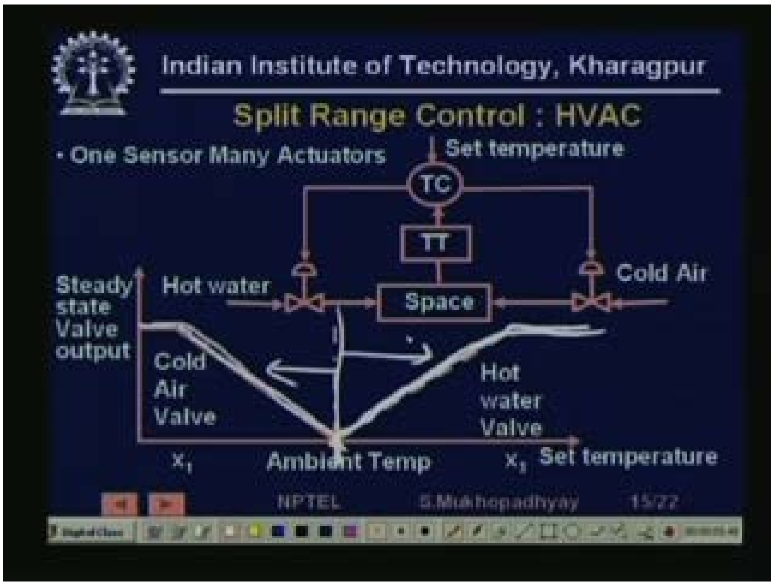

The first example is of heating ventilation air conditioning. So, we have the standard, this is the space that we want to control. There is a temperature transmitter and there is a temperature controller, and we also have a set temperature which we generally set using a dial or sometimes using remotes nowadays.

And the temperature is affected either by hot water you know, if you in countries abroad for heating rooms they have, they have heat exchangers installed in rooms, various corners of the room and through which they send a hot water. Or you can have cold air as in, as in air conditioning and depending on whether you want to heat the room or cool the room, that is depending on the set temperature, which if, whether it is greater than ambient or less than ambient. You have to either activate this actuator or activate this actuator.

So, this is, so on some range of error, so some range of the set temperature. So, when the set temperature is greater than the ambient temperature, in that range you use this actuator, there is a hot water actuator. And when the set temperature is below the ambient temperature, in that range you use the cold air actuator. So, the, this is why it is called as split range control because the range is split into two different control modes.
So, you see that, typically speaking this is the ambient temperature point, this is the ambient temperature point, and if the set temperature is above it then as the error

increases, the hot water valve gradually gets opened. So, the, so the control input, that is the overall control input to the, to the process we changes its temperature. In this temperature range, it will gradually rise and then finally, will become stable. Similarly, when the set temperature is below ambient temperature, the cold water valve characteristic will be followed and that will rise.

So, the overall control input characteristic is like this, over the two ranges and in this range, in this range you operate the cold water valve, and in this range you operate the hot water valve. So, this is the standard HVSC control of spaces.

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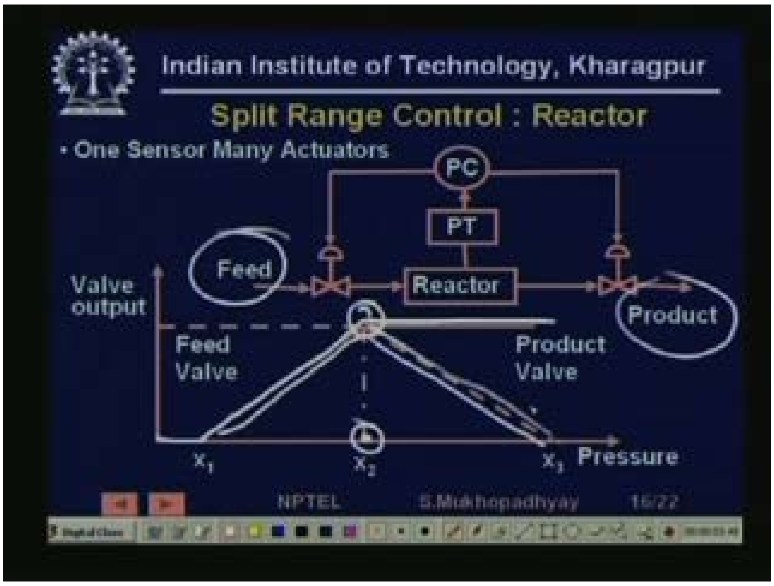

Here is another example, which is for a reactor which is very similar. So, here what you do is, the reactor, you want to control the pressure in the reactor. So, the pressure in the reactor could be either caused by controlling the feed rate or by controlling the product out flow rate, right.

So, in the initial part of pressure, you control the, you gradually open the, you gradually open the product valve, so you see this is the product valve characteristic. After sometime the product valve is fully open, so it cannot measure the pressure is increasing, so you gradually open the product valve. Now, if at this, after this point, the pressure cannot be affected by the product valve because the product valve is fully closed. So, in that situation, you start closing the feed valve. So, the feed valve is operated here, so actually your true operating characteristic is this time you open product valve, and this time you close feed valve. So, this is split range control where you have only one sensor, but many actuators. So, we this is, we have come to the end of the lecture and just want to have some concluding remarks.

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Firstly, on this kind of these multi sensor, multi actuator control which is processor often need supervisory control logic. So, you see that, apart from your basic control logic which is there in the, either in the hot water valve or in the cold water valve. There will be the an automatic controller, but even we will, we above that, you need some logic based on again process variables which we ensure which one will be working, which sensor will be active, which actuator will be active, which controller will be active.

So, this is called supervisory control logic and they of for process operations you often need that. So, this is sometimes achieved by these control loops. So, you can switch among operational modes, and the supervisory control logic schedules sensors, actuators connects sometimes use this actuators, sometimes use that actuator. So, based on operating points and set points. And only one thing is that, when you are, you must ensure that, when you are switching from one mode to another too much, you know bumps, we have considered bump less transfers in the context of PID control. So, we should not have too much, too many bumps when you are transferring the from one mode to another because that sometimes is not good for actuators or plants. So, that brings us to the end of the process control module. From the next lesson, we will enter at different module of sequence control. So, what did we learn in this module?

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You know industrial just of I mean concluding remarks that, industrial processors have sometimes very complex dynamics, they have phase lag, they have nonlinearity, gains will change, but, so that creates complexity. But at the same time, the process dynamic is slow, so sometimes it is good in the sense that you know, fast processes are difficult to control. But at the same time sometimes you know, disturbances also travel slow and they are, they should be detected early, otherwise the large errors may perceive, may persist for unacceptably long times.

So, one has to take care of sensor and actuator nonlinearities the, one of the major actuator called flow valves have significant nonlinearities. Several sensors like you know temperature sensors, flow sensors, also have nonlinearities, so they should be taken into account. And typically in, I think around 90 percent of the cases, PID controllers are used, sometimes with various special configurations for anti wind up, for bump less transfer, etcetera.

As we have seen for special structure, for feeding back derivatives, but generally the controllers as PID, they are very extremely common. And PID controllers have to be tuned, you know controlled tuning can have significant impact on controllers and there are various for example, modern day, modern day controllers come with various quite sophisticated features of tuning software. So, tuning is very much required, and you also need sometimes some supervisory logic to you know, improve performance, prevent failures, carryout diagnostics, so all these are also necessary.

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Similarly, supervisory logic may also be used to treat interaction between multiple control loops. And finally, often for taking care, for getting results often various kinds of special control structures have to be used, but the good thing is that, with years of experience for most of the common industrial processes very well known solutions exists, so one will not worry too much. So, that is, that brings us to the end of the process control module.

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From the next lesson, we shall take up sequence control and coming to a lesson review, we have seen problems of single sensor control, cascade control, and multi sensor, multi actuator control in the form of selective override and split range.

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Points to ponder give, so you have, you mention what, for what kind of processes cascade control is likely to be effective. So, take some examples and examine how the, how the two subsystem should be thought that process controlling is effective, is effective.

Why higher stability margin leads to improve transient response? That is why, that try to explain, it is related to the basically related to the range of control and gains that you can have. And draw the block diagram of a cascade control loop for a practical industrial process. This is very important and one should be able to draw it.

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Similarly, block diagrams of selective control loops and override and split range control loops are useful exercises to be done. So, thank you very much. We meet next lesson again.

Thank you.

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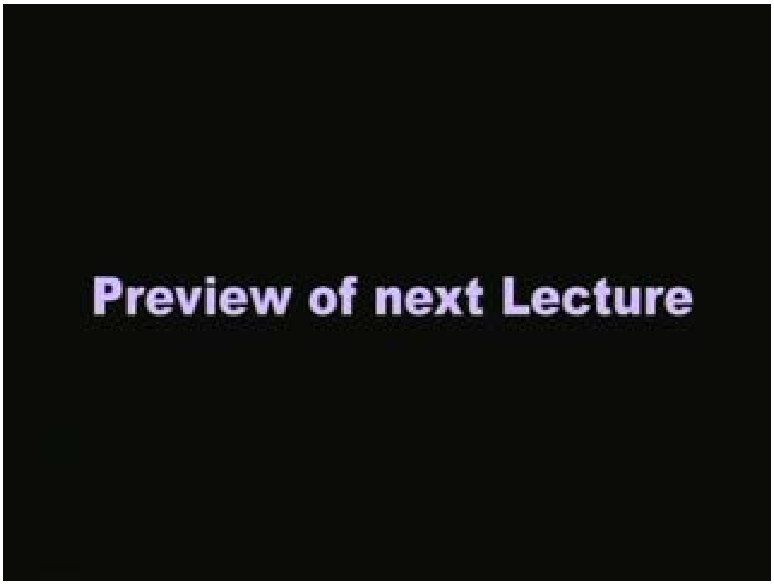

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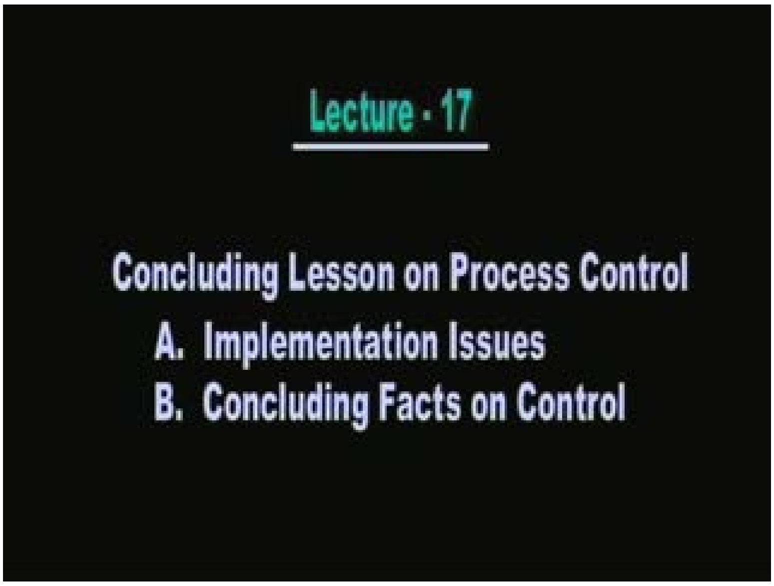

Welcome to lecture number 17, which is the concluding lesson on process control of this course on industrial automation. So, in the concluding lesson, we shall look at two things, we have seen the PID algorithm, we have seen several control structures. Today we are going to talk about the implementation issue. If you really want to make a control loop work for a process, there are several things that you have to do. If you go to buy a PID controller in the market, you find controllers with several features and you briefly need to understand them.

And secondly because since, we are closing our important module on process control, so we will take a bird’s eye view of control again, and mention certain facts, which we have to remember. Because while we study control in engineering, typically electrical engineering, we often focus on, we often focus very intently on one part of the control problem and tend to neglect the others. But they are very-very important parts for control and I would like to draw your attention to them. So, that is the purpose of this lecture.