INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

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Topic lecture – 12
P-I-D Control
(Contd.)

Good morning and welcome to lesson 12 of this course on PID control 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 term there are there are there are many most processes will also allow the operator to give input that is if we wants in 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 give manual input to the plant and you can slowly build it up and then at maybe for some purpose right oh and then but then finally you do not want to run the run the plant manually all the time so you want to switch over to the automatic control now during this switch over problems can occur as been see here.

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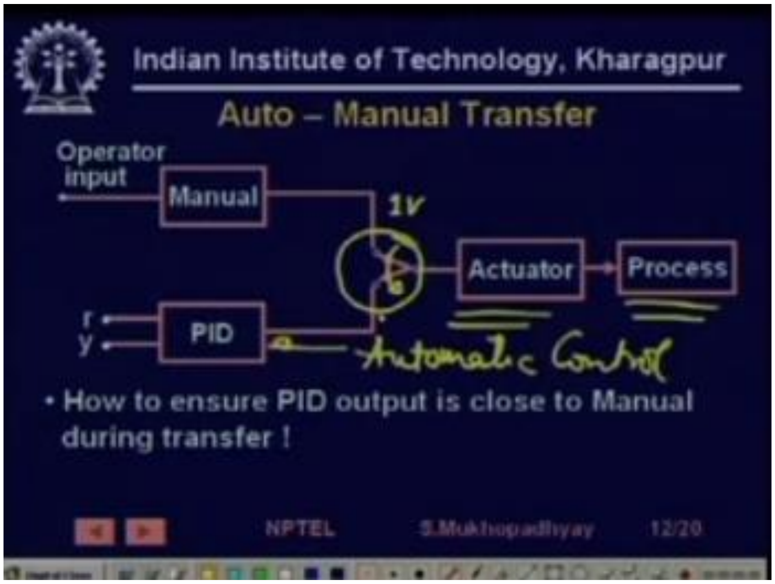

So here is the case where so you see that this is the process this is the actuator and the input to the actuator can come either from the automated PID controller so this is automatic control automatic controller and this is manual so the operator is actually giving some input here and here is a switch here is the switch which you can flick so that the actuator get its gets its input either from the PID controller or from the manual controller.

Now imagine now the main question is that when I am transferring how do I know for example suppose here the input was let us say 1 volt now how do I know that when I flick this switch to auto I shall I shall also here the input existing may be 10volt so now what will happen that previously the actuator was in was in 1volt was getting an input of 1 volt now from 1 volt suddenly a 10 volt output will suddenly a 10 volt will go to the actuator.

So the actuator if it is a motor or if it is a valve will it might get a shock similarly the process also will get a very will tend to get very high inputs so this shock that is we normally try to operate the processor so that we if we want to increase the input we ramp it up gradually here on give an input 1 volt now 10 volt then again minus 2 volts so such inputs are sometimes detrimental to the equipment either in the process or to the to the actuator equipment. So the question is question is how to ensure.

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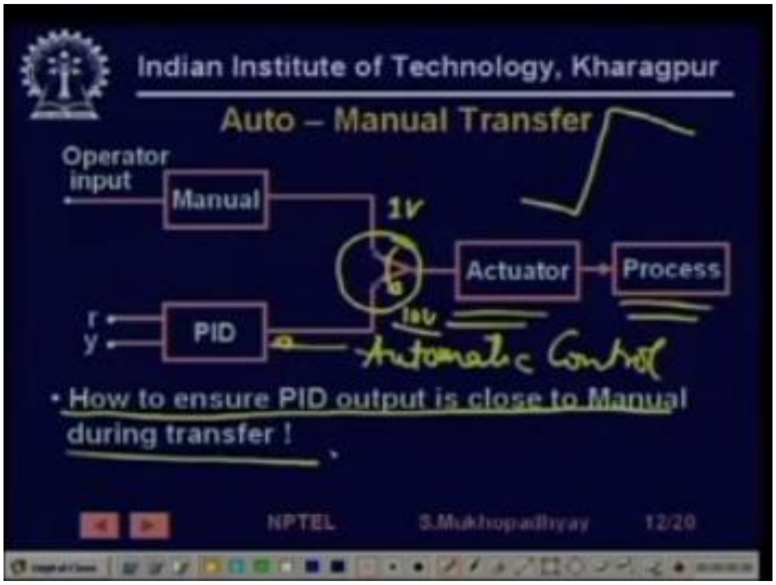

That the PID output is close to the manual during transfer in fact it often it is not because of the fact that the PID control remembers that its output is not going to the actuator.

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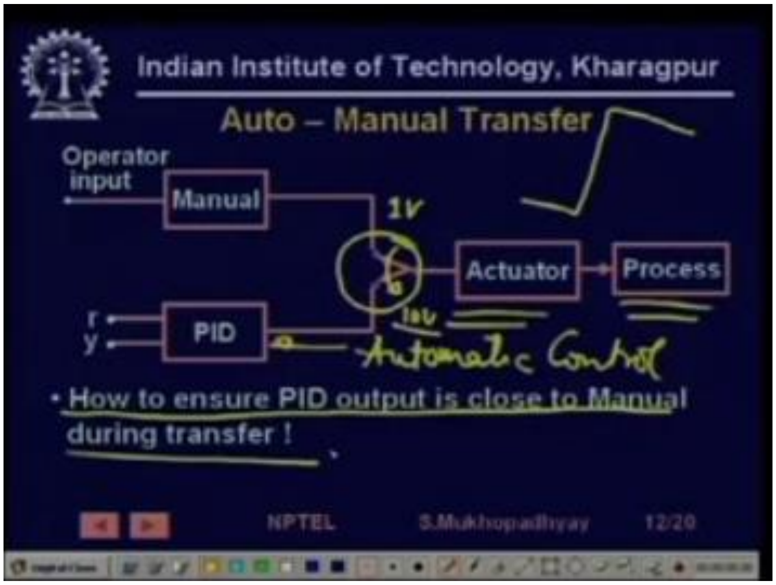

But it is all the time getting both the set point and the measurement so it is all the time computing the error computing its integral everything it is doing so it is quite likely that the PID control output is actually saturated during the time that you are manipulating the process with manual control it is quite possible that the PID output has got saturated it is start either at its negative maximum or its positive maximum.

So now if you if you suddenly flick the switch over you are likely to give the plant a shock and we want to avoid that.

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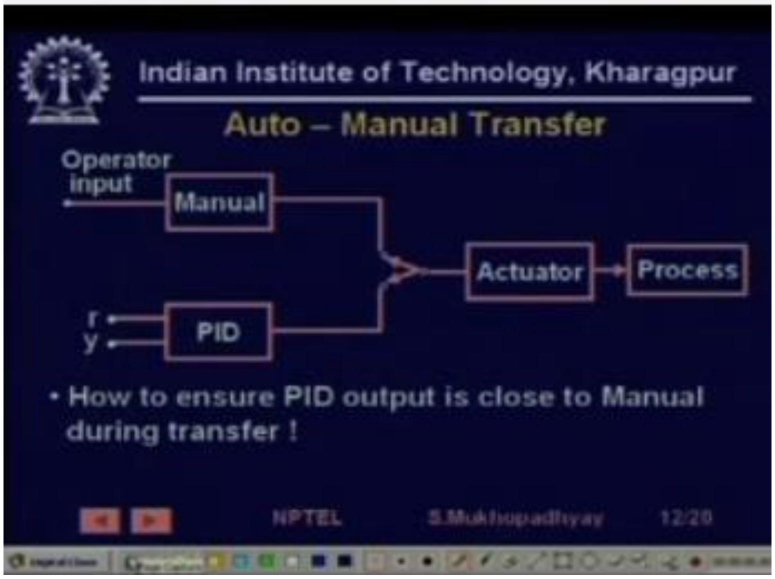

So how do you avoid that so for avoiding that sorry for avoiding that we rather than giving the input you we would like to give the input ΔU.

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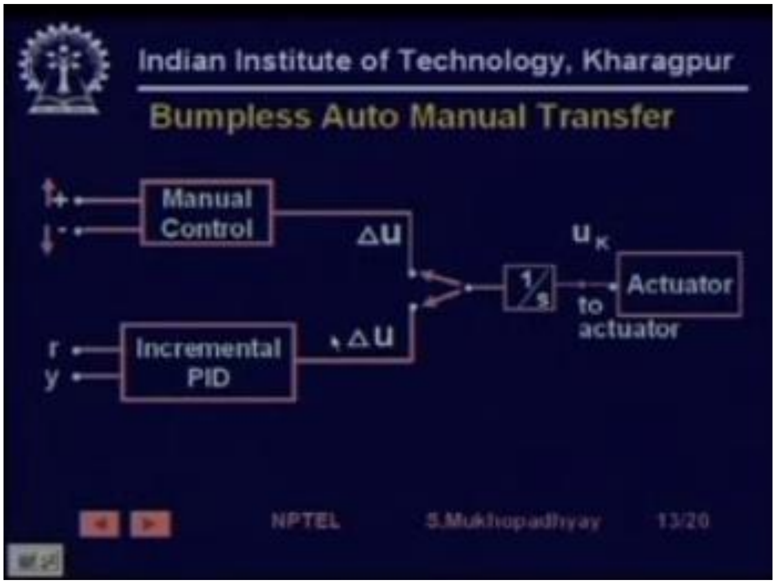

So you see that this is a clever scheme which avoids that process so you suppose you are in manual control so you are every time you are actually giving ΔU so you are maybe there is a plus minus reach and you are flicking the switch to plus so the input is going up every time you are giving positive ΔU if the flicking the switch to minus you are giving the negative ΔU.

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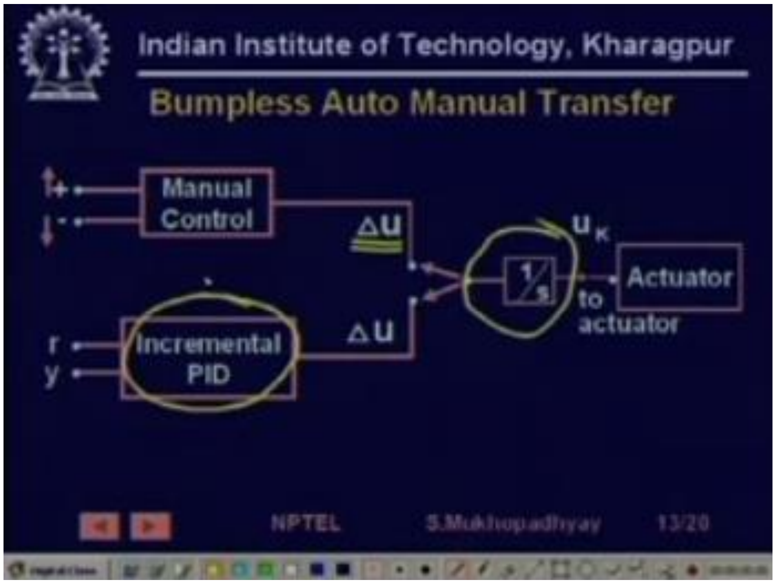

And this ΔU is getting integrated here by some device okay. Maybe in the actuator now and the PID controller is also not does not give you U but does give you incremental input ΔU every time it computes ΔU how it confuse ΔU, we will see very soon but suppose the PID control is implemented in a form which is known as the incremental PID form and it gives you ΔU right so now.

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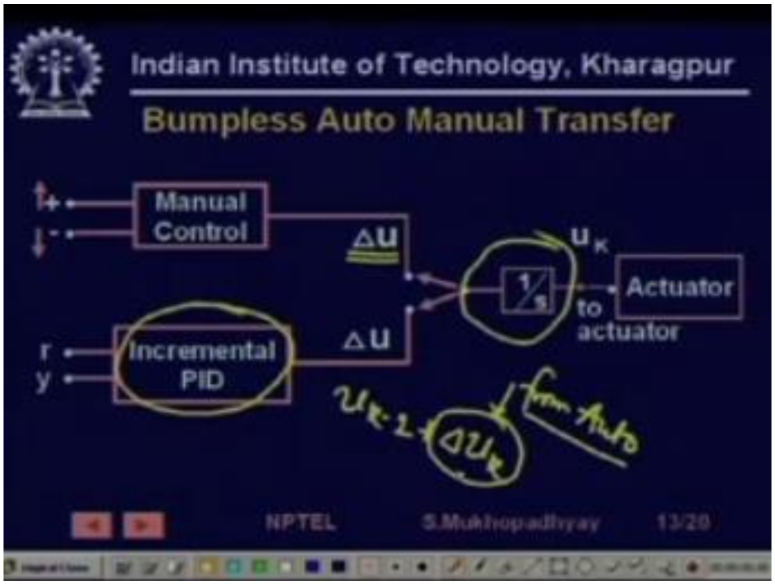

Now what is going to happen now suppose up to U_K - 1 U are in manual now suddenly in U_K just between U_K - 1^3 key between the time instants k -1 to K you have flicked the switch to auto so what will happen is that now a U_K - 1 + ΔU_K will turn will be added to the actuator and this is will come from auto this will come from the auto moor. But you see that this is actually a delta term so it is an increment so it cannot be very large. So the process will that will get the old manual input plus a little change.

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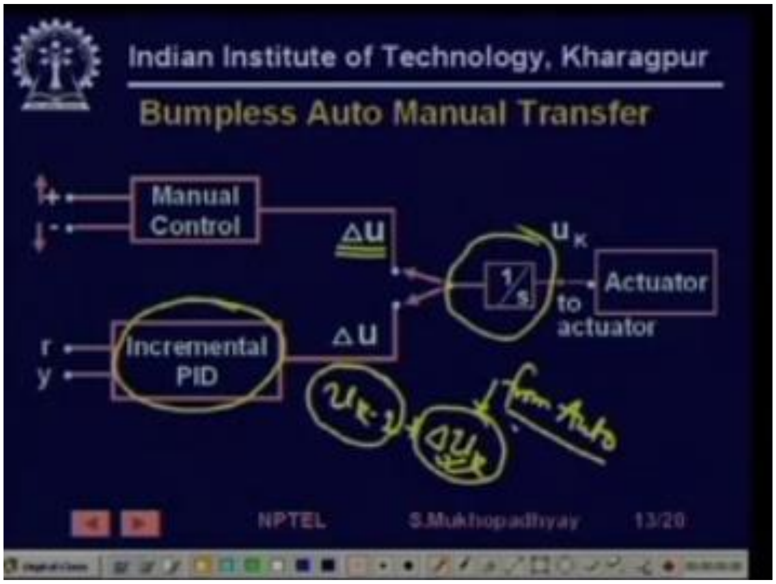

Which is due to auto so it will not get a shock so gradually these ΔU_K will build up and will slowly take the process from one input to another input so the transfer from auto to manual mode is going to be bumped less that is the terminology which is used okay so these are some problems which you need to convert a care of when you are trying to implement especially when you are trying to implement integral terms.

Now let us come to the derivative term so let us look at the first problem with derivatives that is that that derivatives.

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I am sorry that derivatives typically tend to blow up high frequency noise and where does high frequency noise come from high frequency noise comes from sensors amongst one things for example typically let us consider.

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Some you know a flow sensor flow sensor flow is always turbulent so you know the fluid actually flows in random facials whenever you have a flow beyond a certain velocity flow is turbulent so whatever sensor you now the turbulent induces frequencies which are much higher than the average volumetric flow rate so while the average volumetric flow rate.

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May be varying like this the signal that you will get from the sensor main use very high frequency components so the signal these signals are actually due to due to the turbulence so this is this gives a noise right now the point is that if you take this signal and if you suppose if you consider the case that consider the case that.

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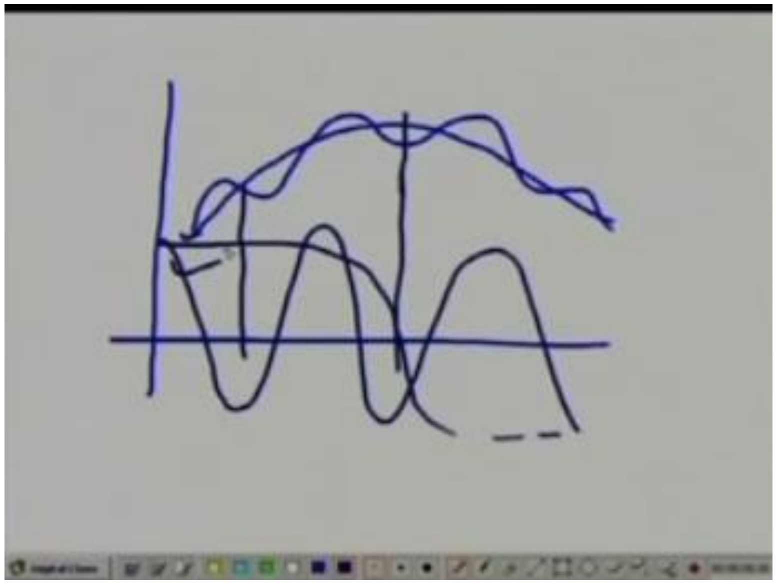

You have a this point needs to be understood suppose you have a signal which goes like this and you on this you have a noise I am drawing actually noise will be much more higher frequency now if you take derivative of this signal what will happen the derivative of the derivative of the low frequency original signal will remain positive up to this point will slowly fall and then will become negative here, the derivative around this is going to be positive then we will fall to zero then become negative.

What happens to the derivative of the other signal see the derivative of the other signal is going to start from positive bit within this short time it will reach a negative maximum and then it will again so it will be it will be widely vary so you see that while these signals are more or less close to each other there derivative terms are completely different so if you calculate a derivative exact pure derivative then.

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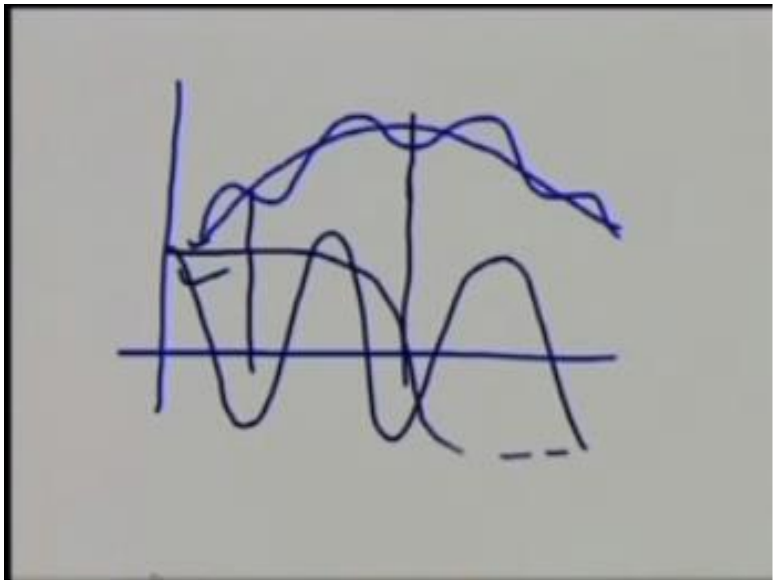

Even a small amount of high frequency noise is going to give you a lot of difference in the control input so therefore you need to use a derivative which will act like a derivatives up to a certain frequency but beyond a certain frequency its gain will not be will not blow up right so we need to limit the gain for high frequency noise.

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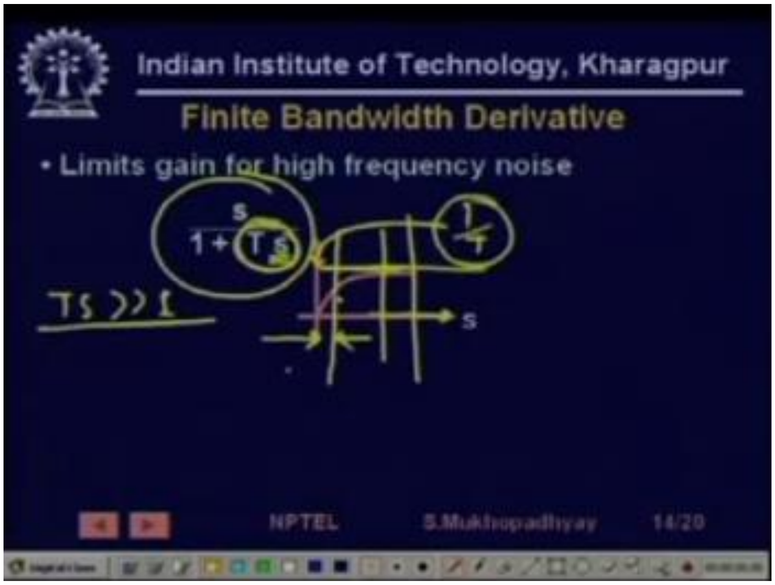

So to do that we simply the transfer function of a derivative is guess if we now consider the transfer function of the of the signal S/1 + T S imagine so this need to select the pen so that what is the gain of the S varies that is as the frequency varies S/1 + T S will at low frequencies this term is small compared to 1 so it is act so it acts like I do not know okay so it so it is acts like s in this part of the region.

While in this part of the region where S is large then it acts like this then it TS is TS is much greater than 1 and therefore this gain becomes equal to 1/ T so this level is 1 / T so you see that we have in the lower frequency region we are having a derivative but in the higher frequency region we are having a constant gain of 1/T so that is what so that is how you need to really need to realize your derivative.

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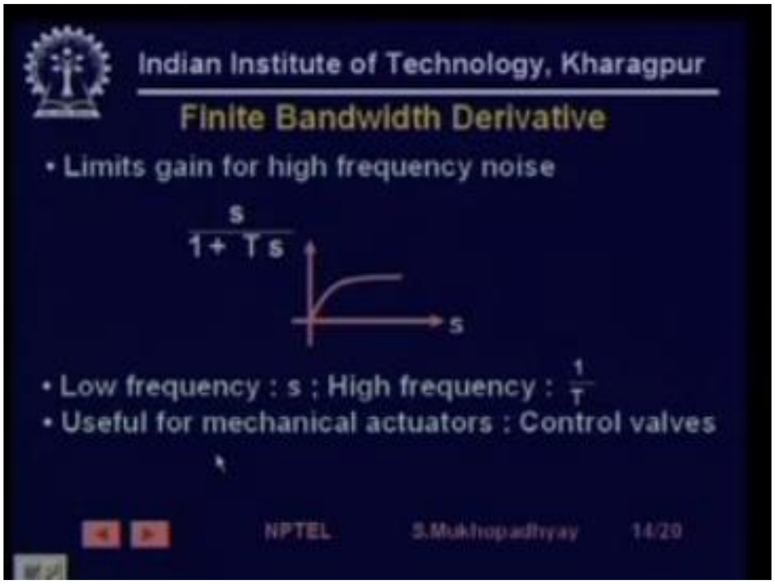

So the idea is that for low frequency it is S for high frequency it is 1 / T now this is also useful for some kinds of mechanical actuators as I said that if you give a very high frequency signal and then creates derivative then you are going to give it very high frequency positive and negative torques which is not good for a mechanical actuator like a control valve is it might damage the valve.

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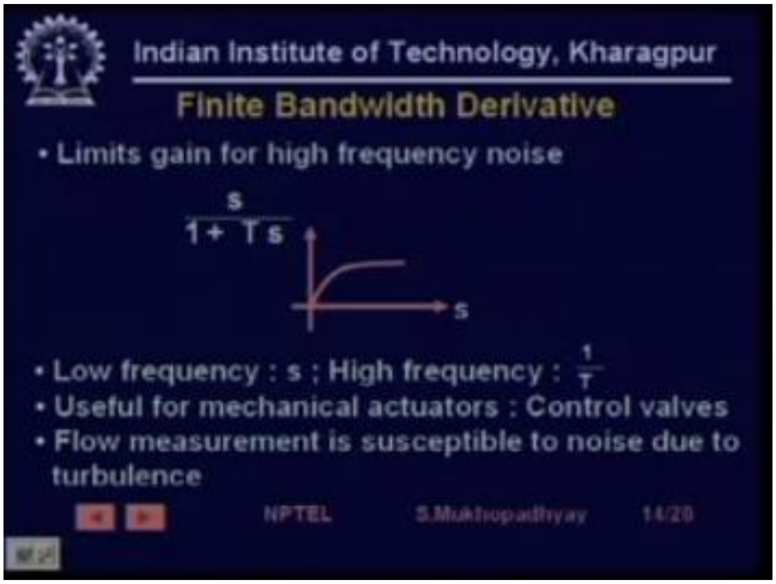

And as I have given an example that such noise may come from various kinds of measurements especially flow measurements which are very common in an industrial process.

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So now we come to the now there is there is a second problem associated with the derivative control structure and so far as we have seen we have implemented we have we have implemented the PID control like this that is the error term the error term goes here gets multiplied by K_P gets x K_I and gets multiplied by K_D also now as we have seen that we want to avoid giving shocks to the process right. So what happens?

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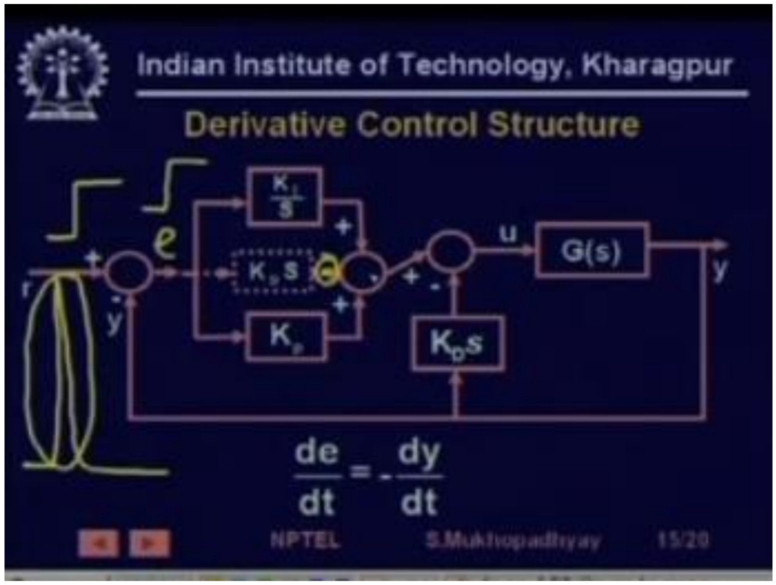

When you in many cases the set point is changed like a step so if you change the step what is going to happen to the error it is also going to change like a step so then what will happen to the derivative output here it is going to be at this time is going to raise very much and then it is going to fall to zero so you are going to give a shocking input to the plant if you put the derivative here so now the question is that how can I avoid such shocks. But if the if R is not changed.

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If when r is constant if there is if Y changes due to various other factors like disturbances mean I need to keep the derivative control I do not want to sacrifice derivative further level to have it except for the instance where R changes like a step so clever way of doing that.

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Is by realizing that when R is constant DE/R = E= R-Y so de / dt is equal to when r is constant it is minus of dy / dt so rather than having d / dt here I can also take Y here and then change the sign and implement the same block here so when R is not changing I am going to get the same effect as d / dt but when R is R goes as goes to a step there is there is absolutely no effect here so during that time it will simply slowly raise and corresponding effect you will get as Y rises you will again getting get the PDFI but this shock will not come.

So this is something which is to remembered when a derivative control is to be implemented now we come to the last topic that is the digital realizations because nowadays most controllers are actually implemented using micro processors so how do we right implement the PID equation in a in a microprocessor.

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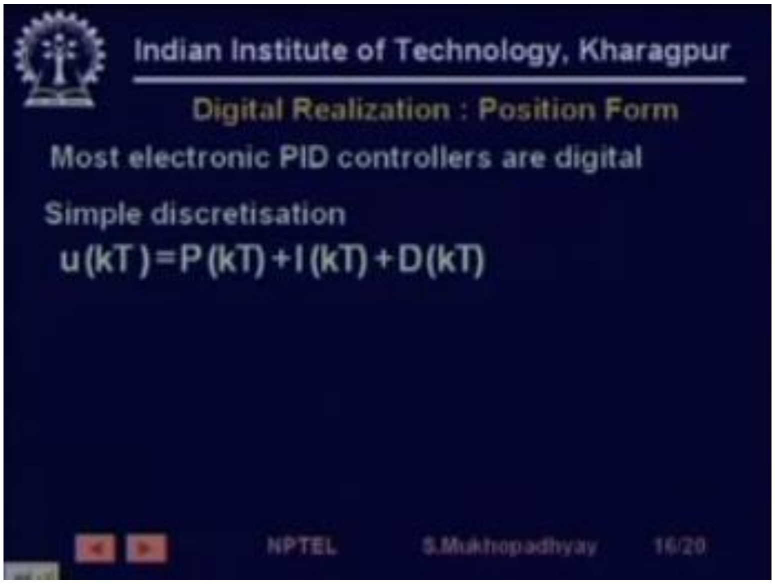

So that is very simple that is we do what we do what is known as a discretization in other words the integral we simply replaced by a sound so we say that in a detail controller we can compute inputs at certain instants of time so if T is that those instants of time are called sampling instance so at the KF sampling instant where the time value is equal to K of T k into t.

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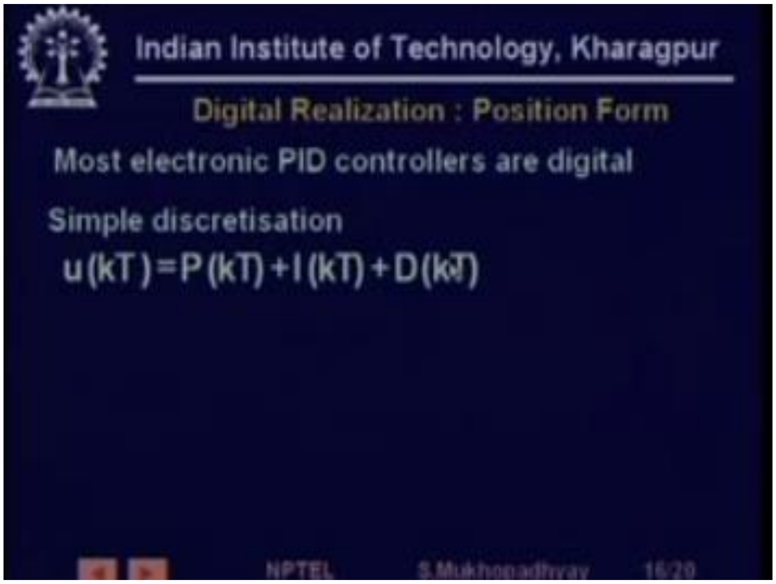

The input is again consists of three terms there is a proportional value at KT the integral value at KT and the derivative value at KT now the question is how do we compute this proportional integral and derivative terms so the proportional controller is.

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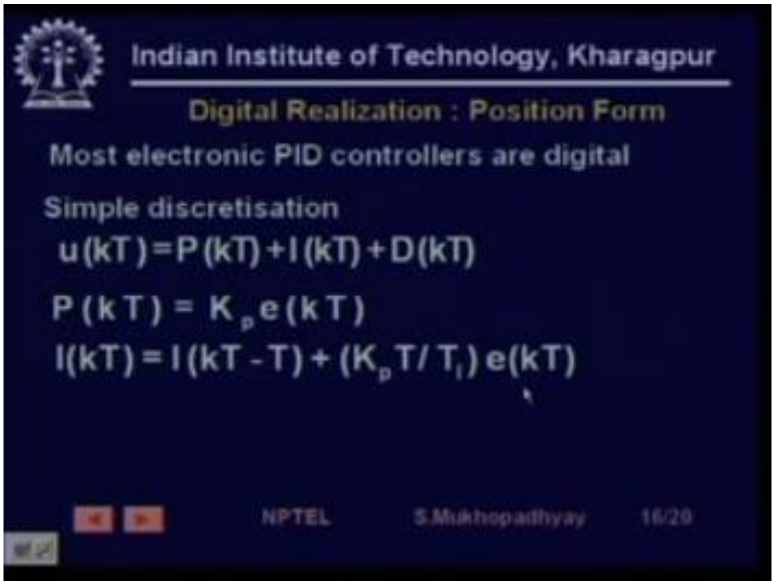

Simply P K T is equal to K_P x e k t so we just sample the equation the integral controller is the integral is actually realized by air what is known as a trapezoidal integration right not even not even trapezoidal this is this is you know what is called backward difference integration right so what we are doing is that we simply assume that since e k t is going to be constant over that time interval k - 1 to k. So the integral so we want to actually what okay.

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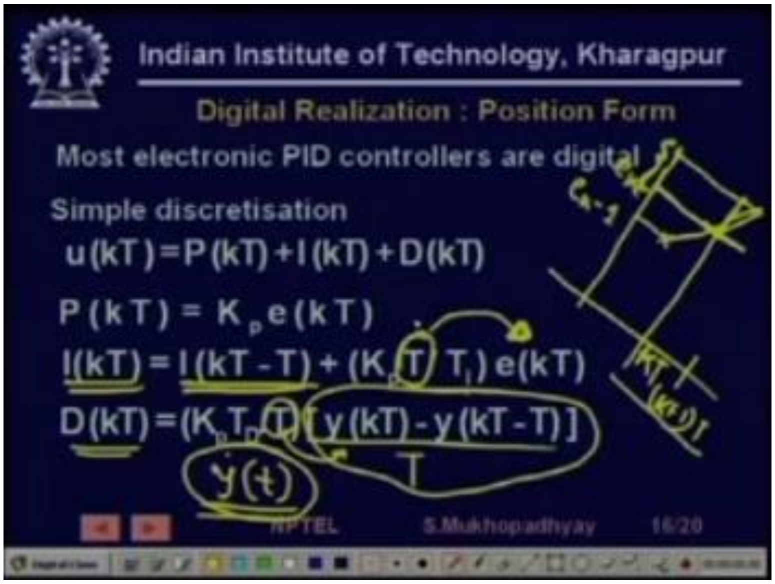

So what we are doing is that basically we are doing that simple thing that if this is e (K T) this is e K -1 and this is e K then after we get EK what is going to be the integral and this is e k + 1 that is the error is decreasing like this so between EK to EK - 1 that is between rather K T + K+1 T, I assume that this error is going to be maintained so the integral will raise simply as a rectangle so I write so I multiply this integral I realize by multiplying EKT/T that will be the integral and then I add it with my previous value of the integral to get the present value of the integral.

Similarly the derivative term we make a simple bring this T here so then you get this is a wrap this is a basically an approximation of Y dot T so basically I construct I have to construct approximations of the derivative of Y and integrals of Y using samples so that is what we do.

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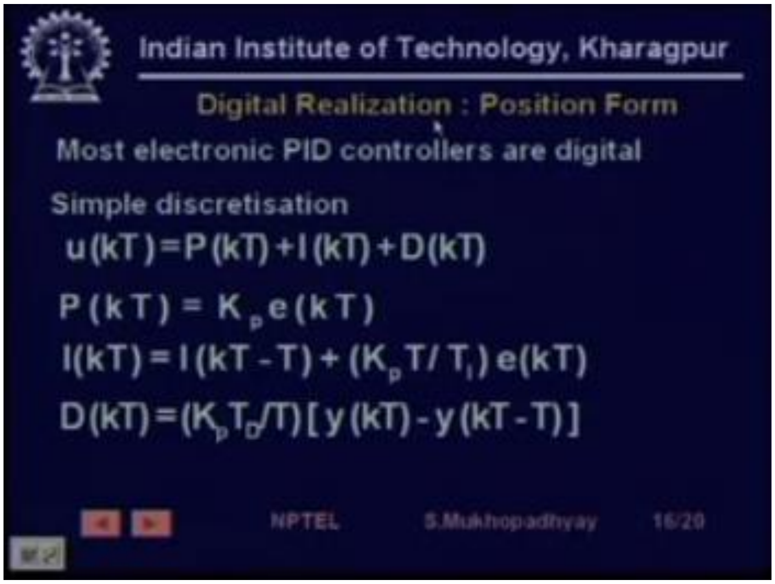

And this implementation form is often called a position form so it is called a position form because the whole input U is calculated now as we have seen that in some cases it is rather necessary to generate ΔU rather than U as we have seen right so then now the question is that how do we generate ΔU that is called an incremental realization of the PID controller or sometimes called a velocity form.

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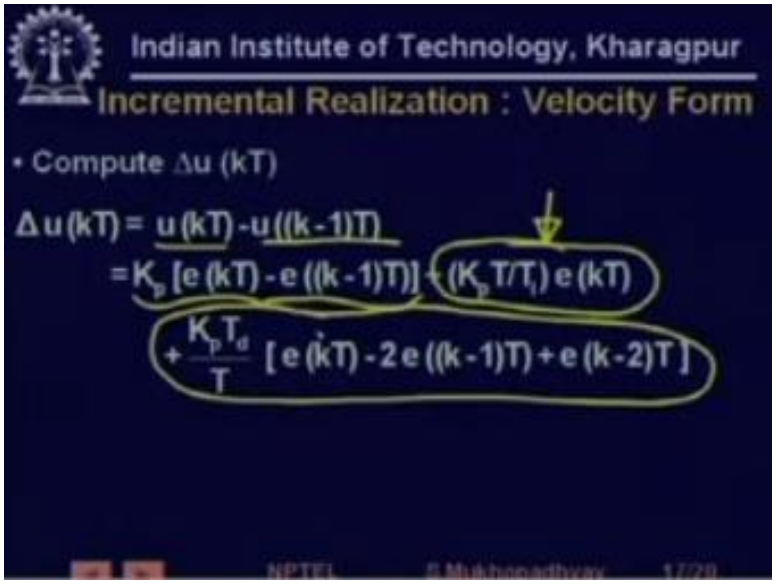

So what happens in the velocity form we need to compute ΔU KT, so ΔU KT is very simply computed ΔU KT is nothing but UKT – UK – 1, so we sub the simply substitute the previous formula of UKT and UK - 1 and then subtract so what will happen is that see the what happens is the proportional term subtraction gives this KP x e (k t) - EK - 1similarly the integral term is basically IK – 1T, so it will give that additional term which I obtained.

So this is the integral part of ΔU and the derivative part of ΔU is this which is basically the difference between this and the same thing at K - 1 so basically by taking a difference of these terms you can generate the general ΔU very simply it is not a difficult problem.

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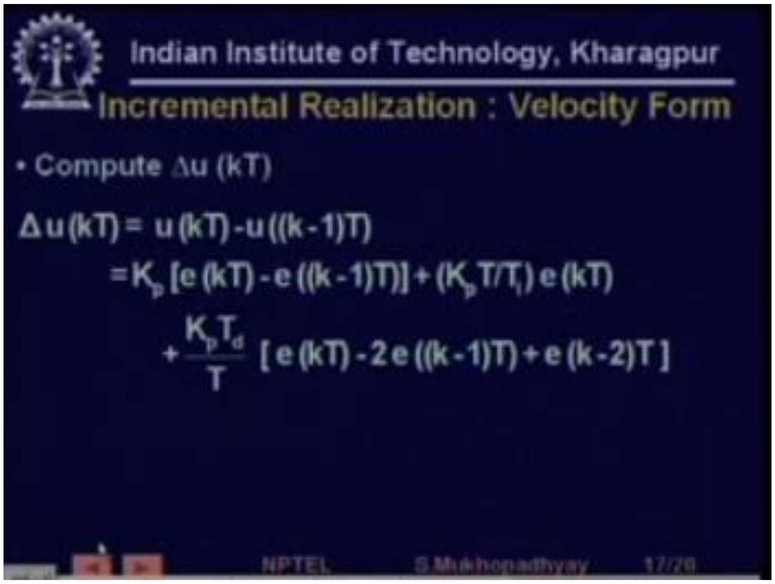

And then finally we have to give U we cannot do to the plant finally we have to give U so we simply add.

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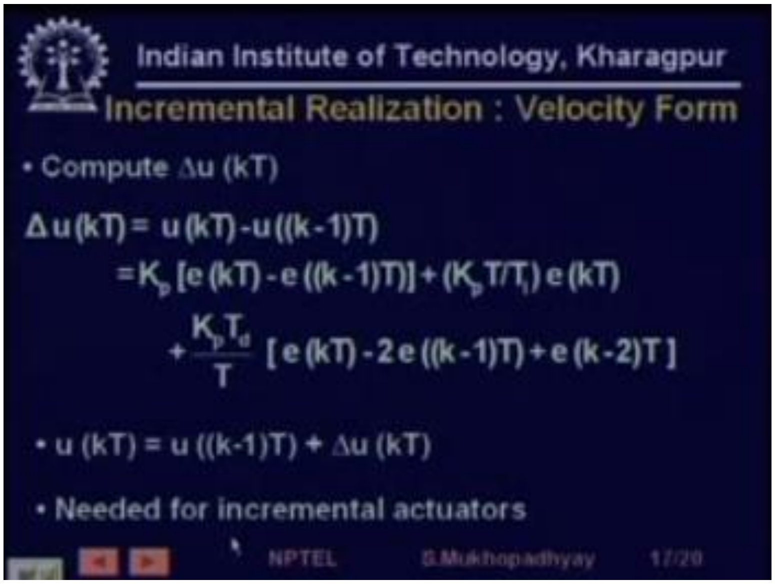

UK minus ΔU KT we have computed so we have to simply add you k - 1 t with that and there are also some kinds of actuators where let us say like you know step motors where the actuator itself integrates the output so this summation you need not you need not give you just give keep on giving the Δ use and the actuator will gradually move and will continuously add it so in a let us say now in a position control using some let us say stepper motor it is very convenient to give the Δ use in fact it is a delta use which have to be given.

And so therefore the PID control has to be implemented in this form so as we have seen that there are the.

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There are some disadvantages of this of the incremental realization because of the sample realization and because we in this case we are actually making a second order derivative not a first order derivative because there is also already a derrick derivative term in ΔU and we are making another derivative because we want to compute ΔU so because of sampling approximations a high amount of noise may be introduced there that needs to be taken care of.

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So your sampling interval should be good small enough and the advantages as we have seen is that is very simply possible to give bump less auto manual transfer and also for some actuators it is what needs to be given now there is an interesting phenomenon that happens is that sometimes generally this.

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Mode is implemented in this form there is a PID controller when there is an integral mode basically because of the fact that if you see the ΔU term you will find that one component contains EK - EK – 1 that is the proportional component now in this component there is no R.

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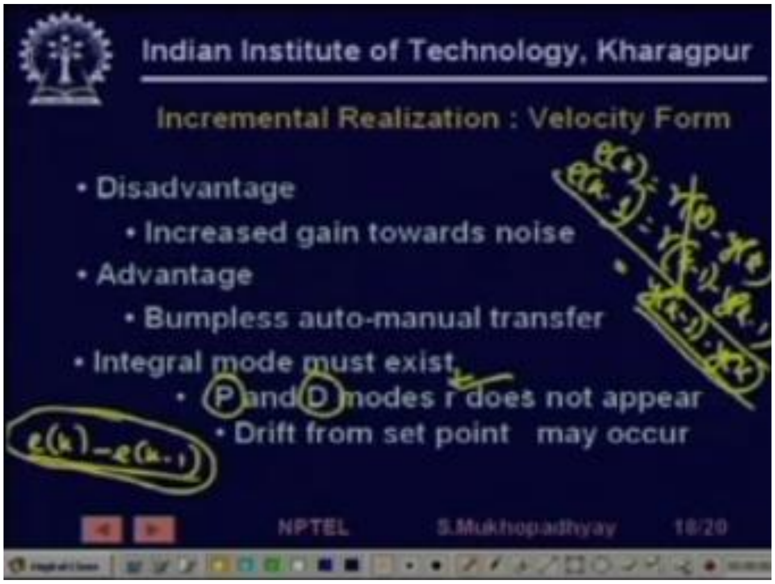

There is no that is the that is the reference input does not appear because E K is equal to RK - YK similarly EK - 1 is equal to R K - 1 -Y K -1, so if you subtract and if R is remaining constant then this will get constant and you will simply get YK - 1 – Y, so and the same thing happens to the D mode so the P and in the P&D modes R does not appear so the reference input so even if the in you know even if the output drift slowly even if because R does not appear.

So it will so the total value of error does not come is not reflected in the in the control input but in the integral term there is an EK term.

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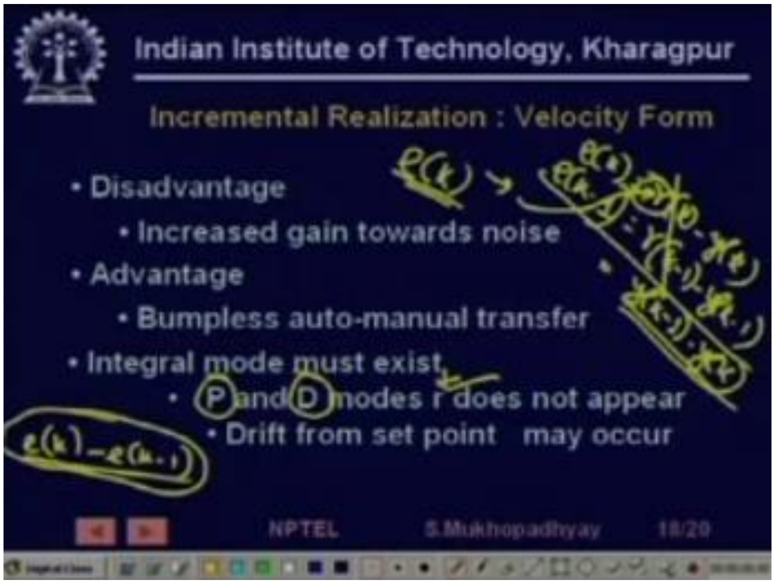

Just simply k so that contains R get that content R there RK is not cancelled so it is said that generally when you implement detail controllers in incremental form you should have an integral mode.

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Otherwise the process may slowly drift from set point without the controller taking corrective action so having said that so that brings us to the end of our lesson let us review the lesson once.

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So we looked at the P I and D modes and looked at the various terms their definitions proportional band integral time and derivative time the meanings how they can be measured so and so then.

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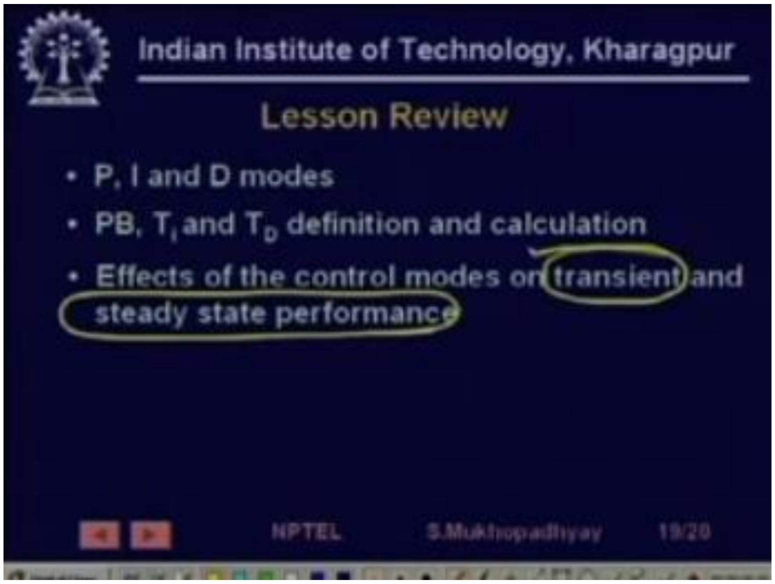

We saw that the various control modes can give you various kinds of transient and steady-state performance for example we have seen that the integral control mode can cause integral wind-up it can cause integral wind apps similarly we have seen that the derivative control mode can give you a lot of noisy performance if you have sensor noise. So some effects of these control modes on performance are discussed.

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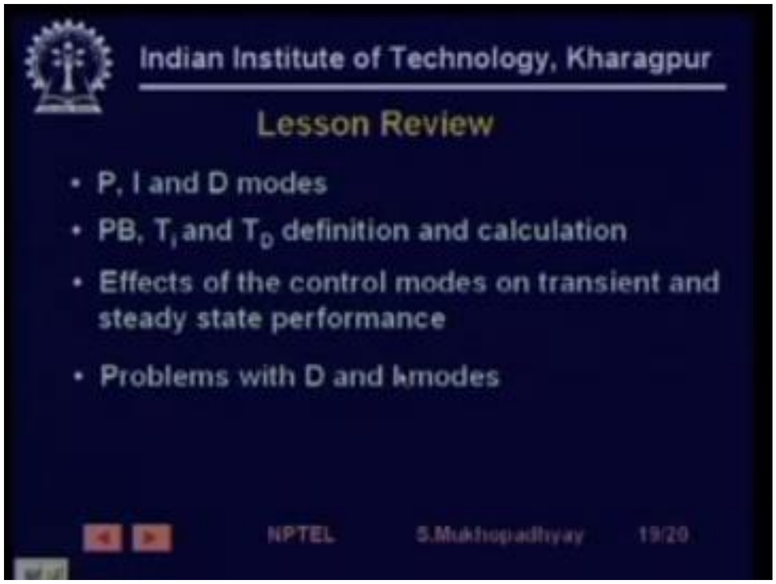

That is these problems with d and i modes.

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We have discussed and finally we have discussed also a digital realization now let us look at some you know points to ponder whose answer again just like earlier lessons you will find within this presentation itself if you look carefully.

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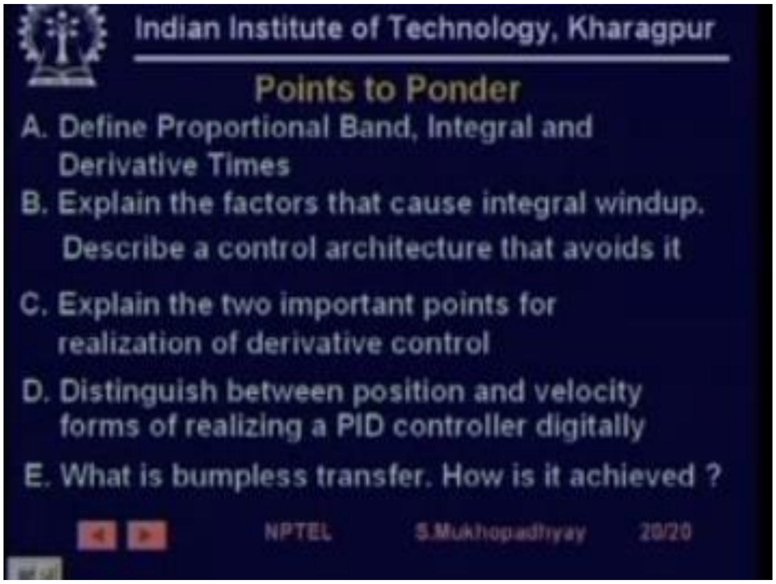

So you might like to write yourself the definition of proportional bands integral derivative times it is you would like to explain the factors that cause integral wind-up so integral wind-up is basically caused by two factors so what are those factors and we have discussed in this lecture two control architectures which will avoid integral wind-up so how to avoid that and 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 shocks to the plant.

So what are they and finally you have seen that a PID controller may be realized in what is known as the position form and velocity form so you need to think how to distinguish between them when which one is required and also what is the bump less transfer and how it is achieved so the answers to these questions have exists in many text books and also within the within this lecture, thank you very much.