INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

By Prof. S. Mukhopadhyay
Department of Electrical Engineering
IIT Kharagpur

Topic Lecture – 21
Concluding Lesson on Process Control (Self Study)

Welcome to lecture number 17 which is the concluding lesson on process control of this course on industrial automation.

(Refer Slide Time: 00:33)

(Refer Slide Time: 00:35)

So in this 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 what 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 briefing, you 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 he 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 of control and I would like to draw your attention to them so that is the purpose of this lecture.

(Refer Slide Time: 01:57)

Instructional objectives are firstly described typical features of an industrial controller what you might expect in a typical controller there are lots of variations, but we will only have the opportunity to look at a particular case. There are various variants of the PID equation which you read the PID equation, sometimes you feel that, that is the only variant and you might implicitly assume the same variant to be existing your controller that is not the case, the several manufacturers implement PID controllers in various ways.

And you need to understand that before setting gains describe major practical features of PID controller implementation if you want to build a PID controller then there are certain facts that you need to pay attention to. So those things and understand the factors that limit control performance in the feedback loop. So one needs to understand what is possible, what is not possible, what causes problems before being able to make control work for a particular process.

(Refer Slide Time: 03:12)

So let us begin with the implemented issues implementation issues.

(Refer Slide Time: 03:15)

So let us first look at an industrial PID controller specification, this is a very typical specification, this one is adapted from a Honeywell PID controller which is very, very and well it is a standard company very well known company in the field of process control. So we first have, we have several features first with that you have it says that you have PID with alarm and relay outputs.

So you could have, you could depending on process conditions you could set certain alarm outputs maybe it will lighten up some annunciation or ring and ring a buzzer, and it also provided some pride some relay output so that if you need you can switch off things or transfer it from automatic to manual you can do various things. Configuration in engineering units is very important because generally the process control engineers they are not electronics people, neither they always experience control engineers they are generally plant engineers.

So they understand things in the domain of the process. So it is important to be able to understand gains, times, outputs and inputs in terms of the engineering units of the process. So if you are taking a flow feedback then might be interested in knowing that what is the flow in let us say meter cube per minute rather than actually the feedback is coming as a possibly as a voltage or a current 0 to 5 volts or 4 to 20 milli amperes.

But learning the, if you, it will be a lot easier for the process engineer if the, if everything is expressed in terms of engineering units these are this may seem trivial when you are studying an engineering course, but they are very important in the field. There is most PID controllers will support communication, communication standard communication using standard communication protocols like RS232 and RS485.

So these are used for a variety of purposes for example, provision for SCADA interface, SCADA stands for this one which is a white plain supervisory control and data acquisition it means that the controller can be in the field close to a machine or in a separate place while the controller can be monitored from a different place, maybe a central control room. So if you want to do that then you need to have a supervisory control and data acquisition interface by which sitting in the control room you can monitor the controller and see the performance of the control loop.

So this is usually provided, this can be done using these communication standards and interfacing it with a PC and then using a visualization standard, visualization software there are very good visualization software is available on the PCs. So you could use them, then there are facilities for temperature time, this particular controller was mainly built for temperature control application, you will many times you will find that controllers are marked as temperature controllers, flow controllers, pressure controllers.

So they are, there may be all PID controllers but they are marked as such because of certain reasons. For example, first of all you will find that they will be able to take inputs of that particular kind right. So for a temperature controller probably there will be a direct facility to interface thermocouples or RTDs. Similarly for a flow controller there will be direct interface to a flow sensor that is possible.

Second thing is that we realize that temperature, flow, pressure these control applications typically work at different bandwidths. So while a temperature controller may be, it may be adequate to have a temperature controller which is within say 10Hz for flow control you may require a bandwidth of something like 100Hz, and for pressure control you may require even higher bandwidth, you know something like maybe 500Hz.

So the devices themselves that is the electronics inside everything is to be made according to that. So you might have an, if you know you might have an anti-aliasing filter in the controller and the anti-icing filter bandwidth will have to be decided by the sampling time as we all know and this may be decided based on what kind of control it is. So the anti-aliasing filter for a temperature controller is likely to be quite different from that use for a pressure controller right.

So this is a temperature controller that is that we are seeing here, so there is a facility to provide a temperature time profile set point ramp, you know there are, there could be certain processes where you do not need to keep the temperature constant. On the other hand you need to maybe keep it constant at t1 for some time maybe 10 minutes, and then ramp it up to t2 within two minutes, and then keep it at t2 for 20 minutes, and then ramp it down to 0.

So such temperature profiles need to be set up for various chemical processes because they are often very temperature sensitive. So here they have provided a facility by which you can actually set up this, you know this set point ramps and their temperature time profiles that would that would be very useful in this case. Similarly processes keep changing because of you know, because of the characteristics, you know furnaces, fire lining of bricks degenerate heat transfer coefficients change, depositions typically heat exchanges heat transfer coefficients tend to change because of depositions for example in let us say there is a plant where

Similarly processes keep changing because of you know because of the characteristics you know furnaces fire lining of bricks degenerate heat transfer coefficients change depositions typically heat exchanges heat transfer coefficients tend to change because of depositions for example in let us say there are there is a plant where you say in this in the Middle East people make drinking water by using sea water.

So that is called a desalination process and it turns out that there is huge amount of it is a very energy intensive process and the heat transfer coefficient is very important so that incidentally the heat transfer coefficient tends to change because there are in the pipes you get depositions from seawater so in such cases you for efficient response as well as for things like energy efficiency you need to tune PID controllers from time to time and that is so they have provided algorithms for doing that using you know this fuzzy means.

If there is a there is a special technique called using called fuzzy set theory which is used to design controllers so, you so you can have fuzzy an adaptive tuning means that the controller continuously keeps adapting as the plant changes so you could choose one of these to get the PID settings you could use some special purpose alternative control algorithms which the manufacturers are providing in a bundled fashion.

So they are actually they have some experience they have designed some algorithms which are which I work well in certain applications so they are providing you some alternate control algorithm maybe some variants of PID so you are free to use them if you want then sometimes you may require two different sets of PID parameters and you need to have so you need to give dual set points so all the same process you could use two different PID parameters maybe depending on two different modes.

For example there could be you know for example suppose there are heat cool PID controllers okay so sometimes the same device has to heat let us say building let us take a heating ventilation air conditioning HVAC application so down in the basement you have the heater which will probably operate a operate basically controller steam boiler or you could have a chiller which will operate the centralized air conditioning using cold water so you could use so both of these may be controlled from the same controller box but since these are controlling two different equipment.

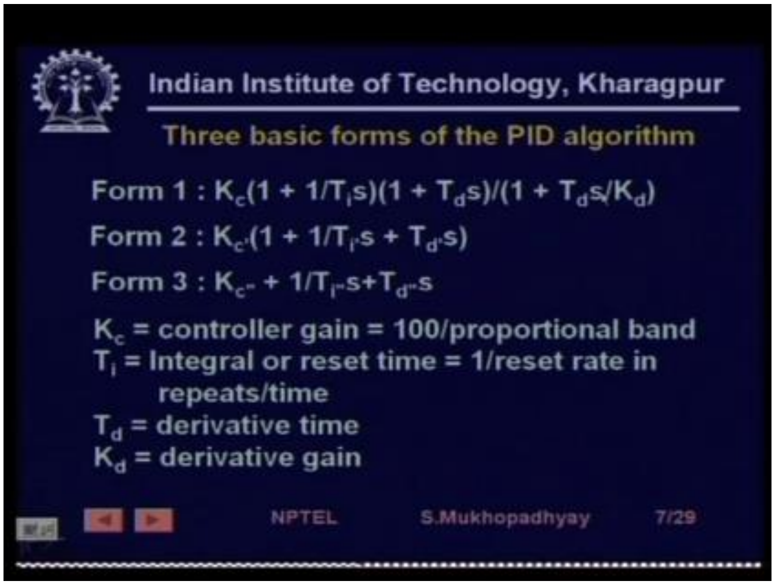
So it is obvious that two different sets of PID controllers will be required and for them you might need two different set points so such facilities have been provided here and finally you could have remote set point operation where basically this remote set point is actually a subset of SCADA so if you have supervisory control from a remote place then you could you could given give set points maybe the operator sitting in the control room can give set points okay.

So this is a this is what a typical PID controller looks like and if you look at this input outputs for all controllers input outputs are very important.

(Refer Slide Time: 13:31)

So it provides 0 to 5 volt dc or 125 volt dc15 volt dc sometimes provided to you know detect wire breaks or shorts to ground or you could have 4 to 20 mA or so you have two inputs on one of them it can take 0 to 5 volt or 1 to 5 volt dc and 4 to 20 mA and in the in the in the other input it can take 125 volt dc and for 20 mA and as output it can provide 0 to 5 volt dc and 4 TO 20 mA and similarly it can directly take a type k thermocouple or PT 100 RTDs it can take it can give digital alarm outputs or it can also give relay outputs in the form of N/O and N/C contacts and all these that you have are actually configurable you can actually view the configuration you can change the configuration and set the controller. So this is a typical industrial PID controller having seen that.

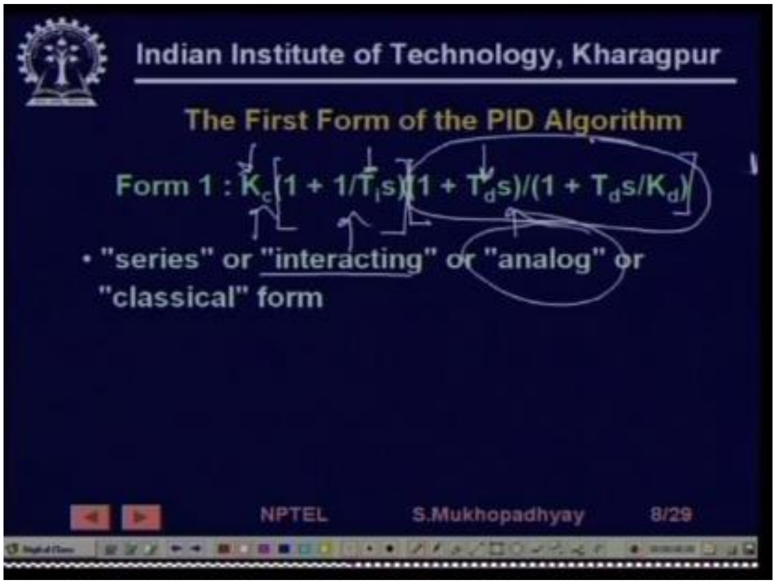
(Refer Slide Time: 14:45)



Let us remember let us come to this point that what is the PID controller and what are the interpretation of it is gains it turns out that there are several PID controllers which are several forms of the PID equation which are in use in the industry today so for example you have this form which is called switches which I call form one you have the other form which is formed two which is probably the most popular in textbooks and form three which is a rather you know which is an abstract control systems kind of form typically if you ask an if you ask any an electrical engineers you would like to see it in this form okay.

So while chemical process engineers will probably use this form and these two forms so as we know that in this K_c $K_{c'}$ $K_{c''}$ all sides form controller gain T_i is integral or reset time or one by reset rate and T_d is derivative time and K_d is derivative gain right so sometimes you know here we have a we have a K_d so this K_d is this K_d is used for a certain purpose we will discuss it right now.

(Refer Slide Time: 16:03)



So you see that we have three different forms why is it so let us look at the first form in slightly more detail you need to understand you need to find out which of these forms your PID controller is using because if you mentally assume that it is using one of the forms with which perhaps you are familiar and if the controller is actually using another form then the gain settings that you're going to compute are not going to be right for that form okay.

So let us look at form one actually turns out that form one is sometimes called the series or interacting or classical form the reasons for this names is that firstly series that you can understand that this is in series so this is one term and this is the other term and this is the other term, so there are three terms which are getting multiplied.

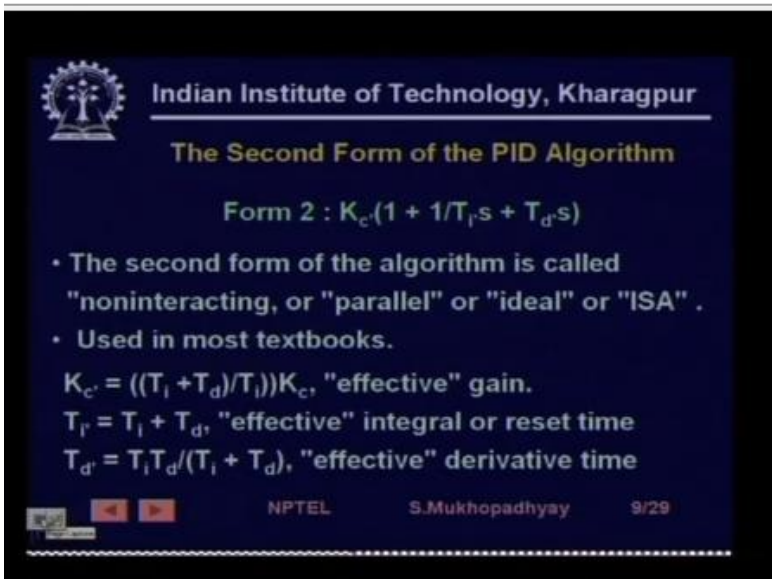
So therefore they are in series why is it interacting it is interacting because for example if you change if you change with respect to the with respect to the second form which is probably the probably the most popular if you change any one of these let us say if we change K_C then integral time and is basically the integral and the derivative gains will change if you change T_i also they will change if you change T_d also they will change and then all of them will change so you see that internal they interact that is you cannot independently unless you do it very carefully by actually solving equations if you just change T_i

That is not just that the integral time is going to change the derivative time will also change and the proportional gain will also change so therefore they the changes are interacting with one another that is why it is called an interacting controller this is called analogue because this controller has it is origin in the old days pneumatic controls actually it turns out that it was easier to generate the PID equation in this form using pneumatic elements you know things like since like OD flushes and then bellows flapper nozzles so you with such things it is easy to build it in this form and not in the parallel form right. So therefore it is called analog and classical so similarly.

(Refer Slide Time: 18:35)

So basically this form came or originated from the pneumatic controllers and still persists most major vendors of regional controllers provide this form of the algorithm because again you know legacy is going on okay so if you look at the second form this is the most common.

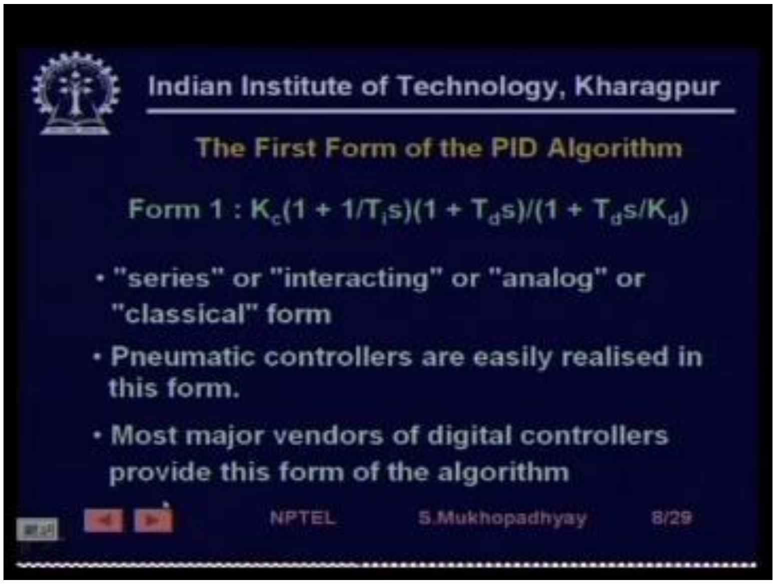
(Refer Slide Time: 19:02)



It is called non-interacting although it is actually partially non interacting in the sense that if you can change T_i without affecting T_d and you can change T_d without affecting T_i however if you change K_c both T_i and T_d change so to that extent it is partially non-interacting it is called parallel because rather than having multiplication of three terms here you have sum of three terms so you have some of three terms so that is why it is called parallel although there is a multiplication.

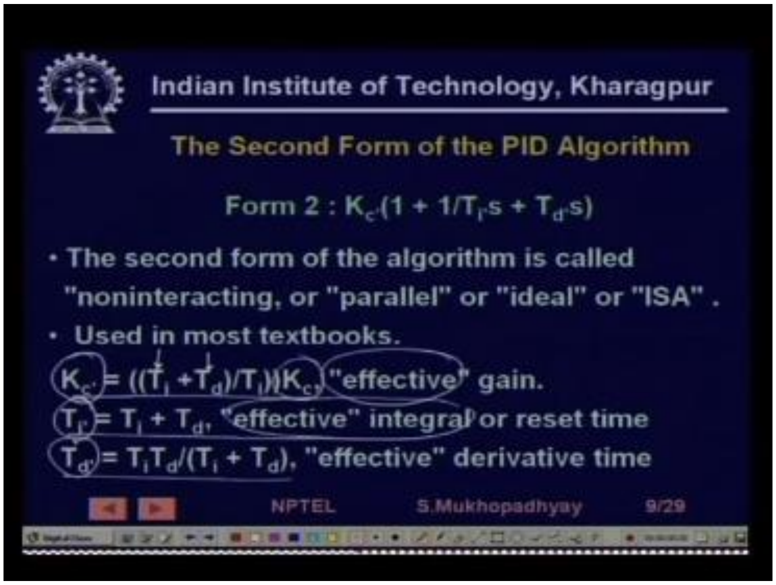
So it is again partially parallel sometimes ideal or is a means instrument society of America I do not know whether how far these ideal or ISA are so valid it is it is used in most of the textbooks and if you now you know you could you could you could try to convert right so what is the relationship between form one and form two for example so it turns out if you solve by equating coefficients of s in the numerator and in the denominator then you would find very easily that Kc' if you that is there is a catch that catch is that if Kt is high that is that one plus that is this factor let me just go back that is this factor.

(Refer Slide Time: 20:26)



This particular factor if you ignore then it turns out that you can match the games right and how do you match the gains so you match the gains.

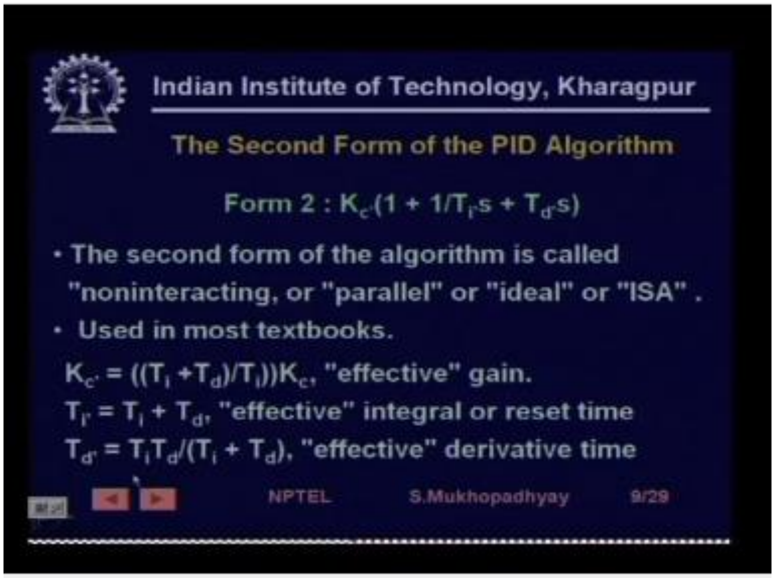
(Refer Slide Time: 20:43)



Second form so if you so it turns out that you get such formally that Kc ‘ turns out to be equal to this Ti’ turns out to be equal to this and Td ‘ turns out to be equal to this, so as so you see that if you set if you set gains TI and TD in the first form you are actually setting if you set TI, TD, and Kc in the first form then the actual gain which sometimes is called the effective gain and the effective integral time.

Are will be actually obtained according to your understanding suppose you have read this equation and you are going to a controller which implements in the first form and if you set some values then these the actual values will be realized.

(Refer Slide Time: 21:31)

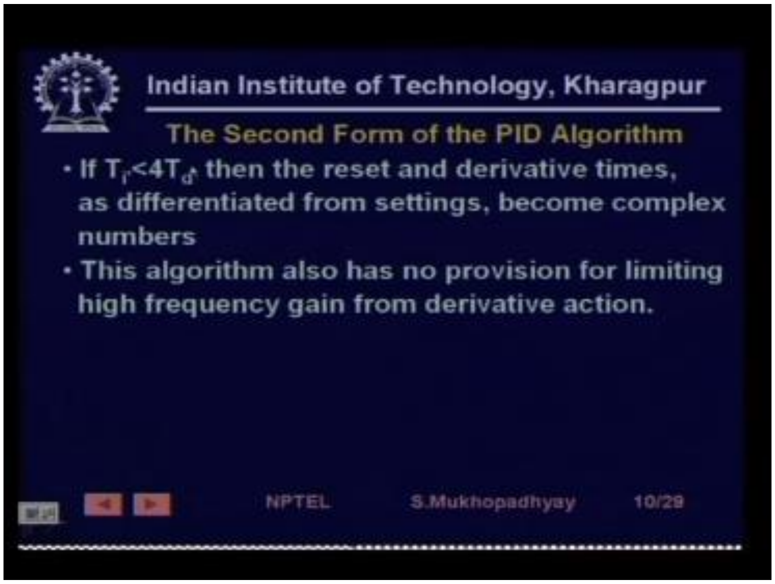


Are been will not be equal so that needs to be remembered all right.

(Refer Slide Time: 21:40)

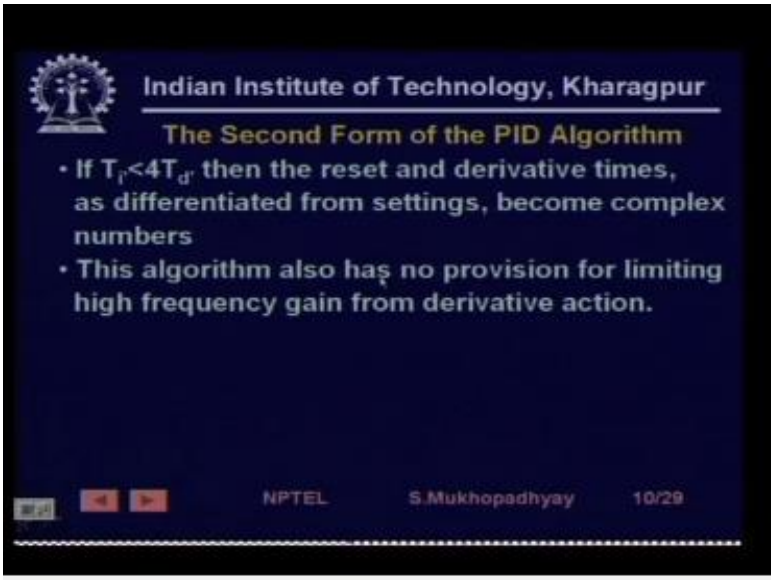
So on in fact interestingly it turns out that sometimes you get you get you get absurd readings for example if you set some value.

(Refer Slide Time: 21:53)



In the second form where Ti' is less than equal to 4Td' if you want to say it you actually cannot set it in the first form because it turns out that that if Ti' is less than 4Td' then Ti, Td values are complex they are not they are not you would not get real numbers TI and TD which will be able to realize this. So you see the first form is somewhat constrained, on the other hand the second form in the second form.

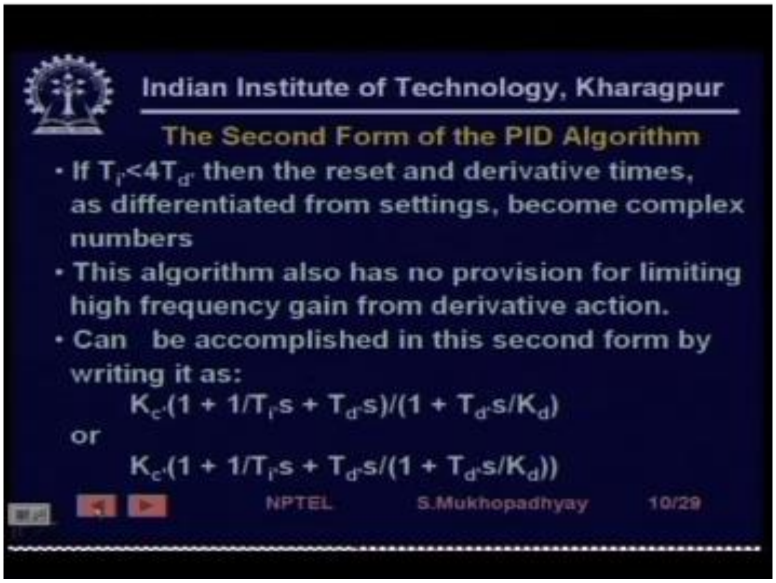
(Refer Slide Time: 22:25)



There is no the second form does not have that one plus the that denominator with the derivative term so there is that denominator can be is actually used for limiting the derivative gains as we have as we have pointed out earlier that the derivative gain needs to be checked because of the fact that the sensor signal may contain noise and then the then the derivative will give you very noisy signals.

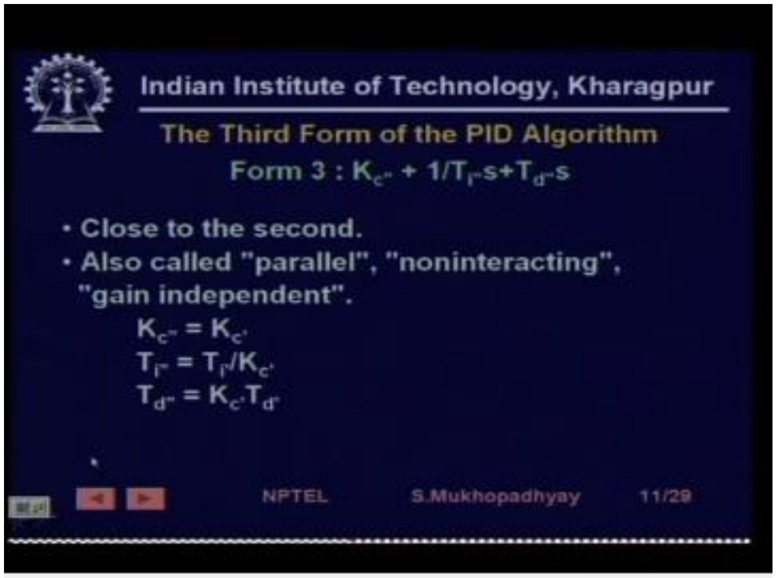
If you try to differentiate noisy signals we get very noisy signals so there is a there is a need to restrict the high frequency gain of the derivative, so that noise is not amplified while the process signal gets differentiated so that is possible in the first form while the second form it is it is as such not possible but you could add such factors for example.

(Refer Slide Time: 23:16)



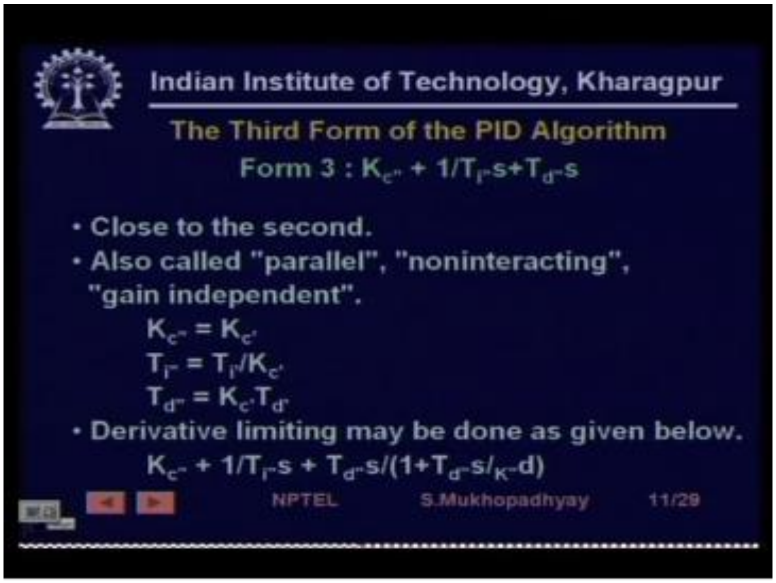
You could add that factor by adding such a term so by adding such a term with the overall equation or by adding that only with the derivative part what are these two things you can do.

(Refer Slide Time: 23:35)



So if you look at the third form that is the most you know what on good theoretical form it is close to the second but it is what is completely parallel in the sense that the D3 coefficient K CTI and TD a totally decoupled you can change anyone of them without changing the other, so in that sense it is completely parallel and completely interacting and to stress the fact.

(Refer Slide Time: 23:55)



That that even a by j even Kc is not interacting it is sometimes called gain independent and these are the standard equations which you get by so this is the relationship between the third form and the second form you already have a relationship between the second and the first so you can substitute and get the other one and you can similarly do a do a derivative limiting by having another you know lag term with the derivative term.

So this is so this it needs to be understood that PID equations come in different in different formats, so now let us quickly run through some of the you know just putting the PID equation is not going, okay. So we first looked at the hardware the PID controller we have looked at the PID equation and now we are going to look at some of the software features of the PID controller so that we have a we have some idea about the whole PID controller implementation.

(Refer Slide Time: 24:59)

So you have I just list them there is no particular order and some of them you have already seen so this you have already seen that the option to have the derivative function act only on the process variable and not on set point changes because set point changes can be stepped like so that would give sudden suddenly have induce a very high input to the to the plant so the input will rise like and like almost like an impulse and will come down if you make a step change.

Because of the derivative term so you never apply the such set point changes on the derivative term but you take the derivative term through the through the only from the process variable.

(Refer Slide Time: 25:48)

So you need to provide provision for reset windup protection this we have discussed in detail, you need to provide bump less auto manual transfer this also we have provided discussed sometimes apart from you know there is there are in a controller there are different kinds of filters which are used so one filter is t o limit derivatives you could use special purpose filters not to excite certain modes of a process which are very oscillated.

For example if you are imagine that if you are trying to trying if you are if you are having a container which contains molten steel liquid steel and if you try to move that control container then what will happen is that the steel surface will try to move and it might spill over molten steel so you need to construct so for such operations which are typically used in you know steel melting steel melting what is called a basic oxygen furnace.

Which has to be tilted where the molten steel has to be slowly moved so for such controllers standard PID controller is all right but apart from that just before the actuator you put certain filter size that those oscillatory modes this liquid surface spilling can be linked to a can link to a resonant behavior very highly un-damped oscillate I mean very lonely lamped oscillatory behavior at a certain frequency.

So you do not want to excite that so you so you do not want to give input at that frequency so for such purposes you sometimes use notch filters which have which will give you which will pass all signals but only in a very so they have you know they have gained characteristics over frequency I am sorry.

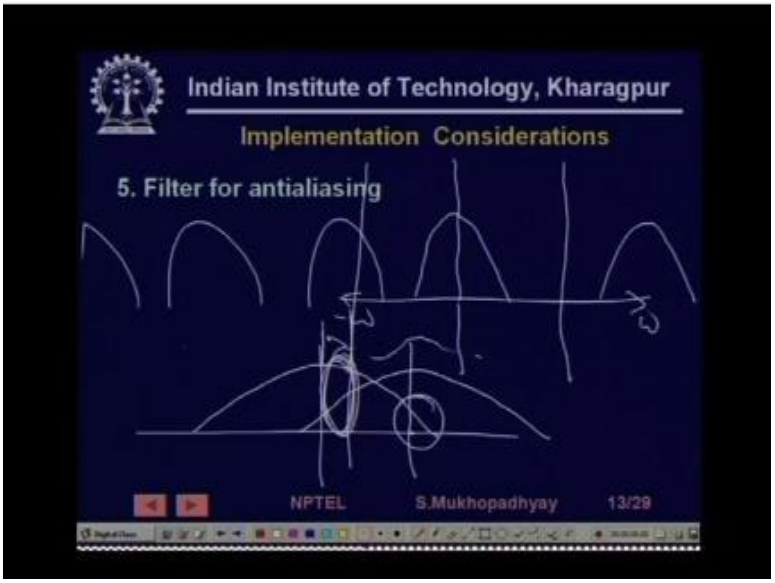
(Refer Slide Time: 27:44)

Somewhat like this you know so in this range they will pass control signals in this range also they will pass control signals but in this narrow range they will stop the signal, so if you have your resonant frequency in this range this is omega this is say U Omega J Omega so in this range this one this notch filter other is this is actually gain of the notch filter so it is GJ Omega so in this range the notch filter will not allow any inputs to come.

(Refer Slide Time: 28:27)

So such things need to be done you need filter for anti-aliasing you are you are probably aware of this that the after all these PID controllers are actually digital devices now today they all contain micro processors and they will do all kinds of computation using digital signal processing methods so it is it is well known that if a signal is sampled then its analog spectrum gets repeated. So you can you can this is a very standard signal processing phenomenon.

(Refer Slide Time: 29:06)



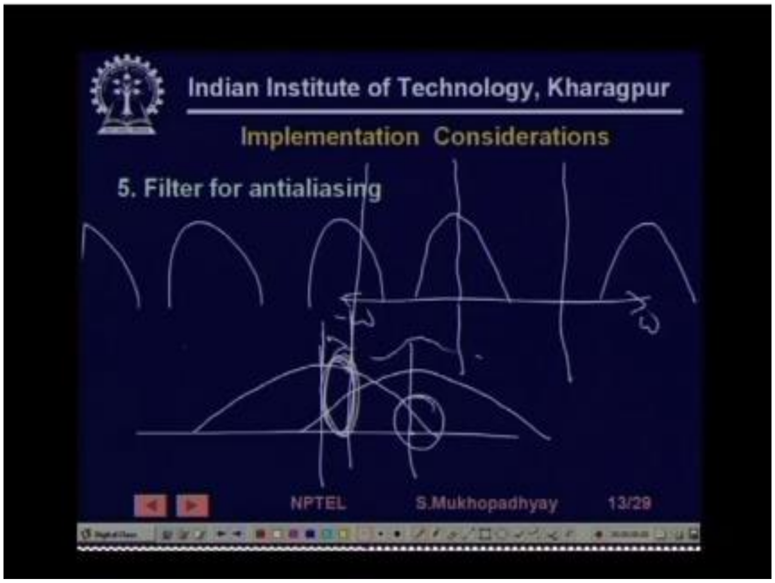
So if you if you take a signal which is which is low pass so its spectrum this is omega minus omega complex spectrum we are talking about so if a spectrum is like this then and if you are sampling it at this rate then it gets repeated actually the spectrum of the sampled signal is going to be repeated so it will be repeated repeating indefinitely, okay. So now imagine that if you want to if you make this if you make the sampling frequency low.

Then it turns out that suppose you suppose apart from suppose now I am just exaggerating the other way suppose the filter is signal is the signal has this bandwidth then you are filtering it at this frequency then this these lobes will now come and start overlapping so this will be one of the lobes and probably this will be the other lobe, so what will happen is that effectively once these two lobes if you take summation then you are going to get a frequency spectrum of the digital signal will look something like this.

So you see that but this is a very important part of the signal this generally for control low pass low frequency part is very important so you see that the high frequency part of the signal which was not so important for control has got kind of folded back and it has come on the low frequency part it is now affecting the low frequency part.

Which is important I am Telling in within in very briefly so for this purpose you need to you need to end sure that it does not happen so you need to ensure that you only.

(Refer Slide Time: 30:49)



You first cutoff the analog signal such that the high frequency part cannot fold back to the low frequency part so for that purpose you need filters and such filters are called anti-aging filters so you need such filters we must remember that.

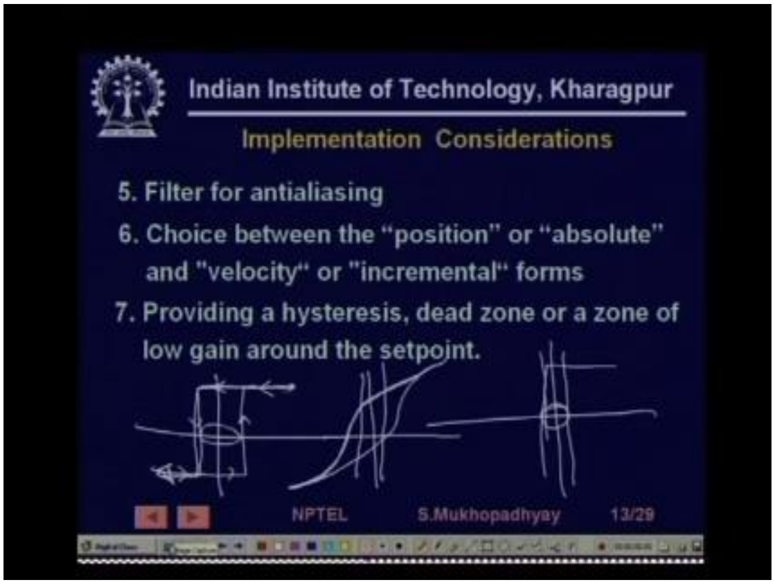
(Refer Slide Time: 31:08)

Similarly this also we have seen that we need to decide whether we are going to realize the PID algorithm in the position or in the app or absolute or in other words or the velocity form or incremental form there are certain advantages with respect to auto manual transfer there are certain actuators which will take incremental output so that needs to be decided.

(Refer Slide Time: 31:34)

Sometimes you know typically as we have learnt the electronics also we have seen that suppose comparators so comparators if you have ideal comparators then the output will keep on switching right so therefore we put a we put a either a hysteresis or a or a small dead zone around the 0 point.

(Refer Slide Time: 31:55)



So we say that if the error is little bit here within this zone then I am NOT going to I am going to keep my control output as before so you put a hysteresis you know let me draw it clearly so you have an input output characteristic and you have a hysteresis curve so you have so you say that if the error is in this zone then i am going to maintain basically maintain so if i am i was here i will maintain unless the error goes out of this zone and then i will so this is a this is a hysteresis switch right now you can have a smoothie stress is comparative you can have something like this also so you say that I am going to keep the gain.

And they slowly change the game so in this zone the gain is the output is not switched so this things can be done to avoid noise.

(Refer Slide Time: 33:11)

Of course, because they because maybe you can actually tolerate that much of error and it otherwise it will it will unnecessarily be all the time moving the actuator because of noise so the actuator so for some actuators this may not be good then you need to provide producer for manual bias you know Manuel, Manuel inputs is are very important and you may like the operator will sometimes provide manual bias that is if he operate as a very experienced and the themselves can act sometimes as very nonlinear and sophisticated controllers.

So if it does not like the PID output you might like to give them an opportunity to change it having said this let so these are you know typically.

(Refer Slide Time: 34:01)

Implementation features and now we will come to some facts on control I wanted to start with the early tasks in control because these are the parts that we generally in an undergraduate control course we never pay attention to neither have I paid attention and to them here but at least let me mention that these are very important tasks so first of all selection of manipulated variables.

(Refer Slide Time: 34:31)

Which variables are to be manipulated selection of controlled variables which variables are to be controlled selection of extra measurements sometimes required or you know choice is required for achieving good control performance like disturbance rejection as we have seen in the case of Cascade loops so how are you going to do the cascade which are the variable you want to sense and feed it as an inner loop feedback you need to understand that.

(Refer Slide Time: 35:00)

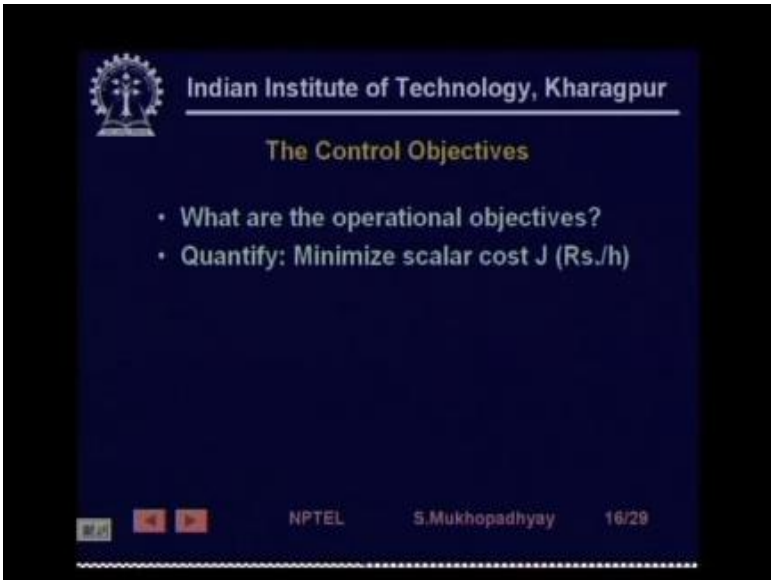
Selection of control configuration that is how you are going to connect the controllers and the sensors are you going to connect it in cascade with feed-forward or you have seen some special features like you know Smith predictor so these needs to be need to be done.

(Refer Slide Time: 35:21)

And selection of controller type so then you are going to use a set of single loop controllers or whether we are going to use multivariable controllers or you are going to use as set of single variable controllers with a de-coupler so all these things these choices need to be made and only after that we will come the question of once you have selected these then will come the question of setting I mean the control loop design which we pay so much attention to so that comes at a much later stage this is something I wanted to mention however it turns out that many of these questions.

Are generally for given class of plants these questions are generally settled that is if you are trying to control a reactor which of the variables are to be wit sense is generally in well-known right so but typically when you have a large plant this may not be so clear these options next you have to find out so once you have done that roughly you need to set the control objectives that is you need to know where you want to which are the variables you want to control in what way and where do you want to set the values such that you have you have good performance from the plant and generally performance is measured in terms of money right.

(Refer Slide Time: 36:52)



So you have to once you have the you have you broadly understand the operational objectives you need to quantify them so you need to actually set values which will minimize some scalar cost right scalar means a single overall cost of operation in perhaps expressed as rupees of rupees per hour.

(Refer Slide Time: 37:15)

So you need to understand that the various constraints on flows if you want to do that you want to you need to identify the constraints on flows the various equipment constraints actuator input constraints and you also need to understand the product specifications that is what are the Watauga there is a product composition bounds or whether the product dimension bounds so these are very important to be to be identified before the control objectives can be specified only after that you can aim you can you can even start doing a controller design.

(Refer Slide Time: 37:55)

It turns out that costs j that is the cost that you want to minimize depends generally depends much more on steady state values of variables especially in process control such as flows because process controls are not processes are typically not always not all the time oscillating right they will they will oscillate once in a while but most of the time they are going to stay you know in their steady state and therefore it is the steady state values which are which mainly decide the cost.

So this also needs to be identified this should be understood for people like us who pay a lot of attention to dynamics but sometimes ignore the steady state operation I want to emphasize that it is the steady state operation that generally decides cost of operation in a process control plant.

(Refer Slide Time: 38:48)

Now this cost optimization to sort to what extent it is possible that depends on the degrees of freedom now what is the degrees of freedom degree the freedom basically means basically it tries to answer this question that suppose you say that okay, I have these as this is the plant, these are the governing equations, these are the things which are which can be controlled or the manipulated those are the things which cannot be manipulated they are given to us there you know disturbance some feed coming from at some flow rate or some temperature no control on that.

Then given this situation is it possible to independently set values for let us says some temperature and some level. So such questions, you know what is possible that you know degrees of freedom that is, what is possible to achieve how, what kind of control objectives are possible to achieve given the situation with control. So that is very important to understand before setting the control objectives.

(Refer Slide Time: 40:05)

For example if n is the number of process equations typically equated to the number of states and f is the number of variables and n_d is the number of externally constraint variables, external or constrain you know sometimes they maybe when we constrain the sense that you cannot move them because of certain specifications, sometimes they are externally coming just like I said the some flow of some feed.

(Refer Slide Time: 40:37)

And if n*star is the number of control objectives or specifications typically we have taken our steady-state objectives so something should be maintained at this value constant, this is one control objective. So if you have n* number of such objectives then.

(Refer Slide Time: 40:52)

The degree of freedom is typically called f-n-n_d basically what that is you have f number of variables, free variables. Now n of them so I mean ideally you would have f degrees of freedom because these are f variables which could move in the space, but because of the n equations they are first constraint so they, so it is f-n, right. So if you have three variables and if you have two equations then only one particular linear combination you can assign or one particular variable you can assign but you cannot assign three variables independently to satisfy these two equations, right like that.

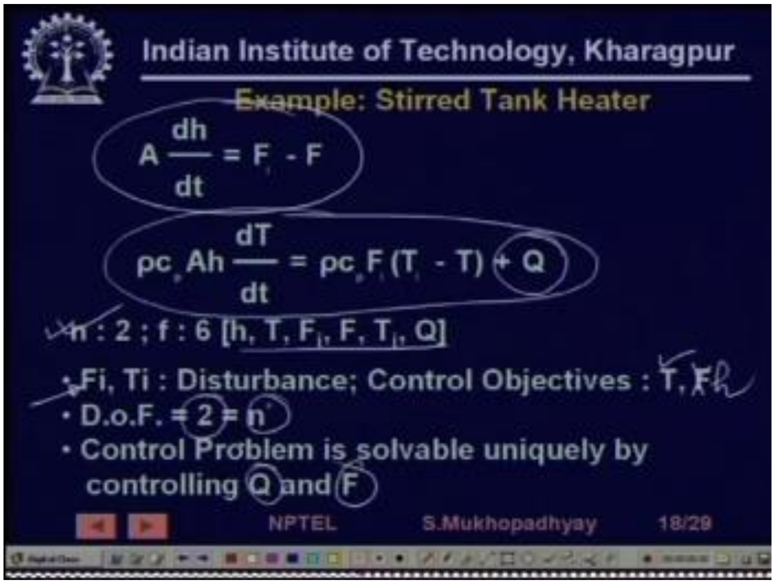
(Refer Slide Time: 41:42)

So then it becomes f-n and then more than that then of these f-n some more other degrees of freedom are lost because some of the variables are externally set so you cannot vary them. So then the remaining degrees of freedom are f-n-n_d and that must be greater than the number of control objectives, so if it is so if the number of control objectives is equal to that.

(Refer Slide Time: 42:05)

Then your solution you will get a unique solution to the control problem if it is more than that then you cannot satisfy it because you have more number of equations than unknowns or and if it is less than that then you have some further chance of optimizations you can put you can actually bring in some more objectives.

(Refer Slide Time: 42:29)



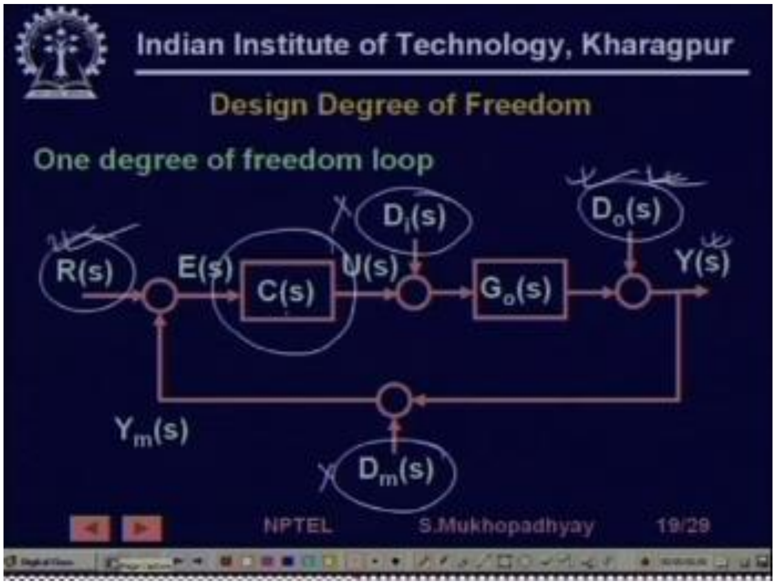
So just to give you a brief example consider what is known as a start tank heater basically a tank in which some flow is coming and you want to maintain the temperature of the tank as well as the level, so you so these are the two governing equations very easy so this is the level equation and this is the temperature equation. We are assuming that we are giving some heat input which we can control.

So there are two equations so n=2 there are six variables, so f=6 of these two are disturbances so Fi and Ti that is flow rate and the temperature of the feed so we assume that we cannot so those are lost so two are lost so from 6-2-2 so the remaining degrees of freedom is 2 so that means that it can take up to 2 control objectives. So therefore if you want to set if you want to set T and not F, T and H by controlling Q & F this would be possible.

(Refer Slide Time: 43:44)

So this is what degrees of freedom is about similarly you see that sometimes typically in a control loop you can you have typical control loop that we consider actually one degree of freedom, this is this very important to understand.

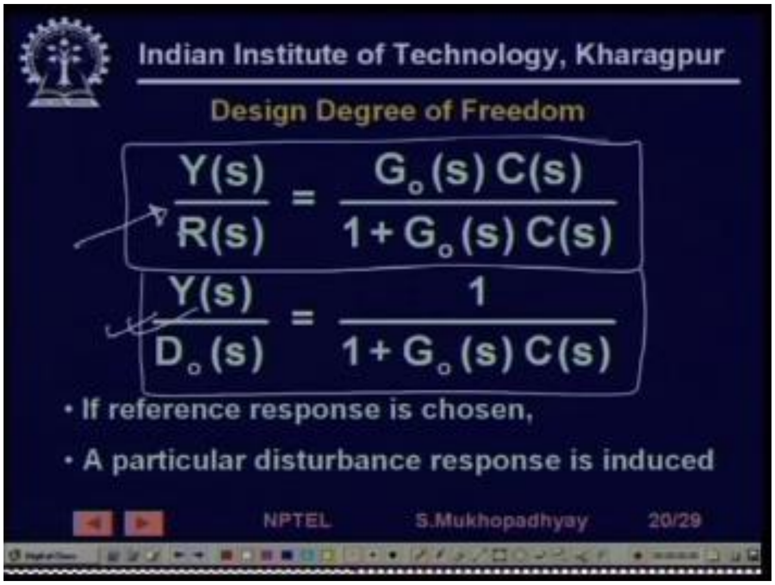
(Refer Slide Time: 43:58)



So you see that this is a typical control loop right, in which several disturbances maybe acting here, here, here as well as R(s) so what is it that we want, we want let us say for the time being considered forget about these two and consider only this one, so what do we want, we want that good set part tracking so this is the response Y is by R(s) you want to share and we want to at the same time we want good disturbance, this response Y(s)/ D_0(s) also we want to share, but that is not possible.

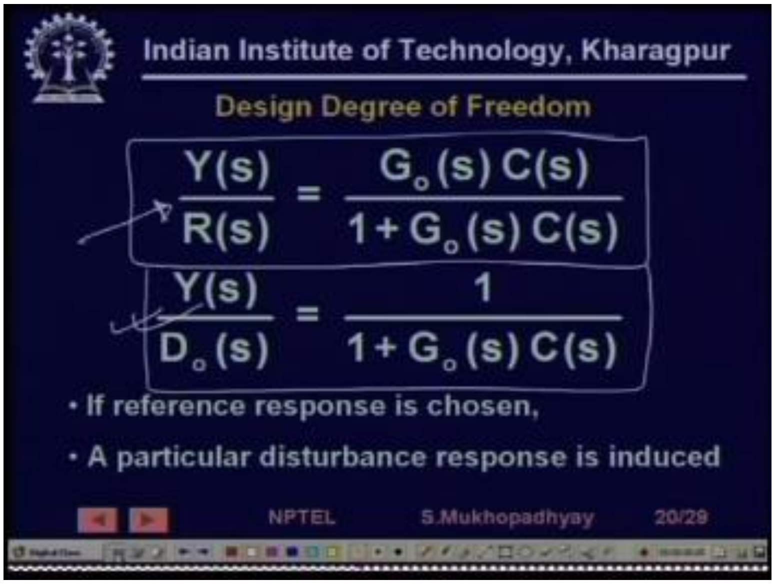
Because this is a one degree of freedom controller, so using C(s) you can either you can, you cannot select both of them independent right that is there is obvious from the equations.

(Refer Slide Time: 44:41)



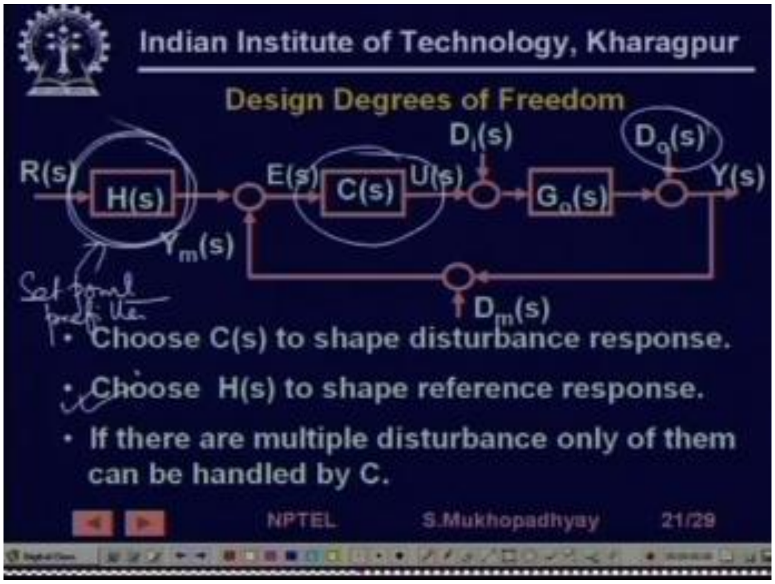
So this is what it says, it says that this is the transfer function between Y(s) and R(s) and this is the transfer function between Y(s) and D_0(s) so you see that if you if you choose C(s) this gets fixed suppose, so you suppose you choose D(s) C(s) to design your disturbance response then your set point response is fixed you cannot change it, so you have only one degree of freedom you can only set the response to one variable right.

(Refer Slide Time: 45:19)



So or vice versa if you are choosing C(s) to get a particular reference response than your then your disturbance response is decided.

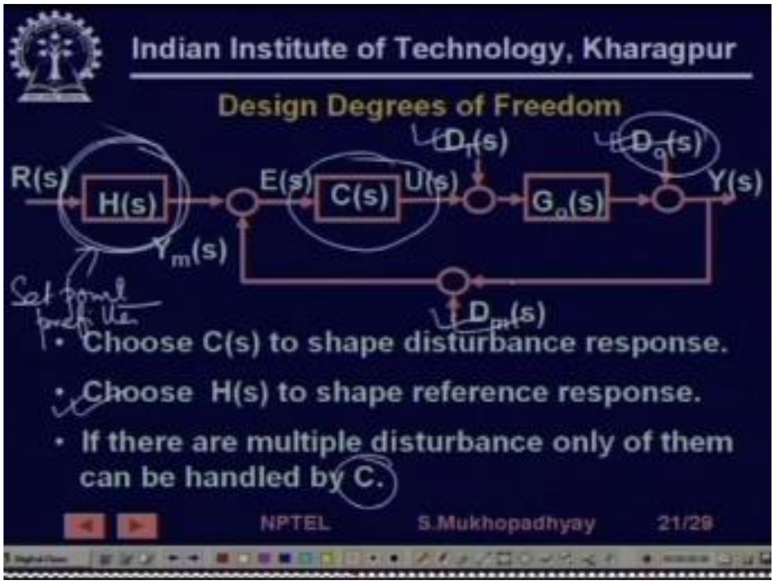
(Refer Slide Time: 45:34)



Now you could you could improve the improve the situation by having this, so for example in this case there are two degrees of freedom why, because you have introduced a set point pre-filter this is called a set point pre-filter. So what you are doing is you choose C(s) to assign a response to D_0(s) and then once you have done that then you choose H(s) to assign to shape the reference response.

Although there are constraints still you cannot have arbitrary responses realized to this structure but still you have now created two independent avenues for shaping that reference as well as shaping the disturbance. But remember that still you do not, you if you choose only one C.

(Refer Slide Time: 46:36)



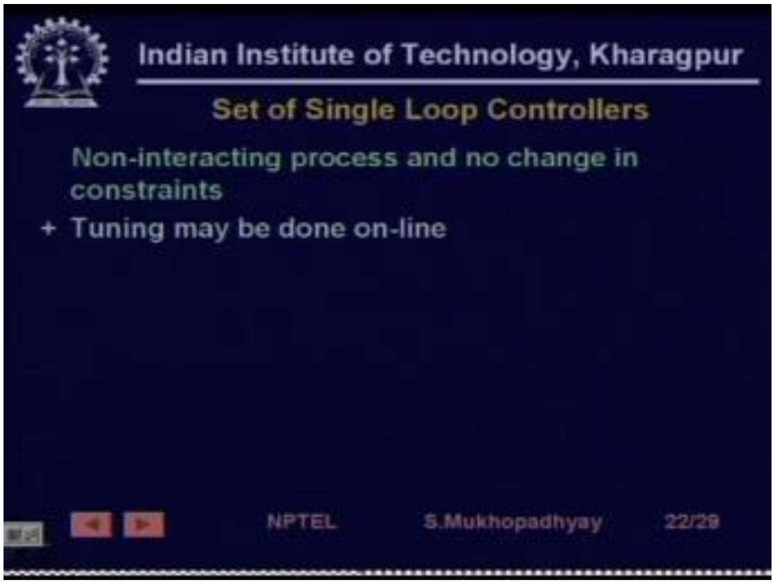
Then you cannot shape your shape your response to D_0 and D_i and D_m simultaneously, you can do it for only one of them right. So you are these have to be realized to be able to choose the control structure so if you really so this tells us that if we want to assign independent disturbance and reference set points then we cannot use the conventional control structure, because that is one degree of freedom right.

(Refer Slide Time: 47:11)

So similarly suppose we are we have two options we actually have to simultaneously control a number of process variables. So we have options so what are our options that either we could use a set of single loop controllers that is manipulated variable A controls variable B manipulated variable C controls variable D, so A to B one single loop controller give feedback of B and drive A, if feedback of D drive C so you have a number of set of single loop controllers.

Compared to that you could what is the other option, the other option is have one big multivariable controllers which will take all the feedbacks and which will drive all the actuators and it is a multivariable system, this is more modern. So when do you do what.

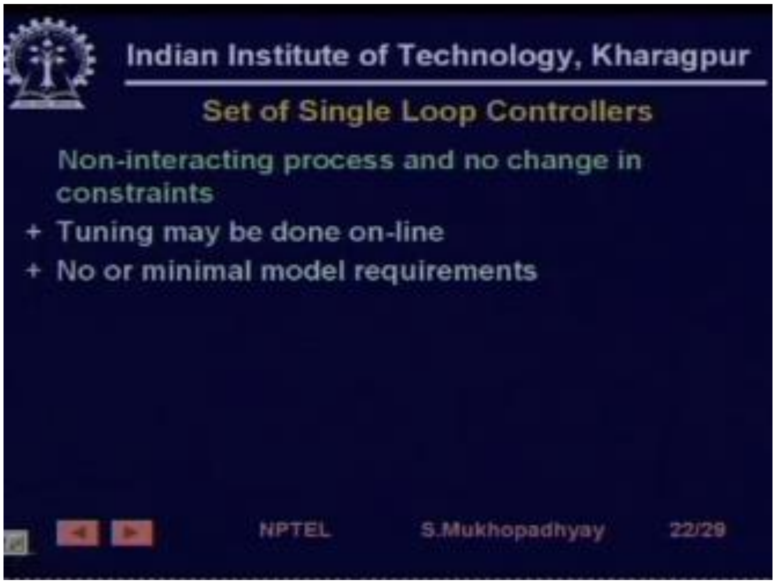
(Refer Slide Time: 48:00)



So you have to have non-interacting processes you see that you are actually very well if you have a single loop controller then when you are trying to control one process one variable you are not you cannot take care of the fact that a there are change in this variable can cause a change in another variable this fact cannot be considered so if there is interaction between the variable dynamics then set of single loop controllers can be very problematic and should not be used.

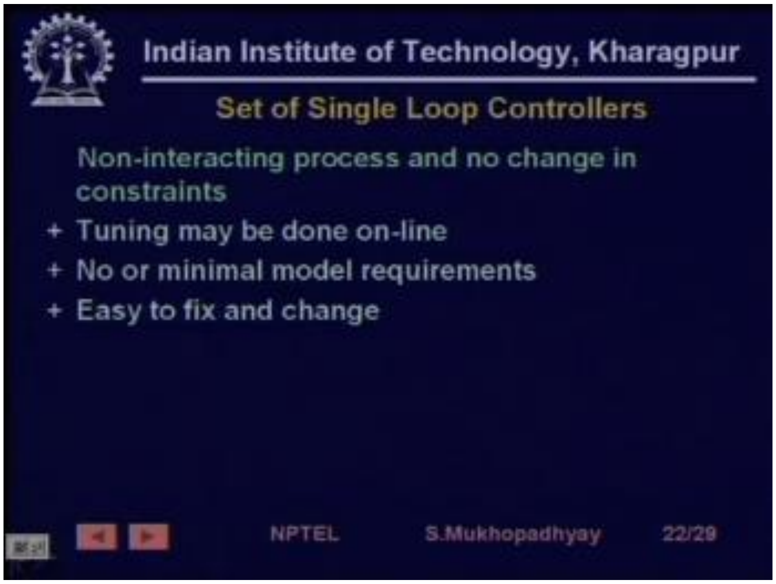
Similarly you may have to maintain constraints over several of these variables but then each controller is actually controlling only one so then if you have such constraints which keep changing then is very difficult to use this set of single loop controllers.

(Refer Slide Time: 48:48)



So I mean on the other hand tuning is very simple there are some plus points that is you need to you in fact there they are used and they you can use it in various situations where there is not significant interaction or constraints changing dynamic constraints so you need.

(Refer Slide Time: 49:06)



Your modeling requirement is low you can build models by simple experiments they are generally simplicity general plus points are simplicity on the other hand you need to determine Peary this is very important this which manipulated variable you will choose to set up a loop with which for which controlled variable this is called Parry you know pairing outputs two inputs so this is this is an this is an interesting point and people have various methods we did not study them but this needs to be done.

(Refer Slide Time: 49:38)

Similarly it turns out that you have performance loss you cannot achieve such control such good control as you can with multi variable control and when we have active constraints then you have you have very complicated logic you must have above these set of single loop controllers you must have supervisory logic which will look at all these single loop control as and probably carefully manipulate the set points.

So such logic such additional logic is required so all the comp it is not that simple on the other hand if you have multivariable controllers.

(Refer Slide Time: 50:18)

Then in process interactions as well as constraints are handled very seamlessly actually things like you know MPC model predictive control which are very popular in the industry today are our control methods we did not study a busy our methods which are designed to handle multivariable processes with interactions and having constraints so they are all built in into the method and they are handled very efficiently. Alright, so you have.

(Refer Slide Time: 50:51)

Significantly improved performance in presence of interaction you have easy handling a feed forward control again feed forward is you know tends to make the system multivariable you have easy handling of changing constraints as we have mentioned and it requires a multivariable dynamic model tuning is obviously difficult much more difficult than a set of single loop controls difficult to understand less transparent and this is important thing that that failures can be very damaging.

So what happens is that is you know you know you have put you have put the loops now into one box so if that box fails then the complete controls for your process is lost this is a this is this needs to be understood and so this could be a major reliability threat having a multivariable controller so sometimes you need redundancies.

(Refer Slide Time: 51:44)

Performance in a in a control loop gets can be limited either by sensor noise limits the close to bandwidth if you increase the close to bandwidth the noise will go to the output if you have sensor bias this we have discussed exactly same bias especially in unity feedback control exactly same bass will appear at the output.

(Refer Slide Time: 52:07)

Sensor dynamics you know sometimes some sensors for example thermocouples they are they not directly put into the process they actually put through a well so that well too for the temperature to for the heat to flow through the well it takes time constants and such time constant can cause stability problems right.

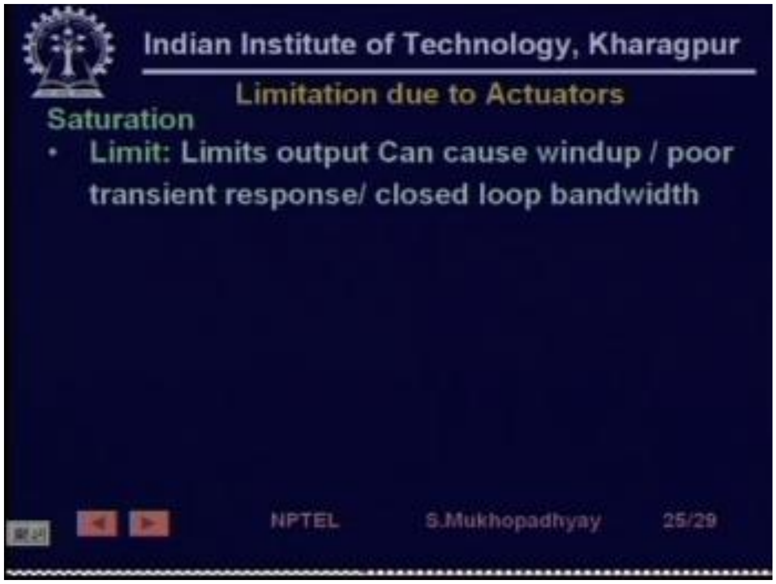
(Refer Slide Time: 52:27)

They can be sometimes cancelled by high-pass filtering but again that will build up noise so there is no escape you have to pay prices sensor non-linearity you know sensors if the senses are non-linear for example tell let us take a orifice meter sensor it has a it has a square root law in its basic sensing mechanism so as this so if you take it as a linear sensor then what happens is that the process gain keeps changing depending on where you are operating.

If you are operating at hundred percent flow then there will be one process gain if you are operating at twenty percent flow there'll be another process gain so the so the controller gains needs to beset conservatively so you will have to, for stability considerations if you are setting a constant gain controller then you need to set the gain which will work for all the processes without all the process gains without causing oscillation.

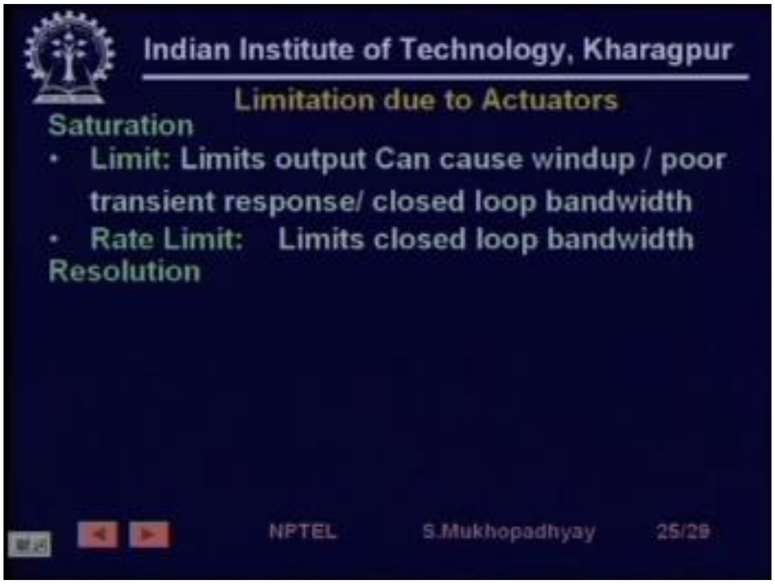
So obviously now the now you will set the gain low and when the process gain will become low then it will lead to sluggish behavior sometimes this can be very nicely cancelled by having an inverse on-linearity in the actuator so that overall loop the sensor non-linearity gets cancelled by the actual neural net actuator non-linearity and in fact it happens by using valves because valves have inverse non-linearity sometimes we are going to see all these later.

(Refer Slide Time: 53:51)



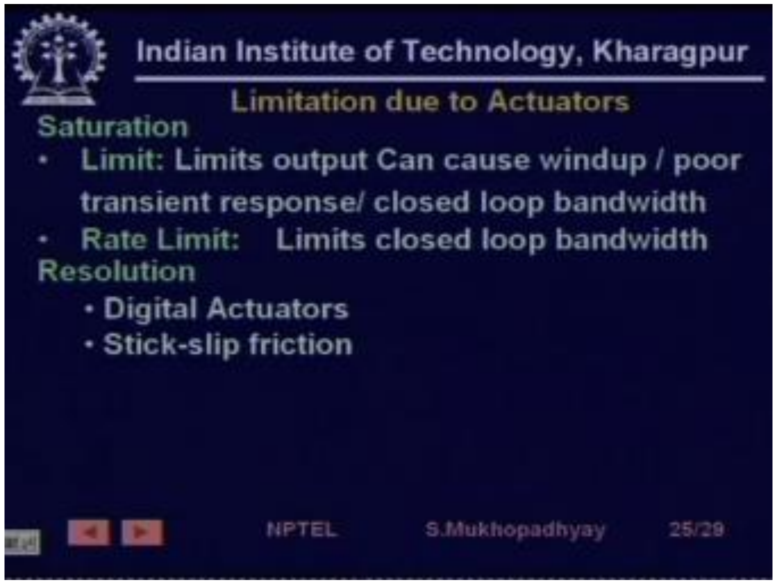
Similarly for actuators you can have saturation will actually limit transient response because you are not I mean how do you move a system fast by giving it a lot of input and by giving it fast.

(Refer Slide Time: 54:04)



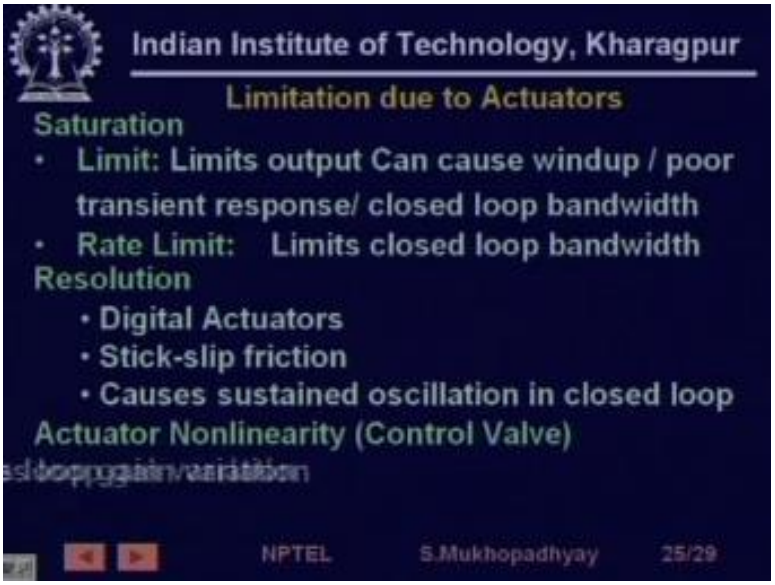
So you need good input and you need rate limits you need high rate limits that is you can jack up the input very fast so if you have any of these limits then you cannot push the plan hard enough and you lose intransient response as or close to bandwidth.

(Refer Slide Time: 54:21)



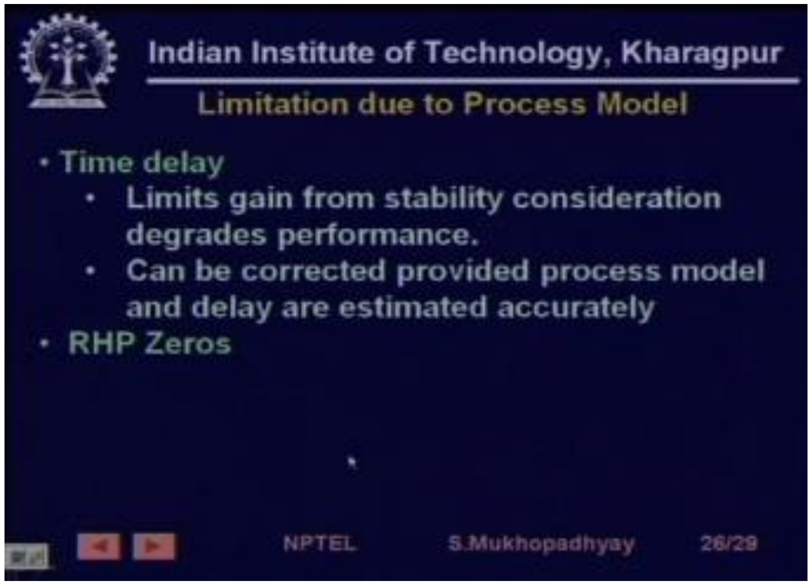
Similarly the sometimes resolution you know some actuators cannot make small movements either because of you know stick-slip motion so if you they move it they will move and then they legged get started so for such if you have such stick-slip motions then the then the actuator cannot actually because of resolution it keeps oscillating so it will move there will that is actually too much correction will come back again it will move there. So it keeps on doing this and that causes you know oscillations so typically.

(Refer Slide Time: 54:51)



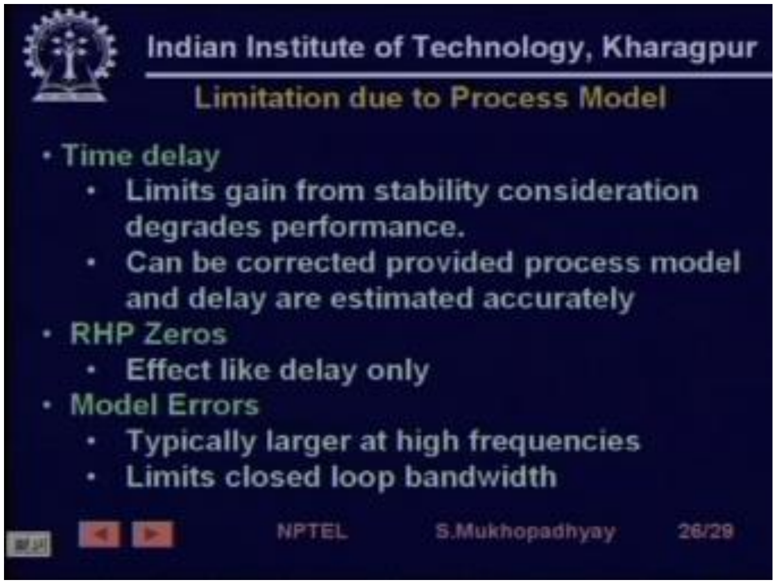
Such resolution problems are caused either by detail actuators like step motors or they could be caused by sticky-slip friction and the effect is that it may cause a strain oscillation in closed loop similarly actuator on-linearity we have already mentioned this.

(Refer Slide Time: 55:09)



Similarly the process models this we have already seen time delay causes stability problems and degrades performance gain has to be kept low and if the time delay the process parameters are known accurately then some of them may be corrected it is very difficult to know it accurately and the process model also keeps shifting right.

(Refer Slide Time: 55:27)



Half-plane zeros are like delays and model errors so remember that models model errors are always high in the high frequency zone so increasing the bandwidth you are going into the uncertain soon.

(Refer Slide Time: 55:42)

So you need to limit the close to bandwidth such that the models are fairly accurate so here we have come to the review we have reviewed controller implementation.

(Refer Slide Time: 55:50)

In under that control structures control algorithms you have seen the PID equations and the control hardware and the software we have also seen looked at control performance and seen that what kind of performance can be expected is reasonable to achieve we have seen the various kinds of plant dynamics and constraints that can affect control performance and we have seen the hardware and software features which will limit performance that is of course algorithms.

(Refer Slide Time: 56:20)

(Refer Slide Time: 56:21)

So you might ponder on these questions for example what kind of processes single loop control is likely to be effective so can you give an example some typical features of an industrial controller or can you state the different forms of the PID control law and make their conversion. For example, three-to-one form three to form one we have not yet done can you can you look at that explain in what ways a sensor can limit control performance and sensor or actuator and compute the degrees of freedom in a heat this is a nice problem so compute the take a standard heat exchanger with bypasses on the autumn the cold flow put valves on them and then try to compute the degrees of freedom so that is all for today, thank you very much.