**Industrial Automation and Control**
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**Lecture - 13**
**P-I-D Control Tuning**

Good morning. So, today we are going to have lesson 13 of the course which is on PID controller tuning.

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As we will see that controller tuning is very important phase of the overall controller design, and it very critically determines the performance of the control loop which in turn affects the overall quality of the product affects costs. So, it is a very important method to be learnt in the in the overall context of industrial automation. So, before we get into the business proper, let us first see what are the instructional objectives of the core of the, of the lessons as is the usual practice.

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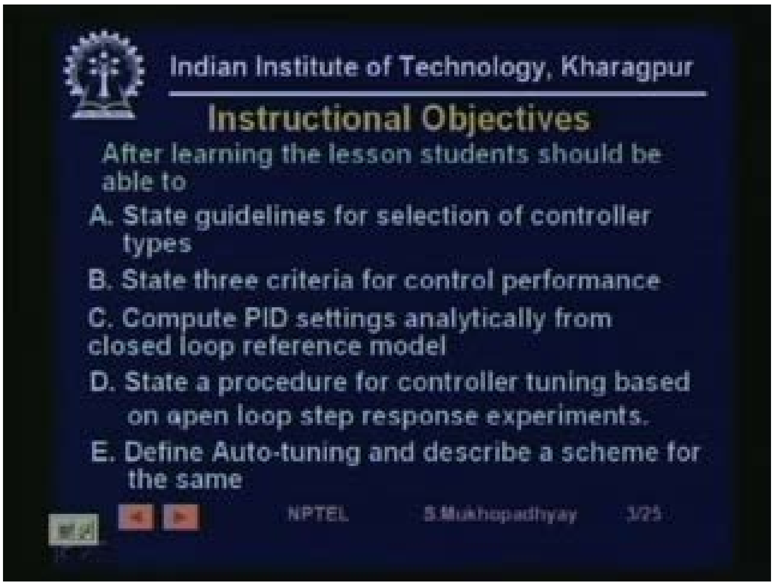


So, as we state in every lesson, after learning the lesson the student should be able to, firstly state guideline for selection of controller types. When I said PID controller, I actually mean a class that is a 3 classed of controller that is P control, PI control and PID control, which are most often used in the context of industrial automation.

So, the student should be able to select one of these types now, once he selects one of these types, he or she should be able to assign the various parameters in that controller like gains, integral times, derivative times, etcetera. So, in this lesson we are going to look at various methods of doing that, and all of them will affect control performance in various ways so what will be the values of these settings actually depends on the control performance.

So, there are various criteria which can be adopted depending on the application and the student should be able to state let say 3 of many criteria, then he or she would be able to compute PID settings analytically. First, actually solving out the controller parameter values, and in some cases where exact solution is not possible sometimes we because a reference model is not may not be available, so we sometimes set controller parameter settings based on experimental data and there are 2 basic approaches. One is on, one is a one is an open loop approach, which is based on step response, so should be able to state procedure for doing that, and the other one is for closed loop.

So, that one is also should be able to do that also. And finally, there are certain cases where we need to online while the plant is operating without performing a special very special experiment for a long time or whether we can quickly perform an experiment to set the gains of the plant when we think that the plant characteristic has changed that is called auto tuning.

So, the student should be able to define what is auto tuning, when it is needed, and describe a scheme for the same. So, having the, so these are the basic things that we are going to discuss and that one should be attention to, so having them that let us first look at the concept of control performance.

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If you take a bird eye view it is very important to understand that, control performance directly affects product quality. Whether, it is a chemical process control, whether it is a steel plant, it will always affect product quality. And the basic objectives is to meet specifications as stated every plant every product has a stated, has some stated properties and their limits.

So, we should be able to meet them if we have a violation of that, then our cost goes up because in today's era of stringent quality control we may produce something in the factory, but we may not able to sell it if the status specifications are not met. So, that means, there it will resulting things like scrap, lot of loss of material energy, so the cost will go up.

On the other hand if you try to do try to over satisfy, then also cost may go up because we may unnecessarily require more sophisticated equipment and or more refined raw material. So, the basic objective of control is actually to meet the specifications as stated, neither violate it nor try to satisfy it beyond the levels of specification. So, having said that let us see that how the performance of a control loop in various applications can actually decide the product quality.

So, we are looking at the quality determinants, for example, let us took at a rolling process right? So, if you have a rolling process what is happening is that, actually if you see in a rolling process there are 2 rolls, right? And some material some plate comes in with some thickness and when it goes out it has a lower thickness.

So, there is a, so there is a dimension reduction through the rolling that is the job of the rolling process. Now obviously, you would like to strictly control the diameter of the, of your finished product which depends on, so many things for example, it crucially depends on the roll gap. So, if you have now you always state that your, that your product is going to have a thickness within some plus minus limits.

So, whether a whether a product is going to violate your specifications actually depends on the maximum that is the maximum amplitude of the error. So, if the, so if the roll gap is suppose to be d, and if the roll gap d star let us say and if the actual roll gap is d then that will lead to an error in the final product thickness. So, in this case the amplitude of the error, the amplitude of the error actually decides product quality.

Let us look at another example, so in that example suppose we are to looking at composition control in a petroleum refinery, so what is the product there? The product is some hydrocarbon fuel let us say petrol or let us say kerosene. Now, after the product is produced it is going to be stored in some tanks. So, and then finally, after the tank gets filled up it is going to be transported to the, to the customer eventually.

So, now what is the, so the properties of the product which you properties of the product in the tank is actually an depends on the integral of the error because, suppose we are talking of octane number. So, suppose sometimes octane number is going a little high for some time when you are producing, sometimes it is going a little low. Now, all that product is actually going into the tank and they are getting mixed. So, the, so the finally, the average octane number is what you are going to specify.

So, in this case it is the integral of the error that is the deviation from the octane number that we are trying to produce which is going to be important in determine in determining the final quality. So, in this application it is the, it is the error integral which is which is of crucial importance, and while designing the loop we should try such that the error integral is actually minimized.

Similarly, if you take another example, let us take an example of you know pH control in a in a discharge stream of some, so chemical process. So, in today's strict environmental regimes, it is stated that whatever effluent you are suppose you are releasing some effluent into a, into a river then the pH factor that is whether it is acidic or basic or neutral, should be as close to neutral as possible and it should be neither acidic nor basic.

So, now remember that there is no, there is no averaging strictly speaking because, of the fact that there is no tank you are actually directly realizing the effluent into the river. So, if you are, if you are product is has positive error which might mean that it is acidic, then also it is bad and if it is negative error then also it is bad and in this case positive error does not cancel negative error.

So, therefore, in this case choosing an error integral will not be proper because, you cannot release effluent you cannot release, acidic effluent for some time and then release basic effluent for some time and then say that my, that my integral error is actually 0, that would not be proper. So, for such a process we should rather try to ensure that the integral of the error that is the absolute value of the error, integrated over time should be minimized, right?

So, in these examples we see that depending on the application, we have to choose different performance criteria based on typically based on errors, right? So, next, so having said this let us now see how we are going to do this, right? So, first of all in the, in the PID controller tuning process even before you want to tune the tuning the parameters, you have to do a do what is known as selection of controller type, that is you have to determine that whether you are going to use a P controller or a PI controller or a PID controller. Always you should choose the simplest controller that you need which will suffice, right?

So, we want see that when the, when is P control good enough, when it is not good enough and we must go for PI, and when that is also not good enough and we must go for PI. Only thing you must remember that before doing the selection of controller types, it is assumed that we have already selected which one is the manipulated variable. Because, sometimes there are, there are situations where you can, you can achieve a same control performance by choosing different manipulated variables. I mean a very typical example would be let us say, if I try to control the temperature of the room in which I am, I am right now sitting and giving this lecture, then it is an air condition room and suppose I want to maintain the temperature of this root.

Then there are 2 ways that I can do it. That is either I can take a constant temperature air, and depending on the heat being produced at present in this room, or depending on the temperature error I can try to send more or less volume of air per second. So, I can either try to control the volume flow rate or I can try to control the, or I can say that no I will not control the volume flow rate,, so I am going to run the fan at the same speed, but I am going to control the temperature of the air which I am pushing in.

So, you see that the temperature of the room which is the controlled variable, can be controlled either by selecting the flow rate of air as the manipulated variable or the temperature of the air as a manipulated variable. So, here we are assuming that this kind of selections have already been done and now, we have the look fixed only we need to select the controller types and then the controller parameter settings in those parameters.

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So, let us first look at the P control now, we already know that P control leads to offsets in most cases. So, obviously, you can use P control only when that offset is acceptable when with feasible values of the gain, what is it, what is you mean feasible value of the gain? You can always, you can always say that I can always, I mean increase the gain, but you cannot. You cannot increase the gain basically for reasons, one reasons is stability. If you increase the gain too much it may happen that the process will become unstable. Second thing is that you often have actuator constraints. So, even if you increase the gain is, it may happen that you are not able to give more input to the process.

So, we will assume that with the feasible. So, P control can be used with this when the offset that may arise with a feasible value of K c is acceptable. Second case is as we have seen that mean, some processes let us say, let us say a tank, we have seen that the condition for a 0 offset is that the overall loop gain should have one integrator at least in the loop.

So, that integrator can be included either in the controller or it can be included in the plant. So, if the plant if the plant already includes an integrator, then even with a proportional controller you will not get any offset. So, in such a case typically in liquid level control, gas pressure control where you have a, when you have a tank and you are putting in fluids you the plant has an integrator. So, in such cases a P control can be used.

So, you have liquid level or gas pressure control and now, the, so the point is now when there are situation for example, in liquid level or gas pressure control, not only that you always have an integrator actually, that depends on whether there is a whether there is a constantly I mean there the fluid is also being drained. If the fluid be, if the fluid is being drained then it will not be a, then it will not be an actual integrator, but in such cases it is often the case that the control of the level is not that critical that is the, there is a steady state error we have seen that the steady state error that results in a P control loop actually depends on the load.

So, since the since, the load is since the load is not exactly in our control. So therefore, it may happen that the steady state error keeps changing little bit. But in many cases we especially when we have tanks or we have cylinders our only objective is that the gas pressure or the liquid level does not fall below a certain limit. So, as long as it varies little bit within that limit it is generally considered acceptable.

So, in such cases also even if the plant does not include an integrator, having a proportional control is ok, but there are various situations where an a steady state offset cannot be tolerated, in such a case obviously, you must go for PI controller. So, PI control is to be considered when P control results in an unacceptable offset, right? So, you do not want any offset and therefore, you would, you would like that you would like to use PI control because you know that, then you are, you can exactly ensure 0 steady state error.

Now, as we have seen that what happens generally in PI control especially, is that the loop generally stabilizes because, of the eye action the loop generally tends to oscillate and it take some time to settle,, so in that sense the loop becomes little sluggish. Now, the point is that suppose let us look at this. So, suppose you are having considered the step response, so this you are new set point which has been changed and the plant under PI control is oscillating like this and then finally, achieving 0 steady state error.

Now, the question is that when is this, when is this oscillation acceptable? This, these errors when are they acceptable? So, obviously, you will find that they are acceptable when see the set point every time there is a set point change such an oscillation will actually result, it will die down and then from then on after it dies down the loop will exactly achieve 0 steady state error.

So, if this interval, this interval over which there is some errors is actually small compared to the frequency of set point changes, then you can say that ok, even if during this period I have some error and my control performance is may be affected depending on whether have if I have an integral error criteria. Then it will be less affected because, this positive error is going to cancel this negative error, but even then I am able to tolerate this much of error because, of because, it is going to die down reasonably fast for me and then it will stay on for a long time, right?

So, in a such case, so in other words the this interval is actually small which means that the that the open loop dynamics actually fast enough it is fast enough, compared to what?

Compared to the frequency of set point change, and, so that the closed loop transient response is actually acceptable. Typical example is flow control.

In flow control the step response is actually very fast,, so therefore, even if you include a PI controller and it little bit osculates for some time that interval suppose, you are trying to control temperature with flow control, which is very common try to increase or decrease the steam flow rate to maintain the temperature and the reactor.

So, the reactor temperature set point change will be, so in frequent compared to the, compared to the settling of the flow loop is that in I mean in such a case PI control is generally considered adequate enough, but there may be some situations where this is not the case and the plant itself is supposed to be slow and then slowing this further is not desirable. So, in such a case what you have to do is now, if you want to make a plan faster you will have to increase the gain. Now, increase the gain in a PI control will actually…

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take it closure to instability. So, therefore, you have to correct for that additional phase by adding derivative terms, as we have seen. So, now what we do is that we want to have both sides of the coin. We firstly, we want to have good steady state performance in the sensor we want to have 0 steady state error, we know that we can get PI we can get it from PI as well as PID control, but we also at the same time we want that my transient response typically to a to a step input is better than the PID controller.

So, in such a case the slow down by the PI controller which is which is unacceptable, that can often be realize using a PID control because, of the fact that you have a derivative term and because of that you can actually have larger gains. So, typically for you know for multi capacity processes, where you have, where you have to control temperature, then you temperature or composition control that is why you use PID control. Because in any case you do not want to lose out too much on the transient response to gain the advantage in the steady state response of 0 steady state error. So, these are you know broad thumb rules of selecting P, PI or PID controls. Now, we come to the, if having selected these controller settings these controller types, how do we select a particular controller setting?

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So, there are, so there could be various ways for example, the first one is that if you suppose, somewhat I know ideally suppose you assume that the plant model processed plant model is exactly known. It can be nicely expressed by a transfer function, also another thing is known that is the closed loop reference model is also known which means that the open loop plant is know very accurately and our control requirement also. We can express it in terms of a reference model that is we can say that after control I want the closed loop plant to actually behaved like another transfer function, right?

So, once we can do that, then you see we can you can sometimes from these 2 requirements of we can solve out the controller, right? So, this method is applicable only we have the process model of sufficient accuracy available. You have a you have closed loop desired behavior can be described by a reference model, and then if you can if you have these 2 conditions satisfied then analytically the controller parameters can be solved from the above 2 models, how?

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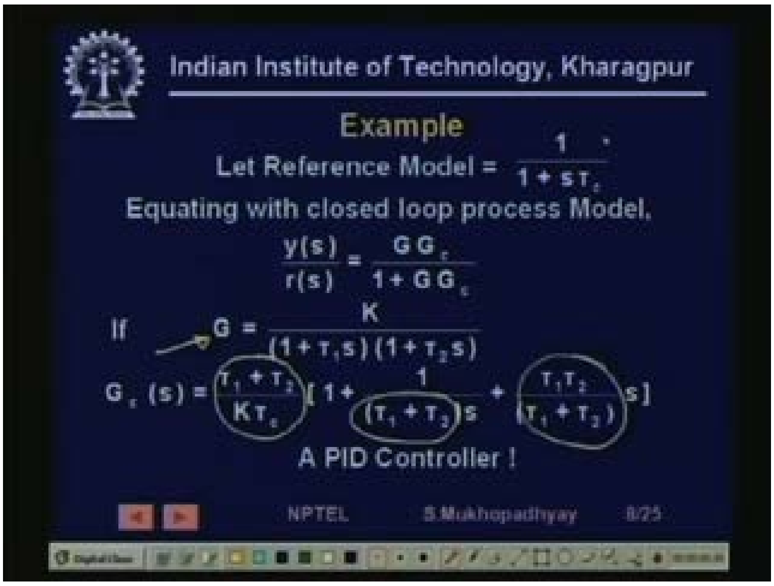


So, we have an example, in this example, let the reference model be 1 by 1 plus ST c. So, it let us suppose, I want that the closed loop plant actually behaves like a like a first order process with some time constant T c. Now, if I also now, what is the, what is the closed loop process model transfer function?

We know that it is given by GG c by 1 plus GG c this is I mean one of the elementary facts of control theory where G is the transfer function of the open loop plant and G c is the transfer function of the controller which is in the which is in the forward plant, and we have unity feedback. So, now so now I obviously, I want that this transfer function, this transfer function this transfer function GG c by 1 plus GG c must equate this transfer function.

So, if I equate them and then what I find is that now, if the now, what is the plant? So, I said that the plant model to be known,, so I am I am assuming that the plant in the second order process over damped it has 2 time constants, one is T 1 and T 2. Typically, they will be larger that T c, will be control something we want to make it response generally we want to make it response faster. So, T c is going to be smaller than T 1 and T 2. So, after solving this, what we will, what kind of a G c shall we get?

So, it turns out that if you solve this equation that is GG c by 1 plus GG c with G this value of G and this value of the reference model, then it turns out one can easily solve that the controller transfer function comes out to be this, right? So, now you can immediately see that this becomes your KP. So, this becomes your KP, this becomes your PI and this becomes your TD, right?

And in very interestingly see we did we never said that we never said that we actually want a PID controller. We just wanted to, wanted this plant to behave like this model. It turns out that for having that the controller that you need is actually a PID control. So, it is very good. So, you see PID controllers can give you good response, right? So, this is, this is a rather simplistic way of doing things and depends on, so many things like you know more often than not people may not be able to express their model behavior exactly like this or may not be exactly able to give a reference model.

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So, such a such a simple procedure may not always be applicable, but what people do is that they do state certain rather than stating a complete reference model they often state some behavioral parameters of that reference model.

For example, they can state that in the step response, of the closed loop model I want an over shoot which is generally stated as lower than something, maybe I want less than 10 percent. Or you can say that I want less than, so many seconds or minutes of rise time, which means that if a if I make a step change it will quickly rise to that value. You may say that I want less than, so much of settling time which means that after that after the after the settling time, we will get nearly 0 error or you can say sometimes you can say that I want to certain K amount of decay ratio.

Now, what is DK ratio? DK ratio is, so you see that if you have a step response typical step response, closed loop plants are typically have exhibit an under damped response. So, our requirements may be based on terms of the over shoot, this is the first one. It may be based on some 10 percent to 90 percent rise time, which is this time. It may be based on a settling time which is this time, or it may be based on a decay ratio which says that, what is the ratio of the first overshoot to the second overshoot? That is this divided by this second overshoot by first overshoot.

Now, if the DK ration is small, it means that even if you have a, even if you have a first overshoot which you which you which is slightly large, but it quickly comes down. So, the ratio of second to first will be let us say, if you require 25 percent there will be one-forth, then third to second will again be one-forth. So, which means that you are error is rapidly converting to 0. So, in some sense it is good.

So, you see that such things are often required, otherwise in various other controller designs. Obviously, stability is the consideration and we have our well know gain margins and phase margins, which are basically protections that the, that the loop will not oscillate. Even if the, even if the process gain changes by little bit or the, or the overall loop phase changes by little bit because, process models based on which we are going to calculate the controllers they will not be exact. So, these are you know some of the common simple response parameters and stability parameters which are often considered in designing in designing controller settings. So, let us let us see how? So, one example.

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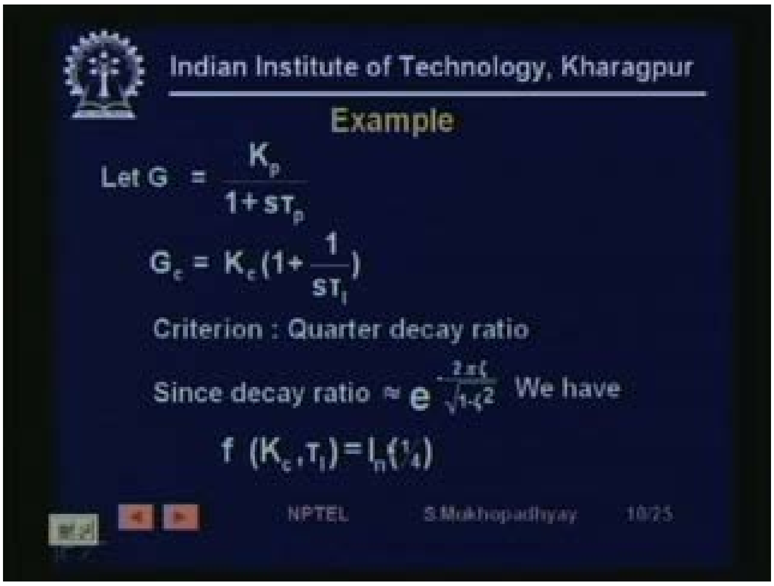


For example suppose, I have a plant which is K p by 1 plus ST p. I am considering very simple example, if you have more complicated examples they actually the solution process becomes more complicated, and you need numerical procedures for actually solving out. But in essence the method remains the same, and suppose, I am considering a PI control I have already selected a PI controller. And I want to set the value of K c and T i. Suppose, my criterion is quarter decay ratio; that means, the second overshoot the ratio of the second overshoot to the first overshoot will be point 25 to be, right?

So, it turns out that t K ratio will be given is actually it given by this formula. So, this value should be should be less than point 25 which means that the we can we can just simplify matters of solutions by saying that saying that the saying that the log of the decay ratio, we can take log on this side. So, we can have you know l n of the decay ration is approximately equal to this is gone then approximately equal to this or equal to let us say, so now, so this I want to be equal to one-forth, right?

So, this becomes equal to l n of 1 fourth. Now, what should be the value? So, what I have to find out essentially is what should be the value of this zeta, such that this function evaluates to be less than l n 1 fourth. Now, what is zeta? So, if I compute GG c by 1 plus GG c, then I will get in the denominator, I will get some parameter in the form SS square plus twice zeta omega and S plus omega n square.

So, we it will it will turn out that omega n is also a function of these parameters and zeta is also another function of these parameters. So, this zeta is going to be some function of K c and T i. So, that is what we are saying that if you try to solve this finally, it turns out to be an equation of the type will get an equation f of function of K c and T i is equal to l n of 1 fourth.

So, now we got one equation, but we need to find out 2 parameters. So obviously, we cannot find the unique solution there are actually many solutions. So, which means that to be able to find unique solutions we need to have some other criteria. So, we can actually accommodate some other criteria.

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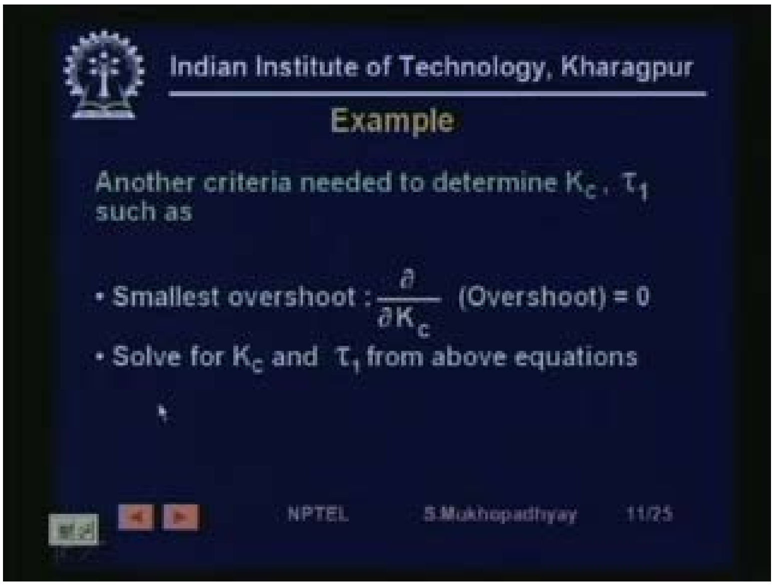


For example, if we consider in addition. So, we have another criteria needed to determine K c and I am, I am sorry about this one. So, if I if, so I need another criteria and then suppose I could use various kinds of criteria. So, for example, one another criteria I could choose is that smallest overshoot I will choose that value of K c which for a given value of T 1 gives me the minimum overshoot.

So, I am I not only want that the overshoots will decay fast, I also want the first overshoot to be small. So, that I will reach settling time will become even smaller, right? So, if I want to do that then I will I will take the overshoot function and then I will differentiate it with respect to K c, and then set it to 0 that will give me another equation. So, now I have 2 equations and I have 2 unknowns. So, now, I can solve for K c and T i.

So, you see you, so it is essentially stating properties of the closed loop function, then expressing them in terms of the unknowns that is the gain various times of the PID setting and then solving those equations. This is the, this is the essential procedure.

So, these are you know direct solving procedures and now we see that it is not always that we are going to state them in terms of you know this kind of overshoot or settling time or decay ratio. There are various other ways that we can that we can specify control parameter performance and essentially numerically we have to solve out the various parameters.

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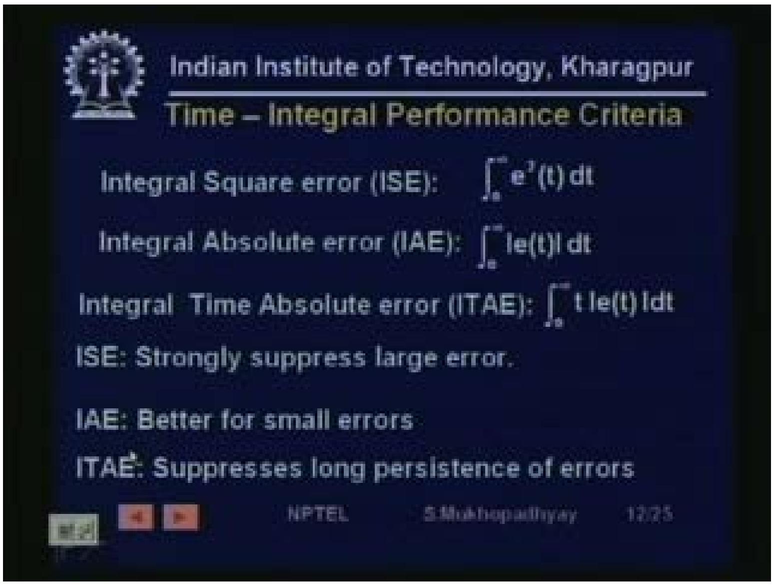


These are generally not able will not be able to solve them analytically in such cases excepting some rare cases. For example, we can select that the integral square error that is after a step response is generated there will be error. So, if I integrate the error, the error will eventually come to 0. So, if I integrate the error the square of error, then I should choose such values of gain such that this function is going to be the least.

Now, why should I choose a square of error? Why not cube of error? Why not whole to the power 4 of error? Generally square of error is actually very popular because, in what because of 2 things. First thing is that in square of error we are able to weight higher error, that is we are saying that if you commit an error of two, you are four times better than if you commit an error of four. So, double errors if the error magnitude goes double, then the control performance criterion, which is to be minimized goes four times up. If you go 3 times you will go nine times up, which means that we are heavily penalizing large errors.

So, when we want to heavily penalize large errors, we generally choose powers of e, and square is chosen because the square criteria generally leads to very you know, nice solution equations. Because, by differentiating square you get linear equation which are very easy to solve. But in some cases, as we shall as we have seen that in the case of the pH control of the water discharge system, we may be interested in and if you are not interested in, not interested in penalizing high errors too much. Then, we may choose integral of absolute error sometimes you may like that fine let there be error initially, but let they error not persist.

So, in the which case, I can choose what is known as an integral time absolute errors where you can see that if an error occurs earlier after the step change it is not penalize so heavily. But if it occurs later as time goes high the same amount of error is more and more heavily penalized. So, what we want is that if you want to have errors even large errors have them in the beginning, but after that step change within certain times the errors must quickly converts to 0. So, the errors must not persists for long times.

So, this is what we are saying. So, that is what this says that the integral square error strongly suppresses large errors. The integral absolute errors are better for small errors because, in small errors e square t becomes even smaller. So, the smaller errors are not penalized. And in ITAE what we want is that we want that quickly errors converts. So, we want suppressed long persistence of errors.

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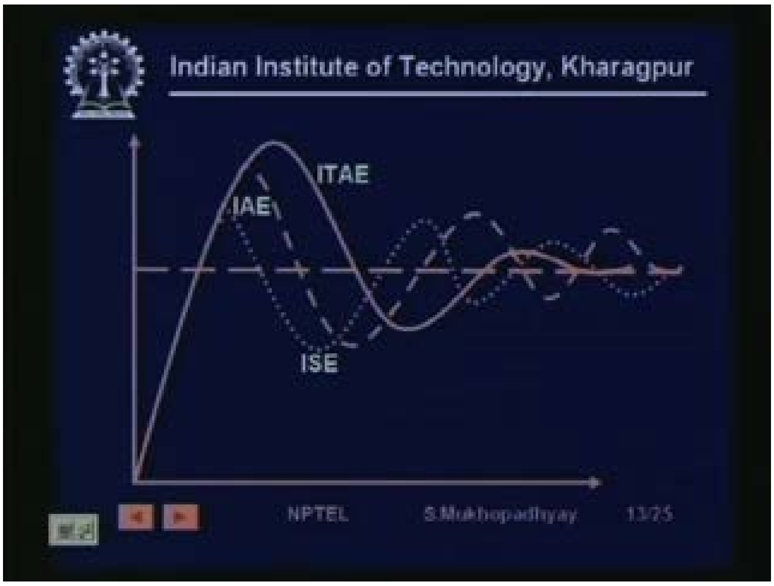


So, for example, if you took a typical this is, this is a typical waveform that if you took step. If you took a control loop which is designed based on ITAE it may, so happen that you will get that you will initially get a high overshoot. But it will probably die down faster, because that is what is penalized heavily.

On the other hand if you take an IAE, if you if you compare between IAE and ISE you will find that in ISE error magnitudes are going to be less than IAE because in, because in ISE bigger errors are actually heavily penalized. So, the, so the error will not rise very much, but it, but it will, it may not fall,, so fast also that is when it reaches the, when it reaches the low level it may persist for long times. So, this is what happens if you, so depending on the your choice of your performance criteria and you can get different kinds of transient performance in the loop.

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So, in the remark we are saying that sometimes we have more than one criterion some time criterion may be conflicting also. If you want to increase, if you want to cut down on rise time you generally have to increase the gain too much, if you increase the gain very heavily then you tend to have very large overshoots. So, having a small rise time and having a small overshoot are generally conflicting criteria. So, you have to strike a compromise.

In many cases what will happen is that you are criteria may be stated in terms of inequalities, so you actually have a feasible region in which you can you can operate. And in many cases so when you have complex processors. And you have complex performance criterion, the calculation of the gain may require large amounts of you know, numerical trial and error over you know if using sophisticated optimization algorithms which search for a good value of the parameter over some feasible space. And therefore, you need software and various kinds of tuning software actually sell from the manufactures.

Now, all these that we have so for talked about generally, employs assumes that the that model forms are available. But in, but in many cases you may not exactly be able to obtain a the form of a model, and then you must model the process using some simple model structure and based on some experiments. So, you actually perform an experiment, see the response measure certain properties of that response and then design your controller based on that, right? So, typically you can have either open loop response, open loop experiments or you can have closed loop experiments. So, we are going to look at these two.

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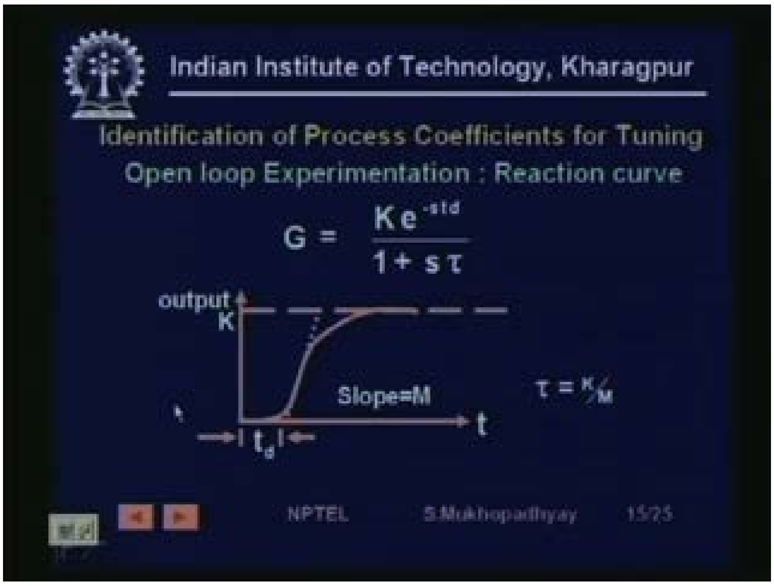


So, for example, if you a typical very popular way of open loop experimentation is the reaction curve, that if you take the open loop plant which is typically of this assume to be of this shape, but it is not directly in the in the experimentation this form is not used. So, you do a do a step response experiment, so the output is going to rise this is for the open loop plant. So, the output is going to rise like this.

So, now numerically you find out that typically in this model if you consider the step response of this model, then this step response will actually rise after a time t d because, of this e to the power minus std term and then it will rise just like a first order system K by 1 plus S tau. So, the slope of this line the slope of this line is going to be given by K by that is M is equal to K by tau or rather tau is equal to K by M.

So, perform an experiment assume that the plant is of this form which is which is the reasonable approximation for actually many plants. And then measure out what is the value of t d and then what is the value of what is the slope M. And based on the slope M and the, and the final settling value which will give you the value of K.

So, now after the experiment you know this t d you know this K and you know this M. So, now you then based on this people have various kinds of empirical rules. Empirical rules means process control experts have actually done through their experience by many simulation and experiments actual experiment they have given some thumb rules that, if you find that K is of so much value, and M is of so much value, and t d is of so much value, then use. If you are using a P controller use this value of gain, if you are using a PI controller use this value of K and this T i. So, there are certain rules which are not analytically derived, but are empirically derived. So, empirically means just by doing experimentation from experiments can they cannot be explained.

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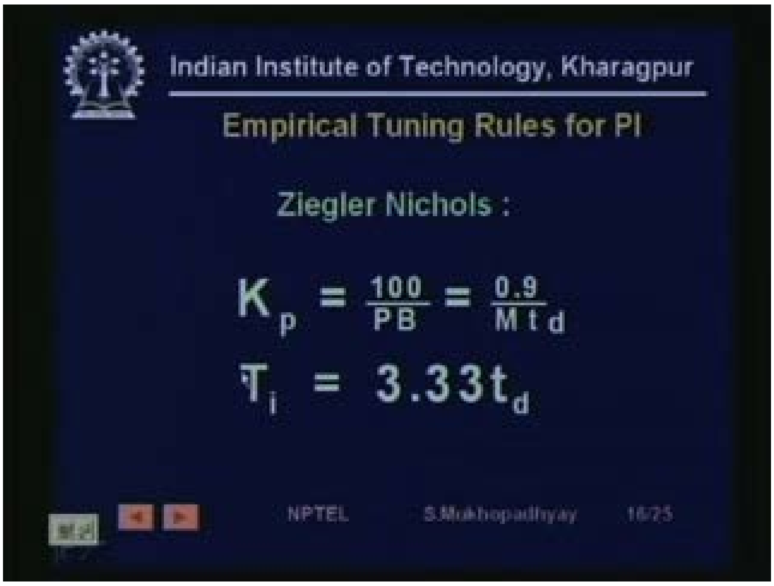


So, very famous rules which are Ziegler Nichols. So, the Ziegler Nichols tuning rule says that if you do this experiment and if you are designing a PI controller then the value of the gain K p should be this much. So, you see in terms of t d and M, and the value of the value of Ti should be given in terms of t. This is what Ziegler and Nichols found virtual. Now, obviously, it will not work well everywhere. So, various people will say various. So, we have various other kinds of rules also.

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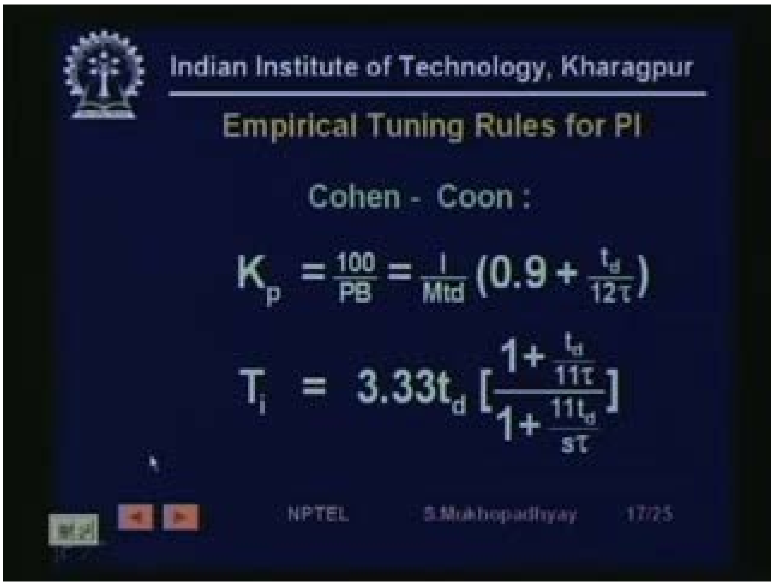


For example we can have a, we can have another rule which is known as the Cohen and coon rule, which looks like this. So, you see that there they are actually fairly is fairly close only thing is that Ziegler and Nichols said that K p should be this much now, Cohen and coon are actually adding another term. So, here also you see that in case of he is adding apart from this t d he is adding a factor here, right?

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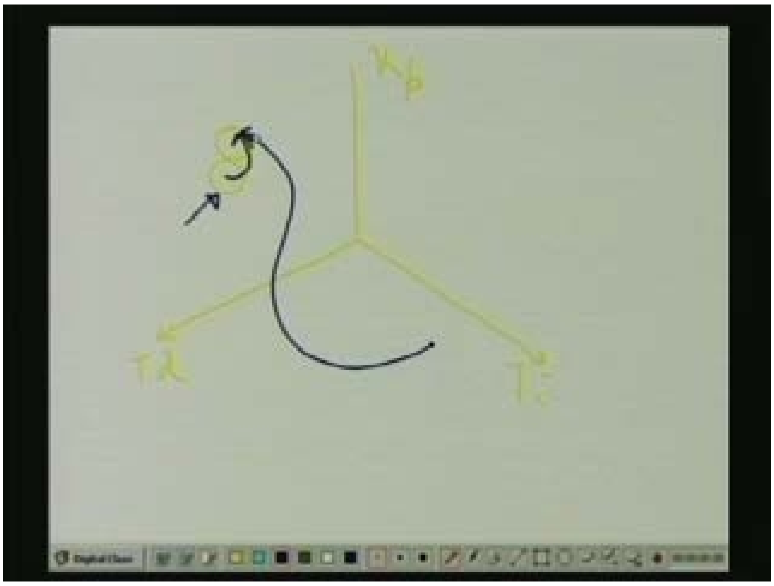

So, you see that various kinds of empirical rules are given and, then you can, you can apply now. Actually what happens? One must realize this that one must realize this that, actually what is going to happen is that say look at this that you are looking for you are searching for some good parameter let us say in the, let us say in the K p t d and T i space, right?

Now, suppose they the real best value of parameter actually lies here. So, now you have to you can exhaustively search the space and may be finally, you will actually locate that is the best value of parameter which is very expensive. So, that, so the idea is that if you can if you can search, if you can by some simple rule if you can locate a value which is actually which is lightly to be very close to the real true optimal value then your, then your search becomes easier. You actually quickly converge on you actually quickly converge on, you can quickly converge on to the optimal.

While if you if you do not have the benefit of this rule which is given by this Ziegler Nichols Cohen coon a kind of rules, then you may search start search from here and then after long amount of search you may reach here. So, it is basically these rule should be treat taken in that spirit that they generally give you a good first guess for the values and, then you have to, you may have to do some amount of tuning to actually, be able to get the real good parameters controller parameters for your process, right?

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So, an overall assessment of this of this open loop process is that, you need only a single experiment just once give a step input and collect the values. No trial and error is needed and for some processes loop cannot be opened, this is a big problem that we here we are we want to do an open loop experiment. Now, some processes are there already in closed loop you cannot open them. You nobody will allow them allow you to open the loop and do an open loop experiment. So, in such cases this is not applicable, and sometimes determining the these slopes etcetera can be actually very difficult especially when you have noise. When you have noise finding numerically the slope from data can be, can be very complicated and you have to use some good approximation procedures. And finally, note that procedure is actually applicable only for over damped processes not for under damped processes.

So, you cannot use take an under damped open loop under damped process and then use this procedure. Although you may be able to find out some value of K t d and M. So, we need a closed loop procedure, and the closed loop procedure goes like this.

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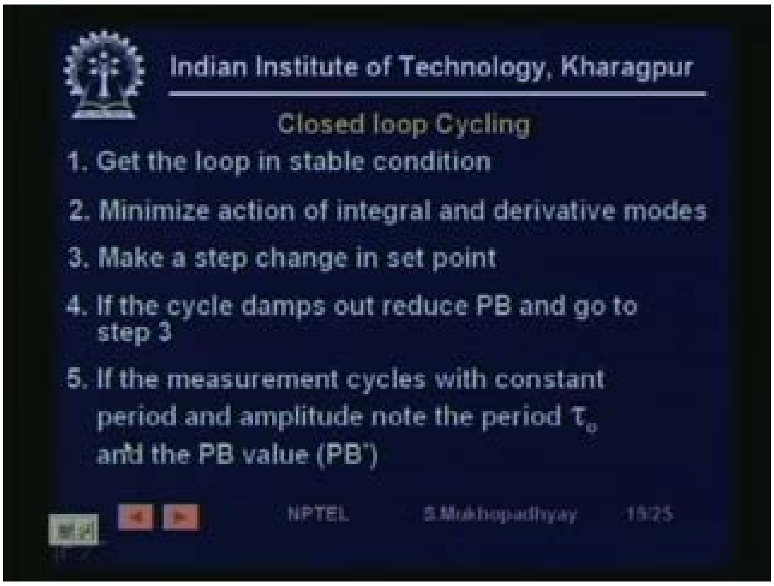


It is essentially an iterative procedure that is it involves trial and error. So, what it does is that first get the loop in a in a stable condition, probably the loop is already in a stable condition operating. Then, minimize action of integral and derivative modes, reduced those integral and derivative gains if necessary reduce the K p also. So, that the loop is stable.

Now, make a step change in the same point right? So, make a change. So, if you make a step change in the set point, if you make a step change in the set point. So, you make a step change in the same point. So, the process loop rises it dies down. If it is dies down, then if the cycle damps out, then you reduce PB, reduce PB means increase the gain. So, if you increase the gain your gain margin will reduce, which means that the process will be closure to on oscillation. So, may be when you reduce the gain next time you give another step. So, you go to step 3 and then make another step change may be in the negative direction.

So, then it may happen that this loop will tend to persist for longer time, still it damps out. So, still it damps out again go to step 3 and, then reduce gain little bit and make a step change in set point. So, go on doing this till the loop oscillates. If the measurement cycles with constant period and amplitude note this period tau and the PB value that is the gain which has made the plant oscillate, this is called the ultimate gain, right? So, now you have got 2 values one is this PB star which is the ultimate gain and another is the period tau naught. So, now based on these there are again I am sorry based on this there are again empirical formulae.

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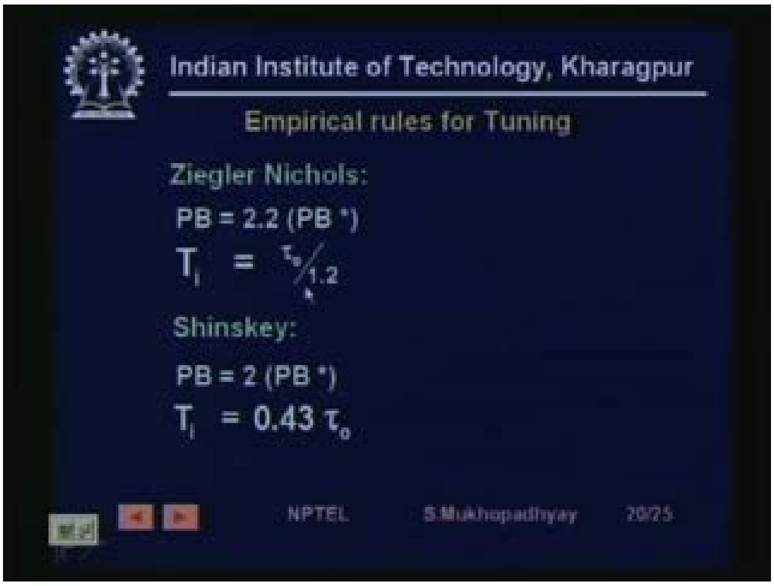


So, once so for example, Ziegler Nichols says that, if you have found a particular value of PB star and found the particular value of tau naught. Then, for a PI control, set the proportional band value as 2.2 times this value and set that Ti as this value again empirical, purely empirical found, so called by experiments.

Similarly, some other process control expert Shinskey says that you know choose these 2 values of gain. So obviously, you are going to have difference in this, difference in this property. For example, here you have a larger gain, and here you have a larger time constant 2. Here you have a smaller gain, here you have a no, here you have a smaller gain and you have the smaller time constant, here you have a larger gain and you have larger time constant right. Larger gain and a smaller time constant, so you will get different properties. So, what is the assessment of these closed loop methods that some trial and error is needed.

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And often the settings obtained, so as I have already told that the settings obtained are to be treated as good first estimates. And further trial and error after around that you may like to tune little bit and see whether you are getting still better performance then you select those values.

Now, for some it, so happens that this cycling when you when you want to make the loop cycle by continuously increasing PB the cycling amplitude that is the amplitude of the cycle may increase. It is, it is actually not in your control when a process oscillates its cycling amplitude and period are actually not in your control. So now, but, then that may be disastrous because a process may not be allowed to cycle with a, with a very large amplitude. So, then what are you going to do?

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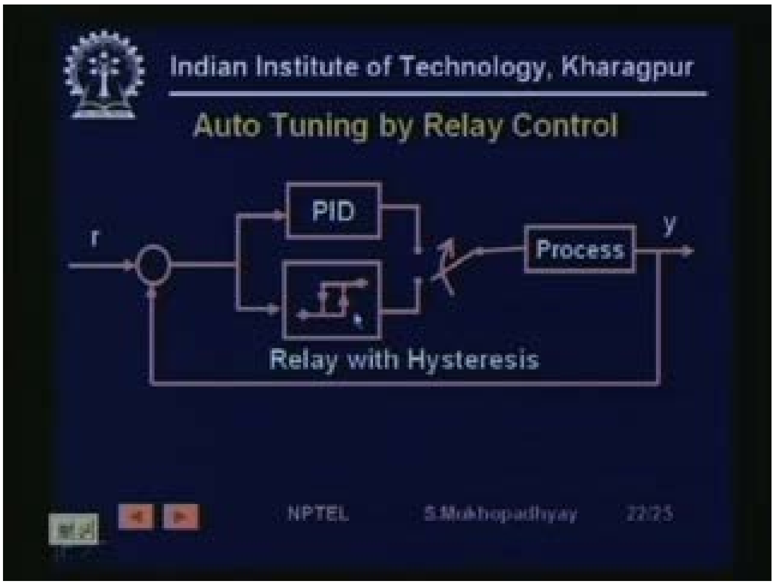


So, in such a case there is a nice procedure which says that in set up the control loop like this. So, you have the normal PID controller, and you have a relay with hysteresis here. So, what is the, what does it mean that if the error goes positive, then the relay will switch with, switch in one direction, if it is negative it will switch in the other direction. So, now what will happen is that, the with because of this relay if you now fix the switch and then try to control the plant with this relay then what will happen is that the relay will continuously toggle.

So, the relay will give you an oscillating input. So, what will happen is that the plant will actually oscillate immediately it will start oscillating that is there is there will be no trial and error needed and the amplitude of oscillation can now be controlled by the properties of the relay.

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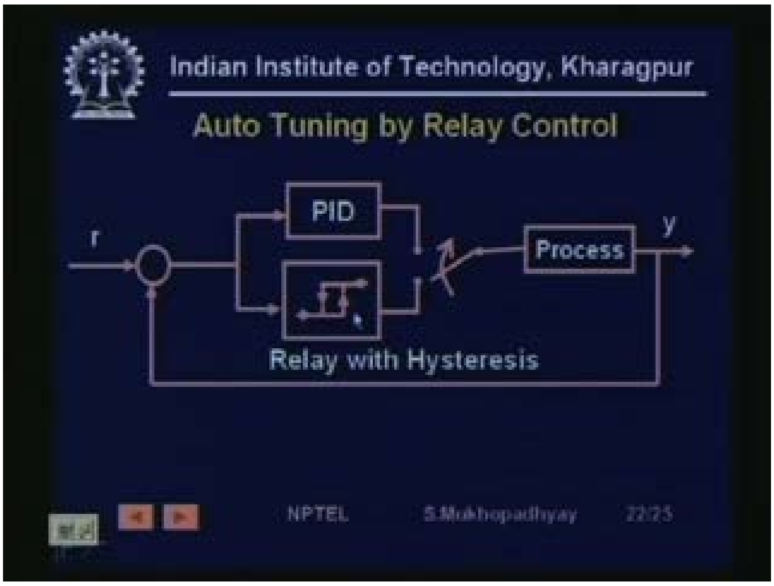


So, now you have got a nice situation where the so that the oscillation can be directly induced by the relay without trial and error and its amplitude can be controlled. So, you can have induce a small oscillation and it let the, and then note the period of this oscillation and it turns out by an analysis called which is called the describing function analysis in non-linear control. That if you have if you have if you have an oscillation of this kind in the process, which is of amplitude A, which can be controlled. And if the relay switching are of amplitude 2 d, then the ultimate gain which you want to go which you wanted to find out to be able to apply the closed loop tuning formulae can be given by this formula.

So, you see you are still finding out that same gain PB star, but now using an experimental procedure which lets you set of an oscillation at one shot of a control level amplitude. So, that is a big advantage and then now you can you can easily apply those formulae and, then get the gain and it so happens that people have actually implemented this this commercially in the PID controller.

So, that whenever the operator feels that the process needs to be retuned, then the process can be momentarily flict on to the relay and immediately an oscillation will be setup and then by noting the amplitude of oscillation and the period of oscillation the gains can be set up in very quickly. So, no separate experimentation necessary and then automatically the controller can be tuned just by the flick of a push bar therefore, it is called auto tuning, right. So, here the here the whole tuning process has been automated. So, this is the end of our lesson and what we have basically reviewed are the various performance criteria for control loops.

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Then, we saw a method of direct computation of controller settings based on a process model open loop plant model and the reference model Then, we found out some empirical tuning rules which are based on open loop and closed loop experiments that you can perform on the plant. And finally, we saw procedure called auto tuning, where we could quickly and automatically do an experiment and find out the controller settings.

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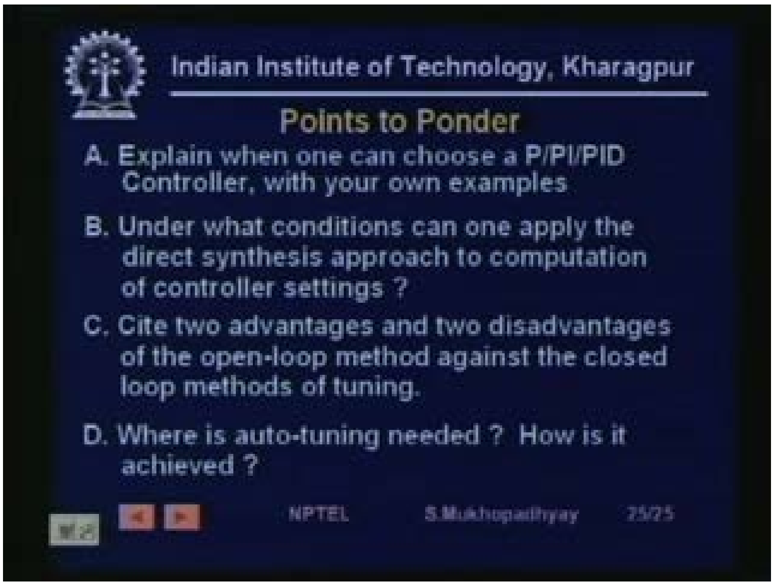


So, some of the points to ponder for you are is that you can try to find out in in what situations P PI and PID controller are to be used all the answers are in this lecture only and you can try to find out your own examples of processes. And, then under what conditions you can find under what conditions one can apply a a direct synthesis procedure let say in your application processes whether you can apply or not or if you can apply why you can apply or why you cannot apply all these things. You can also cite two advantages and disadvantages of open loop method against the closed loop method and finally, you can you can find under what situation and auto tuning future will be needed and how is it achieved. How is it, how an order tuning is achieved one procedure is already given in the lecture.

So, here we end. Thank you very much.

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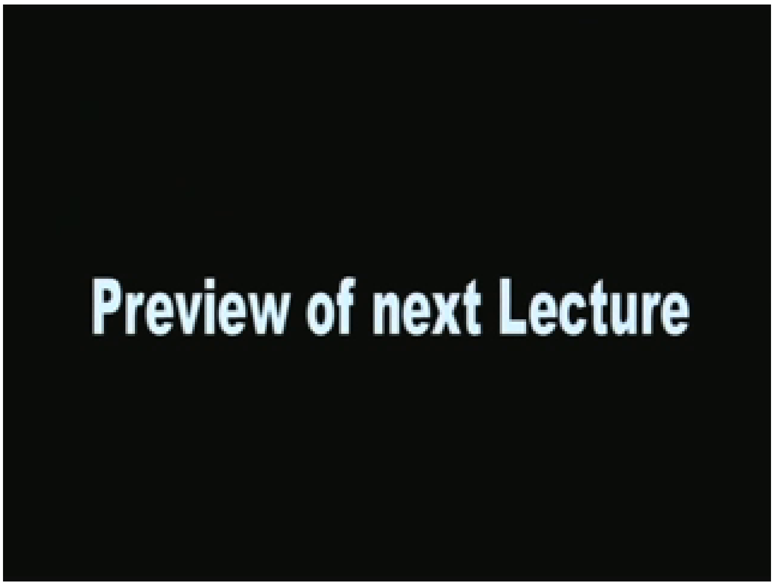


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Good afternoon and welcome to the 14 th lesson of this course.

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Today we are going to look at feed forward control and ratio control.

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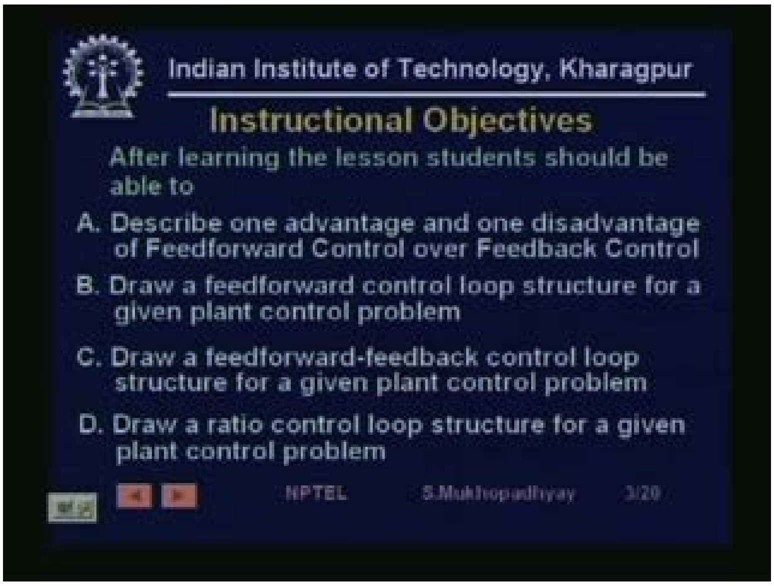


So far, we have looked, always looked at the classical control structure, but today we will look at some other control structures which would, which are fundamentally different in principal. So, before we do that, we have to take a look at the instructional objectives. So, after learning the lesson, the student should be able to describe one advantage and one disadvantage of feed forward control over feedback control. There are some, there is a fundamental disadvantage of feedback control. So, which is an, this is, there is fundamental disadvantage of feedback control, which is overcome by this feed forward structure. And on the other hand the feed forward structure also suffers from a disadvantage, which is overcome by feedback controls. So, we will comparatively assess these two and we should be able to draw, given a control problem, we should be able to draw the feed forward control loop structure.