**INDIAN INSTITUTE OF TECHNOLOGY**
**KHARAGPUR**

**NPTEL**
**ONLINE CERTIFICATION COURSE**

**On Industrial Automation and**
**Control**

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**Topic Lecture – 13**
**PID 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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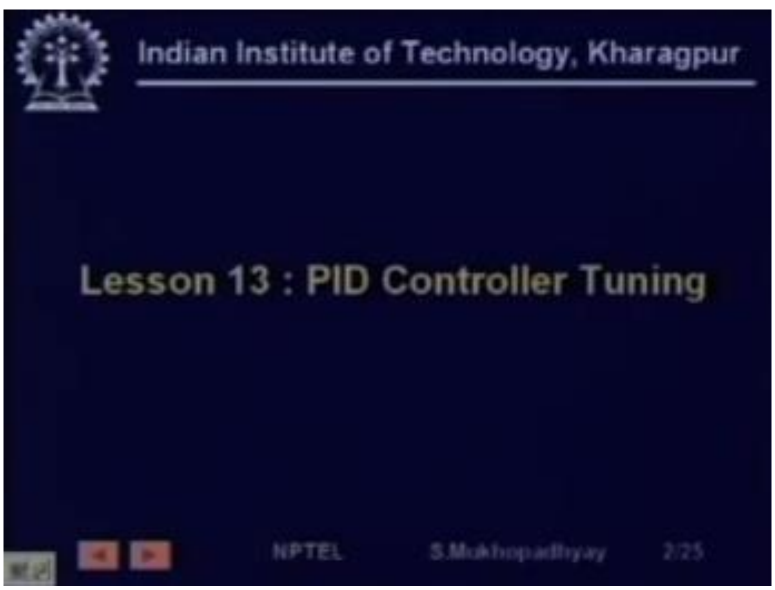


As we will see that controller tuning is a very important phase of the overall controller design and it very critically determines the performance of the control loop which in turn affects the overall quality of the product affect costs, so it is a very important method to be learnt in the overall context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

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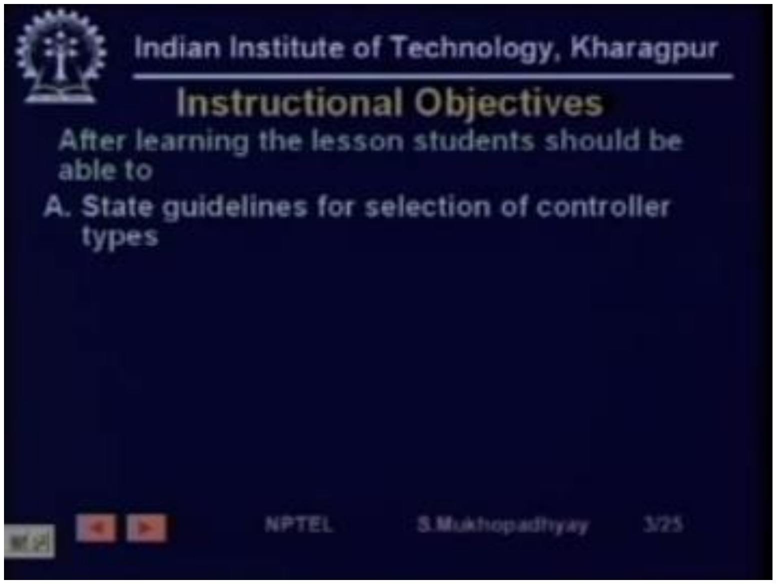


So as we stated in every lesson after learning the lessons the student should be able to firstly state guideline for selection of controller types when I said PID controller I actually mean a class that is the three classes of controllers that is P control PI control and PID control which are most often used in the context of industrial automation. So the student should be able to select one of these types.

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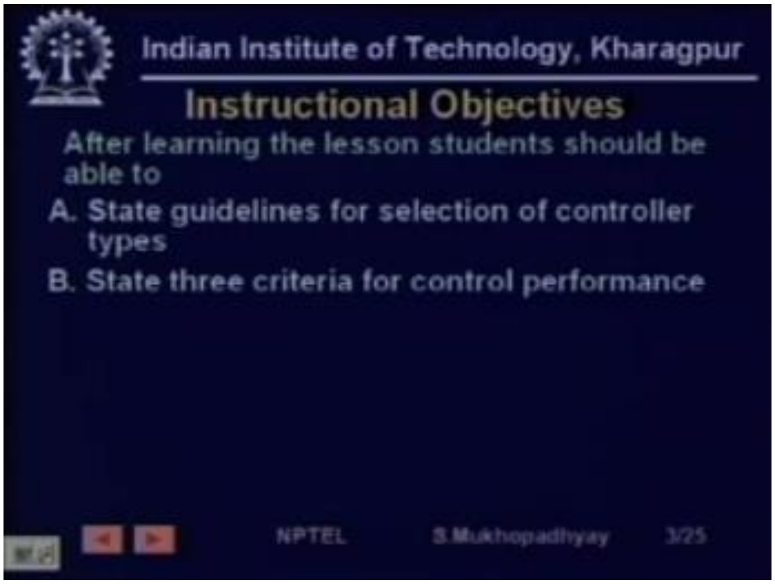


Now once he selects one of these types he or she should be able to assign the various parameters in that controller like gains integral times, derivative times extra. So in this lesson we are going to look at various methods of doing that and all of them will affect control performance in various ways, so what will be the values of the 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 us say three of many criteria.

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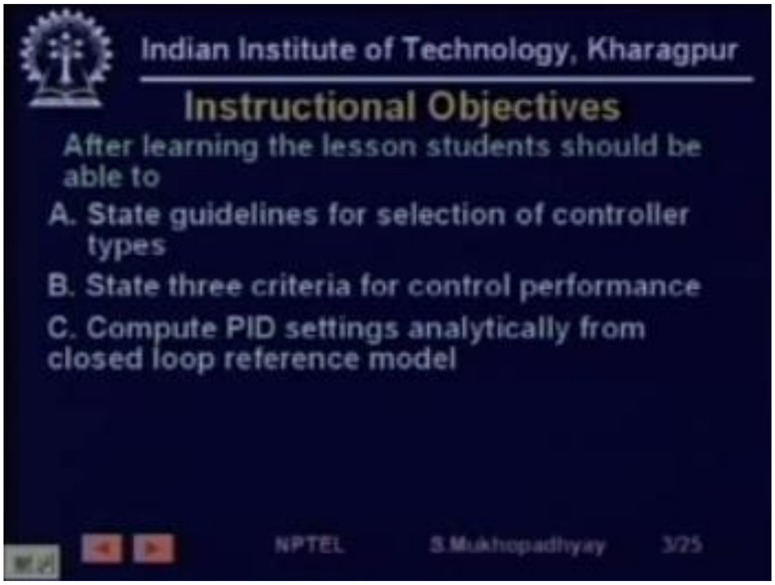


Then he or she would be able to compute PID settings analytically first actually solving out the controller parameter values and in some cases where.

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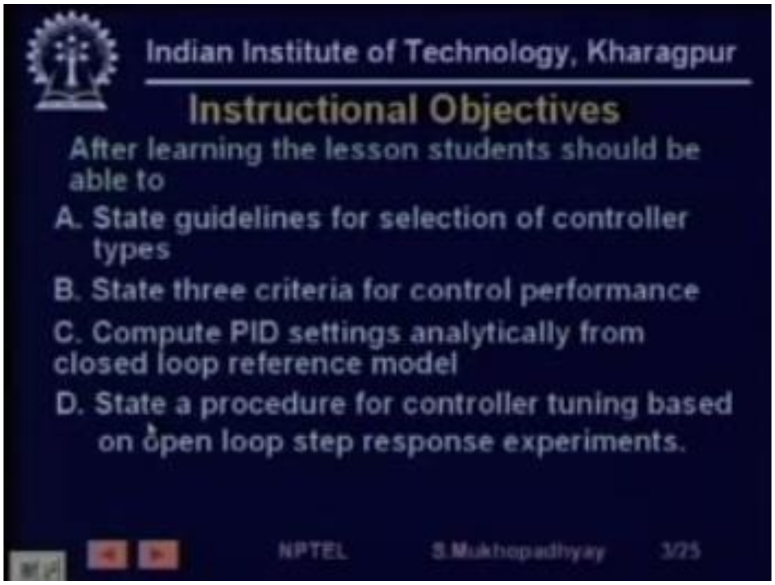


Exact solution is not possible sometimes we because a reference model is not may not be available so we sometimes set controller parameter settings based on experimental data and there are two basic approaches one is on one is an open loop approach which is based on step response so should be able to stay the procedure for doing that and the other one is for closed loop.

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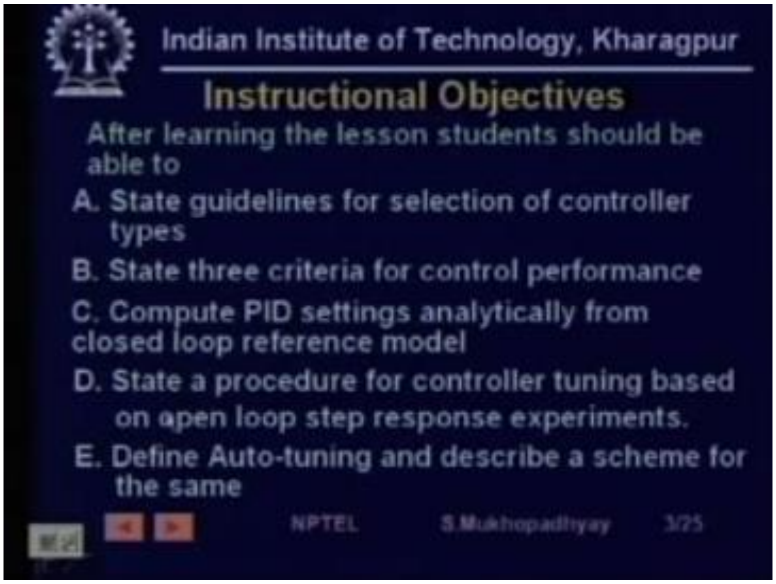


So that one is also you should be able to do that also and finally there are certain cases where we need to online while the plant is operating without performing a special, very special experiment for a long time or whether we can quickly perform an experiment to set the gains of the plant when we think that the plan 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, so these are the basic things that we are going to discuss and that one should pay attention to, so having done that let us first look at the concept of control performance.

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If you take a birds 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.

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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.

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Then our cost goes up because in today era of stringent quality control we may produce something in the factory but we may not be able to sell it if the stated specifications are not met, so that means that it will result in 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 violated 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.

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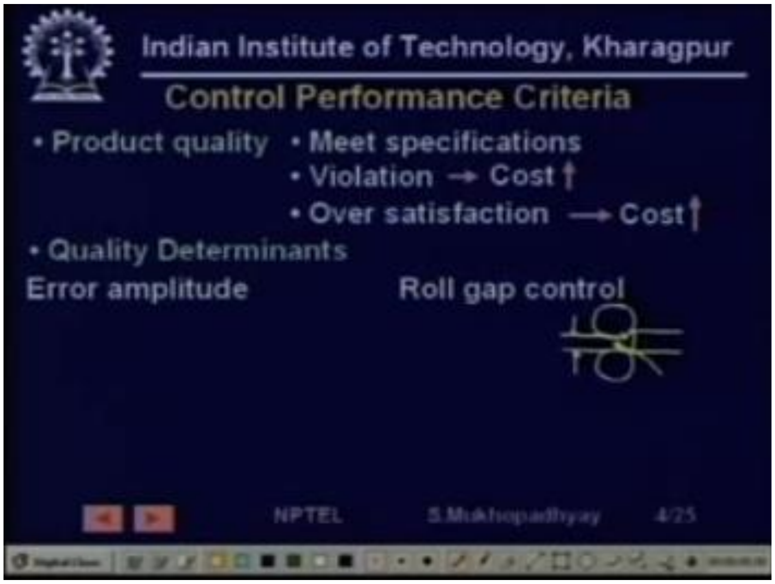


For example, let us look at a rolling process, right so if we have a rolling process what is happening is that actually if you see in a rolling process there are two rolls, right and some material, some plate comes in with some thickness and when it goes out it has a lower thickness. So there is a dimension 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 role gap.

So if you have now you always state that your product is going to have a thickness within some plus minus limits, so whether your product is going to violate your specifications actually depends on the maximum that is the maximum amplitude of the error, so if the role gap is supposed to be d.

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And if the role gap d* let us say and if the actual role gap is d then that will lead to an error in the final product thickness, so in this case the amplitude of the error actually decides product quality. Let us look at another example, so in that example suppose we are 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 customer eventually. So now what is the so the properties of the product which you properties of the product in the tank is actually and it 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 to the tank and they are getting mixed 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 you are trying to produce which is going to be important in determining the final quality. So in this application it is the error integral.

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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.

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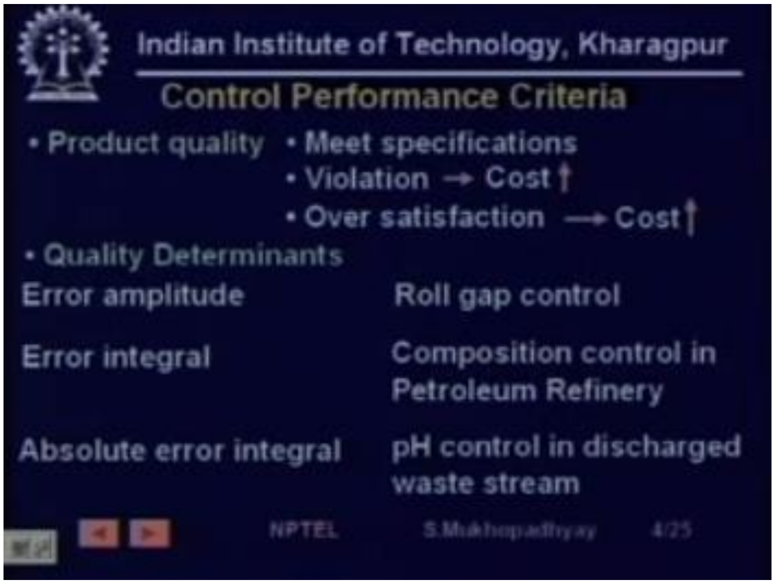


Let us take an example of you know pH control in a discharge stream of some chemical process so in today strict environmental regimes it is stated that whatever effluent you are, suppose you are releasing some effluent into a river then the pH factor that is whether it is acidic or basic or neutral should be as close to neutral as possible and it should be neither acidic nor basic. So now remember that there is no averaging strictly speaking, because of the fact that there is no tank you are actually directly releasing the effluent into the river.

So if your 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 if you cannot release acidic effluent for some time and then release basic effluent for some time and then say that my average, 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 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 PID controller tuning process even before you want to tune the tuning the parameters you have to do what is known as selection of controller types 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 to see that when is P control good enough, when it is not good enough and we must go for P I and when that is also not good enough and we must go for PID, only thing we 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 situations where you can achieve 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 right now sitting and giving his lecture then it is an air-conditioned room and suppose I want to maintain the temperature of this room, then there are two ways that I can do it there 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 a 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 loop 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 does it mean by feasible value of the gain, you can always say that I can always increase the gain, but you cannot increase the gain basically for two reasons, one reason is stability. If you increase again 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 when this when the offset that may arise with a feasible value of $K_C$ is acceptable.

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Second case is as we have seen that some processes let us say at let us say tank, we have seen that the condition for a zero 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 plan 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 tank can you are putting in fluids you, the plant has an integrator so in such cases a P control can be used.

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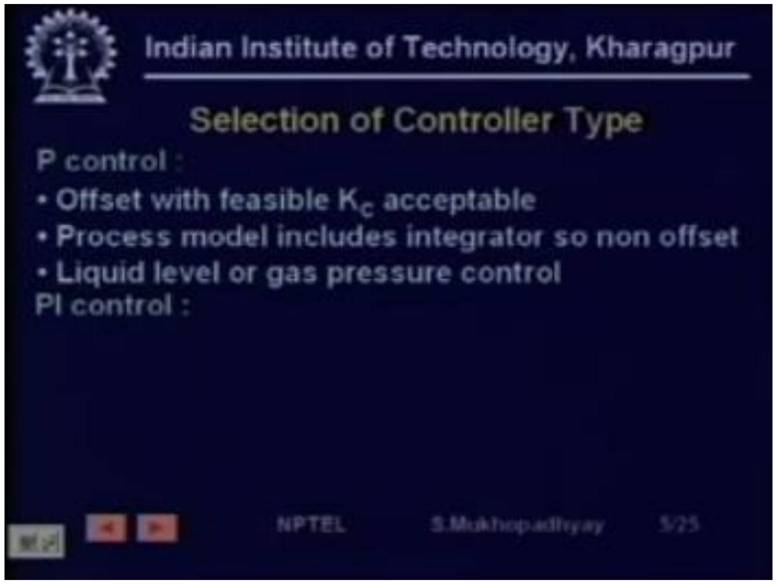


So you have liquid level or gas pressure control and now, the so the point is now when there are situations for example, in liquid level or gas pressure control not only that you always have an integrator actually that depends on whether there is a constantly I mean there the fluid is also being drained, if the fluid is being drained then it will not be a then there 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 load, 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 plan does not include an integrator having a proportional control is okay, but there are various situations where and a steady state offset cannot be tolerated, in such a case obviously you must go for PI control.

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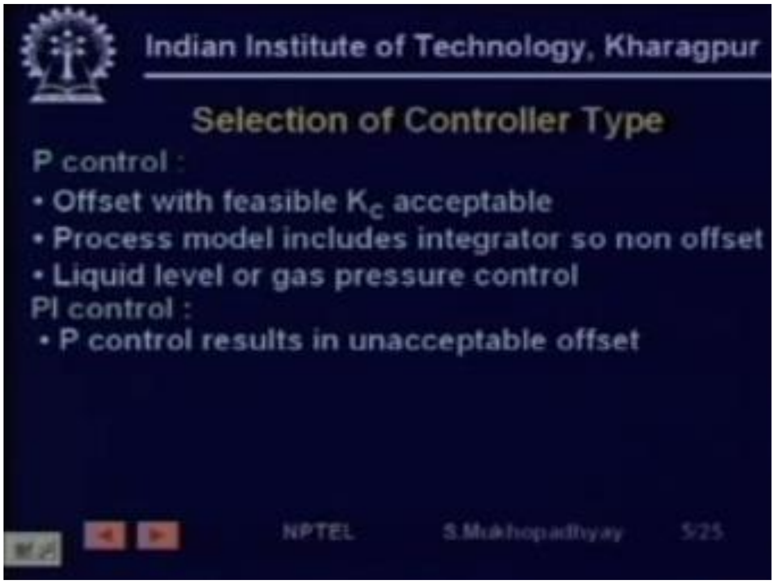


So PI control is to be considered when P control results in an unacceptable offset, right so you do not want any offset and therefore you would you like that you would like to use the PI control because you know that then you are, you can exactly ensure zero steady state error.

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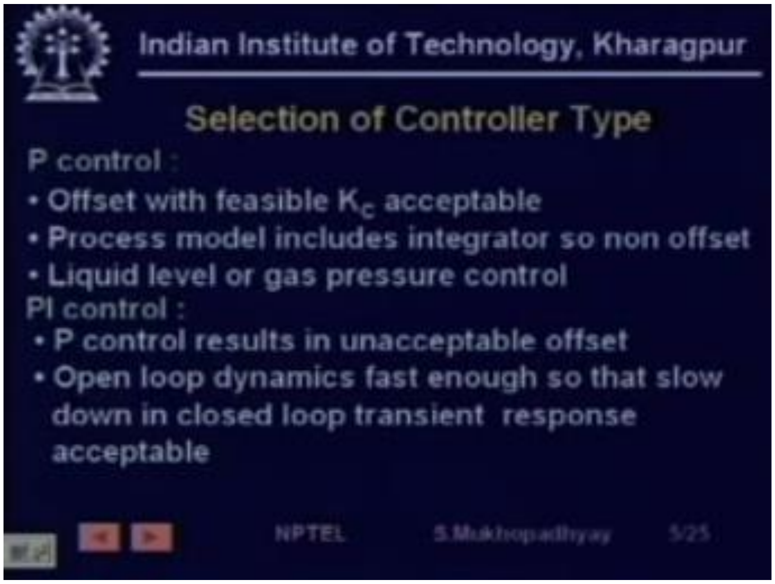


Now as we have seen that what happens generally in PI control especially is that the loop generally stabilizes because of the PI action the loop generally tends to oscillate and it takes some time to settle, so in that sense the loop becomes a little sluggish. Now the point is that suppose let us look at this.

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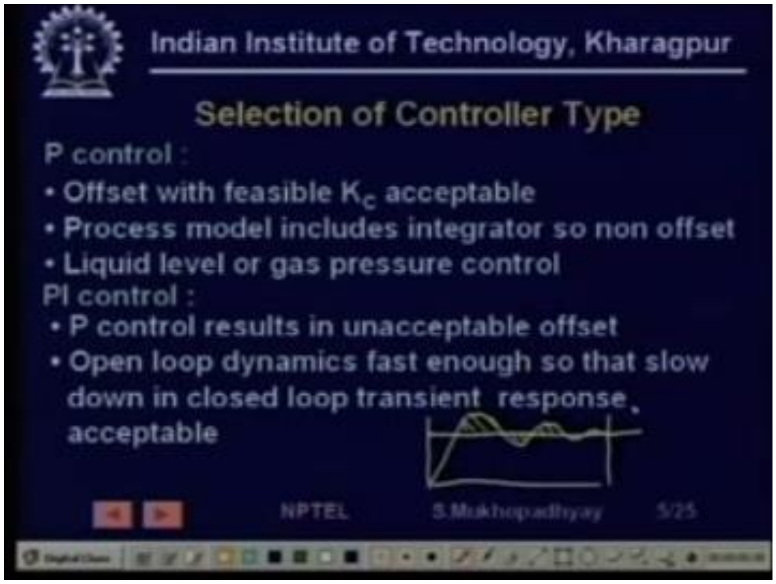


So suppose you are having, consider the step response so this is your new set point which has been changed and the plant under PI control is oscillating like this and then finally achieving zero steady state error. Now the question is that when is this oscillation acceptable this, these errors when are 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 zero steady-state error.

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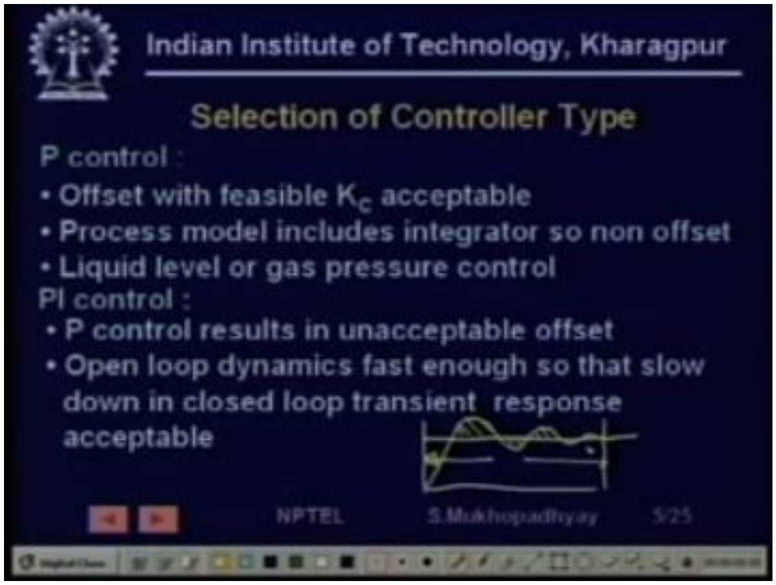


So if this interval over which there is some error is actually small compared to the frequency of set point changes, then you can say that okay.

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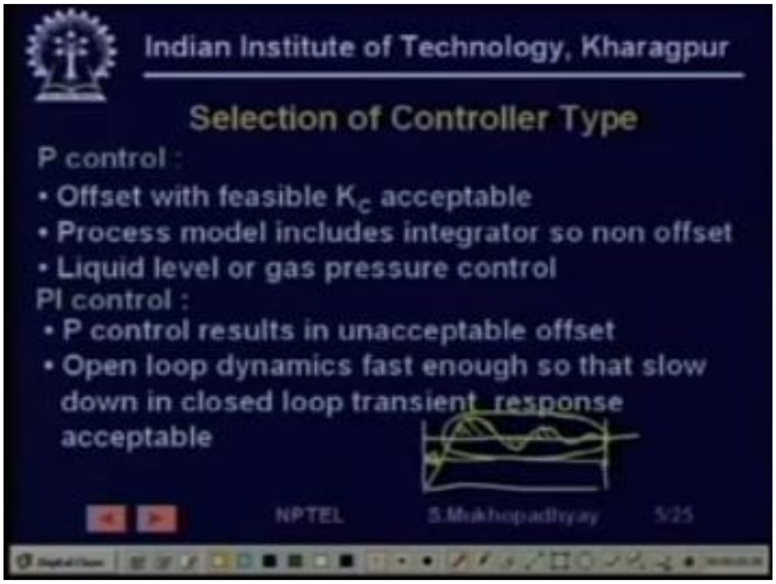


Even if during this period I have some error and my control performance is may be affected depending on whether I have an integral error criterion then it will be less affected.

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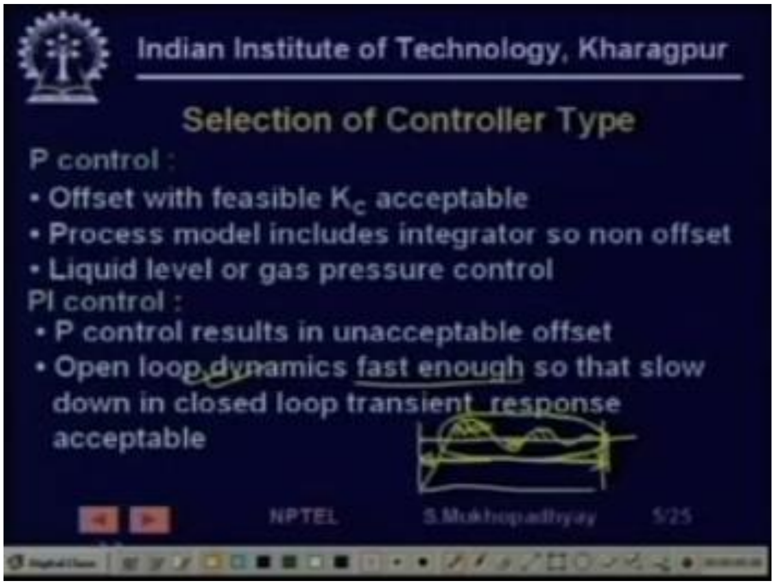


Because this positive error is going to cancel this negative error, but even then I am able to tolerate this much of error because it is going to die down reasonably fast for me and then it will stay on for a long, long time, right so in such a case so in other words the this interval is actually small which means 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.

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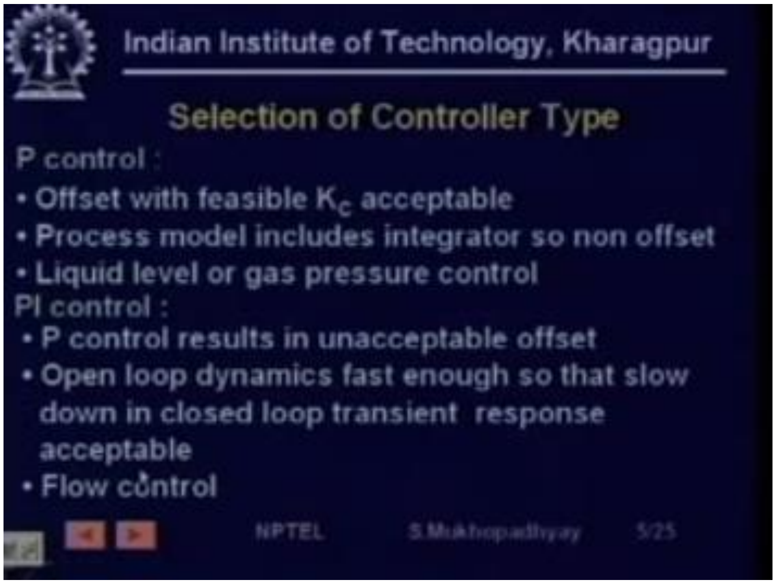


In flow control the step response is actually very fast, so therefore even if you include a PI controller and it little bit oscillates for some time that interval suppose you are trying to control temperature with flow control which is very common you try to increase or decrease the steam flow rate to maintain the temperature in the reactor. So the reactor temperature set point change will be so infrequent compared to the settling of the flow loop is that in I mean in such a case PI control which 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 take it closer to instability.

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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 sense that we want to have zero 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.

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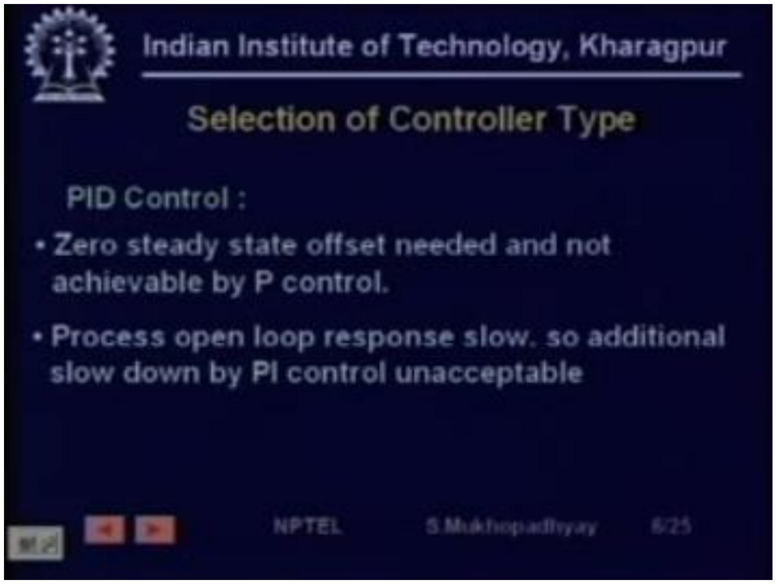


My transient response typically to a step input is better than the PID controller, so in such a case this slow down by the PI controller which is unacceptable that can often be realized using a PID control because of the fact that you have a derivative term and because of that you can actually have larger gains. So typically for you know for multi capacity processes.

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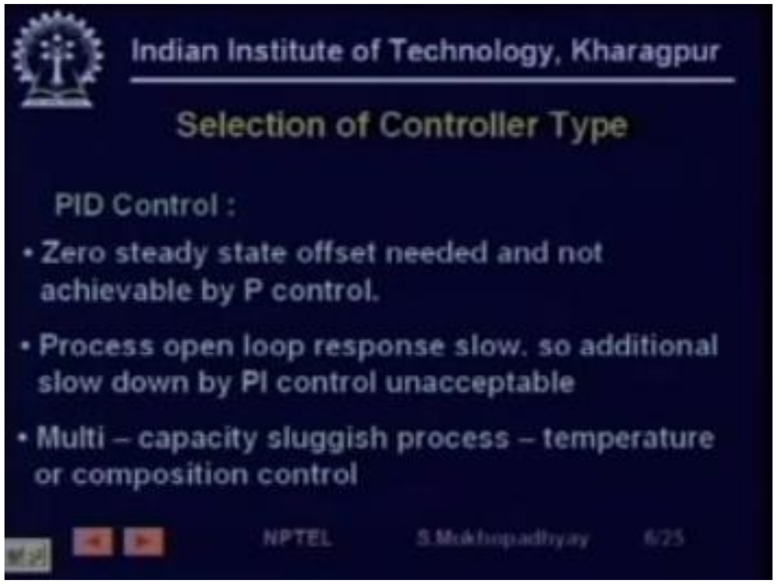


Where you have to control temperature then you temperature or composition control that is why you use PID control because in any case you do not want to lose out too much on the transient response to gain the advantage in the statistics response of zero steady state error. So these are you know broad thumb rules of selecting P, PI or PID controls. Now we come to the, if having selected these, this controller settings these controller types how do we select a particular controller setting.

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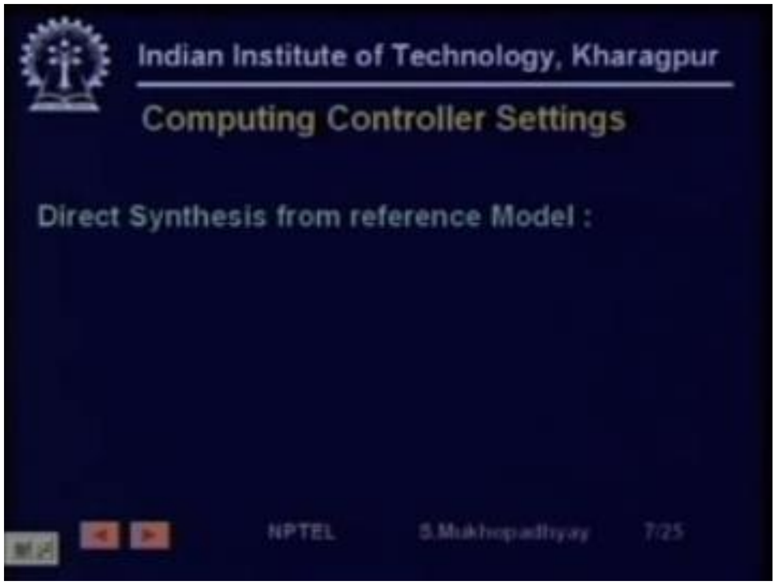


So there are so there could be various ways for example, the first one is that if you suppose somewhat you know ideally, suppose you assume that the plant model, process plant model is exactly known. It can be nicely expressed by a transfer function also another thing is known that is the closed-loop reference model is also known which means that the open-loop plant is known 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 behave like another transfer function, right.

So once we can do that then you see we can, you can sometimes from these two requirements we can solve out the controller, right.

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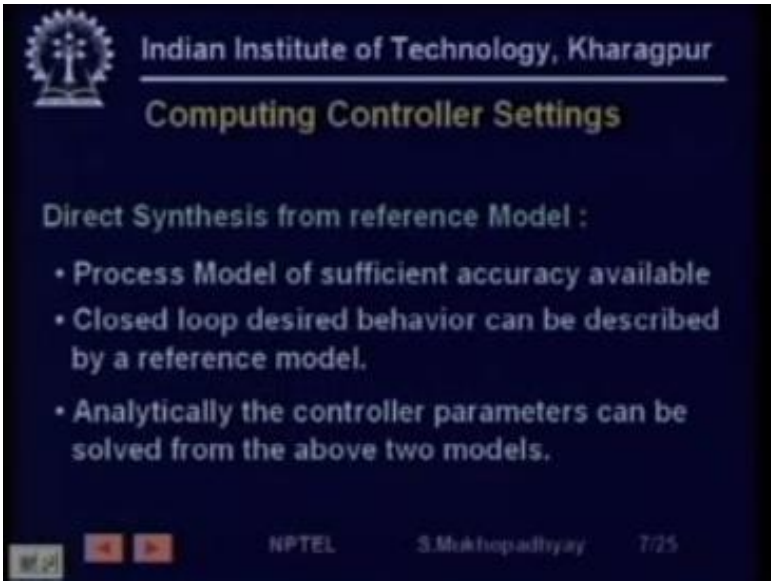


So this method is applicable only we have the process model of sufficient accuracy available. You have a closed loop desired behavior can be described by reference model. And then if you can, if you have these two conditions satisfied then analytically the controller parameters can be solved from the above two models how?

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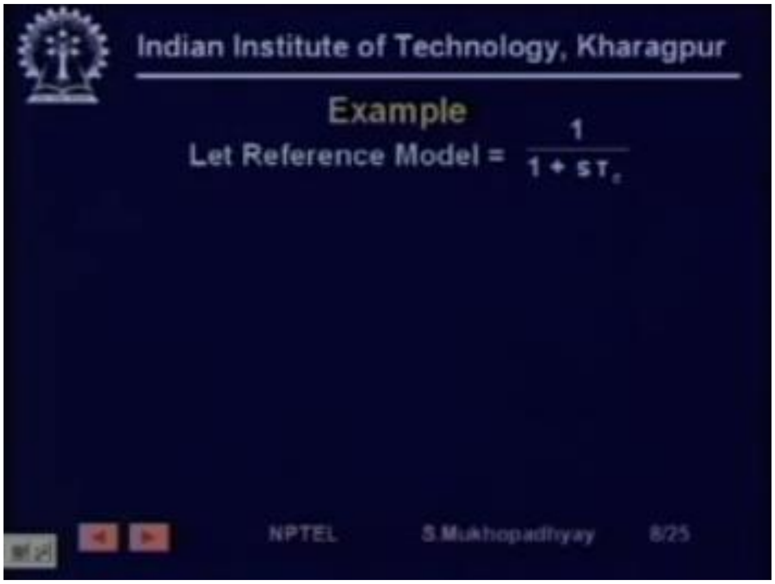


So we have an example, in this example let the reference model be1/1+$ST_c$ so it let us suppose I want that the closed-loop plant actually behaves like a first order process with some time constant $T_c$.

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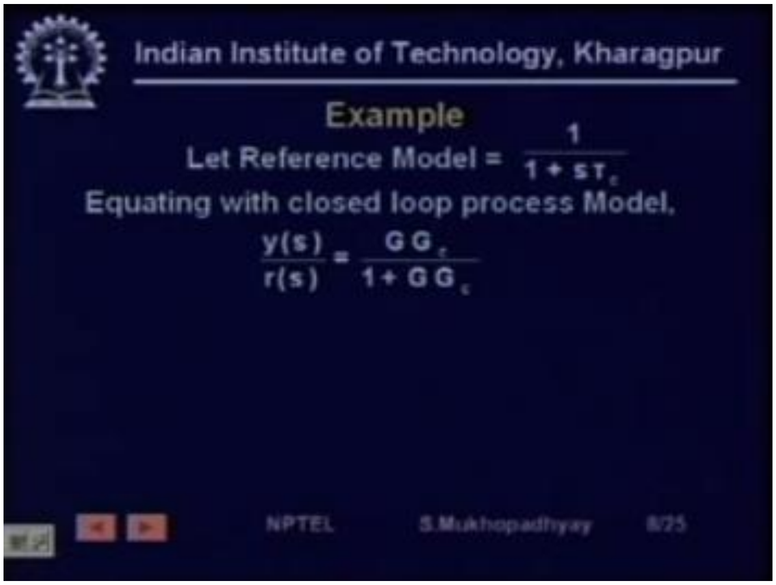


Now if I also, now what is the closed-loop process model transfer function, we know that it is given by Zero steady state/1+Zero steady state this is, one of the elementary facts of control theory, where G is the transfer function of the open-loop plant and $G_c$ is the transfer function of the controller which is in the feed which is in the forward path and we have unity feedback. So now I obviously, I want that this transfer function.

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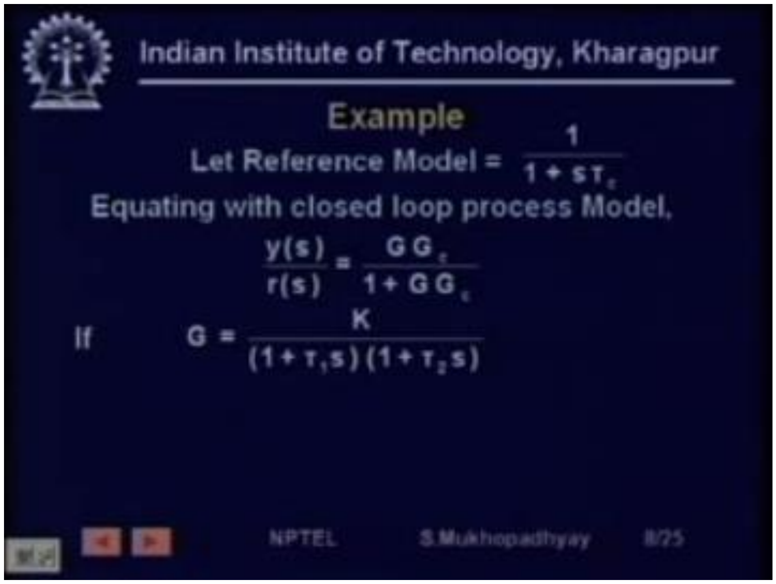


This transfer function zero steady state/1+Zero steady state must equate this transfer function. So if I equate them and then what I find is that now if the, now what is the plant so I said the plant model should be known I'm assuming that the plan to the second order process over damped it has two time constants, one is t1 and t2 typically they will be larger than $T_c$ when we control something we want to make its response, generally we have to make its response faster. So $T_c$ is going to be smaller than t1 and t2.

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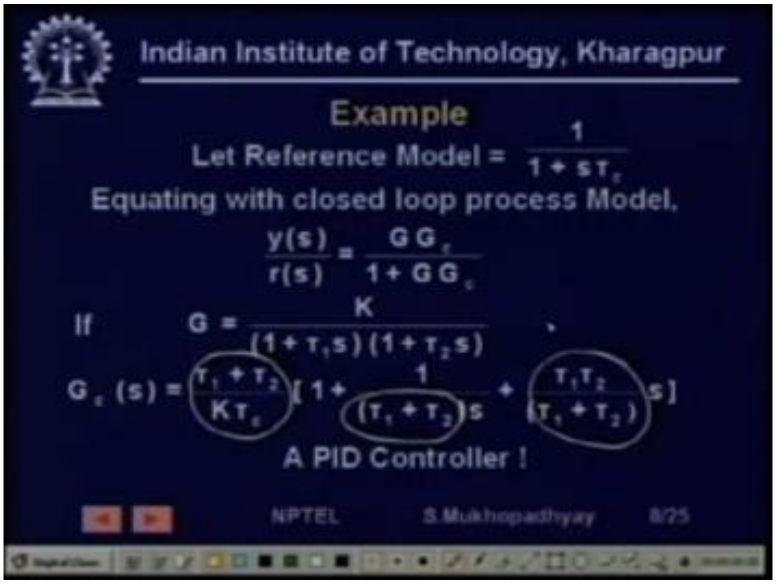


So after solving this what will, what kind of a $G_c$ shall we get, so it turns out that if you solve this equation that is $GG_c/1+GG_c$ with G this value of G and this value of the reference model, then it turns out one can easily solve that the controller transfer function comes out to be this, right. So now you can immediately see that this becomes your $K_p$ so this becomes your $K_p$ this becomes your $T_i$ and this becomes your $T_d$ right, and it is very interestingly see, we did we never said that we actually want a PID controller we just wanted to, wanted this plant.

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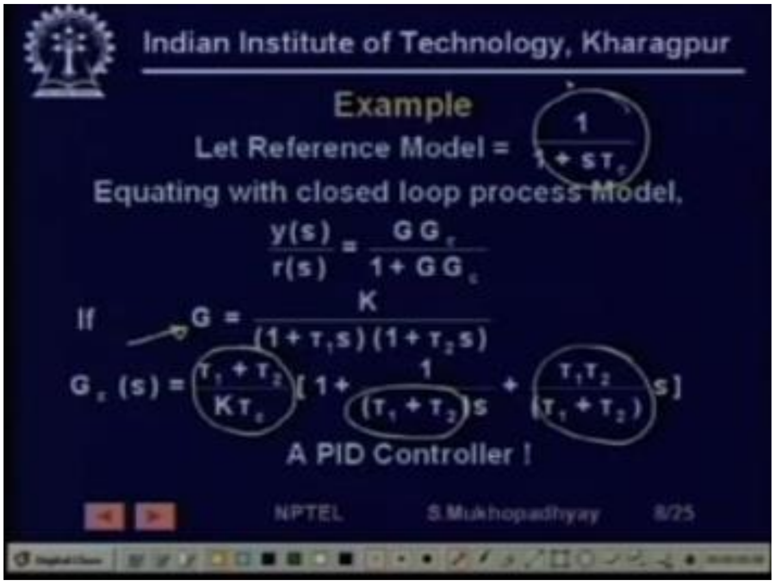


To behave like this model that turns out that for having that the controller that you need is actually a PID controller, so it is very good so you see PID controllers can give you good response.