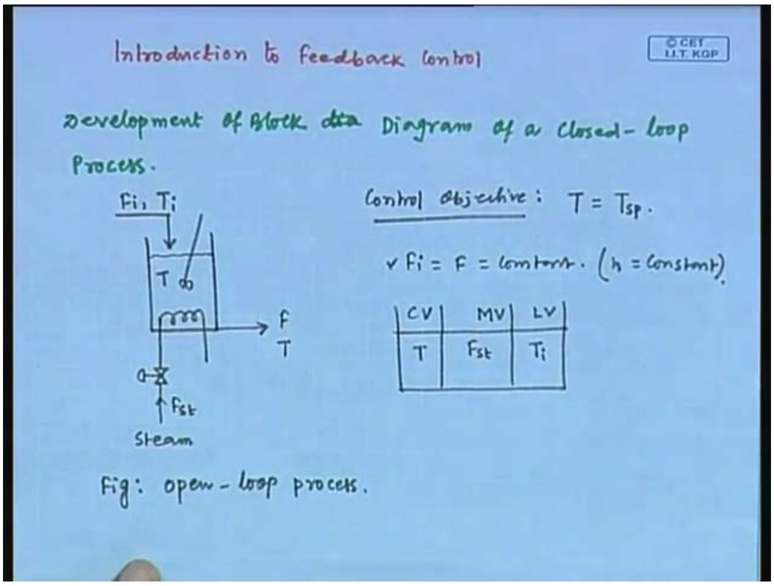
Process Control and Instrumentation
Prof. A. K. Jana
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 15
Feedback Control Schemes

(Refer Slide Time: 01:00)

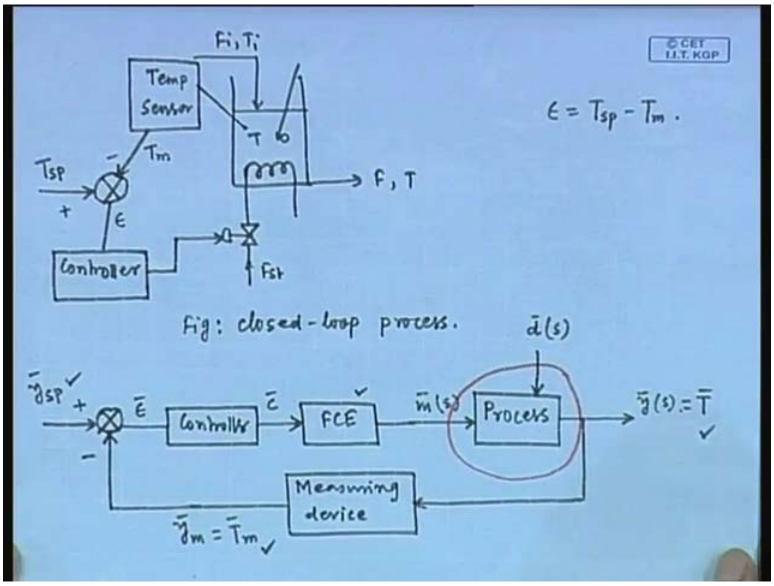


Now, we start the topic introduction to Feedback Control. We will discuss the topic introduction to Feedback Control. Now, before discussing the feedback controlling schemes, we will develop the block diagram for a closed loop system. So, development of block diagram, of a closed loop process we have develop the block diagram for open loop process. So, now we used to develop the block diagram of closed loop process, for this purpose we will consider one example that is hitting tank system, for the development of block diagram, we consider the hitting tank system.

Steam is introduced through this coil with a flow rate of f s t in food flow rate is f i and temperature is T i outlet stream is going out at the flow rate of f and temperature T. Now, what is the control of objective the control of objective is to maintain the temperature at it is desired value. The control of objective of this example process is to maintain the temperature at it is desired set point value and we assuming that, f i and if their identical and their constant quantities. We are assuming that a f i if both are identical and their constant.

So, what is the control variable, what is the manipulated variable and what is the load variable, that we can detect. Now, control variable is temperature, what is the manipulated variable, corresponding manipulated variable is steam flow rate and load variable is T i. Now, this is the schematic of an open loop system, this is the schematic of the open loop hitting tank system. Now, we have assumed that the inlet and outlet flow rates are identical and they are also constant, it indicates there is no variation of height, it indicates height is also constant. Now, we will configure the control around this process, we have already dictated that control variable, manipulated variable and load variable. Now, we will configure the feedback control scheme for maintaining the liquid temperature.

(Refer Slide Time: 06:19)



So, this the hitting tank system we considered as an example, now first we need to measure the temperature by using a measuring device, we need to measure the temperature using a measuring device. So, this is the block for temperature sensor which is employed to measure, the liquid temperature. Now, this measure temperature usually defers, from the original temperature habit, this measure temperature we can represent by t suffix n, in the next step this measure temperature is compared with it is set point value represented by T s p. So, this is positive and this is negative.

Then the output of this comparator is the output of the comparator is represented by it is epsilon, it is epsilon is equal to set point temperature minus measure temperature, the comparator output can be represented by it is epsilon or epsilon is equal to T s p minus t m. Then this information is supplied to the controller, this information is supplied to the controller, based on the error signal the controller takes action and that action is physically implemented to these control hall, the controller action is physically implemented to the final control element that is control hall.

This is the configuration of the controller, employed around this hitting tank system. And this is the schematic of the closed loop hitting tank system, this is the schematic of the closed loop hitting tank system or closed loop process, by the introduction of the controller the loop is closed. Now, in the next week we used to develop the block diagram for this closed loop process. So, we will consider a block process, this block is representing the process, input to this process is suppose, m bar is input to the process is represented by m bar s that is nothing, but the final control output.

And another input is considered, that is the disturbance d bar s. So, there are two inputs affecting the process, one is the final control element output, another one is the disturbance. Disturbance is represented by d and final control element is represented by here m, the output of the process is y in Laplace domain we can write y bar s, this is the open loop process, this is the block diagram of the open loop process, there is no controller involve with these open loop process.

Now, what we doing first, we are first measuring the temperature using a measuring device. So, one block we can draw for the measuring device, this measuring device is measuring the temperature, basically this y is T only. The control variable y is here the temperature of the liquid in the tank. So, first we measuring the temperature using this measuring device. What is the output of this measuring device, output is y suffix m that is nothing, but measure temperature sensor output is measure temperature T m.

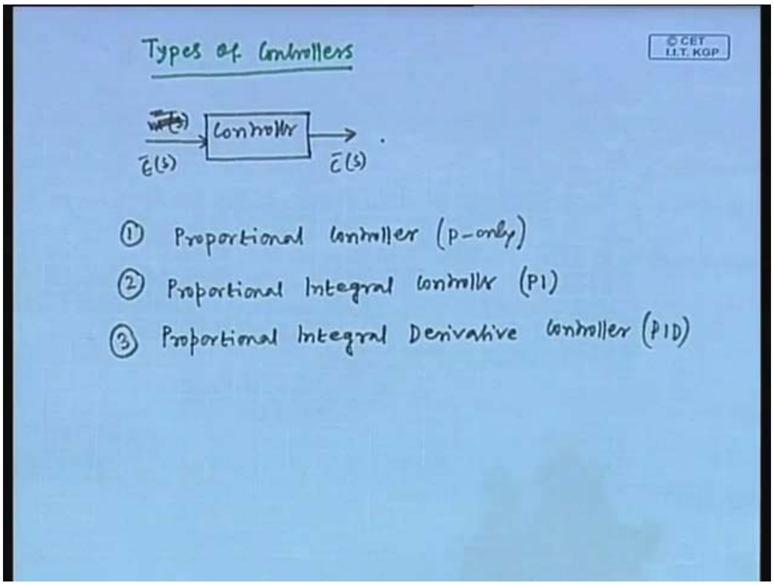
Now, this measure temperature, this measurement signal goes to the comparator and the sign is negative, you just compare the configuration with this block diagram. Now, another input to this comparator is y said point, that is y suffix s p and we use positive sign for this. So, there are two input signals considered for the comparator, what is the comparator output, epsilon in Laplace domain we can write epsilon bar, this comparator output is supplied to the controller.

So, one block we can draw for the controller, the error signal epsilon goes to the controller, then the controller calculates the control action. We can represent the controller output by c and in Laplace domain c bar, this controller output goes to the final control element, that is the control half, the controller output c is supplied to the controller output c goes to the final control element and final control element output is m.

So, this the block diagram of the closed loop process this the process which as two inputs, one is the final control element output and another one is the disturbance, these two inputs effect the process. If we consider the liquid tank system hitting tank system, the output is the temperature this temperature is first measured by using one measuring sensor.

Sensor output is T suffix m that is measure temperature, then that measure temperature is compared with it is said point value, comparator output is represented by here it is epsilon, that information is goes to the controller. And using that information controller calculates the control action, then control information is physically implemented to this final control element. So, this the closed loop block diagram of a process.

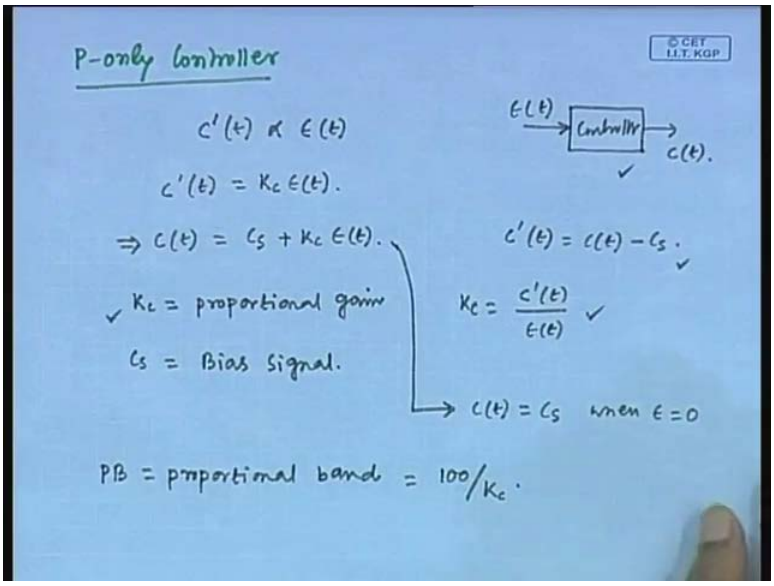
(Refer Slide Time: 16:39)



Next we will discuss the different types of controllers. Now, if we redraw the controller block, then we see that input is m bar s output is sorry input is epsilon bar and output is c bar s. So, the basically the controller relates c to it is epsilon. So, various types of controller differ in the o a they relate c to it is epsilon. So, first we will consider three types of controller, which are classical controllers and which are definitely fee back controllers.

These three controllers are proportional controller, this is also called I mean this is also named as p only controller. Second controller is Proportional Integral controller, which we can call as PI controller, proportional integral. Proportional integral controller additional includes the integral term. Third controller is Proportional Integral Derivative controller, which we can call as PID controller, these are the basic feedback controllers. And we will discuss one by one so, first we will consider proportional controller.

(Refer Slide Time: 19:45)



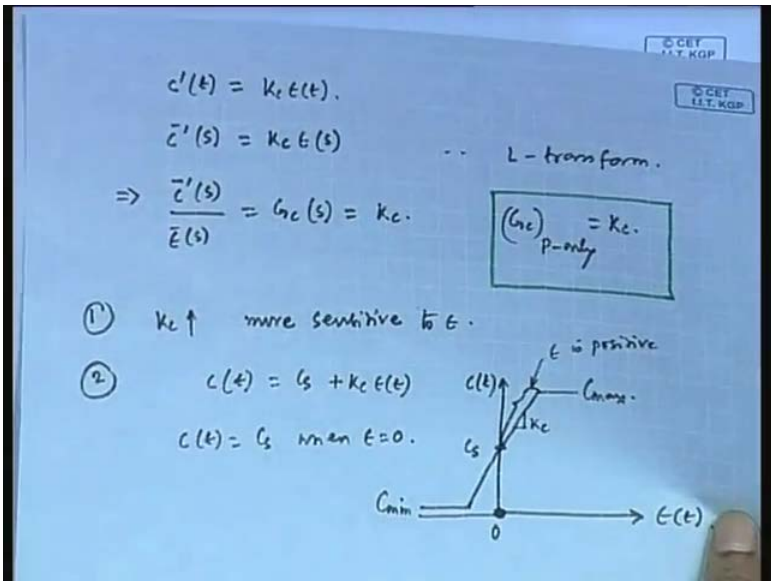
First we will discuss proportional or p only controller the controller output c which can be written in terms of divisional variables as c prime t is proportional to the error signal. If you see the control block, will observe that its epsilon t is the input and c t is the output. Now, we have written c in terms of divisional variables. So, c prime t is proportional to the error signal that is the input to the controller and that is why the name I mean that is why it is called proportional controller. So, you can write this against as c prime t equals k c it is epsilon t.

And finally, we write c t equals c s plus k c it is epsilon t or c prime t is equal to c t minus c s. I have mentioned that c prime is the divisional variable. So, c prime t we can write as c t minus c s. Now, k c is the proportional gain of the controller. It is very obvious you see k c we can write as c prime t divide by epsilon t can we write this, k c is equal to c prime t is divided by epsilon t you just see this block c t is the output. If epsilon t is the input I have already mentioned that gain is change in output per units change in input, it is obvious in this correlation.

So, we can say k c as the proportional gain. Now, what is c s, c s is the bias signal, controllers bias signal. We can define it as c s is the controller output and there is no error, if you see this equation. We can write that c t is equal to c s when the error is 0. So, bias signal is the controller output and error equals 0. This k c is one tuning parameter controller tuning parameter, the value of that parameter we need to determine. So, one equivalent term is also used in different soft wares and industrial factories, that is proportional band.

One equivalent term of k c called proportional band is also used in different process simulator and in industrial practice. Proportional band, which is 100 divided by k c proportional band is 100 divided by k c. Now, we used to determine the trans perform of the controller.

(Refer Slide Time: 25:20)



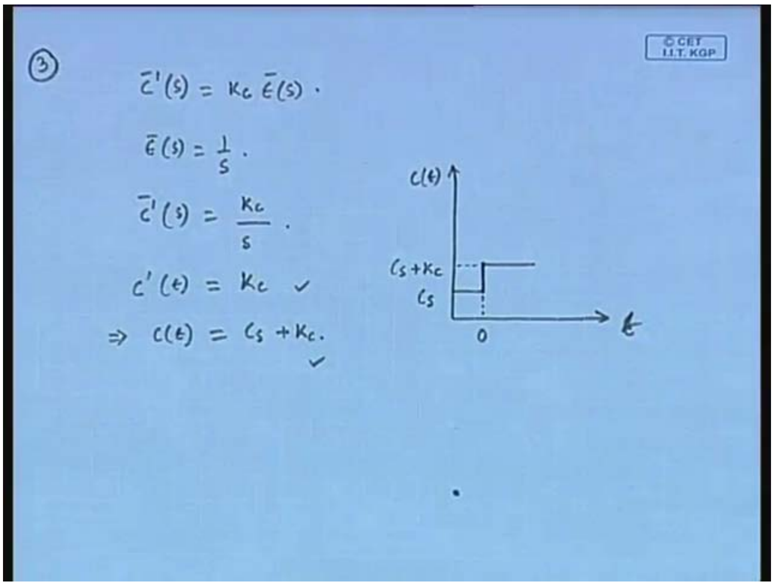
You see for the p only controller we got c prime t is equal to k c it is epsilon t. Now, if we take the Laplace transform for this, then we obtain c prime bar s equals k c epsilon s, if we take Laplace transform we obtain c prime bar s is equal to k c epsilon s. Now, what is the output of the controller, c prime bar s what is the input to the controller epsilon s, and this can be represented as transfer function of the controller G c s and G c s is equal to k c. So, for PI controller transfer function is sorry for the p only controller transfer function is equal to k c.

Now, we will conclude the p only controller, with the increase of k c the controller becomes more sensitive to error, this is the first conclusion which we can draw for the p only controller. With the increase of k c the controller becomes more sensitive to error epsilon. If we increase the k c value the controller become more sensitive to it is epsilon. Now, we want to see the behavior of the p only controller, how the controller behaves that we want to represent graphically.

So, remember the controller equation that is c t equals c s plus k c epsilon t this is the p only controller equation in time domain. Now, if we plot c verses epsilon, we obtain the c s when it is epsilon is equal to 0. So, this pointing is representing c s because, we know that c t equals to c s when it is epsilon is equal to 0. So, we are considering this or epsilon is equal to 0, so the corresponding c value is c s and when we increase epsilon, it increase like this, it is a slope of k c. So, slope is k c.

And the last value of c is c max maximum value of c we cannot consider c as infinity due to the some physical limitation of final control element, we have to put constants on c. So, the higher limit is c max and lower limit is c min. Now, this variation is obtained when it is epsilon is positive similarly, we obtain this line, when it is epsilon is negative and the minimum value of c is c min. So, this is the second conclusion on p only controller. Next we will discuss how the controller response, which it is take place in error signal.

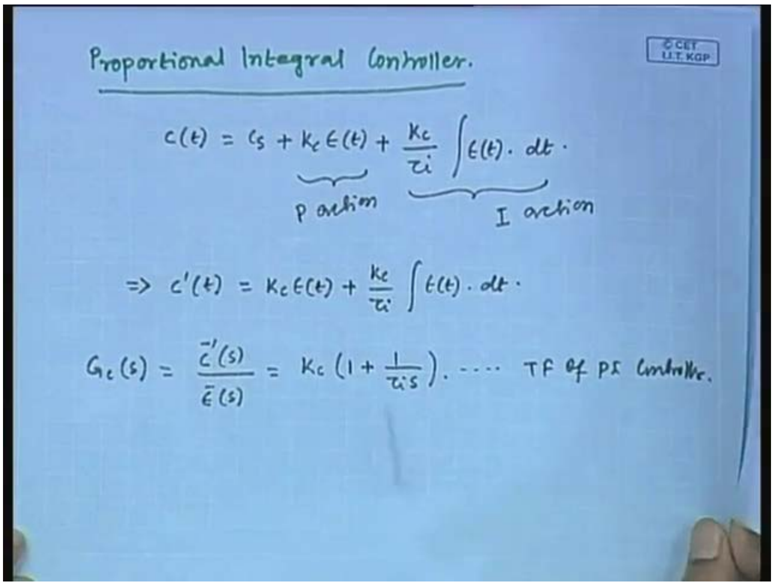
(Refer Slide Time: 31:02)



So, we will use the controller equation in Laplace domain. This is the p only controller, equation in Laplace domain. Now, we will consider a unit place change, we will consider a unit step change in error signal, then the controller equation is c bar prime s is equal to k c by s. If we take in words of transform, then we get c prime t equals k c if we take in terms of transform we obtain c prime t equals k c; that means, c t is equal to c s plus k c. Finally we get c t equals c s plus k c.

Now, we will produce the plot to represent this concept, this is time t and this is c t. Now, initially the process was, initially the controller has the value of c s. Now, we are introducing a unit step change at time t equals 0, then the controller output provides the value of c s plus k c. This is the controller behavior against a unit step change in error signal. Next we will discuss the second controller that is PI controller Proportional Integral controller.

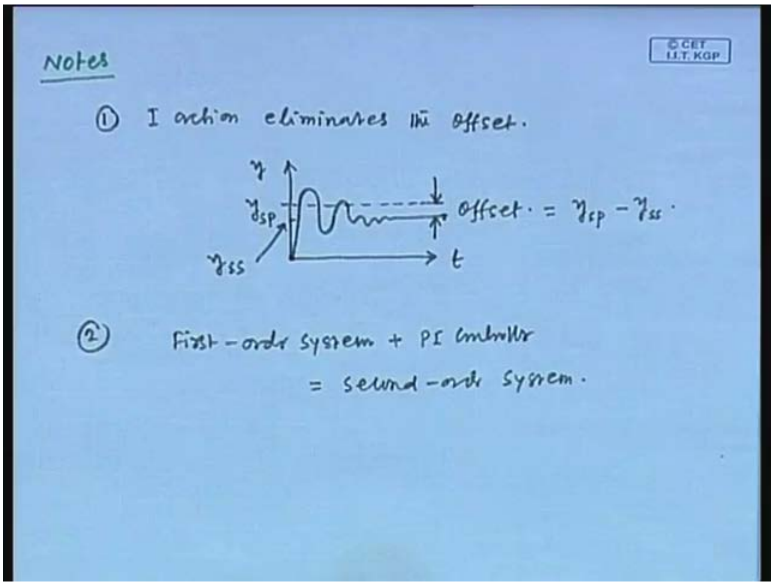
(Refer Slide Time: 33:50)



Next we will discuss, proportional integral controller c t equals c s plus k c it is epsilon t this the representation of p only controller. Now, additionally we include the integral term in poly n controller, to obtain PI controller. That integral term is represented by k c divide by tau i integration of error t d t. So, this is the integral action and this the proportional action, combining this two actions we obtain t i controller.

Now, we can represent this terms in divisional variables for finding the trans form function of PI controller. Accordingly we write, c prime t equals k c it is epsilon t plus k c divided by tau i integration of error t d t by taking Laplace transform and rearranging we obtain the transform function, as G c s equals c bar prime s divided by it is epsilon by s equals k c 1 plus 1 divided by tau i s by taking Laplace transform and rearranging finally, we obtain the transfer function of PI controller as G c s k c multiplied by k c 1 plus 1 divide by tau i s this is the transfer function of PI controller. Now, we will make some demarks on these PI controller.

(Refer Slide Time: 37:04)

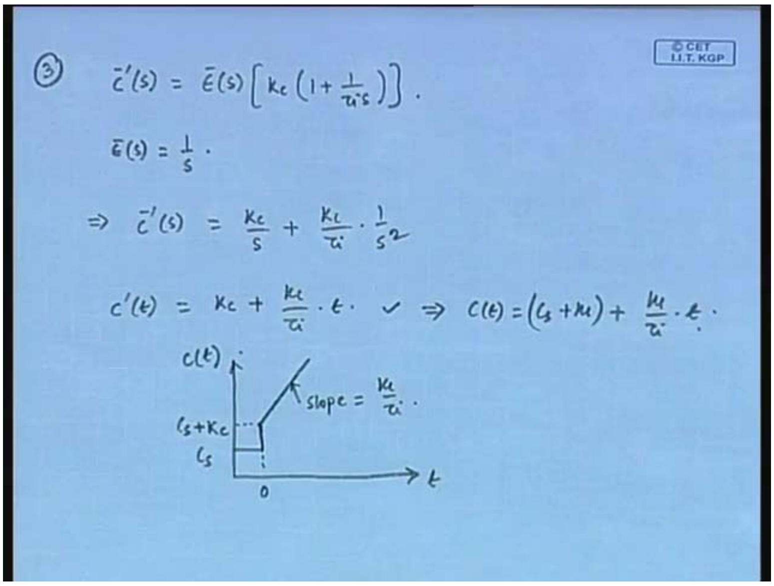


The integral action eliminates the offset, first conclusion is the integral action eliminates the offset. Offset is basically the steady state error. If we plot y verses time t we may get this type of response under a controller, this is the set point value and the value who which we are getting finally, that is the steady state value. So, this corresponding value, this value is the steady state value y steady state. Now, the difference between the set point value and steady value is called offset.

So, offset is basically y set point minus y steady state. Now, this theory controller can eliminate the offset due to the inclusion of integral action I mean p only controller cannot eliminate the offset due to the inclusion of integral action. I mean the p only controller can not eliminate offset, this is the first conclusion. Now, due to the additional of integral action, the overall response becomes more sluggish, this is the second conclusion due to the addition of integral action the overall response become more sluggish, due to the increase of order by one due to the increase of integral action the overall response becomes more sluggish.

Say for example, if we consider a first order system and if we employ the PI controller, then the overall system becomes second order system. If we consider a first order system and if a controller is employed, then the overall system response becomes second order dynamites, that means order is increased by one. Now, in plot we have compared the dynamites of first order, second order and fourth order systems and we have observed that increasing the number of capacities in series, increases the sluggishness. So, by that line we can say that by inclusion of integral action the order is increased by one, it means the overall response becomes more sluggish. So, this is the second conclusion. Now, we will consider a unit step change in error signal and we will observe the response of the PI controller.

(Refer Slide Time: 41:56)

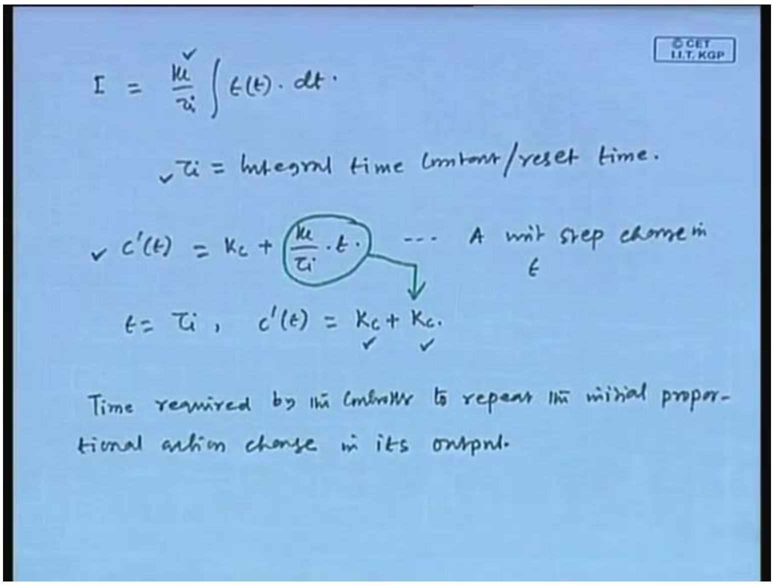


So, PI controller equation in Laplace domain, we can write as c bar prime s equals it is epsilon s multiplied by k c 1 plus 1 divided by tau i s can we write this, the PI controller in Laplace domain. Now, we will consider a unit step change in error signal. We will consider a unit step change in error signal; that means, epsilon bar s equals 1 by s, then we obtain c bar prime s equals k c divided by s plus k c divided by tau i 1 by s square.

Now, inverting this, we obtain c prime t equals k c plus k c divided by tau i multiplied by t. Taking inverse of Laplace transform we obtain finally, c prime t equals k c plus k c divided by tau i multiplied by t. Now, we will represent this graphically, this is time t this is c t. Now, at time t equals 0 the controller as the value of c s and we are introducing a unit step change at time t equal was 0 accordingly the controller output becomes c s plus k c.

So, c s plus k c we can obtain from this c s plus k c plus k c divided by tau i into t. So, it is obvious that the time t equals 0 c t equals c s plus k c and when time is greater than 0 the c increases linearly, with a slope of a c divided by tau i slope equals k c divided by tau i. This is the behavior of PI controller against the unit step change in error signal. And that error signal the change in error signal introduced at time t equals 0.

(Refer Slide Time: 45:26)



Now, this integral action, we can write as k c divided by tau i epsilon t d t, k c is the proportional gain and tau i is the integral time constant, one additional tuning parameters is there, that is tau i and tau i is called as integral time constant, it is also called as reset time, unit of tau i is time.

Now, for the PI controller we got c prime t equals k c plus k c divided by tau i into t by introducing a unit step change in error signal. We obtain for PI controller c prime t plus k c plus k c divided by tau i into t. Now, if we consider t equals tau i. The controller output is c prime t equals k c plus k c. So, this term is given this yielding k c understood or not, for the PI controller one additional term is there that is integral action. The integral action can be represented by this form, integral action equals k c divided by tau i integration of error t d t.

Now, the tuning parameter k c is present also for p only controller. Now, the additional term tau i is present with this PI controller that tau i is called integral time constant or reset time. The unit of these integral time constant is time. Now, we obtain these form c prime t equals k c plus k c divided by tau i into t considering it a unit step change in error signal this form we obtain.

Now, we are just considering time t equals tau i then the controller output is c prime t equals to k c can we define now reset time. What is reset time, reset time is a time required for the controller, reset time is the time required by the controller to repeat the initial proportional action change in it is output you see the initially we had one proportional gain that is k c. Now, due to the addition of integral term and considering time equals tau i we are getting another proportional action, and therefore we can say that, the reset time is the time required by the controller to repeat the initial proportional action change, in it is output.

Thank you.