**Process Control and Instrumentation**
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**Lecture - 31**
**Advanced Control Schemes**

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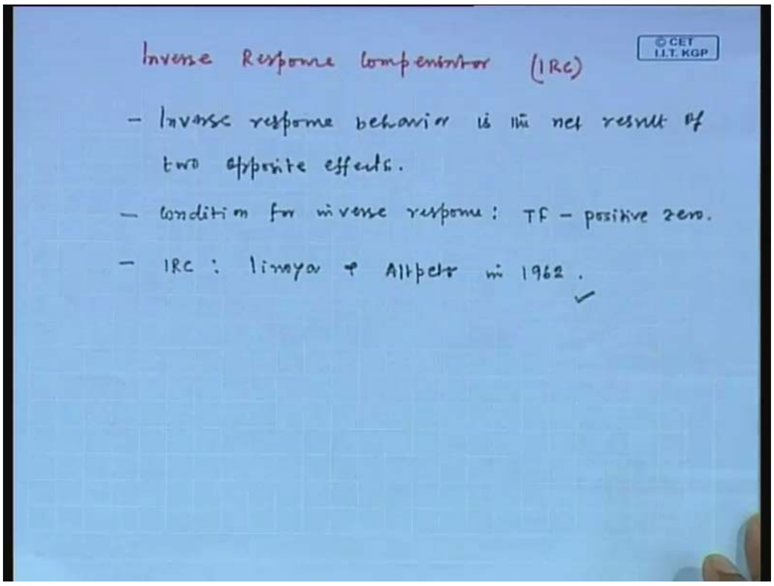


So, today, we will discuss inverse response compensator. In the last class, we discuss the dead time compensator. Inverse response compensator can be derived based on the same concept. Now, inverse response behavior we started earlier fine. Inverse response behavior is the need result of 2 opposing effects. Inverse response behavior is the net result of 2opposing effects. What is the condition for inverse response behavior? What is the condition for inverse response? Transform function has a positive zero, transform function should have positive zero then only the inverse response behavior it is obtained. Now, this inverse response compensator was proposed by Linoya and Altpeter in 1962 based on the general concept of smith predictor or dead time compensator. They have proposed this inverse response compensator based on the general concept of smith predictor or dead time compensator. Next, we will discuss development of inverse response compensator.

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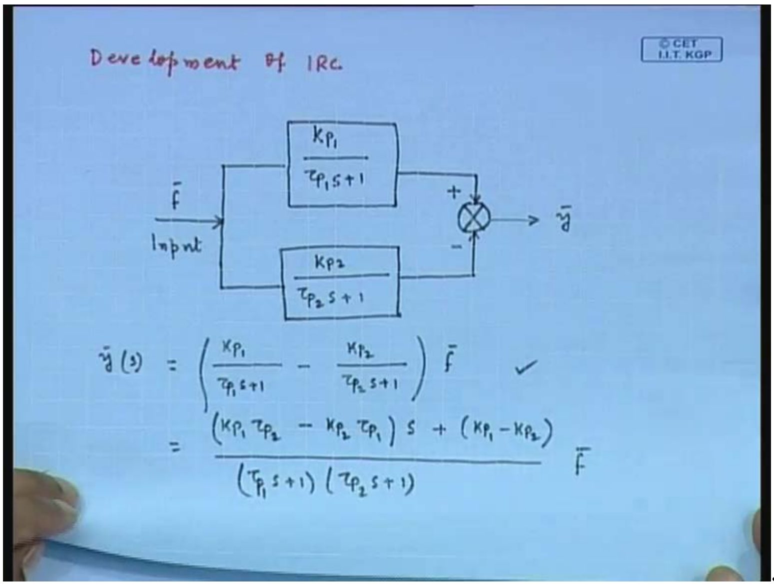


Next, we will discuss the development of inverse response compensator. Consider to first order processes acting in parallel. Consider to first order processes acting in parallel and the first order processes are represented by K p 1 divided by tau p 1 s plus 1. And another process has the transform function of K p 2 divided by tau p 2 s plus 1, this two first order processes acting in parallel Input to this first order processes is f just is a input. Now, it is mention that inverse response behavior is the net result of 2 opposing effect.

So, we will consider one output positive another positive negative. Then the output is say y fine it is obvious, that this 2 process first order processes are acting in parallel and they have opposing effects. Now, we can write the expression for y as K p 1 divided by tau p 1 s plus 1 minus K p 2 divided by tau p 2 s plus 1 multiplied by f bar. Can we write this output equal to transform function multiplied by input? Rearranging this we can write as K p 1 tau p 2 minus K p 2 tau p 1 s plus K p 1 minus K p 2 divided by tau p 1 s plus 1 multiplied by tau p 2 s plus 1 f. This we can get from this expression. Now, can we find the 0 from this expression? What will be the expression for 0?

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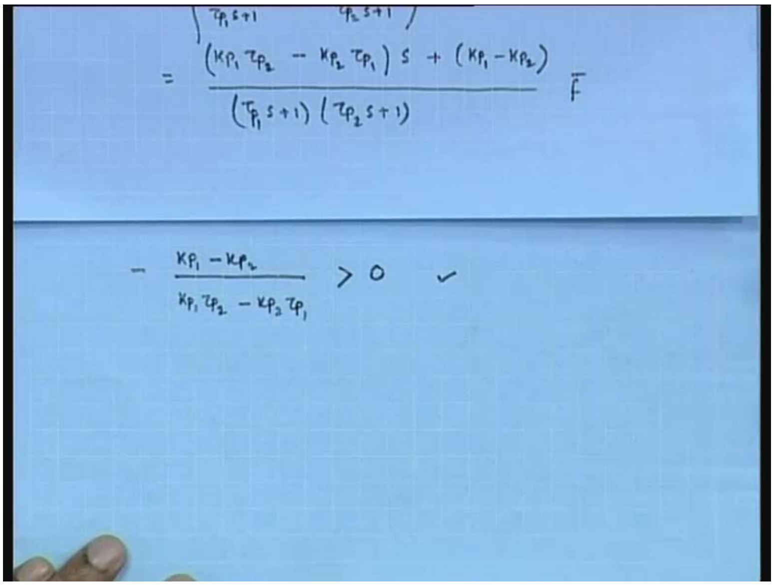


Minus K p 1 minus K p 2 divided by K p 1 tau p 2 minus K p 2 tau p 1 this is a 0 agree. So, what is the condition for inverse response behavior? This 0 should be positive; that means, the condition is this should be greater than 0, this is the condition for inverse response behavior. Next, we will implement the controller i mean we want to develop the closed loaf block diagram.

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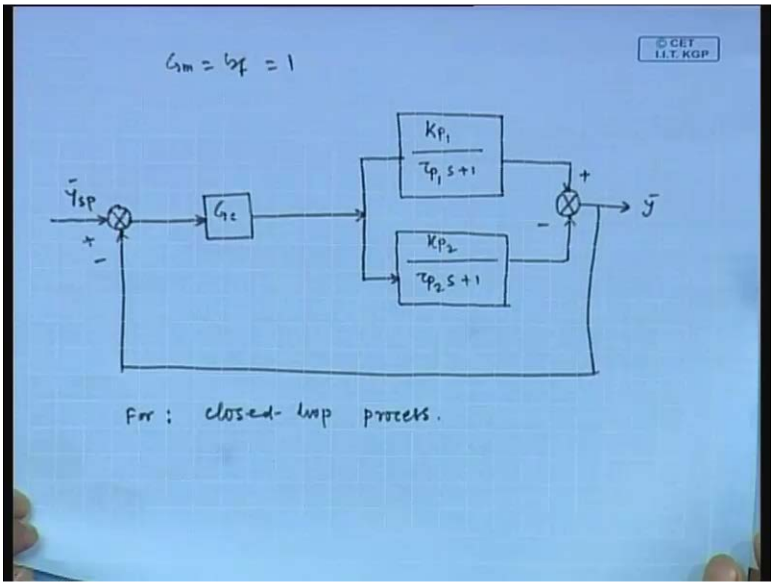


So, our process has the transform function of K p 1 divided by tau p 1 s plus 1 and K p 2 divided by tau p 2 s plus 1 with opposite effects. The transform function for the controller is G c input to the comparator is set point fine here we consider G m and G f both are equal to 1 for simplicity. So, this is the closed loaf process, fine we have just included the transform for the controller with the process sowing inverse response.

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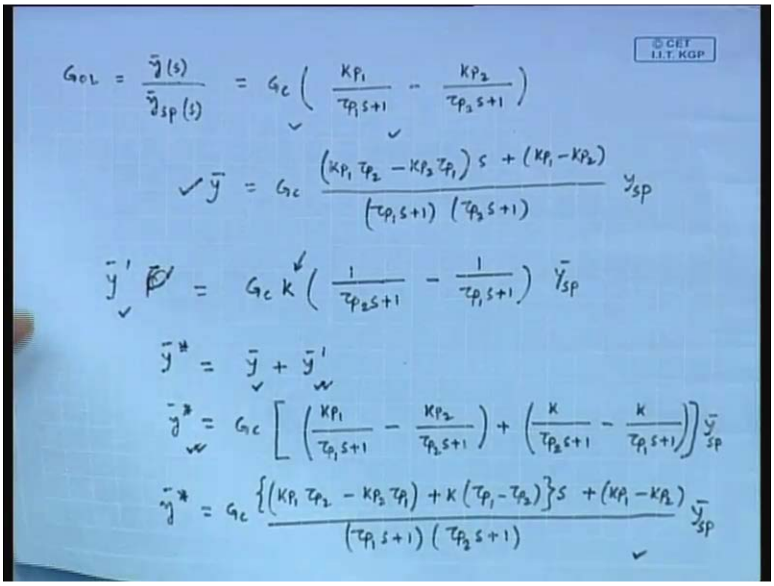


Now, what is the open loop transfer function? Open loop transfer function; we can write as y by y set point; this is the open loop transfer function. And this can be expressed in terms of individual transfer function as G c multiplied by K p 1 divided by tau p 1 s plus 1 minus K p 2 divided by tau p 2 s plus 1. Because we assumed G m G f both are 1. So, G c multiplied by G p this we can write as G c K p 1 tau p 2 minus K p 2 tau p 1 s plus K p 1 minus K p 2 divided by tau p 1 s plus 1 tau p 2 s plus 1. Now, as we determined f prime for dead time compensator. Similarly, here also we need to find the expression for f prime f prime is nothing but the output of the compensator a prime is the output of the compensator.

And this is written as G c K 1 divided by tau p 2 s plus 1 minus 1 divided by tau p 1 s plus 1 y set point bar fine basically this is the output y bar. Now, this is not a prime this is y prime y is the process output y prime is the compensator output y prime is calculated. Show that ideally, we obtained inverse free response and that is y star, y is the process output y prime is the compensator output. If we add this 2, we obtain y star that is the ideal response which is inverse free response. We did the same thing for the case of dead time compensator and another thing I want to mention here that this K basically the, determine the condition. Based on this K fine we will determine the condition based on the K, any way what is the ideal, what should be the ideal response y star?

Now, we can calculate this y star substituting the expressions for y and y prime substitute. Now, G c multiplied by K p 1 divided by tau p 1 s plus 1 minus K p 2 divided by tau p 2 s plus 1. Then K divided by tau 2 s plus 1 minus K divided by tau p 1 s plus 1 multiplied by y set point substituting the expressions of y. And y prime we obtain this; this is y star, we can write this as G c K p 1 tau p 2 minus K p 2 tau p 1 plus K multiplied by tau p 1 minus tau p 2 s plus K p 1 minus K p 2 divided by tau p 1 s plus 1 tau p 2 s plus 1 y set point. Rearranging the initial expression previous expression we get this. Can you find the expression for 0, what will the expression for 0, which we can obtain for this expression?

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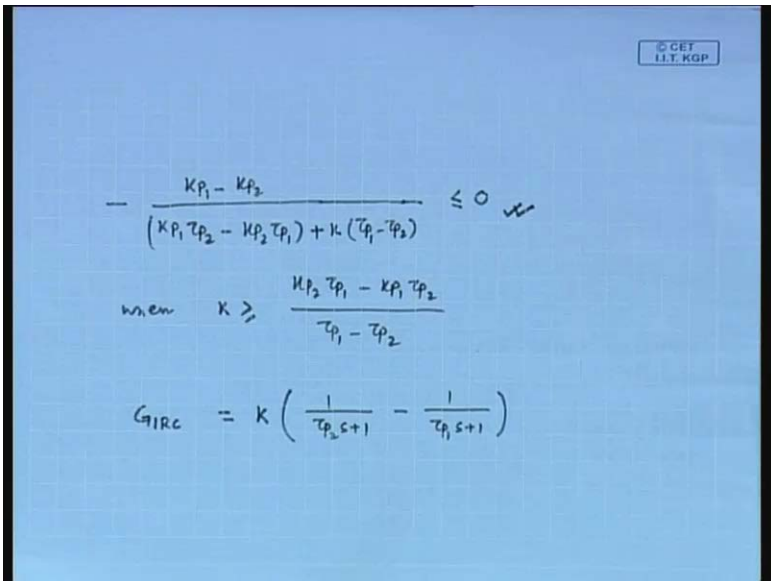


The expression for 0 will be minus K p 1 minus K p 2 divided by K p 1 tau p 2 minus K p 2 tau p 1 plus K tau p 1 minus tau p 2. Basically 0, we obtain by considering this enumerator equal to 0. So, this is the expression for 0. Now, to avoid the inverse response behavior this should be less than or equal to 0 agree. The condition for inverse response behavior is this 0 should be greater than 0. Now, to avoid the inverse response behavior it should be less than 0. Now, question is that what condition of K this is true at what condition of K this is true; this is true when K is greater than or equal to K p 2 tau p

1 minus K p 1 tau p 2 divided by tau p 1 minus tau p 2. This 0 should be less than 0 when this condition is satisfied.

Now, what is the transfer function for the inverse response compensator? The transfer function for inverse response compensator, we can write as K 1 divided by tau p 2 s plus 1 minus 1 divided by tau p 1 s plus 1. This is the transfer function for the inverse response compensator. This is the transfer function for the inverse response compensator; you just consider the expression which we consider for y prime. This is a output; output is inverse response compensator transfer function then this is the controller transfer function multiplied by set point. So, it is obvious, that this is the transfer function for the inverse response compensator which I have written here. Now, we vesture incorporate the block of inverse response compensator in the closed loop block diagram as we deed for the case of dead time compensator.

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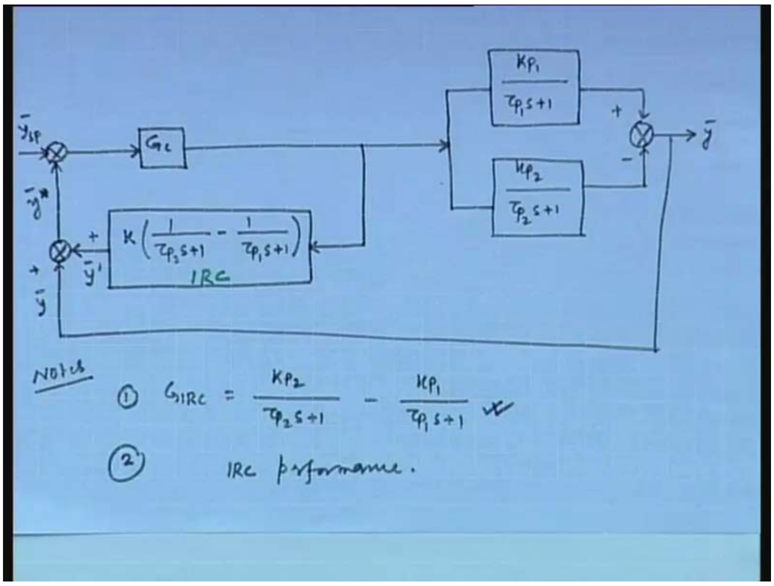


Now, our process has the transfer function of K p 1 divided by tau p s plus 1 and K p 2 divided by tau 2 s plus 1. They have the opposing effect output is y this is the controller G c this is set point y. Now, we will place the compensator here you see the transfer function, the transfer function of the compensator can be expressed as K multiplied by 1 divided by tau p 2 s plus 1 minus 1 divided by tau 1 s plus 1 agree. This is the transfer function of the inverse response compensator definitely it is multiplied with G c. So, we can consider this input output is y prime and y is a output of the process this is y. if this 2 signals are added.

Then we obtain ideal response i mean inverse response inverse feed response. Now, if you see this expression this expression y prime is the output y prime is the output. That is multiplied that is equal to G c this is G c multiplied with K into this one which is the inverse response compensator then this s y set point y set point. So, to obtain this y prime this block is included in the closed flop block diagram. So, this is basically the inverse response compensator. Now, how I mean at what situation we can get perfect compensation at what situation we can get perfect compensation?

If it is represented by K p 2 divided by tau p 2 s plus 1 minus K p 1 divided by tau p 1 s plus 1. This is the original transfer function of inverse response compensator; we can get perfect compensation if the inverse response compensator has this transfer function. You can substitute the y prime related to this expression in the expression of y star to see the perfect compensation. So, this is first point we can get perfect compensation if the inverse response compensator has this form. Second point is inaccurate model degrades the inverse response compensator performance. Inaccurate model degrades the I R C performance inaccurate model degrades the inverse response compensator performance. So, this is all about the inverse response compensator. So, we discussed the 2 compensators one is dead time compensator. Another one is inverse response compensator. In the next, we will discuss another advanced control scheme that is cascade control scheme.

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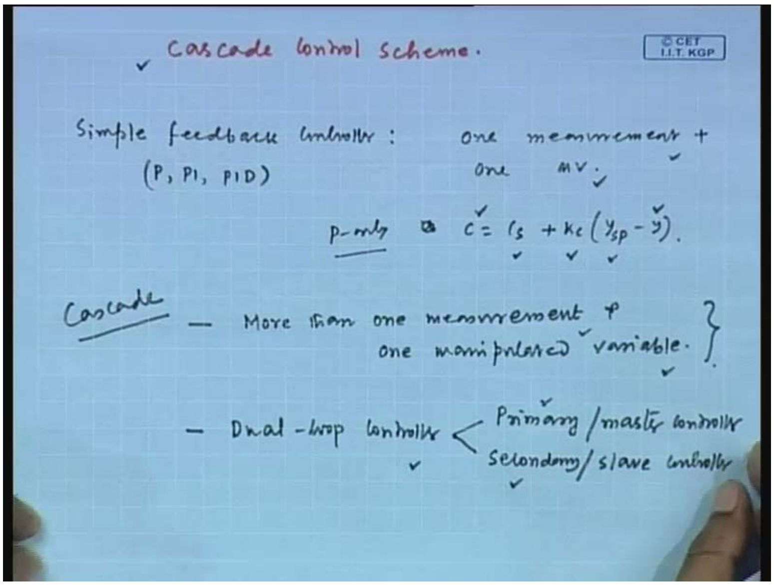


Cascade control scheme previously we discussed 3 different controllers P P I and P I D controllers all are feedback controllers. And we will designate them as simple feedback control schemes previously we discussed P P I and P I D which we are calling now simple feedback controller. Now, for those controllers one measurement and one manipulated variable are involved. If I write a simple equation I mean if I write a equation for the simple P only controller we can writes that as c equal to c s plus K c y set point minus y.

This is the equation for P only controller you see in this equation the measurement y and manipulated variable c are involved. Because c e s c s bias signal which is basically constant and K c is the tuning parameter and this is pacified by the control engineer. So, in the simple feedback control engineer one measurement and one manipulated variable are involved in a single loop. Now, we will discuss cascade control scheme in which more than 1 measurement more than 1 measurement. And 1 manipulated variable are involved in cascade control scheme for the simple feedback scheme 1 measurement.

And 1 manipulated variable are involved, but for the case of cascade controller more than 1 measurement and 1manipulated variable are involved. Secondly, it involves dual loop controller involves dual loop controller the cascade controller involved dual loop controller 1 controller is called primary or master controller. Aanother controller is called secondary or slave controller. The cascade controller also involve say dual loop controller; first one is called the primary or master controller and second one is called secondary or slave controller fine Now, to discuss this cascade control scheme, we will take one example.

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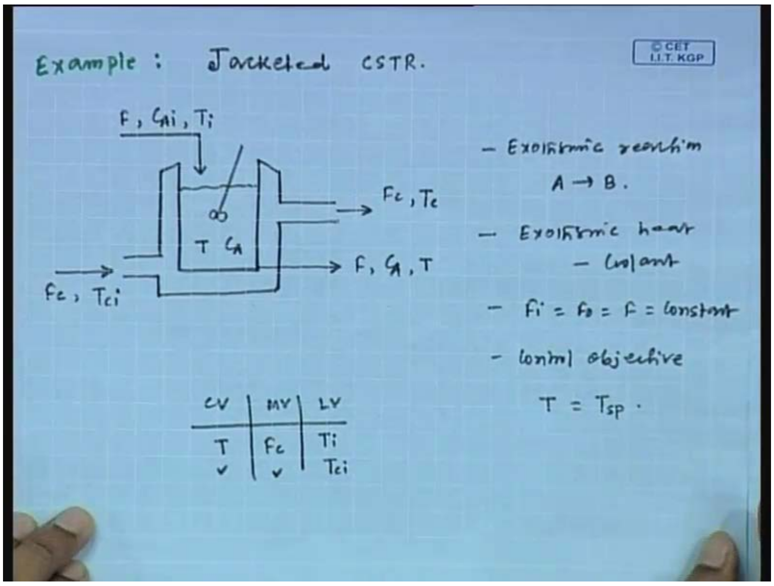


We will consider the example of a jacketed C S T R will consider the example of a jacketed C S T R. This is a schematic of a jacketed CSTR in lets steam has the flow rate of f with concentration C A i. And temperature T i outlet steam has a flow rate of F composition concentration C A and temperature T an exothermic reaction occurs in the reactor and exothermic a reversible a reaction occurs in the reactor. Now, the exothermic heat is removed by the coolant exothermic heat is removed by passing a coolant through the jacket.

So, suppose the coolant flow rate is F C and the temperature of the coolant is T c i the outlet coolant flow rate is F c and temperature is T c. We assume that both the inlet and outlet flow rates are identical and they remain constant F i equal to F not equal to F. And they both are constant for this example system out control objective is to mention the reactor temperature T at its set point value. The control objective is to mention the reactor temperature T at its set point value. Now, we will try to find the pears controlled variable is reactor temperature T corresponding manipulated variable is coolant flow rate F c and possible disturbances are T i and T c i. Control variable is reactor variable T corresponding manipulated variable is F c and possible disturbances are T i and T c i. Now, we will configure the simple feedback control scheme

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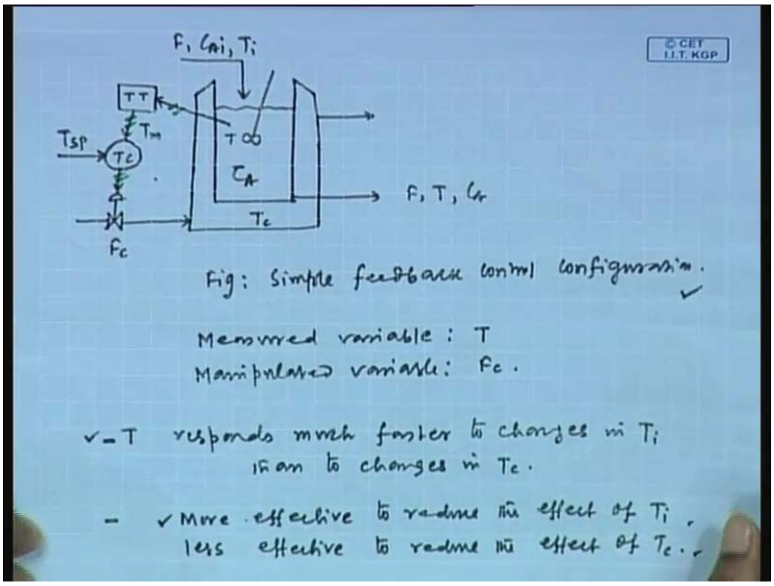


Inlet flow rate has the flow rate of F concentration c i temperature T I, outlet flow rate is F temperature T and concentration C A fine our contain objective is to mention the temperature. So, first it is required to measure the temperature T by using a sensor temperature measuring device. Then this measure temperature T m is feedback to the temperature controller T c measure temperature T m is compared first with set point value T s p. Then the calculated control action is implemented through the final control element.

This is the simple feedback control configuration temperature T is measured using the temperature measuring device represented by T T. Then the measure temperature T m is compared with set point value T s p. Then the control action is calculated and that action is implemented through this valve. So, this is the simple feedback control configuration. Now, in this configuration which one is the measured variable measured variable is T which one is the manipulated variable manipulated variable is F c. Now, it is obvious, that T response much faster to changes in T i then to changes in T c. There are 2 disturbances there are two possible disturbances; one is T i another one is T c. Now, this T response much faster to changes in T i. Then to changes in T c T response much faster to changes in T i then to changes in T c it is very obvious you see T i can directly affect T.

Because it is affecting to the reaction mixture directly, but T c is first effect the jacket then to the process fine T c is not directly going to the reactor. It is going to the jacket then the effect is then the effect goes to the I mean the reactor is affected. Then therefore, we can say that the reactor temperature response much faster to changes in T i then to changes in T c. So, accordingly can we say the simple feedback controller is more effective to reduce the effect of disturbance in T i, and less effective to reduce the effect of disturbance in T c. The simple feedback controller is more effective to reduce the effect of disturbance in T i and the controller is less effective.

To reduce the effect of disturbance in T c this conclusion, we can draw based on this simple feedback control configuration. The simple feedback controller is more effective to reduce the effect of disturbance in T i and less effective to reduce the effect of disturbance in T c. Now, basically we want more effective for both the cases I mean the controller should be more effective to reduce the effect of T i. And more effective to reduce the effect of disturbance in T c and therefore, we need the cascade controller. Now, we will discuss the cascade controls scheme, how it is more effective for both the cases.

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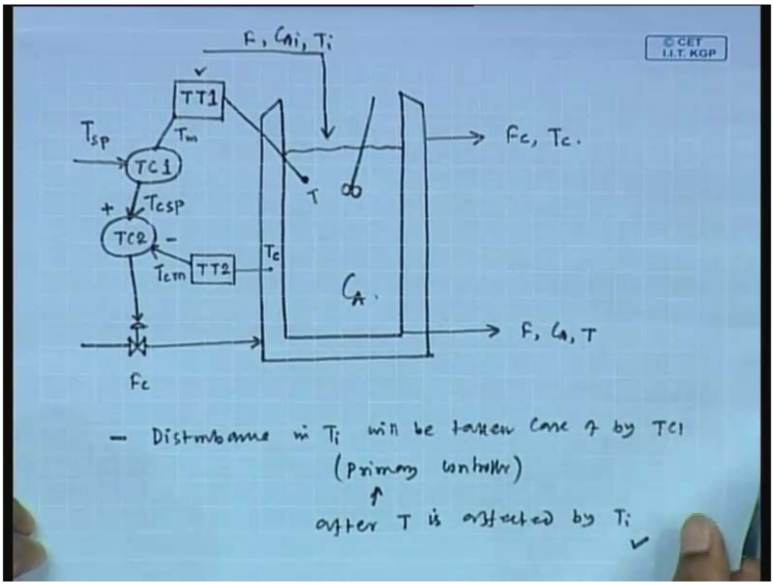

So, this is the CSTR jacketed CSTR. Now, first we measure the temperature T using one temperature measuring device which we are representing by T T 1 this is the first measuring device I mention earlier that cascade controller involves to more than 1 measurement. So, this is a first measuring device T T 1. Then the measure temperature information which is T suffix m goes to the controller the temperature controller which is T c 1. Then the output of this first temperature controller goes to another temperature controller that is T c 2. The second measuring device T T 2 is use to measure the disturbance T c.

This s negative this is positive and then the control action is implemented through this final control element.. So, I am repeating the steps again our control objective is to mention the temperature the T. So, this reactor temperature is measured by the measuring device T T 1. Then the measure temperature T T m is compared with its set point value then T c one calculates the control action for the simple feedback controller the control action of T c 1 is implemented. But here another controller is included that is T c 2 here the first temperature controller T c 1 calculates basically the set point value of coolant temperature.

The first temperature controller basically calculates the set point of coolant temperature that is T c set point. And the second measuring device T T 2 basically measure T c which is the disturbance involved with the manipulated variable. So, this signal is basically T c m measured T c. So, T c set point compared with T c m and the second controller T c 2 calculates the control action that action is implemented through this control valve. So, T c 1 is the primary controller or master controller and T c 2 is the secondary controller or slave controller. So, here 2 measurements are involved; one is reactor temperature T and second one is coolant temperature T c. But manipulated variable is one I mean only one manipulated value is involve that is F c fine

For the feedback controller scheme there is no action with respect to any change in T c, but this controller takes action if there is any change in T c this is the difference. So, disturbance in T i disturbance in T i will be taken care of will be taken care of by T c 1. And this is done by primary controller T c one is primary controller; this primary controller basically takes action after T is effected by T i this primary controller takes action after T is effected by T i. I want to say that if there is any change in T i that should be reflected through T then only the controller takes action. So, this disturbance first effect the process then the controller takes action. So, disturbance in T i will be taken care of by this primary controller. And it takes action after T is effected by T i next point is disturbance in T c.

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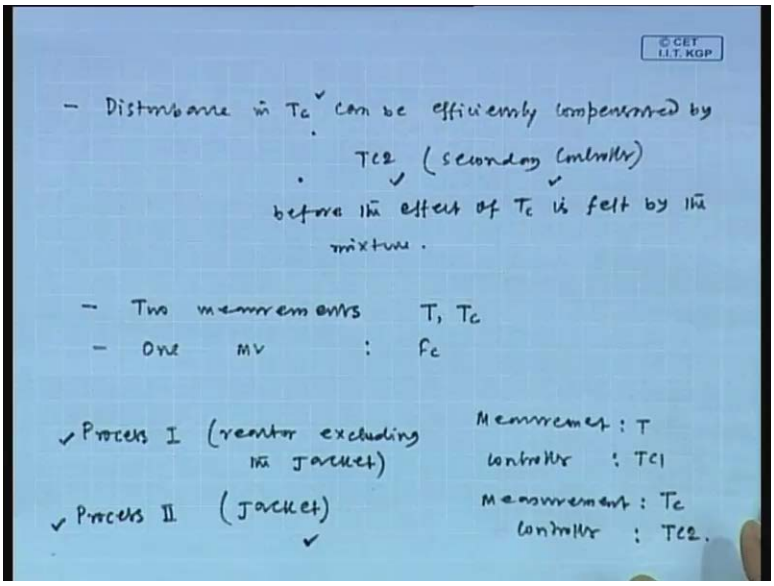


Can be efficiently compensated by T c 2; this is the secondary controller. If there in any disturbance in T c that can be efficiently compensated by T c 2. This is the secondary controller and it takes action before the effect of T c is felt by the mixture. So, previously I mentioned that there are 2 possible disturbances; one is T i another one is T c. Now, if there is any change in T i that will be that will taken care of by T c 1 and if there is any disturbance in another load variable T c. That can be efficiently compensated by secondary controller T c 2. But primary controller takes action after t is effected by T i and secondary controller takes action before the effect of T c is felt by the mixture.

So, here 2 measurements are involved; one is T, another one T c, but manipulated variable is 1 I mean one manipulated variable is involved that is F c. Now, basically this jacketed CSTR consists of 2 processes; one is process 1. Process one is basically the reactor excluding the jacket, the jacket its CSTR consists of 2 processes. One is process one which is the reactor including the jacket and here measurement variable is T controller is T c. One another process is process 2 that is the jacket and for process 2 the measurement is coolant temperature and controller is T c 2. So, the jacket is CSTR consists of 2 processes; one is process 1, another is process 2. Process 1 is the reactor excluding the jacket and process 2 is the jacket. So, in the next class, we will discuss will derive basically the closed loop block diagram for this cascade control scheme.

Thank you