Process Control and Instrumentation
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Lecture - 32
Advanced Control Schemes (Contd.)

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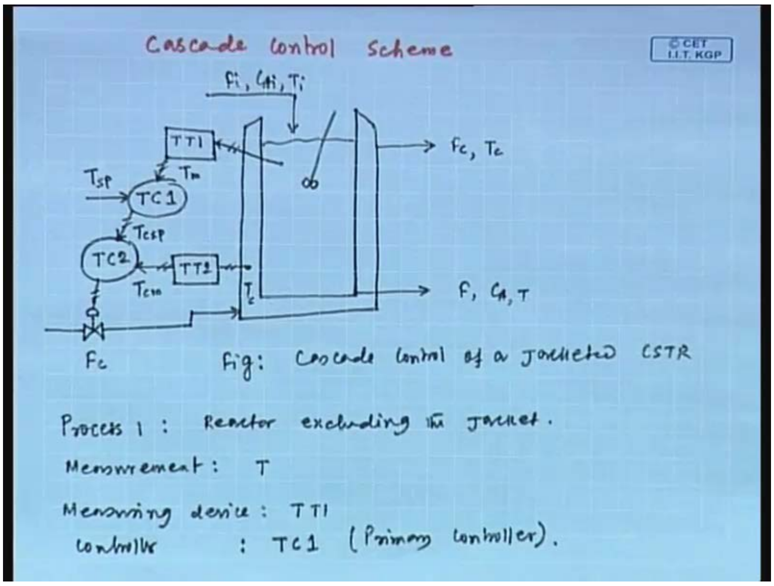

In the last class, we have discussing the cascade control scheme. So that topic will continue today. Cascade control scheme to discuss this cascade control scheme we considered a jacketed CSTR example. So, I am drawing that jacketed CSTR configured with cascade control scheme. First, we measure the reactor temperature using one measuring device, temperature measuring device T T 1, then this information goes to temperature controller one which is the primary controller, the measure temperature T m is compared with it set point value that is T s p. Then the temperature controller output goes to another controller, that is T C 2; coolant temperature is measured by a measuring device namely T T 2, and this measured coolant temperature T C m is compared with T C set point supplied by T C 1.

Then this control action is implemented through the control valve to manipulate the coolant flow rate F c, fine. So, this is the cascade control scheme, and coolant outlet flow rate is F c with temperature T C. This is cascade control of a jacketed CSTR. We also discussed that this process includes two processes, I mean process one and process two. Process one is the reactor excluding the jacket, process one is the CSTR excluding the jacket, fine. And for the process one measurement is reactor temperature T, measuring device is T T 1 and controller is T C 1, this is basically the primary controller or master controller, fine.

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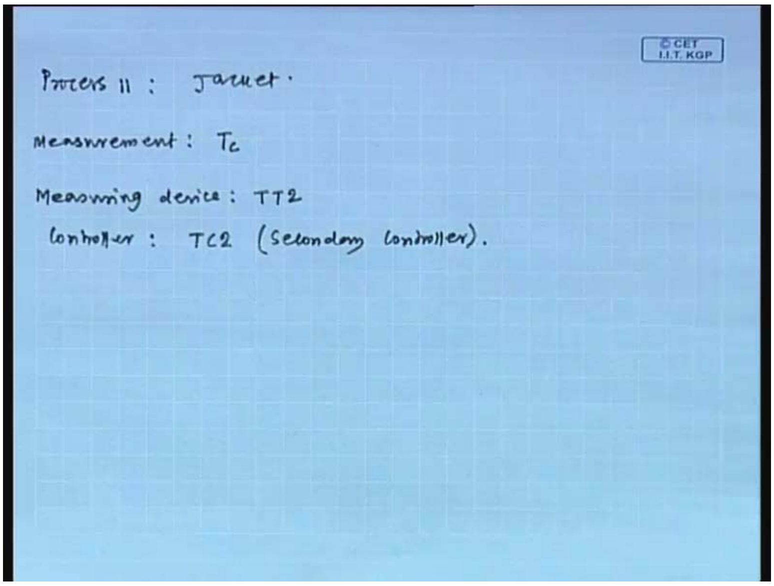

And process two is the jacket. Process two is the jacket, measurement involved in process two is coolant temperature T C measuring device used is T T 2 and for process two, the controller is T C 2, which is the secondary controller fine.

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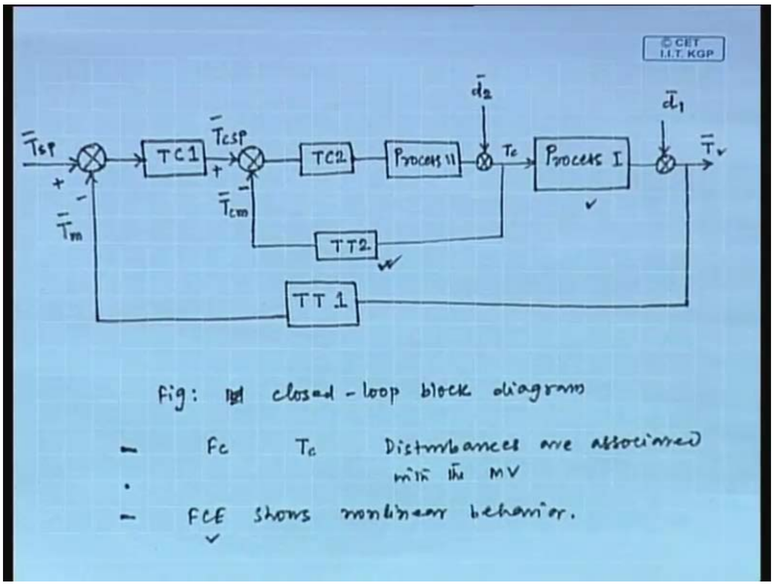

In the next step, we will develop the block diagram for this complete closed loop process. So, process one is the reactor excluding jacket. So, we can use one block for this, and we consider for process one disturbance d 1 fine, what is the output is the reactor temperature T, fine. So, what we did first we measure this temperature using T T 1. So, this is T T 1 temperature transmitter, which is used as a measuring device. So, first we measure the reactor temperature T and we denote the measure temperature as Tm fine. Then this measure temperature is compared with set point value, you see the schematic based on that, we are only developing this block diagram, this measure temperature is compared with its set point value, that is T suffix s p then the error signal goes to first temperature controller.

That is primary controller denoted by T C 1 agree, error signal goes to the primary controller denoted by T C 1. T C 1 output is the set point of coolant temperature T c s p fine, it is done in the schematic diagram. I mean we configure the cascade controller in this way T C 1 output is the coolant temperature set point, and this set point value is compared with T c m, agree, this T C set point which is supplied by the primary controller is compared with measured coolant temperature measured coolant temperature we obtain from T T 2 fine, then the error signal T C set point minus T C m goes to another controller that is secondary controller T C 2, T C 2 output is implemented through the final control element this action is implemented through the final control element, and this control action goes to process two that is the jacket process two.

Secondary controller output enters the process two through the final control element. Now, we can consider the disturbance for process two denoted by d2. Like for process one, we consider d1 then this output effect process one that is nothing but T C, and this TC is measured basically using temperature transmitter two, understood. This is the block diagram for the closed loop cascade control system of the example jacketed system. I am repeating this process one is the reactor excluding jacket our control objective is to maintain the reactor temperature at its desired value. So, process one output is temperature T that is first measured using T T 1 measured signal we denote by T suffix m that then T m is compared with its set point value T suffix s p output of this comparator is the error signal which goes to primary controller T C 1.

The primary controller output is the coolant temperature set point, which we represent by T C set point. Now, this set point is compared with measured coolant temperature that is

T suffix c m. We measure the coolant temperature by the use of this temperature transmitted two. Now, if we compare T C set point and T m then we obtain the error signal i mean the error signal is then goes to the secondary controller T C 2, and T C 2 is T C 2 output is implemented through the controlled valve and this action goes to the process two that is a jacket we used here the disturbance d2 for the second process and the output is coolant temperature which effects process one and coolant temperature here we measured by the user T T 2. So, this is the block diagram.

This is the close loop block diagram, fine. Now, cascade controller is usually used when the disturbances are associated with manipulated variable it is very obvious from this example that that cascade controller takes care of the effect of disturbance associated with manipulated variable our manipulated variable is F c. So, related disturbance is coolant temperature T C. So, this is almost common that the cascade controller is useful when the disturbances are associated with manipulated variable. This is useful particularly when the disturbances are associated with the manipulated variable another situation is when the final control element exhibits non-linear behavior, the final control element shows non-linear behavior, here final control element control valve, fine. So, these are the two common cases here the cascade control scheme is used. So, we developed the cascade control configuration for a jacketed CSTR. We will take another two examples for configuring this cascade control scheme.

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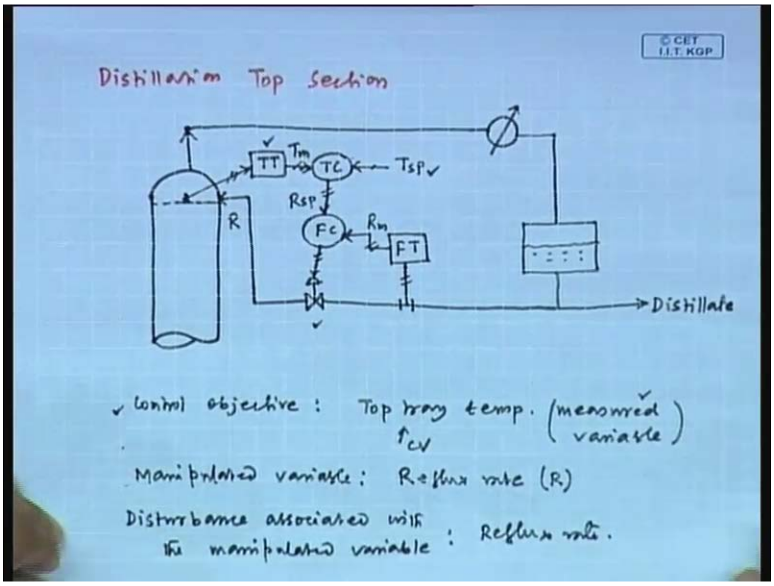

So, now we will consider distillation top section. We will configure the cascade control scheme for the top section of distillation column. At the top of this tower a vapor steam namely if overhead vapor is condensed by the use of a condenser the condensed liquid is then accumulated in a reflux drum, this is a reflux drum a part of this liquid is withdrawn as top product that is distillate. Another part is recycling back to the top tray of the column fine. This is the top section of a distillation column the overhead vapor is condensed then the liquid is accumulated in the reflux drum a part of this accumulated liquid is withdrawn as the top product namely distillate or distillate product and a fraction is recycle back to the top section of the distillation column.

Now our objective our control objective is to maintain the top tray temperature, fine. So, we are considering this is the measured variable, fine. So, this is the top tray. So, we are first measuring the top tray temperature by the use of temperature measuring device represented by TT, fine. Then this goes to the primary controller that is T C measured temperature is then compared with t set point, fine. Primary controller output goes to another controller that is flow controller F c. We measure this flow rate reflux flow rate by the use of one flow measuring device.

So, this is the set point of this flow rate, and this is the measured value if we represent this reflux flow rate by R then this is R measured R m and the primary controller output is R set point, then this flow controller action is implemented through this control valve, fine. So, this is the cascade control configuration for the distillation top section. Our control objective is to maintain the top tray temperature. So, we consider that as the measured variable this top temperature is measured by the use of one temperature measuring device represented by TT then this measured temperature T m goes to the temperature controller in which, the measured temperature is compared with its set point value.

Then this primary controller calculates the set point value for R represented by R suffix s p. And this flow transmitter which is measuring this flow rate as R suffix m. Now, these two are compared in this flow controller F c and that action is implemented trough this final control element. So, this is the cascade control scheme for the top section of the distillation column. So, here this is basically the control variable. Top tray temperature is the control variable what is the corresponding manipulated variable manipulated variable is reflux rate, which is R disturbance associated with the manipulated variable disturbance associated with the manipulated variable that is also reflux rate.

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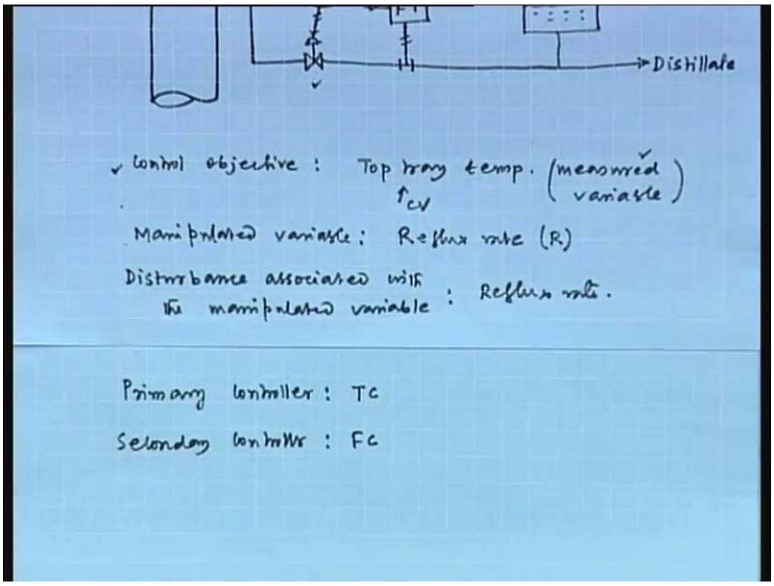

Which one is the primary controller? Primary controller is the temperature controller denoted by T C, and secondary controller is the flow controller denoted by F c, fine. So, this is the second example for configuring the cascade control scheme.

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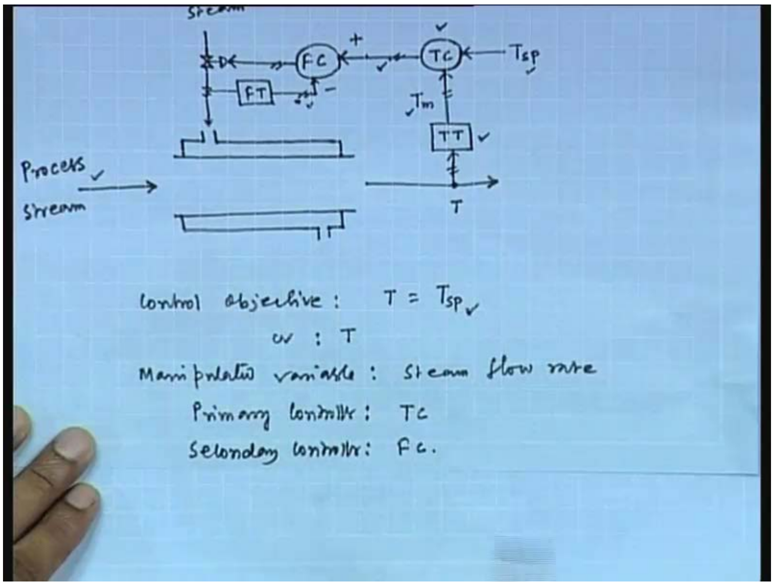

Next, we will consider another example that is a heat exchanger heat exchanger. Next, we will configure the cascade control scheme for the heat exchanger this is the cell side of a heat exchanger through which a process stream is flowing we are interested to maintain the temperature of this process stream T, fine. So, our control objective is to maintain the temperature of this process stream at its set point value now to maintain the temperature we need one heating medium, which flows through the cell side possible I told this is cell side.

Now, this is tube side through tube side the process stream is flowing our control objective is to maintain the temperature at its set point value for maintaining the temperature we need a heating medium. So, for this particular case we need a heating medium for maintaining the temperature of the process stream. So, we will consider the process stream temperature as the as the measured variable, we can measure this temperature by using one temperature measuring device then this information is supplied to the primary controller T C, this is a T suffix m this measured temperature is compared with its set point value T s p.

This is basically indicating the steam flow rate then this is the primary controller T C primary controller output goes to the secondary controller denoted by F c that is a flow controller, and this flow rate is measured the steam flow rate is measured by the use of one flow meter F t. So, this temperature controller gives the set point value of this flow rate, and this is the measured flow rate these two are compared I mean this is positive this is negative then this flow controller flow control action is implemented through this control valve, fine. So, this is the cascade control scheme for the example heat exchanger.

So, our control objective is temperature and we considered that as a measured variable T T is used to measure the temperature then this measurement signal is compared with its set point value then the temperature controller calculates the set point value for this flow rate. So, this is the set point value of this flow rate, and this is the measured value of this flow rate there again compared within this block F c. Then this flow controller calculates action and that action are implemented through this control valve. So, this is the cascade control scheme for a heat exchanger here control objective is T.

So, this also the control variable process stream outlet temperature is the controlled variable what is the corresponding manipulated variable manipulated variable is the steam flow rate. Disturbance associated with the manipulated variable that is also steam flow rate then primary controller primary controller is the T C temperature controller which one is the secondary controller secondary controller is the flow controller, fine. So, for we discussed three examples for configuring the cascade control scheme one is jacketed C S T R then distillation top section and finally a heat exchanger.

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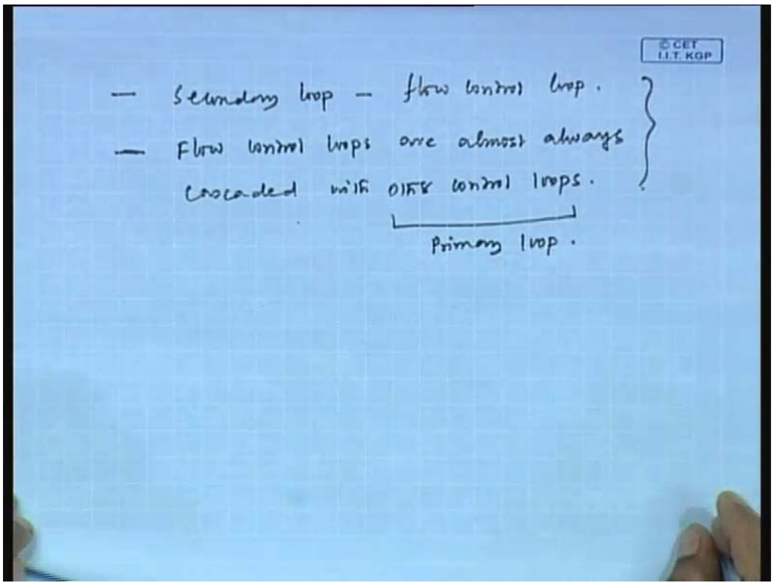

In all three cases we observe that the secondary controller is the flow controller fine in all three cases we observe that the secondary loop is the flow control loop, and it is almost common for all processes and therefore, we can say that flow control loops are almost always cascaded with other control loops. Therefore, we can say that flow control loops are almost always cascaded with other control loops; other control loops means this is primary loop basically, fine.

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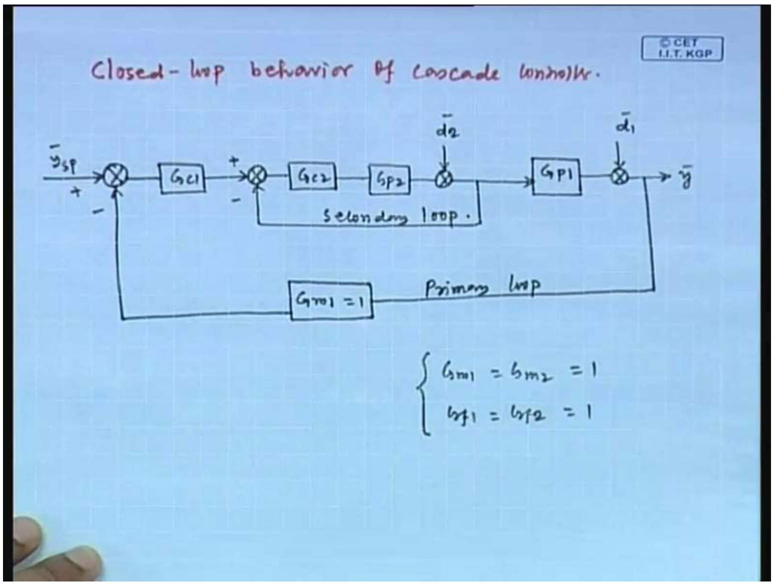

So, next we will discuss the closed loop behavior of cascade controller, fine. To discuss this close loop behavior we will consider a simplified block diagram. Process one has the transfer function of say G P 1. We are representing the transfer function of process one as GP1 previously consider the disturbance for process one is d1 output is say y, G m1 is the measuring device for process one suppose this is one. So, this is the comparator set point of y is y set point primary controller transfer function is say G c 1 another comparator secondary controller transfer function is say G c 2 process two transfer function is suppose G p 2 disturbance for process two is suppose d 2.

We are considering G m 2 equal to 1. Fine previously we develop the block diagram for the cascade control system it is same thing only. We have included here the transfer functions, and in addition to that we are considering here G m 1 G m 2 both are equal to 1, and G f 1 G f 2 both are equal to 1 for simplicity we are considering this, fine. So to discuss the close loop behavior of cascade controller, we will consider this block diagram. So, you see this is the primary loop. And this is the secondary loop this is the primary loop, and this is the secondary loop. We will consider one by one, first we consider secondary loop.

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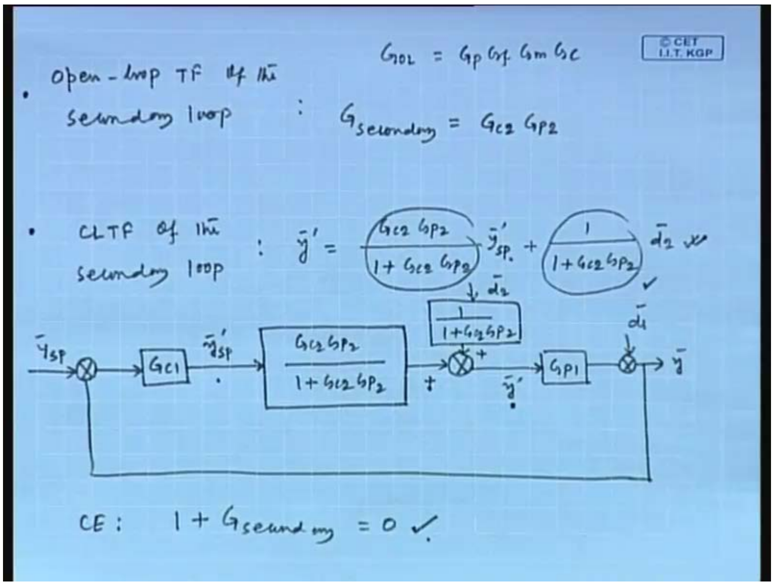

So, what is the open loop transfer function of the secondary loop, how we can represent the open loop transfer function of the secondary loop open loop transfer function is determined as the multiplication of four individual transfer functions G c G p G f G m; Here for secondary controller G c is G c 2 for secondary loop process has a transfer function G p 2 and G f 2 G m 2 both are 1, fine. The general expression for open loop transfer function is written as G p G f G m G c for the secondary loop you see G m 2 and G f 2 they are 1, g m two g f two. So, we can write G secondary G c 2 G p 2 agree.

Similarly, can you write the close loop transfer function for the secondary loop what will be the close loop transfer function of the secondary loop; suppose an output is y prime and the output to the secondary loop is y set point prime this is the secondary loop output is y prime and input is y set point prime. So, what will be the expression for the close loop transfer function output is y prime which is equal to G c 2 G p 2 divided by 1 plus G c 2 G p 2 y set point prime plus 1 divided by 1 plus G c 2 G p 2 d 2 prime here, G d is one, fine. So, this is the close loop transfer function for the secondary loop. Can we include this close loop transfer function in the block diagram? Yes, we can.

Then the block diagram becomes like this G c 2 G p 2 divided by 1 plus G c 2 G p 2 then the disturbance is added 1 divided by 1 plus G c 2 G p 2 then the process one disturbance for process one is d1, output is y. So, previously we considered that the primary controller output is y set point prime and input to the process one is y prime, if you consider this equation I hope this is incorporated in this block, fine.

Y prime is equal to this; this is one multiplied by y set point prime plus this and these are added plus this is this one multiplied by d 2, fine. Now for the secondary controller how we can analyze the stability I mean what is the characteristics equation which can be used for stability analysis. For secondary controller the characteristic equation we can write as 1 plus G secondary equal to 1 and this yeah equal to zero, and this can be used for stability analysis. So, this is the characteristics equation for the secondary controller.

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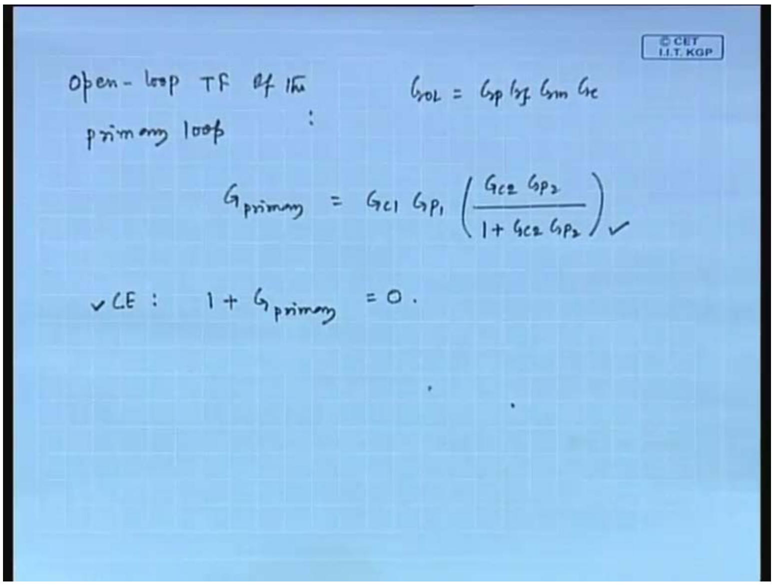

Next we will consider the primary loop, what is the expression of open loop transfer function of the primary loop. So, primary which is equal to G c 1 G p 1 G c 2 G p 2 divided by 1 plus G c 2 G p 2, agree. I mention that the open loop transfer function is calculated by multiplying four individual transfer function G p G f G m G c. Now, if you considered this block this block diagram and if you multiply the four individual transfer functions then we obtain the open loop transfer function for the primary loop, fine. Like the secondary loop for stability analysis, we need the characteristic equation for primary loop and that we represent as 1 plus G primary equal to 0, this is the characteristic equation for the primary loop which can be used for stability analysis, fine.

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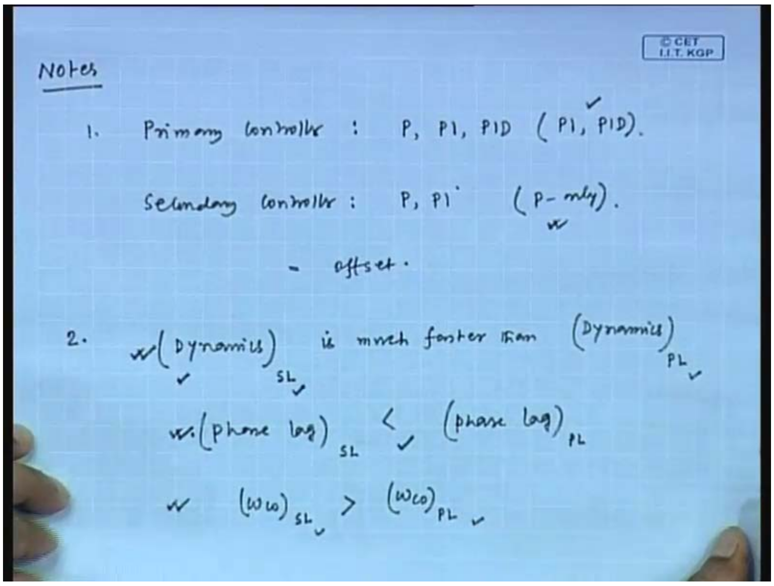

In the next, we will note down few important notes in the cascade control system there are two control schemes, one is the primary controller, and another one is the secondary controller. So, what type of feedback controller we can use? For the primary loop or sorry and secondary loop usually for primary controller P, PI and PID, these three feedback controllers are conventionally used, and commonly PI and PID controllers are used commonly; PI and PID controllers are used as primary controller. For secondary controller P and PI controllers are used and P only is the most common as secondary controller P only controller is the most common because if offset exists under P only controller that is not important because our control objective is not to maintain the output of the secondary loop.

If offset exists under P only controller that is not so important, because our control objective is not maintain the output of secondary loop our control objective is to maintain the output of primary loop I mean our control of objective is the measured variable T not T C. So, this is the first point. So, if you see the characteristic equation for primary and secondary loops. We can say that the dynamics secondary loops are much faster than the dynamics of primary loop, the dynamics of secondary loop is much faster than the dynamics of primary loop, fine. You see the characteristics equation for primary and secondary loop, and you observe the order of the polynomial with the increase of the order of a system the response becomes more sluggish.

Therefore, we can conclude that the dynamics of this secondary loop is much faster than the dynamics of primary loop. So, based on this can we write the phase lag for secondary loop is less than phase lag for closed primary loop based on this common can we say that phase lag of closed secondary loop is less than the phase lag of closed primary loop. Again can we say the cross over frequency of secondary loop is greater than the cross over frequency of primary loop, if first comment is true then we can make the second comment if second comment is true, then we can say that the cross over frequency of secondary loop is higher than the primary loop.

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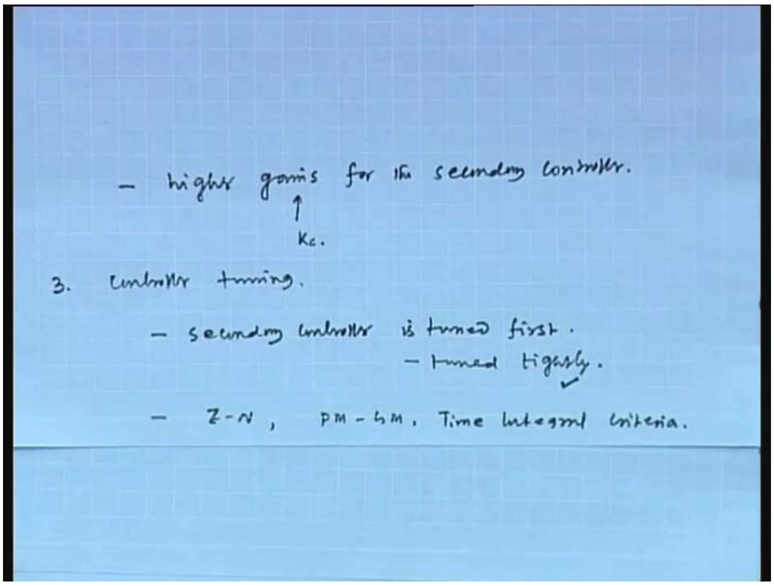

If the third comment is true, we can say that we can use higher gains for the secondary loop higher gains for the secondary controller; this is basically K c controller gain. So, we can conclude that for secondary controller we can use higher gain compared to the primary controller, fine. In the third note we to discuss the cascade controller tuning so, cascade controller basically involve two controllers; one is primary controller, and another one is secondary controller. Secondary controlled is tuned first, secondary controller is tuned first, and it is tuned tightly as high a proportional gain value as possible it is tuned tightly means as high a proportional gain value as possible, and for tuning, we can use the Cohen cutn technique ziglar nicoles technique, we can use phase margin gain margin technique.

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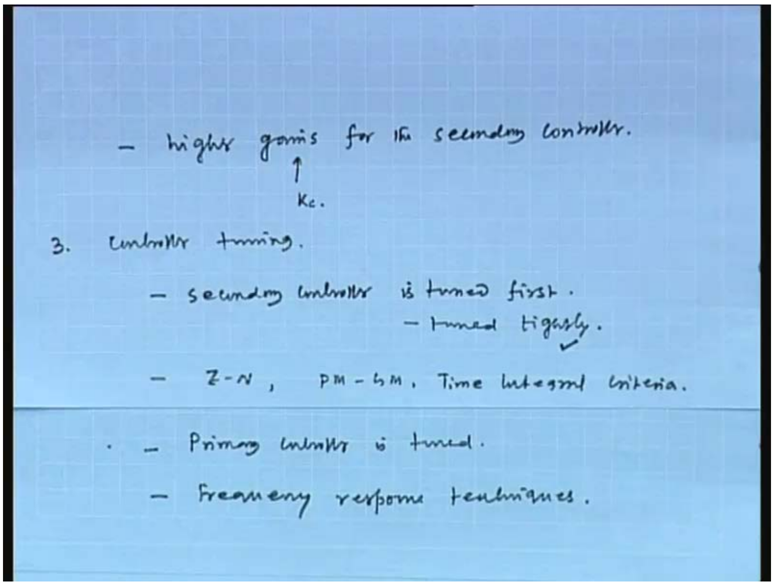

We can use time integral performance criteria, fine. After tuning the secondary controller the primary controller is tuned the primary controller is tuned. First, we tune the secondary controller then primary controller is tuned, and for this we usually use frequency response techniques frequency response techniques, like phase margin gain margin method, zeglar nicoles technique, etcetera. So, by this way we tune the cascade controller, fine.

Thank you.