Process Control and Instrumentation
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Lecture - 30
Advanced Control Schemes

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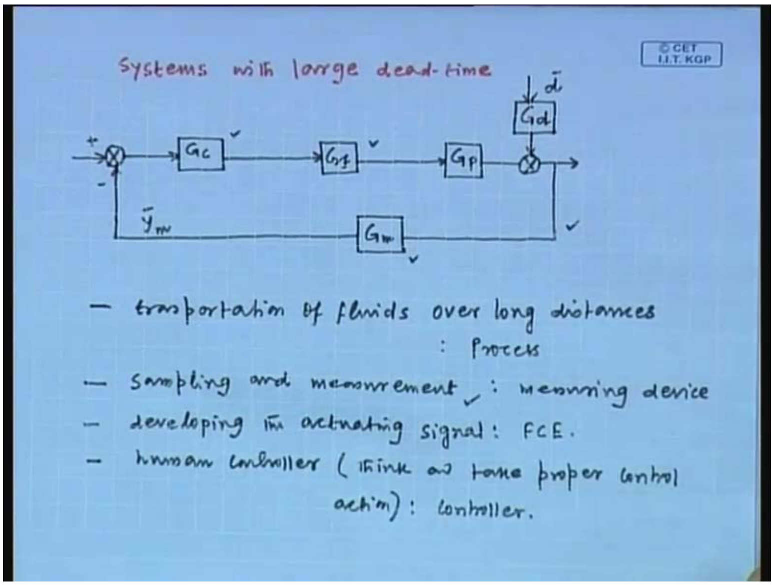

So, for we discussed a number of interesting topic under process control part and in the next phase we will discuss advanced control schemes under advanced control schemes today we will discuss this system with large dead time. So, our topic is systems with large dead time fine this under advanced control schemes now a closed loop process consist of a number of dynamic elements like the process the measuring device the controller the final control element a closed loop process includes a number of elements one is the controller the final control element the process, and the measuring device.

So, if we connect all these elements we obtain the close loop block diagram this is the close loop block diagram almost all the dynamic element may include time delays almost all the dynamic element may include time delays like time delay is involved in transportation of fluids over long distances see here controller final control element process and measuring device construct the close loop block diagram all this dynamic element may include time delays like time delay is involved in transportation of fluids transportation of fluids over long distances fine time delays like time delay is involved in transportation of fluids over long distances this is related to which element this is related to the process time delay is involved in sampling. And measurement time delay is involved in sampling and measurement it is obvious in this close loop block diagram that the controller needs output information y that the controller needs output information y now that information we can get by collecting the sample and that and measuring that sample fine. So, that takes some time therefore, we can say that the time delay is involved in sampling and measurement of y.

So, this is related to which element measuring device this is related this is related to measuring device similarly time delay is involved in devil upping the actuating sig signal time delay is involved in devil upping the actuating signal and this is related to the final controlling element this is related to the final controlling element time delay is involved in human controller time delay is involved in human controller to thing and take proper control action to thing and take proper control action and; obviously, this related to the controller now in all of the situations noted above the feedback controller would provide unsatisfactory performance due to the presence of dead time in all of the above situations the feedback controller would provide unsatisfactory performance.

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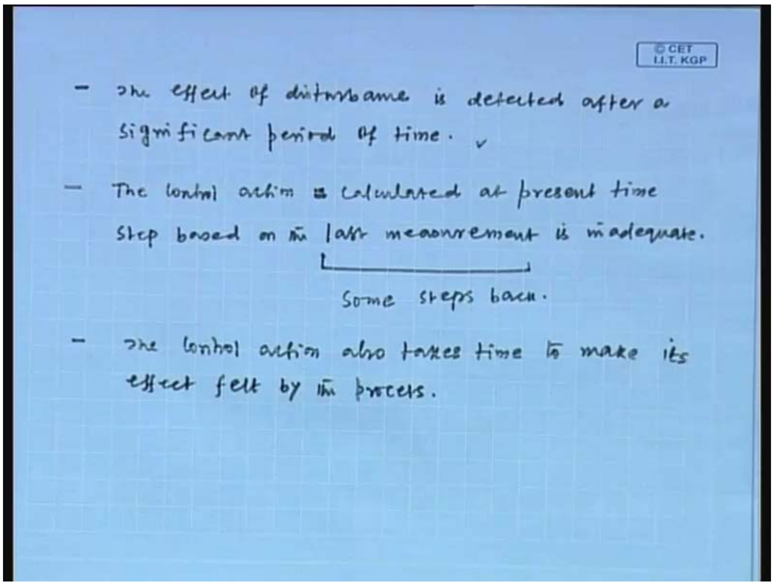

Due to the presence of dead time and we will discuss few other reasons which are related to dead time like the effect disturbance is detected after a long period of time. So, the effect disturbance is detected after a significant period of time why the controller provide unsatisfactory performance, we are discussing the reasons first reason is the effect of disturbance is detected after a significant period of time second reason is the controller calculated the control action at present time step based on the last measurement is not adequate next is the controller or the control action calculated at present time step based on the last measurement is in adequate see the controller calculates the the control action at present time step based on the last measurement originally, it is not last measurement due to the dead time this is actually the measurement some steps back. So, this originally not last measurement this is some steps back measured signal which is some steps back therefore, the control action is not adequate for the existing situation third one is the control action. Also takes time to make its effect felt by the process these are the reasons for which the feedback controller would provide unsatisfactory response.

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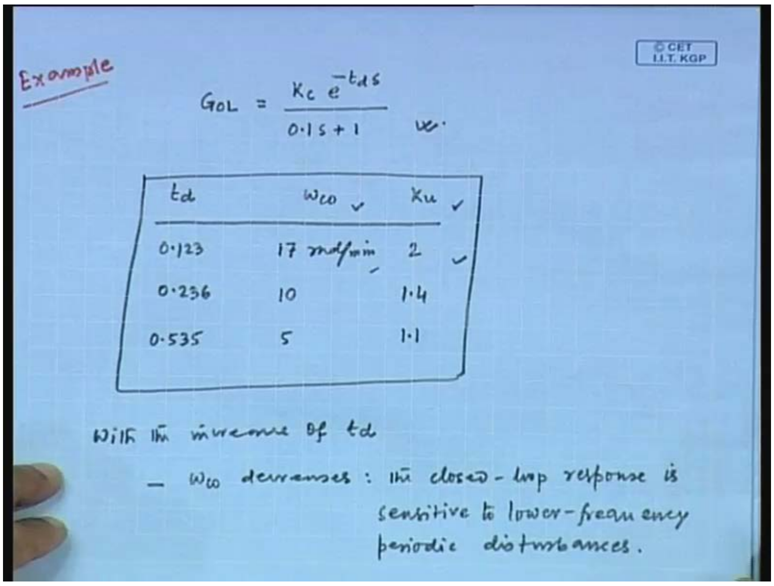

In the next we will take one example to observe the effect of dead time in the next we will consider one example to investigate the effects of dead time. Consider the open loop trans verve function given as K c exponential of minus t d s divided by 0.1s plus 1 this is the open loop trans verve function which we considered earlier fine now t d cross over frequency and ultimate gain if t d is 0.123, as we considered earlier we can easily calculate the cross over frequency seventeen radian per minute if t d is 0.123 minute then the cross over frequency is 17 radian per minute this we can calculate and the corresponding ultimate gain is 2 similarly if we increase t d 0.236 then the cross over frequency is reduced to 10 radian per minute and ultimate gain is also reduced to 1.4, if we increase further t d to suppose 0.535 then the cross over frequency is decreased to 5 and the ultimate gain is also decreased to 1.1, this datum. We obtain based on this open loop trans verve function fine now it is very obvious that with the increase of t d the cross over frequency and ultimate gain both decreased. So, with the increase of with the increase of t d the cross over frequency is decreases it means the close loop response is sensitive to lower frequency periodic disturbances it means the the close loop response is sensitive to lower frequency periodic disturbances this is the first observation. Secondly, with the increase of t d ultimate gain decreases.

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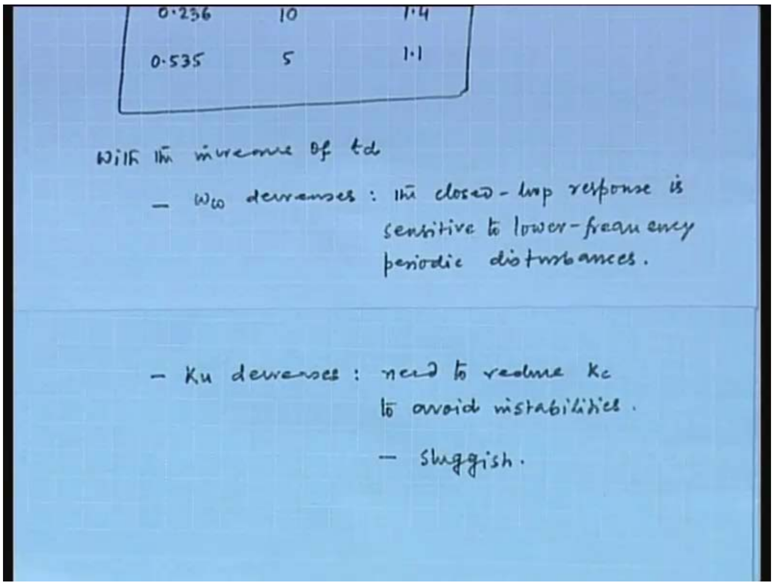

That means, we are force to select K c values low low values we have to select I mean we have to we need to reduce K c to avoid instabilities fine because the ultimate gain is the maximum values we can take. So, if K u decreases we have to select lower value. So, if we select lower K c value then what happen? The response becomes shiggish. So, if we decrease K c value then the close look response becomes sluggish. So, these are the effect of dead time. So, due to the presence of dead time we observe that the close loop response or the controller performance is degraded therefore, there is a need to devise a dead time compensative, fine.

So, our next topic is the derivation of dead time compensative dead time compensative for deriving the dead time compensator we will consider the simple close look block diagram the block diagram looks like this, this is the controller block we are assuming G f G m both are one this is the process fine this the process this the process.

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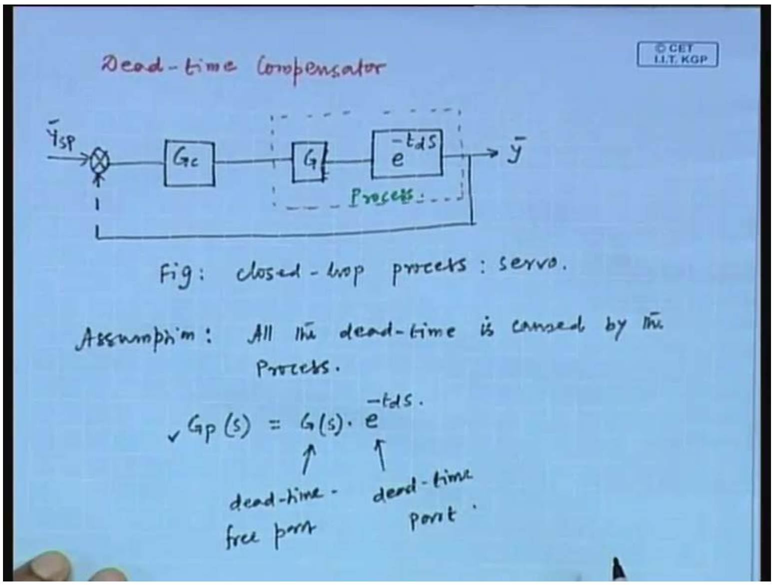

So, this is the closed loop process for servo case fine now we assume here that all the dead time is caused by the process here we assume here that all the dead time is caused by the process fine usually we consider we we denote g p to represent the process. So, here G p is equal to G s multiplied by exponential of minus t d s this is the dead time free part G s is the dead time free part and this is the dead time part fine this is the trans verve function of the process which we consider in this block diagram.

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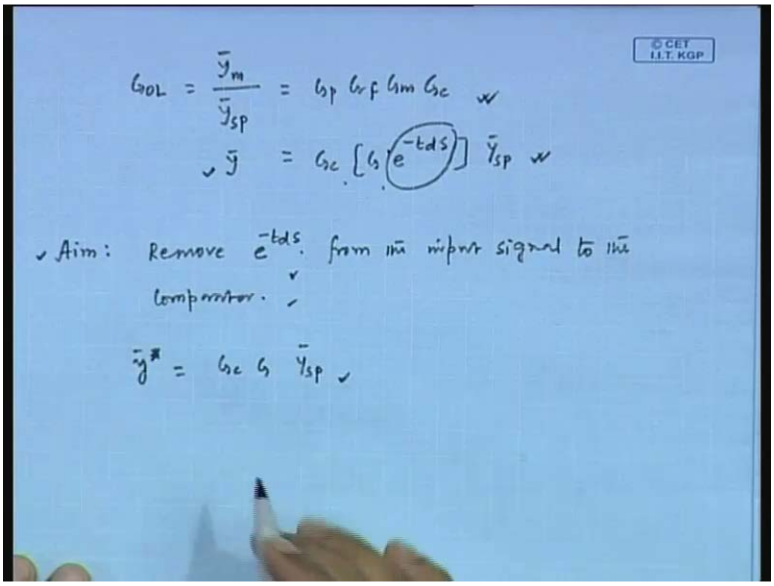

Now, the open loop response we write G o l which is equal to y m bar divided by y set point bar, and this is written as G p G f G m G c multiplication of four individual trans verve functions this is the generalized form of open loop trans verve function fine we know all these individual trans verve. We know the expression for all these trans verve functions substituting those we obtain y bar here y m bar and y bar both are identical because we are considered G m equals one then we obtain G c G s exponential of minus t d s y set point bar this is the expression for output response y, if we substitute all these individual trans verve functions in this equation we obtain this now it is obvious that this. is delayed by time t d it is obvious from this expression that it is delayed by tow d minute Now what is our aim basically this information y bar is feed back to the comparator our target is to gives dead time free response to this comparator. So, that the controller is not effected fine. Now, if we consider this is the ideal response I mean if we represent anyways first I am just mentioning the aim aim is to remove this dead time part from the input signal to the comparator this is our aim aim is to remove this dead time part from the input signal to the comparator, fine.

So, ideally the response should be G c G y set point bar agree this response includes this dead time part we have to devise the comparator. So, that the input signal to the comparator does not include this dead time part. So, if we represent the ideal response by y star then y star should be G c G y set point. Now how we can obtain this y stat we can obtain this y star this suppose y star and the information which is coming from process to deduct measurement that is y bar we are just adding some thing with this y bar.

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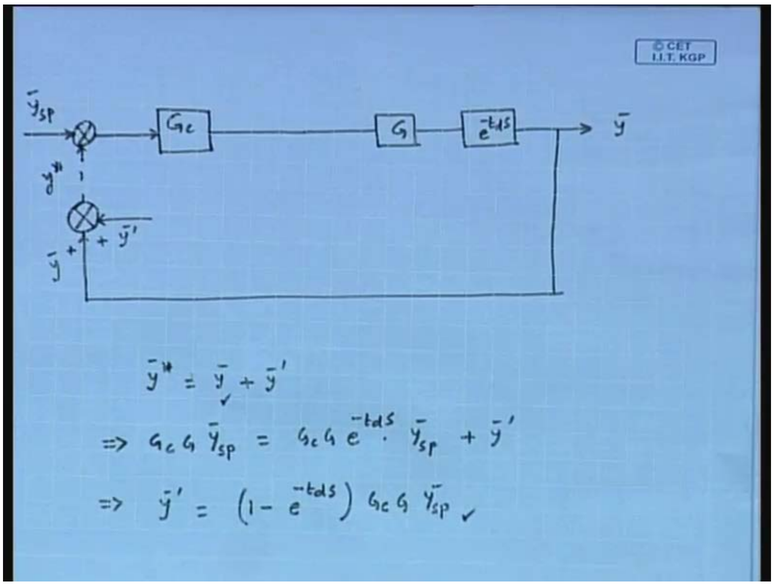

So, that we can obtain y star anyway I am just drawing this figure this is G c this is our process that includes dead time part this y bar this is comparator y set point our target is to give y star information to the comparator, but originally we getting y bar fine, but we need to give dead time free response to this comparator. How that is possible suppose we adding another signal denoted by y bar with this y to obtain y star it is straight forward to calculate this y prime I mean y star is basically if the summation of y and y prime y star is known to us that is G c G multiplied by y set point y is G c G exponential of minus t d s y set point what will be the y prime that we calculate that will be if one minus exponential minus t d s multiplied by G c G y set point. So, if we add this expression with the expression of y then only we get dead time free response which can be feedback to the comparator fine.

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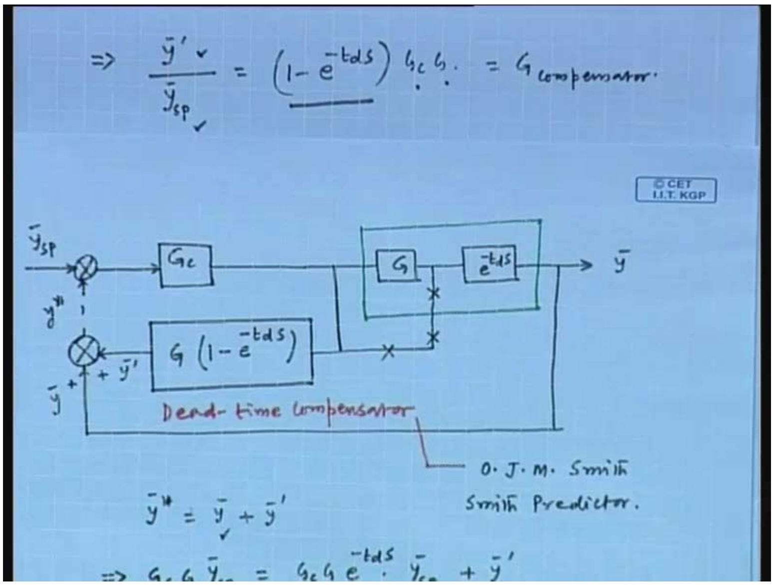

Now we need to include this expression in this block diagram how we can do that you see, we can write this equation further as y prime divided by y set point which is equal to G c G. So, this is the output and this is the input then the trans verve function can be represented by this expression and this is nothing, but the trans verve function of the dead time compensator this is the trans verve function of the compensator output of the compensator is y prime input is y set point, fine. Now we will just include this compensator in this block diagram. So, this is the block diagram this is the expression for compensator this is the block diagram output is y prime and input is y set point. So, I am writing here one minus exponential minus t d s can I connect this block like this, output is y prime which is equal to this multiplied by G this is G multiplied by G c this is G c multiplied by y set point this is y set point can we do this no we cannot do this because the actual process includes G and this exponential term in the actual process, we cannot separate I mean we cannot get information from the actual process excluding this dead time part.

So, this not correct we can connect like this then you see in the expression output is y prime then this part which is written here multiplied by G c this is G c multiplied by G c this G c multiplied by g we can write here G fine. So, this block represent the dead time compensator this block represent the dead time compensator and this compensator is proposed by O J M smith this is this was proposed by O J M smith therefore, sometimes it is called as smith predicator it is also called as smith predicator fine.

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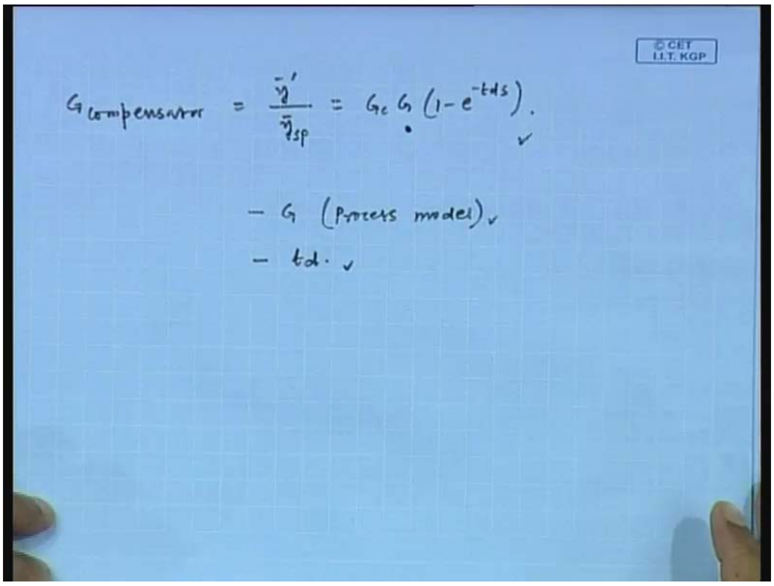

So, we obtain the block diagram for the compensator G compensator output is y prime and input is y set point which is represented by G c G one minus exponential of minus t d s fine now in this expression G and t d are involved now G is the process model and t d is the dead time. So, t d is the dead time. So, the dead time compensative depends on the accuracy of process model as well as the value of dead time this dead time compensator depends on the process model represented by G this also depends on the value of t d we can get perfect compensation only if G d and t d r exactly known we can get perfect compensation if the process model and t d value are exactly known, but in practice this never known exactly.

So, they are known approximately fine in practice the both process model and t d are known approximately if that is the case then we will represent the approximate model as g prime and the approximate t d as t d prime fine we will represent the G prime for the approximate model and t d prime for approximate dead time, then what will be if y star we know y star is y bar which is which is the actual process output plus y prime which is the output of dead time compensative y bar is G c G exponential minus t d s.

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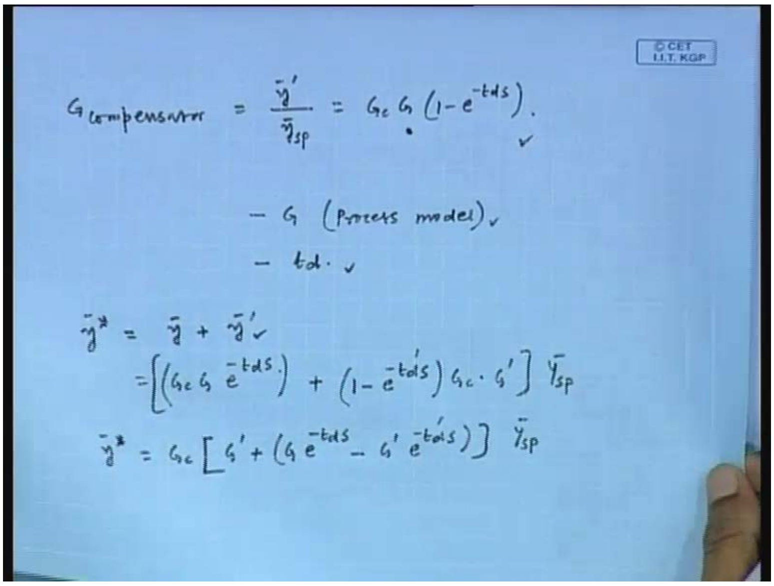

This y bar and how much will be y prime if G and t d are not exactly from this equation from this block y prime will be one minus exponential of minus t d prime s multiplied by G c G prime and this will be multiplied by y set point bar agree just in this expression of y prime we considered t d prime and G prime in place of t d and G rearranging this we obtain G c multiplied by G prime plus G exponential of minus t d s minus g prime exponential of minus t d prime s y set point bar rearranging we obtain this expression for y star fine.

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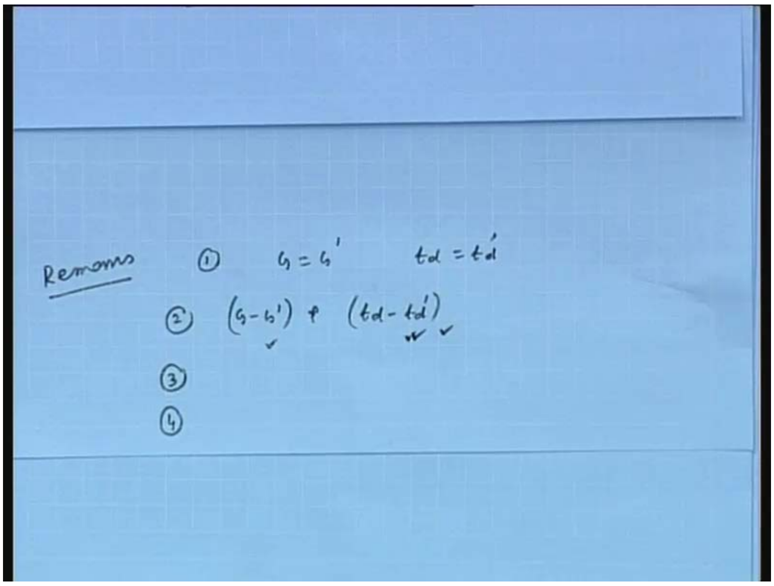

So, what conclusion we can make based on these expression when we get perfect compensation we can get perfect compensation when G equal to and t d equal to t d prime I mean when the process model and dead time value exactly known then only we can get perfect dead time compensation the larger the modeling error that is G minus G prime and t d minus t d prime that less effective is the compensation fine third remark which one is more crucial

on the dead time compensation I mean error in G or error in t d has sever effect on dead time compensation t d because it is related to exponential term. So, this is more crucial to the dead time compensation because of the exponential function fourth remark see In this dead time compensator expression t d is considered as constant quantity, but some time the t d is vary with the time some time the dead time t d may vary with time that is not taken into the account in the dead time compensator expression. So, that is you can say that is a draw back.

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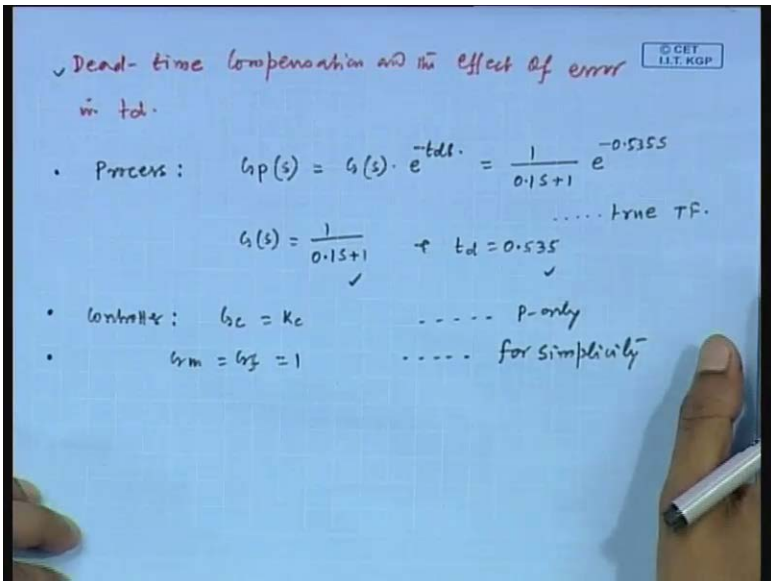

Next we will discuss the dead time compensation and the effect of error in t d next we will discuss the dead time compensation and the effect of error in t d we observe that there may the possibility of the error in both G and t d, but we are considering only error in t d. So, for this purpose we are consider a process represented by G s exponential of minus t d s which is again 0.1s plus 1 exponential minus 0.535 s fine to discuss this topic we are considering this trans verve function to represent the process see this the trans verve function of the true process I mean this is g. So, this true trans verve function of the process; obviously, G s is 1 divided by 0.1 s plus one and t d is 0.535 it is obvious that G s is 1 divided by 0.1 s plus 1 and t d is 0.535 we will consider P only controller. So, controller trans verve function, we can write as K c this P only controller we will consider here both G m and G f equal to one for simplicity, we are considering G f G m and G f both are one.

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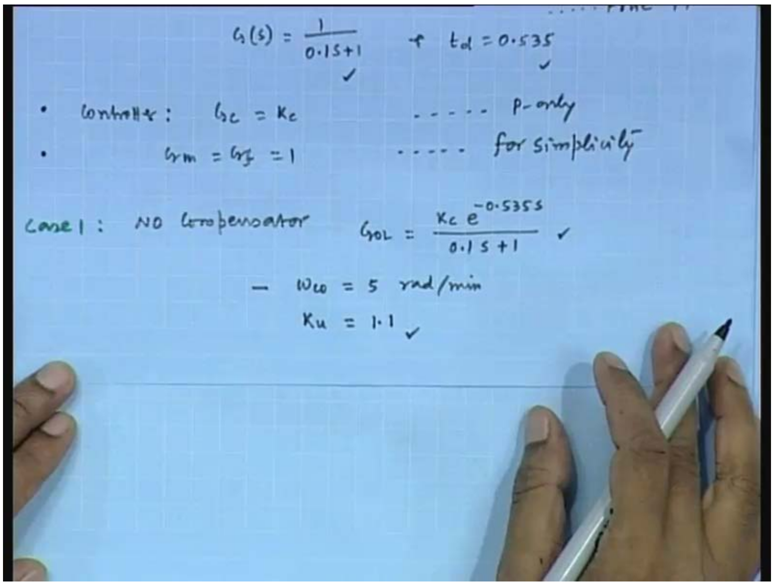

Now we will consider three different cases in the first case we will consider there is no compensator case 1 in case 1 we consider no compensator fine the open loop trans verve function which we are considering is represented by K c exponential minus 0.535 s divided by 0.1 s plus 1 fine this is given to us. So, based on this trans verve function we can calculate the corresponding cross over frequency that is 5 radian per minute.

In fact, this problem we discussed previously and we obtain the cross over frequency is 5 radian per minute corresponding ultimate gain is 1.1 fine. So, what value for K c we can select we have to select the K c value lower than 1.1 fine this is the ultimate value at which we get sustain oscillation.

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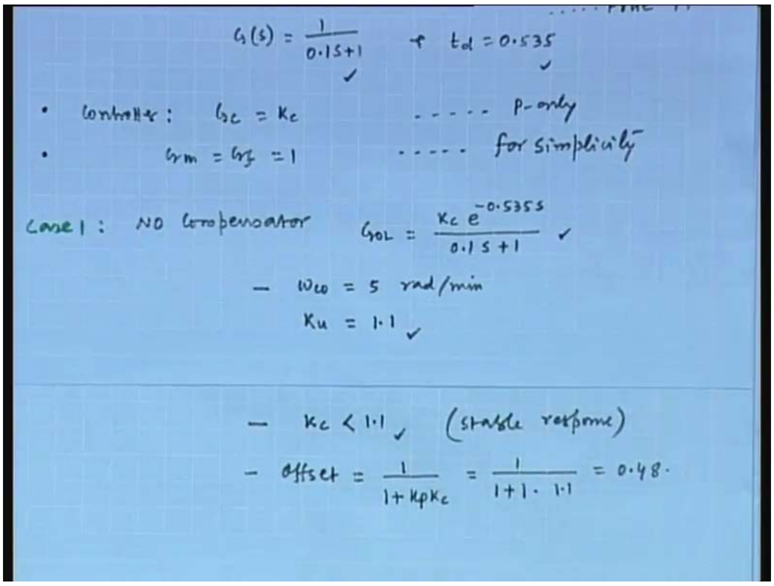

So, for stability if we K c should be less than 1.1 for stable response, we have select K c value lower than 1.1 if that is the case what will be the offset maximum holus we can select for K c that is 1.1 fine at which we obtain sustain oscillation if that is the case what will be the offset the expression for offset for the example system we can derive as 1divided by 1 plus K p K c this is the expression for the offset. For the example system fine. So, if we substitute the values then we obtain 1 divided by 1 plus how much is K p one how much is K c, suppose we are considering 1.1 then it is0.48 this is the large offset if we consider the maximum holus of K c that is 1.1 then we obtain the offset 0.48 say this is time this y this is suppose one this is the offset which is equal to 0.48.

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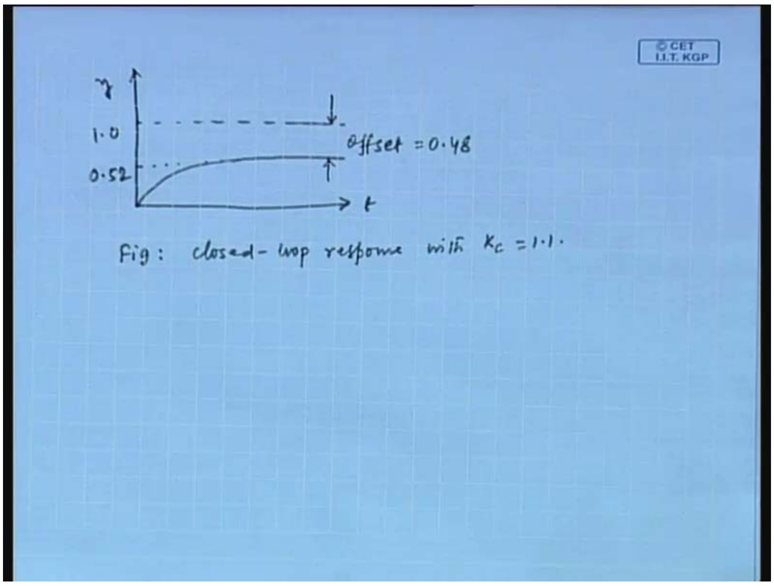

That means, the corresponding values is 0.52 this is closed loop response with K c equal to 1.1 fine. So, this case 1 if we do not use dead time compensator and if we use maximum permissible K c value that is 1.1 we obtain offset 0.48.

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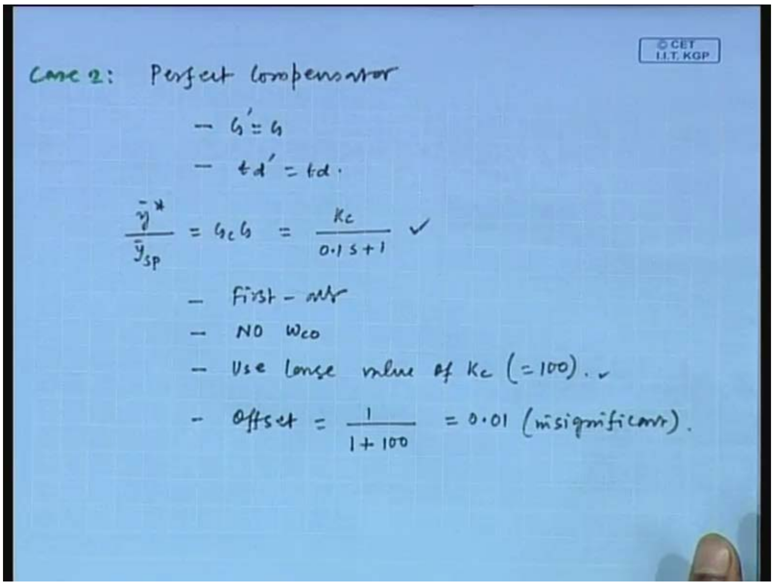

Next, we will consider case 2 and that is perfect compensation in case 2, we consider perfect compensation in case 2, we consider perfect compensator it is true when G is G prime is equal to G perfect compensation is possible when G prime is equal to G; that means, process model is perfectly known. Secondly, this t d prime is t d; that means, the dead time value is exactly known for the case of perfect compensation y star by y set point is equal to G c G I mean there will be not dead time part. So much is this 1 K c divided by 0.1 s plus 1 agree there is no dead time part. So, for perfect compensation we get y star by y set point equal to k c divided by 0.1 s plus 1 now this is first order trans verve function this is a trans verve function of a first order system K c by 0.1 s plus 1 is there any cross over frequency no because if we vary omega from 0 to infinity we obtain the variation 5 from 0 to minus 90. So, there is no existence cross over frequency if there is no existence of cross over frequency then we can use any large value of K c we can use any large value of K c there will not be instability problem fine since there is no existence cross over frequency. So, we can use any large value of K c suppose this value is hundred since there is no instability problem we are considering large value of K c and that is 100.

If K c is 100 what will be the offset 1 divided by 1 plus K p K c that is 0.01 fine without using dead time compensator we got 0.48 we using perfect compensator we are getting insignificant offset this is insignificant offset fine, but we mentioned that in practice g and t d they are not known exactly.

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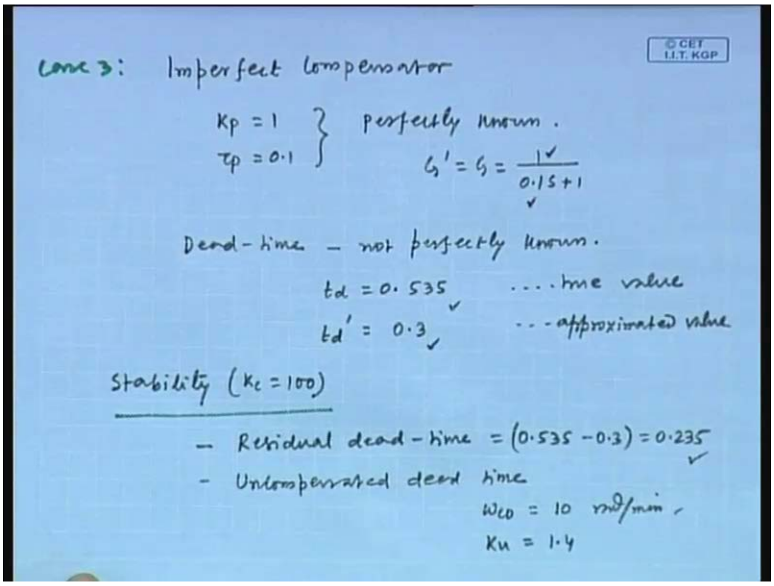

So, that will consider in third case in case three we consider imperfect compensator, imperfect compensator fine process gain for the example system is one time constant for the example system is 0.1 suppose these are perfectly known; that means, G prime equal to G equal to 0.1 s plus 1 this is the K p which is 1 this tow p which is 0.1 the dead time, that is not perfectly known this is not perfectly known to us true value of this dead time 0.535 this is true value and approximate holus is 0.3 fine original holus is 0.535, but we have the devil up the compensator based on this holus of 0.3 now question is we are using K c holus 100, we know that our compensator is perfect question is what about stability when K c equal to 100 what about stability when K c equal to 100 original holus is 0.535 we are using 0.3. So, how much is the residual dead time residual dead time is 0.535 minus 0.3 that is 0.235, that is residual dead time it is clear that the compensation is not perfect.

Now uncompensated dead time corresponds to omega c not 10 radian per minute fine uncompensated dead time corresponds to K u 1.4 at beginning of today class we got this values fine for the dead time of 0.235, we obtain cross over frequency 10 radian per minute and ultimate gain 1.4, but how much we are using what holus of K c we are using K c equal to 100, but maximum I mean I mean limit is up to 1.4 what about stability unstable system becomes unstable fine. Now conclusion is be conservative in selecting the K c holus for the process having dead time be conservative for selecting the K c holus for the process having dead time.

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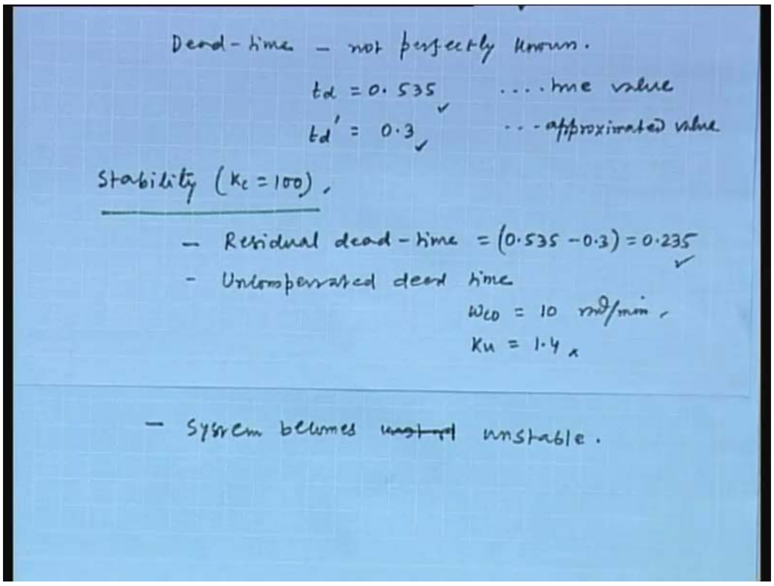

So, this is all about the smith predictor and dead time compensator. In the next class, we will discuss the another compensator that is inverse response compensative.

Thank you