Advanced Control Systems

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Module No. # 03
Time Domain Based Identification
Lecture No. # 06
Identification of FOPDT Model

A new technique to identify dynamic model of a real time system will be discussed in today's lecture. The dynamic transform of function model can have a stable pole or an unstable pole.

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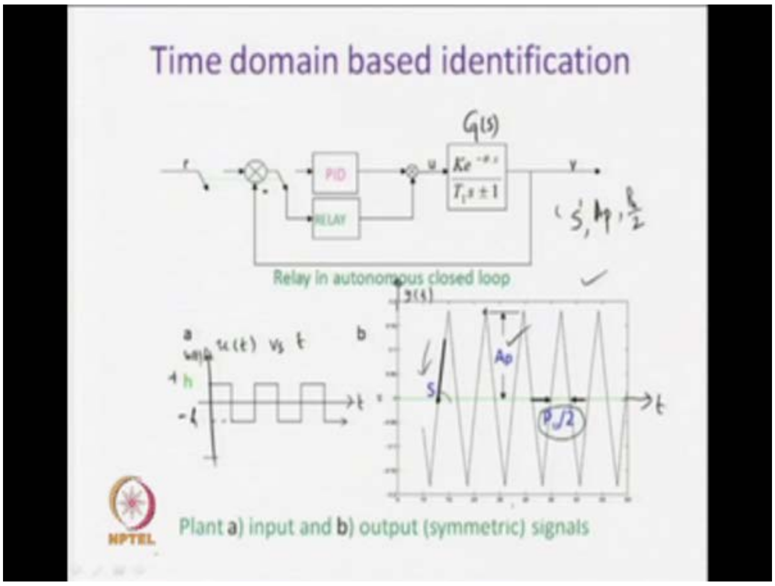

Let us see the relay autonomous closed loop system where the system, real time system is represented by the dynamics given as Ke to the power minus theta s upon T 1 s plus minus 1. So, the denominator shows us that a pole in the right half or in the left half can be there for the dynamic model of the real time system. Then a relay is connected in this fashion disconnecting the controller, PID controller to induce limit cycle output. Then the limit cycle output or the sustained oscillatory output assumes this form, where this is y(t) versus t, the output we get from the system corresponding to the input to the system which is generated by the relay. So, the input to the system is now u (t) verses t given as… this is our u (t) versus t and we assume the relay amplitudes to have magnitudes of plus h and minus h.

So, we shall make now three measurements on the sustained oscillatory output unlike the previous lectures, where we used to take two measurements only and those are nothing but the peak amplitude given by A p half period denoted by pu by 2 where p U(s)tands for one period of output of the output of the system.

Now, we make additional measurement and that is nothing but the slope of the output signal at the zero crossing and slope will be designated bY(s). So, immediately after the zero crossing, we shall sense we shall measure the slope of the sustained output sustained oscillatory output of the relay control system. So, the relay induces this type of typical signal and we shall make three measurements namely: s the slope of the output signal at the zero crossing, A p the peak amplitude of the output signal and half period of the output signal given by pu by 2.

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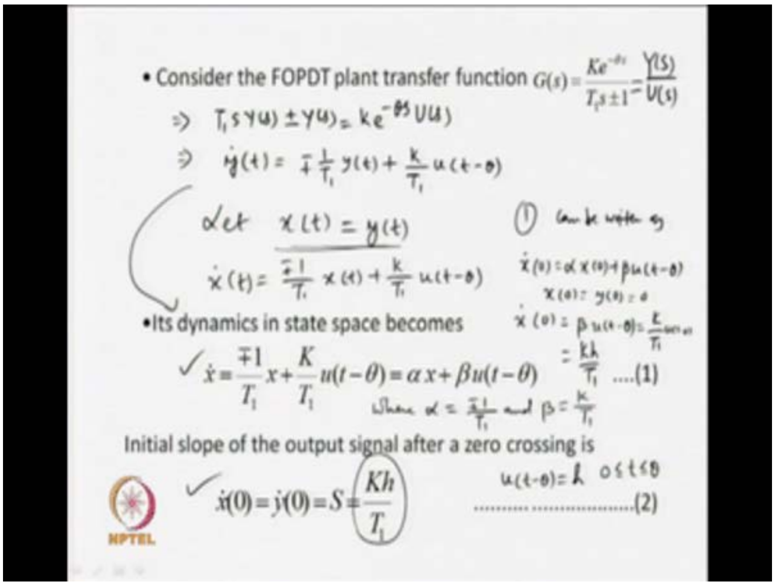

Consider for analysis of the dynamic system now, closed loop system now relay control system now, consider the first order plus dead time plant transfer function G(s) is equal to K e to the power minus theta s upon T1 s plus minus 1 which is nothing, but equal to Y(s) upon U(s) where Y is the output and U is the input to the system. Then cross multiplication will result in T 1 s Y(s) plus minus Y(s) is equal to K e to the power minus theta s U(s). Again, when the inverse Laplace transform is taken, the same expression is given by y dot (t) is equal to minus plus 1 upon T 1 y (t) plus K upon T 1 u (t minus theta). Thus, we have got delayed input to the system u (t minus theta). When the state variable x (t) is introduced, x (t) is equal to y (t), then the dynamic equation in state space can be written in the form of x dot (t) is equal to minus plus 1 upon T 1 x (t) plus k upon T 1 u (t minus theta). That is what we have obtained.

Let us assume x dot (t) to be expressed in the form in the standard state equation form of x dot (t) is equal to alpha x plus beta u (t minus theta), where alpha is now minus plus 1 upon T 1 and beta is equal to K upon T 1. Why we are writing this in this standard state equation form? Because we know the solution of the standard state equation which can be used further for analysis.

Now, the initial slope of the output signal after a zero crossing which is nothing but this one (Refer Slide Time: 06:11) at the zero crossing. If we take the time T equal to 0 from this instant onwards, then the output at that instant will be y (0), y(0) whereas the first derivative of the output at that instant will be y dot (0) and we know that y (t) is equal to x (t). Therefore, y dot (0) is equal to x dot (0) is equal to the slope of the signal as K h by T 1. How do we get this K h by T 1? From this equation number 1.

Now, I can write the equation number 1. 1 can be written as written as x dot(0) is equal to alpha x(0) plus beta u (t minus theta). We know that x(0) is equal to y(0) is 0. x(0) is equal to y(0) is equal to 0 at the zero crossing. Therefore, x dot(0) will be equal to beta u (t minus theta) which is nothing but K upon T 1 u (t minus theta). Now, u (t minus theta) will have two values, either plus h or minus h depending on the time range. Now, u (t minus theta is equal to h for because we know that the input to the system u (t minus theta) is equal to h for the time range 0 is less than equal to t is less than equal to theta. Therefore, x dot(0) will be equal to k h upon T 1. That is what is given in equation number 2. So, the slope of the output signal at the zero crossing is given as s is equal to k h upon T 1.

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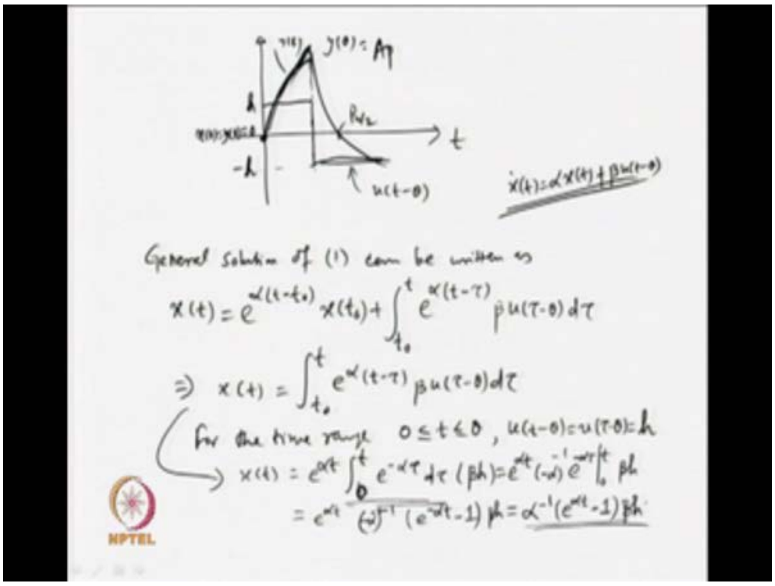

What type of output and input signal we get? Let us consider half period of the output signal where the output signal will be of this form. This is the time axis. So, time pu by 2 because we are considering the half period. Then the input to the system will be of the form where this is h and this one is minus h (Refer Slide Time: 08:52). Now, what is the output - peak output? Peak output is nothing but y theta is equal to A p, the peak amplitude and also we know that x(0) is equal to y(0) is equal to 0. So, the output at a zero crossing is equal to 0.

This is the plot for u (t minus theta). Keep in mind this is not the plot for u (t). This is the plot for the rectangular pulse. We are getting the plot for u (t minus theta), delayed input to the system, whereas this is the plot for output sustained oscillatory output of the system. Now, we know that the general solution of the standard state equation given in 1 can be written as x (t) is equal to e to the power alpha (t minus t 0) x (t 0) plus integration from t (0) to t e to the power alpha (t minus tau) beta u (tau minus theta) d tau. So, this is the standard solution for a state equation given in the form of x dot (t) is equal to alpha x (t) plus beta u (t minus theta).

So, when the state equation is of this form, we get a solution of the state equation of this form. Now, we shall use this standard solution to find analytical expressions for the output, sustained oscillatory output of the system till time t equal to pu by 2. We know that x(0) is equal to y(0) is equal to 0. Therefore, the expression for the present case can be written as x (t) is equal to integration from t 0 to t e to the power alpha (t minus tau) beta u (tau minus theta) d tau, but for the time range for the time range time range 0 is less than equal to t is less than equal to theta, we know that the input u (t minus theta) is equal to u(tau minus theta) is equal to positive h.

Then the x(t) can be written as x(t) is equal to e to the power alpha t then integral t 0 now t 0 equal to 0 we start the analysis from time t equal to 0. Therefore, this will be 0 to t, then e to the power minus alpha tau d tau times beta h.

This integral can further be simplified giving the expression x(t) as e to the power alpha t. I will take minus alpha inverse. Then e to the power minus alpha tau with the limits 0 to t with beta h, which becomes now e to the power alpha t minus alpha inverse, or we can write this in the form of minus alpha whole inverse. Then it becomes e to the power minus alpha t minus 1 beta h, which can ultimately be written in the form of alpha inverse e to the power alpha t minus 1 beta h.

So, what we have got from the analysis, that the output of the signal can be expressed. The analytical expression for the output of this part of the output signal can be given by x(t) is equal to y (t) is equal to alpha inverse times e to the power alpha t minus 1 beta h.

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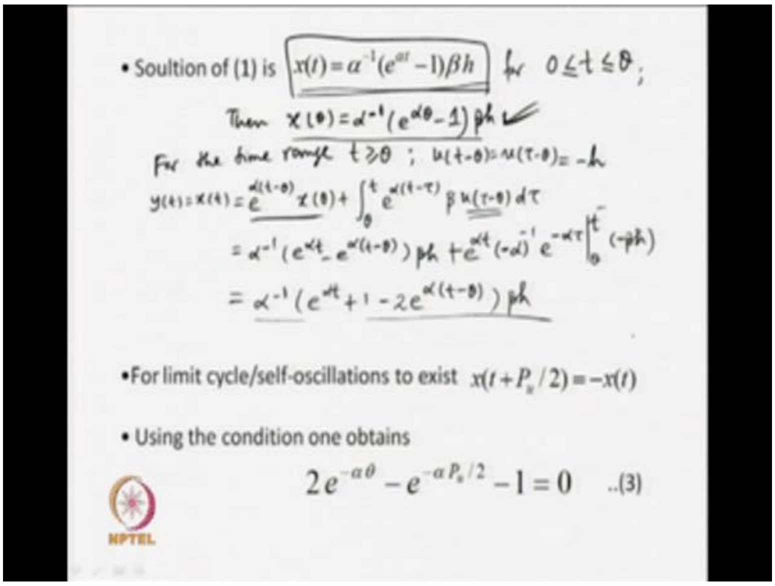

Now, the solution of (1) has been found in this form for the time range for 0 is less than equal to t is less than equal to theta. What about when t is greater than equal to theta? Let us find the solution for that dead time range first. So, since x(t) is equal to alpha inverse e to the power alpha t minus 1 beta h, then x (theta) will definitely be equal to alpha inverse e to the power alpha theta minus 1 beta h. But for the time range for the time range t is greater than equal to theta, we know that the input changes. u (t minus theta) is equal to u (tau minus theta) is equal to minus h; h we have seen that the input. This is time t equal to theta; so, when t is greater than equal to theta, the input becomes minus h. Then, the solution of the state equation y (t) is equal to x(t) will be e to the power t alpha (t minus theta) x(theta) plus theta to t e to the power alpha (t minus tau) beta u (tau minus theta? d tau? While that is so, we need to substitute t 0 equal to theta in the general solution for the state equation. Then, we get this expression.

Then, substitution of x(theta) in the above, results in alpha inverse e to the power alpha t minus e to the power alpha (t minus theta) beta h. This is what we get from the simplification of the first term and by substitution of x(theta) where x (theta) is given as alpha inverse times e to the power alpha theta minus 1 times beta h. Then, the second part, the integral part can further be simplified giving us e to the power alpha t (minus alpha inverse) e to the power minus alpha tau with the limits theta to t now and we are left with minus beta h because the input is minus h now; so, which further upon simplification, gives us alpha inverse e to the power alpha t plus 1 minus 2 times e to the power alpha (t minus theta) beta h. So, this is what we get for the time range t is greater than equal to theta.

Let us see whether this expression is valid or correct or not. The correctness of this expression can be found by the substitution of t equal to theta. So, when t equal to theta, what do I get? t equal to theta will give me x(theta) is equal to alpha inverse e to the power alpha theta plus 1 then minus 2 e to the power 0 times beta h. So, this is nothing but it is equal to alpha inverse e to the power alpha theta minus one times b h; that we have obtained earlier. Therefore, the expression we have obtained for the time range t is greater than theta is correct.

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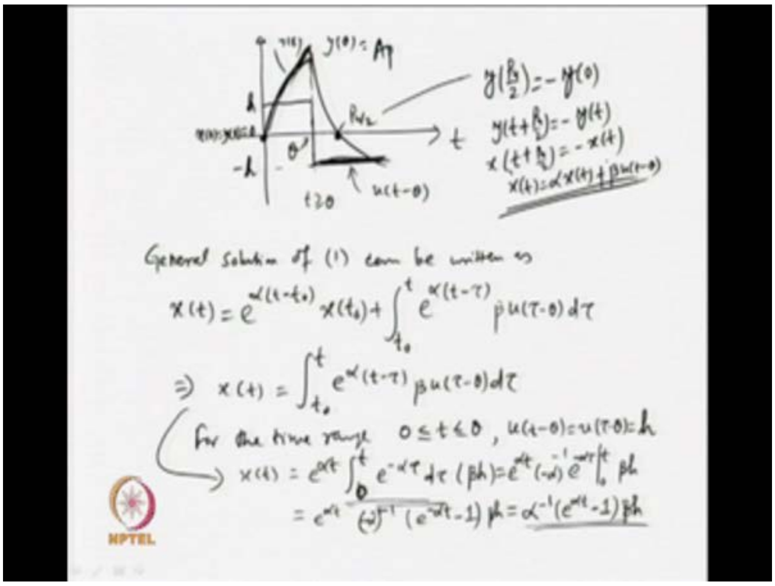

After ascertaining that, we will go to the analysis of the half period of the sustained oscillatory output, where we know that the output becomes 0 at time t equal to pu by 2. So, that can be given in the form of y (pu by 2) is equal to y(0). Actually, since we get sustained oscillatory output, y (pu by 2) has to be equal to minus y(0). As we know the output possess possesses half wave symmetricity, therefore, y (pu by 2) has to be minus y(0), or in general form I can write y (t plus pu by 2) has to be minus y (t) and since y (t) is equal to x(t) which can further be given in the form of x(t plus pu by 2) is equal to minus x(t).

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So, the limit cycle condition or the output will have sustained oscillatory form provided that condition is made. What is that condition? x(t plus pu by 2) has to be minus x(t) or I can write this by substitution of t as 0 x (pu by 2) is equal to minus x(0). What is x(0)? The x(0) is equal to y(0) which is nothing but 0 because we start our analysis from time t equal to 0, at which we have the output of the system 0. Therefore, this is equal to 0.

So, when I substitute t is equal to pu by 2, when t is substituted by pu by 2, then x (pu by 2) will be equal to e to the power alpha inverse e to the power alpha e to the power alpha pu by 2 plus 1 minus 2 e to the power alpha (pu by 2 minus theta) beta h and this has to be equal to 0; that we know from this condition. Then, this expression now can be written in this form; 2 e to the power minus alpha theta minus e to the power minus alpha pu by 2 minus 1 is equal to 0. Why that is so? Because alpha is a constant and beta is a constant, this expression is equated to 0.

Again, if I multiply both sides of this expression by e to the power minus alpha pu by 2 , So, multiplication of this factor to both sides of this equation will result in this (Refer Slide Time: 21:30). So, one can say this is the extended version of this one for each in analysis. So, this expression (3) meets the requirement on the limit cycle, condition for the limit cycle. So, this has to be satisfied; otherwise, one cannot guarantee sustained oscillatory output from the system.

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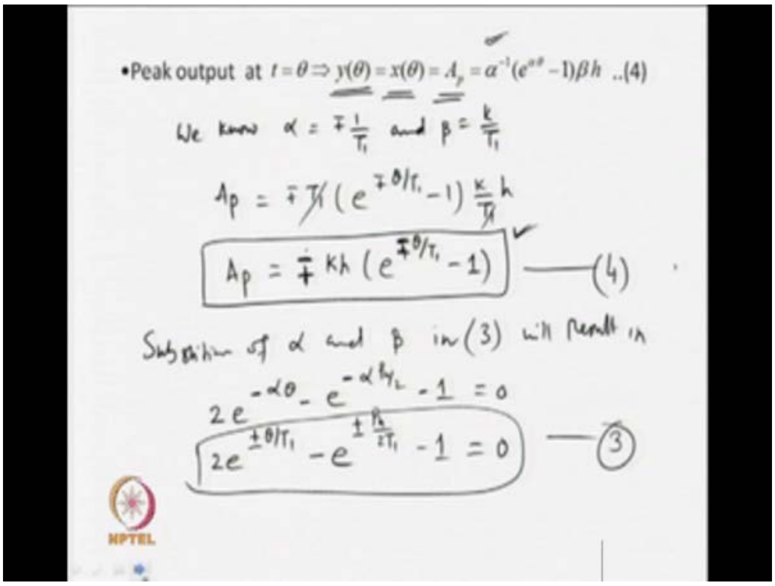

Now, peak output of the system occurs at time t equal to theta. Now, that peak output expression for the peak output can be given in the form of t equal to theta implies y (theta) is equal to x(theta) is equal to the peak amplitude given as alpha inverse e to the power alpha theta minus 1 beta h. What has been done here in this expression? The t has been substituted by theta. Then, we get the expression for the peak amplitude, peak output of the sustained oscillatory signal.

Now, we know that we know that the constant alpha is equal to minus plus one upon T 1 and beta is equal to k upon T 1. So, substitution of alpha and beta in (4) results in an expression of the form A p is equal to minus plus T 1 (e to the power minus plus theta by T 1 minus 1) k upon T 1 h which is equal to T 1; T 1 is cancelled out. So, that way we are left with minus plus k h (e to the power minus plus theta upon T 1 minus 1). So, this is the expression for output of the first order plus time delay transfer function model.

So, when we take minus sign and when we take plus sign, so, for stable process models stable process models we shall use the upper symbol and the upper one and for unstable system for unstable system the systems dynamics will be or can be obtained using this expression where we shall choose the bottom sign.

So, for an unstable first order plus dead time model, we shall go for the lower symbols plus here and plus here (Refer Slide Time: 24:30 to 24:33), but for a stable first order plus dead time transfer function model, we have to use the upper symbol minus here and minus here. Now, after obtaining this one, let me give this as the same equation number equation number 4. Again, substitution of substitution of the same alpha and beta in equation number 3 will result in what is equation number 3. We know that this is our equation number 3. 2 e to the power minus alpha theta minus e to the power minus 2 e to the power minus alpha theta minus e to the power minus alpha pu by 2 minus 1 is equal to 0.

So, substitution of alpha here will result in 2 e to the power, this will be, plus minus theta by T 1. Because of this minus sign, the pair will get inverted and then we will get 2 e to the power plus minus e to the power sorry it will be two times e to the power plus minus theta upon T 1 minus e to the power again plus minus pu by 2 T 1 minus 1 is equal to 0. So, this is our equation number 3.

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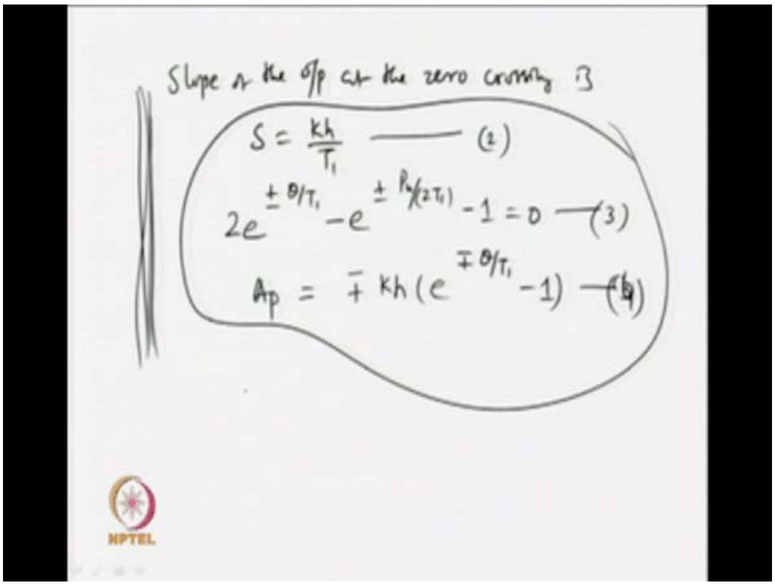

We know that the slope of the output signal, the slope of the output at the zero crossing is S is equal to k h upon T 1 which is given the same equation number 2. Thus, we have got three important equations. Let me write down those three important equations: S is equal to k h upon T 1; then 2 e to the power plus minus theta upon T 1 minus e to the power plus minus pu upon 2 T 1 minus one is equal to 0, which is given the equation number 3 and the peak amplitude given as minus plus k h e to the power minus plus theta upon T 1 minus 1. This is given as equation number 4. Then, we have obtained three important expressions and also we are making three measurements on the output signal. Thus, the three expressions can be solved simultaneously to estimate three unknowns: k, theta and T 1.

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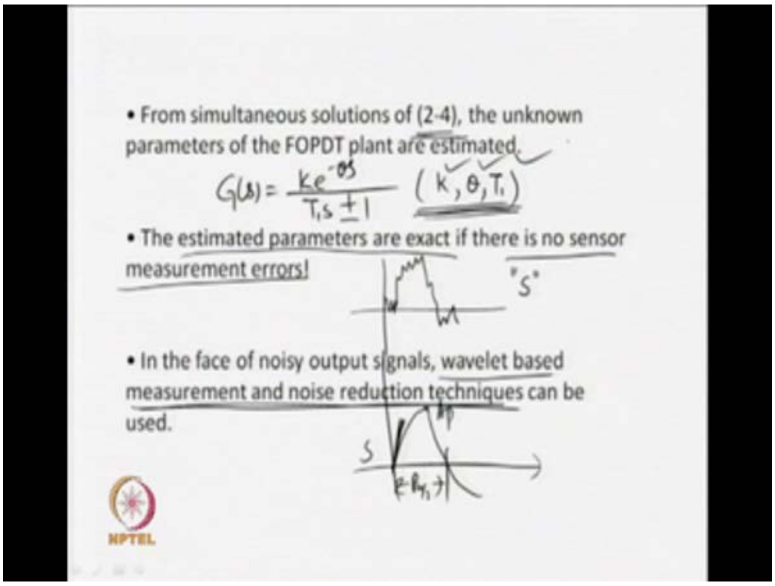

From the simultaneous solution of those equations 2 to 4, the three unknowns of the transfer function model, we have got the transfer function model now - k e to the power minus theta s upon T 1 s plus minus 1. So, the three unknowns in the transfer function model k, theta and T 1 can be estimated using the three expressions. Now, one needs to solve the three equations simultaneously because they have the parameters in them; all the three parameters are found in all the three expressions so to say. That way, simultaneous solution of the three non-linear or linear equations are required to estimate the three unknowns.

Now, the estimated parameters are exact; we will find exact estimation provided there are no sensor measurement errors; that means, if the output is let us take this case. If the output is not error free, rather we get some output of this form (Refer Slide time: 28:49). Then one may not be able to make measurement of the slope. So, the information, the slope information may be inaccurate. In that case, the estimation of k theta and T 1 may be erroneous. So, one must take care of this fact.

In those situations what happens? One can make use of alternate techniques. Wavelet based measurement and noise reduction technique can be made use to obtain clean signal from the noisy output signal. So, the noisy output signal can be can be filtered out of all the noise components and then we can get some smooth output signal of this form. Now, this smooth output signal may enable us to make all the three important measurements accurately. What are those measurements? The initial slope S, peak amplitude A p and the half period pu by 2.

So, when the measurements are error free and when the output is clean or output is not subjected to measurement errors or the output is not subjected to external errors, erroneous or not subjected to extrageneous error signals, in that case it is possible to estimate the three unknowns using the three expressions we have found earlier. Those expressions are given by the equations 2, 3 and 4.

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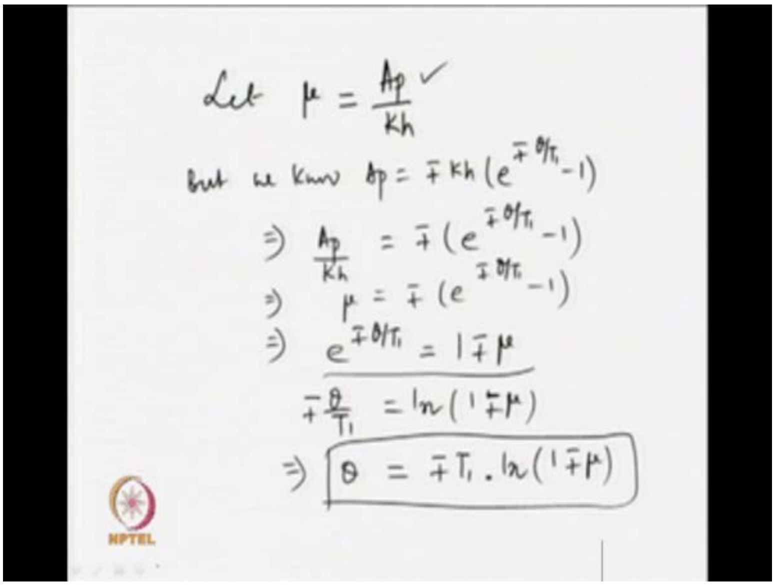

Now, let us little bit extend this analysis. Let us introduce one more parameter. Let mu is equal to A p by k h, but we know that A p is equal to, the peak amplitude can be given in the form of minus plus k h into e to the power minus plus theta upon T 1 minus 1. Then, the expression A p can be written as A p by k h is equal to minus plus e to the power minus plus theta upon T 1 minus 1 or mu is equal to minus plus e to the power minus plus theta upon T 1 minus 1.

Likewise, then it is not difficult to write an expression of the form e to the power minus plus theta upon T 1 is equal to 1. Then 1 will come here; so, that way 1 minus plus mu. why that is How that is obtained? If I multiply minus plus on the both sides, if I multiply minus plus, then this will go out; this will be out (Refer Slide Time: 31:51).

So, that is how we are able to obtain an expression of this form, ultimately which taking the natural logarithm further gives us minus plus theta upon T 1 is equal to lan of 1 minus plus mu implies theta is equal to minus plus T 1 times natural logarithm of 1 minus plus mu. So, this is an important expression for us. The theta can be obtained using this expression later on or using mu, for mu is equal to A p by k h.

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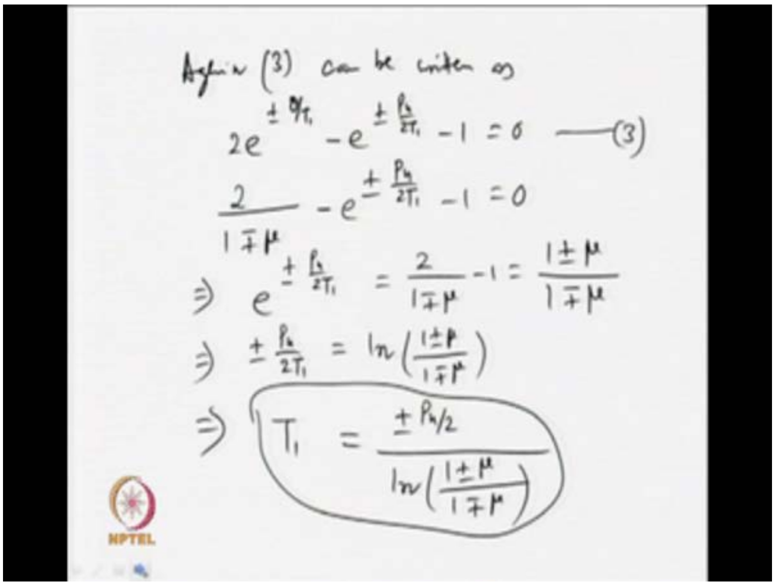

Similarly, we can start analysis for the third equation. So, again third can be written as 2 e to the power plus minus theta upon T 1 minus e to the power plus minus pu by 2 T 1 minus 1 is equal to 0. This is the equation number 3. Now, what I will do? We know that e to the power plus minus theta by T 1 can be obtained from here. Using this, e to the power plus minus theta by T 1, sorry not this one, the upper one, using this e to the power plus minus theta by T 1 will be 1 upon 1 minus plus mu. So, I can substitute that giving us 2 upon 1 minus plus mu minus e to the power plus minus pu by 2 T 1 minus 1 is equal to 0. That implies e to the power plus minus pu by 2 T 1 is equal to 2 upon 1 minus plus mu minus 1 is equal to 1 plus minus mu by 1 minus plus mu.

Further taking the natural logarithm of both sides, we can get plus minus pu by 2 T 1 is equal to lan of 1 plus minus mu by 1 minus plus mu giving us T 1 is equal to T 1 is equal to plus minus pu by 2 divided by plus minus pu by 2 divided by lan 1 plus minus mu by 1 minus plus mu.

So, this is another expression for the one of the unknown of the transfer function model. Earlier, we have got an expression for one unknown of the transfer function model theta.

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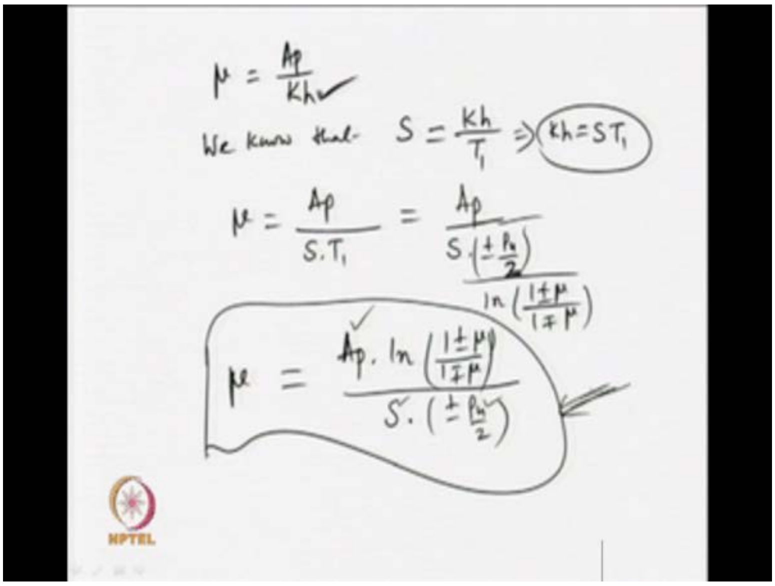

Further analysis will be done and we know that mu is equal to A p by k h. We know that mu is equal to A p by k h; that we have taken the approximation, we started our analysis with the assumption that with the introduction of a new variable mu h A p upon k h. Then, we know that the slope of the output signal can be given as k upon k h upon T 1, which means k h is equal to S T 1.

So, substitution of this k h in this denominator gives us mu is equal to A p upon S T 1. Further, we know that T 1 is this much. Therefore, if I substitute the expression for T 1 over here (Refer Slide Time: 36:13), I get A p upon s times plus minus pu by 2 lan 1 plus minus mu by 1 minus plus mu. So, that will give us here plus minus pu by 2 divided by lan 1 plus minus mu by 1 minus plus mu. So, which will be ultimately mu is equal to A p times lan 1 plus minus mu by sorry lan 1 plus minus mu by 1 minus plus mu divided by s times plus minus pu by 2.

So, this is an important expression for us because if you look carefully then you can see A p is measured, S is measured, then pu is also measured. So, from the output measurement on the output, we get information about A p, s and pu. Therefore, in this expression, there is only one unknown - mu. Then this can be solved, this expression can easily be solved to find out find out the mu and once mu value has been found out, then substitution of mu and making use the measurement pu, we can estimate T 1. Further, making use of T 1 and use of mu will give us theta. That is how all the unknowns, unknown of the transfer function model can be estimated.

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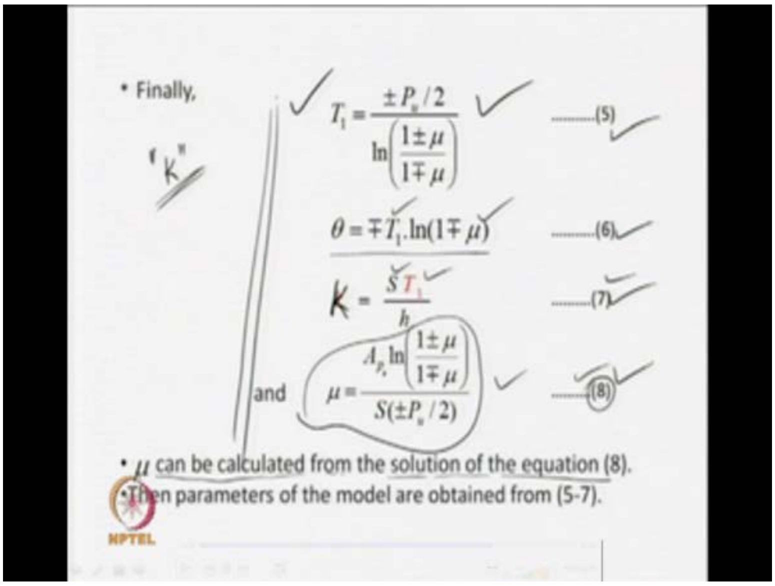

So, let me summarize. So, the expression for T 1 is given as plus minus pu by 2 divided by lan (1 plus minus mu by 1 minus plus mu). Theta is equal to minus plus T 1 time natural logarithm of 1 minus plus mu. And the steady state gain k is equal to S T 1 by h because we know that the slope is given by s is equal to k h by T 1. Then your k is nothing but S T 1 by h; that is how we get expression number 7. And also we have found in our last slide that mu is equal to A p times natural logarithm of 1 plus minus mu by 1 minus plus mu divided by S times plus minus pu by 2 .So, mu can be calculated from the solution of the equation 4.

We have got one non-linear equation where there is only one unknown and since A p, pu and S are measured or obtained from the sustained output, sustained oscillatory output of the relay feedback test, in that case mu can be calculated estimated using expression number 8. So, using this expression 8 or equation 8, mu can be estimated or can be calculated. Once mu is known, then we can find T 1 because pu is measured and mu has been estimated. Next, after getting T 1, we can get k. Because h is known, T 1 has been calculated and S is measured, then also we can find theta using mu. mu T 1 can be used to estimate theta. Thus, all the transfer function model parameters of the first order stable or unstable transfer function model can be estimated using the three measurements using the three measurements made on the output of the system.

So, this gives us some freedom unlike the earlier case, where we had to obtain the steady state gain by some other technique or assume to be known a priori. We need not make any assumption in this case. The new technique enables us to estimate the three transfer function models conveniently using equations 5, 6, 7 and 8.

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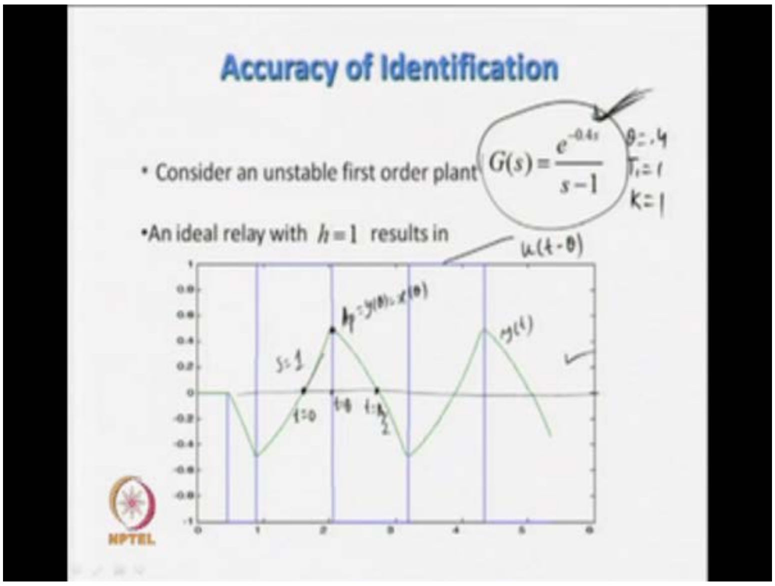

Now, we shall go to some simulation example to verify accuracy of identification. Let us see whether our technique is accurate or not. So, in this simulation study, an unstable system, an unstable first order plus dead time system, transfer function has been considered where the time delay theta is equal to 0.4 second. Now, the time constant T 1 is equal to 1 second and the steady state gain k is also equal to 1. If I look at this transfer function model for unstable first order plus dead time model, the three parameters those have been given are k is equal to 1, theta is equal to 0.4 and T 1 is equal to 1.

Let us try to estimate back these values from the equations. Now, when the relay test is conducted on this plant, on this first order plus dead time transfer function model, the sustained output is obtained and the waveform of the sustained oscillatory output is shown over here, where this is our output y (t). Now, let me draw the x axis and what is the blue line? This is nothing but the input to the system; delayed input to the system.

So, we have got the blue lines are nothing but the rectangular lines are nothing but plot for u (t minus theta). Let me start my analysis from the first zero crossing over here. So, this time is t is equal to 0 and we see that at time t equal to theta, t equal to theta a peak amplitude or peak output occurs. Now, what is this? This would be the half period t equal to pu by 2 (Refer Slide Time: 43:36).

So, if I look at the plot, my peak amplitude is obtained here at time t equal to theta which is nothing, but, A p equal to y (theta) is equal to x (theta). Now, how much is that A p? That accurate value we will try to estimate. If I look at this plot, how much I get this for the time half period of the signal? Half period of the signal is almost of one second or so and the time delay the time delay till t equal to theta will be also of magnitude 0.4 or so. We will make Measurement has been made using some software, or theoretically we have to make use of some software to accurately estimate the parameters A p pu by 2 and the slope at the zero crossing. So, if I look at the plot over here, the slope is found to be 1 the slope is found to be 1. So, let us see, what sort of measurements are obtained from this output signal.

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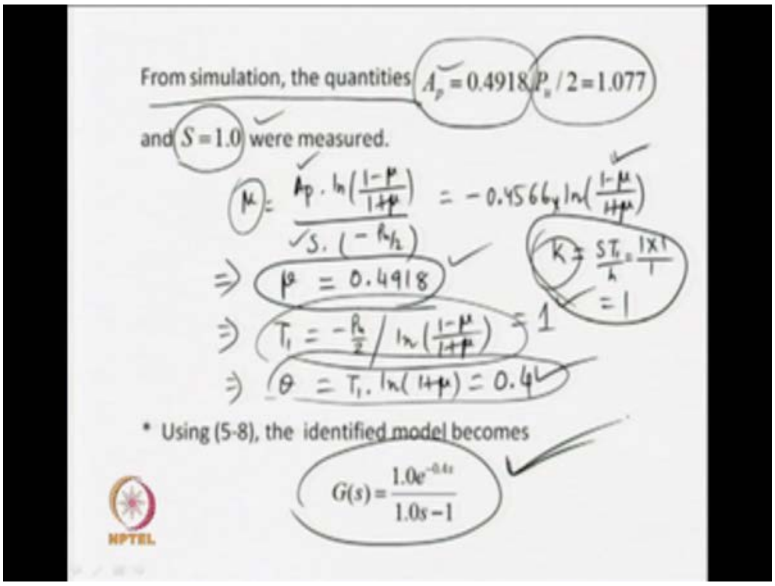

So, from the simulation with the relay testing with the relay setting of plus minus 1 a peak amplitude of magnitude 0.4918 is obtained; half period of the output signal is found to be of 1.077 and S is equal to 1.

So, these were estimated using some software. Now, I shall make use of the expressions we had for estimation of transfer function model for this system. Now, we know that mu is equal to A p times lan 1 minus mu by 1 plus mu by S times minus pu by 2. While I am writing in this form, as I had mentioned earlier for unstable system, we have to choose pick up the bottom sign. So, mu will be equal to A p times lan 1 minus mu divided by 1 plus mu upon S times minus pu by 2. So, that I have written over here (Refer Slide Time: 46:10).

So, as I know A p and S are already obtained from the measurement. So, this is equal to minus 0.4566 times lan of 1 minus mu by 1 plus mu. So, when this non-linear equation mu is equal to minus 0.4566 time lan 1 minus mu by 1 plus mu is solved, the solution gives us mu as mu is equal to 0.4918. So, one may has to employ a non-linear equation all over or intuition can be applied. Many techniques are there to find or solve one unknown from one non-linear equation.

So, employing that technique, the mu can be estimated and the mu is found to be of the magnitude 0.4918. Then, the T 1 using the formula becomes T 1 is equal to minus pu by 2 divided by lan 1 minus mu by 1 plus mu is equal to 1. Further, theta is equal to by formula it is T 1 times lan 1 plus mu. So, substitution of mu and T 1 over here gives us theta is equal to 0.4. Thus we have found that if mu can be estimated accurately, in that case the T 1 and theta can be estimated accurately. What what was the transfer function model we had? we had G(s) is equal to e to the power minus 0.4 S upon S minus 1. As I have already mentioned, theta is equal to 0.4, T 1 equal to 1 and k is equal to 1.

So, our calculation from here, the k is equal to as we have seen the expression for k; so, k is equal to k is equal to for our case, S T 1 by h S T 1 by h and S is equal to 1 T 1 has been estimated as 1 h is equal to 1. So, k is also equal to 1. Thus the estimated values theta T 1 and k are found to be accurate and thus the dynamics of the real time system the unstable plus first order plus dead time system has been found as G(s) is equal to 1 e to the power minus 0.4 s upon s minus 1.

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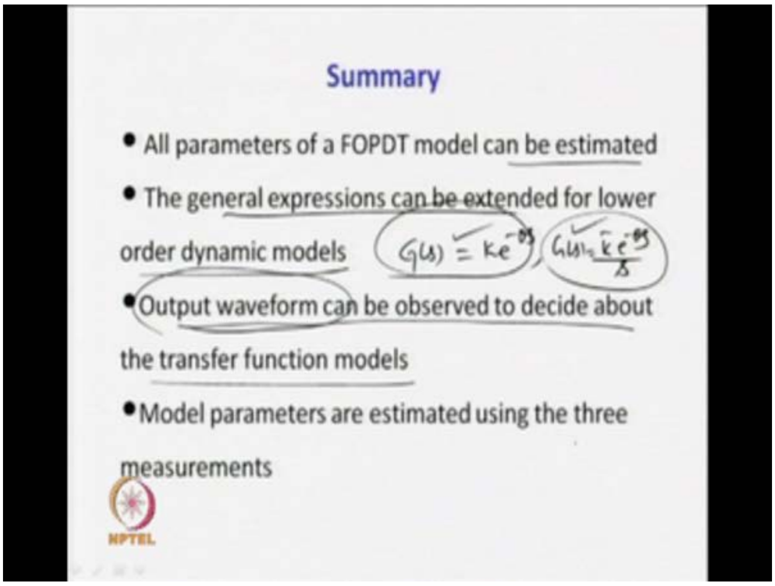

So, let me summarize. All the parameters of a first order plus dead time transfer function model whether the transfer function model is for stable or unstable, first order plus dead time systems does not matter. All the parameters of the transfer function model can be estimated using the expressions we have derived. So, three expressions can be made use of to estimate the three known unknowns of the first order plus dead time transfer function models.

The general expressions we have obtained can be extended for lower order dynamic models. What I mean by lower order a dynamic model? When G(s) is equal to k e to the power minus theta S or G(s) is equal to k bar e to the power minus theta S upon S, those type of transfer function models or dynamics of real time systems can be obtained. Now, output wave form can be observed to decide about the transfer function model.

So, whether we have to identify simpler model or first order plus dead time model, those informations can be obtained from the observation of the output wave form. Now, model parameters are estimated using the three measurements and using the three expressions we have derived.

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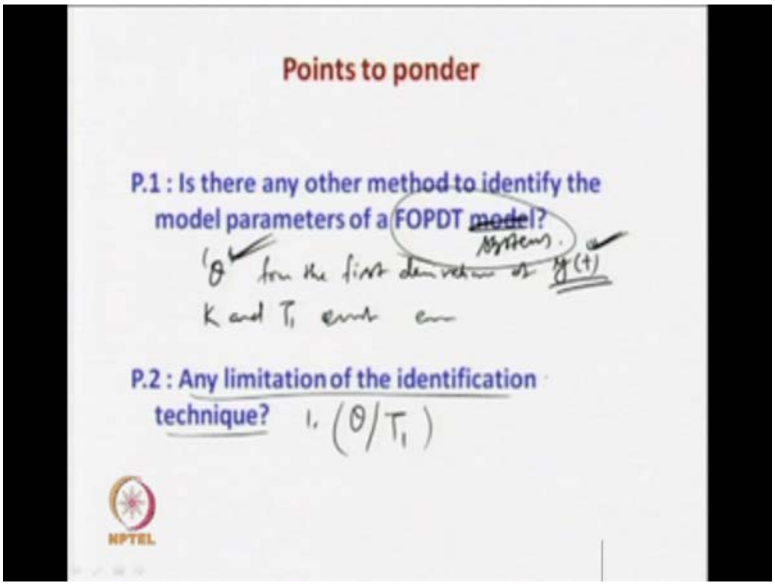

Some points to ponder - is there any other method to identify the model parameters of a first order plus dead time model or first order plus dead time systems rather? Yes. There are many techniques. To name a few, one can estimate the time delay parameter from the first derivative first derivative of the sustained oscillatory output when there will be large change in the output or when there will be discontinuity in the output, then the time taken to that point from any zero crossing can be taken as the time delay associated with the dynamics of that system. Then the remaining two parameters K and T 1 can be estimated using any two expressions we have derived earlier.

So, there are other techniques also to identify the model parameters of first order plus dead time systems or third order systems in terms of first order plus dead time transfer function models.

The second point is any limitation of the identification technique. Certainly, the identification technique is subjected to mainly two limitations: one is the ratio between the dead time to unstable time constant of the first order plus dead time unstable systems. If this ratio is not large, then only a sustained oscillatory output can be obtained. That is one of the limitations of this identification technique. Secondly, sustained oscillatory output must be noise free; otherwise, it will be very difficult to make measurement of the slope which is an important parameter and which expression which expression has to be used to estimate the three unknowns associated with the transfer function model.

Thank you.