Advanced Control Systems

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Module No. # 03
Time Domain Based Identification
Lecture No. # 05
Identification of Simple Systems

So, welcome to the lecture titled identification of simple systems. In this lecture, the analytical expressions we have derived in our previous lecture shall be made use of for estimating model parameters of some simple systems. The simple systems include an integrator with delay or a gain with delay.

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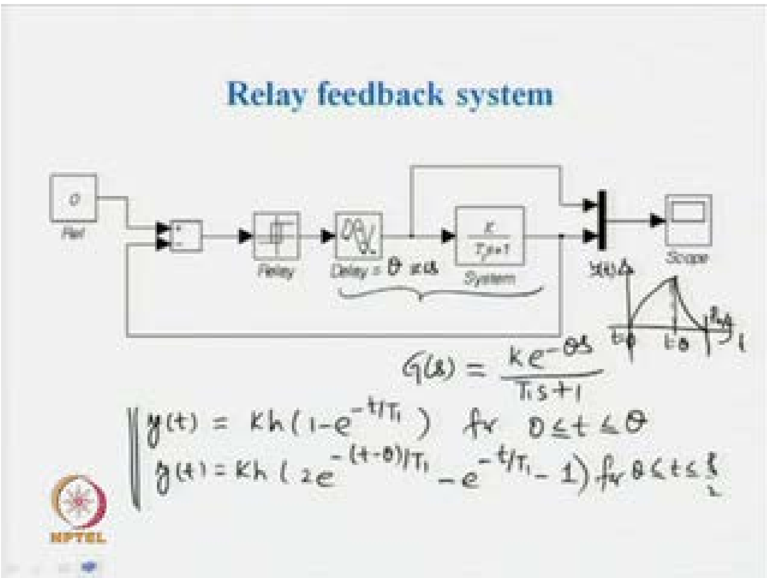

Now, let us consider this relay feedback system, where the system is given by the transfer function model G s is equal to k e to the power minus theta s upon T 1s plus 1. Therefore, the delay is of theta seconds now. Now, we have derived analytical expressions for this simple system, the first order plus dead time system. And we have found that the output of the system is governed by two expressions namely, y t is equal to k h 1 minus e to the power minus t upon T 1, for the time range 0 is less than equal to t is less than equal to theta and y t is equal to k h 2e to the power minus t minus theta by T 1 minus e to the power minus t by T 1minus 1, for the time range theta to P u by 2. So, these two equations y t can be plotted. And in that case the output will take the safe y t of this form, where we have seen that this is the time P u by 2. The peak occurs at time t equal to theta. And the plot starts begin with time t equal to 0. Then, we have also derived analytical expressions which are explicitly meant for stable first order plus dead time system and those analytical expressions are found to be of these forms.

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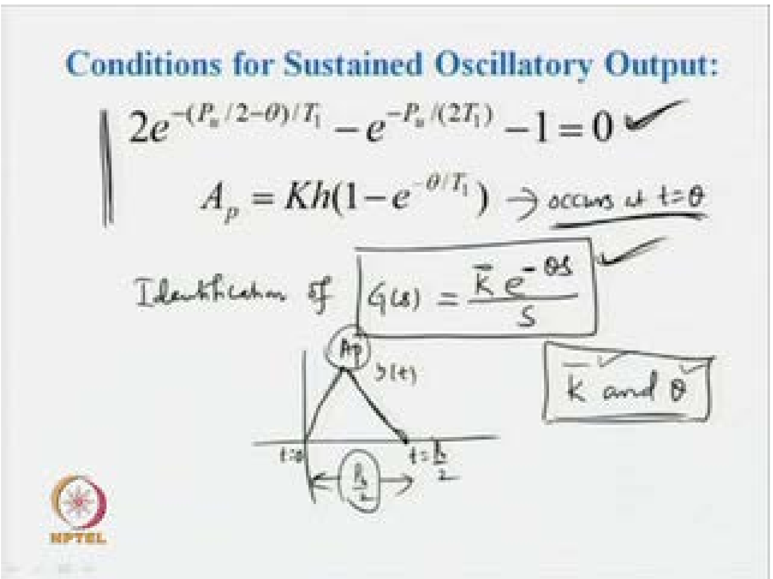

So, conditions for sustained oscillatory output is given by the expression 2 e to the power minus P u by 2 minus theta by T 1 minus e to the power minus P u by 2 T 1 minus 1 is equal to 0. So, this condition has to be made, then only one can expect sustained oscillatory output from a first order plus dead time system. The peak amplitude of the relay test is expected to be obtained from the expression over A p is equal to K h time 1 minus e to the power minus theta upon T 1, assuming that the peak occurs at time t equal to theta.

So, this peak occurs at time t is equal to theta. It is not an assumption. Definitely as far as first order plus dead time systems and their relay tests are concerned, the peak occurs at time t equal to theta, where the analytical expressions have given that we can have a plot for y t up to time t equal to theta, after which the values go on decreasing because the input to the system changes from positive h to minus h. Because of the changes in input the output slides down, goes down and it comes down to 0 at time t equal to P u by 2.

Now, these two expressions can be used further for identifying simple transfer function model. What do we mean by simple transfer function model? Let us consider initially the identification of an integrator with delay. So, the identification of a system given by the transfer function G s is equal to k bar e to the power minus theta s upon S. So, when the system is of this form, what sort of output is expected from the system under relay test? We know that for such system, the output will be triangular pulses only. So, that way it will be triangular pulses only. We will concentrate on only positive half of the output for developing analytical expressions.

So, let this be y t, for time t is 0 to time t is equal to P u by 2. Where the peak occurs, I do not know? But what we shall do. We shall make use of these expressions to find explicit expressions for the parameters of this transfer function model. How many parameters are there in this transfer function model? We have got two unknowns in this transfer function model. Therefore, explicit expressions will be obtained for the unknowns K bar and theta, using the measurements like peak amplitude and the half period P u by 2.

So, measurements made on the output sustained oscillatory output of the relay test are the peak amplitude, A p and the half period, P u by 2. So, if we can establish some relationship of k bar and theta with A p and P u by 2, then we can easily estimate the unknowns associated with the transfer function model G s is equal to k bar e to the power minus theta s upon S.

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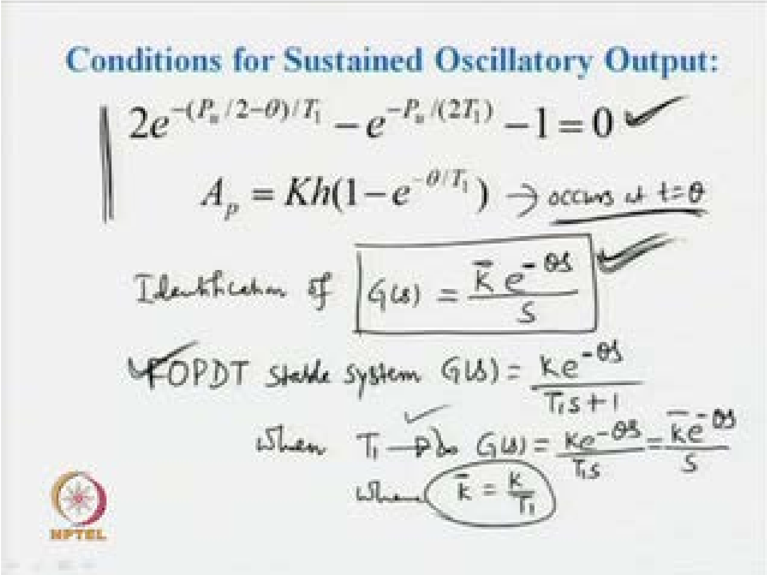

Now, it is very easy to get this transfer function from the transfer function for a first order plus dead time system. What is the transfer function for first order plus dead time stable system? We know that the transfer function is nothing, but G s is equal to k e to the power minus theta s upon T 1 s plus 1. So, when T 1 tends to infinity, T 1 is very large number, in that case this G s becomes k e to the power minus theta s upon T 1 s. T 1 tends to infinity, T 1 is a large number. Therefore, this term will be dominating and we can approximate the denominator by T 1 s, which can further be written in the form of k bar e to the power minus theta s upon S, where k bar is equal to k upon T 1. This condition has to be also made. Keep in mind that only setting T 1 to a large value will not help us because when T 1 is very large, then overall this G s will be 0, unless and until k upon T 1 is a finite value. So, this has to be maintained.

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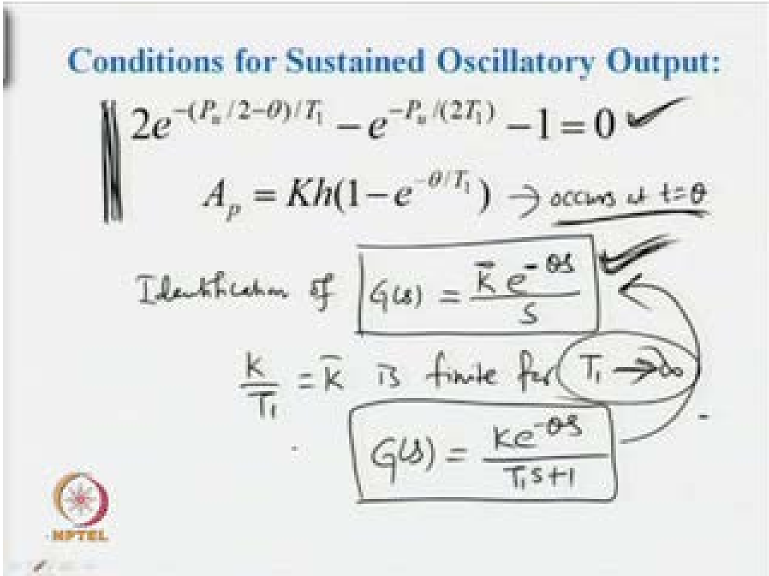

So, we assume that the first order plus dead time stable transfer function model can be brought to this integrator with delay model, with the assumption that k by T 1 is equal to k bar is finite for T 1 becoming a large value. Then only it is possible to obtain such type of transfer function model from the general transfer function model for a first order plus dead time system, k e to the power minus theta s upon T 1 s plus1. So, again let me repeat. So, this first order plus dead time transfer function model can give us this integrator with delay model with the assumption that T 1 is a large number, T 1 tends to infinity and k upon T 1 is equal to k bar is finite. Then, if we put these two conditions like T 1 tends to infinity, alone this condition is enough. If this condition is put in the above two expressions, then the two expressions shall be enable to give us the explicit expressions that is required for estimating parameters of transfer function model, such as integrator plus dead time model.

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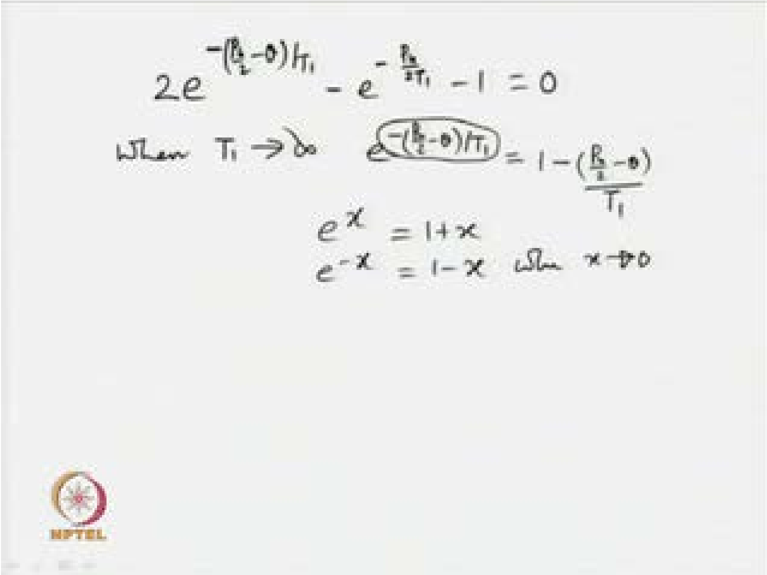

Now, let me make use of these expressions now. So, we have got the first expression as 2 e to the power minus P u by 2 minus theta by T 1 minus e to the power minus P u by 2 T 1 minus 1 is equal to 0. So, when T 1 tends to infinity, what we get? The exponential terms, e to the power minus P u by 2 minus theta by T 1 can be written in the form of 1 minus P u by 2 minus theta by T 1. Why that is so? Because when T 1 tends to infinity, the exponent will be a small number and exponentiation of a small number can always be approximated by the term 1 e to the power x, when x is a small number becomes 1 plus x. And e to the power minus x becomes 1 minus x, when x tends to 0.. So, when T 1 tends to infinity, the whole exponent part will be a small number. That enables us to write the exponential term in the form of 1 minus P u minus theta by T 1.

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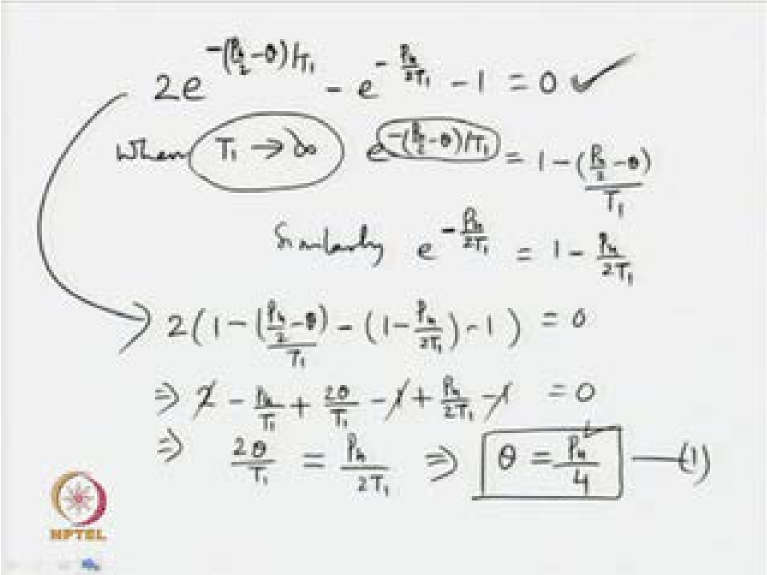

Similarly, e to the power minus P u by 2 T 1, when T 1is a very large number can be written as 1 minus P u by 2 T 1. So, when these are substituted in the expression, we obtain 2 times 1 minus P u by 2 minus theta by T 1 minus 1 minus P u by 2 T 1 minus 1 is equal to 0. So, which upon simplification again gives us 2 minus P u by T 1 plus 2 theta by T 1 minus 1 plus P u by 2 T 1 minus 1 is equal to 0. Now, this minus 1minus 1 and plus 2 cancels out leaving us 2 theta by T 1 in the left hand side and P u by 2 T 1 in the right hand side.

So, ultimately when this limiting condition is substituted in the limit cycle condition of a first order plus dead time system, in that case what we get? We get an expression 2 theta upon T 1 is equal to P u by 2 T 1, which gives us further theta is equal to P u by 4. So, let this be equation number 1.

So, what we have obtained from this analysis that, for simple system like an integrator with a delay. The delay can be estimated within the measurement P u or period of the output signal and using equation 1. So, theta is estimated using the information or measurement P u. So, theta is equal to P u by 4. This is what one explicit expression, we have been able to obtain using the analysis and using the measurement P u or P u by 2, half period of the oscillation.

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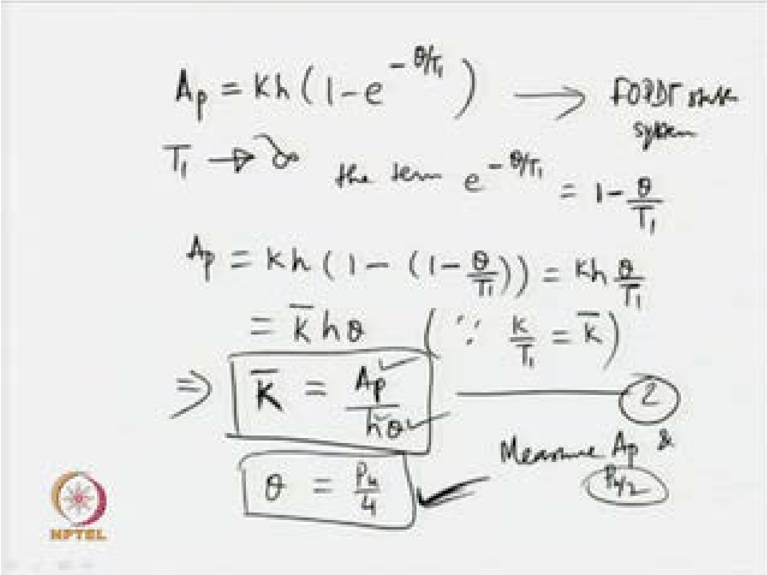

Let us use the second expression. Now, we also know that the peak amplitude of the output signal A p is obtained with the expression A p is equal to K h 1minus e to the power minus theta upon T 1. This is what we get for the first order plus dead time stable system. Now, when the limiting value is put here also, when T 1 tends to infinity, then A p will be equal to K h 1minus e to the power minus 0. So, it will be equal to. No, we cannot put sorry, again I have to make use of the condition that when T 1 tends to infinity, the term e to the power minus theta upon T 1 will be given by 1 minus theta upon T 1. Like the way we have obtained earlier using the condition that e to the power x is equal to 1plus x and e to the power minus x is equal to 1 minus x, when x tends to 0.

So, when T 1 tends to infinity, we get e to the power minus theta upon T 1 as 1 minus theta upon T 1. Thereby, giving us A p as A p is equal to K h time 1 minus theta by T 1. So, which is ultimately K h times theta by T 1. Again, we know that k by T 1 is k bar. So, which gives us k bar h theta, since k by T 1 is finite and given by k bar. k by T 1 is equal to k bar. So, thus this enables us to write an expression of the form k bar is equal to A p by h theta. So, this is equation number 2 for us. How can we use this expression for estimating unknowns of the transfer function model? Measure A p, theta has been earlier obtained using the expression theta is equal to P u by 4.

So, let me write down that expression once more. Theta is equal to P u by 4. Then, how can we estimate the unknowns of the transfer function model? Measure A p, the peak amplitude and half period, P u by 2. Then, using this, theta can be estimated, half of the half period P u by 2 gives us theta. Thus, the unknown time delay associated with the transfer function model is estimated. After estimating theta, use equation 2 which is again given by k bar is equal to A p by h theta, h is known is user defined or user set value. Now, theta is estimated and A p is measured. Thus, enables us to estimate the unknown k bar.

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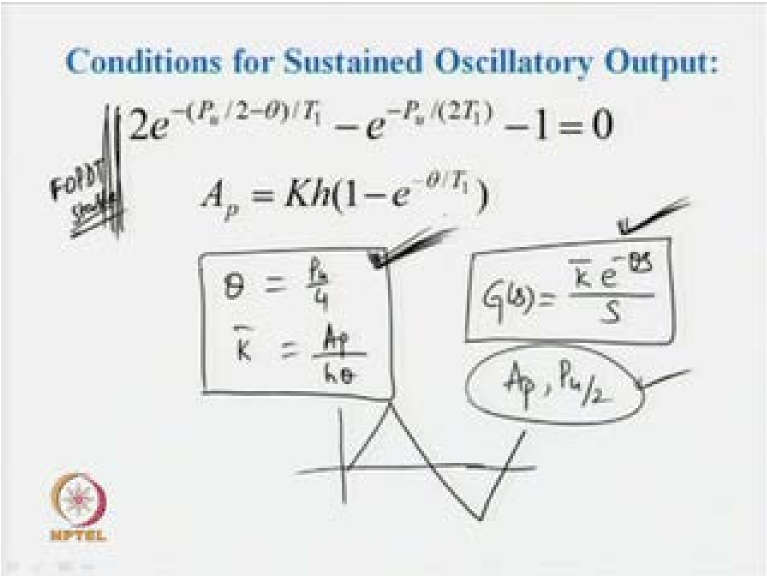

So, let me summarize these two things. Using these two expressions conditions for sustained oscillatory output, using two expressions both are obtained for a first order plus dead time stable system, it is possible to find the expression like theta is equal to P u by 4 and k bar is equal to A p by h theta, which can be used to estimate the unknown parameters k bar and theta, associated with our transfer function model G s is equal to k bar e to the power minus theta s upon S.

So, if a system has got such dynamics. If we have got integral system with dead time, then it is possible to make measurements of the output signal. Measure A p and P u or A p and P u by 2, make use of these explicit expressions and estimate the unknowns associated with this transfer function model. Then, question may come, how can we apply these technique for estimating the transfer function model? We have to observe the output signal. The output signal from the relay test must be of triangular form. Then only we are allowed to make use of these two expressions to find the transfer function model for the dynamics of the system.

So, the actual system is expected to have the dynamics of this form. Then in that case, this can be translated, the measurements can be translated into the transfer function model parameters using these two expressions. Again we shall extend this concept for identifying some other type of simple transfer function model that we have considered in our earlier lecture. Let the relay test results in output of the form shown over here.

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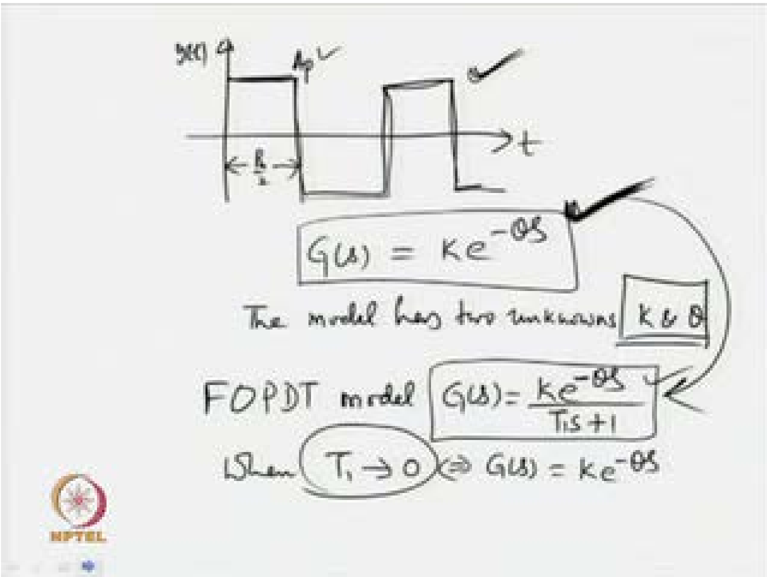

So, when the output of a relay test is of this form, then in that case what sort of transfer function we have to find for the dynamics of that system? The transfer function can be of the form G s is equal to k e to the power minus theta s. This we know. Because when a relay test is conducted on a system of this form, a system having this dynamics, then in that case rectangular or square pulses are obtained as the output of the system. Now, from here, what is the half period again? Then, P u by 2 is this much. And what is A p? A p is the output we obtained here. So, this is A p and this is P u by 2. This is how we can make measurements on the output of the relay test. And the output will yield us or will give us parameters like A p and P u by 2.

So, assuming that the relay test is inducing output of this form, in that case we shall go for identification of the dynamics of the system in the form of G s is equal to k e to the power minus theta s. Then, the transfer function model, the model has got two unknowns, k and theta. Therefore, we need to find again two expressions associated with k and theta in terms of the measurements A p, P u by 2 and k and h, the relay, the input to the system or the relay output. Then, how can we obtain such a model? We can obtain such a transfer function model from the general first order plus dead time model, given by G s is equal to k e to the power minus theta s upon T 1 s plus 1. Why I target this particular first order plus dead time transfer function model? Because we have derived analytical expressions for the first order plus dead time transfer function model. And those two analytical expressions can be exploited, can be used to obtain analytical expressions for simpler models of this form, provided it is possible to get this transfer function model from the general one.

So, how can we obtain? When T 1tends to 0, then the first order plus dead time transfer function model will be G s is equal to k e to the power minus theta s. Then, this limiting value can be put in the expressions obtained for first order plus dead time transfer function model. And that will enable us to establish or to find derived simpler expressions, explicit expressions to find the unknowns of the transfer function model G s is equal to k e to the power minus theta s. So, we shall make use of those expressions now with the limiting condition that T 1 tends to 0. One has to be very careful when you are applying the limiting conditions to the analytical expressions.

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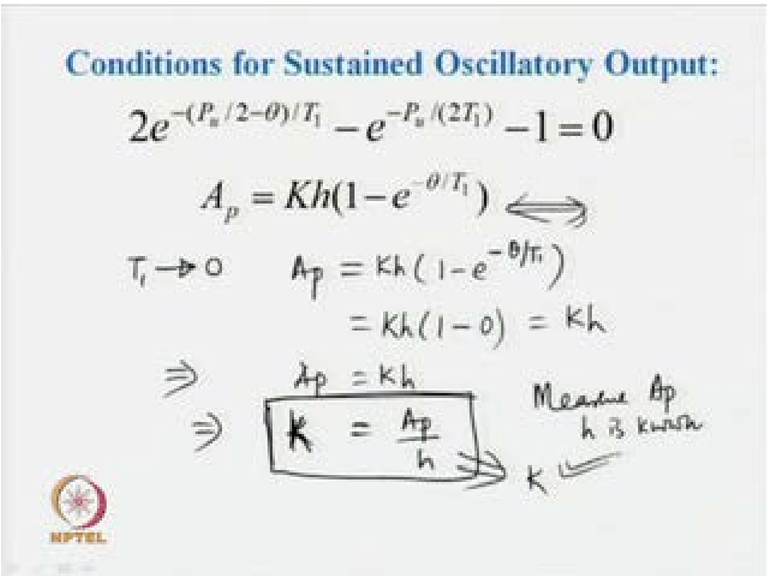

You must follow some logic. Now, when T 1tends to 0. Let us see the second expression, the output expression, peak amplitude expression first, which is a bit simpler to us. A p becomes A p is equal to k h 1minus e to the power minus theta upon T 1. So, this will give us the condition that when T 1 tends to 0, this will be equal to k h 1minus 0, which is equal to k h. Why that is so? Because T 1 tends to 0 e to the power minus theta by T 1will be equal to e to the power minus infinity which is equal to 0. So, that way A p becomes k h, when T 1 tends to 0. And which gives us an expression of the form A p is equal to k h, which can ultimately be expressed in the form of k is equal to A p by h.

So, one unknown of the transfer function model can be estimated using this relationship, where k is equal to A p by h. So, measure the peak amplitude A p and h is known, use this expression and estimate one unknown parameter associated with the transfer function model, using k is equal to A p by h. So, how simple these are? When the same analytical expressions are used for estimating different type of simple transfer function models, provided the output sustained oscillatory output of relay tests are of some specified form.

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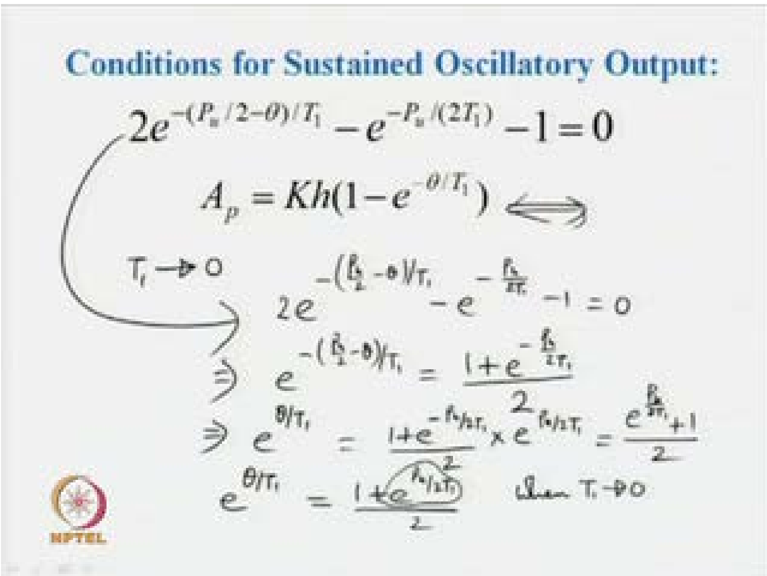

Now, we shall make use of the first expression now to estimate the time delay associated with the transfer function model. Now, when T 1 tends to 0, the expression 2 times e to the power minus P u by 2 minus theta upon T 1 minus e to the power minus P u by 2 T 1 minus 1 is equal to 0 can be written in the form of e to the power minus P u by 2 minus theta by T 1 is equal to 1 plus e to the power minus P u by 2 T 1 by 2. So, this is by 2. Now, further this is same as e to the power theta by T 1 is equal to 1 plus e to the power minus P u by 2 T 1 by 2 times e to the power P u by 2 T 1, which gives us in the numerator terms like e to the power P u by 2 T 1 plus 1 by 2. So, the first condition results in an expression of the form e to the power theta by T 1 is equal to 1 plus e to the power P u by 2 T 1 by 2.

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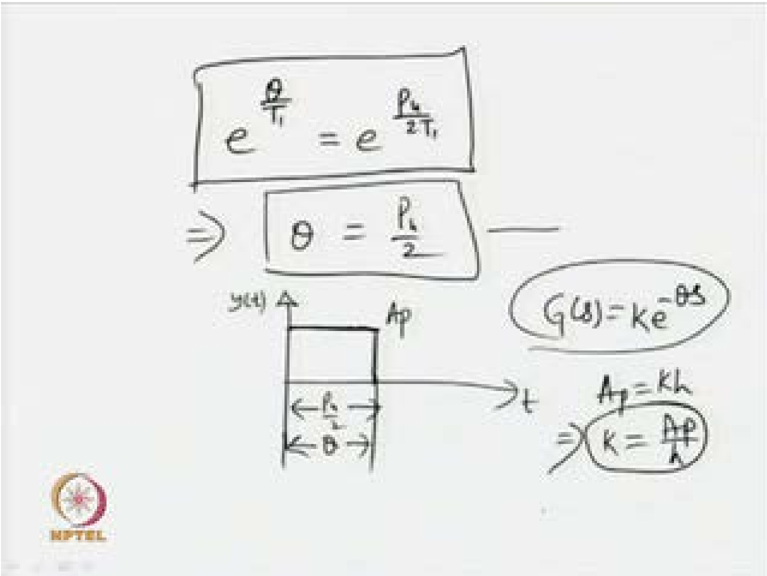

Now, when T 1 tends to 0, this term will be a large number. Therefore, the same can be written in the form of e to the power theta by T 1 is equal to e to the power P u by 2 T 1. Why that is so? Let me explain. If you look at these expressions, T 1 tends to 0, it is there in the numerator of this exponent. Therefore, this is a large number, e to the power infinity is a very large number compared to 1. Therefore, the numerator can be expressed as e to the power theta by T 1 is equal to e to the power P u by 2 T 1 by 2. Again this 2 has no meaning because e to the power P u by 2 T 1, when T 1 is a very large number. That means, when T 1 tends to 0 e to the power P u by 2 T 1 is a very large number. Therefore, very large number divided by 2 also results in a very large number, which enables us to ultimately get in the form of e to the power theta by T 1 is equal to e to the power P u by 2 T 1, implies theta is equal to P u by 2.

So, analysis has given us that theta is equal to P u by 2. Now, measurement of the half period will enable us to estimate the other unknown associated with the system, which has got two unknowns, k and theta. Now, theta can be obtained from the measurement of P u by 2. Then, when the relay test is yielding you rectangular pulses or so, concentrate on only positive half and measure this half period P u by 2. And this is nothing, but the delay associated with the transfer function model, k e to the power minus theta s. So, directly this parameter is nothing, but the time delay associated with a system.

Similarly, we have seen that A p is equal to k h. And what is A p in our case? It is the output signal y t, this the A p, so this is constant. So, the measure A p and estimate the other unknowns associated with the transfer function G s is equal to k e to the power minus theta using the expression k is equal to A p by h. So, it has been illustrated how powerful the two expressions are. The two expressions we have obtained for the first order plus dead time model.

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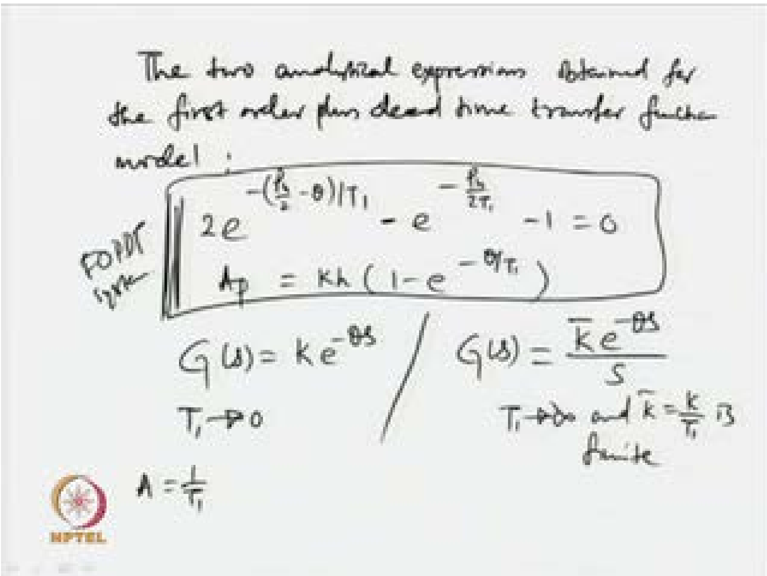

The two analytical expressions obtained for the first order plus dead time transfer function model. These are 2 e to the power minus P u by 2 minus theta by T 1 minus e to the power minus P u by 2 T 1 minus 1 is equal to 0 and A p equal to k h 1 minus e to the power minus theta by T 1. These two can easily be extended for finding transfer function models of the form G s is equal to k e to the power minus theta s or of the form G s is equal to k bar e to the power minus theta s upon S, with the limiting values of, in this case T 1 tends to zero, and in this case, T 1 tends to infinity and k bar is equal to k upon T 1 is finite.

So, we have really developed two powerful equations for the first order plus dead time stable system. What happens to these expressions when we have got first order plus dead time unstable systems? There will be changes in the sign, as I have stated earlier, simply we will get expressions like, when A becomes 1 upon t 1, then there will be changes to the sign simply in that case. What we will get? The output will get, the expressions we will get will be, this will be plus, this will be plus and here also we will be getting plus. So, basically by mentioning that, what I wish to point out that these two expressions are quite powerful as far as analysis of first order plus dead time systems are concerned. So, first order plus dead time systems results in output of some specified form. The output we get are of this form.

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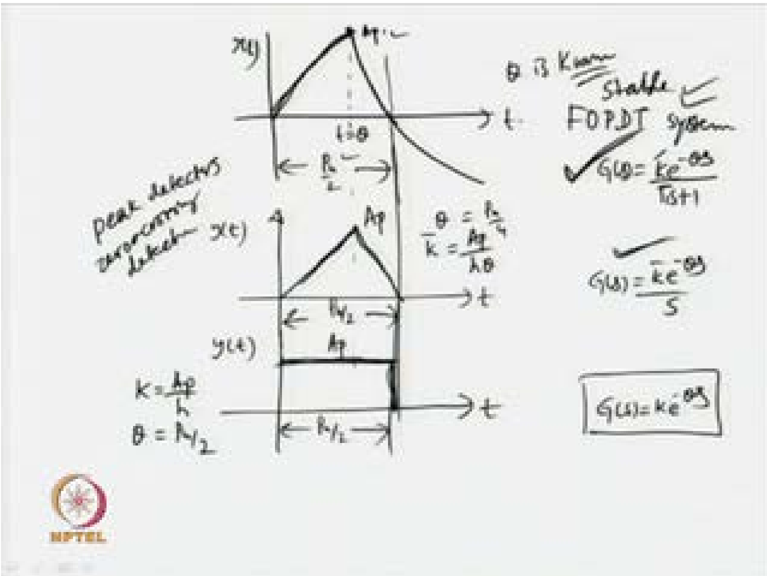

So, let us concentrate on the half period. This is the half period P u by 2, this is my y t and this is t. So, this is what you get from first order plus dead time systems. Now, when we have got a simpler system, which dynamics is given by the transfer function G s is k bar e to the power minus theta s upon S, then the corresponding output becomes triangular in fashion. And when the system has got dynamics k e to the power minus theta s, the corresponding output from the system assumes a pulse of this form. So, looking at the shape factor of the output signal, or I can mention looking at the shape of the output signal. Now, we can decide about the type of transfer function model we should choose for obtaining the dynamics of the real time system.

So, in this case, it is k e to the power minus theta s upon T 1 s plus 1. Assuming that we have got a stable first order plus dead time system, an output of this form is expected. Then, when we have got a simpler system which has got an integrator with delay, the output will be having this shape. When we have got a system with a gain and delay only, then the output will be of this form.

So, point of mentioning all these things that, we can easily measure the peak amplitude in all cases A p, A p and this is the A p. And we can easily measure the half periods, P u by 2m P u by ,2 employing the zero crossing detectors and peak detectors to find the peak amplitudes employ peak detectors. And for finding the half periods, you employ zero crossing detector. Measure A p and P u by 2, use the analytical expressions we have found. So, for the stable first order plus dead time system, what are the analytical expressions? Use the first two analytical expressions and solve the two expressions simultaneously to obtain the unknowns associated with the transfer function model. Whereas, when the output of the system is of this form, rectangular form, then use the expressions k is equal to A p by h and theta is equal to P u by 2. But in this case, k is equal to, sorry we have got k bar, not k. k bar is equal to A p by h theta and theta is equal to P u by 4. So, whole point of discussion about this wave shapes are that, look at the shape of the output signal, then go for a particular type of transfer function model for describing the dynamics of the real time system. Once you have identified the transfer function model, then it is all about estimating the unknown parameters associated with the transfer function model. Now, in the stable first order plus dead time case, we have got three unknowns, but we have got two equations which are analytical expressions, which can be made use of for estimating the unknowns. Therefore, for the stable first order plus dead time case, you have to find the gain or one parameter, either gain, steady state gain or any other parameter of the system by some other method.

So, there are numerous techniques to find the other parameters also. Particularly, the dead time associated with a system can be estimated from these output wave forms also. And how can we find? As we know, as far as first order plus dead time systems are concerned, the peak occurs at time t equal to theta. This is an interesting observation. At time t equal to theta, the peak amplitude occurs. Therefore, the time at which the peak occurs t is equal to theta, which can be easily read from the output signal.

So, the theta parameters can easily be obtained from that. What I mean to say is that, theta need not be estimated using the analytical expressions, rather theta can be obtained from the output information from the output signal. Like at the peak amplitude of the output occurs at time t equal to theta, read of this value time t equal to theta. Therefore, theta is known for us, theta is known. Then, the remaining unknowns are k and T 1.

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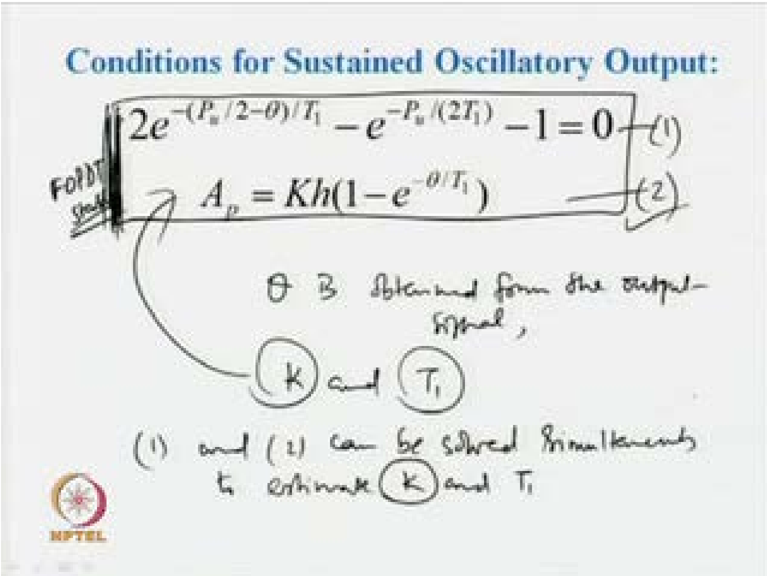

 Then, the two analytical expressions. These two can be used to estimate k and T 1, instead of theta and t 1. Why I am mentioning? Suppose the theta time delay of the transfer function model theta is obtained from the output signal, then we are left with two more unknowns. Those are k and T 1. Then, k and T 1 can be estimated from the solution of the two non-linear equations.

So, 1 and 2 can be solved simultaneously to estimate k and T 1. In that case, k need not be known a priori. k can be estimated as well, k can be obtained using the analytical expressions. Now, there is one more technique to find the time delay t at the time delay theta associated with the transfer function models. One can take first order derivative of the output signal. In that case, there will be a sharp change in the first order derivative of the output signal at time t equal to theta. Why that happens? We know that the input to the system is changing at time t equal to theta. So, input becomes minus h at time t equal to theta. But prior to that the input remains as h, positive h. So, that concept can be made use of to find time delay associated with transfer function models.

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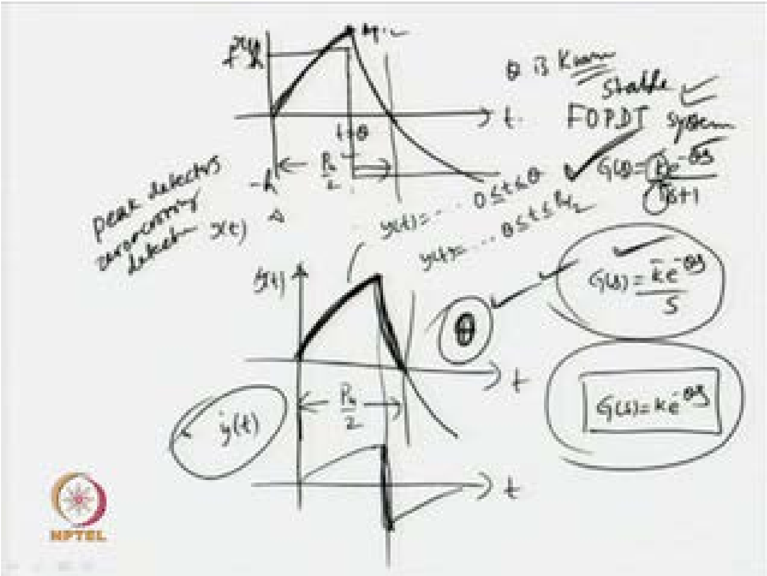

So, what I mean by that? Given a first order plus dead time system, when a relay test is conducted, it is expected to obtain the output in this form, y t. Now, if I wish to find y dot t, then what will happen? There will be a sharp changes to this y dot t at time t equal to theta. Why that is so? Because we have got the output signal which is not continuous, as far as half period P u by 2 is concerned. We have got the outputs from different inputs. The inputs are changing. Therefore, we have got two segments. One for this and one for this. Or indirectly speaking, I cannot have the plot for the whole half period using one analytical expressions.

So, I have got two expressions for that. To have this part of the plot of the output signal, I use y t is equal to something for time 0 to theta. Similarly, for obtaining other part of the output, I use some expression y t is something from the time range starting from time t equal to theta to time t equal to P u by 2. That means what? We have got discontinuity. So, this output is not continuous. Therefore, when its first order differentiation is obtained, definitely we will have discontinuity in the output at time t equal to theta. That is how employing that concept, it is possible to estimate the time delay parameter of the transfer function models. And once the time delay parameter one unknown of the transfer function model is obtained using the same output signal, in that case we are left with two more unknowns in the first order plus dead time model. And those are k and t 1. Therefore, k and T 1 can be estimated using the two non-linear equations we have obtained.

Fortunately for simpler systems, like a system with an integrator and delay, and a system with a gain and delay, we have got two unknowns. Therefore, the two explicit expressions we have obtained can be made use of to estimate the unknowns associated with the transfer function model. So, this is one powerful technique we have for the identification of simple transfer function model using relay test or conducting relay test. I will summarize now.

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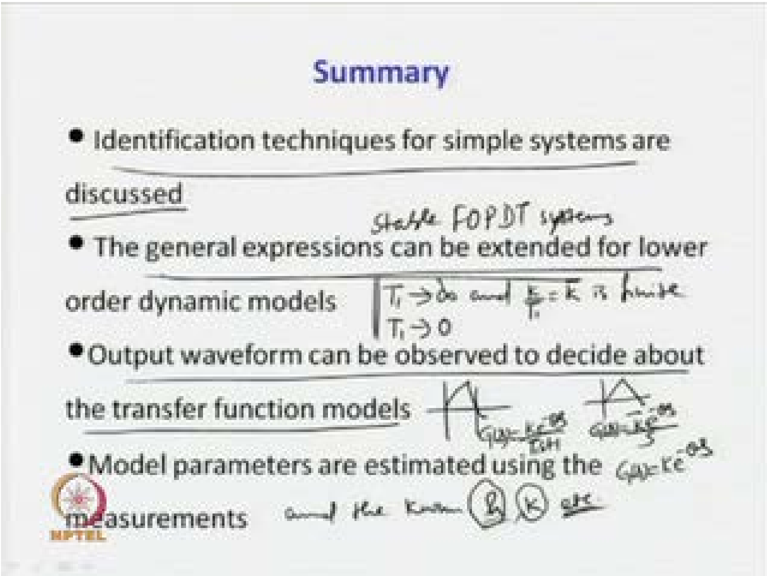

So, what we have studied in our lecture? That identification for simple systems are discussed. We have obtained analytical expressions, rather I would say explicit expressions for the parameters of a simple transfer function model, like a transfer function with an integrator and delay and other simple transfer function, like a gain with a delay. So, we have been able to derive explicit expressions for the unknowns of those simple transfer functions, in terms of measurements made on the output wave form.

Now, the general expressions found for the stable first order plus dead time systems have been extended for lower order dynamic models. How that has been possible? With the limiting condition that T 1 tends to infinity such that k upon T 1 is equal to k bar is finite. And the other limiting condition, T 1 tends to 0. Using these two limiting conditions in the general expressions, we have been able to find simpler explicit expressions for the transfer function models of simpler systems.

Now, output waveform can be observed to decide about the transfer function models. That also we have decided. When the output of the relay test is some exponential form of this form or this shape, then we go for a transfer function model of the form G s is equal to k e to the power minus theta s upon T 1 s plus 1. When the relay test is yielding triangular pulses only, in that case the transfer function model to be identified can be of the form k bar e 2 to the power minus theta s upon S. Whereas, when the output is either rectangular or square pulses only, in that case the transfer function model can be of the form G s is equal to k e to the power minus theta s.

Now, the model parameters are estimated using the measurements and the unknowns h and k etcetera. Why these are known? Because these are user defined or users basically set the relay parameters. And in the first order plus dead time transfer function model case, a priori information about the steady state gain is there. Then, that information also can be used in the explicit expressions or in the analytical expressions to find the unknowns of transfer function models.

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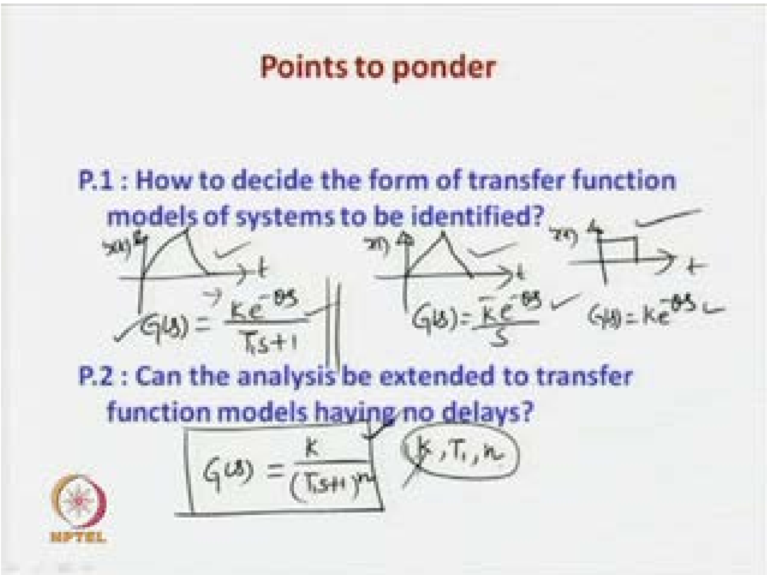

Now, some points to ponder. How to decide the form of transfer function models of systems to be identified? As I have already mentioned while I summarized the lecture, when the output of the relay test is of this form, go for the transfer function model G s is equal to k e to the power minus theta s upon T 1 s plus 1. And assume that one unknowns of this transfer function model is known a priori, then estimate the remaining two unknowns using the analytical expressions. Or when the wave shape, waveform, shape of the waveform is triangular, go for the transfer function model of the form k bar e to the power minus theta s upon S. When the output y t is rectangular, in that case go for the transfer function model G s is equal to k e to the power minus theta s.

Now, what happens when the output is not of these forms? In that case, we may have to consider higher order transfer function model. That we shall discuss in our subsequent lectures. And the question is like this, how can the analysis be extended to transfer function models having no delays? As you see in these transfer function models, a time delay is there in all these models. Is it possible to identify transfer function models without involving time delay? Yes, it is possible. We can have some transfer function model of the form G s is some k upon T 1 s plus 1 to the power n. So, this typical transfer function models also are often used for identifying system dynamics or real time system dynamics.

Now, these also involves three unknowns now, k ,T 1 and n. So, the three unknowns can be obtained using the analytical expression. Again in that case, what will happen? We have to have prior information about one of the unknowns. And we can use the analytical expressions for finding the remaining two unknowns, T 1 and n, or a set of the unknowns k, T 1 assuming n is known and so on. So, we have got transfer function model of different form without involving time delays in it. That is all in this lecture. Thank you.