Advanced Control Systems

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Module No. # 03

Time Domain Based Identification

Lecture No. # 15

On-Line Identification of TITO Systems

Welcome to the lecture titled on-line identification of TITO systems. In our last lecture, we have studied the off-line identification of TITO systems. In this lecture, we shall see how simple on-line identification scheme can be applied for TITO or two input, two output systems.

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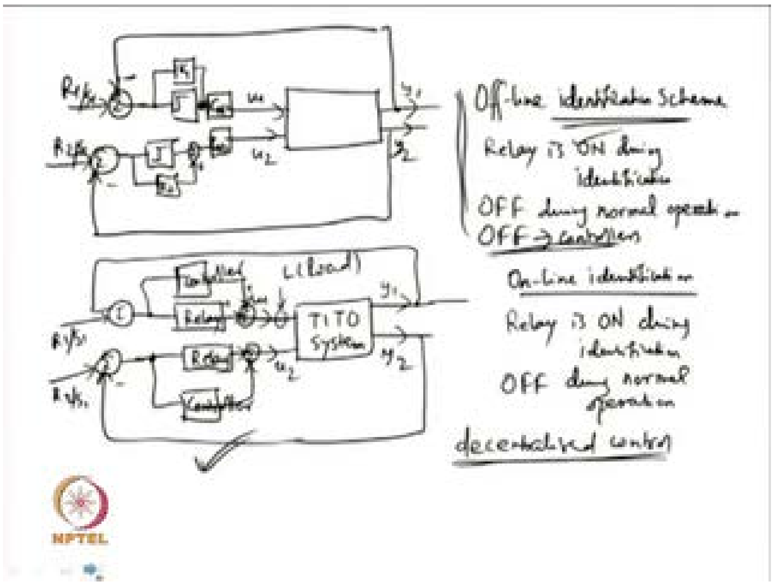

What we have described in our last lecture is that given a TITO system, which has got two inputs U 1 and U 2, and two outputs y 1 and y 2. We can add a modified relay of the form - a relay with one controller C N 1, and again in parallel K 1. And similarly, a controller C N 2 - a relay, and again in parallel with the relay K 2 can be added; these modified relays can be put in closed loops with negative feedback. With of course, the set values R 1, and R 2. So, this how we get an off-line off-line identification scheme, where the relay is switched on or modified relay is on during identification, whereas it is switched off. The modified relay is off, during normal operation of the decentralized control system, normal operation. So, how it is different from an on-line identification scheme that, we shall see. Given a TITO system again this is your TITO system which has got - two outputs y 1 and y 2, and corresponding inputs U 1 and U 2.

I can add relay relay of course, in parallel with a controller. So, we will have controllers in parallel with the relay. And then, put the relay in closed loop in this form. So, similarly for the second loop, we will have the negative feedback in this form. And of course now, we can have the set values R 1 and R 2 or s 1 and s 2, as we have used in our last lecture S 1 and, S 2 - these are the reference inputs or set point inputs. So, how this is accomplished, how this is on on-line identification now is done on-line identification. In the on-line identification, relay will be on during identification, and off during normal operation.

Now, when relay is off during normal operation, what happens? The TITO system will be subjected to decentralized control decentralized control. Whereas, in the earlier case, when the relay is on, the controllers are to be switched off. So, basically not only the relay, the controllers are also to be switched off off. So, controllers here unlike the on-line identification case, in off-line identification scheme; the controllers remain off, during the identification which is not so in on-line identification scheme. I mean to say, the controllers are always there in the loop. That means, when decentralized control is effected that time relay is switched off, otherwise relay is switched on, for identification of parameters of parametric models of the TITO system.

So, these are the basic difference between the two, and not only we are getting getting a simple scheme, simple on-line scheme. The other advantage of this one that, if the TITO system is subjected to some load inputs; some static load disturbance has like load inputs, then the output is not getting affected by the presence of controllers, in the loop during identification. This is the major advantage, we get with the on-line identification scheme. And unlike off-line identification scheme, the controller need not be switched off during identification. So, this is the fundamental difference, we have between the off-line identification, and on-line identification schemes.

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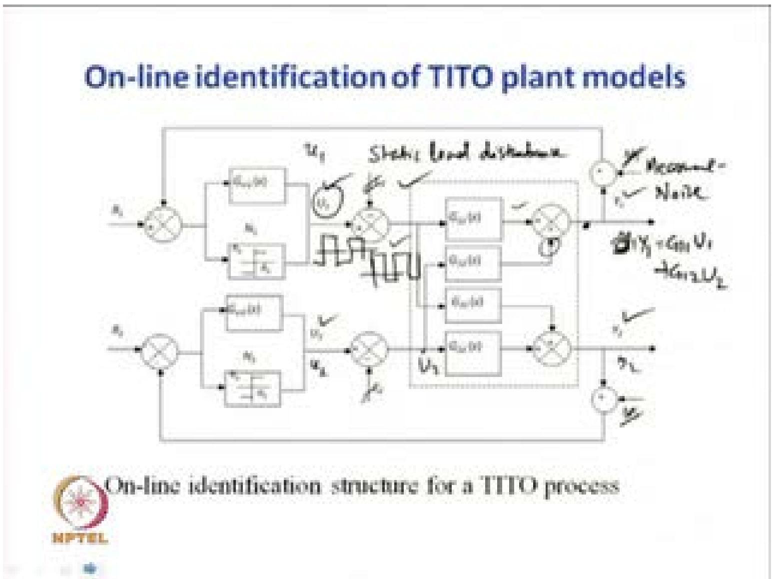

Now, I shall go to the on-line identification scheme which can be given in this form. Now, in this structure as you see the L L 1, and L 2 represents the static load disturbances, and M 1 and M 2 also represents the measurement noise, measurement noise. So, we have got a controller connected in parallel with the relays throughout the operation of the system, and during the relay experiment as well. So, that is the basic difference, we have between the off-line identification scheme, and the on-line identification scheme.

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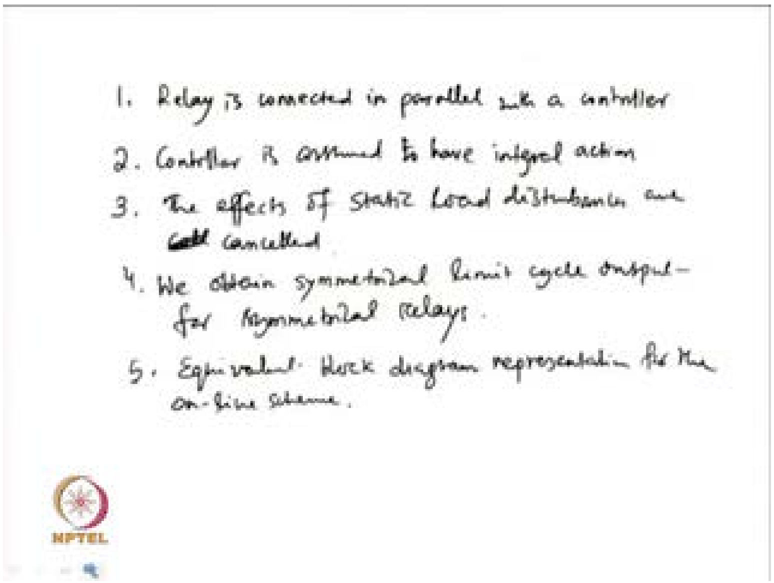

So, what are the major benefits one get from this arrangement, this on-line identification scheme. First is how you have to do, the relay is permanently connected in parallel with with a controller; and the controller is assumed to have, controller is assumed to have integral action, integral action. So, what type of controller we have to used either PI or PID or I controller. Now, what is the benefit you get by that, then the effects of the effects of static load disturbances - static load disturbances are cancelled. And we guarantee, we obtain symmetrical limit cycle output output for symmetrical relays. If the controller is disconnected as you can see from here, suppose I disconnect the controller during the relay experiment, what will happen? The static load disturbance will influence the input to the TITO process.

That means, whatever signal you are getting whatever rectangular pulses you are getting, that will get added by the static load disturbance, and ultimately you will you will get a symmetrical input to the system. Now, a symmetrical or shifted version of the input signal to the system. So, you will get a an input of this form, and corresponding to this asymmetrical input, the output will become asymmetrical. So that, that will not happen provided, we have a controller during the relay experiment. So, that is the major benefit we get from the scheme. Now, the further we can get a simpler equivalent representation, equivalent block diagram representation for the on-line scheme compared to that of the off-line scheme, a simpler one can be obtained.

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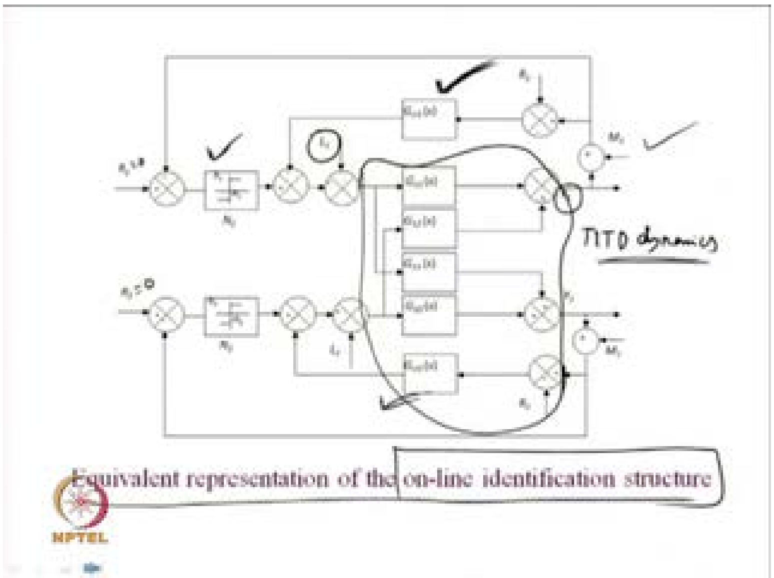

How it will look like, then the equivalent representation of the block diagram for on-line identification scheme looks like this. Where the relays is basically a TITO system sorry, this will cover like this. So, the relay will experience, and inner feedback controller subject the TITO system is subjected to inner feedback controllers. So, that is the beauty of the scheme, when the on-line identification scheme scheme is given or shown in equivalent form, then it is apparent from this figure that the relays is basically the TITO dynamics, subjected to to inner feedback controllers.

And what is the benefit of this inner putting inner feedback controllers, that the TITO dynamics can get modified or the open loop TITO dynamics can be modified with the help of the two inner feedback controllers G cl1(s), and G cl2(s). And thus, we can relocate, the poles of the open loop TITO dynamics to suitable positions. Thus the relay feedback will result in not only symmetrical output, rather it can result in symmetrical output for difficult TITO processes as well. So, that is the major benefit one gets from the on-line identification structure, we have provided.

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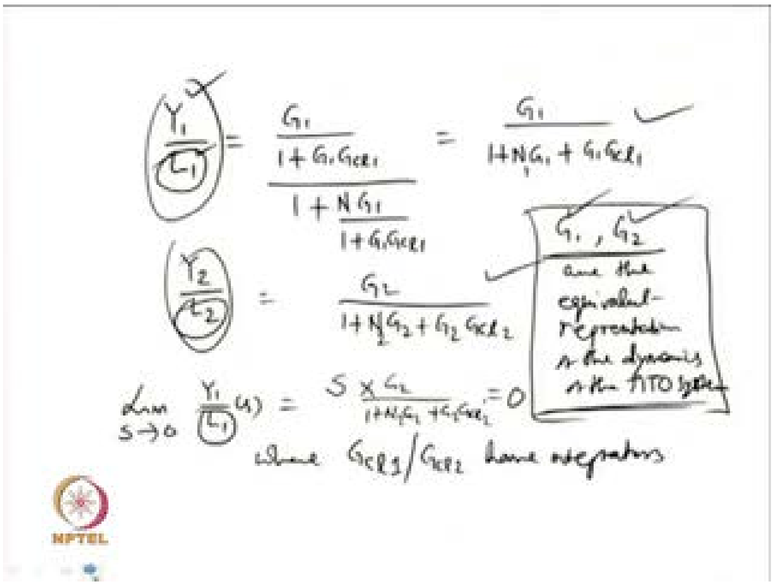

Now, also I can get the relation between the output to the static load disturbances in the form of Y 1 upon L 1 is equal to G 1 upon 1 plus G 1 G cl1 upon 1 plus N G 1 upon 1 plus G 1 G cl1. What I mean by that, let us find the transfer function between Y 1 to L 1. Then assuming R 1 to be 0 that time, R 2 to be 0 that time for the upper case, when the TITO process or dynamics is assumed to have decoupled dynamics, that that time the transfer function between the output to that of the static load disturbance can be given in this form. Upon simplification is which gives us in the form of G 1 upon 1 plus N G 1 plus G 1 G cl1.

This is for one loop, similarly I can find the transfer function of Y 2 upon L 2 to be of the form G 2 1 plus N G 2, in this case this will be N 1, this will be N 2- N 2 G 2 plus G 2 G cl2. So, what are G 1, and G 2 here; G 1 and G 2 are the equivalent representation equivalent representation of the dynamics of TITO system of the dynamics of the TITO system. When it is assumed that the TITO system is decoupled. So, when the TITO system is decoupled; obviously, we get the equivalent representation of the whole TITO system dynamics in the form of G 1, and G 2. That means, as if we have got two single input, single output systems of the form G 1(s), and G 2(s). Corresponding to that the transfer function between the output, and load disturbances can be expressed in this form. So, why I am expressing this the reason is that, if you find the steady state values of the output corresponding to the load inputs or static load disturbances, limit S tends to 0, Y 1 upon L 1(s) will give you zero.

When the G cl1 or G cl2 or the controllers have integral action or integrators, when the controllers have integrators basically one S will appear in the numerator. So, ultimately it will be it will be S times your G 2 upon 1 plus N 2 G 2 plus G 2 G cl2 dash. It will be available in this form, when S tends to 0 whole term becomes zero. And that is how the effects of the load disturbances L 1, and L 2 are nullified in the output of the system. So, the limit cycle experiment or the relay feedback experiment will not be disturbed by the presence of static load disturbances. So, this the major benefit you get from the on-line identification scheme.

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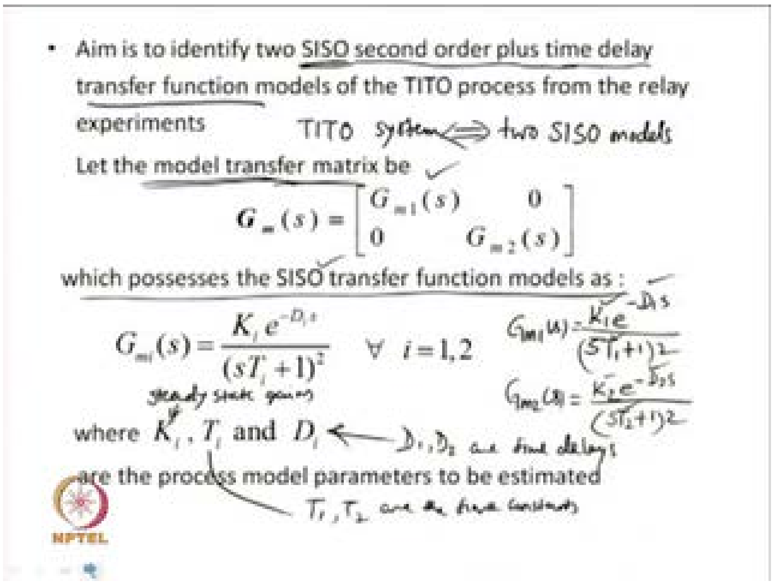

Now, I will describe the the dynamics of the TITO system by the model transfer matrix. Now, the TITO system will be identified by or will be represented by 2 single input, single output second order plus time delay transfer function models. So, the TITO system will be represented by two single input, single output models - transfer function models. Then the transfer model transfer matrix will be G m(s) is equal to G m1(s), 0, 0, G m2(s). So, we can write the model transfer matrix in the diagonal form. Now what what form of G m1, and G m2(s) will help, we one can choose the single input, single output transfer function models to be of the form G mi(s) is equal to K i e to the power minus D i s upon ST i plus 1 square for all i equal to 1 to 2. That means, G m1(s) will be equal to K 1 e to the power minus D 1 s upon ST 1 plus 1 square, and G m2(s) will now become K 2 e to the power minus D 2 s upon ST 2 plus 1 square.

So, the TITO system dynamics has got how many unknowns means as far as the two single input, single output transfer function models are concerned number of unknowns will be 1, 2, 3, 4, 5, 6. So, we will have 6 unknowns - those are to be identified or estimated. What are those K's, D's and T's; K's are the steady state gains. So, we will have two steady state gains K 1, and K 2. So, K's are the steady state gains, what are the T's? T's are the time constants. So, T 1, T 2 are the time constants, and what are the D's? D's are the D 1, and D 2 are the time delays.

Please see the changes, earlier I have used the theta variable for the time delays, but in this study, we are introducing D's for the time delays. So D 1, D 2 are the time delays of the transfer function models. Now, we have assumed a second order transfer function, model for the dynamics of for two SISO models of the TITO dynamics.

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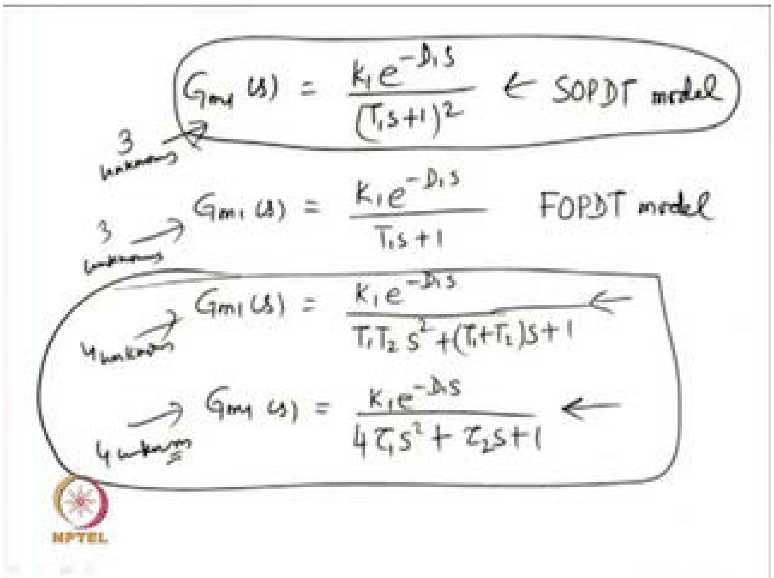

Why we have assumed the second order dynamics I mean to say, G m1(s) I have written by K 1 e to the power minus D 1 s upon T 1 S plus 1 square. Often one can use any sort of transfer function model here. So, G 1(s) can be of the form K 1 e to the power minus D 1 s times sorry divided by T 1 s plus 1 also. So, we can represent the SISO transfer function model by some first order plus dead time model. Unlike the second order plus, dead time model that, we have assumed for our study. Now, can we take any other set of models G m1(s) is equal to say your K 1 e to the power minus D 1 s times T 1 T 2 S square plus T 1 plus T 2 S plus 1. Can we take any other form like G m1 1 is equal to K 1 e to the power minus D 1 s upon your tau 1 S square plus 4 tau 1 S square plus tau 2 S plus 1. Can I take in this form?.

That means, this represents the dynamics for an under damped system, this represents the dynamics for a second order transfer function model with two distinct poles. So, we can no doubt the analysis cannot be or may not be restricted to only the second order plus dead time model, we have chosen rather we can use any sort of model, but there is one limitation which shall make use of describing function in our analysis. So, when you make use of describing function in your analysis, the describing function does not result in more analytical expressions. Only the phase, and magnitudes of describing function or the analytical expressions involving describing function can be considered, in that case number of unknowns - the number of unknowns that can be identified will be limited.

So, since we are using describing function, and the describing function does not give more analytical expressions, we are force to choose simple transfer function model, that has got less number of unknowns. So, if I look at the transfer function models, number of unknowns who have in the second order plus dead time model; this second order plus dead time model are 3. So, we have got 3 unknowns here. Similarly, the second one we have got 3 unknowns, you have got 1, 2, 3, 4 - 4 unknowns, and 1, 2, 3, 4. So, you have got 4 unknown.

Now, since the last two transform function models are having more number of unknowns, I am not using those in our analysis. Coming to the first two, now the first order plus dead time model has got 3 unknowns; whereas, the second order plus dead time model of this form has got 3 unknowns. So, why not to use the higher order transform function model, that can replicate the dynamics of many practical systems. So, that is the benefit, we get from this second order plus dead time model. And that is why I am going to use this transform function model in our analysis.

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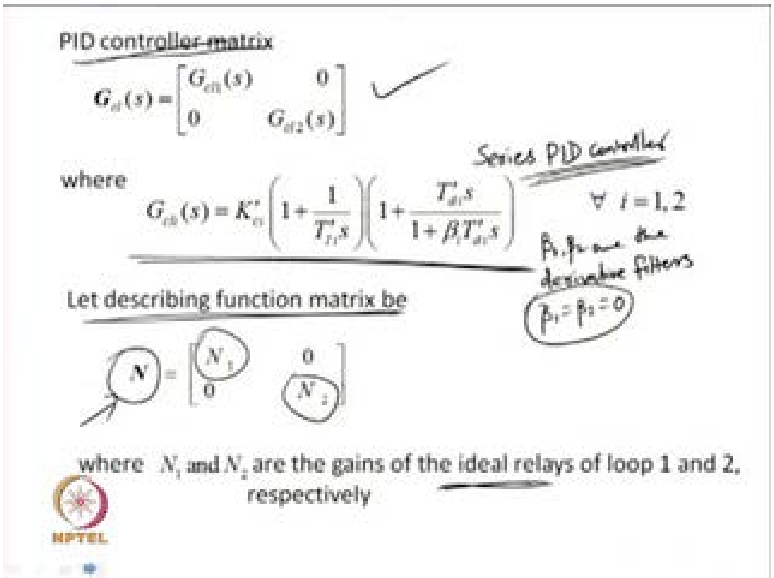

Now, the PID controllers will be given by the series form of PID controller. So, this give the dynamics of a series PID controller, where you have got beta in the PID controller, as beta 1 and beta 2, when i equal to 1 and 2, beta 1 and beta 2 are the derivative filters. Which are of very small value. So, for practical purposes for each in analysis of analytical expressions, we are going to handle later on what will be done beta 1, and beta 2 will be assumed to be 0. There is no harm, because normally these values are very small percentage of that of the time constants T d i dash.

Now so, the controller in the matrix form, and that to in diagonal form are given by G cl (s) is equal to G cl1(s), 0, 0, G cl2(s) square, G cli(s) will be equal to K ci dash times 1 plus 1 upon T Ii dash S times 1 plus T d i dash S upon 1 plus beta i T d i dash S. So, we are using series form of PID controllers. Now, let the describing function matrix for the two relays be given by the non-linear matrix, and is equal to N 1, 0, 0, N 2 - where N 1, and N 2 are the gains of the ideal relays for loop 1 and 2.

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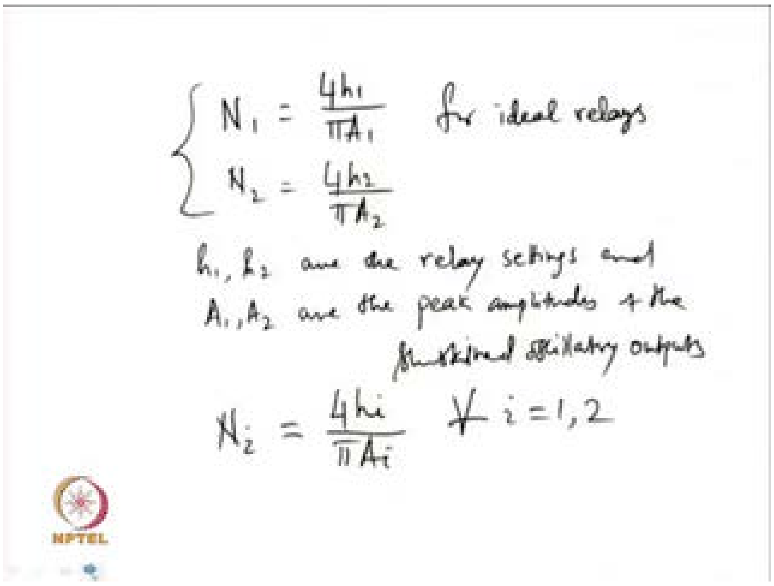

So, how the gains are described now N 1, as you know N 1 is equal to 4 h 1 upon phi A 1, and N 2 will be equal to 4 h 2 upon phi A 2 for ideal relays. So, when the relay possesses, when the relay possesses some hysteresis in that case these expressions are to be modified. Now, what are h 1, h 2, A 1, A 2? h 1, h 2 are the relay settings, and A 1, A 2 are the peak amplitudes of the sustained oscillatory output . So, thus we get the dynamics of the relay in general form; N i is equal to 4 h i upon phi A i, for all i going from 1 to 2. So, this is how, we get the dynamics for N also.

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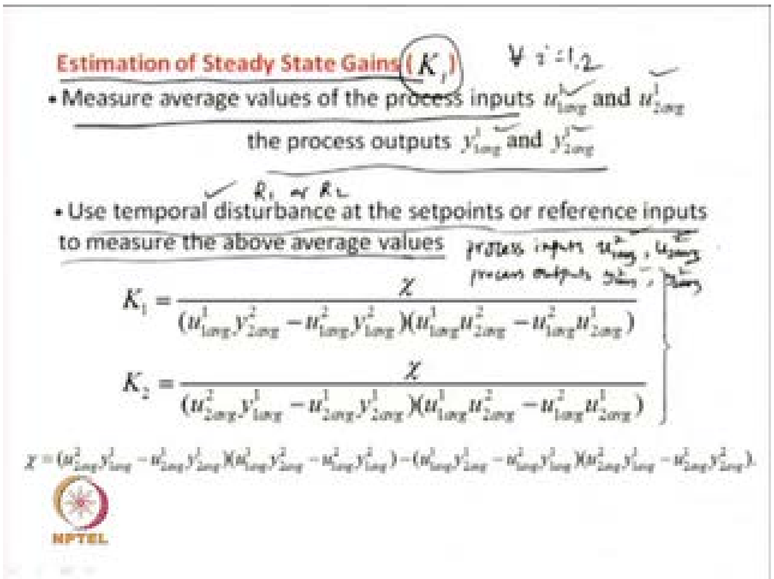

Now, we will start with the (( )) process or stages or the procedure for estimation of the parameters associated with transfer two SISO transfer function models. First, we will try to identify the steady state gains given by K i for all i equal to 1 to 2. That means, how to find K 1, and K 2 will be described now. Now, measure average values of the process inputs, what are the process inputs U 1 and U 2? These are the two process inputs, but in first instant or at any instant of time when R 1, and R 2 the two set values are not equal to 0, that time you measure the process inputs, and denote that by U 1 1, and U 2 1. When you measure the average values of the process inputs - the average of process inputs that time denote the average values of the process inputs by U 1 1 average, and U 2 1 average. Where are those U 1 1, U 2 1; you see what are the process inputs, and output, if you go back to the model.

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We have got the input U 1, and output y 1. Similarly, input U 2 and y 2 - the second output. Now, in in in variable form you have to right the lower case letters, U 1 in laplace transfer form is the upper case, and in variable form are lower case in the signal form it gives you U 1. Similarly, the output is y 1, and U 2, and y 2. So, measure those values average values when R 1, and R 2 are having some values, and that time denote the process inputs by U 1 1 average, and U 2 1 average. Similarly, the process outputs at that instance are denoted by y 1 1 average, and y 2 1 average.

Now, use some temporal disturbance at the set point or reference inputs to measure the above average values in the second instance, where the process inputs will be when you give some disturbance like. Change the value of R 1 or R 2 by some small magnitude, then you will have different inputs, and outputs variables or measurements. So, at that time let the process inputs, when the temporal disturbance is applied be process inputs be U 1 average 2, and U 2 average 2 at the second instance. Similarly, the process outputs y 1 average 2, and y 2 average 2.

So, this is how I obtain how many 1, 2, 3, 4, 5, 6, 7, 8 - 8 measurements are obtained. So, with those measurements, it is possible to estimate the steady state gains using the expressions, K1 is equal to xi upon U 1 U 1 1 average times U 2 2 average minus U 1 2 average times y 1 2 average whole of times U 1 1 average U 2 2 average minus U 1 2 average U 2 1 average. Similarly, K 2 can be having an expression of this form. So, use the measurements, and estimate the steady state gains K 1, and K 2, where xi is given by this horrible expression. Now, these are very simple to obtain the procedure for obtaining obtaining the expression for steady state gains will be explained now.

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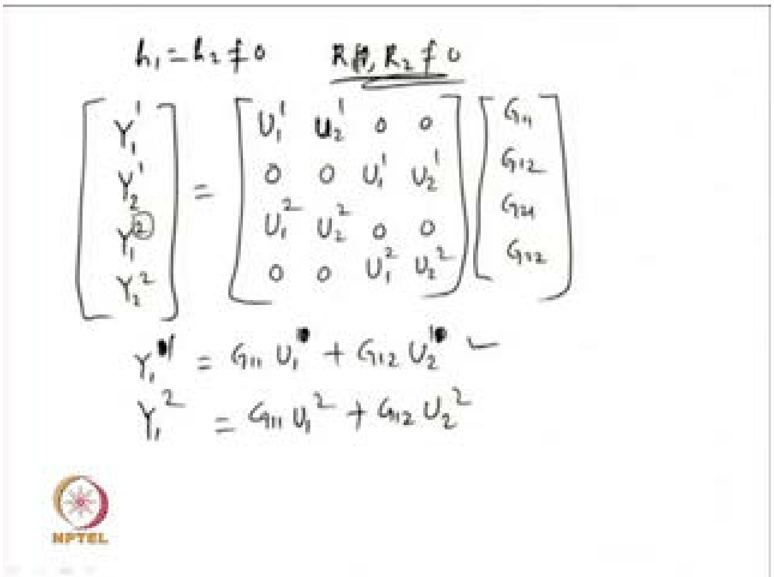

How do I get those expressions now, if limits cycle occurs for some non-zero h 1, and h 2, and non-zero R 1, R 2. So R 1, R 2 are not equal to 0 not equal to 0 at that time make the measurements - and take the measurements in laplace variable form first. Let then the outputs Y 1, and i Y 2 at first instance will be denoted by Y 1 1, Y 2 1. And similarly, the outputs at the second instant, like when the temporal input is given is given by Y 1 2, and Y 2 2.

When you put that in the matrix form, what you get basically these are nothing but your measurements U 1 1 U upper case, U 2 1, 0, 0 with G 1 1, G 1 2, G 2 1, G 2 2. And let me complete this 0, 0, and you will have U 1 1, U 2 1. Similarly, you will have U 1 2, U 2 2, 0, 0, 0, 0, U 1 2, U 2 2 or if you expand this, let me write one simple expression, how do I get Y 1 1. Y 1 1 is nothing but G 1 1 U 1 1 plus G 1 2 U 2 1. So, in the first instant; forget about this first instant. Then what you are getting Y 1 is equal to G 1 1 U 1 plus G 1 2 U 2. Is it so or not yes, definitely if you see the block diagram now, what is your Y 1 - Y 1 will definitely is made up of two components G 1 1 U 1 plus G 1 2 U 2 G 1 2 U t.

So, Y 1 is given by, this Y 1 the signal at this point is given by G 1 1 times U 1. So, G 1 1 U 1 plus this signal is getting added here. So, G 1 2, and the input is U 2 now. So, at that time assume this to be 0 l 1, and l 2 to be 0, and signal measurements M 1 and M 2 errors are to be 0. Then you get the expression G 1 2 U 2. So, it is not difficult to get those simpler expressions first, which can ultimately be converted to some matrix form, and to some ultimate form given by this. So, after obtaining this, what I will do then if this way we can find the expression for first instant - put 1 1 at the first instant. Similarly at different instant of times, second instant the output Y 1 will be Y 1 2 will be nothing but U 1 2 or G 1 1 U 1 2, U 1 2 plus G 1 2 U 2 2.

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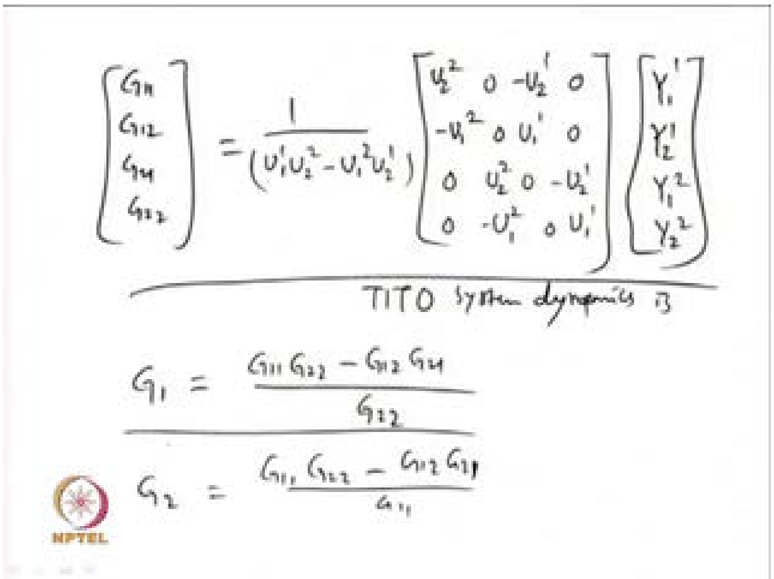

So, we obtained the signal in transfer in in laplace domain in this form, which ultimately can be given written as, now G 1 1, G 1 2, G 2 1, G 2 2 will be equal to the matrix inversion will get involve. So, which can be solved, and found as U 1 1, U 2 2 minus U 1 2, U 2 1 times, you will have again your U 2 2, 0, minus U 2 1, 0 then minus U 1 2, 0, then U 1 1, 0, then 0, U 2 2, 0 minus U 2 1, 0 minus U 1 2, 0, U 1 1. So, when you find the matrix inversion - inversion of this one, because ultimately G G 1 1 sorry stop.

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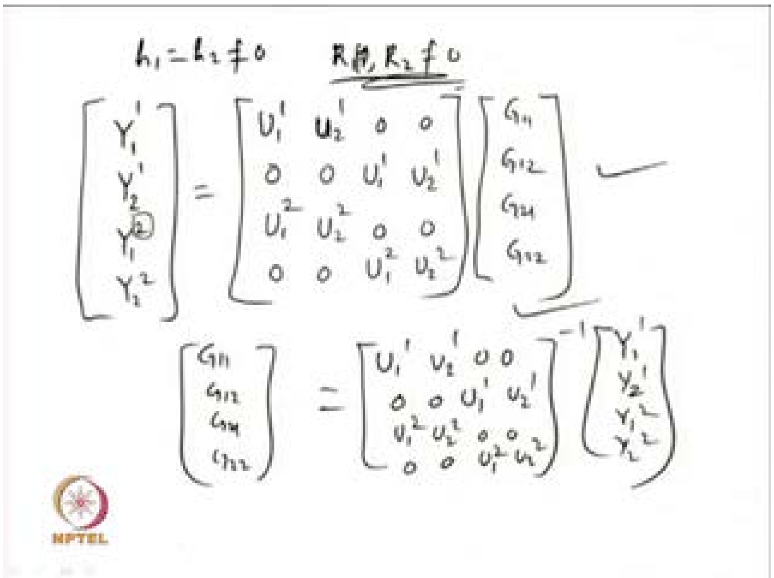

So, when I write this in the form of G 1 1, G 1 2, G 2 1, G 2 2 is equal to, take this to the left hand side. So, you will have the inversion now, matrix inversion U 1 1, U 2 1, 0, 0, 0, 0, U 1 1, U 2 1, then U 1 2, U 2 2, 0, 0, 0, 0, U 1 2, U 2 2 inverse times Y 1 1, Y 2 1, Y 1 2, Y 2 2. So, this is how get? You get. So, I find the matrix inversion which comes out to be of this form; times it will be your y 1 1, y 2 1, and y 1 2, y 2 2. So, this is how you get the expression for G now.

Now when the TITO dynamics, when the TITO dynamics - dynamics is represented by 2 single inputs, single output dynamic model form; assuming that there is decoupling between the two loops. Then we know that G 1 can be given in the form of G 1 1, G 2 2 minus G 1 2, G 2 1 divided by G 2 2. Similarly an expression for G 2 can be written, for in this case what will happen G, it will be G 1 1 to G 2 2 minus G 1 2 to G 2 1 divided by G 1 1. So, these are the two decoupled transfer function representation of the TITO system dynamics. So, when I consider the upper one, then upon substitution of G 2 2 - upon substitution of G 1 1, G 1 2, G 2 1, G 2 2 here in this expression, then I get finally, these K expression for K 1, and K 2.

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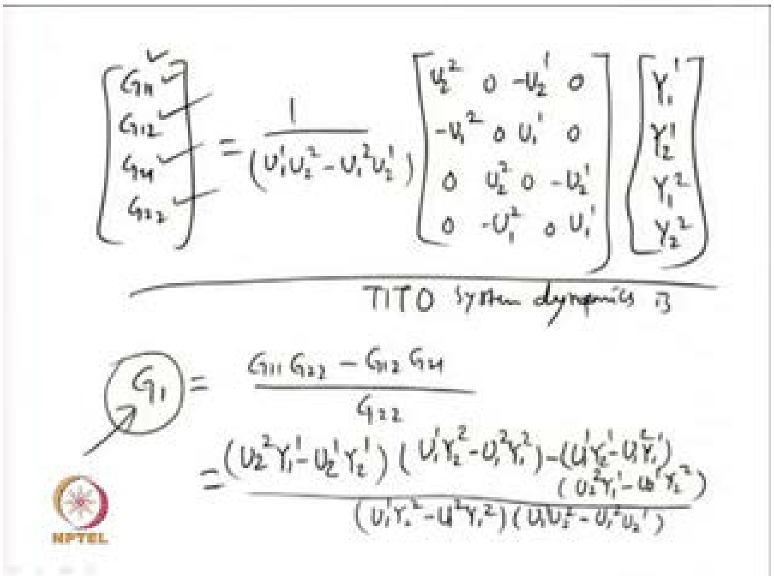

How do you get, after obtaining the substitution of this one here, how much you will get basically G 1 will result in U 2 2 Y 1 1 minus U 2 1 Y 2 1 times U 1 1 Y 2 2 minus U 1 2 Y 1 2 minus of U 1 1 Y 2 1 minus U 1 2 Y 1 1 times U 2 2 Y 1 1 minus U 2 1 Y 2 2. What is, when I substitute this G's values G 1 1, G 1 2, G 2 1, G 2 2 in this expression, I get in this form divided by U 1 1 Y 2 2 minus U 1 2 Y 1 2 times U 1 1 Y 2 U 2 2 minus U 1 2 U 2 1. Now, when you take the… How we find the steady state gains, now when I take the average value of this one, when I take the average value average value of this one, then I get the K.

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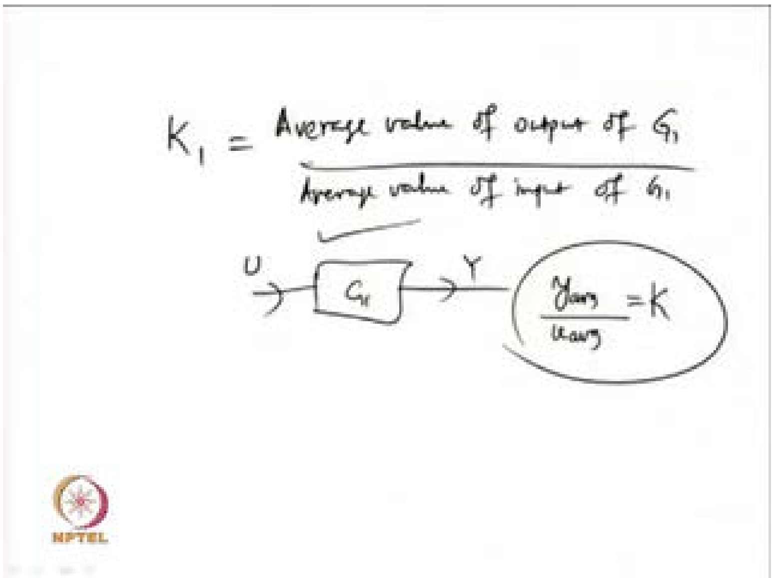

What is that K 1? K 1 is now average value of average value of output of G 1 upon average value of input of G 1. So, basically what has happened, I have got a G 1 dynamics suppose, and the outputs, inputs is now U, and output is Y. So, when I take the average; that means, y a v g upon U sorry, this will be the small letter now, because I am measuring the signal, and finding the signals average value then U a v g will give you the steady state value or d c value. Which gives you, the steady state gain K. This is how, the steady state or static gains associated with the transfer function models are estimated.

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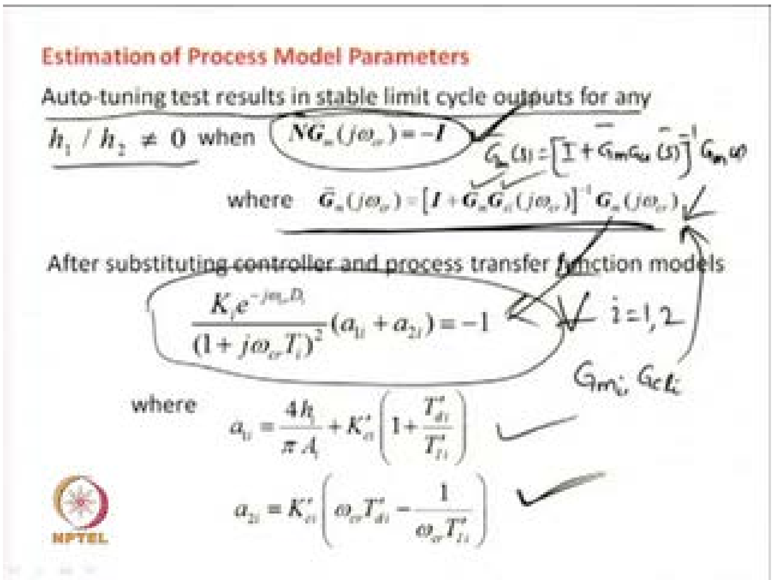

Next, we will go to the estimation of the remaining parameters of the TITO transfer function matrix models. So, the auto-tuning test results in stable limit cycle outputs for any h 1 divided by h 2 is not equal to 0. That means h 1, h 2 are not equal to 0. Then from the loop equation, that loop dynamics gives out the characteristic equation of the form identity matrix I plus N G n bar(S) is equal to 0. And that in frequency domain can ultimately be expressed in the form of N times G m bar j omega c r is equal to minus I, where omega c r is the loop frequencies. So, omega c r we assume the omega c r to be the loop frequency of both loops.

So, loop one, and loop 2 are assumed to have same signal assumed to have signal with same frequency - critical frequency. That is given by omega c r. Now, G m bar j omega c r is further, when you look at the block diagram from there, you can you can easily find out, what is G m bar j omega c r. This in transfer function form will be G m bar(S) is equal to i plus G m G c l(s) inverse G m(S). So which in, frequency domain is given in this form. So, this is how we get from the loop equation or the characteristic equation of the loop this analytical expression.

Now substitution of G m, and G c l in the expression results in this expression. So, simply substitute for G m 1, G m 2, G c l 1, G c l 2, and get that in the general form of K i times e to the power minus j omega c r d i upon 1 plus j omega c r T i square times a i a 1 i plus a 2 i is equal to minus 1, for all i equal to 1 to 2. So, we will get two analytical expressions basically, but in general form I put the this expression upon substitution of various G's G's, G m and G c l, either I get an expression of this form. Where 1 a 1 i is equal to 4 h i upon phi A i plus K c i dash times 1 plus T d i dash upon T i i dash. And A 2 i is equal to K c i dash times omega c r T d i dash minus 1 upon omega c r T i i dash. These are not difficult to get these expressions, it is very easy simply substitute the expressions for G m and G c l or G m i and G c l i in this expression - general expression which will result in another general expression of this form.

Where the constants A - A's are given by these. So, after obtaining this what you do, since we have got an equation in complex variables. So, that way often simplification means equating the magnitudes of both sides of that equation. So, when you equate the magnitudes of both sides; take the magnitudes of both sides. So, what you will get basically, when you take the magnitudes of both sides of this expression.

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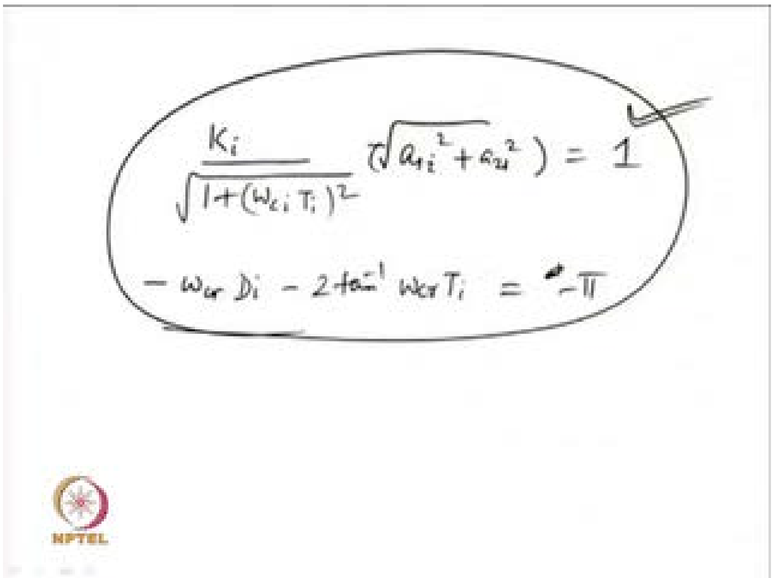

So, I will get expression in the form of K i upon 1 plus omega c i T i square root is equal to or again we have got complex number say a 1 i square plus a 2 i square root is equal to 1. So, this is what you get from the magnitude, and from the phase angles you get minus omega c r D i minus 2 times tan inverse of omega c r T i is equal to, then again given by angles minus plus tan inverse of no these are constants. So, no need of tan inverse. So, angle wise they do not contribute is equal to minus phi. So, using these two expressions what I will get, when those are solved again, when the first two are solved.

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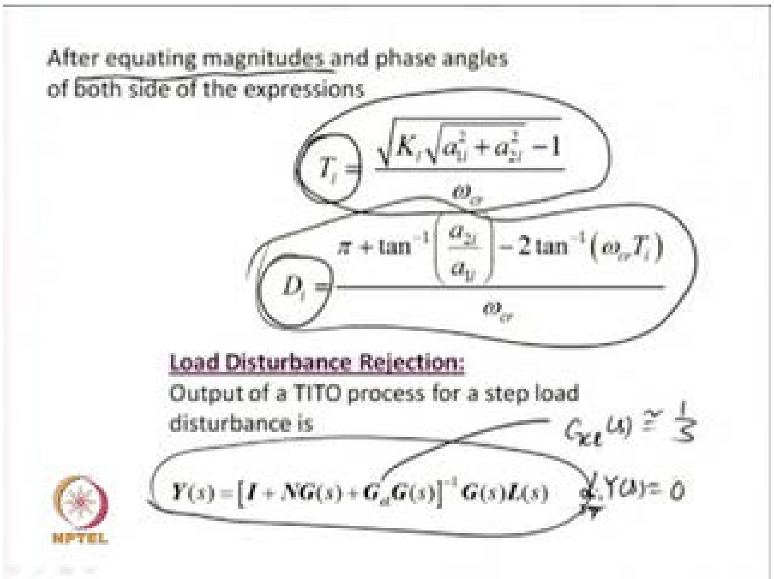

Then obviously, one gets T i is equal to root of K i times root of a 1 i square plus a 2 i square minus 1 upon omega c r, and D i is equal to phi plus tan inverse a 2 i upon a 1 i minus 2, 10 inverse omega c r T i upon omega c r. So, this is how you get the expression final or explicit expressions for unknowns associated with the transfer function models. Now, load disturbance rejection already I have described. So, this is repeated in the matrix form as Y(s) is equal to I plus N G(s) plus G c l G(s) inverse G s L(s), and G when G c L(s), G c L(S) has got some integrator then this in final limit s tends to 0, Y(s) becomes 0. So, the contribution or the effects of load disturbances are nullified.

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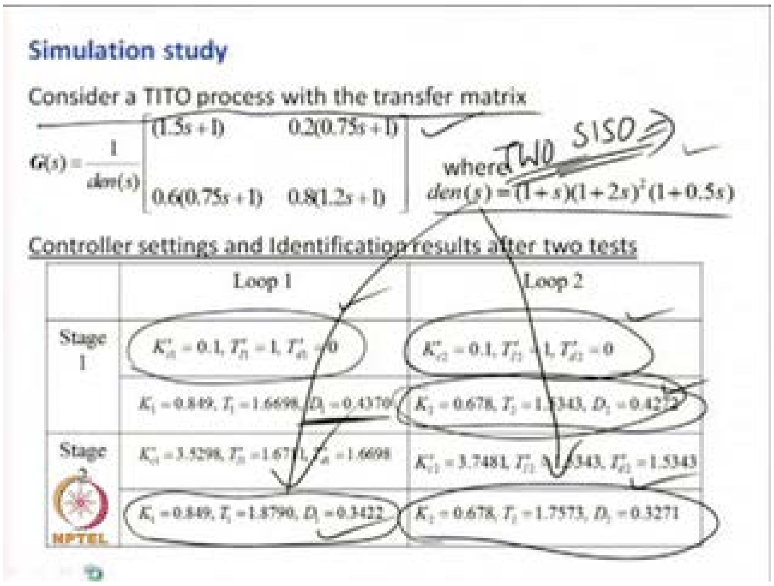

Let us go to a stimulation study, consider a TITO process with transfer matrix of this form, where the denominator d e n(s) is given by 1 plus s times 1 plus 2 s square times 1 plus 0.5 s. For this what initially the PID controller values are chosen as K c 1 dash is equal to 0.1, T i 1 – T i 1 dash is equal to 1 T D 1 dash is equal to 0. And for loop 2 the PID controllers have the values K c 2 dash is equal to 0.1, T i 2 dash is equal to 1 and T D 2 dash is equal to 0, with these two controllers settings relay experiment is conducted. And the dynamic model parameters are found to be K 1 is equal to 0.849, T 1 is equal to 1.6698, and D 1 is equal to this much.

Similarly, for the second loop - the second SISO process model parameters are obtained as this. Now, another stage of relay experiment is conducted with these settings of the PID controllers, with the then you get the final parameters for the 2 SISO transfer function models, as K 1 is equal to 0.849, T 1 is equal to 1.879, D 1 is equal to 0.3422, and K 2 equal to 0.678, T 2 equal to 1.7573, and D 2 equal to 0.3271. Thus we obtained 2 SISO transfer function models with these parameters, after two relay experimentations or two relay tests. And these are the final values, and found to be representing the dynamics of the TITO process.

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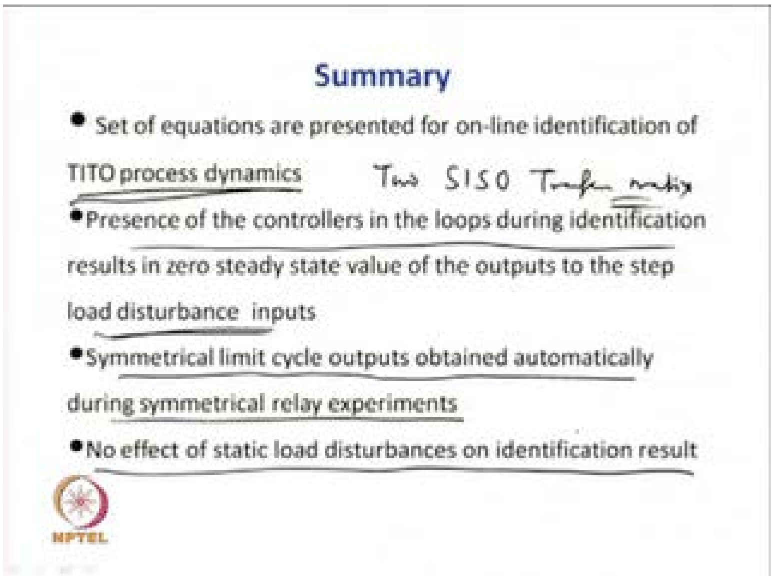

So, what we have studied here, set of analytical expressions are presented discussed for on-line identification of the TITO process dynamics. So, two SISO transfer function models, transfer matrix are obtained. Now, presence of the controllers in the loops ensures that the starting load disturbances, do not affect the system system outputs or sustained limit cycle or sustained oscillatory outputs. Now, symmetrical limits cycle outputs are obtained automatically; during the symmetrical relay experiments, because of the presence of the controllers during the relay experiments. Now, no effect of static load disturbances on identification result, and the analytical expression has been given, and proven.

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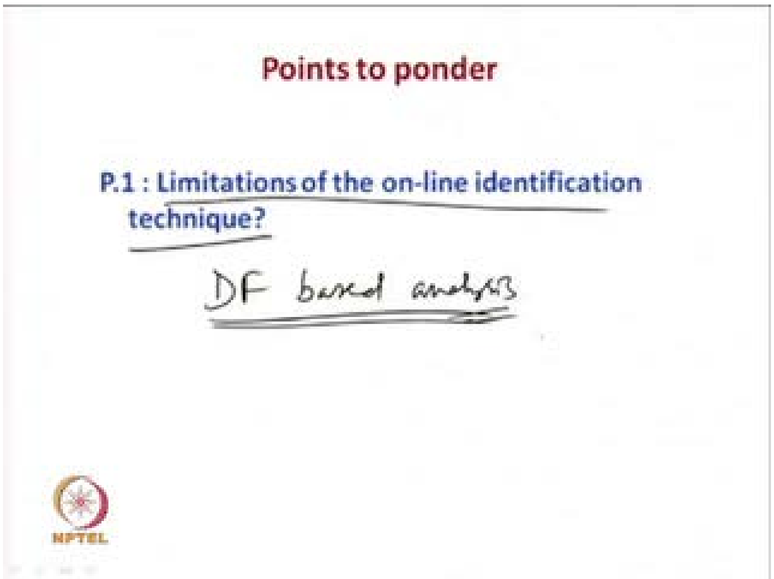

Now, what are the limitations of the on-line identification technique - one major limitation associated with this technique is that, we are using the describing function based analysis. Now, the describing function does not yield more number of inequalities, as far as analysis based on describing function is concerned. Therefore, one has to assume the transfer function models. The SISO transfer function models having less number of unknowns that is all, thank you.