Oil Hydraulics and Pneumatics
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Modeling and Simulation in Hydraulic Components
Lecture - 96
Part 3: Steady-state FE analysis, Torque balance, Feedback loop using user subroutines, Dynamic analysis and results

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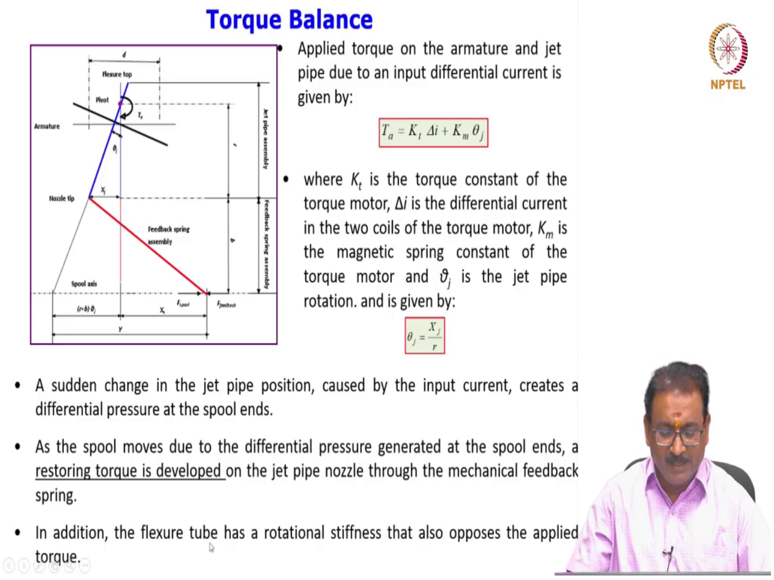

My name is Somashekhar, course faculty for this course. Quickly we will see the torque balance how to achieve using the simple model. Here as I have shown you; this is a jet pipe assembly and this is the feedback spring assembly jet pipe, this is a jet pipe and this is an armature jet pipe is pivoted at the pivot point, correct friends? From the here to jet pipe nozzle is r, from the top of these two feedback spring end is a b, correct friends? Very simple, I have shown you all here.

Now, let us we will see, the applied torque on the armature and jet pipe due to input differential current is given by T a equal to K t into delta i plus K m into theta j where K t is the torque motor constant of the torque motor, delta i is the differential current in the two coils of the torque motor, K m is the magnetic spring constant of the torque motor and theta j is the jet pipe rotation and is given by theta j is X j divided by r correct; based on this triangle.

A sudden change in the jet pipe position caused by the input current, creates a differential pressure at the spool ends. As the spool moves due to the differential pressure generated at the spool ends, a restoring torque is developed on the jet pipe nozzle through the mechanical spring. In addition the flexure tube has a rotational stiffness that also opposes the applied torque.

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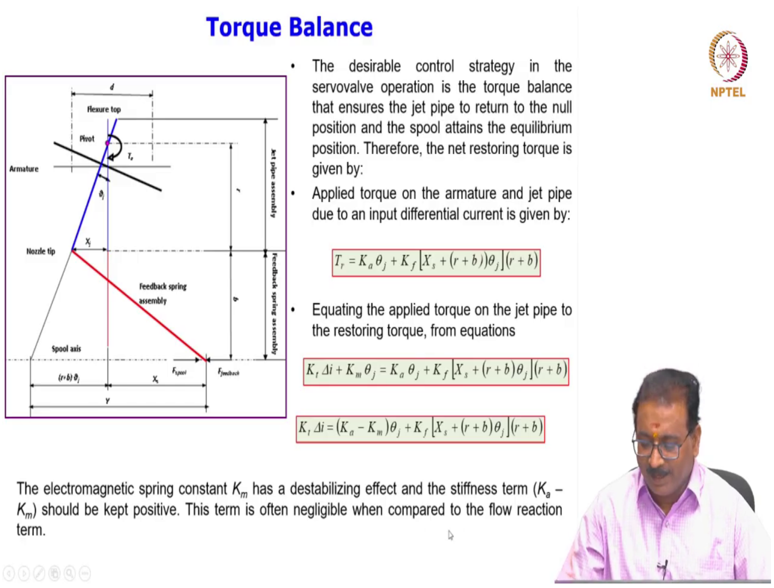

The desired control strategy in the servovalve operation is the torque balance that ensures the jet pipe to return to the null position and the spool attains the equilibrium position. Therefore, the net restoring torque is given by applied torque on the armature at the jet pipe due to the input differential current is given by T equal to K into theta j plus K f into X s plus r plus b theta j into r plus b.

Here r plus b, you will see this is a thing what we considered here, what I considered here is total is a X s plus r plus b into theta j multiplied by torque how it is r plus b, correct here. Now, equating the applied torque on the jet pipe to the restoring torque from the equation, I am equating the previous equation and this equation.

Finally, I will get it these things. The electromagnetic spring constant K m has a destabilizing effect and the spring stiffness K a minus K m should be kept positive. This term is often negligible when compared to a flow reaction term.

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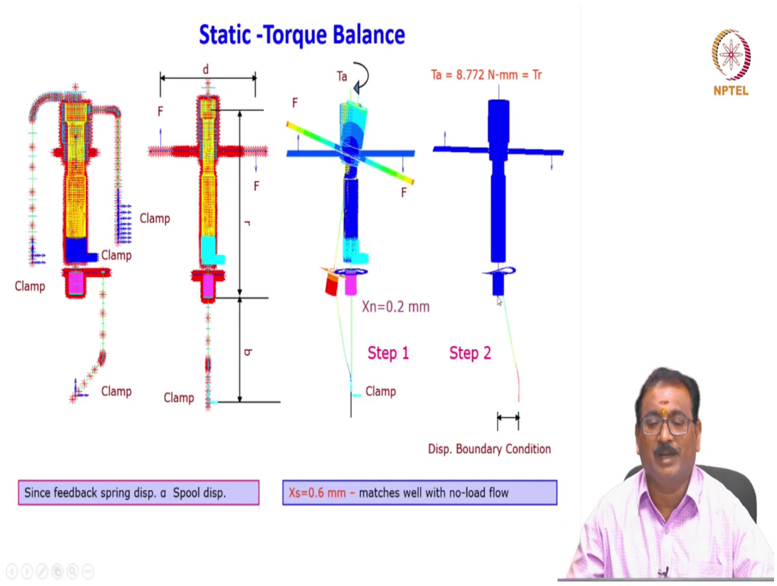

Now, quickly I will show you how to achieve this torque balance apply torque and restoring torque using finite element model. Just see here friends same thing what I have considered schematic diagram previous, same way it is. You will see here, this is a torque motor, this is a feedback spring. I have done the two ways here two steps to show the study state analysis.

In the first step look here, i am holding the down feedback spring, I am not allowed to move, then I applied the torque. Look here one force upper, one force downward to deflect the jet pipe to 0.2 mm. Then what I did here? I released this and goes on pulling the feedback spring end such that this jet pipe will come back to the null position.

See now here what is the torque balance applied torque is balanced by the restoring torque. This movement point 6 mm of the spool motion matches well with the no load flow analysis. This is a beauty of feedback spring and the rotational stiffness of the torque motor.

How it is balanced? You will see here. Applied torque is balanced by the restoring torque coming from the new position of the spool to bring back jet pipe to the null positions.

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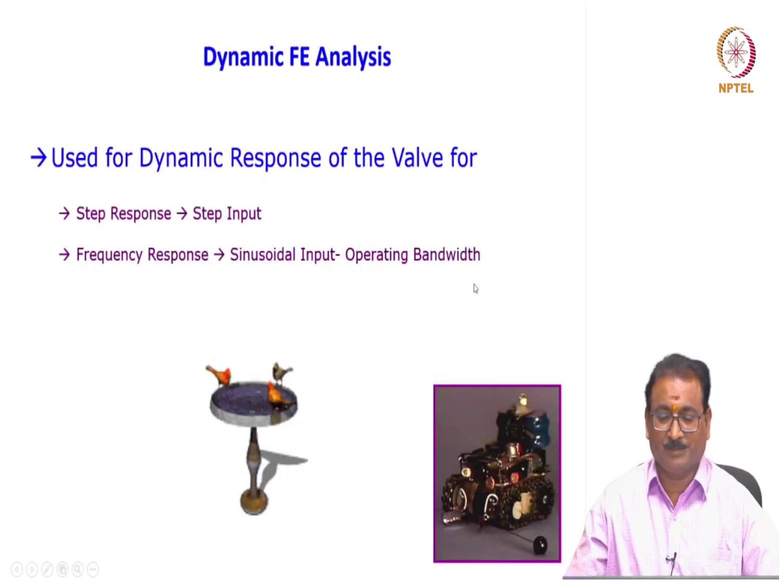

Now, very quickly I will show you the dynamic FE analysis. Here very important thing we studied both step response by giving the step loads; 25percent, 50 percent you know 75 percent, 100 percent load on the armature to study all the jet pipe positions, in a spool position all. Then frequency response also we studied.

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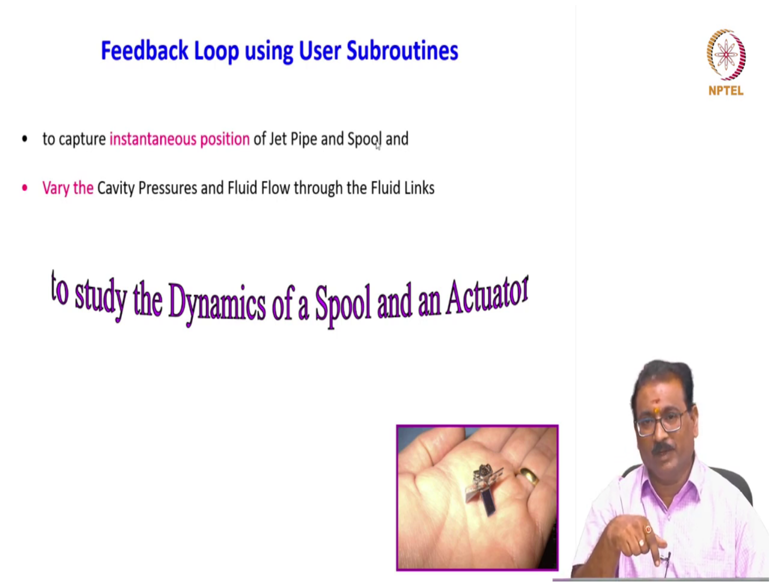

Now very very important thing here is a feedback loop using the user subroutines, we implemented here to capture the instantaneous position of the jet pipe and the spool. Instantaneous position every moment of time when the jet pipe will deflect slowly.

How the pressure and flow varies you have to capture it which is we are getting from the your theoretical model, Similarly when the spool will move for every instant of time how the pressure and flow is going to the actuator we have to feed in the model correct.

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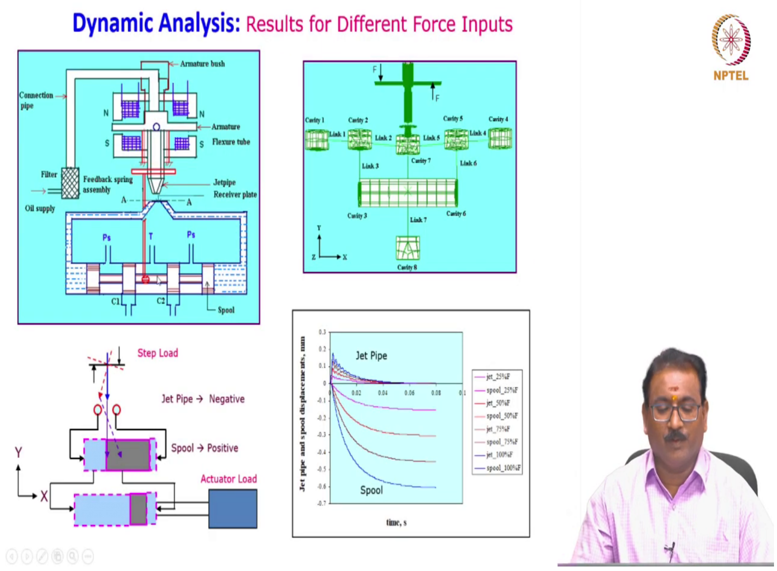

Now I will show you. Here it is a one to one model, it is friends. All the parts whatever I have shown, here you will see in the finite element model.

Now, if the jet pipe will deflect assumed to be in the left side direction, you will see how it is going for the different force input on the armature.25 percent, 50 percent correct; all correct both jet pipe as well as spool position. See here friends for any given input jet pipe will deflect to the maximum.

Then it will come back to the steady state because of the new spool positions, apply torque, deflect the jet pipe due to the spool moment, it come back. For any torque input, always there is a torque balance. This is one of the important condition to be achieved in the servovalve.

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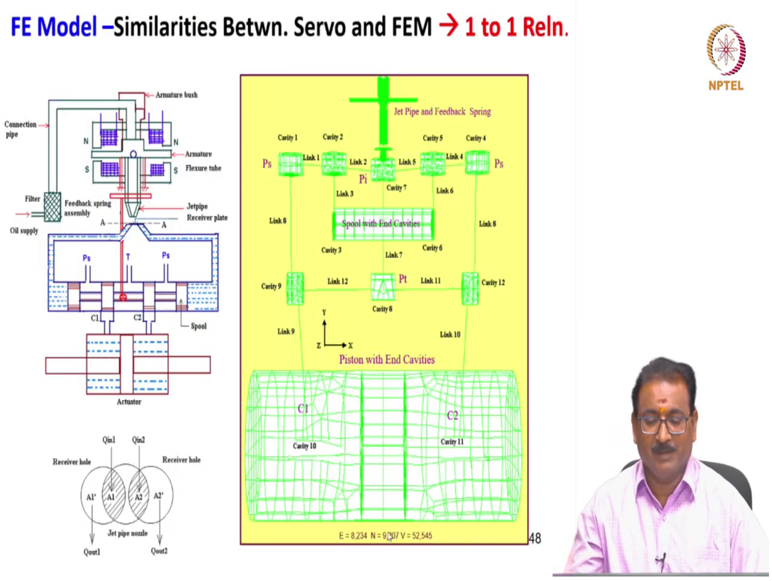

Then similarly we will see, again actuator I added here. Here you know jet, pipe torque motor assembly all valve assembly and then here what it is actuator. Now we will see all the fluid cavities are added here friends 1 to 1 fluid cavities are added and then we are simulated these things

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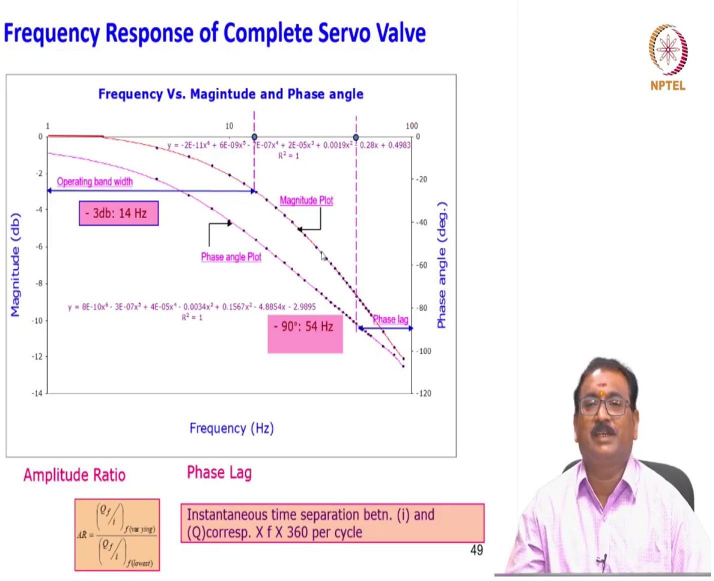

Then later we subjected this for the frequency response by giving a input to the sinusoidal input on the armature, then we have drawn the bode plot.

As we know bode plot for minus 3 db line, it will show you the operating band width correct; the frequency versus magnitude and a phase angle here ah. Minus 3 db, you will see the 14 hertz is a operating bandwidth for the valve considered and also phase lag, you will see.

Phase lag how we are doing now minus 90 degree line, you will draw, you will get the minus 90 degree 54 hertz is the phase lag. How to calculate all these things? They are written here.

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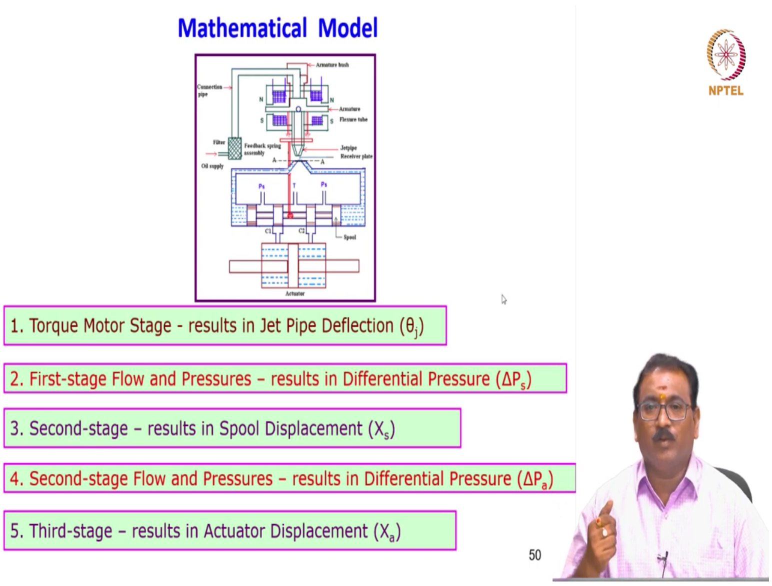

Quickly I will show you the after knowing the finite element modeling is also one of the method to predict the performance parameter. Now to validate the finite element, as I have told you it is the numerical method. The mathematical model is developed for the first stage, second stage and the third stage.

In the first stage, torque motor stage is resulting in the jet pipe. The first stage pressure and flow resulting in the what is that differential pressure across the spool valve, second stage results in spool displacement access which results in the second stage pressure and flow resulting in differential pressure across the piston and cylinder.

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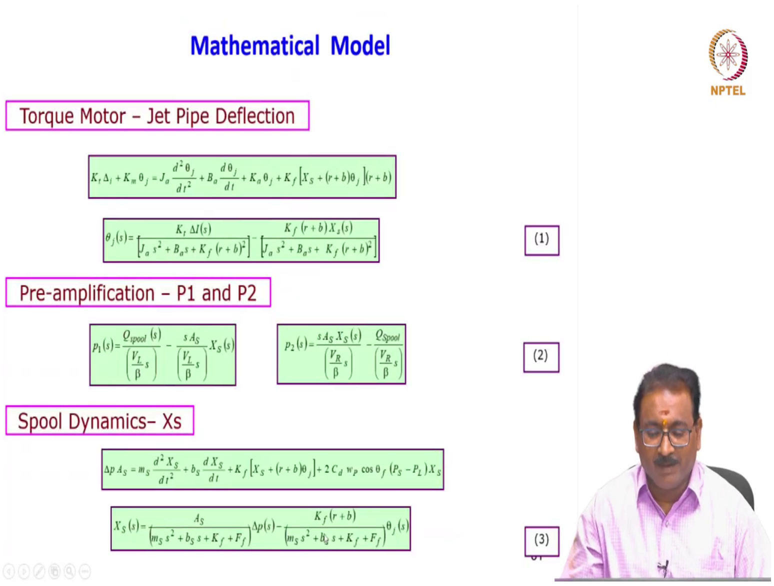

Third stage is resulting in actuator displacement. Keeping in that keeping in mind simple mathematical analysis is formulated here. I will not touch much here because of the time limitation. The torque motor is jet pipe deflection; torque balance equation, it is very simple. Applied torque, it is a restoring torque you know j theta dot plus b theta dot plus K theta.

This is the feedback spring stiffness, then you will calculate the theta. Then pre amplification p 1 and p 2 you will calculate considering the left cavity dimension, right cavity dimension, bulk modulus all. Then spool dynamics f equal to m into a forced balance included the flow forces also.

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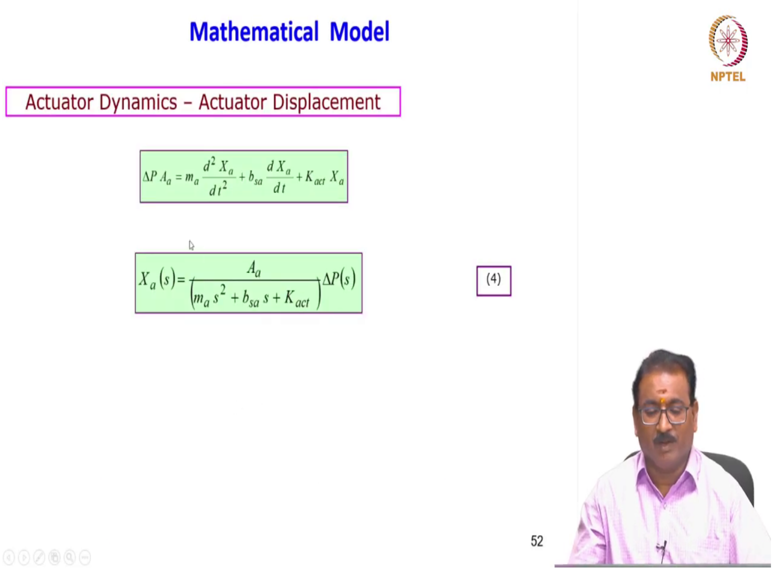

Once you know all these things friends, what you will do?

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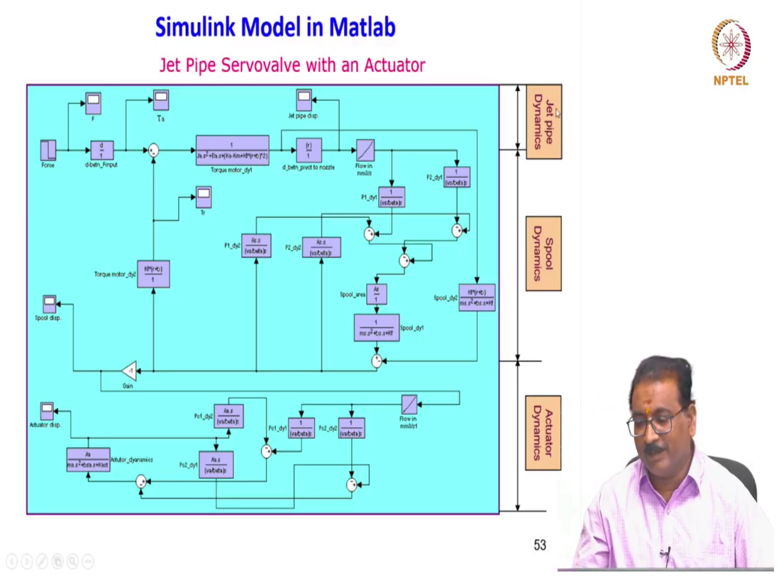

Actuator dynamics same, then after doing the mathematical modelling of the servovalve, converted all these things into the you are seen previously s domain. Once I will convert into the s domain, I am inputting in the MATLAB simulink. You will see MATLAB simulink is a user friendly blocks are there.

You will only pick and place it and double click and add all the equations whatever I have modeled in the previous one which includes the jet pipe dynamics is possible to model, spool dynamics is possible to model, actuator dynamics is also possible to model.

At any instant of time, you will calculate what is the force you are applying, torque how much it is generating, jet pipe displacement, correct spool displacement, actuator displacement; very easy friend here. Also the pressure and flow variation with respect to the jet pipe will add it here using the tabular form or a equation form. Similarly here the spool positions all are modelled here.

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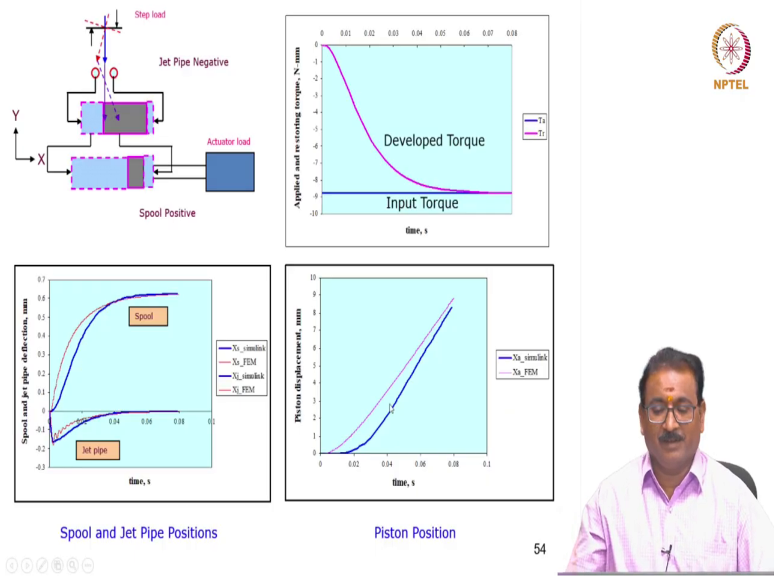

You will see the simulation as well as the finite element result how close relations are there you will see here. Here you know this is a jet pipe deflections, it will come back to the null position due to the new spool position. It will show you the simulink model and a fem models similarly for the piston.

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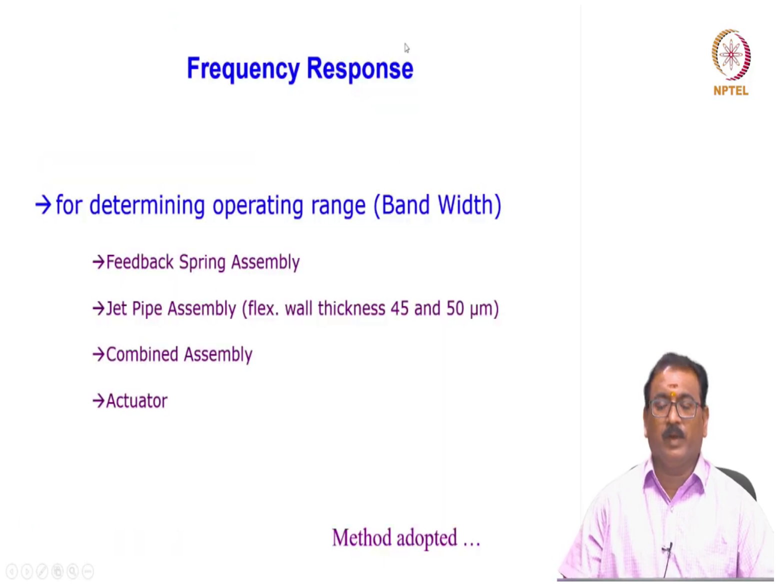

Now, quickly we will see the frequency response of the critical components and their bandwidth. Here I am considered feedback spring assembly, jet pipe assembly for the different flexural tube thickness, then combined assembly of these two and actuator.

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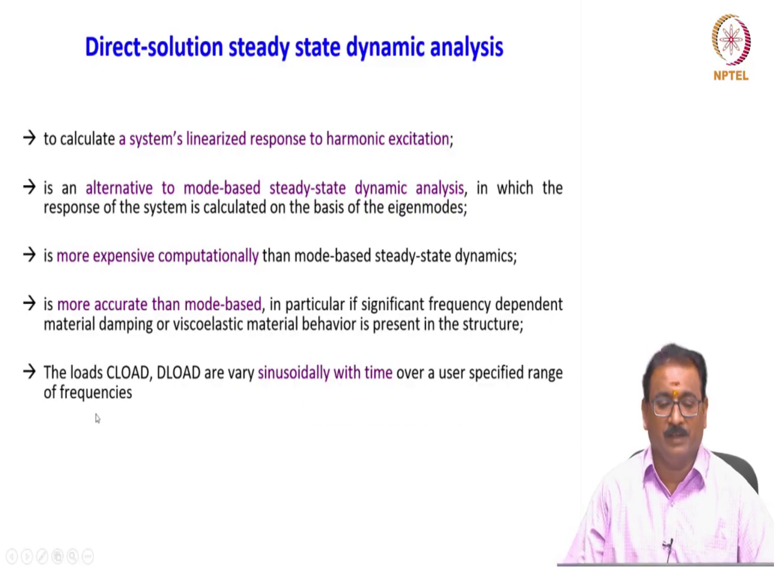

Direct solution steady state dynamic analysis: To calculate the systems linearized response to harmonic excitation which is an alternative to mode based steady state dynamic analysis in which the response of the system is calculated on the basis of Eigenmodes is a more expensive computationally than mode based steady state dynamics; is more accurate than mode based.

In particular if significant frequency dependent material damping or a viscoelastic material behavior is present in the structure. The load CLOAD or a DLOAD distributed load, CLOAD means concentrated load are vary sinusoidally with a time over a user specified range of frequencies that is a beauty here.

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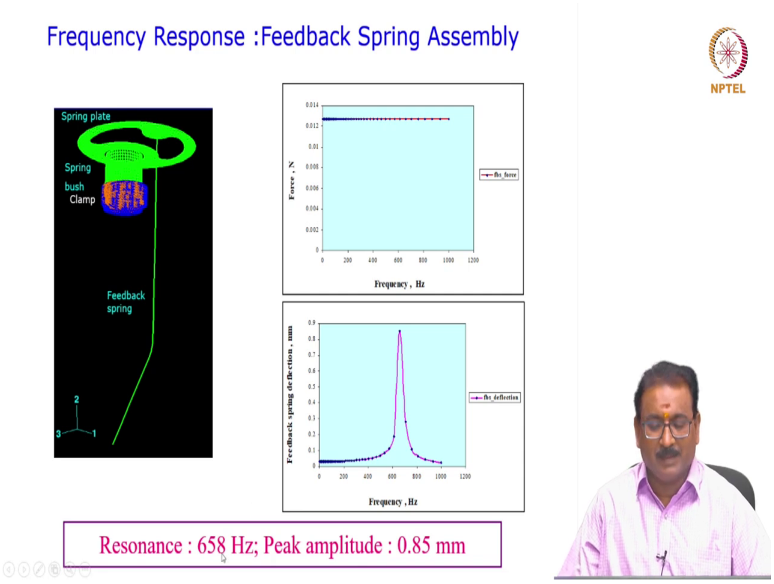

I will show you the feedback spring here same spring now. I sweeped the feedback spring load with proper boundary condition 0 to 1200 hertz, that time we will see the natural frequency of the feedback spring which is 658 hertz peak amplitude, I am getting 0.85.

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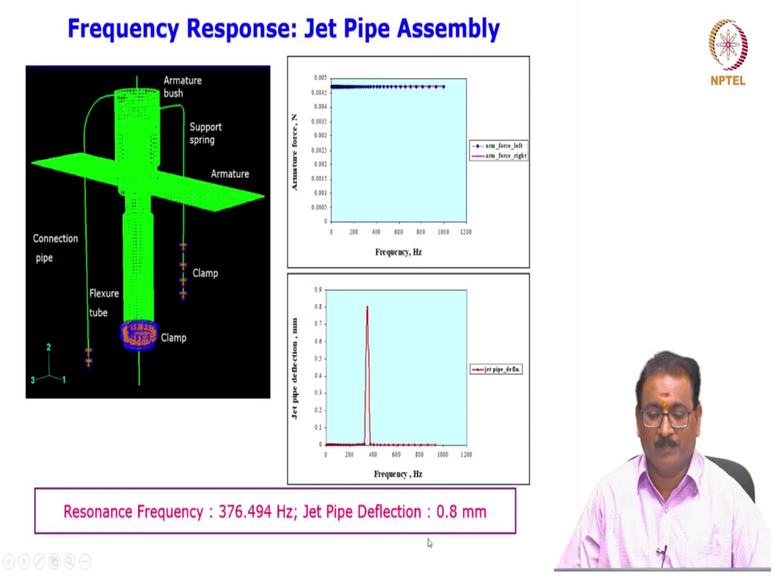

Similarly, the jet pipe assembly same thing I sweeped from 0 to 1200, now I am getting resonance frequency 376.494 hertz jet pipe deflection is 0.8.

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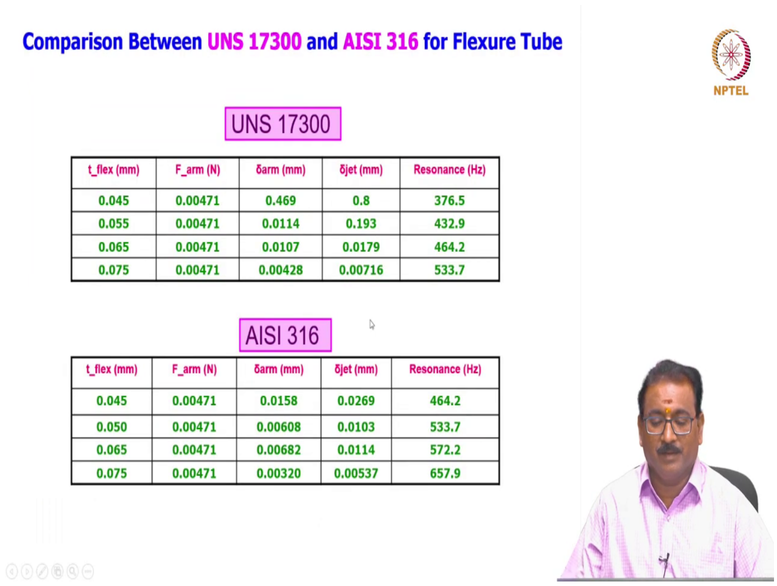

UNS 17300

t_flex (mm)	F_arm (N)	δarm (mm)	δjet (mm)	Resonance (Hz)
0.045	0.00471	0.469	0.8	376.5
0.055	0.00471	0.0114	0.193	432.9
0.065	0.00471	0.0107	0.0179	464.2
0.075	0.00471	0.00428	0.00716	533.7

AISI 316

t_flex (mm)	F_arm (N)	δarm (mm)	δjet (mm)	Resonance (Hz)
0.045	0.00471	0.0158	0.0269	464.2
0.050	0.00471	0.00608	0.0103	533.7
0.065	0.00471	0.00682	0.0114	572.2
0.075	0.00471	0.00320	0.00537	657.9

Different materials for the flexural tube UNS 17300 and AISI 316 for the flexural tube. These are the resonance frequencies and these are the deflections. Once your model is ready, you have to change any material property and any thickness of the tube, you will predict the responses; that is the beauty here.

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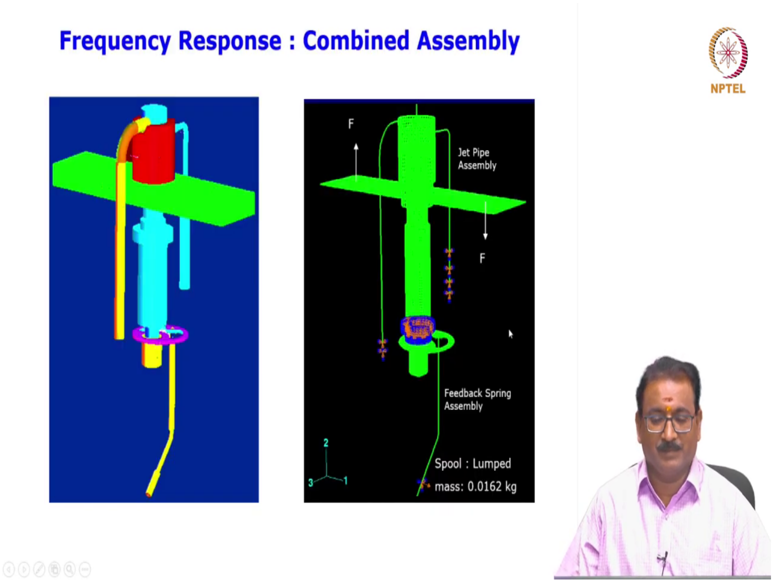

Similarly, combined assembly torque motor and the feedback spring assembly.

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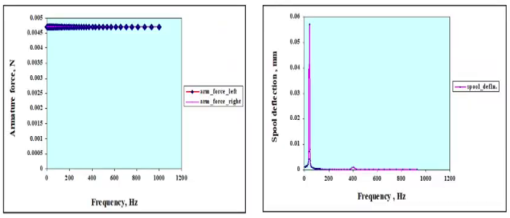
Armature Force and Spool displacement



t_flex (mm)	F_arm (N)	δjet (mm)	δspool (mm)	Resonance (Hz)
0.045	0.00471	0.0174	0.0571	46.4
0.055	0.00471	0.00369	0.0165	49.8
0.065	0.00471	0.00321	0.144	49.8
0.075	0.00471	0.00126	4.01	49.8

Now again further different flexural tube and what is a resonance frequency?

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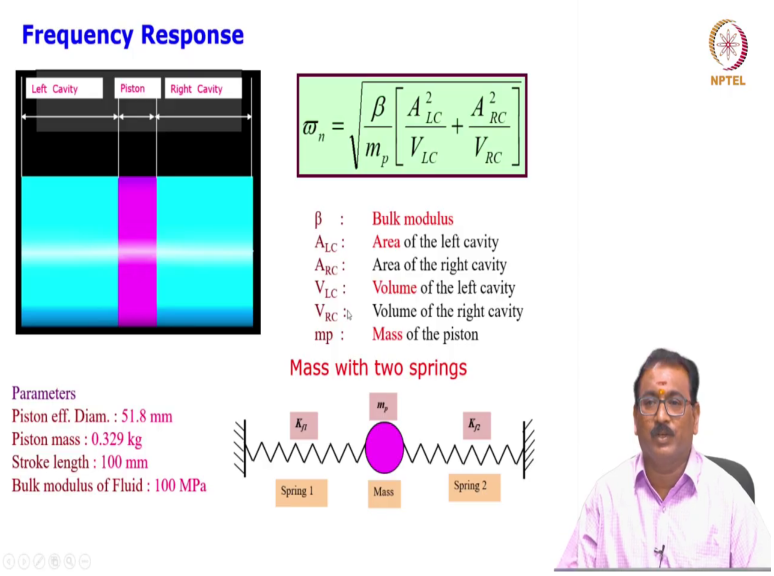

Now, to validate this also what we did is whether how much your fluid structure interaction model is correct. We took a very simple case which is already well established in the vibration book. This is the piston and cylinder, this is the piston is I am taken here, left side cavity, right side cavity correct friend. These are the particular dimensions I am taken from the model.

Now, already we know that natural frequency of the piston and cylinder is omega n equal to square root of beta by m p into bracket A LC square by V LC plus A RC square by V RC. What are these friends? A LC means area of the left cavity, volume of the left cavity, area of the right cavity, volume of the right cavity and bulk modulus and m p is mass of the piston.

This is equivalent to mass with the two spring on either side. This is a well established model in all the vibration book, then what we did is same way to validate our fluid structure interaction model, what we did? We conducted for the different bulk modulus simulation as well as the theoretical.

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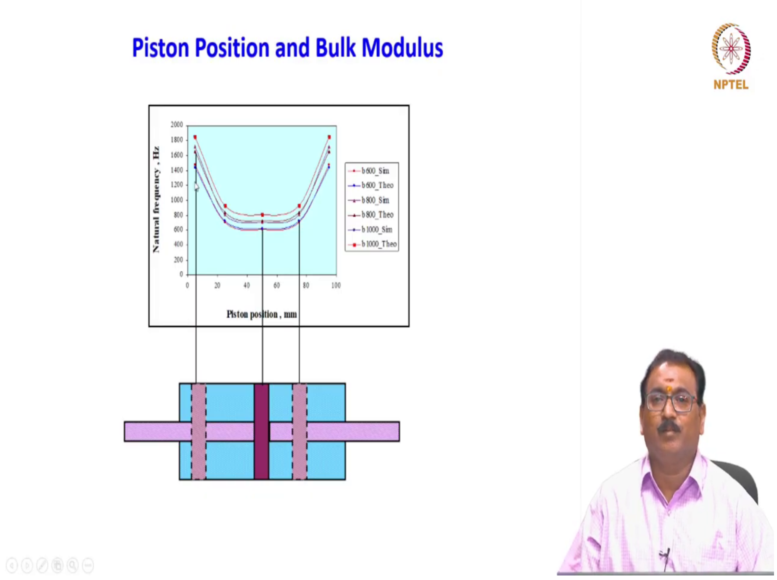

Now, we will see here friends the piston position and bulk modulus effect, I have drawn here; both we have carried out the theoretical as well as the finite element model. They will show the very close relationship between the obtained result this will show the your fluid structure interaction model is matching with the theoretical model.

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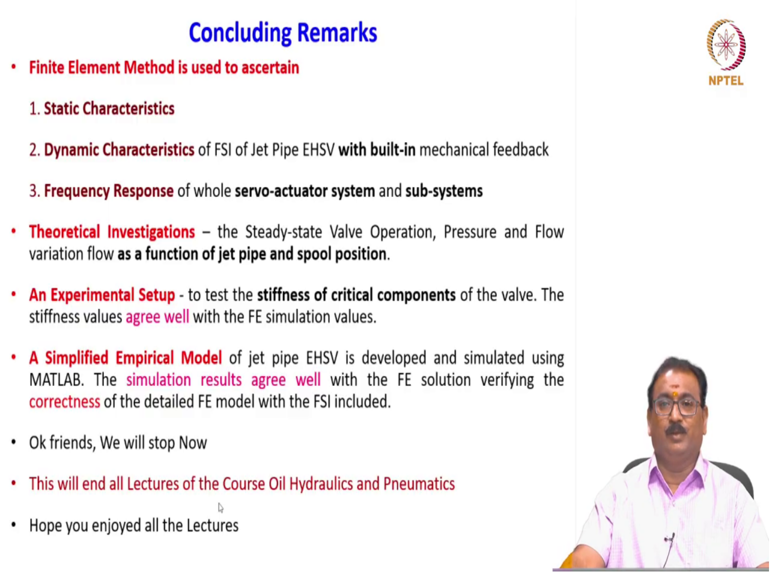

Yes friends, now we reached the last slide concluding remarks. Finite element method is used to ascertain the static characteristics, dynamic characteristics of fluid structure interaction of jet pipe servovalve with a built in mechanical. Feedback frequency response of whole servo actuator system and a subsystems.

Theoretical investigation to study the steady state valve operation, pressure and flow variation as a function of jet pipe and a spool position. An experimental setup to test the stiffness of the critical components of the valve, the stiffness values well agree with the FE simulation values.

A simplified empirical model of the jet pipe is developed and simulated in the MATLAB. The simulation results agree with the FE simulation verifying the correctness of the detailed FE model with FSI.

Ok friends, we will stop now. This will end all the lectures of Oil Hydraulics and Pneumatics, but this last lecture is only to give you the glitch of how system simulation modelling is used. Otherwise the many places people are using the bond graph modeling, MSM modelling many ways to predict.

This will show you the some of the glitch on how finite element analysis is used to predict the stress distribution, you know displacement correct you know fluid structure interaction how to establish. Only that is the motto of this lecture. Hope you enjoyed all the lectures.

Thank you one and all for your kind attention [FL]. Best of luck for your end semester examination.