Wind Energy

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Lecture 46: Mechanics: Linearized analysis

Welcome back. So, looking at this flap-wise forces and moments and ease-wise forces and moment, so, continuing from the last session discussion that we had, started in the last session we are trying to look at this now the so, for this we as I said that age wise forces and moments this kind of the age wise moments gives rise to the power producing torque. So, these are usually fairly less significant than clockwise motion. But due to blade's silk weight, it can be quite significant in larger turbines. So, for larger turbines, due to silk weight, it can be quite significant. So, let's say the mean torque which is Q can be estimated as R divided by omega which is rotational speed.

For an ideal rotor, what we can have Q is P by omega, which is one by omega, 16 by 27, half of rho pi R square U cube, which is eight by 27 rho pi r square u cube by omega. So, what we can do in the more general case torque can then be expressed in terms of a torque coefficient which is let's say CQ is CP by lambda essentially is the power coefficient divided by the tip speed ratio and, so, then what we can write, so using this, what we can write Q is CQ of rho pi R squared U squared. So, what happens is that for an ideal rotor, omega varies with wind speed. So, q square of the wind speed.

For an ideal rotor, $Q = P/\Omega = \frac{1}{\Omega} \cdot \frac{16}{27} \cdot \frac{1}{2} \rho \pi R^2 U^3 = \frac{8}{27} \rho \pi R^2 \frac{U^3}{\Omega}$

In the more general case, torque can then be expressed in terms of a torque coefficient. ($C_Q = C_P/\lambda$) $\Rightarrow$ $Q = C_Q \cdot \frac{1}{2} \rho \pi R^2 U^2$

For an ideal rotor, $\Omega \propto U$, $Q \propto U^2$, ...

Now if you have routers designed for high speed ratios, let's say the rotors design for higher speed ratio operation have lower torque coefficients, lower torque And they experience lower torques. So, when you talk about lower torque, when you talk about lower torque, it is not necessarily lower stresses. Lower stresses. OK. So, again here, According to this simple model, there is no variation in torque with azimuth.

So, that's how it. Now, you can also this edgewise or, as we say, lead lag moment. So, the bending moment in the edgewise direction which is designated by xi at the rotor of single blade is Mxi can be Q by B. So, there is no simple correlation for SOS shear force. so, is wise shear force is Sxi so the tangential force so this is how this this can be found out for this as well as this thing.

Edgewise (Lead-Lag) moment

bending moment in the edgewise direction (designated by ξ) at the rotor of single blade is $M_\xi = Q/B$

Edgewise shear force $(S_\xi) = \int_0^R dF_T$

Now, we'll look at the linearized. So, now we'll look at linearized int Hinge-spring blade rotor model. This is kind of an, I mean, kind of an, which, I mean, one can, just like an, the elastic behavior of these rotor blades. So, which in a similar fashion one could expect that people do in the helicopter rotor dynamics. So, here it's a rotor system.

the wind turbines this can get quite complicated during operation because your loads are variable structure itself may move in ways that affect the loads so now to analyze all such interacting effects which one needs to have a very detailed mathematical model. Or, you can go for typical CFD calculations where you have detailed analysis technique or approach to find out those things. but here what we are trying to do is that we can use this simplified model for the rotor and examine its response to this simplified load so, that this is more like an initial design procedure one can use this kind of linearized system and estimate those forces, moments, states and all these things so, that the first part design can be obtained. So, the one that we'll talk about here, which is primarily methods by product in 1987 they have talked about this so this model provides good or depth in depth insight not only into the turbine response to steady loads but also to cyclic loads so, this simplified model is known as the linearized hand spring blade rotor model or sometimes also it's called also it's called inch ring model. So, both are same.

So, the essence of this model is to incorporate enough details to be useful, but it is sufficiently simplified that analytical solutions are possible. So, it's a Simplified model, but incorporating the interacting effects. OK? So, by Examining the solutions, it is possible to have some of the most significant causes and effects of wind turbine motion. So, this hinge pin model, it has four parts. Number one, that is a model of each blade as a rigid body attached to a rigid hub by means, of, hint, and, strings.

To, a, linearized, steady state, uniform flow aerodynamic model three consideration of non-uniform flow as perturbations. And fourth component is sometimes an assumed sinosoidal form for the solutions. So, this has this four components for this linearized model. So, when we start with that, so the thing that we start with types of blade motion. So, this hinge spring model allows for three directions of blade motion and incorporate hinges and springs for all of them.

The three directions of motion which are allowed by this hinges are three directions of motion, which are allowed by this one flapwise, two edgewise or lead lag, and three torsion. and the spring return the blade to its normal position on the hub. The spring returns the blade on its normal position on the hub. So, that's what it is called hinge spring motion. So, what happens is that the hinges allow the three directions of motions, flapwise, edgewise, that is lead lag, and torsion.

And, the spring brings the blade to its normal position on hub. So, that's what it's called the hinge and spring model or the simplified system. And as we have already talked about it, the flapwise refers to the motion. The flapping is motion parallel to the axis of rotation. This is the rotation.

So, Now the rotor which is aligned with the wind flapping would be in a direction of the wind or opposite to it. So, it could be like this. So, one can find out the thrust forces along the direction. Flapping directions and then the stresses on the blades due to flapper is bending. Lead lag motion lies in the plane of rotation.

So, which kind of refers to the motion relative to the blades rotational motion. In leading motion, the blade will be moving faster than the overall rotational speed. And in lagging motion, it will be moving slower. For lead lag, in leading motion, in the leading motion the blade will be moving faster than the overall rotation speed. and in lagging motion, it will be slower.

This lead lag motions and force is it fluctuations in the main shaft and with fluctuations from the generator. So, this is what is there for this. Now, comes to the torsional motion. torsional motion refers motion about the pitch axis for a fixed pitch wind turbine for a fixed pitch turbine torsional motion is generally not of great significance but in a variable pitch and was fluctuating loads in the pitch control mechanism. So, what we would be primarily focusing on the flapping motion and the lead lag and torsional motion we can use the standard available from the literature.

So, that's what we are going to use in analyzing this. So, that means this simplified

Hinge-spring model that we are talking about that will have, I mean, kind of that known as this linearized spin model so it is simplified model but essentially incorporating the interacting effects between the forces and the moments and obviously, it has four basic components or parts essentially assume a rigid blade and also connect to the rigid hub linearized steady-state uniform flow aerodynamic model non-uniform flow as i mean if you have non-uniform flow that considers the perturbation so that how that affects and obviously some sinusoidal motion for solutions and things like that. And the blade motions, when you talk about in this hinge spring models, the hinge spring models allows three directions of the motions. Lapwise, edgewise or, lead lamp and the torsional. And, The spring brings back the position on the hub.

Obviously, flapwise motion happens like this. Lead-lax motions are kind of going from the rotational axis. Obviously, there would be leading motion. There would be lagging motion. That is why we call it a lead-lax motion.

So, in leading motion, the blades are moving faster. Lagging motion, these are slower. That is why you get this lead lag. And obviously, this will have impact on the fork and then associated shaft and the generator. Then torsional motions are there about the pitch axis.

Then you can have fixed pitch wind turbine, variable pitch wind turbine. So, if you have a fixed pitch, then the torsional motion is not that important. But, if you have variable pitch, then this torsional motion can have some fluctuating loads in the pitch control mechanism. So, these are all that since the torsional and the lead legs are kind of obtained from the literature and all this primary focus should be on the analysis of the flapwise motions and all this so that is what we are going to focus to derive this linear system okay we'll stop the discussion here and continue in the next session. Thank you