Wind Energy

Prof. Ashoke De

Department of Aerospace Engineering, IIT Kanpur

Lecture 45: Mechanics: Blade oscillations

Welcome back. So, we continue the discussion on this structural analysis or the basic structural analysis. Now, we would like to see how this we can correlate with the blade oscillations and the centrifugal stippling. So, what we would do kind of try to see is the looking at this blade oscillations. Okay. And, the centrifugal stiffening.

So, what we do is that. Is. The blade. Oscillation.

Blade oscillations. Mostly. Occur. In. Clapwise direction.

That is. Forward. And. Backward. So, if I have a.

Unit like. So, the blade can go like that. Blade can go like that. So, that's essentially the forward and backward operation. So, that's typically how the blade oscillation takes place.

However, however, rotation the blade and as higher frequencies and it would have without rotating. So, that means since the blade actually oscillates flapwise, this gets stiffened and since the blade gets sharpened, they can have higher Eigen frequencies than it would have without rotation. So, how that happens? Let's see. Let's see how that happens. We can take a situation of rotating hinged beam.

obviously, no elasticity so that's let's say we'll have and this is how the okay So this would be P, FC. This is the rigid beam and that hinge. So, what we can have moment of inertia i mu r, r squared here. We have voice oscillation angle phi. you have restoring moment m of phi so, what we have i phi double dot equals to m of p so that is how this now this restoring moment m of P.

Let's see

Rotating, hinged beam (No elasticity)

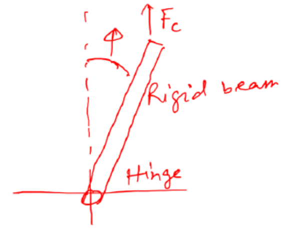
Moment of Inertia : $I = \int_0^R \mu(r) \cdot r^2 dr$

Flapwise oscillation angle = ϕ

Restoring moment : $M(\phi)$

$$\boxed{I\ddot{\phi} = M(\phi)}$$

Comes from centrifugal force



So, this comes from centrifugal force. So, which we can estimate as M of P zero to r mu mu r omega square r dot cos phi sine phi r dr so this is one this is phi that comes from the i mean essentially this one can write from small angle approximation from there we can write this kind of situation okay so, what we have then minus p omega square zero to r r squared here minus p omega square i so, now if we put this back in the this equation and then we have i if we double dot equals to minus omega square i in that omega t. So, it's again frequency equal frequency. So, that's what you can get. So, now One more thing that.

Well, you can see. Let's say a rotating beam. Rotating beam. It's.

That's not. OK. So if I. draw this is angle phi so this is torsional spring okay so here the being constant is K. Now, the natural frequency that you have, natural frequency or the natural resonance omega in R over K by I. M of phi is minus omega squared I phi minus K phi.

$$M(\varphi) = -\int_0^R \mu(r)\,\Omega^2 \cdot r \cdot \underbrace{\cos(\varphi)}_{\approx 1} \cdot \underbrace{\sin(\varphi)}_{\approx \varphi} \cdot r\,dr$$ (small angle approximation)

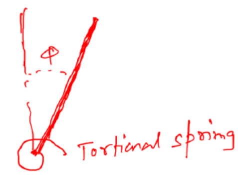
$$\approx -\varphi \cdot \Omega^2 \int_0^R \mu(r)\, r^2\, dr = -\varphi\, \Omega^2 I$$

$$I\ddot{\varphi} = -\Omega^2 I \varphi \Rightarrow \varphi(t) = A \sin(\Omega t)$$

Eigenfrequency equals ~~to~~ rotor frequency !!

Rotating beam with torsional spring

spring constant K



Natural frequency/resonance : $\omega_{NR} = \sqrt{K/I}$

$$M(\varphi) = -\Omega^2 I \varphi - K\varphi$$

$$I\ddot{\varphi} = -(\Omega^2 I + K)\varphi$$

$$\omega_R^2 = \omega_{NR}^2 + \Omega^2 \rightarrow \text{centrifugal stiffening}$$

I phi double dot is minus omega squared I K phi and then what we have omega r squared omega in r squared plus r squared so this term is centri. So, this is where the blade actually, when this oscillates forward and backward motion, so essentially the flapwise motion, this can actually stiffen. So, we have seen from a hinged beam analysis that if it is rotating which essentially a situation that happens in your rotor blade that when it rotates that creates that kind of situation but we said that, Since, the blades are basically oscillate like this, but at the same time, they are also rotating. So, one hand you have rotation along with that so flapping. So, this is kind of an like this and they can rotate.

So, that's make things quite complicated. Obviously, you can see that the design procedure of the rotor blades are quite involved and a multidisciplinary, or rather multi scale analysis one has to carry out to come up with proper design parameters and things like that. And now, since we have, so this kind of gives you why this so the stiffening happens, which is because of your centrifugal stiffening. These are giving a broad idea about these things which are kind of taken into account while talking about. So, what we would like to take this forward is now this analysis essentially we want to look at that wind turbine rotor dynamics analysis okay where we can look at some kind of an so so far we in fact we are talking about that only and we started with the kind of types of load if we recall that what we talked so we talked about types of loads which could be steady load that can include static and rotating which could be cyclic load you can have transient loading which essentially includes the impulsive loading stochastic loading resonance induced load so, these are the loads we talked about that goes in the rotor and obviously that kind of exposed to the so while talking about that those steady loads are the ones that do not vary over relatively longer period of time so they could be either of static or routing i mean for example a steady wind blowing on a stationary wind turbine that would induce static loads on various parts of the machine and at the same time a steady wind blowing on a rotating wind turbine rotor while it's generating power would induce steady loads on the blades and other parts of the machine then we had these cyclic loads which are vary in a rectangular or periodic fashion.

Obviously, here we are talking about loads because these are connected or arise due to your rotation of the rotor. So, cyclic loads arise as a result of such factors as the weight of the blades, width shear, yaw motion. Also, cyclic loads can be associated with the vibration of the turbine structure or some of its components. Okay. Then you can have transient loads, which are essentially going to be time-varying, which again arises in some temporary external event.

And there could be some oscillations which could be associated with the transient response. But obviously, it's not amplifying. Then it decays with time so that the system becomes stable and all these things. Obviously, sudden impulse, which could happen due to sudden change in speed or due to some mechanical component, those impulse load can also be transient for a short duration of time. Then, we have talked about stochastic loads, which are also time-varying, slightly transient, impulsive, because that primary load arises due to the turbulence in the wind because the turbulence is a stochastic field or stochastic in nature so, kind of give rise to that kind of stochastic loading then one can have resonance induced loads which are cyclic loads dynamic response of some part of the wind turbine which are being excited at one of its natural frequency This may reach high magnitudes.

Obviously, any resonance induced load that has to be avoided wherever or whenever it's possible. But during operation, they may arise during under certain operating conditions or due to poor design. So one has to be. Then, we have talked about forces of loads which are coming from aerodynamic the gravity dynamic interaction mechanical control obviously the aerodynamics loads are primarily due to the wind turbine so that's what we have looked at how the aerodynamic forces can be generated and how much what would be the Then gravity is there which could be a source of loads on the blades for large turbines although it is less for smaller machines. Then you can have dynamic interactions which is motion induced by aerodynamic and gravitational forces in turn can induce loads in other parts of the machine.

For example, virtually all horizontal axis wind turbines allow some motions about an EO axis. While the EO motion occurs, while the rotor is turning, there will be an induced gyroscopic forces. If the EO rate is high, then these forces could be quite substantial. then the mechanical control which is can be sometimes the source of significant loads. For example, starting off turbine which uses an induction generator or stopping the turbine by applying a break and things like that.

Now, I mean, then there are effects of loads because this loading experienced by a wind turbine are quite important in two primary areas. One is that ultimate strength and second is the fatigue. I mean, wind turbines sometimes occasionally experience very high loads and they must be able to withstand those loads. Typical normal operation which is kind of accompanied by widely varying load due to starting, stopping, yawing, or passage of blades through continuously changing wheels.

But those are normal. But these varying loads can cause fatigue, damage in missing components. And sometimes that component may eventually fail at much lower load than it would have been when new. So, that means in the design, one has to be very careful that how much strength it can withstand and then so that these damages can be caused. So, this is where we have used our fundamental principle of solid mechanics or structural or structural so where we have looked at these different forces which would arise due to rotation so inertia forces i mean, since they are rotating I mean, for example, the effect of centripetal acceleration associated with the rotation of the rotor is accounted for by the inertial centrifugal force. So, due to the rotation, then we have had bending of Cantilever beam.

We looked at the beam bending equation. So, these are coming from typical strength of material analysis. Why this is important? Because the blade is basically cantilevered beam so that is what we have and then we looked at the bending moment the equation of the bending moment then maximum strength all estimated from there then we have talked about or rigid body planar rotation So, have this two-dimensional rotation which act as angular momentum. Obviously, you have the angular momentum. You could correlate by Newton's law of motion.

The magnitude of some moments could be i mean the j alpha or mass moment of inertia into alpha those are the things one can i mean obviously you can correlate with the angular acceleration angular rotation then you can have rotational energy or frequency then you have this basic gears and their mechanism So, because in the NASA or the housing, you have two different kinds of gears. One is in size and larger and smaller so that the, uh, the speed ratio varies those things that is there. Then obviously important aspect of it is, uh, gyroscopic motion. and which is quite important in terms of for design of wind turbine because so this is something very very critical the reason being during the turbine when the rotor is spinning can result in significant gyroscopic loads So the gyroscopic motions can have significant impact on the, so obviously this gyroscopic due to this gyroscopic motion the loads and the rotations the moments those things can be also estimated and should be considered well then we have looked at vibration so we kind of looked at single degrees of freedom which is as a spring mass damper system and multi degrees of freedom and then again you have a system which is vibrating then you have eigen modes eigen vectors and then try to see when you talk about the both tower nacelle and the rotor blade blade passing frequency rotational frequency and most important thing all this and this is that one has to one has to tell in such that she avoided because once all because due to frequency and oscillations there could be a structural damage that is the thing one has to avoid that's why this analysis that we have discussed about based on one degrees of freedom system two degrees of freedom system and also we have looked at kind of an vibration of delivery their modes and when you have hinge and rotation so they could have obviously they are leading to different frequency or natural frequency and then we have looked at personal systems okay can be also modeled by series of discrete . So these are the things that we address using our fundamental principle of the structural mechanics.

And now we'll extend this for the analysis of the rotor dynamics. Okay, so we'll continue in the next.