Technical University of Denmark

# On the dynamics of a teeter hinge with delte3 angle on a two bladed multi MW wind turbine

**Kallesøe, Bjarne Skovmose; Aagaard Madsen , Helge; Larsen, Torben J.; Rasmussen, Flemming**

*Published in:*
Conference proceedings

*Publication date:*
2008

# On the Dynamics of a Teeter Hinge with $\delta_3$ Angle on a Two Bladed Multi MW Wind Turbine

**B. S. Kallesøe, H. Aa. Madsen, T. J. Larsen and F. Rasmussen**
Wind Energy Department, Risø National Laboratory, Technical University of Denmark, DK-4000 Roskilde, Denmark.
E-mail: bjarne.skovmose.kallesoee@risoe.dk

## 1. Introduction

For two bladed turbines the $\delta_3$ angle of the teeter hinge is said to stabilize the teeter angle deflections. However the literature does not give a clear answer for what size and sign the $\delta_3$ angle should have. Furthermore the upscaling of turbine blades has change the dynamics of the teeter hinge with $\delta_3$ and therefore the potentials for using $\delta_3$ angle on modern multi MW turbines. This study analysis the effect of $\delta_3$ angle on multi MW turbine using the analytical model for teeter motion suggested by [1] and aeroelastic simulations. The analysis shows that the model describes the basic behavior of teeter motion well, but realistic loading from e.g. a yaw error is not described. The effect for yaw error and wind shear are analysis and incorporated in the analytical model. The potentials for using $\delta_3$ angle on modern multi MW turbines is discussed.

## 2. Method and Preliminary Results

### 2..1 Analytical Model

Ref. [1] suggest that a teeter hinge with a $\delta_3$ angle can be described by a second order system

$$\ddot{\beta} + 2\xi\omega_0\dot{\beta} + \omega_0^2\beta = F \tag{1}$$

where the natural frequency is given by

$$\omega_0 = \Omega\sqrt{1 + \lambda K_p/8} \tag{2}$$

and the damping by

$$\xi = \frac{\lambda}{16\sqrt{1 + \lambda K_p/8}} \tag{3}$$

where $K_p = \tan(\delta_3)$ and $F$ is the forcing on the blade cause by e.g. changes in wind speed or operating in yaw. The so called lock number $\lambda$ is the ratio between aerodynamic forces and inertial forces and Ref [1] gives an analytical expression for a blade with a simple geometry

$$\lambda = \frac{2\rho R^4 C_{L_\alpha} c}{I} \tag{4}$$

where $R$ is the radius of the blade, $\rho$ is the air density, $C_{L_\alpha}$ is the slop of the lift curve, $c$ is the chord and $I$ is the polar moment of inertia of the blade around the teeter hinge. It is seen that this expression is dependent on the specific blade layout and linearly dependent on the air density.

### 2..2 Determine Lock Number

For a realistic blade layout the lock number can be determined by measuring the frequency and damping of the teeter motion for the specific turbine setup at different air densities. Figure 1 shows results from simulations with the aeroelastic code HAWC2 [2] of transient behavior of the given turbine setup at different air densities. The natural frequency is seen to be almost constant for all air densities as predicted by the model (2) and the damping has a linearly dependency on the air density as predicted by (3)

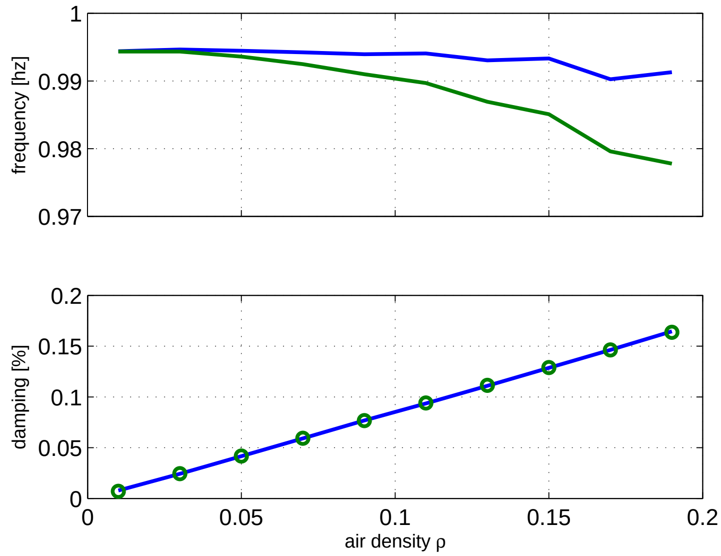



*Figure 1:* Frequency and damping dependency of air density. Top graph: frequency, bottom graph: damping ratio. Blue line top graph: natural frequency, green line top graph: resonance frequency, blue line bottom graph: simulated damping, green line bottom graph: linear regression to fit lock number to simulations.

Since the damping is described by

$$\xi = \frac{\lambda(\rho)}{16\sqrt{1+\lambda K_p/8}} \tag{5}$$

and $\lambda(\rho) = \lambda_0 \rho$ the lock number dependency of $\rho$ can be found from the slope of the damping on Figure 1. For the particular turbine setup the lock number is found to be $\lambda = 13.9\rho$

The lock number depends on the aerodynamic characteristics and the inertial of the blade, and the up-scaling of turbine has changes the relations between these parameters of modern turbines and therefore changes the effect and potentials for used of $\delta_3$ angle. This study will clarify the size effect on the potentials for use of a $\delta_3$ angle.

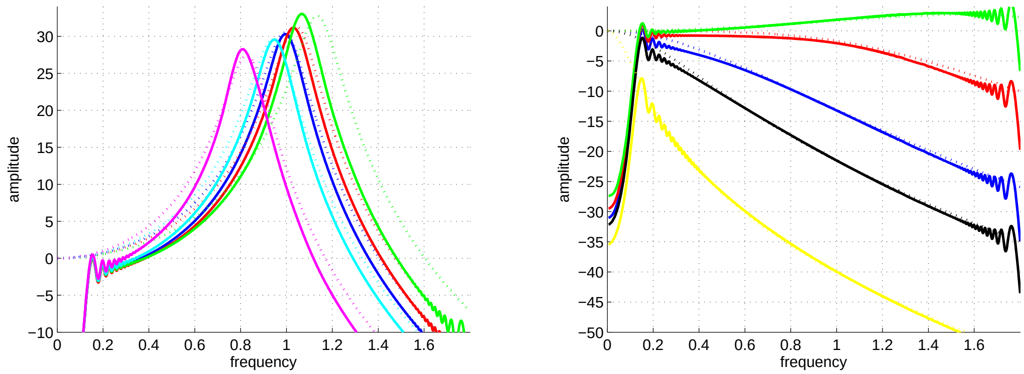
### 2..3 Effect of $\delta_3$ and Verification of Analytical Model

Figure 2 shows the frequency response curves for direct excitation of the teeter motion for two different values of air density. The simulated frequency response is seen to agree very well with the response predicted by the model, especially for the realistic air density (Figure 2(b)). The $\delta_3$ angels effect on the natural frequency of teeter motion is clearly seen on the resonance peaks for the simulations with low air density (Figure 2(a)). For the simulations with realistic air density (Figure 2(b)) the teeter motion is over damped and therefor it has no resonance peak. Figure 2(b) suggest a strong reduction of teeter motion for negative $\delta_3$ angels.

### 2..4 Operation in Yaw

To analysis the effect of the $\delta_3$ angle under more realistic loading conditions the turbine is simulated for operation with a 30 deg yaw error with different $\delta_3$ angles. Figure 3 shows the amplitude for teeter angle oscillations at steady state conditions for two different air densities.

Figure 3 shows only a small effect of a $\delta_3$ angle for alleviating teeter oscillations caused by yaw error for realistic operation conditions for a multi MW turbine. The model predict much lager effect of the $\delta_3$ angle. The disagreement between the simulated response and the predicted teeter responses is caused by the loading form yaw error is imposed through the aerodynamic and not




(a) (b)

*Figure 2:* Frequency response functions for direct excitation of the teeter motion. Solid line is the simulated response and the dotted line is the prediction of the model. Green line $\delta_3 = -60$ deg, red line $\delta_3 = -30$ deg, yellow line $\delta_3 = -20$ deg, black line $\delta_3 = -10$ deg, blue line $\delta_3 = 0$ deg, cyan line $\delta_3 = 30$ deg, magenta $\delta_3 = 60$ deg. a) $\rho = 0.1 \mathrm{kg/m}^3$ b) $\rho = 1.225 \mathrm{kg/m}^3$.

directly at the teeter motion. The changes the yaw error impose on the aerodynamic also changes the aerodynamic effect of the $\delta_3$ angle.

The interaction between aerodynamic loading from yaw and wind shear with the $\delta_3$ angle will be analyzed and described. The loading will be incorporated both in the analytical model and analyzed through aeroelastic simulations.

## 3. Conclusion

This work shows how the behavior of the teeter motion with $\delta_3$ angle can be described by the model suggested by [1]. The results from the model are compare to aeroelastic simulations of a multi MW turbine showing good agreement. The prediction of teeter motion for operation in an yaw error is however not well described, since the loading from yaw interact with the effect of the $\delta_3$ angle. This aerodynamic interaction is analyzed with aeroelastic simulations and by incorporated the oscillating aerodynamic loading into the analytical model. The aeroelastic simulations and analysis of the analytical model clarify the potentials for using $\delta_3$ angles on two bladed MW watt turbines.

## References


[1] M.B. Anderson, A.D. Garrad, and U. Hassan. Teeter excursions of a two-bladed horizontal-axis wind-turbine rotor in a turbulent velocity field. *Journal of Wind Engineering and Industrial Aerodynamics*, 17(1):71–88, 1984.

[2] T.J. Larsen, H.Aa. Madsen, A.M. Hansen, and K. Thomsen. Investigations of stability effects of an offshore wind turbine using the new aeroelastic code HAWC2. *Proceedings of the conference "Copenhagen Offshore Wind 2005"*, 2005.

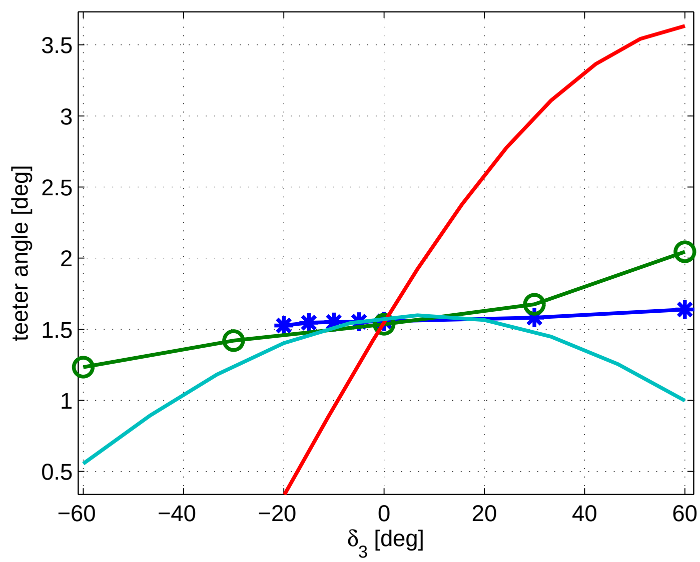



*Figure 3:* Amplitude on teeter angle oscillations for operation at 30 deg yaw at different $\delta_3$ angles. Blue line $\rho = 1.225$ kg/m$^3$, glue line $\rho = 0.1$ kg/m$^3$, red line predicted response for $\rho = 1.225$ kg/m$^3$, cyan line predicted response for $\rho = 0.01$ kg/m$^3$