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ANALISYS OF A FLOATING WIND TURBINE SUBJECTED TO GYROSCOPIC MOMENT EFFECT AT INCLINATION

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Abstract. *Nowadays there is a growing demand for the production of electricity by wind turbines, which should be installed mainly in flat areas with reduced numbers of barriers that block the continuity of wind flow. The sea, especially the regions far from the cost, satisfies these both necessities and even it is a place which there is not much restriction with respect to noise pollution nor about generated diseases in people that live close wind farm. This work deals with the interactions between the structure of an offshore wind turbine of Spar type with wind and water. This kind of wind turbine is proposed to be installed in depths greater than 80m, so it is subject to different types of loadings in its structure, from small waves and moderates wind flows until typhoons and storms. Based in a computer simulation, this work analyzes the different dynamic answers produced by the wind turbine impacted by external excitations involving small inclination angles from regular waves, as well as huge sea instability. The results of this work are relevant for the creation of new models of floating wind turbine, even as the improvement of what currently exists.*

Keywords: *Floating Wind Turbine, Spar, Finite Elements*

1. INTRODUCTION

After the rigorous restrictions imposed by the arabic nations to the oil trading in 70s decade, was triggered one new world pursuit for alternatives energy sources. Which was stimulated by the ephemerality of the global availability of fossil fuels and was ratified by the recent issue of BP Statistical Review World Energy. Company. (2012) (Tabel 1).

Table 1. Global Provision and Availability of the Main Fossil Fuels

	Petroleum	Natural Gas	Coal
Total Provision (end of 2011)	1652.6 billion of barrel	208.4 trillion m^3	861 billions of tons
Production (2011)	30.5 billion of barrel	3.27 trillions m^3	3.95 billions of tons
Time of availability	54 years	64 years	218 years

This worry about the shortage of fossil fuels linked to preoccupation due the climate changes, which are intensified by the burn of this type of fuel, put in evidence studies and investment that aim the use and the upgrading of energy generation by renewable sources.

The wind power is among the main types of alternatives method to generate electricity. Since it is clean, safe, virtually endless and it is getting cheaper along the years.

The devices used in this type of technology are wind turbines, which can be compared to fans operating conversely, i.e., instead to consume energy to produce wind, it convert the kinetic energy of wind wind to generate eletricity. (Kurian *et al.* (2010))

Among the mainly wind turbines, the ones which dispose of more power are those installed at the sea (offshore), in which is deliberate a more intense and less turbulent wind flow then in those installed at the coast (onshore). (Kurian *et al.* (2010))

Regarding the implementation of offshores wind farms, we can observe serious impediments in the last years to those projected to shallow water. As the of the offshore farm of Cape Wind in Nantucket Sound, Massachusetts, USA. About which there were many disputes, the last one was led by native tribes which argument the the wind farm would obstruct the sunset vision, and therefore, would affect they religious and spirituals rituals. (Roddier and Weinstein (2010))

One way to avoid this question is to construct the wind farm far from the coast, in deep water. And the benefit of doing so is not only limited to litigation, but to the fact that in deep water the wind currents are more abundants and of greater intensity.

The first floating wind turbine of big power was the Spar type, Hywind, installed approximately 12km off the cost of KarmÃÿy, Norway, in 220m depth (Figure 1). It has an output of 2.3MW, its rotor diameter is 82m of length, 65m of its structure are beneath of water surface and its 100m rest remain submersed. (AG (2009))

Figure 1. Floating Wind Turbine of Spar Type Hywind.

2. OBJECTIVE

Based on a analysis using the finite element methods (FEM), two numerical simulations are performed using a FEM software, with the objective of determine the different dynamic responses produced by the wind turbine, by external excitations involving small tilt angles β from regular waves, as well as those arising from large maritime instability.

3. METHODOLOGY

Consider the axis of cartesian coordinates (x, y, z), with xy plane traverse to the floating wind turbine structure as expressed in the Figure 2.

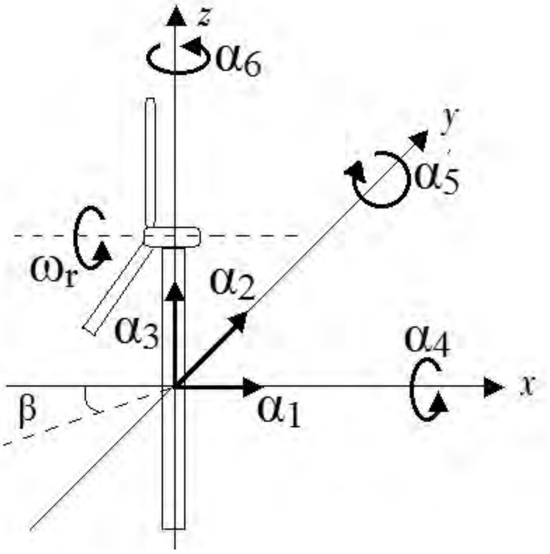

Figure 2. Coordinate System Implementation in Floating Wind Turbine.

We assume in this study that the turbine Spar has 6 degrees of freedom in its movement, represented by translational displacements α_1, α_2, α_3, together with the angular displacement α_4, α_5, α_6, which are also represented in Figure 2

The dynamic equation of motion of the turbine in question is expressed by:

$$\{(M+m)\ddot{\alpha} + N\dot{\alpha} + C\alpha\} = F \tag{1}$$

where M is the mass matrix 6×6, m is the 6×6 matrix of the added mass to the loading, N is the 6×6 damping matrix and C is the 6×6 restoration matrix. Finally, α and F are the answer vector and excitation force of wave, respectively, both with six degrees of freedom.

Other factor that directly influences the motion of the turbine is the gyro moment induced by the rotation of turbine rotor. This moment is added to Equation 1 through of the inclusion of a coordinate axis centered on the rotor (Murai and Nishimura (May)) expressed in Figure 3.

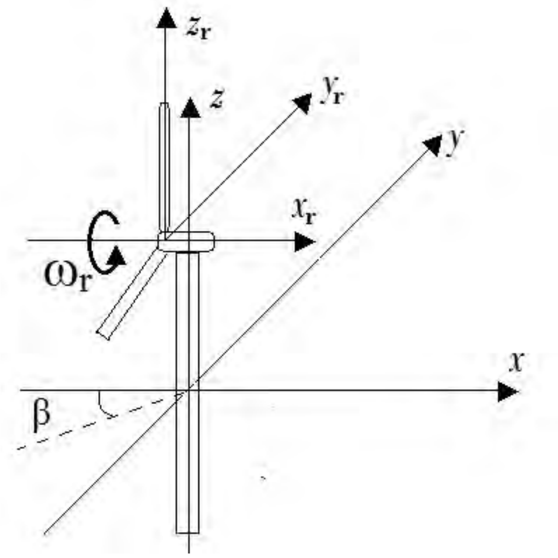

Figure 3. System for Rotor Coordinates

Let the vibration angles around the axes x_r, y_r e z_r be, respectively , α_{r4}, α_{r5}, α_{r6}.

The speed of these angles depends on the angular velocity ω of periodic external force.

Such angles are represented by:

$$\begin{aligned} \alpha_{r4} &= \alpha_{r4}^{0} e^{-i\omega t} \\ \alpha_{r5} &= \alpha_{r5}^{0} e^{-i\omega t} \\ \alpha_{r6} &= \alpha_{r6}^{0} e^{-i\omega t} \end{aligned} \tag{2}$$

Where α_{r4}^{0}, α_{r5}^{0}, α_{r6}^{0} represent the amplitudes of the angles of rotation.

Deriving the expressions of Equation 2 with respect to time and noting that only the in axis x_r there is the component ω_r of the angular velocity, we obtain:

$$\begin{aligned} \omega_{r4} &= \omega_r - i\omega\alpha_{r4}^{0} e^{-i\omega t} \\ \omega_{r5} &= -i\omega\alpha_{r5}^{0} e^{-i\omega t} \\ \omega_{r6} &= -i\omega\alpha_{r6}^{0} e^{-i\omega t} \end{aligned} \tag{3}$$

Deriving the equations 3 again with respect to time, we get:

$$\begin{aligned} \dot{\omega}_{r4} &= -\omega^2\alpha_{r4}^{0} e^{-i\omega t} \\ \dot{\omega}_{r5} &= -\omega^2\alpha_{r5}^{0} e^{-i\omega t} \\ \dot{\omega}_{r6} &= -\omega^2\alpha_{r6}^{0} e^{-i\omega t} \end{aligned} \tag{4}$$

Let M be the moment of the body, I its rotational moment of inertia and $omega$ its angular velocity. We have, by Euler's equations of motion, that: (Symon (1971))

$$I \cdot \frac{\omega}{dt} + \omega \times (I \cdot \omega) = M \tag{5}$$

Applying Equation 5 in the coordinate system (x_r, y_r, z_r) with their respective moments of inertia M_{r4}, M_{r5}, M_{r6}, we obtain:

$$\begin{aligned} M_{r4} &= I_{r1}\dot{\omega}_{r4} - (I_{r2} - I_{r3})\omega_{r5}\omega_{r6} \\ M_{r5} &= I_{r2}\dot{\omega}_{r5} - (I_{r3} - I_{r1})\omega_{r6}\omega_{r4} \\ M_{r6} &= I_{r3}\dot{\omega}_{r6} - (I_{r1} - I_{r2})\omega_{r4}\omega_{r5} \end{aligned} \tag{6}$$

Where I_{r1}, I_{r2}, I_{r3} are the moments of inertia of the blades with respect to the respective axes.

Substituting equations 3 and 4 in 6, we have:

$$\begin{aligned} M_{r4} &= -I_{r1}\omega^2\alpha^0_{r4}e^{-i\omega t} + (I_{r2} - I_{r3})\omega\alpha^0_{r5}\alpha^0_{r6}e^{-2i\omega t} \\ M_{r5} &= -I_{r2}\omega^2\alpha^0_{r5}e^{-i\omega t} + (I_{r3} - I_{r1})i\omega\alpha^0_{r6}e^{-i\omega t}(\omega_r - i\omega\alpha^0_{r4}e^{-i\omega t}) \\ M_{r6} &= -I_{r3}\omega^2\alpha^0_{r6}e^{-i\omega t} + (I_{r1} - I_{r2})i\omega\alpha^0_{r5}e^{-i\omega t}(\omega_r - i\omega\alpha^0_{r4}e^{-i\omega t}) \end{aligned} \tag{7}$$

Considering small the vibration amplitude of the Equation 7, the product of vibration amplitude can be neglected. Therefore the Equation 7 can be written as:

$$\begin{aligned} M_{r4} &= -I_{r1}\omega^2\alpha^0_{r4}e^{-i\omega t} \\ M_{r5} &= -I_{r2}\omega^2\alpha^0_{r5}e^{-i\omega t} + (I_{r3} - I_{r1})i\omega_r\omega\alpha^0_{r6}e^{-i\omega t} \\ M_{r6} &= -I_{r3}\omega^2\alpha^0_{r6}e^{-i\omega t} + (I_{r1} - I_{r2})i\omega_r\omega\alpha^0_{r5}e^{-i\omega t} \end{aligned} \tag{8}$$

Note that the second terms of the Equation 8 to M_{r5} and M_{r6}, represent the moment gyro blades. Therefore, the gyroscopic moment is expressed in Equation 1, such as:

$$\{-\omega^2(M + m) - i\omega(N - M_{\text{giroscÃ§pio}}) + C\}\alpha = F \tag{9}$$

Onde $M_{\text{giroscÃ§pio}}$ Ãľ escrito como:

$$M_{\text{giroscÃ§pio}} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & (I_{r3} - I_{r1})\omega_r \\ 0 & 0 & 0 & 0 & (I_{r1} - I_{r2})\omega_r & 0 \end{bmatrix} \tag{10}$$

Multiplying both sides of the Equation 9 by the inverse matrix of the term in braces, we have:

$$\alpha = \{-\omega^2(M + m) - i\omega(N - M_{\text{giroscÃ§pio}}) + C\}^{-1}F \tag{11}$$

4. RESULTS AND DISCUSSION

To the simulation, was used a modeling of NREL S809 profile, developed in a Finite Elements Software. The loading specifications was obtained from LEANDRO, (de Assis Filho (2012)).

The mesh consists of elements of 63 shell types. This component has 6 degrees of freedom (3 of rotation and 3 of translation) in each node, according to the predicted analytical model.

The resultant load applied by the waves is $50N$ (normal condition) and $500N$ (extreme condition) with incidence angle $\beta = 30^o$, According to (de Assis Filho (2012)). The material considered is steel with Young's modulus of $210GPa$ and density of $7800kg/m^3$.

To smooth condition, the displacements and Von Misses Tension are disposed in the Figure 4.

To this case the maximums displacements in x, y and z axis are, respectively, $4.11mm$, $25mm$ and $1.11mm$. This results reveals that the displacement in y axis is the bigger one. It makes sense, since is in this direction the gyro moment takes place more significantly. Regarding the Von Misses tension, was concluded that it assumes maximum value of $15MPa$ near the foundation.

The Figure 5, shows the displacements and Von Misses tension when is considered that the wave loading is $500N$.

In the extreme condition, due the gyro effect, the $y = 25.36mm$ axis displacement is also predominant related to $x = 1.37mm$ and $z = 5.5mm$ axis. The maximum Von Misses Tension, in this case, is equal to $16MPa$.

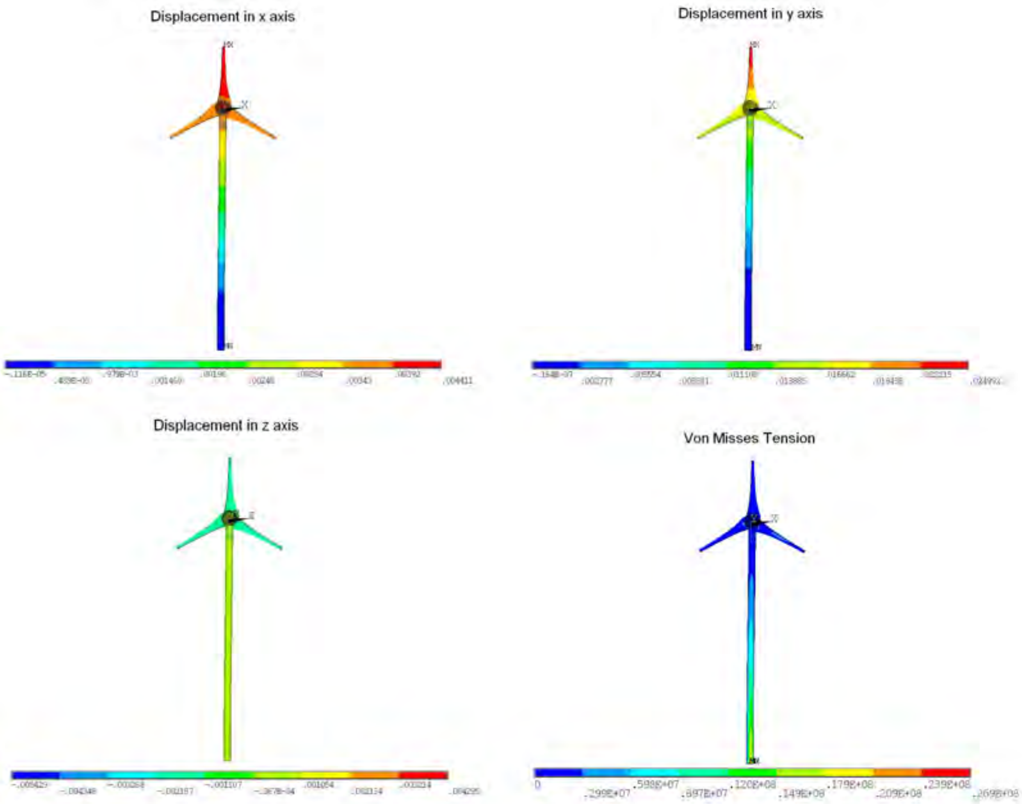

Figure 4. Displacement and Von Misses Tension Regarding the Smooth Condition.

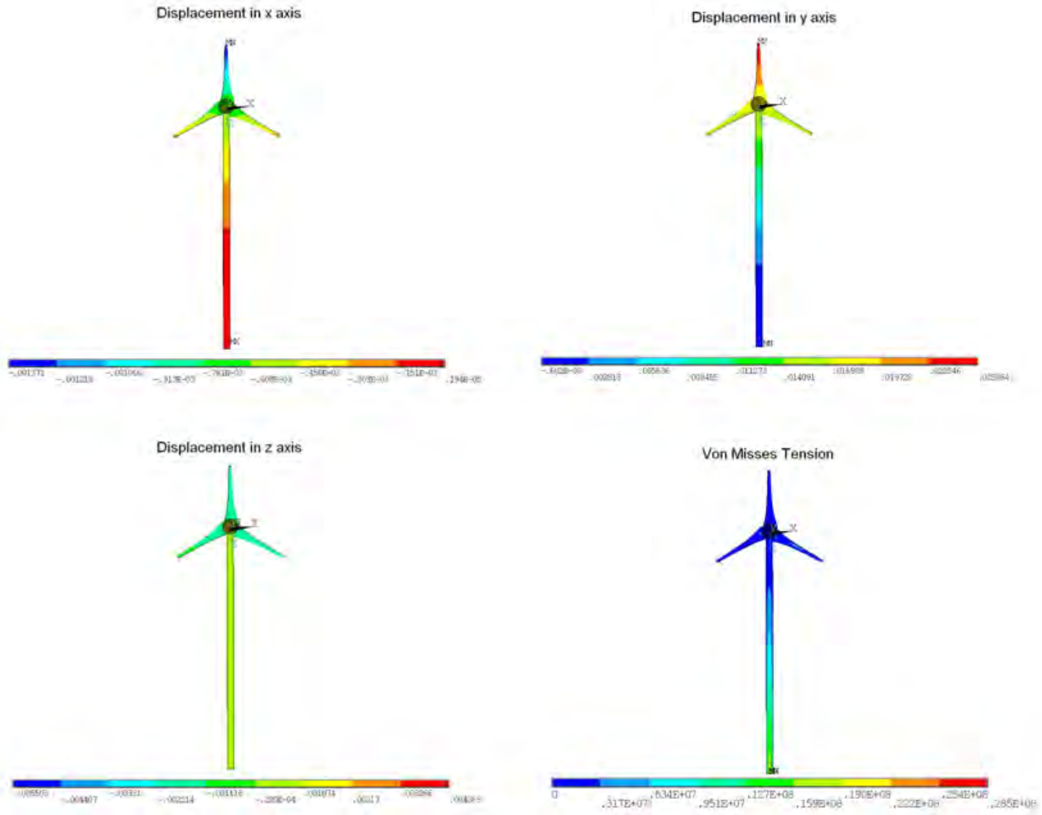

Figure 5. Displacement and Von Misses Tension Regarding the Extreme Condition.

5. CONCLUSION

The data for the present study are relevant, since they exhibit the behavior of the turbine studied in normal and extreme conditions.

Was noticed a substantial displacement in the y direction when compared to the others axis, which evidentiate the importance of gyro effect in the displacement analysis of wind turbine.

Future work may make an analysis using a dynamic loading in the wind turbine structure and can infer about the feasibility of the material and geometry in its construction.

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