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# Dynamic Effects of Anchor Positional Tolerance on Tension Moored Floating Wind Turbine

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## Abstract.

For water depths greater than 60m floating wind turbines will become the most economical option for generating offshore wind energy. Tension mooring stabilised units are one type of platform being considered by the offshore wind energy industry.

This paper examines the issue of tendon anchor position tolerances. The dynamic effects of three positional tolerances are analysed in survival state using the time domain FASTLink.

The worst anchor misposition combinations are highlighted and should be strongly avoided. Novel methods to mitigate this issue are presented.

## 1. Introduction

For water depths greater than 60m floating wind turbine (FWT) will become the economical option for generating offshore wind energy. Tension mooring stabilised platforms are restrained in heave, pitch and roll and compliant in surge, sway and yaw. Excess buoyancy provides the restraint through tendon pretension. For tension moored FWT, tendons are generally designed to be vertical. The "as installed" position of the anchors however may not be in exactly the same position as was designed. This anchor misposition leads to an increase in platform motions and loads. Tension moored platforms are thus extremely sensitive to anchor position.

For proposed Atlantic sites, the availability of enough weather windows to carry out installation, operations and maintenance on marine energy devices has been predicted. Thus any method to increase the temporal or sea state conditions required is vital for deployments in these harsher environments.

### 1.1. Anchor Type

A number of different types of anchor systems have been proposed for tension moored floating wind turbines, these include; pile, gravity, suction, and grouted rock anchors. High vertical load drag embedment plates have also been proposed by Glostren Associates for the PelaStar device, but due to the operational loading limit of 45° are not compatible with the vertical moorings used in this paper. Positional tolerances for drag embedment anchors will also be much greater than for the previously mentioned anchor types. The anchor choice will depend on seabed characteristics, which may not be uniform across a proposed wind farm. To give a

scale of the challenge facing the offshore floating wind industry, as of 2002 only  $\approx 500$  suction piles had been installed worldwide [1], a similar number which would be required for a single wind farm with number of turbines  $\approx 100$ .

### 1.2. Anchor Positional Tolerance

The DNV codes [2] state that the permissible installation tolerances shall be determined taking into account the increased difficulty in accurate seabed positioning caused by large water depth and environmental conditions. Position tolerances can be an absolute, for example 1m, or depth dependant, for example 1% of water depth.

Installation of anchors requires special anchor handling vessels with dynamic positioning (DP) systems. DP systems can keep a vessel "on location" by applying an active thrust, thus making it easier to achieve the required positional accuracy. In order to apply the appropriate reactive thrust, DP systems measure wind speed but calculate wave and drift loads and thus control systems integrated a feedback feature and require some time to become positionally stable.

It is hypothesised that increasing the anchor positional tolerance will allow the anchors to be installed in shorter weather windows, more severe sea states, or by less expensive vessels that have less capable DP systems. This paper investigates what the effect of increasing these positioning tolerances will have on the platform dynamics (motions and tendon forces). A literature review of the topic found only a single paper. In 1993, Hamilton [3] presented a method to calculate the linear effects of anchor misposition by using linear pitch and roll but keeping quadratic terms in yaw. Although no results using this method were presented. Figure 1 shows a trigometric view of anchor misposition.

## 2. Methods

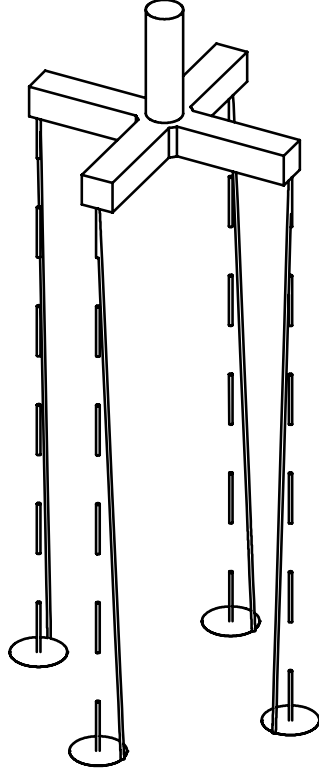
The tension moored floating 5MW NREL reference wind turbine platform; TLPWT 4 [4] was used for this study. The water depth is taken as 150m. Hydrodynamic parameters are computed from Ansys Aqwa for 8 wave directions and 50 frequency's from 0.008Hz- 0.4Hz. Time domain modelling is carried out using the coupled Orcaflex and Fast package FASTlink v8 [5]. Additional quadratic viscous damping of the platform is added to the model using modified Morrison's equation elements. Mooring Tendon stiffness is not mentioned in the cited paper and are modelled with an axial stiffness of  $1.5 * 10^9$  N using Morrison's equation elements.

Eight anchor offset positions are chosen for each anchor ( $360^\circ/8 = 45^\circ$ ) and with four anchors this allows for 4096 possible combinations. Figure 2 shows the possible anchor positions. These combinations result in a number of duplicate simulations, were the effective spacing of the anchors is equal, for example all are offset in the same direction. These duplicate simulations are used as verification runs to test the repeatability and sensitivity to exact wave position. The anchor position tolerances are chosen as absolute values of 1, 2 and 3m (Tolerance/depth ratio of 0.0067, 0.0133 and 0.02). This study assumes the worst case scenario, where anchors are positioned along the limits of these tolerances.

Survival state is modelled using a Jonswap spectrum with Hs of 12.7m, Tp of 14.1s and Wind Speed 50m/s for 1300s (Ignoring the first 100s to give a usable time of 20 minutes or 1200s). Wave and wind were modelled as being directionally aligned.

## 3. Misposition Results

Displacements and rotations are measured at the platform's centre of gravity, Accelerations are measured at the centre of the nacelle. Anchor misposition is weighted by the perimeter distance multiplied by the square of the in wave positions and then normalised by the base case of 0m misposition. It should be noted that this normalisation process does not represent any physical quantity and is solely used in order to visually represent the results. Equation 1 shows the normalisation function, where  $\bar{P}$  is the normalised position,  $p$  is the perimeter length,  $n$  is the

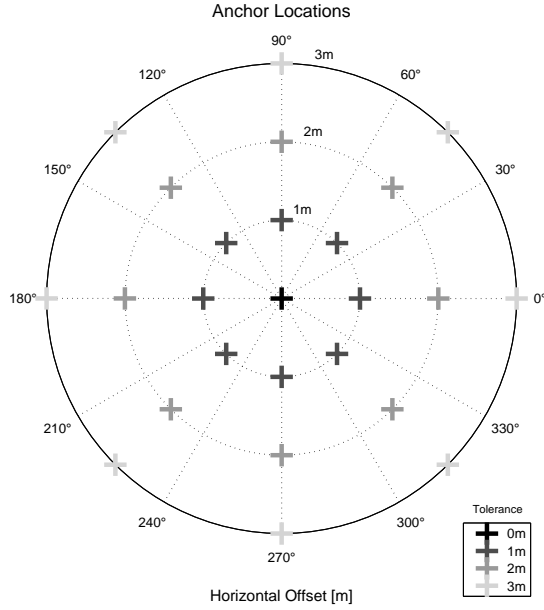


**Figure 1.** Trigonometric view of platform and anchor misposition. Dashed tendon line is the design case with no misposition, solid tendon line is the misposition case. Seabed circles indicate the anchor target area. Horizontal distances are exaggerated to retain clarity

number of anchors,  $x$  is the in wave position,  $j$  is the misposition number and 0 is the zero misposition baseline case.

$$\bar{P}_j = \frac{p_j + \sum_{i=1}^n x_i^2}{p_0 + \sum_{i=1}^n x_0^2} \quad (1)$$

Figure 4 shows the worst case mooring misalignment, where the anchors parallel (Tendons 1 & 3) and the anchors perpendicular (Tendons 2 & 4) to the wave direction are shifted to the maximum relative distances. Figure 4a shows this relative anchor position, the reader should note that the X and Y axis dimensions are distorted for the inter anchor cases to retain clarity. Figure 4b shows the surge displacement, Figure 4c the nacelle Acceleration and Figure 4d the tension in Tendon 1. Of most significance is a 53% increase in maximum nacelle acceleration. Figure 5 shows all the cases. Figure 5a-d shows the maximum surge, heave and pitch displacement and maximum nacelle acceleration, Figure 5e-h shows the maximum tendon forces. Of particular note are the large motions and forces that are located in the range of 0.95 - 1.1 normalised anchor position.



**Figure 2.** Possible Anchor Positional Locations

#### 4. Mitigation Methods

This paper proposes two novel mitigation methods for the issues addressed here. Both methods involve changing the target anchor position based on the position of previously installed anchors. Firstly a nearest neighbour installation method is proposed, followed by a furthest neighbour installation method. If the distances between the anchors are equal, one is chosen at random. The ten anchor offsets, at 3m tolerance, that show the most severe results are used as test comparison cases to determine these methods effectiveness. An example for the same offset positions of both of these methods is shown in Figure 3.

##### 4.1. Nearest Neighbour Installation Method

The nearest neighbour installation method (NNIM) installs the anchors in order of which is closest to those already installed. The offset of each previous anchor is used to determine the location of subsequent anchors as follows. The first anchor is installed in the original target area. The as installed position of the anchor is recorded. The order of subsequent anchors are chosen based on which minimises the distance to the already installed anchor(s). A new target area for this next anchor is identified based on position of previous anchor(s). This procedure is continued for each subsequent anchor using the average offset of the previous anchors. The methodology is described for the four anchor case in Equations 2 to 5 with the governing formula in Equation 6. Here the X and Y positions are a subset of P ( $P = [X, Y]$ )  $P_I$ ,  $P_D$  and  $P_O$  denotes the installed, design and offset positions respectively.

$$P_{I,1} = P_{D,1} + P_{O,1} \quad (2)$$

$$P_{I,2} = P_{D,2} + P_{O,2} + P_{O,1} \quad (3)$$

$$P_{I,3} = P_{D,3} + P_{O,3} + (P_{O,2} + P_{O,1})/2 \quad (4)$$

$$P_{I,4} = P_{D,4} + P_{O,4} + (P_{O,3} + P_{O,2} + P_{O,1})/3 \quad (5)$$

$$P_{I,i} = P_{D,i} + P_{O,i} + \frac{\sum_{n=1}^{i-1} P_{O,n}}{(i-1)} \quad (6)$$

#### 4.2. Furthest Neighbour Installation Method

The furthest neighbour installation method (FNIM) follows the NNIM, except in the order of anchor installation. In this method the order of subsequent anchors are chosen based on which are furthest apart from those already installed. The first anchor is installed in the original target area. The anchor that is furthest from this first anchor is then installed using the first anchors offset position. Subsequent anchors are installed in order of which are furthest from their nearest neighbour first. The anchor target uses the nearest  $k$  offsets, which may be weighted by distance.

### 5. Mitigation Results

Figure 6 compares the results of the two proposed mitigation methods against the "as designed" plus offset case. Results for the NNIM are inconclusive, with some offset cases showing reduced and some showing increased peak dynamics. Results for the FNIM show conclusive results. With all cases showing decreased platform motions and nacelle accelerations over the design case. The upwind T1 tendon shows decreased peak loadings but these positive results come at the expense of increased peak loadings in all other tendons. The peak surge motion reduces by an average of 9.8% with a maximum reduction of 11.9% and a minimum reduction of 7.7%. The peak pitch motion reduces by an average of 22.3% with a maximum reduction of 37% and a minimum reduction of 7.1%. The peak heave motion reduces by an average of 18.8% with a maximum reduction of 23.5% and a minimum reduction of 13.3%. The peak acceleration reduces by an average of 9.5% with a maximum reduction of 15.3% and a minimum reduction of 3.3%. The peak load in T1 reduces by an average of 5% with a maximum reduction of 7.1% and a minimum reduction of 2.9%. T3 increases by an average of 6% with a maximum increase of 8% and a minimum increase of 3.8%.

Results for rms motions and loading follow the same trend as the peak values presented here and are thus not shown.

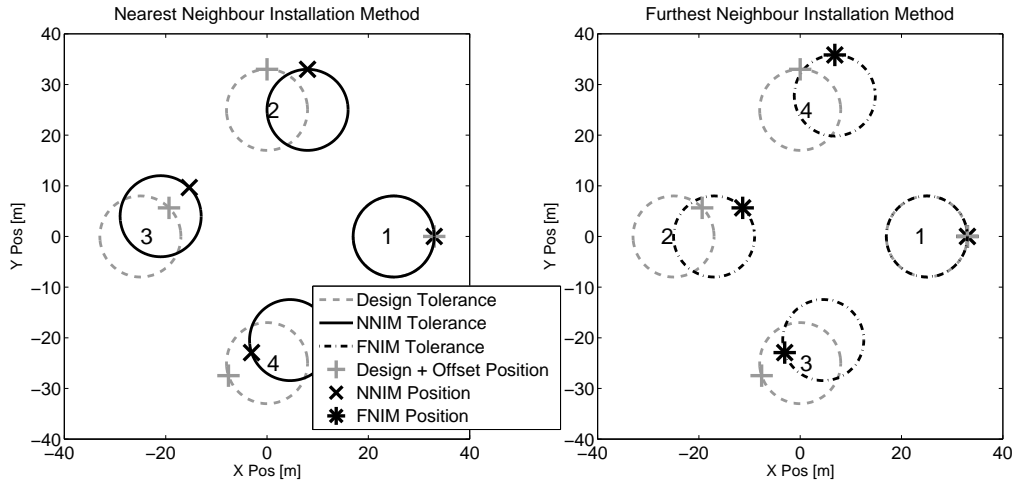
### 6. Conclusions

This paper identifies anchor misposition as a major design concern for the deployment of tension moored floating wind turbine platforms. The results from this paper rule out the possibility of using vertical ( $90^\circ$ ) loaded drag embedment anchors with current positional accuracy technology for this anchor type.

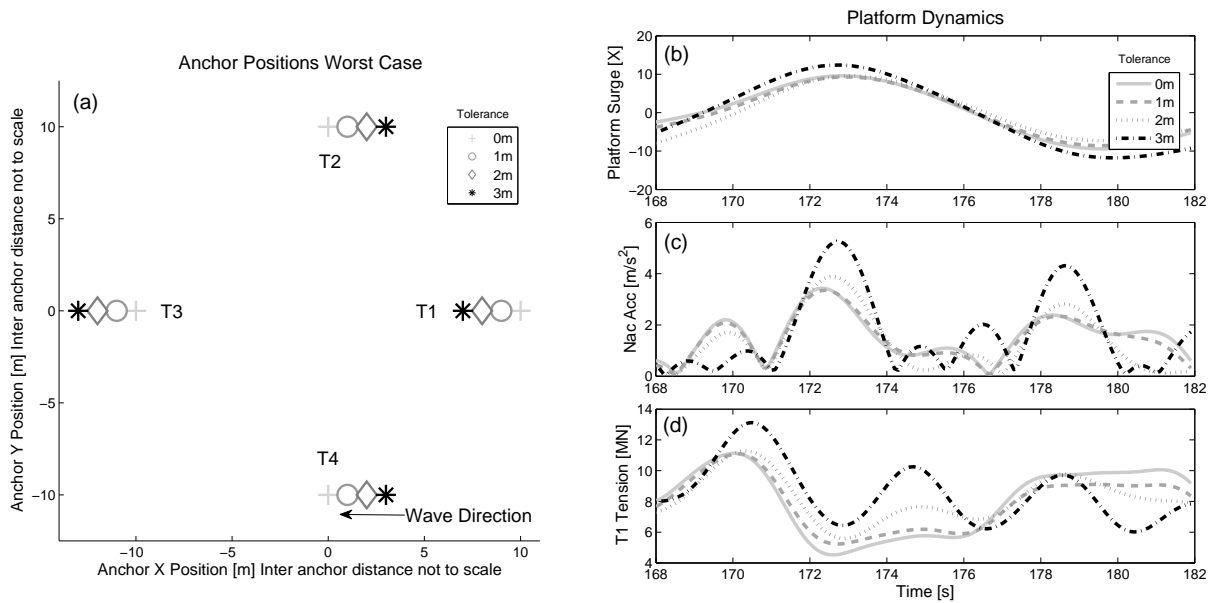
The dynamic effects of anchor misposition are shown, especially which positional combinations should be strictly avoided. The worst case misposition locations at a 3m tolerance increase nacelle acceleration by 53%. Two mitigation methods are proposed and tested in order to reduce the need for positional accuracy. The FNIM shows great promise for reducing platform dynamics, although at the expense of increased downwind tendon forces. Future work will involve refining this method to take this into account and testing for wind and wave misalignment.

### Acknowledgments

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**Figure 3.** Examples of NNIM and FNIM Positional Results. Horizontal offset distance has been distorted to retain clarity



**Figure 4.** Anchor Misposition effects on Dynamics: Worst Case

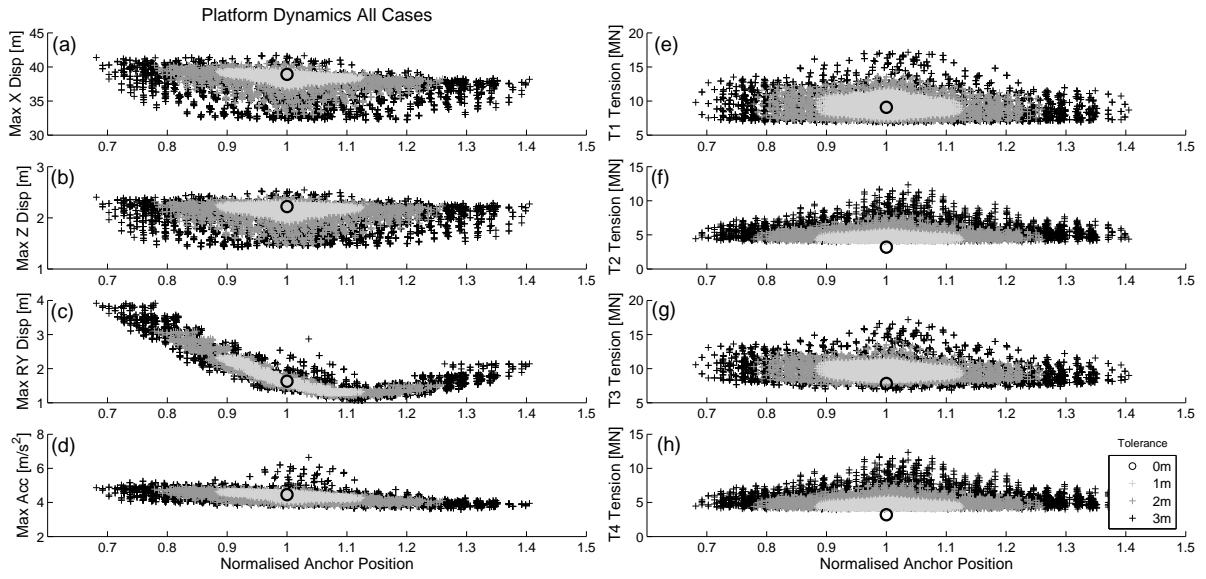


Figure 5. Anchor Misposition effects on Dynamics: All Cases

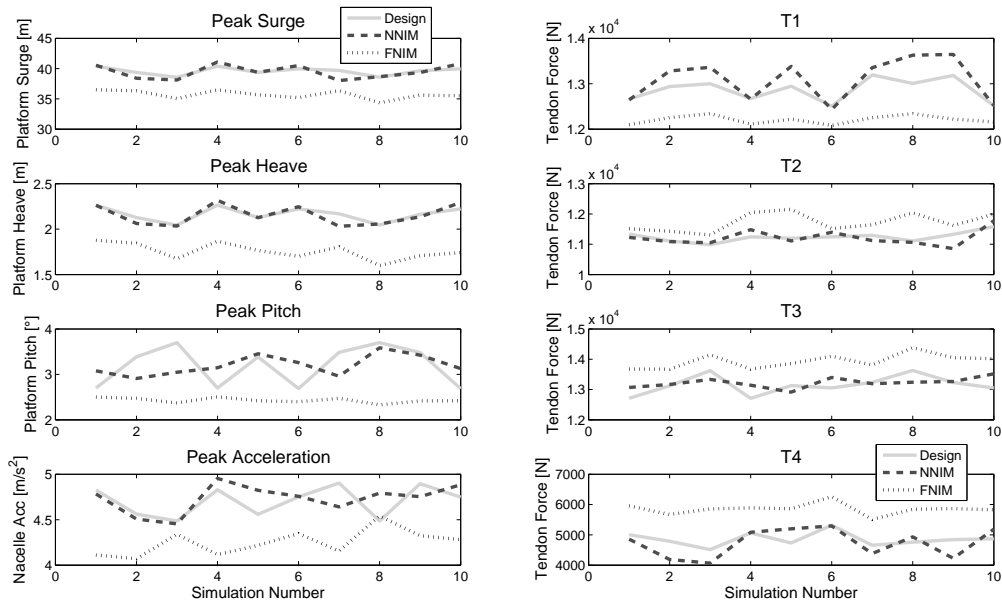


Figure 6. Results of NNIM and FNIM Compared to the Design Offset for Ten Worst Case Simulations

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