CONSIDERATIONS ON THE DESIGN AND EVALUATION OF DYNAMIC POSITIONING SYSTEM

Hélio Mitio Morishita *
Hernani Luiz Brinati *
Sylvio Henrique Sá Correa **

* Depto. Eng. Naval e Oceânica - Universidade de São Paulo
** PETROBRÁS, E&P/GERPRO/GETIMP

Abstract—The mathematical modelling of a dynamic positioned vehicle is analysed. The basic equations for the slow vessel dynamics in the horizontal plane are presented, followed by a brief description of the models adopted to represent the hydrodynamic reaction and environmental forces. A more detailed analysis is dedicated to the forces imposed on the vehicle by the riser. The relative importance of the term is evaluation in a static forces balance. The thruster system force is evaluated based on the environmental forces and the thruster performance degradation due to interaction effects. The vessel dynamics is simulated, with a PID control for the thruster forces and moment in order to evaluation if thruster system was properly designed.

INTRODUCTION

In the recent years the offshore oil industry has increased its operation in deep water requiring more and more dynamic positioned ocean vehicles mainly to short term activities as drilling and work over. It can not be omitted that there has been a significant technological development in the field of anchoring systems with the introduction of synthetic materials for the mooring line, the utilisation of taut-leg configuration as well as special anchors that are able to withstand vertical loads. All these facts have contributed to enlarge the domain of technical and economic feasibility of anchoring systems. It may be even questioned that DPS is an option better than mooring systems for water depth up to 1500 meters.
In some applications, however, DPS has a clear advantage over mooring system even in shallow water. It can happens, for instance, in very congested area where there is a lot of interference to configure the mooring line of a new vessel in a safety way. This is the case of some areas in Campos Basin where, due to the requirement of a rapid increase in the oil production, many vessels have been installed very close to each other, and the multitude of mooring lines and risers as well as pipelines make very difficult the installation of other mooring lines.

The utilisation of DP vessels by Petrobras tends to exhibit a considerable increasing in the next years. Since there is a limited number of DP units available in the world market, it seems very likely that in a short term, besides the contraction of new buildings, it will be necessary to proceed the conversion of anchoring positioned semi submersible platforms.

The construction of a new vessel as well as the conversion of an existing one arises the discussion of some aspects that should be considered in the design of dynamic positioning systems. This is the scope of the present paper.

It is focused initially the mathematical models required to represent the dynamic of an ocean vehicle. Following the presentation of the equations of motion for the horizontal plane, it comes a brief description of the formulation used to represent the several forces acting on the vehicle. A more detailed analysis is carried out for the forces induced on the vessel by the riser, taking into account the effects of the ocean current and the vehicle motion. The magnitude of the resultant forces is compared with those produced by the environmental elements.

Afterward it is discussed the design of the thrusters system, more specifically the estimation of the total thrust required, considering the effects of thruster performance degradation due to the thruster- thruster and hull- thruster interactions.

Finally, the performance of the dynamic positioned vehicle is evaluated by simulation of the mathematical models. A simple PID law is adopted in order to compute the commanded total thrust forces and moment. The tests were designed with the purpose of providing an evaluation of the total thrust installed in the vessel, as well to complement the evaluation of the effects of riser forces.

It is selected as an illustrative example to evaluate the relative importance of the riser forces as well as the magnitude of the total required vessel thrust Petrobras semi submersible platform P-XVII which is supposed to incorporate a DPS system to operate in a water depth going from 1500 to 2000m.
MATHEMATICAL MODELS

In order to represent the motion of the ocean vehicle two co-ordinate systems are used as shown in Figure 1. The first one, OXYZ, is an earth-fixed co-ordinate system and in this paper its origin is chosen to coincide with the lower end of the riser; the second one, GXYZ, is a body fixed co-ordinate system with the origin located at the centre of gravity of the vehicle and its axes coincide with the principal axes of inertia of the vehicle. Based on these assumptions, the low frequency horizontal motion of the vehicle in a body fixed co-ordinate system can be expressed as:

\[ m(\ddot{u} - vr) = X \]
\[ m(\ddot{v} + ur) = Y \]
\[ I_z \ddot{r} = N \]  

where: \( m \) is the mass of the vessel, \( u \) and \( v \) are the surge and sway velocity respectively; \( r \) is the yaw rate; \( I_z \) is the moment of inertia about GZ axis; \( X \), \( Y \) and \( N \) represent the total external efforts in surge, sway and yaw direction, respectively and the dot means time derivative of the variable.

The position of vessel related to earth fixed co-ordinate system is obtained integrating the following equations:

\[ V_x = u \cos \psi - v \sin \psi \]  
\[ V_y = u \sin \psi + v \cos \psi \]  
\[ \dot{\psi} = r \]

where \( V_x \) and \( V_y \) are the speed of the vessel in the OX and OY axes respectively and \( \psi \) is the vehicle heading angle.

Figure 1 - Body fixed and earth fixed co-ordinate systems
Offshore Engineering

The external forces and moments can be considered as the sum of six components that can be expressed, say in GX direction, as:

\[ X = X_A + X_v + X_w + X_wv + X_T + X_r \]  

(3)

where the subscripts \( A, v, w, wc, T \) and \( r \) indicate added mass, viscous, wind, second order wave, thrusters and riser forces respectively. In the following it is summarised the standard way to get all above efforts, with exception of the riser forces which are presented in more details.

**Added Mass Forces**

The added mass forces, considering a constant speed current, are given by (Fossen):

\[ X_A = X_{\text{in}} u - [Y_{\text{in}} (v - v_c) + Y_r r] \]  

(4a)

\[ Y_A = Y_{\text{in}} v + Y_r r + X_{\text{in}} (u - u_c) \]  

(4b)

\[ N_A = N_r r + Y_{\text{in}} v + [Y_{\text{in}} (v - v_c) + Y_r r] (u - u_c) - X_{\text{in}} (v - v_c) (u - u_c) \]  

(4c)

where \( u_c \) and \( v_c \) are current speeds in the GX and GY direction, respectively, and the coefficients in equations (4) are known as hydrodynamic derivatives.

**Viscous Forces**

The viscous forces that appear due to the vehicle motion are included in the formulation of current forces, since it is used the relative current speed.

\[ X_v = \frac{1}{2} \rho V^2_v A_c C_{cx} (\psi_c) \]  

(5a)

\[ N_v = \frac{1}{2} \rho V^2_v A_c C_{cn} (\psi_c) + \frac{1}{2} \rho r |r| A_w C_r \]  

(5b)

where \( V_v \) is the current speed relative to the vessel; \( A_c \) the reference area; \( C_{cx} \), \( C_{cn} \) and \( C_r \) are the force and moment coefficients. The expression to calculate viscous force in GY direction is similar to equation (5a).

The relative speed \( V_c \) and the current angle \( \psi_c \) are calculated as:

\[ V_c = \sqrt{u_r^2 + v_r^2} \]  

(6a)

\[ u_r = V_c \cos(\psi_c - \psi) \]

\[ v_r = V_c \sin(\psi_c - \psi) \]

\[ \psi_c = \arctan(v_r / u_r) - \psi \]  

(6b)

where \( \psi_c \) is the current angle.
Wind Forces
In order to determine the wind load it is usual to suppose that the rig speed is much lower than the wind speed in such way that only incidence angle need to be considered. The force for instance in the GX direction is given by:

\[ X_w = \frac{1}{2} \rho_a V_w^2 A_w C_{wx} (\psi_{wr}) \]  

(7)

where: \( \rho_a \) is the air density; \( V_w \) is the wind speed; \( A_w \) is the reference area; \( C_{wx} \) is the wind force; \( \psi_{wr} \) is the wind incidence angle. Similar expression is valid for GY and GZ direction.

Wave Drift Forces
The second order wave force can be split in mean wave drift and slow wave drift components. In this paper only first one is taken into account to study DPS and it can be determined as, say in the GX direction (Faltinsen²):

\[ \bar{X}_{ow}(\psi_{owr}) = 2 \int_0^\infty S_{ow}(\omega) \frac{T_x(\omega, \omega, \psi_{owr})}{\zeta_a^2} d\omega \]  

(10)

where \( \bar{X} \) is the mean wave drift force into surge direction \( S_{ow}(\omega) \) is the sea spectrum; \( T_x \) is a quadratic transfer function; \( \psi_{owr} \) é the direction of the wave relative to the vehicle; \( \zeta_a \) is the wave amplitude.

Riser Forces
The force that the riser applies in the vehicle depends on the subsea current and its own interaction with the vessel. A complete mathematical model describing the dynamics of the system is very complex since there are efforts in different directions. But in the analysis of DPS only horizontal forces acting on the vehicle are of interest. Therefore, in order to evaluate the influence of riser in the horizontal plane motion of the floating vessel, a simple model for the riser was adopted. It is assumed that the riser is a beam with a ball joint at the sea bottom and its upper end following the floating unit motions as shown in Figure 2. The longitudinal forces acting on the riser are assumed to be in equilibrium and their projections on the horizontal plane is not considered. The current profile has a constant rate of speed along the length of the riser but its direction is kept constant. In order to develop the mathematical model a beam fixed frame Oxyz is considered. The origin O coincides with earth fixed co-ordinate system and the Oz axis is chosen to coincide with the riser longitudinal axis. Based on these assumptions and considering that the riser moment of inertia along the Oz axis is negligible, the mathematical model of the riser dynamic can be derived from:
The angular speed of the riser and its angular momentum are given by:

\[
\vec{\omega} = -\dot{\varepsilon}\sin\phi \hat{i} + \dot{\phi} \hat{j} + \dot{\varepsilon}\cos\phi \hat{k}
\]

(12)

\[
\vec{H}_O = -I_r \varepsilon \sin\phi \hat{i} + I_r \phi \hat{j}
\]

(13)

where \( I_r \) is the moment of inertia about Ox and Oy axes. The angles \( \varepsilon \) and \( \phi \) are defined in Figure 2.

Remembering that \( \vec{\Omega} = \vec{\omega} \) and substituting (12) and (13) into (11) yields:

\[
-I_r (\varepsilon + 2\phi \dot{\varepsilon}) = N'_{rx} + Y'_r L_r
\]

(14a)

\[
I_r (\dot{\phi} - \dot{\varepsilon}) = N'_{ry} - X'_r L_r
\]

(14b)

where \( N'_{rx} \) and \( N'_{ry} \) are the moments due to current on riser in the Ox and Oy direction, respectively; \( Y'_r \) and \( X'_r \) are the forces on the riser due to vehicle in the Oy and Ox axes, respectively. \( L_r \) is the length of the riser. It was considered that \( \sin\phi = \phi \) and \( \cos\phi = 1 \) in the above equations since \( \phi \) is usually less than 5 degrees. These assumptions will be adopted henceforth.

Now it is necessary to perform a coupling between the riser and vehicle models which can be established remembering that in the joint point the upper end of riser and the vessel have the same speed. The speed of the upper end of riser can be calculated from:

\[
\vec{V}_r (L_r) = \vec{\omega} \times \vec{L}_r = \dot{\varepsilon} \sin\phi \ L_r \hat{j} + \dot{\phi} L_r \hat{i}
\]

(15)

For simplicity it will be assumed that the upper end of riser coincides with the origin of the vessel fixed co-ordinate system. Therefore the speed given by (15) can be expressed in vessel fixed co-ordinate system and then related to vessel speed:

\[
u = -\dot{\varepsilon} L_r \phi \sin\alpha + \dot{\phi} L_r \cos\alpha
\]

(16a)

\[
v = \dot{\varepsilon} L_r \phi \cos\alpha + \dot{\phi} L_r \sin\alpha
\]

(16b)

where \( \alpha = \varepsilon - \psi \). The angles \( \varepsilon \) and \( \phi \) can be calculated as:
where $x_G$ and $y_G$ are the position related to $OX$ and $OY$ axes of the vessel.

\[ \varepsilon = \tan^{-1}\left(\frac{y_G}{x_G}\right), \quad \phi = \tan^{-1}\left(\frac{\sqrt{x_G^2 + y_G^2}}{L_r}\right) \]

Figure 2 Riser fixed and earth fixed co-ordinate system

From equations (16) one can get:

\[ \dot{\phi} = \frac{v \sin \alpha + u \cos \alpha}{L_r} \]  \hspace{1cm} (17a)

and

\[ \dot{\varepsilon} = \frac{v \cos \alpha - u \sin \alpha}{L_r \phi} \]  \hspace{1cm} (17b)

Taking the time derivative of equation (17a) and (17b) one can get:

\[ \ddot{\phi} = \frac{\ddot{v} \sin \alpha + \dot{v} \cos \alpha + \dot{\varepsilon} L_r \phi \dot{\alpha}}{L_r} \]  \hspace{1cm} (18a)

and

\[ \ddot{\varepsilon} = \frac{\ddot{v} \cos \alpha - \dot{u} \sin \alpha + L_r \dot{\phi} \dot{\psi}}{L_r \phi} \]  \hspace{1cm} (18b)

In order to make easy the study equations (14) can also be expressed in terms of vessel fixed co-ordinate system:

\[ -I_r (\ddot{\varepsilon} \phi + 2\dot{\varepsilon} \dot{\phi}) \cos \alpha - I_r (\ddot{\phi} - \dot{\varepsilon} \phi) \sin \alpha = N_{rx} + Y_r L_r \]  \hspace{1cm} (19a)
where $N_{rx}$ and $N_{ry}$ are moments due to current on the riser in the GXYZ co-ordinate system.

The equations (19a) and (19b) require the moment due to current on the riser and its calculation is not straightforward since the relative speed between riser and current changes along the length of riser. Although it is always possible to make use of a numerical evaluation, an analytical solution to get the moment due to current is considered in this paper. The advantages of this approach are short computer running time during digital simulation and ease to analyse the influence of all parameters. The handicap is that only a simple current profile and riser speed model can be considered.

The moment related into earth fixed coordinate system is:

$$
\vec{N}_r = \int_0^{L_r} d\vec{N}_r^O (l) \approx \int_0^{L_r} l \cos \phi \vec{K} \wedge d\vec{F}_r^O \cos \phi \approx \int_0^{L_r} l \vec{K} \wedge d\vec{F}_r^O
$$

where $d\vec{F}_r^O$ is the drag force on the elementary area $dA$ of the riser and $l$ is the distance of the force $d\vec{F}_r^O$ from centre O.

The force $d\vec{F}_r^O$ can be calculated from:

$$
d\vec{F}_r^O (l) = \frac{1}{2} \rho C_r D_r \| \vec{V}_c (l) - \vec{V}_r (l) \|^2 (\cos \psi_f \vec{I} + \sin \psi_f \vec{J}) dl
$$

where

$$
\vec{V}_c (l) = (V_1^* l + V_2) (\cos \psi_c \vec{I} + \sin \psi_c \vec{J});
$$

$$
\vec{V}_r (l) = \frac{V_l}{L_r} (\cos \psi_v \vec{I} + \sin \psi_v \vec{J});
$$

$$
V = |V_x \vec{I} + V_y \vec{J}|
$$

$V_c$ is the sub-sea current speed; $V_1^* = (V_1 - V_2) / L_r$; $V_1$ and $V_2$ are defined in Figure 3; $V_r$ is the tangential speed of the riser; $\psi_v$ is direction of the speed of the vessel related to the earth fixed co-ordinate system; $\psi_f$ is the direction of the force related to the earth fixed co-ordinate system; $D_r$ is the riser+floater diameter; $C_r$ is a constant; Notice that the general current profile is a trapezoidal one. However taking $V_1 = V_2$ or $V_2 = 0$ a constant or triangle current profile can be obtained.
Substituting (21) into (20), one can obtain:

\[
\bar{N}_r^O = \frac{1}{2} \rho C_v D_r \left[ \frac{\int_0^L (-\Delta V_y(l) \sqrt{\Delta V_x^2(l) + \Delta V_y^2(l)} \, dl)}{\int_0^L (\Delta V_x(l) \sqrt{\Delta V_x^2(l) + \Delta V_y^2(l)} \, dl)} \right] \bar{J} + \tag{22}
\]

where

\[
\Delta V_x(l) = (V_1^* l + V_2) \cos \psi - \frac{V}{L_r} l \cos \psi,
\]

\[
\Delta V_y(l) = (V_1^* l + V_2) \sin \psi - \frac{V}{L_r} l \sin \psi.
\]

The integration of (22) yields:

\[
N_{rx}^O = -K^1 \left\{ \frac{1}{192 K_3} \left[ K_6 \sqrt{K_5} + K_7 (K_{8x} - K_{6x}) \right] + \frac{K_4^2 - 4 K_3 K_5}{128 K_3^2} \left( 8 K_3 K_2 K_4 - 5 K_{1x} K_4^2 + 4 K_{1x} K_3 K_5 \right) \ln(K_y) \right\}, \tag{23a}
\]

\[
N_{ry}^O = K^1 \left\{ \frac{1}{192 K_3} \left[ K_6 \sqrt{K_5} + K_7 (K_{8y} - K_{6y}) \right] + \frac{K_4^2 - 4 K_3 K_5}{128 K_3^2} \left( 8 K_3 K_2 K_4 - 5 K_{1y} K_4^2 + 4 K_{1y} K_3 K_5 \right) \ln(K_y) \right\}, \tag{23b}
\]

for \( \psi_x \neq \psi_c \) and \( V_1^* = V / L \).
Particular results of (23a) and (23b) can be obtained in the following cases:

i) $\psi_v = \psi_c$ and $V_1^* = V / L$

$$N_{rx}^O = -K \left[ L_r^2 \sqrt{K_3} \left( \frac{K_{1x} L_r}{3} + \frac{K_{2x}}{2} \right) \right]$$

$$N_{ry}^O = +K \left[ L_r^2 \sqrt{K_3} \left( \frac{K_{1y} L_r}{3} + \frac{K_{2y}}{2} \right) \right]$$

ii) $\psi_v = \psi_c$, $V_1^* < V / L_r$ and $V_1^* \cdot L_r + V_2 - V = 0$

$$N_{rx}^O = -K \left[ \frac{L_r^2}{12} \right] \left[ V_1^* L_r - V \right] \left\{ (V - V_1^* L_r) \sin \psi_c \right\}$$

$$N_{ry}^O = K \left[ \frac{L_r^2}{12} \right] \left[ V_1^* L_r - V \right] \left\{ (V - V_1^* L_r) \cos \psi_c \right\}$$

iii) $\psi_v = \psi_c$, $V_1^* < V / L_r$ and $V_1^* \cdot L_r + V_2 - V \neq 0$

$$N_{rx}^O = -K \left[ \frac{L_r^2}{12} \right] \left[ (V_2 - V + V_1^* L_r) \right] \left\{ \left( 6V_2^2 + 8V_1^* V_2 L_r + 3V_1^* \right) L_r^2 - 8V_2 V - 6V_1^* L_r + 3V^2 \right\} \sin \psi_c$$

$$N_{ry}^O = -K \left[ \frac{L_r^2}{12} \right] \left[ (V_2 - V + V_1^* L_r) \right] \left\{ \left( 6V_2^2 + 8V_1^* V_2 L_r + 3V_1^* \right) L_r^2 - 8V_2 V - 6V_1^* L_r + 3V^2 \right\} \cos \phi_c$$

iv) $V_2 = 0$

$$N_{rx}^O = -K K_{1x} \sqrt{K_3} L_r^4 / 4$$

$$N_{ry}^O = K K_{1y} \sqrt{K_3} L_r^4 / 4$$

Definition of the constants of equations (23) are addressed to appendix. The moments of the riser in GXYZ axes are given by:

$$N_{rx} = N_{rx}^O \cos \psi + N_{ry}^O \sin \psi$$

$$N_{ry} = -N_{rx}^O \sin \psi + N_{ry}^O \cos \psi$$

DETERMINATION OF THE THRUSTER SYSTEM

Required Thrust Capacity

The first step of DPS design is the determination of the thruster system capacity which is required to counteract the external forces that act on the vessel. The thruster system capacity is usually calculated with basis on the static balance of equation (1). It should be assumed a given set of environmental conditions corresponding to a specified return period.
However, differently from the design of rig mooring system, there is no established criteria to define the environmental conditions. Anyway, it is common practice to assume that wind, current and wave forces are collinear. The incident angle of the environmental elements relatively to the vessel is varied in order to determine the maximum resultant force. This value will be used to compute the effective thruster system capacity.

It should be pointed out that it is not usual to include the riser forces in the computation of the required thrust forces. Nevertheless the authors understand that this component can not be neglected for drilling rigs operating in large water depths.

The nominal or available vessel thruster force is evaluated considering the thruster-thruster and hull-thruster interruptions which degrade the thruster system performance. The interaction effects can be minimised with careful thruster layouts, selection of appropriate thruster design, and the definition of allowable azimuth angles. With all these aspects taken into account a 10 percent degradation coefficient can be assumed.

Finally, since the required thrust force was computed considering the static balance of the external forces, it is usual to apply some arbitrary margin to define the total installed thrust force. Although a so called dynamic factor equal to 0.2 is prescribed by Lough, the authors understand that the appropriate value should be determined by simulation of dynamic position system performance.

Thrusters Configuration
The number of thrusters on a DPS is defined taking into consideration the required thruster capacity, the vessel type and layout, the specified reliability and the maximum force provided by a single thruster. Usually in semi submersible rigs the thruster are mounted at suitable locations under the bottom of the pontoon hulls, as close as possible to the columns. A large number of units may lead to a more reliable system but it may also generate a thruster system more sensitive to interaction (losses) effects. Although a variety of thruster types may be employed, azimuth thrust units, with either fixed or controllable pitch propellers, are the most used type specially for semi submersible platforms.

Two types of drivers have been traditionally used in the thruster system, namely, dc and ac electric motors. The first one is used with fixed pitch propeller and the second one with variable pitch propeller. More recently a new thruster-driver system has been adopted, consisting in fixed pitch propeller driven by variable frequency ac induction motors. This solution combines the advantages of fixed pitch propellers and ac motors.
ILLUSTRATIVE EXAMPLE

Petrobras semi-submersible platform P-XVII was used in an illustrative example to evaluate the effect of riser forces in the determination of the required thruster capacity as well as their influence on the performance of DPS. Table 1 presents the main characteristics of P-XVII rig.

It was assumed that the riser is a circular cylinder 1500 m long that with the inclusion of the floaters has an external diameter equal to 1,0 m.

Statitical Calculation

The environmental conditions adopted in the study are shown in Table 2, corresponding to return periods equal to 1 and 10 years. The environmental forces on the platform are presented in Table 3 for two different angles of incidence - 0 and 90 degrees. It is also included in this table the forces induced by the riser assuming the subsea current profile shown in Figure 3. It may be seen in Table 3 that current drag forces represent the most important effort on the vehicle, corresponding to near 47% of the total force for the angle of incidence equal to 0 degree and 63% for 90 degrees. It may be seen also that the riser forces can not be neglected since they represent, depending on the values of return period and angle of incidence, about 9% to 15% of the total forces, being almost three times higher than the mean wave drift forces.

<table>
<thead>
<tr>
<th>Deck</th>
<th></th>
<th>Pontoonos</th>
</tr>
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<tbody>
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<td>length:</td>
<td>72,25 m</td>
<td>number: 2</td>
</tr>
<tr>
<td>width:</td>
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<td>length: 92,00 m</td>
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<tr>
<td>height</td>
<td>5,9 m and 3,9 m</td>
<td>width: 14,00 m</td>
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<thead>
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<th>Columns</th>
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<th>Draught</th>
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<tr>
<td>number:</td>
<td>6</td>
<td>working conditions: 21,60 m</td>
</tr>
<tr>
<td>diameter:</td>
<td>9,40 m</td>
<td>height: 6,10 m</td>
</tr>
<tr>
<td>height to main deck:</td>
<td>37,10 m</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - Main Dimension of semi-submersible P-XVII

<table>
<thead>
<tr>
<th>Wave</th>
<th>Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 year</td>
</tr>
<tr>
<td>Significant Height (m)</td>
<td>5,1</td>
</tr>
<tr>
<td>Period (s)</td>
<td>7,9</td>
</tr>
</tbody>
</table>

| Wind | |
|------|
| Speed (m/s) | 21,22 | 29,22 |

<table>
<thead>
<tr>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (m/s)</td>
</tr>
</tbody>
</table>

Table 2 - Environmental Condition
In the determination of the installed thrust capacity it is assumed that the interaction losses represent 10 percent of the nominal thruster forces; it is adopted a dynamic factor equal to 1.2. Considering a return period of 1 year and an incidence angle equal to 90 degrees, the installed thrust capacity in P-XVII rig is 3430 kN.

<table>
<thead>
<tr>
<th>Return Period</th>
<th>1 year</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (kN)</td>
<td>844</td>
<td>1211</td>
</tr>
<tr>
<td>Wind (kN)</td>
<td>531</td>
<td>1007</td>
</tr>
<tr>
<td>Mean drift (kN)</td>
<td>97</td>
<td>119</td>
</tr>
<tr>
<td>Riser (kN)</td>
<td>270</td>
<td>343</td>
</tr>
<tr>
<td>Total Force (kN)</td>
<td>1742</td>
<td>2680</td>
</tr>
</tbody>
</table>

Table 3 - Forces on the Platform P-XVII

**Dynamic Simulation**

Since the mathematical model of the ocean vehicle is nonlinear, the analysis of the riser effect on the vehicle dynamics, and the prediction of the maximum required control effort and vehicle offset, during a transient manoeuvre, can be carried out only by means of simulation.

The maximum required thrust depends on how severe is the vehicle manoeuvre. Therefore, it is necessary to define an appropriate simulation test in order to obtain a realistic extreme thrust value. Usually, the speed and direction of wind vary faster than current and wave parameters do. On the other hand the current drag force is the predominant environmental load on the vessel. Thus, the transient analysis should include a change of current speed. Bearing these facts in mind, it seems reasonable to perform a simulation test imposing a quiescent initial condition to the vehicle but requiring the thruster system to counteract a low environmental load. Then the extreme thrust value could be obtained by rising the current and wind load on the vessel through a step function.

It is necessary to point out that the dynamic simulation performed in the present study takes into consideration only low frequency motions and it does not intend to emphasise the control law optimization. Therefore, to make simple the simulation, three independent conventional PID controllers, one for each motion direction, were implemented; and a first order delay for control efforts was imposed to take account of inertia of thruster-driver system.
Two simulation tests were selected to illustrate the influence of riser forces on DPS performance. The environmental forces were assumed to be collinear with an angle of incidence equal to 90 degrees. The current speed was varied from 1.0 to 1.4 m/s and the wind speed was increased from 0.0 to 21.0 m/s.

The results of the first test, which includes riser forces on the vessel, are shown in Figures 4a and 4b. Figure 4a presents the vehicle position and velocity and the total thruster force. It may be seen that the maximum value of the effective thrust is about 2900 kN corresponding to a 3220 kN nominal thrust and it occurs close to the point where the vessel speed relatively to current reaches its maximum value. Since the installed thrust capacity is 3430 kN, it may be concluded that the adopted dynamic factor 1.2 gives a satisfactory allowance. It may be seen in Figure 4a that the maximum vehicle offset is about 16 m, i.e., around 1% of the water depth, which may be considered a satisfactory result since the maximum allowable offset is normally 3% of water depth. Figure 4b presents the variation of the external forces on the vehicle along the test.

The results of the second test, where the riser forces are neglected, are shown in Figures 5a and 5b. It may be seen in Figure 5a that the maximum thrust, as it may be expected, is lower that the value obtained in the previous test, the difference being practically equal to that obtained in the computation of the static forces.

The results of the second test show that the maximum vessel speed and offset are a little bit higher than the values obtained in the previous test, which indicates that riser increase the system damping.

![Graph of vehicle position, velocity, and total thruster force](image-url)
Figure 4 - Performance of DPS with the inclusion of riser forces

Fig. 5 - Performance of DPS under the effect of environment forces
CONCLUSIONS

Some aspects of DPS design for an ocean vessel were analysed in this paper. A mathematical model for representing the riser forces on the vehicle was proposed and a procedure for determining the installed required capacity was presented.

It was shown that for a semi-submersible platform operating at Campos Basin in a 1500 m water depth, the riser forces can represent 10 percent of total exciting forces and, therefore, they should be included in the thruster system design.

The results of simulation tests indicated that a dynamic factor not less than 1.2 should be used in the determination of installed thrust capacity.

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REFERENCES


APPENDIX

The definitions of the constants of the riser equation are:

where:

\[ K = \frac{1}{2} \rho C_D D_r \]

\[ K_{1x} = V_1^* \sin(\psi_c) - \frac{V}{L_r} \sin \psi_v \]

\[ K_{1y} = V_1^* \cos(\psi_c) - \frac{V}{L_r} \cos \psi_v \]

\[ K_{2x} = V_2 \sin(\psi_c) \]
\[ K_{2y} = V_2 \cos(\psi_v) \]
\[ K_3 = \left( V_1^* - \frac{V}{L_r} \right)^2 + 2V_1^* \frac{V}{L_r} (1 - \cos(\psi_e - \psi_v)) \]
\[ K_4 = 2[V_1^*V_2 - V_2 \frac{V}{L_r} \cos(\psi_e - \psi_v)] \]
\[ K_5 = V_2^2 \]
\[ K_{6x} = 24K_{2x}K_3K_4^2 - 15K_{1x}K_4^2 - 64K_{2x}K_3^2K_5 + 52K_{1x}K_3K_4K_5 \]
\[ K_{6y} = 24K_{2y}K_3K_4^2 - 15K_{1y}K_4^2 - 64K_{2y}K_3^2K_5 + 52K_{1y}K_3K_4K_5 \]
\[ K_7 = \sqrt{(K_3L_r^2 + K_4L_r^2 + K_5)} \]
\[ K_{8x} = 16K_{2x}K_3^2K_4L_r - 10K_{1x}K_3K_4^2L_r + 24K_{1x}K_3^2K_5L_r + 64K_{2x}K_3^2L_r^2 + 8K_{1x}K_3^2K_4L_r^2 + 48K_{1x}K_3^3L_r^3 \]
\[ K_{8y} = 16K_{2y}K_3^2K_4L_r - 10K_{1y}K_3K_4^2L_r + 24K_{1y}K_3^2K_5L_r + 64K_{2y}K_3^2L_r^2 + 8K_{1y}K_3^2K_4L_r^2 + 48K_{1y}K_3^3L_r^3 \]
\[ K_9 = \frac{K_4 + 2K_3L_r + 2\sqrt{K_3K_7}}{K_4 + 2\sqrt{K_5K_3}} \]