The Feasibility of a Central Turret in FPSO Systems

The use of Stabilizers in FPSO (floating production, storage, and offloading) systems with a turret is investigated under the light of a reviewed, perhaps new, stability analysis specifically for the turret and an order of magnitude analytical approach. This has been made together with model testing results and time-domain nonlinear simulations. It is shown by these various and independent methodologies that stabilizers, never considered so far for applications on FPSOs, are naturally feasible, opening the field for novel designs.

Introduction

This work has a strong practical motivation. During the last years, PETROBRAS decided to install FPSO (floating production, storage, and offloading) with a turret to exploit its deepwater oil fields in the Campos Basin (offshore Brazil) (Carneiro, 1995). By the same time, several of the VLCCs (very large crude carriers) hulls, which were owned by PETROBRAS, were about to be decommissioned and became available to be used as FPSOs. The technical community (both international and Brazilian) has accepted the challenge, and several of the VLCC FPSOs are about to be produced. A typical VLCC has a length $L = 320$ m, which is an impressive number by all standards, and a key aspect is the horizontal plane dynamic stability properties. If the wrong characteristic is acquired, the FPSO may be hit by a storm laterally, and drastic consequences for the mooring integrity may be expected.

It is a current practice to build the turret well ahead, towards the bow (sometimes, when convenient, towards the stern). In some cases, the ratio from the distance of the turret axis to amidships ($a$) to ship length ($L$) is $a/L = 0.47$; that is, almost at the bow. If a yoke arrangement is chosen, then $a/L > 0.5$.

From the turret, besides the mooring lines, the risers depart to the bottom of the sea. In some cases, the riser set is composed of 70 lines (umbilicals, export lines, import lines, etc.). These lines have been installed in a free-hanging configuration, a usual way that seems to be working properly (field-proven) with the wave transparent hulls like semi-submersibles. This configuration is preferred since it minimizes the installation problems and is generally cheaper. However, if the same criteria are used for others hulls like the VLCCs, even the mild Campos Basin weather (100-yr return period wave with significant wave height of 7.6 m and up-zero-crossing period of 11.5 s) may be critical. Due to the combination of heave and pitch, current designs have imposed on the riser connection points motions of the order of 20 m and accelerations of 4 m/s$^2$ (both double amplitude). The consequence is that there is a dynamic compression at the riser TDP (touchdown point) that may lead to failure. The pitch response is no surprise since the radius is about $L/2 = 160$ m, which amplifies any angle. Hence, to consider the location of the turret in the central regions of the ship is natural.

The intention of this work is to present the idea of using passive stabilizers that may compensate with advantage the articulation close to the center (Fernandes, 1997). The basic fundamental Routh-Hurwitz analysis is then applied specifically to the turret problem. Since the turret introduces new variables, this problem is different from the better-known SPM (single-point mooring) system with a hawser, that is similar to the classical ship-towing problem.

Next, the predicted properties for a VLCC are evaluated by model testing results and by a simulation with the time-domain nonlinear computer program SDYN.

Before the Conclusions, the work discusses some ideas for the stabilizer's actual construction.

Stability Theory for the FPSO With a Turret

Figure 1 extracted from Fernandes and Sphaier (1997) illustrates an SPM-turret departure when submitted to a current field with intensity $U$. In this analysis, it is usual when one wants to assess the fundamental stability characteristics, only the current is considered. For the multi-environment case, with wind and waves coming from different directions, the same properties will come up, but in a more complicated fashion, and the use of time domain programs may be essential.

The equations of motion may be written as (see Nomenclature)

\begin{equation}
(m - X_e)\ddot{u} - mL\dot{v} = X(u, v, r) + kd\cos\omega
\end{equation}

\begin{equation}
(m - Y_e)\ddot{v} + mL\dot{u} - Y\dot{r} = Y(u, v, r) - kd\sin\omega
\end{equation}

\begin{equation}
-N_e\ddot{r} + (I_e - N_e)\dot{y} = N(u, v, r) - k\ddot{d}\sin\omega
\end{equation}

In these equations, $m$ is the mass of the vessel; $u, v, r$ are the relative velocity of the vessel with respect to the water; $X_e$, and $Y_e$ are the (negative) surge and sway added masses; $N_e$ is the (negative) yaw added inertia; $Y$ and $N$ are the coupled yaw-sway and sway-yaw added masses; $a$ is the distance between the turret vertical axis and the center of gravity of the vessel, both on the ship center plane; $X(u, v, r), Y(u, v, r),$ and $N(u, v, r)$ are the hydrodynamic forces that will be expressed in terms of hydrodynamic derivatives (H-derivatives); $k$ is the restoring force coefficient from the mooring system connected to the turret, what is supposed here to be linear and axisymmetric. The variable $d \approx 0$ is the distance between the turret static equilibrium position and the instantaneous dynamic position. Figure 1 also leads to

\begin{equation}
x = u\cos\psi - v\sin\psi - U
\end{equation}

\begin{equation}
y = u\sin\psi + v\cos\psi
\end{equation}

\begin{equation}
r = \dot{\psi},
\end{equation}

and

\begin{equation}
\omega = \gamma + \psi
\end{equation}

As shown in Fernandes and Sphaier (1997), these equations are valid as long as the articulation angles are small enough. A more general stability analysis allows to write the equations in their general form of

\begin{equation}
\begin{align*}
\ddot{u} & = f_1(u, v, r) + kd\cos\omega \\
\ddot{v} & = f_2(u, v, r) - kd\sin\omega \\
\ddot{r} & = f_3(u, v, r) - k\ddot{d}\sin\omega
\end{align*}
\end{equation}

where $f_1, f_2, f_3$ are the hydrodynamic forces. }

\cite{PETROBRAS} patent pending

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