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Dynamics and control of a two-body floating system under realistic environmental loads

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Abstract

In this paper a systematic study of the dynamics of turret FPSO in single and tandem configuration is carried out for further application in the formulation of control strategy of the shuttle vessel. As a preliminary step equilibria are calculated along with their stability properties for a range of values of the main parameters defining each configuration: wind speed, significant height and mean period of waves and relative angles of incidence. The influence of the position of the turret is also assessed. Static solutions are obtained numerically due to the complexity of the mathematical models and then their stability properties are investigated through time-domain simulations. The system displays a variety of different regimes of solutions in which both their number and their stability may change as one or more parameters are varied. The results are summarized in a series of bifurcation diagrams in which the evolution of steady-state heading response of the ships is displayed as a function of parameters characterizing the environmental state. Finally the application of the bifurcation diagram for a control strategy for the shuttle vessel is suggested.

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1. Introduction

In some countries such as Brazil oil is found in offshore deep-water fields where fixed platforms cannot be employed and the oil has to be taken to the shore through a shuttle vessel. Among several systems to exploit the oil, the floating production, storage and offloading (FPSO) system has received special attention due to its economical and technical advantages. In general, an FPSO is a tanker converted to function as a temporary oil storage system. This vessel has to be kept in the desired position in spite of forces and moments due to the current, waves and wind. Different types of station keeping systems have been developed in order to adequate the cost and safety of operations. Two common two station-keeping systems are Differentiated Compliant Anchoring System (DICAS) and turret-type. The DICAS is composed of a set of mooring lines that connect the vessel to anchors on the seabed in which different pre-tensions of the lines assure some freedom to the ship to adjust itself to the predominant direction of the incoming weather. On the other hand, turret-type allows a complete yaw freedom of the vessel since it is positioned through a large cylindrical structure (turret) that cuts through the vessel vertically, working as a vertical bearing. Then, the mooring lines connect the turret to anchors on the seabed. In both cases, during the offloading a shuttle vessel is connected to the FPSO through a hawser in tandem configuration. One of the main concerns in the design and operation of these large systems is clearly their dynamical behavior under the action of wind, current and waves in order to avoid collision of the vessels. However, the comprehensive understanding of the dynamics of those kinds of systems is extremely difficult due to non-linearity of their mathematical model. The Newtonian six-degree-of-freedom model results in a set of 12 first-order non-linearly coupled differential equations [1]. Previous works have shown the dynamics of the system can exhibit quite a complex scenario that includes bifurcations of static equilibria, limit cycle and chaotic motion [1–5]. Those features have been observed even in a study of shuttle vessel-only [1,3] or FPSO-only [2,6]. Clearly, a more intricate diagram of bifurcation occurs for ships in tandem configuration with turret-FPSO, in particular, in which the equilibria of two ships have to be calculated simultaneously [3]. In fact, the fixed points of the system depend on the combination of the relative angle of incidence of the current, wind and waves and their intensity as well. Furthermore, those forces play different roles depending on the system parameters such as ship displacement or position of the turret. Due to the complexity of the system model, Souza Jr and Fernandes [7] have proposed an archetypal model, the stability of which is analyzed through the concept of the potential wells.