Nonlinear Dynamics Analysis of a Rotating Drill Pipe Model Incorporating the Magnus Effect and Rotary Inertia of the Pipe

Hanny Tun, Hiroyoshi Suzuki* and Taito Koga
Department of Naval Architecture and Ocean Engineering, Osaka University
Suita, Osaka, Japan

Thant Zin Htun
Engineering and Technology Development Department, Hitachi Zosen Corporation
Suminoe-Ku, Osaka, Japan

Tomoya Inoue
Institute for Marine-Earth Exploration and Engineering, JAMSTEC
Yokosuka, Kanagawa, Japan

This study investigates the nonlinear dynamic motions of the rotating drill pipe model caused by the Magnus effect by using a three-dimensional fully parameterized beam element based on the absolute nodal coordinate formulation, which can account for the rotary inertia of the pipe. Nonlinear coupling of bending and torsional deformations was imposed by a rotation matrix transmitted twisting along the length of the pipe. The three-dimensional hydrodynamics forces of the pipe model were computed using ANSYS Fluent and applied as an external force vector on the pipe model. The applicability of the presented model is confirmed by the comparison of simulation results and experimental results.

INTRODUCTION

During riserless drilling operations in oil and gas explorations, the rotation of the drill pipe generates lift force when operating under ocean currents, which is called the Magnus effect, as shown in Fig. 1. The dominant lift force parameters that can influence the Magnus effect are the flow velocity and the rotational velocity of the pipe. Depending on the length of the drill pipes used in the drilling operation, the bending deformation as a result of the Magnus force and the drill pipes can also be assumed to be flexible structures compared with their diameter and length ratio, although these pipes are generally made of steel.

Thus, experimental and numerical studies of the drill pipe resulting from the Magnus effect and other drill pipe dynamics were conducted to know the dynamic behaviors of the drill pipe in previous studies (Inoue et al., 2013, 2019; Inoue, Suzuki, et al., 2017; Suzuki et al., 2016, 2018). Then, the behavior of the rotating drill pipe model in uniform flow was examined and considered for various flow velocities and rotational velocities by Suzuki et al. (2022). Besides this, the detailed formulation for hydrodynamic force estimation of the absolute nodal coordinate formulation (ANCF) beam element was also stated by Takehara et al. (2011), and the dynamic analysis of mooring lines was evaluated by Nakajima et al. (1983).

During drilling operations at sea, the drill pipes are subjected to ocean currents and a downward force; weight on bit (WOB) is exerted on the drill bit while rotating on its longitudinal axis.

*ISOPE Member.
Received July 27, 2023; updated and further revised manuscript received by the editors August 12, 2023. The original version (prior to the final updated and revised manuscript) was presented at the Thirty-third International Ocean and Polar Engineering Conference (ISOPE-2023), Ottawa, Canada, June 18–23, 2023.
KEY WORDS: Model drill pipe, nonlinear dynamic motions, Magnus effect, rotary inertia, ANCF.

These forces play a significant role in the correct representation of the drill pipe’s underwater dynamics, which is yet to be properly investigated. However, it may be challenging to adequately maintain WOB and rotate the drill bit because of the complex nonlinear dynamic motions of the drill pipe in deep drilling operations.

Moreover, excessive bending stress and fatigue caused by the occurrence of a high magnitude of Magnus lift force leads to drill pipe failure, which was investigated by Inoue, Wada, et al. (2017). In addition, it is also still difficult to monitor the entire length of the long drill pipe in deep drilling operations because the dynamic behaviors of the pipe can be observed for only 30 m on top of the pipe currently.

On the basis of this fact, the numerical simulation of the rotating drill pipe model can accomplish the investigation for the study of the underwater behavior of a drill pipe in deep drilling operations.