Application of State-space Model Based on Complex Exponential Decomposition to Analyze Dynamic Response of Semi-submersible Controlled by Thrusters

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ABSTRACT

Rapid time-domain dynamic response analysis of a semi-submersible platform is important to the control strategy of thrusters. Nevertheless, the convolution items in Cummins equation make the calculation of dynamic response inefficient. For this reason, the method using state-space model to replace the convolution items is applied to rapidly obtain the dynamic response. The state-space model is constructed by poles and corresponding residues, which are obtained by implementing complex exponential decomposition to the retardation functions. A numerical model is applied to investigate the performance of the method, which shows that the calculated responses match well with those of the Newmark-β method.

KEY WORDS: Semi-submersible platform; thrust; dynamic response analysis; retardation function; state-space model; complex exponential decomposition

INTRODUCTION

With the increasing demand of ocean exploration and exploitation, marine equipment and technology have been constantly updated. Benefiting from the good performance, semi-submersible platforms are widely used in the exploitation of oil and gas resources. To ensure safe service, the dynamic response analysis of the semi-submersible platform is essential.

Most researches focus on the dynamic responses of the semi-submersible platforms under free and moored conditions. Nevertheless, the mooring system is no-longer economical when the water depth is beyond 1000 meters. Thus, dynamic positioning (DP) system is employed on semi-submersible platforms in order to keep their position by proper action of the propulsion system at deeper water depth above 1000 meters (Balchen et al. 1980). The advantages of entirely DP operated vessels include the ability to operate in deep-water, and the flexibility to quickly establish position and leave location (Sørensen et al. 2001). When it comes to the six-DOF dynamic responses of floating structures with a DP thrust system, few studies have been carried out. Meanwhile, the studies of DP system have put emphasis on the control system and the three-DOF dynamic responses in the horizontal plane. However, the thrusters operating under the bottom of a platform may lead to angular motions like roll and pitch, which may cause security risks similarly. Thus, this paper aims to utilize an efficient method to estimate the dynamic responses of a semi-submersible platform with thrust.

Cummins (1962) presented the acknowledged Cummins equation when considering the force and motion of the floating structures in time domain. Nevertheless, the convolution term in the Cummins equation needs to be calculated step by step at each sampling point and is thus time-consuming (Fossen, 2002; Kashiwagi, 2004; Perez, 2010). Liu et al. (2016; 2017) proposed an efficient dynamic response estimation method for floating structures in frequency domain. However, considering that the thrust generated by a thrust system is time-varying, the frequency domain method may no longer be applicable.

In this paper, a practical dynamic response estimation method for floating structures is utilized, which is based on state-space model by applying complex exponential decomposition. In this method, convolution items in Cummins equation are replaced with a state-space model which is constructed by poles and corresponding residues. The dynamic optimal thrust allocation logic is introduced to demonstrate the contribution of the thrust system to the external loads of the semi-submersible platform. Cases with and without thrust are employed to investigate the performance of the proposed method, the results show that the response calculated by the proposed method matches well with those of the traditional Newmark-β method. The method could prove an application to dynamic response estimation of six-DOFs semi-submersible platforms under environment loads and thrust.

MOTION DIFFERENTIAL EQUATION OF FLOATING STRUCTURES

According to the Newton's second law of motion, the motion equation of a semi-submersible platform excited by complex load can be expressed as following(Liang, 2015):

$$\mathbf{M}x(t) = \mathbf{f}^{H}(t) + \mathbf{f}^{X}(t) + \mathbf{f}^{W}(t) + \mathbf{f}^{R}(t) + \mathbf{f}^{E}(t) + \mathbf{f}^{R}(t) + \mathbf{f}^{F}(t)$$ (1)