Effects of Passive and Active Heave Compensators on Deepwater Lifting Operation

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In deepwater installation and lift, amplified vertical motions of equipment can be caused by axial resonance of wire. This can occur even in operational sea state due to the elastic behavior of the wire. In order to reduce the vertical oscillatory motion of the lifted equipment, heave compensation systems have been frequently used in the subsea installation operation. In the present study, a nonlinear time-domain analysis has been applied to investigate the effectiveness of the heave compensator in reducing the vertical amplification near its wire resonance during deepwater lifting operation. Analysis of coupled crane vessel and equipment dynamics connected via crane wire were carried out in time domain. A passive heave compensator was modeled as a combination of nonlinear spring and damper in the axial direction. An active heave compensation system was numerically implemented using classical PD feedback controller. A series of numerical simulations was conducted for a wide range of wave periods and water depths to find effective operational ranges of passive and active heave compensators.

INTRODUCTION

A typical deepwater installation operation consists of 4 main phases: liftoff from the deck of a transport barge, lowering through the wave zone, deepwater lowering/lift operation, touchdown on seabed and retrieval. During the deepwater lifting operation, a heave compensation system can be employed to mitigate the vertical resonant motion of the lifted equipment which reduces the dynamic loads in the hoisting wire system. There are 3 types of heave compensators that have been used in deepwater lifts: Passive, active and combined heave compensators. A passive heave compensator (PHC) is a kind of spring-damper system which shifts the resonant frequency of the vertical motion of the hoisting wire system. The passive heave compensator is also designed to reduce impacts on offshore cranes by adding damping in the hoisting wire. An active heave compensator (AHC) uses either controlled winches or hydraulic pistons, and reference signals. The active heave compensation systems generally use information from the vessel motion reference unit (MRU) to control payout length of the winch line.

In 1976 Chung (2009) measured the then-unexpected resonance in the axial pipe motion of a heavy-duty ocean-mining pipe with the pipe’s bottom end free, and he tested the effects of full-scale heave compensators used in lifting pipe for 5,000-m water depth during the sea operations in the North Pacific Ocean. To identify the existence of the axial resonance and pipe stress, Chung and Whitney (1981) numerically showed the results of the dynamic vertical resonant stretching oscillation of a 5,000-m ocean mining pipe, a problem which is physically similar to this study. They identified primary parameters for the pipe stretching and explained basic characteristics of axial oscillation of deep-ocean pipe for seafloor equipment operation. Clauss et al. (2000) presented a comparative study of the operation capabilities of floating cranes. They also reported nonlinear phenomena of the coupled system of floating structure and swinging load. Shiraishi et al. (2001) suggested a device which can decrease swinging of the hanging hook of a floating crane vessel. Than et al. 2002) applied a nonlinear dynamic analysis program (FEDEM) to simulate offshore crane operations. This study mainly focused on how dynamic amplification can be reduced by proper operation and design of the hydraulic and control system. Cha et al. (2009) carried out time domain simulations of the block lifting with a floating crane vessel by using multi-body system dynamics. Kimiaei (2009) presented a simplified numerical model for the accurate estimation of hydrodynamic forces on subsea platforms and compared the results with the DNV guidelines. Nam et al. (2012) developed a time-domain analysis program for floating crane vessel systems. They investigated the effect of a heave compensator during the lowering operation of subsea equipment.

In this study, we carried out nonlinear time-domain analysis for the deepwater installation problem by using a house code, KIMAPS_CRANE (Nam et al., 2012). Fully coupled dynamics of floating crane vessels, crane wires and lifted equipment were simulated in time-domain. The passive heave compensator was modeled as a generalized spring-damper system, and the active heave compensator was implemented using a classical PD feedback controller. In the numerical simulations, focus was on the heave compensator effects during the deepwater lift operation. The basic characteristics of the vertical motion of lifted equipment were investigated in view of amplification factor. Then, the overall performance of passive and active heave compensators was numerically examined. The effective operational range of heave compensators in real sea applications was discussed.

TIME-DOMAIN ANALYSIS OF LIFTING OPERATION

Crane Vessel System

In the nonlinear time-domain analysis, the coupled dynamics of floating crane vessel, crane wire and lifted equipment shown in Fig. 1 were considered. The motions of the crane vessel are