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Optimization of a Direct Drive Active Heave Compensator

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ABSTRACT

Heave compensation systems enable vertically tethered systems to operate in dynamic sea states. Both passive and active systems can be implemented to reduce tether tension fluctuations and submerged equipment oscillations. This paper presents work completed on the analysis of a winch-controlled active heave compensator for a vertically tethered system. Simulation-based design methods were used to evaluate the heave compensation given the complete nonlinear coupling between environment, tether, and winch behavior. The analysis provides insight on the controller gain values and power requirements of the winch to operate in a variety of system configurations and sea state conditions. In addition, the benefit of a passive compensator system coupled to the active system highlights the potential utility of a hybrid heave compensator system.

KEY WORDS: heave compensation; finite element; dynamic simulation; active control; variable length cable dynamics

INTRODUCTION

Vertically tethered systems are commonly used to deploy equipment and materials in ocean environments. Examples include large deep sea Remotely Operated Vehicle (ROV) systems, drill strings, equipment and salvage platforms, to smaller oceanographic instrumentation systems such as CTD platforms. Operation in rough seas may result in large oscillations of the payload which can leads to instances of slack tether followed by large snap loads that can damage the structural members and the electrical and optical conductors of the tether (Driscoll et al., 2000b; Niedzwecki and Thampi, 1991).

To mitigate the potential for snap loads, a compliant component, called a heave compensator, is added to the structural chain formed by the ship, tether and payload. If the parameters of the heave compensator are properly chosen, the dynamic payload motions can be mitigated and snap loads eliminated. Both passive (Driscoll et al., 2000a) and active (Korde, 1998) heave compensation strategies have been explored.

The work presented here presents the optimization of a PID controlled winch active heave compensation system suspending a large ROV cage. Because of the nonlinear nature of the system, dynamic simulations were used to ensure the active controller performed adequately under a variety of sea states and operating depths. The controller coefficients and allowable payout rates are used as the optimization parameters. The problem studied uses the same tether properties, operating depths, sea states, and objective weighting functions as those used for a passive heave compensator system design presented in Driscoll et al. (2000a).

First, the simulation components, which include the winch and tether models, are presented. Next, the objective weighting functions are reviewed and the resulting active heave compensator performance is quantified. Finally, the optimal passive heave compensator produced by Driscoll et al. (2000a) is appended to the system and the performance of the hybrid active/passive heave compensation system is quantified.

SIMULATION MODEL

The system of interest consists of a winch drum, tether, and a remotely operated vehicle (ROV) cage. A finite element cable model is used for the tether and the ROV cage is represented by a lumped mass at the bottom. The winch is modeled with a single rotational degree of freedom second order differential equation. The winch is loaded by the tether tension as measured at the surface in addition to torque produced by the winch motor. The winch in turn sets the payout velocity of a variable length boundary element in the finite element tether model. Finally, a PID control scheme is used to compensate tension fluctuations at the surface as well as maintain the operating depth of the ROV cage using the motor throttle as a control signal.

Winch dynamics

The winch drum dynamic equation is:

$$\dot{\omega} = \frac{1}{J}\left(T_e + T_c r_d - sign(\omega) T_b - B_w \omega\right) \qquad (1)$$

where $\dot{\omega}$ is the drum angular acceleration, J is the drum inertia, T_e is the winch motor torque, T_c is the top tension of the tether, r_d is the drum radius, T_b is the brake torque, and B_w is a rotational damping coefficient. A positive rotation of the drum results in payout, or an increase in the length of the tether.

The torque produced by the winch motor is a linear function of the throttle, t, and the maximum motor torque capacity, T_{emax}:

$$T_e = T_{emax} t \qquad (2)$$
$$-1 \leq t \leq 1$$