Hydraulic Multi-axial Levelling Control for Turbine Access System of Offshore Wind Farm

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Offshore wind energy has become the most important green energy globally. Due to the wave the working point of the vessel oscillates and cannot be kept in a fixed position so that the maritime or underwater construction become difficult and dangerous. Therefore, an active levelling controlled multi-axial hydraulic Turbine Access System (TAS) system for offshore wind farms is necessary for improving this problem. This study aims to investigate a new active levelling control multi-axial hydraulic system for Taiwan offshore wind farms including design, dynamic modelling and simulation of TAS mechanism, hydraulic driving system, control system, and test rig set up for dynamic simulation and experiment. The vertical height, the rolling angle and the vertical acceleration of the end effector of TAS can be effectively reduced through the active motion compensation control of TAS for improving the access safety of the offshore wind turbine. For simulation, the dynamic modelling and co-simulation can be implemented by software ADAMS (Automated Dynamic Analysis of Mechanical Systems) for mechanism integrated with MATLAB/SIMULINK for the hydraulic driving system and the closed-loop control system of the active motion compensation control in order to verify the effect of active compensation control system of TAS. Besides, a full-scale test rig of the TAS is set up for verifying the effect of active compensation control system of TAS experimentally.

Keywords: offshore wind turbine access system, active motion compensation control, kinematics analysis, dynamic simulation, experiment.

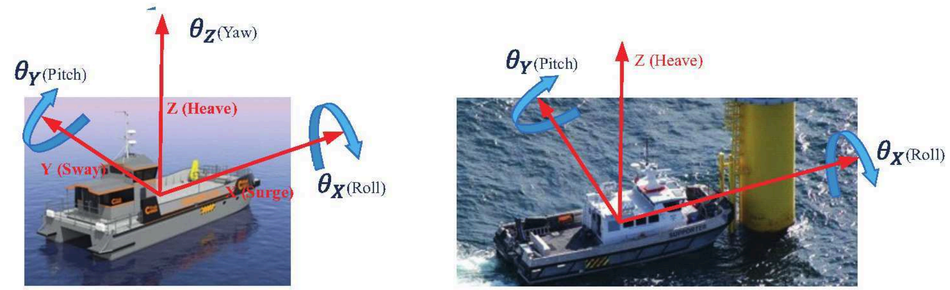
Target audience: Mobile hydraulics, Marine Hydraulics, Motion control

1 Introduction

Offshore wind energy has been developed soon and become the most important green energy worldwide since the past decade. The industries in Taiwan have organized a Marine-Team to develop the localized marine engineering for offshore wind energy development in Taiwan. Due to the wave the working point of the vessel oscillates and cannot be kept in a fixed or stable position so that the maritime or underwater construction become difficult and dangerous. The safety assurance for the maintenance of offshore wind turbines becomes an important issue. In order to prevent maintenance staff from the risk of accessing the offshore wind turbines, the turbine access system (TAS) is one of the necessary equipment. Therefore, it is imperative to develop the TAS of offshore wind turbines, which can not only ensure the safety of maintenance, but also effectively enhance the attendance of maritime ship and reduce the installation cost of maritime works. Thus, this study aims to investigate a new offshore wind turbine access system, including design, dynamic modeling and simulation of TAS mechanism, hydraulic driving system, control system, and test rig set up for dynamic simulation and experiment. The vertical height, the rolling angle and the vertical acceleration of the end effector of TAS can be effectively reduced through the active motion compensation control of TAS for improving the access safety of the offshore wind turbine.

2 System Layout of TAS

Considering manufacturing cost, function and the feasibility of practical application, the TAS is installed in the bow of vessel to compensate the shaking motion of ship. When the ship is docked, it is pushed onto the tower with the thrust of the propeller, which can reduce the freedom of motion of the hull from six-DOF to three-DOF, such as heave, roll and pitch, as shown in Figure 1. Hence, the TAS only requires to achieve the motion compensation control of the three DOF.



(a) (b)

Figure 1: Ship Motions
(a) Six-Degrees of Freedom (b) Three-Degrees of Freedom

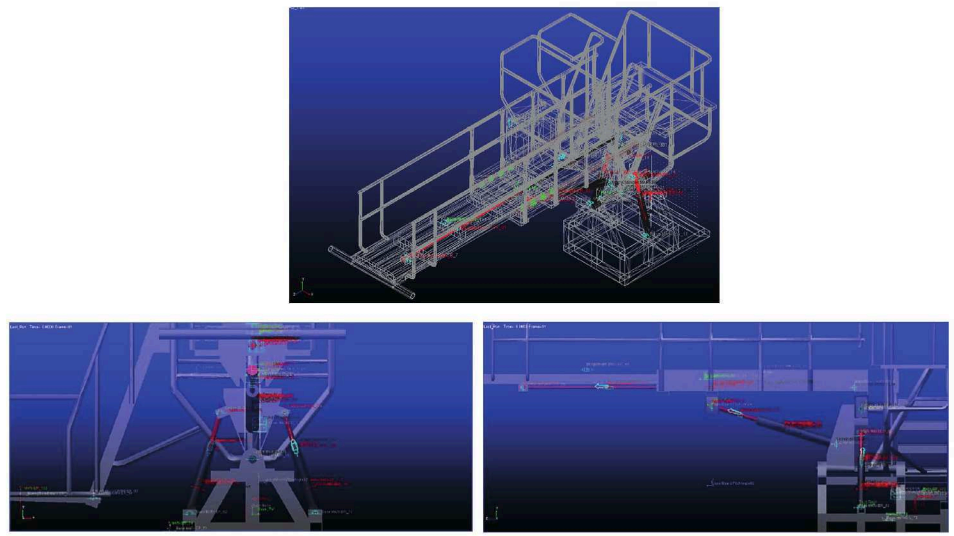


Figure 2: Configuration of TAS.

Figure 2 shows the configuration of the developed TAS. Based on the DOFs of the ship, the design of TAS contains three compensating systems, such as roll, pitch and heave. The roll compensating system consists of a pair of symmetrical hydraulic cylinders moving at same time to balance the motion of ship rolling. In the pitch and heave compensating systems, the hydraulic cylinder is used to balance the motion of ship pitching and heaving simultaneously. In the actual situation, the maintenance staff will go from the side ladder to the upper aisle, with handrails on both sides. The TAS test rig is driven and controlled by the hydraulic servo system. Position sensors are fitted at the cylinders. The A/D and D/A interface cards are used to link the sensors and computer to control the TAS.

3 Kinematic Analysis

In order to decrease the vertical displacement of the end effector, the end effector should be maintained on the initial position possibly. Therefore, it is necessary to obtain the relationship between the end effector and the actuators by kinematics and then implement leveling control. In the study, the geometric analysis of inverse kinematics is adopted to analyze the geometric relationship between the ship motions and the vertical displacement of the end effector in order to obtain the compensative angles and each required hydraulic cylinder elongation, as shown in Figure 3.

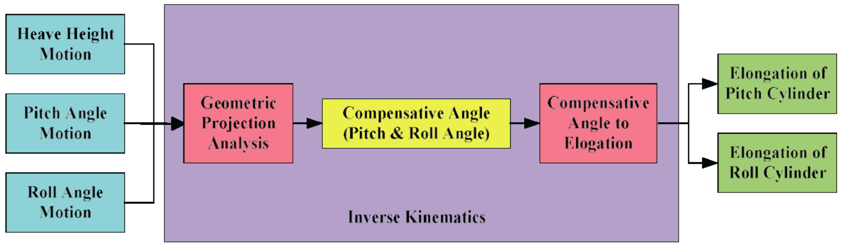


Figure 3: Flow Chart of Inverse Kinematics

Similarly, the forward kinematics, as shown in Figure 4, is to explore the relationship between the elongation of each hydraulic cylinder and the roll angle, the vertical displacement, and the vertical acceleration of the end effector in order to verify the effect of leveling control by TAS.

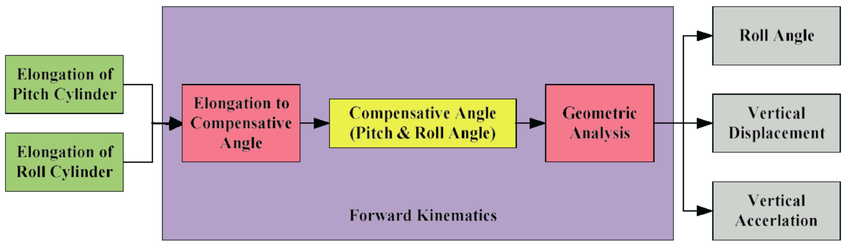


Figure 4: Flow Chart of Forward Kinematics

4 Control System of TAS

The overall control system block diagram of TAS is shown in Figure 5. According to the input ship motion, the target displacement of hydraulic cylinders, X_{roll}, target and X_{pitch}, target can be obtained by the inverse kinematics. The path control of TAS can perform via controllers according to the feedback signals of each sensor. Through kinematics the heave height, roll angle and pitch angle of the end point can be obtained.

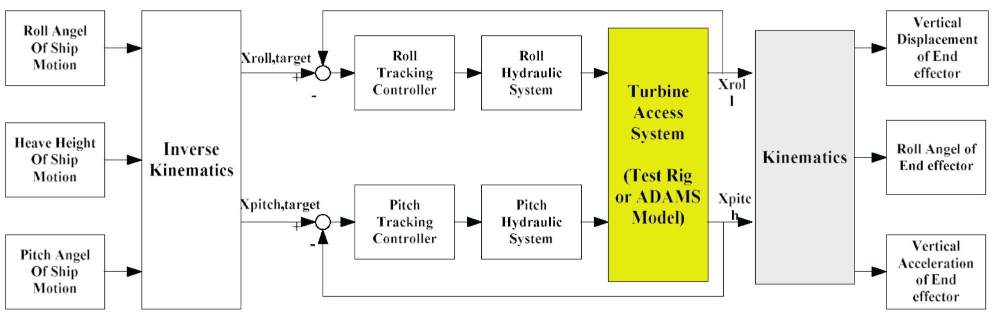


Figure 5: Block diagram of TAS control system.

5 Simulation of TAS

The simulation of TAS contains the mechanism dynamic simulation by ADAMS, hydraulic system by MATLAB/SIMULINK and control system by MATLAB/SIMULINK. The hydraulic system contains two subsystems, including roll compensating system and pitch compensating system. The ship motion which input to the TAS simulation is under the significant wave height 1 m, wave period 7.5sec, and inflow angle 45 degree. Figure 6 shows the direction relation between the ship and the wave. The ship motion under the input sea wave is shown in Figure 7. Figure 8 and Figure 9 show the simulation response of tracking control of pitch and roll compensation system. Finally, the end effector motion simulation comparison between active compensation and uncompensated can be shown in Figure 10, including (a) vertical height of end effector, (b) roll angle of end effector, and (c) vertical acceleration of end effector.

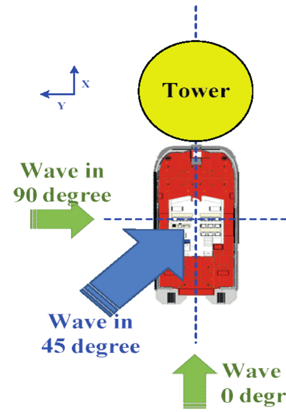


Figure 6: Direction relation between ship and wave.

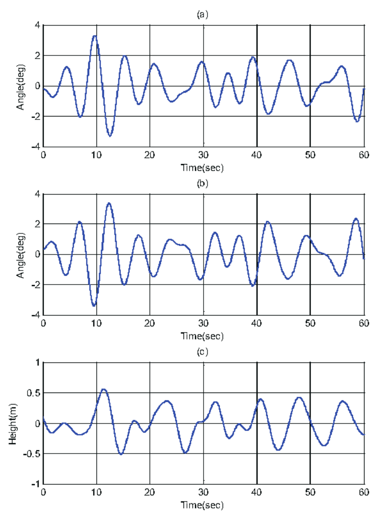


Figure 7: Ship motion under the input sea wave (a) roll angle, (b) pitch angle, (c) Heave position.

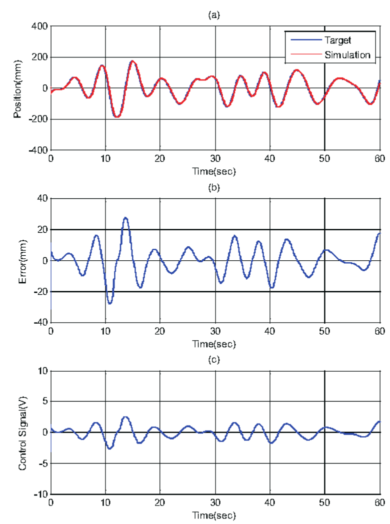


Figure 8: Simulation response of tracking control of pitch compensation system (a) tracking control response, (b) control error, (c) control signal.

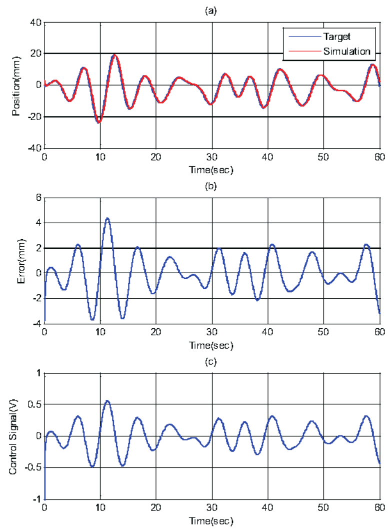


Figure 9: Simulation response of tracking control of roll compensation system (a) tracking control response, (b) control error, (c) control signal.

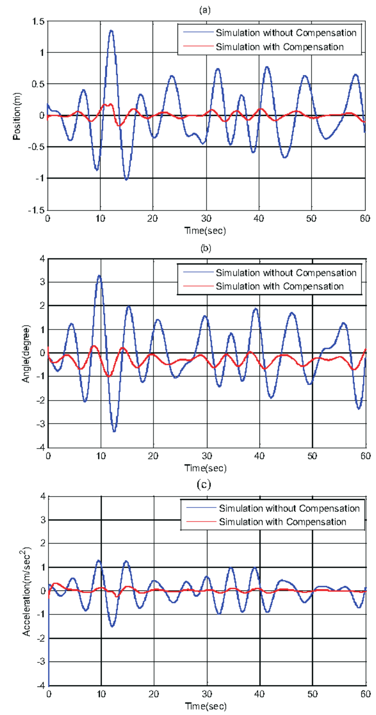


Figure 10: Simulation comparison between active compensation and uncompensated (a) vertical height of end effector, (b) roll angle of end effector (c) vertical acceleration of end effector.

6 Experiment of TAS

The control strategies validated in simulation can be implemented in the test rig of TAS. The condition of wave is the same as that in simulation with the significant wave height 1m, wave period 7.5 sec, and inflow angle 45 degree. The ship motion under the input sea wave is the same as that in Figure 7. Figure 11 and Figure 12 show the experimental response of tracking control of pitch and roll compensation system. Consequently, the end effector motion experimental comparison between active compensation and uncompensated can be shown in Figure 13, including (a) vertical height of end effector, (b) roll angle of end effector, and (c) vertical acceleration of end effector. The maximum cylinder tracking error of pitch and roll compensation systems is about 58mm and 5.4mm. The end effector for the staff can be compensated within ± 0.35m of vertical height instead of ± 1.35m without compensation; ± 1.1^o of roll angle instead of ± 3.3^o without compensation; ± 0.04G of vertical acceleration instead of ± 0.15G without compensation.

7 Conclusions

This study developed a hydraulic multi-axial active motion compensation system of TAS for offshore wind turbines, which is achieve both in the dynamic simulation via ADAMS and MATLAB/ SIMULINK and the practical experiment in the full-scale test rig. The simulation and experimental results show that the TAS can effectively reduce the vertical height, roll angle and pitch angle and the vertical acceleration of the end point.

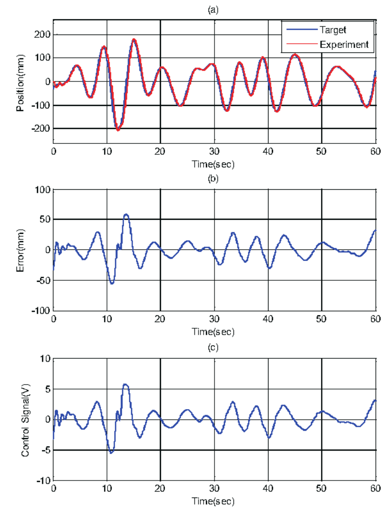


Figure 11: Experimental response of tracking control of pitch compensation system (a) tracking control response, (b) control error, (c) control signal.

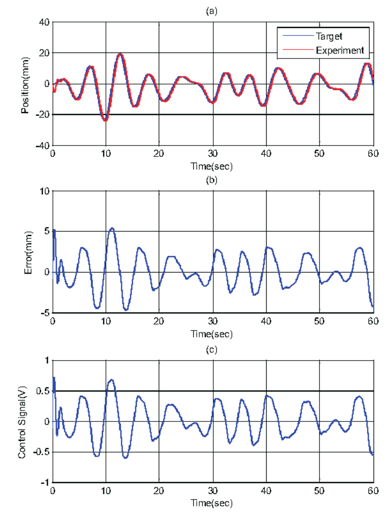


Figure 12: Experimental response of tracking control of roll compensation system (a) tracking control response, (b) control error, (c) control signal.

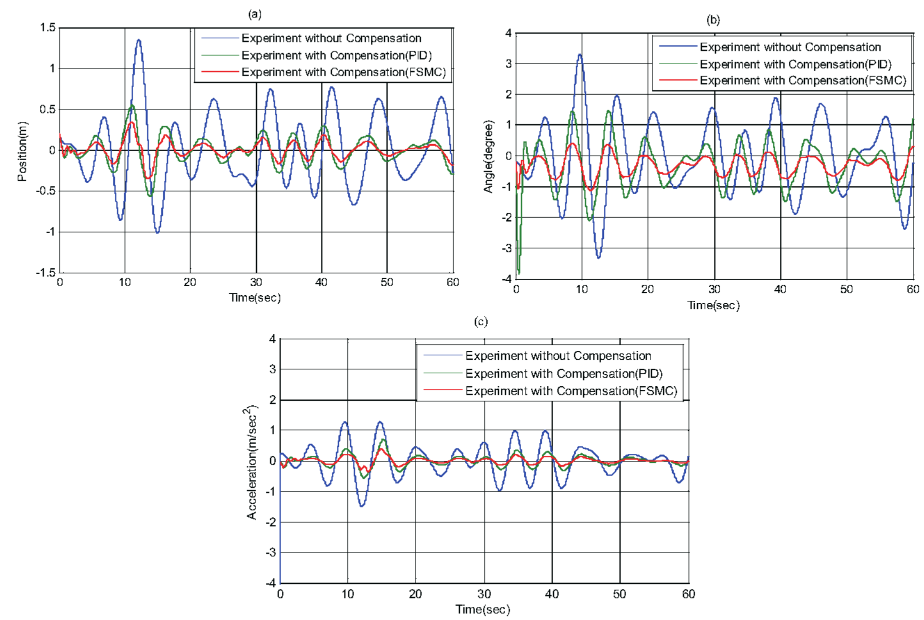


Figure 13: Experimental comparison between active compensation and uncompensated (a) vertical height of end effector, (b) roll angle of end effector (c) vertical acceleration of end effector.

Acknowledgements

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