Dynamics and Control for Deep-Sea Marine Risers

A marine riser is a pipe that connects a floating platform such as an oil rig or drillship on the ocean surface to the sea floor. Used as a fluid conveyer, it transports undersea energy resources from the seabed to the platform on the surface. Marine risers are also used in relief operations for transporting mud, cement, and other materials to the seabed.

Due to winds, waves, and water currents, the floating platform on the sea surface responds in six-degree-of-freedom motions. The surge, sway, and yaw motions of the floating platform are controlled by means of a dynamic positioning system (DPS) or a passive mooring system. Forces on the marine riser can be mitigated with a riser tensioner control system.

Advanced control of marine risers and floating platforms is a crucial enabler for deepwater drilling and safety operations.

Development Driller III drilling relief well at Deep Water Horizon site (Courtesy of Paddy Ryan, www.ryanphotographic.com)

Deepwater Horizon Relief Well Application

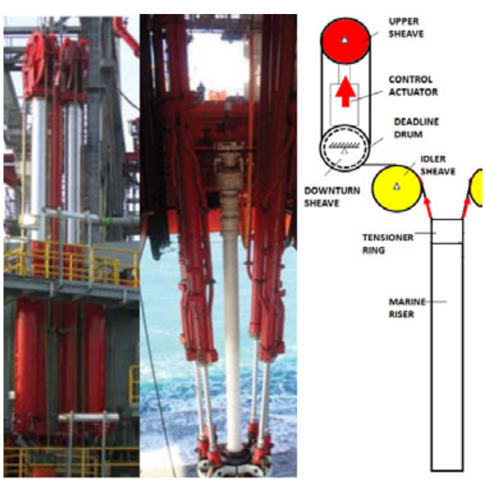
In September 2009, Deepwater Horizon, an ultra-deepwater, dynamically positioned offshore oil drilling rig, drilled the deepest oil well in history at a vertical depth of more than 10,600 m in the Gulf of Mexico. On April 20, 2010, while drilling at the Macondo Prospect, an explosion on the rig caused by a blowout killed 11 crewmen and ignited a fireball visible from 35 miles (56 km) away. On April 22, Deepwater Horizon sank, leaving the well gushing at the seabed and causing the largest offshore oil spill in U.S. history. Over the next several months, relief wells were drilled to cap the well, which was finally declared sealed on September 19, 2010.

Advanced control was crucial to the relief effort. A dynamic positioning system enabled the rig to be quickly positioned automatically in surge, sway, and yaw directions on site without the use of mooring lines. The riser tensioner control enabled the drilling operation to take place despite the heave response of the vessel due to wind, wave, and ocean current forces from the marine environment.

Riser Tensioner System

As the bottom of the riser is fixed on the seabed, forces arising from the motion of the surface vessel must be managed. For vertical motions, if the floating platform heaves downward due to waves or swell, the riser would buckle under its own weight. On the other hand, if the platform heaves upward, the pulling will induce the transmission of high forces through the riser.

This heaving motion is mitigated by the riser tensioner system, which controls the upward pulling force. As shown in the schematic on the left, the upward force is transmitted by a number of wires in contact with sheaves and coupled to the tensioner assembly. Up to eight tensioner assemblies can be used to minimize the force communicated to the riser.



Riser tensioner system

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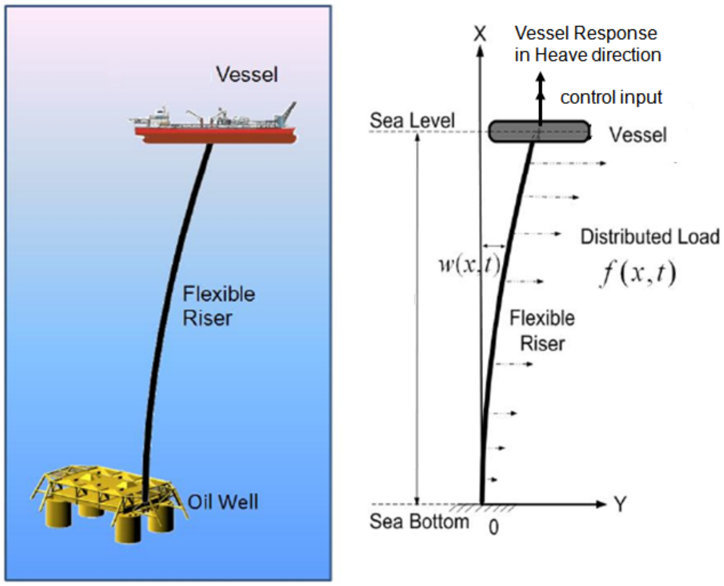
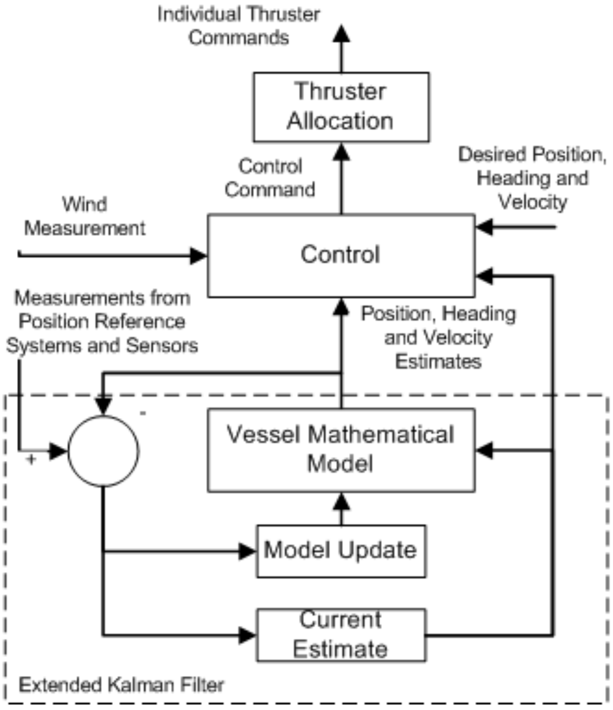


Illustration of the marine riser bottom fixed on the seabed and connected to a floating surface vessel

Vibration Suppression of Marine Risers

The lifting forces in the wire result from the actuation of a tensioner piston using high pressure from hydraulic cylinders. The cylinders are pressurized by a hydropneumatic accumulator that is connected to air pressure vessels via a control valve to maintain the specified pressures. To prevent extreme movement of the tensioner piston, a fluid flow shutoff valve is inserted between the hydropneumatic accumulator and the piston bore chamber of the tensioner. An air shutoff valve is inserted between the accumulator and control valve unit. In the event of a wire break, the control system restricts the flow of the volume via the flow shutoff valves. Thus the top tension of the riser is controlled, allowing the system to operate despite the heave response of the vessel.



Simplified block diagram showing the dynamic positioning system with control, thruster allocation, and the extended Kalman filter

Dynamic Positioning System (DPS)

The DPS actuates the thrusters to keep the vessel within a fixed envelope determined by the operation being carried out. A high-precision control mode can be used for high-accuracy positioning in any weather conditions, at the expense of power consumption and wear and tear of machinery and thrusters. Another mode of control uses the thrusters more smoothly at the expense of a larger positioning envelope for less position-critical operations or during benign weather.

DPS control typically relies on a mathematical model of the vessel that includes hydrodynamic characteristics such as current drag coefficients, added mass, coriolis, and damping. As the mathematical model itself is not a perfect representation of the actual vessel, the model is continuously updated using an extended Kalman filter. The vessel heading and position are measured using sensors such as gyrocompassess, a position reference system, a differential global positioning system, inertial measurement units, and vertical reference sensors.