

HEAVE COMPENSATION SYSTEM FOR MARINE CONSTRUCTION OPERATION

TECHNICAL FIELD

This invention relates to heave compensation systems used in marine construction operations. Specifically, it pertains to both active and passive heave compensation technologies with heave compensation hydraulic system control and monitoring system of the fall pipe position for a rock installation barge

BACKGROUND

Heave compensation systems are essential in marine construction operations to counteract the vertical motion of vessels caused by waves. These systems ensure stability, precision, and safety during operations such as drilling, hoisting, and subsea installations. Existing Heave compensation systems, however, often face challenges in achieving high accuracy and efficiency, particularly in rough sea conditions. This invention aims to address these challenges through using a combination of standard two-chamber hydraulic cylinder (instead of the commonly used three-chamber hydraulic cylinder), a logic control valve (manifold block), a directional proportional valve, a high-pressure accumulator, a low-pressure accumulator, and a hydraulic power unit (HPU).

SUMMARY

The present invention provides a heave compensation system that includes both active and passive heave compensation technologies. When the waves are low to medium sea state, the passive heave compensation is active. In higher sea states, the Active Heave Compensation mode is active and the entire system, including the hydraulic power unit, high- and low-pressure accumulators, logic-integrated hydraulic valve blocks, solenoid proportional valve, hydraulic cylinder, and electrical control system, will operate automatically.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1. illustrates the telescopic fall pipe system with components for heave compensation

FIGURE 2. illustrates the hydraulic system for the heave compensation.

FIGURE 3. Illustrates the user interface screen for control of the heave compensation system.

DETAILED DESCRIPTION

Referring to the components of the system as illustrated in the provided figures:

As shown in Fig. 1, the telescopic pipe is suspended below the gimbal by steel wire ropes at both sides, passes through two sets of guide pulleys, and is connected to the double drum hoisting winch via the moving sheave block(82) attached to the AHC hydraulic cylinder (84).

At the start of operation, the AHC hydraulic cylinder piston is positioned in the middle of cylinder stroke (a linear positioning sensor is inside cylinder rod). The hoisting winch is operated to lower the telescopic fall pipe to the working required position (e.g. the lower end of the fall pipe is one meter from the seabed). At this point, the hoisting winch operation is stopped.

The AHC cylinder reciprocates according to the operating system instructions, with the reciprocating distance executed according to the control system commands. This achieves the goal of controlling the telescopic fall pipe to move up and down in the opposite direction to the ship or waves, thus keeps the tip of the pipe within a certain distance from the seabed as required by the operation, preventing it from going too far or hitting the seabed and causing an accident.

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The Hoisting Assembly: The system is powered by a double drum hoisting winch (81). This winch serves as the primary means of deploying and retrieving the telescopic fall pipe (88). A wire rope (83) is routed from the winch through a series of sheaves to control the mechanical load.

The Heave Compensation Mechanism: Active compensation is achieved through the interaction of the AHC cylinder (84) and the moving sheave block (82).

The AHC cylinder (84) is controlled by an AHC logic manifold block and supported by accumulators (89) and HPU (90), which store hydraulic energy to allow for rapid response times.

As the vessel heaves upward and downwards, the AHC cylinder retracts or extends to pay out wire rope at the exact frequency of the wave, keeping the fall pipe (88) stationary relative to the seabed.

The moving sheave block (82) travels along a dedicated guide track (85), ensuring that the wire rope geometry remains stable. The gimbal (87) supports the telescopic pipe (88). The gimbal mount allows the pipe to remain vertical even as the vessel rolls or pitches. The telescopic pipe (88) can extend or contract to reach specific depths.

Guide sheaves (86) are positioned to ensure the wire rope is fed into the carriage assembly without friction-induced wear, maintaining alignment with the vertical axis of the telescopic sections.

Operation of the System: In operation, the AHC logic manifold block receives data from a Motion Reference Unit (MRU). When a wave lifts the vessel, the AHC cylinder (84) adjusts the position of the moving sheave block (82) along the guide track (85). This adjustment alters the effective length of the wire rope (83), thereby neutralizing the vessel's vertical displacement. Consequently, the fall pipe carriage (87) and the telescopic pipe (88) remain at a constant altitude above the target site.

For the system shown in Figure 2: Hydraulic System the designed and manufactured AHC system uses a combination of a standard two-chamber hydraulic cylinder (instead of the commonly used three-chamber hydraulic cylinder), a logic control valve (manifold block), a directional proportional valve, a high-pressure accumulator, a low-pressure accumulator, and a hydraulic power unit (HPU).

1. System Overview

The present invention relates to a hybrid heave compensation system capable of operating in both Passive Heave Compensation (PHC) and Active Heave Compensation (AHC) modes. The system utilizes a hydraulic circuit to control the displacement of a Hydraulic Cylinder (22), which is mechanically linked to the fall pipe assembly. The system is characterized by its ability to switch between energy-efficient passive damping for low sea states and precise, sensor-driven active control for higher sea states.

2. Primary Hydraulic Components

Referring to the hydraulic schematic in Figure 2, the system comprises:

- **Power Generation:** A Motor (24) driving a Hydraulic Pump (23) draws hydraulic oil from the Reservoir (1). The hydraulic oil is conditioned via a Return Filter (5.1), Air Breather (4), and Air Cooler (6).
- **Pressure Regulation:** High and low pressure thresholds are controlled by Bladder Type Accumulators (20, 21). Safety is ensured by Direct Acting Relief Valves (12.1, 12.2).
- **Control Logic:** A series of 3/2-way Directional Control Valves (15.1–15.4) acts as pilots for Slip-in Cartridge Poppet Valves (18.1–18.3, 19) and their respective covers.
- **Precision Control:** A Proportional Flow Control Valve (14) (referenced as S4) control flow rates, while a Directional Control Valve (13) directs hydraulic oil for active cylinder movements.

3. Operational Modes

A. Passive Heave Compensation (PHC) Mode

The PHC mode is utilized for low to medium sea states (typically wave heights less than one meter). In this mode, the system functions as a hydraulic spring, absorbing vessel motion through the compressibility of gas in the accumulators without constant pump intervention.

- **Logic State:** Valve SV4 (comprising 15.2, 16.1, 18.1) is set to ON.
- **Function:** This engages the cartridge valve assembly in conjunction with the High-Pressure Accumulator (20) and Low-Pressure Accumulator (21).
- **Flow Regulation:** Valve S4 (14) may be toggled ON or OFF to modulate the flow rate and cylinder speed derived from the high-pressure accumulator, providing adjustable damping.

B. Active Heave Compensation (AHC) Mode

In AHC mode, the system responds dynamically to a Motion Reference Unit (MRU). A PLC (Programmable Logic Controller) executes real-time commands to the hydraulic valve blocks.

1. Cylinder Extension:

- i. Primary Valves: S1 and SV1 are activated (ON).
- ii. Flow Control: SV4, SV5, and SV6 are activated to control hydraulic oil transition.
- iii. Speed/Pressure Protection: If the cylinder speed exceeds safety limits or pressure spikes occur, SV3 (15.1, 17, 19) is momentarily activated. This creates a "regenerative" or "bypass" state by connecting the piston chamber and piston rod chamber, equalizing pressure until normal parameters are restored.
- iv. Pressure Control: SV6 is triggered by a pressure transducer (PT4) command when the low-pressure accumulator reaches its upper limit.

2. Cylinder Retraction:

- i. Primary Valves: S1, SV2 and SV6 are activated (ON).
- ii. Accumulator Regulation: SV4, SV5 operate in a toggled sequence based on the PT3 pressure transducer. When the high-pressure accumulator reaches its upper limit, SV4 is deactivated (OFF) and SV5 is activated (ON) to redirect flow and protect system integrity.
- iii. Safety Bypass: Similar to extension, SV3 remains available to momentarily connect the cylinder chambers during over-speed or over-pressure events.

4. Safety and Feedback Mechanisms

The system includes integrated monitoring via a Liquid Level Transducer (2) and Temperature Transducer (3) to ensure the hydraulic oil remains within operating specifications. The use of Winner Fully Adjustable Needle Valves (9.1, 9.2, 10) allows for fine-tuning the responsiveness of the pilot logic, while the Bi-directional Poppet Valves (11.1, 11.2) prevent unintended drift of the telescopic pipe when the system is de-energized.

5. Technical Advantages

- i. the designed hydraulic system uses a combination of a standard two-chamber hydraulic cylinder (instead of the commonly used three-chamber hydraulic cylinder)
- ii. Dual-Mode Efficiency: By providing a PHC mode, the system reduces wear on the Hydraulic Pump (23) and reduces energy consumption during calm weather.
- iii. Rapid Response: The integration of Bladder Accumulators (20, 21) near the control valves ensures immediate hydraulic "stiffness" or "compliance" as required by the MRU.
- iv. Pressure Surge Protection: The automated logic of SV3 provides a fail-safe against mechanical shock caused by rapid vessel heaving.

Fig. 3 illustrates the user interface screen for control of the heave compensation system.

The benefits of the design include Increased Operational Window: AHC systems increase the operational window in bad weather, improving safety and efficiency; Cost Reduction: By enhancing operational efficiency and reducing downtime; these systems contribute to cost savings; Precision and Control: Ensures precise placement of construction components, reducing rework and operational costs.

Claim

1. A system for hydraulic active heave compensation for a subsea rock fall pipe, comprising:
 - at least one two-chamber hydraulic cylinder (22) configured to actuate a telescopic fall pipe (88);
 - a hydraulic power unit (HPU) comprising a motor (24) and a hydraulic pump (23);
 - at least one high-pressure accumulator (20) and at least one low-pressure accumulator (21) fluidly coupled to said cylinder.
 - a logic control manifold comprising a plurality of directional control valves and a proportional flow control valve (14); and
 - a control system comprising a Motion Reference Unit (MRU) and a Programmable Logic Controller (PLC) configured to actuate said manifold in response to vessel motion.
2. The system of Claim 1, wherein the PLC is configured to allow for manual switching or automated switching between:
 - a Passive Heave Compensation (PHC) mode for sea states where wave height is below a predetermined threshold, wherein the high-pressure and low-pressure accumulators enable autonomous compensation; and
 - an Active Heave Compensation (AHC) mode for higher sea states, wherein the HPU and logic manifold drive the cylinder according to MRU commands.
3. The system of Claim 1, wherein the logic control manifold includes a bypass valve (SV3) configured to momentarily connect the piston chamber and the piston rod chamber of the hydraulic cylinder (22) when a sensed cylinder speed or pressure exceeds a predetermined safety threshold.
4. The system of Claim 1, wherein the logic control manifold further comprises:
 - a first pilot-operated cartridge valve (SV4) configured to regulate hydraulic oil flow between the high-pressure accumulator and the cylinder; and
 - a second pilot-operated cartridge valve (SV6) configured to activate when the low-pressure accumulator (21) reaches a specific pressure upper limit.
5. A method for controlling a telescopic rock fall pipe system using the apparatus of Claim 1, comprising the steps of:
 - measuring the heave of a vessel using the MRU to generate a raw heave signal;
 - processing the raw heave signal via the PLC to output an adjusted heave signal;
 - actuating the proportional flow control valve (14) to regulate hydraulic oil flow from the high-pressure accumulator (20) to the hydraulic cylinder (22); and
 - moving the telescopic pipe relative to the vessel according to the adjusted heave signal to maintain a substantially constant distance between the pipe end and the seabed.

6. The method of Claim 5, further comprising a safety regulation step wherein the PLC monitors pressure via a transducer (PT3) and deactivates a first valve (SV4) while simultaneously activating a second valve (SV5) when the high-pressure accumulator reaches a maximum pressure limit.

7. A marine heave compensating device for rock installation, comprising:

- a double drum hoisting winch (1) driven by an AC asynchronous motor via a gearbox and Variable Frequency Drive (VFD).
- a variable speed control is realised through the VFD for said motor configured to adjust winch rotation speed as a function of heave speed; and
- a moving sheave block (2) guided by a linear track (5) and moved by a hydraulic cylinder (22), wherein the hydraulic cylinder extension and retraction is controlled by the logic control manifold of Claim 1.

8. The apparatus of Claim 7, wherein the motor and winch drum are characterized by low-inertia components to facilitate substantially instantaneous response to the adjusted heave signal provided by the PLC.

9. The apparatus of Claim 7, where in the system provides real-time data on heave amplitude, velocity, and acceleration, essential for accurate compensation.