

Efficient Heave Motion Compensation for Cable-Suspended Systems

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ABSTRACT

Despite all the obvious advantages of Heave Motion Compensation, it remains an uncommon addition for overboard launch and recovery systems. Its additional complexity, or umbilical torture, or cost, or deck space requirements, or all of the preceding objections have conspired to eliminate Heave Motion Compensation from consideration in all but the most high-spec systems. A brief comparison and analysis of various types of Heave Motion Compensation Systems is offered, for both active and passive, as well as with regenerative systems. A new type of system is presented which addresses many of the difficulties listed above. This simple, efficient A-Frame based system is retrofittable to many existing launch and recovery systems

INTRODUCTION

Efficient heave motion compensation systems have been wished for since humans started doing things from a boat. The inconvenient motions of the boat in a seaway make everything more difficult, including and especially landing equipment on the bottom, overboard launching and recovering, and connecting suspended items of equipment in mid-water. In addition, with increasingly deeper operations, the possibility of achieving resonance between the ship's motions and the umbilical's reducing natural frequency becomes more dangerously possible.

The principal offender of all the motions, for things suspended by a cable in the water, is the vertical motion or heave. This motion can subject the cable and its suspension system to extremely undesirable shock loads, can hammer the suspended payload into the bottom or into the intended mating object, and can greatly increase the difficulty of launching and retrieving the payload. Rolling and pitching of the ship can increase the vertical motions, depending on the launch and recovery system's position on the ship, and obviously all these difficulties increase with higher sea states.

Various types of heave motion compensation systems have been developed, each having its own merits and limitations. A brief review of these types of systems follows, as well as a short discussion of adaptations and improvements possible to each of these systems. A new system is presented which offers advantages over the previous systems.

REVIEW AND COMPARISON OF TECHNIQUES

The various heave compensation techniques reviewed here involve lengthening and shortening the suspension wire or the wire suspension system in synchrony with the vertical rise and fall of the launch point, in order to maintain the payload at the desired position in the water column.. This is accomplished by: 1) alternately paying out and taking up on the lifting winch directly, 2) alternately stroking in and out idler sheaves over which the lifting wire repeatedly passes, and 3) moving up and down the overboarding sheave, often at the end of a boom.

Additional techniques which have been used include moving the load attachment point, and other techniques specifically adapted for passively controlling the compensation system. These are not considered here.

Comparisons between the various techniques are considered below. A target system, which includes an offshore supply vessel with a midships side-launched ROV launch and recovery system, which is holding station headed nearly into the waves is considered for each case. These simplified conditions allow the ship's heave to be most significant motion, and allow the roll and pitch coupling to be assumed near zero at the launch point. Sea State 5 is considered, and a very rough approximation as to the minimum compensating horsepower required is given for comparative purposes only.

WINCH DRIVE DESCRIPTION

It seems logical to consider the primary winch as a motion compensation device, since it already exists in any launch and recovery system, and its purpose is already to raise and lower the payload. A sketch of this type system and its compensating sequence is shown in Figure 1. Some technical advantages and disadvantages of this type of system are presented in the table below:

Winch Drive Heave Motion Compensation	
Advantages	Disadvantages
No additional deck space required	High inertia of winch drum and umbilical – large power requirement for responsive system
No additional pieces of equipment required	Large active inboard element is a personnel safety consideration
Unrestricted take-up and payout for compensation	Continuous umbilical bend over overboarding sheave as winch pays in and out
	Passive system more difficult to implement
	Increasing cycles on primary lifting device – time to failure shorter
Power index required in Sea State 5 = 180 hp (no passive, no regeneration, only compensation motions)	

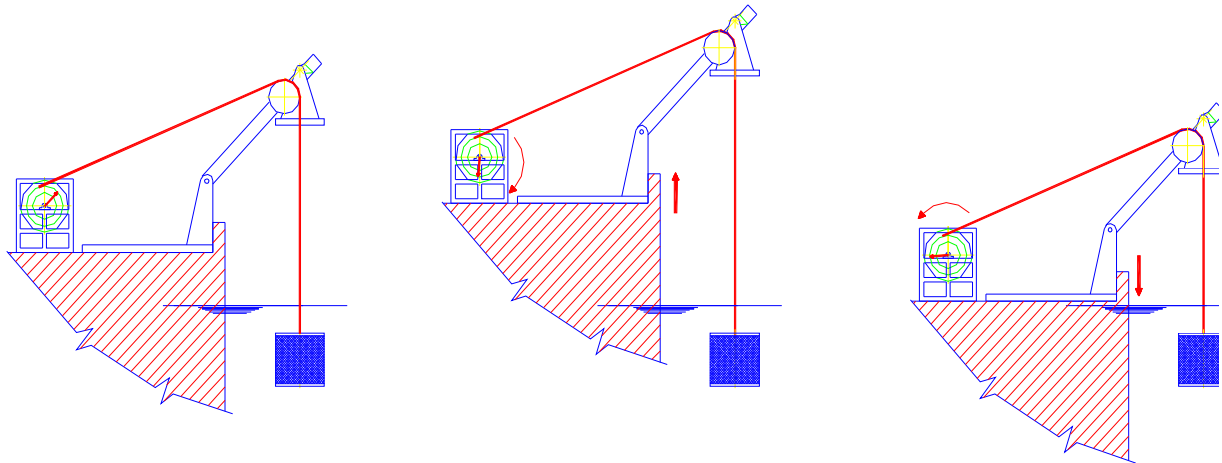


Figure 1 – Winch Drum Heave Compensation

FLYING SHEAVE DESCRIPTION

Multiple sheaves, in a configuration similar to a block and tackle but using a means to forcibly expand and contract the distance between the sheaves is the general configuration of this scheme. In this concept, the lifting and heave compensation functions are separated – the winch does what it does best,

raising and lowering, and the multiple-part flying sheaves alternately pay out more or pull in more lift wire as required. A sketch of this type system and its compensating sequence is shown in Figure 2. Some technical advantages and disadvantages of this type of system are presented in the table below:

Flying Sheave Heave Motion Compensation	
Advantages	Disadvantages
Lower inertia – only sheaves, support head and umbilical – smaller power requirement for a responsive system	Additional deck space required
Passive techniques adapted directly	Continuous umbilical bend over multiple sheaves
Failure does not involve primary lifting device	
Power index required in Sea State 5 = 25 hp (no passive, no regeneration, only compensation motions)	

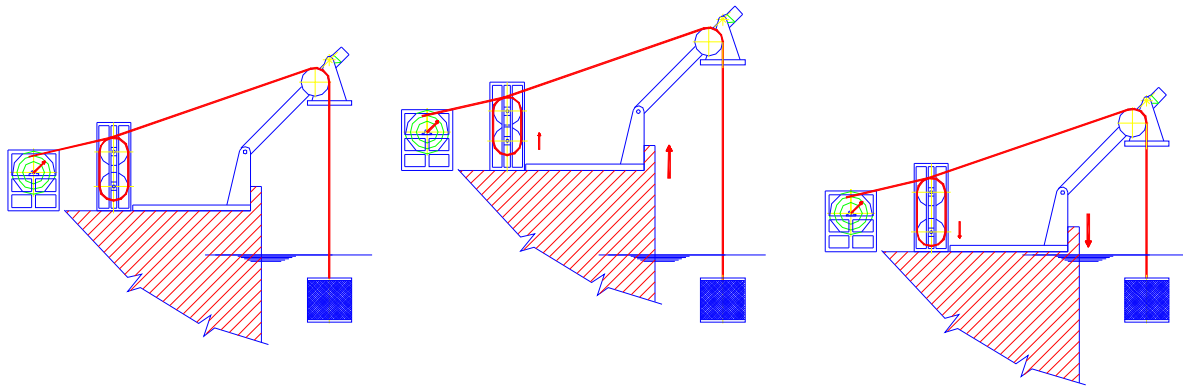


Figure 2 – Flying Sheave Heave Compensation

NODDING BOOM DESCRIPTION

A classical nodding boom system consists of an overboarding sheave supported at the end of a movable boom. The boom is alternately moved up and down so as to move the overboarding sheave in synchrony with the heaving of the ship. The boom is sometimes counterweighted to reduce steady-state operational forces. The winch is strictly a lifting and lowering device in this configuration also.

A sketch of this type system and its compensating sequence is shown in Figure 3. The effect of the motion of the boom, as can be seen in the figure, is to hold the docking head and overboarding sheave in a constant position relative to the earth. Some technical advantages and disadvantages are listed below:

Nodding Boom Heave Motion Compensation	
Advantages	Disadvantages
Kindest to umbilical of all systems	High inertia, high power required for responsiveness
Passive techniques adapted directly	Complex configuration
Failure does not involve primary lifting device	
Power index required in Sea State 5 = 105 hp (no passive, no regeneration, only compensation motions)	

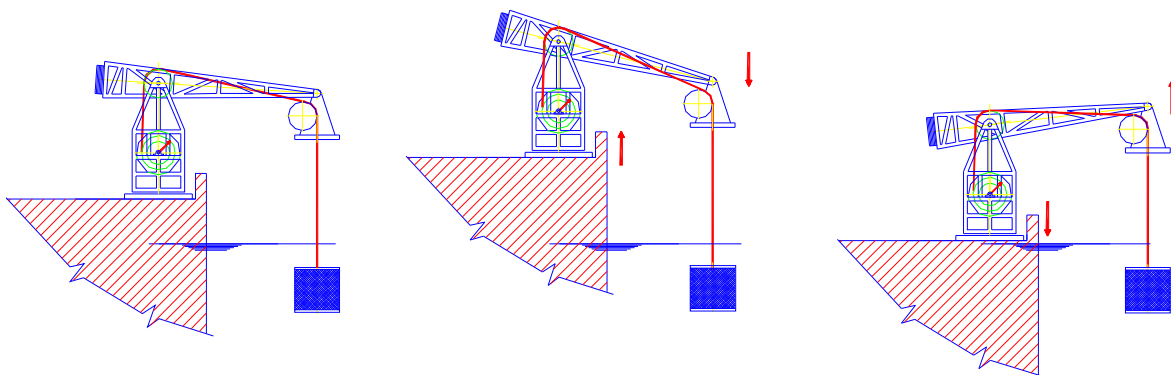


Figure 3 – Nodding Boom Heave Compensation

PASSIVE VERSUS ACTIVE

Passive techniques take advantage of the fact that if the force changes applied to the payload are small then its positional changes are also small. Devices which cause small force changes at the payload for large positional changes of the ship (softer springs) are therefore introduced into the load path. These changes must be applied with care, since reducing the load path's natural frequency in the direction of the ship's (wave's) exciting frequency could create undesirable resonance and umbilical snap loading.

Passive devices most often store energy in one direction and release the stored energy in the other, providing a natural centralizing tendency and requiring no external energy input relative to this central point. Natural damping is important in these passive systems to ensure stability and is provided primarily by viscous drag, both on the payload and on the umbilical.

Active systems, on the other hand, take sensory input as to the instantaneous state of the system, compare it with the desired state of the system, and actively add or remove energy to bring the measured and the desired states into closer accord. Modern controls and sensors allow active heave compensation systems to be more practical now than was ever previously possible, even in much less expensive systems

Sensor accuracy, repeatability and sampling rate are keys in the success of an active system.

Since constant position relative to the Earth is the desired parameter, sensory information to this effect is most desirable. Some direct and many indirect sensing schemes and combinations have been attempted, from altitude sonars, load cells, depth sensors and accelerometers on the payload, as well as accelerometers and load cells at the overboarding sheave, and depth sounders on the ship.

Active systems are required when more precise heave compensation is required, or when adaptability to a broader range of conditions is required.

REGENERATIVE TECHNIQUES

Regenerative techniques, those which feed back part of the energy dissipated during some of the systems' cycle for use during its energy absorption cycle, can be used in any of the systems. These systems add

complexity and possible downtime, but can improve greatly the efficiency of the heave compensation system. They are obviously most important in the least efficient systems. These are mentioned since they are in use, but are not discussed since they can improve the performance of any system.

SUB-A FRAME CONCEPT

This recently patented concept is a descendent of the Nodding Boom concept, reduced in size, complexity, and inertia (power requirements). Its moving element is a reduced size A-Frame whose base is attached to and pivoted from a standard A-Frame. Figure 4 below illustrates a compensating sequence.

A standard Docking Head assembly complete with overboarding sheave is attached and pivoted from the Sub-A Frame at its head, as with a standard A-Frame. This Sub-A frame is then positioned, after a normal launch procedure, by heave compensating elements to synchronize the motion of the Docking Head / Overboarding Sheave Assembly exactly out of phase with the ship's heave motions.

While many different active elements, including auxiliary lifting winches, hydraulic cylinders or other means are potentially useful, for the purpose of simplifying this paper only hydraulic auxiliary lifting winches are described below, and are also shown in the illustration in figure 5.

In operation, standard A-Frame sequences would be used to overboard and inboard the payload. When heave compensation is desired, the lifting winch compensation elements are activated and the Sub-A Frame is pulled up tight against the main A-Frame. The failsafe latches are released, and the Sub-A and its docking head are lowered to the mid-position. The active or passive motion compensation system is then engaged. The overboarding sheave is actively positioned or passively pulled or some combination of both so as to move out of phase with the rise and fall of the ship while the motion compensation system is engaged. When heave compensation is no longer desired, the active or passive motion compensation system is disengaged, the lifting winch compensation elements are activated and the Sub-A is pulled up tight against the A-Frame and latched into position.

Sub-A Frame Heave Motion Compensation	
Advantages	Disadvantages
Kind to umbilical	Low-medium inertia, low-medium power required for responsiveness
Passive techniques adapted directly	Mechanical adaptations
Failure does not involve primary lifting device	Limited range of motion
Power index required in Sea State 5 = 30 hp (no passive, no regeneration, only compensation motions)	

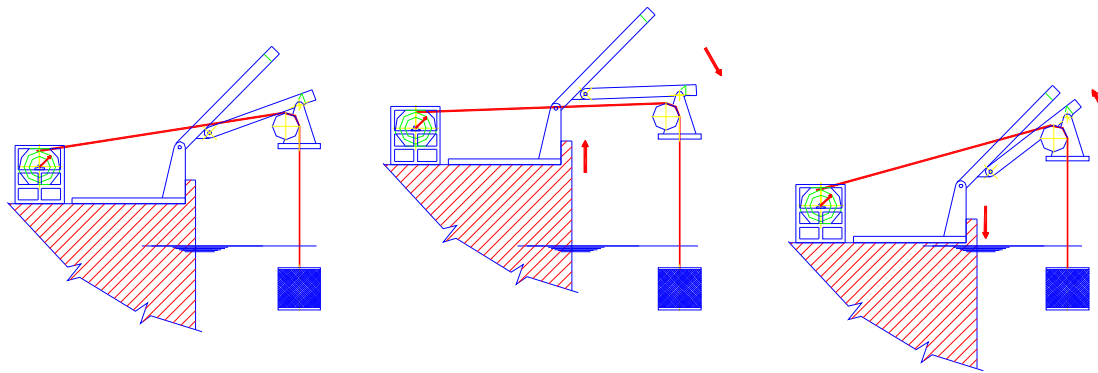


Figure 4 – Sub-A Heave Compensation System

DESIGN DESCRIPTION

The major components of the system include: the Sub-A frame and attachments, the docking head adaptation, the active elements, safety features, control and sensing system, and power plant. These are briefly described individually below, along with their major design considerations.

Sub-A Frame

This element is a structural steel frame whose legs are pivoted from the existing A-Frame at the bottom. It is held in position while inactive by failsafe latches against its host A-Frame, and by lifting wires from the active compensating elements during compensating activities. Its design considerations include:

- Structural support of the docking head, umbilical, and payload in seaway. (Some support and rigidity is provided via the host A-Frame)
- Minimum mass to minimize compensation power.
- Attachment points for bearings, lift elements, Docking Head / Pitch Dampers, Safety Features

Docking Head Adaptation

A considerably wider range of swinging motion is required by the Docking Head attached to the Sub-A frame. In many cases this Docking Head has swing damping design features and /or active positioning requirements. These are accommodated by the

replacement of the existing bearings and dampers with rotary actuators, if they don't already exist in the design. Hydraulic rotary actuators can provide ranges of motion in excess of 360 degrees if required, and are more than adequate for this application.

Active Elements

Lifting wire rope attached to either hydraulic cylinders or winches or other means are used to best advantage here. Hydraulic cylinders will perform best in a passive system, while winches are the most space and weight efficient. These devices are proportionally controlled to position the Sub-A Frame and Docking Head / Overboarding Sheave. Their design considerations include:

- Hoist capacity – these features carry the entire design load in a seaway.
- Redundant design – each of the two cylinders or winches must carry the entire design load.

Low inertia is required for rapid response

Safety Features

Two of the safety features have already been mentioned, the failsafe latches and the redundant active element designs. In addition, safety links will be affixed between the host A frame and the Sub-A frame to further prevent load loss in the event of active element or other failure. Normal E-stops, limit cushions and stops and system health monitoring stops will of course be included in the controls software and sensing.

Sensing and Control

Sensing is recommended for at least monitoring and tuning the passive system, and is required for feedback control of the active system. Sensing and control are briefly described below for an actively controlled system.

For a original design, sensing schemes would include data from a payload-based suite of sensors, ideally providing high frequency response high data update rates and allowing the finest positioning accuracy possible.

For a retrofit to an existing A-Frame design, this payload-based sensing choice may not be possible and the best compromise solution is sensors on the Sub-A frame: an accelerometer and / or an overboarding sheave load cell may provide the best service here. In addition, low update rate data from payload-based sensors, depth sensors, acoustic positioning equipment, and the like may supplement this primary data.

A commercially available stand-alone controller is the most likely choice for this type of control system, as powerful versions of these are currently available that can inexpensively provide such desirable features as PID control, auto-tuning, adaptive control, and the like.

Power Plant

A hydraulic power plant is required if the functions are driven hydraulically as described above. In addition, hydraulics provide a very high power density for any A-Frame mounted features, making an unobtrusive installation. A standalone closed-loop type hydraulic system will provide the most efficient prime mover for the active elements

PERFORMANCE

As discussed in the preceding paragraphs, a wide range of performance is possible for any basic style of heave compensator, depending on at least its: 1) fundamental characteristics, 2) the degree of passive or active compensation employed, 3) the amount of power available for use, 4) the quality of data and update rate from the sensors, 5) the speed, reliability and robustness of the control system, 6) the ship's response, 7) payload, 8) operational depth, 9) suspension wire, and 10) energy conservation tricks such as regeneration, and many others. It is difficult to simply describe a compensation's system without defining at least all the parameters above.

The "Power Index" in each of the four tables above is intended to compare the fundamental characteristics of each of the various styles described. This index was calculated using:

- Assumed ship vertical motions equal to a Sea State 5 ($H_s = 10.5$ ft, $T_c = 9$ sec)
- All handling and compensation equipment suitable for handling a 8000 foot long umbilical at 3 #/ft in water and an 8000 # in-water payload.
- Only the active elements' power is considered, using no energy recovery schemes.
- Perfect system response

These extremely simplifying assumptions allow broad, general power comparisons to be made between these techniques, assuming that improvements can be made with equal ease to each system. By these assumptions, the Flying Sheaves and the Sub-A Frame techniques are not very different in their fundamental power consumption, but both are much more efficient than either of the other two techniques considered.

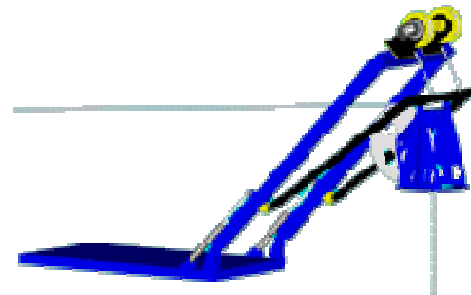


Figure 5 – Illustration of the Sub-A Frame Using A-Frame Mounted Winches

SUMMARY

A useful new adaptation of the Nodding Boom technique has been presented. This technique adopts many of the advantages of the Nodding Boom, most notably umbilical friendliness, and also allows lower inertia (power in the dynamic system) by requiring the host A-Frame to do some of the structural support function. It is appropriate for use with active or passive control systems. It is retrofittable to existing A-Frames in some cases.

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