Heave Compensation: A short overview

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Abstract

This article explains how heave compensation is obtained on offshore vessels. The main goal is to show how heave compensation works and what the main reasons are why to choose a setup. This article only shows the main concepts and what is commonly used on drilling vessels and cranes. Also this article will be restricted to wire line heave compensation.

In the offshore industry heave compensation is commonly used to compensate for the vessel's movement. The vessel's movement requires compensation because the load is either attached to the sea bed, the load is lowered and placed on the sea bed or for instance during drilling to minimize the force variation on the drill bit (called 'weight on bit' in the drilling industry).

In this article only wire line heave compensation is considered. For this kind of heave compensation the load is suspended by a wire as for an example shown in figure 1. A good example is a crane, where the load is supported by the wire. Heave compensation is done by adapting the length of the wire. Other kinds of heave compensation can be obtained by compensating the base of the structure, for example moving the helicopter deck with respect to the vessel, which means that the helicopter deck is not moving on the waves.

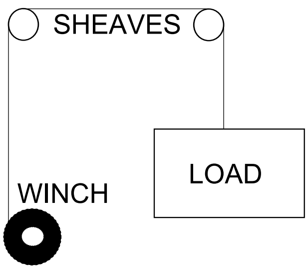

Figure 1: For the heave compensation as described in this article the load is suspended by a wire. Heave compensation is obtained by adjusting the length of the wire.

The first distinction in heave compensation which can be made is between passive and active heave compensation. Passive compensation requires no external power and is most often achieved using a gas spring. The gas spring is obtained by a gas volume which is compressed and decompressed while the cylinder strokes in and out. Due to the relative small pressure variation due to the gas spring, the load is not rigidly connected to the vessel. This means that the vessel can move with respect to the seabed while the load does not. The ideal gas law ($pV^\kappa = mRT$) can be used to calculate the pressure variation. Because the gas (de)compression is relatively short (period time up to 20seconds), an adiabatic process is often assumed. With a relative low stiffness of the gas spring the tension of the wire will be approximately constant, meaning that the load experiences only small force changes. The passive compensation is a reaction on the movement and due to the inertia of the compensator, load and the drag, so it will always lag with respect to the motion itself. Often nitrogen is used for the gas, because it is not corrosive nor toxic, it does not have the diesel effect with hydraulic oil and it is widely available.An alternative is waterglycol instead of oil, which makes it possible to use compressed air instead of nitrogen. Somewhat related to passive heave compensation is constant tension on winches. Hydraulically seen, this is obtained by a fixed volume motor with a constant pressure difference over the motor. When the load pulls harder than the setting will allow, the winch will pay out wire and the hydraulic motor will act as a pump, which also means that there must be a provision to add oil to the low pressure side of the winch to avoid a vacuum. When the load pulls not as hard as the setting, the winch will pay in wire. Mind that the constant tension as described here will require an HPU running, so it does need external power. This is for instance also used for tugger winches, but will not be covered in this article.

Active heave compensation can be achieved on winches and cylinders. Active heave compensation often uses a Motion Reference Unit (MRU) to measure the vessel's accelerations, which lead to the vessel motion. This way it is already known how the vessel is moving, which then is translated to a cylinder movement or winch rotation to compensate the movement of the vessel. This way of feed forward in the control loop of the actuator makes the compensator respond at almost the same time as the movement of the vessel. So where passive compensation does not require an external power source, active heave compensation needs power for the MRU, a computer and/or PLC to calculate the movement of the actuator and power to drive the actuator. The advantage is that the compensation has much less lag in the heave compensation with respect to the vessel motion due to the feed forward control loop to the actuator and the heave compensation is independent on the load, which makes compensation of small or low drag loads possible. Active heave can be combined with passive heave compensation, where the active heave compensation acts directly on the passive compensation, as will be shown later. In some systems active and passive heave compensation are installed separately, but this can mean that they cannot be active at the same time, because the passive compensator will then act on the wire payed out or in by the active compensation. This last option will be showed in the last chapter.

1 Passive Heave Compensation

Passive heave compensation is most commonly achieved with cylinders coupled to a gas volume. It is common to use hydraulic cylinders instead of pneumatic cylinders, because hydraulics makes it possible to lock the cylinder hydraulically due to the high bulk modulus and thus stop the motion on command. Hydraulic cylinders are also capable of a high design pressure. A higher design pressure means that a smaller cylinder can produce the same force, which makes it easier to build the heave compensator. The hydraulic cylinder is then coupled to the gas volume using a piston accumulator, as will be shown later in this article.

The cylinder can be used as a pushing or a pulling cylinder. A pushing cylinder can deliver high forces with respect to the size of the cylinder, but buckling will prevent it from having a large stroke. Pushing cylinders can be used with a short stroke and multiple falls (encirclements of the wire around the cylinder). This means that the cylinder will deliver a force multiple times the wire pull, but it only has to move less. Remember: the work done by the cylinder is force times traveled distance ($W = F\,s$), so with the force a factor larger, the traveled distance will be shortened by the same factor. A pulling cylinder does not have the problem with buckling. Therefore it can be much longer, which makes the traveled distance longer, thus the total cylinder force can be smaller.

The choice between a pulling or pushing cylinder is mainly made on available room. In the following subsections the advantages and disadvantages are shown. As a last remark up front: An engineer should consider a wire break event when designing a wire rope heave compensator.

1.1 Pushing Cylinder

A pushing cylinder in a passive heave compensation is easy to install, mainly because the cylinder is easy to install. It only has a few pipe connections compared with the pulling cylinder, mainly because the pushing cylinder can be made as a plunger cylinder, where rod and bottom side are connected to each other. Pushing cylinders are for instance used for riser tensioners for drilling and well intervention vessels. The rod can be mounted horizontally, but especially for larger cylinders the required (deck) space is too large. When placed vertically the cylinder can be

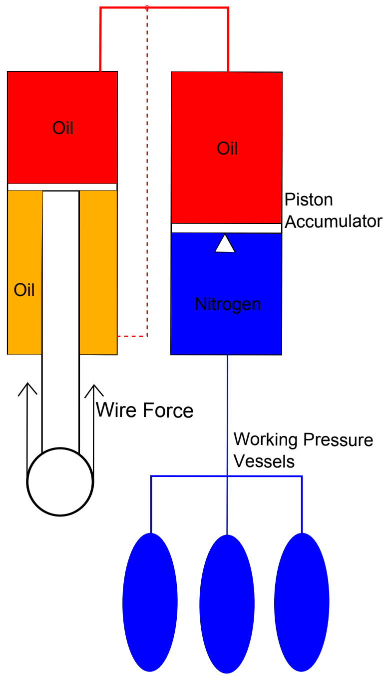

Figure 2: An example of a passive compensator with a pushing cylinder with the rod mounted downwards

mounted rod up- and downwards.

For riser tensioner systems, where pushing cylinders are common, it is common practice to install a main valve to disconnect the cylinder from the gas system. This means that the cylinder can be hydraulically locked and the cylinder can be stopped in the case of a wire break event, which means that the cylinder is no longer launched now it is missing the force of the wire.

In the industry it is more common to mount the rod pointing upwards, which means that the weight of the piston, rod and sheave box helps to slow down the cylinder in case of a wire break event. Mounting the rod upwards requires no extra provisions to be made. Connecting to the rod and bottom side is easy, while the rod can extend upwards (from deck). If the rod side is not connected to the bottom like a plunger cylinder, it can be made as low pressure as possible. An accumulator makes the movement of the cylinder possible and the size can be calculated with the displaced oil over the entire stroke. Mind here that gravity and the small pressure at rod side will be enough to retract the cylinder. For a double acting cylinder at which the rod side is connected to the bottom side in a hydraulic manifold, the engineer should make it possible to retract the cylinder for maintenance. In case of a wire break event the pressure on rod side will stop the cylinder, but the engineer should check whether separate cushioning is required in this case.

In figure 2 a pushing cylinder with the rod mounted downwards is shown. In this configuration the weight of the piston, rod and sheave box helps with tensioning the wire, which means a slightly lower pressure is required in the cylinder, although in most cases this is relatively small in comparison with the total force. Extra provisions are required in a wire break event to stop the cylinder, which could be a 'brake valve' at rod side. The mass of the rod, piston and sheave box will not help to stop the cylinder and a vacuum at bottom side will result in only a very small force trying to stop the cylinder. So a 'brake valve' should make sure that a larger pressure is available at rod side in case of a wire break event.

As stated before buckling should be checked for these kind of cylinders. This is why these cylinders often have a limited stroke and a larger bore. Also the rod can be large, meaning a larger cylinder force due to the plunger effect. A too thick rod can however result in large required forces to retract the cylinder.

1.2 Pulling Cylinder

Pulling cylinders are also used in the industry. Because buckling is not as critical as for pushing cylinders, pulling cylinders can have a larger stroke, limiting the number of falls and the cylinder force.

The setup of pulling cylinders is slightly different than pushing cylinders. These cylinders cannot be plunger cylinders, so the pressure at rod side must be much larger as on bottom side. To limit the pressure on bottom side, an accumulator can be used. Because the bottom side has a much larger volume, it can also be engineered to have gas at the bottom side. The accumulator or pressure vessel would however limit the modularity of the design, which could be an issue when more parties are involved in the con-

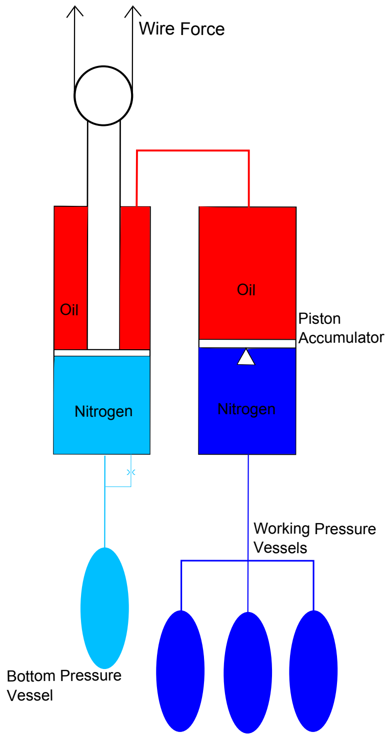

Figure 3: An example of a passive compensator with a pulling cylinder with the rod mounted upwards

struction. However, this does mean that an extra pressure vessel is required to limit the pressure variation over the full stroke. Also, when the cylinder is mounted with the rod upwards, the pressure at bottom side should be sufficient to support the piston, rod and sheave box during slack wire, for instance during maintenance.

Cushioning of the cylinder is often required, mainly for a wire break event and operator errors. Cushioning in a hydraulic cylinder is very common, but for nitrogen it is less common. A specially designed buffer is then required at the gas side of the cylinder, but a separate article describes the design of this buffer and will not be included in this article.

During a wire break event the cylinder will retract fast and an over-speed can be detected. The valve between the cylinder and piston accumulator (which is required for maintenance purposes and to take the heave compensation out of operation when not required) can be closed if over-speed is detected, but in case that this is too late or does not provide enough forces to stop the cylinder in time, cushioning on bottom side is required.

2 Active and combined heave compensation

There are a lot of different kinds of active heave compensation. As stated in the introduction, the active heave requires a measurement of the ship's movement. A MRU is often used in a vessel to provide the measurement.

Active heave compensation can be achieved in several ways: It can be implemented at the winch (either electrical or hydraulically driven) or with a wire reeved through a cylinder, as already seen for the passive heave compensator, or a winch or active cylinder driving a passive heave cylinder. The solution with an active cylinder is normally combined with a passive cylinder, due to the large forces involved. In this article only the hydraulic actuated heave compensators are described. For this article it will mean the secondary controlled winch and a combination of the passive and active system.

2.1 Secondary Controlled Winch

Secondary hydraulics is somewhat different from primary (normal) hydraulics. In primary hydraulics the pressure determines the force, while the flow determines the speed of the motor. For secondary hydraulics the pressure over the motor will be approximately the same at all times, while the stroke volume of the motor will be changed. Because the volume to change the swash plate, and thus the stroke volume of the motor, is small, the motor can respond almost instantly. This means that these winches are capable of following a set point very precisely.

The main difference between primary and secondary hydraulics is that it should not be looked at from a pressure and flow point of view, but from energy or power point of view. The motor delivers a certain torque at a certain swash plate angle. When this torque is lower than the torque induced by the load, the winch will pay out wire. If the torque of the motor is higher, it will pay in wire. This difference is crucial during designing and controlling the winch.

The given swash plate angle will result in a stroke volume. With the constant pressure over the motor, the stroke volume of the motor provides a certain torque. This torque determines the angular acceleration of the winch, which is the second derivative of the angular displacement of the winch. This means that the position is not directly controlled and this kind of system demands more of the controller.

The controller needs to be able to accurately control the swash plate, most often with a servo valve. The control loop should control the speed by controlling the torque. More torque, so a larger swash plate angle, will lead to an angular acceleration of the winch, and visa versa. Therefore the controller is crucial: When the controller fails and gives a maximum swash plate angle, it is most likely (depending on the load) to give a large angular acceleration of the winch. This failure mode should be covered by the control system to stop the winch before an accident happens.

The hydraulic system is often a closed loop system, which means that the flow coming back from the motor will not flow to tank, but back to the pumps. This also makes regenerative systems possible: When the winch will lower the load, the motor acts as a pump and the pump will act as a motor. If possible, this energy can be fed back to the electrical power grid, otherwise the power needs to be dissipated or stored hydraulically.

In figure 4 a simplified hydraulic diagram of a secondary controlled winch is shown. The high pressure side is powered by the pump and kept at a constant pressure, colored red in figure 4. A piston accumulator at the HPU can be used to limit the size of the HPU: At the highest flow demand during the heave compensation, the HPU will not be able to supply all flow, and the piston accumulator will deliver the last part of the requested flow. Keep in mind that the pressure will drop and this should be taken into account. This configuration of the HPU is described in a separate article, so it will not be in the scope of this article.

The hydraulic motor often requires a pressure at the low pressure side to operate properly, called the boost line, colored blue in figure 4. For simplicity the boost pumps are not drawn in figure 4, but these boost pumps deliver the boost pressure and flush part of the oil in the boost line, keeping the hydraulic oil in good shape and preventing premature aging.

2.2 Active Heave with a cylinder

As stated in the beginning of this section, the active heave cylinder is often combined with a passive cylinder. This limits the amount of power required to compensate for the heave: The passive cylinder will hold the load and the active part will drive the passive cylinder to make the heave compensation more accurate. As a rule of thumb, the active cylinder must be able to deliver 20% of the total force to be able to follow a set

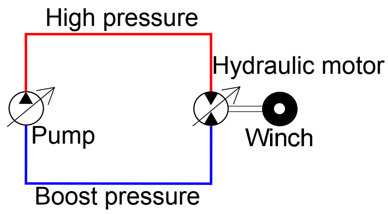

Figure 4: A simplified hydraulic diagram of a secondary controlled winch

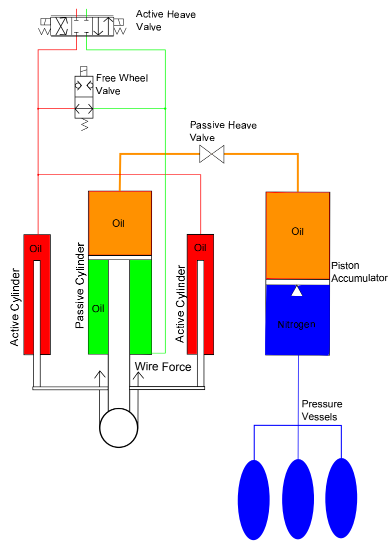

Figure 5: A simplified hydraulic diagram of active and passive heave cylinders

point within reasonable tolerances. This means that smaller active cylinders will not be able to give a benefit above only passive heave compensation. In figure 5 two active cylinders are drawn, to balance the forces on the passive cylinder, but the amount of active cylinders is dependent on the mechanical design and the available space for the equipment. In some applications the active cylinder is included in the passive cylinder, which makes the design of the cylinder more complicated, but reduces the required space.

The passive cylinder is drawn in the middle in figure 5. The passive heave part is shown in orange and is connected to a piston accumulator through the passive heave valve. This part works similar as described in the passive heave section of this article. To enable passive heave, the free wheel valve should not be energized (so as drawn) and the active heave valve should not be energized, so it is in the middle position. The areas of the red and green parts should be equal, so the displacement of oil is equal when the cylinders are moving. This means that when retracting the oil displaced in the red area can flow to the green area, so there is no lack of oil to create a vacuum or there is no pressure build up.

The green and red areas are used for active heave. Once the free wheel valve is switched, the active heave valve can control the position of the cylinder. The green area can retract the cylinder while the red area is connected to tank, and vise versa for extending. To get a proper response and control on the velocity and position, the active heave valve is a proportional valve.

3 Active and passive heave compensation applied separately

Beyond the examples as already shown in the previous sections, there is one combination as shown in figure 6. Although hydraulically seen it has only a passive compensator, as shown before in this article, there are some complications when the active and passive heave are separated as shown in figure 6.

The winch has electrical drives and is capable of active heave, similar as shown before only now with an electrical drive. When the active heave on the winch is enabled while the passive compensator is disabled, the cylinder will not move and the load will be heave compensated by the winch. When the active heave is disabled and the passive heave is enabled, the setup is equal to what is seen earlier in this article.

The complication is when active and passive are both active, for instance while switching between active and passive heave. If the vessel is going upwards, the active winch will pay out wire, meaning that the wire tension will become slightly less. The passive cylinder will still have the same pressure working on the piston, while the force acting on the cylinder becomes slightly less, which means that the passive cylinder will retract, reducing the heave compensation of the winch. This will lead in some motion of the load, although heave compensation is active. Mind that not all heave compensation will be canceled, but the load will move more than expected than during active heave mode. The operator needs to take that into account while switching over or having both heave compensation systems active. Note that the difference with the active cylinders on the passive cylinder, is that in this case the active heave compensation does not directly determine the position of the passive compensator.

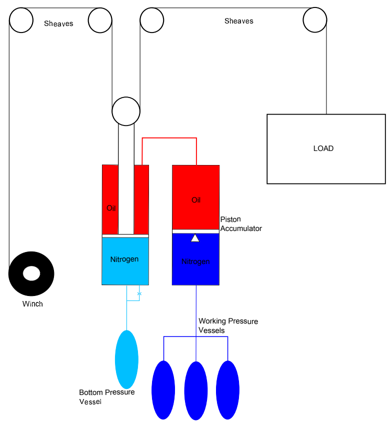

Figure 6: A combination of electrical active heave on the winch and passive heave in the wire.