A New Concept Design of Heave Compensation System for Longer Life of Cables

Shinichi Takagawa

Institute of Industrial Sciences, The University of Tokyo

4-6-1 Komaba, Meguro-ku

Tokyo, Japan 153-8505

***Abstract*-Conventional heave compensation system consists of fixed sheaves and moving sheaves supported by spring.**

Structure of this conventional system is very simple, and it is used in various areas.

However, this system has several inherent problems. Typical one is the wear of cable. When the operator stops paying in/out of the cable and when the ship is heaving, the same parts of the cable are always running over the moving and fixed sheave blocks of the heave compensator, and this motion damages the cable seriously. Other problem is the sheave efficiency. This nominal sheave efficiency can easily be calculated as N-th power of single sheave efficiency where N is the number of sheaves. However, this calculation is focused only on the loss by the friction of the cable on the sheave, but it does not include the bending stiffness of the cable which consumes energy and reduces the total sheave efficiency.

Heave compensator shows seemingly good works for shallow water operation of ROV, but shows little works at deep water even at the same sea condition. We know that the vehicle is still heaving by some significant level of amplitude even when the compensator is seemingly working well. The reason of the little works at deep water is that the heave compensation is done by the spring effect of the cable.

In order to solve these problems, a new concept design of heave compensation system is proposed here. This new system is a type of armed sheaves system, and consists of three or four sheaves connected by two long arms with one sheave located at the hinge position of the two arms. One end of the upper arm is pin-jointed to the structure, and the other end of the lower arm is suspended by spring to support the weight of the cable and the vehicle. As the maximum compensation stroke shall be long, say 4m to 10m, long hydraulic cylinder will be very difficult to apply as this spring, but wires with one-layered winch drums driven by high-torque/low-speed pump/motor will be applicable.

The feature of this system is that the cable runs over the sheave by very short length, and the total sheave efficiency becomes very high, and also the life of the cable becomes fairly longer.

The lower end of the arm can accommodate a docking system, and this whole system can become a launch/recovery system with heave compensation function. Active heave compensation technique can very easily be adapted to the system.

Keywords: heave compensation, cable life, sheave efficiency

I. Introduction

ROV operation requires ship heave compensation system inherently. Especially the ROV operation with TMS (Tether Management System) cannot be done without this system because TMS is suspended by the cable coming from the sea surface, and ship motion is directly transferred to the TMS. As TMS is in the water and receives hydrodynamic force, it cannot move as the same way as the ship motion with no delay. Hence, the cable loosens and tightens repeatedly and it shall be damaged, or broken.

Conventional heave compensator is a passive type one with fixed sheave block and moving sheave block supported by spring as shown in Fig. 1.

It is clear that the cable is always running over any of the sheaves when the ship is heaving. Also it must be emphasized that the specific parts of the cable are running over the sheaves repeatedly when the operator wants to keep the operating depth (cable length) constant. This is just the same as the life test of cable, and shall make the life of the cable shorter and shorter.

During the design process of heave compensation system, “sheave efficiency” is usually discussed and the following result will be concluded as an example that “5 sheaves with

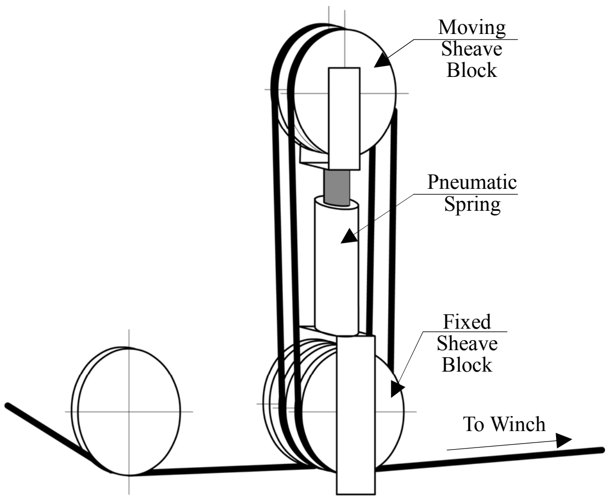

Fig. 1 Conventional Heave Compensation System
The specific parts of the cable are always running over the sheaves repeatedly, and this makes the cable life shorter.

efficiency 0.98 makes the total efficiency $0.98^5=0.904$ and the loss is very small." However, this discussion is neglecting the bending rigidity of the cable. When a cable runs over the sheave, the cable is bent and then stretched repeatedly, and this behavior consumes energy and also tends to damage the cable itself. This makes the actual sheave efficiency worse than the simple calculation results, and the operator shall find that the motion of ROV or TMS is not so much reduced as expected.

If we could get a system where the cable runs 0 or very little span over the sheave, the life of the cable becomes longer and longer, and operation becomes very easy.

II. A NEW CONCEPT

Heave compensation and longer life of wire/cable is a big issue for offshore petroleum industries also, and recent drillship is mounting a unique system on top of the derrick as shown in Fig. 2[1] and Fig. 3[1]. These figures are the heave compensation system installed on science drillship "Chikyu" operated by JAMSTEC, and this is an example of the advanced heave compensation system. The star-like sheaves are the key of the advanced heave compensation mechanism, and the schematic drawing of the mechanism is shown in Fig. 4 where

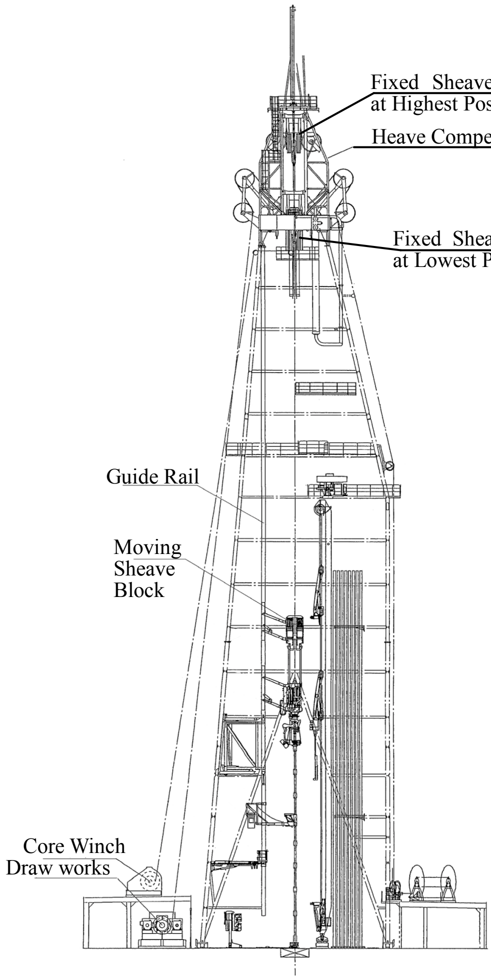

Fig. 2 Derrick of Science Drillship "Chikyu"
The sheaves at the top of the derrick are the key for advanced heave compensation system

Fig. 3 Sheaves at the Top of the Derrick
Left: Fixed Sheave Block is at the lowest position
Right: Fixed Sheave Block is at the highest position

the right half shows the contracted level and the left half shows the expanded level.

From this figure, it is clear that the wire length between A and B is anytime the same and the length between B and C is changing only by the winding angle over the two sheaves S_2 and S_3.

This mechanism can be applied to a heave compensation system for ROV. Fig. 5 shows an example of the application where the sheave 1 is fixed on the basement such as the frame of crane, sheave 2 is connected to sheave 1 via rod 1, sheave 3 is connected to sheave 2 via rod 2. The sheave 3 is suspended by spring mechanism.

In order to calculate the change of cable length in this system, nomenclatures are defined as follows:

R: Pitch circle radius of sheave (the same for 3 sheaves)

L_1: Length of rod 1

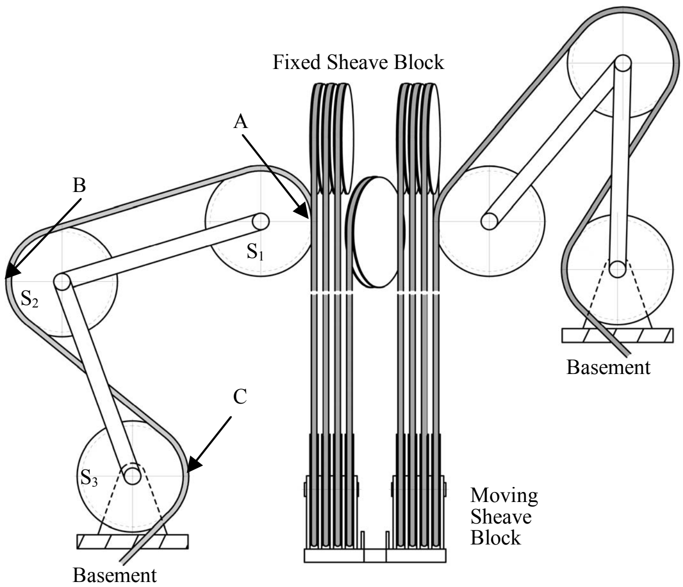

Fig. 4 Schematic Drawing of the Advanced Heave Compensation System Applied to the Derrick of Drillship "Chikyu"
Left: The expanded position
Right: The contracted position

L_2: Length of rod 2

θ_1: Inclination angle of rod 1 from the horizontal line

θ_2: Inclination angle of rod 2 from the horizontal line

The length L_{AB} between A and B can be written as

$$L_{AB} = R\theta_1 + L_1 + R\left(\frac{\pi}{2} - \theta_1\right) = L_1 + \frac{\pi R}{2}$$

and this does not change.

The length L_{BC} between B and C can be written as

$$L_{BC} = \sqrt{L_2^2 - 4R^2} + 2R\left\{\frac{\pi}{2} + \arcsin\left(\frac{2R}{L_2}\right) - \theta_2\right\}$$

θ_2 may change from 0 (horizontal) to $\pi/2$ (vertical), and thus L_{BC} may change by πR at the maximum.

Vertical and lateral distances between the centers of sheave 1 and sheave 3 are as follows:

Vertical distance V is;

$$V = L_1 \sin\theta_1 + L_2 \sin\theta_2$$

Horizontal distance H is;

$$H = L_1 \cos\theta_1 - L_2 \cos\theta_2 = \text{const.}$$

From these equations, the following equation can be derived:

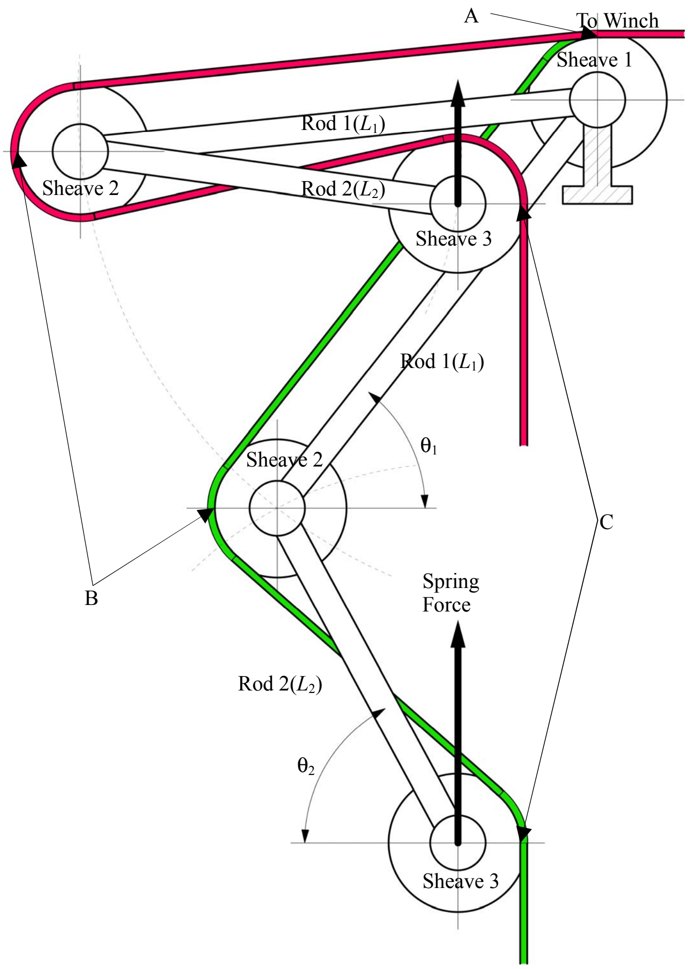

Fig.5 A New Heave Compensation System
Red line is a cable at the contracted compensation situation.
Green line is a cable at the extended compensation situation.

$$\Delta V = L_1 \frac{\sin(\theta_1 + \theta_2)}{\sin\theta_2} \Delta\theta_2$$

For simplification, L_1=L_2 and H=0, then θ_1=θ_2 and;

$$\Delta V = 2L_2 \cos\theta_2 \Delta\theta_2$$

Comparison of this ΔV with ΔL_{BC} becomes as follows:

$$\frac{\Delta L_{BC}}{\Delta V} = \frac{-R}{L_2 \cos\theta_2}$$

This means that cable is anytime running over sheaves (especially on the sheave 3), and when sheave 3 is at upper level, the running span is R/L times of the heaving amplitude ΔV, but when sheave 3 is at lower level, the running span becomes larger by the factor ($1/\cos\theta_2$), and when sheave 3 goes down, the cable is paid out more. This will not be a problem for normal heave compensation, but may become a problem during the recovery operation when the ROV/TMS and sheave 3 become closer because the distance between the sheave 3 and ROV/TMS is anytime fluctuating by the ship heave motion.

The reason of this fluctuation is due to the change of winding direction over the sheaves between sheave 2 and sheave 3. If the cable is wound around the sheaves at the same winding direction as shown in Fig. 6, cable length change does not happen. As the cable in Fig. 6 is going up, the cable path

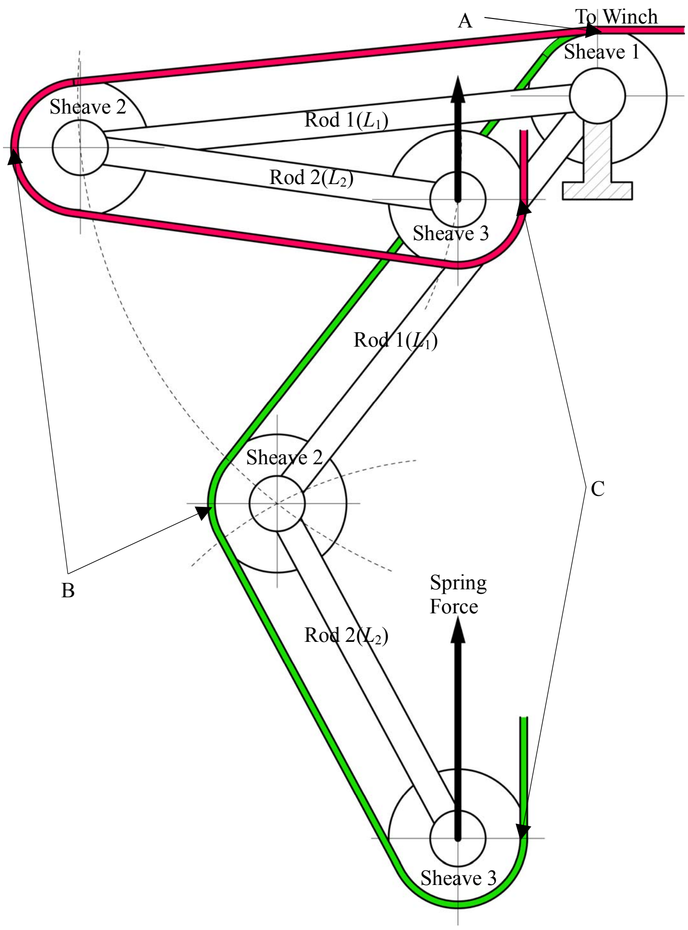

Fig. 6 Fluctuation-free cabling over sheaves
Cabling by the same direction over sheaves gives no fluctuation of paying in/out while in heaving motion.

has to be changed to downward, and any path to downward is available except which crosses the cable itself.

One method is to use a tilted sheave 4 next to sheave 3. Also, wide grooved sheave 3 can be applicable as Fig. 7 shows. There will be other various paths for the cable. To locate sheave 2 at the winch side of sheave 1 (right side in this figure) is also possible. When a wide grooved sheave is chosen to apply, large care must be paid to the cable and to the wide grooved sheave in order to avoid damage on the cable by the flat bottom of the groove.

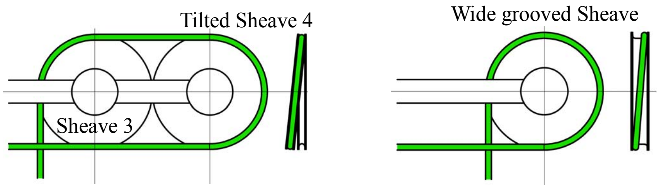

Fig. 7 Adoption of tilted sheave or wide grooved sheave to avoid the cable crossing

III. Suspending Spring

The third sheave is suspended by spring. All the weight of ROV, TMS, cable itself, and their dynamic loads are suspended by this spring.

The stroke of the compensation is very large, and application of hydraulic cylinder may not be good considering the cost vs. effect. Instead, a low-speed/high-torque hydraulic pump/motor is a good candidate as a spring actuator. When sheave 3 is pulled downward, this actuator behaves as pump and delivers high pressure hydraulic oil to the high pressure oil reservoir. When sheave 3 is going up, this actuator behaves as motor by reverse direction of rotation and discharges the hydraulic oil to the low pressure oil reservoir. Radial plunger pump/motor or star shaped crank piston pump/motor will be good candidates for this actuator. Winch drum can be directly fixed to this actuator and the sheave 3 shall be suspended by wires coming from this winch. The actuator is connected to a high pressure reservoir, and this gives spring effect. Additional active heave compensation system can easily be adapted to this system.

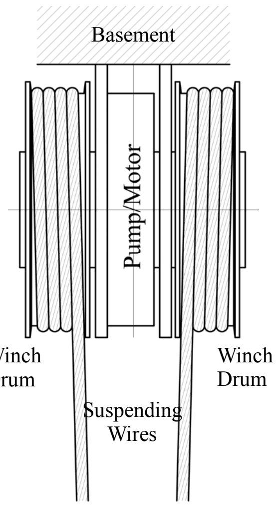

Fig. 8 Concept of Suspending Spring using Hydraulic Pump/Motor, Single Layered Winch Drum, and Suspending Wires

The stroke will be from several meters to about 10m, and the winch drum can be a single layered one. If the drum diameter is 1m, only three turns and a little gives about 10m stroke. Thus, the combination with winch drum and hydraulic pump/motor can be a small sized system.

Maximum lowering/raising speed depends on the sea condition, but it will be around 1m/sec at the maximum for the conventional ROV operation (2.5m height with 6sec period sinusoidal wave gives 1.25m/sec at the maximum). 1m diameter drum winch requires 20rpm to obtain this level of speed. This level of rotation speed for hydraulic pump/motor is of no problem, but quick response is required for the pump/motor.

High-speed/low-torque pump/motor with high ratio reduction gear is very small and easy to handle, but it is not recommended because of bad gear efficiency.

During the operation, the hydraulic system and winch drum is always working, and the wire may be worn out at short duration. So, the wire must be very often replaced with new ones.

IV. Installation Of Docking System

A docking system of ROV or TMS can be installed at the sheave 3 position. As this docking system moves as a part of the sheave 3, the relative distance between the ROV/TMS and the docking system is a key issue for safe and easy docking operation. There is no fluctuation of this distance for the system shown in Fig. 6 even while in heave compensating mode, and simple paying-in operation makes sure docking. Thus, the recovery work is expected to become very easy even in rough sea although swaying and surging motion of this heave compensation system must be controlled by the other methods. The heading of the ROV/TMS can be corrected after it is docked to the system. Fig. 9 shows a concept drawing of the docking system.

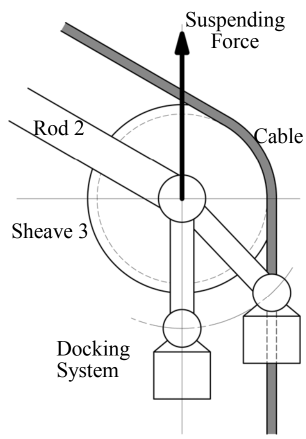

Fig. 9 Concept Drawing of Docking System
When the cable is tightly stretched, the docking system is on the line of cable. When the cable is loosened after docking, the docking system goes just below the suspension point.

V. Conclusion

The umbilical cable is really a life line for ROV/TMS, and a unique method of heave compensation must be pursuit which does not damage the cable. Conventional heave compensation system is a simple system, but the cable life becomes shorter by the repeated runs over the sheaves at the specific parts of the cable. Also the compensation efficiency is not good due to the rigidity of cable itself.

A new concept on heave compensation was discussed here, and it was shown that the damage to the cable would become very small. Docking system can also be adapted to this system, and it was discussed that docking operation would become very easy.

The actual application of this system is very much expected.

Reference

[1] Kinoshita, H. et al: "Chikyu", JAMSTEC, p277, Feb. 2009 (in Japanese)