# THE METHOD OF TRANSHIPMENT OF GOODS BETWEEN SHIPS IN OPEN SEA (STS)

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***Abstract:*** *The transhipment method is using a cable trolley system. The two ships are moving on parallel way in the same direction, between them is suspended carrying the trolley wire. Transhipment of goods is made using container boxes which are caught by the trolley load jacks. The method offers the advantage of high productivity, regardless of sea conditions. Basically, the system is usable at high degree of agitation of the sea. Slack in the cable carrier is assured by an automatic tension-adjusting device.*

**Keywords:** transhipment, derrick, load winch, pitch, roll, hydraulic piston.

## 1. INTRODUCTION

The basic idea from which we started the design work was to enable the transhipment of goods and materials between two vessels in open sea, while the agitation of the sea does not allow boarding ships alongside.

The first step in designing the system was to choose the specific case of transhipment, for which we would calculate the system. Both vessels are in a parallel way moving with equal speed as possible so that the distance between them remains approximately constant.

The link between ships is via cable carrier, suspended between the two ships on which is moving the trolley. Mechanical traction is being provided by a derrick load winch from the loading and unloading system of a ship. Given the difference in level between the cable carrier suspension points on the two ships, we chose the solution of mixed driving, so, the trolley goes up from lower ship to higher ship by mechanical action and downwards by the action of gravity by the weight of the trolley.

The fact that downhill race that requires no mechanical drive but only trolley brake allowed a very simple approach in terms of construction, by two wire, with a carrier cable and pulling cable in an open circuit. The lifting-pulling cable realizes beside the moving motion of the trolley also the lifting. In order to ensure sufficient reserves of height was imposed to adapt a system by proper tensioning of the carrier cable to reduce as much as possible the value of the force vector under load action.

Because the change of distance between the cable suspension points on the two ships occurs a variation in force's vector in cable (arrow increases with decreasing distance for a constant load) and therefore of the reserve height, was imposed to adapt an another system which at the change of distance between the cable suspension points, ensures the maintenance of relatively constant cable tension together with the value of force's arrow in cable– Fig.1.

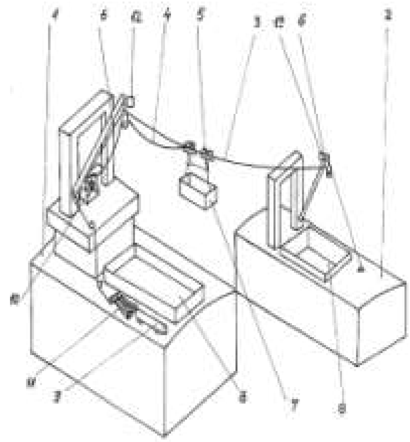

**Fig.1** Diagram of transhipment system:
1, 2 – ships; 3- carrier cable, 4-pulling cable, 5-cart, 6-derricks, 7-load container, 8-cargo hold hatches, 9-hidraulic cylinder, 10-driving winch, 11-automatic carrier cable tensioning system, 12-cart catching system, 13-stopper - trigger.

Carrier cable suspension points are block rollers fixed on ships derrick top. The carrier cable is anchored rigid on deck after it was first passed over the suspension top point on derrick top. The other end of the carrier cable passes over the point of suspension of the other ship derrick through automatic tensioning system and then the cable is anchored rigid to the deck. Pulling cable is connected with one end to the trolley and the other end, after passing over the point of suspension of ship-derrick, is wrapped on winch drum. The trolley jacks catch container crate for transporting goods and materials.

The reels which are points of suspension of the carrier cable are mounted in blocks with one face removable or clamp type to allow easy handling when installing the cable. The blocks are fixed on derrick end using swivel span block. Derrick top end block is double type with one roler for carrier cable and another for pulling cable. Derricks which are holders' suspension points of the cables are derricks from opposite ship's side from which transhipment is made. They are oriented approximately by the ship's longitudinal axis, less inward so that their heads lie approximately two meters from the longitudinal plane of the vessel.

Derrick's balancing angles are normal, so derrick heads projections approximately fall on middle of the hatch. We chose derrick's position indicated above, when the carriage is at one end of travel and we lower container crate in the hold, it should fall approximately on the centre of the hatch, thus excluding the possibility of collision of the box with the hatch walls under wave motion. We adopted a trolley with two jacks because by suspending the box-container by two points it reduces more the swing movements compared to if the box would be suspended in a single point. The main element of automatic tensioning cable system is the hydraulic cylinder. It is kept permanently oil pressurized from a hydro pneumatic accumulator which is under the deck. Hydro pneumatic accumulator pressure oil is fed through a pressure reducing valve from hydraulic system of the ship. At the end of the hydraulic cylinder piston rod is mounted a battery blocks. On deck near the hydraulic cylinder piston rod end position (the position of the piston PMI), is mounted a battery of blocks. Hydraulic cylinder and the two batteries of rollers form the cable automatic tensioning system. Thanks to the heavy sea, the two vessels will have roll and pitch movements.

These movements lead to variations in the distance between the points of suspension of the carrying cable of the two ships. To maintain approximately constant the tension on the cable, regardless of vessel movements (basically between the two points of suspension the cable to be permanently stretched, without developing large arrows and not let it to be dangerous stretch or tear) is required payment of cable (the difference between the cable length between the points of suspension when vessels are inside rolling towards each other) at inside rolling of the vessels and spinning cable respectively (the difference between the cable length between the points of suspension, when both ships are rolling outwards and length cable between the points of suspension when ships are not rolling) at ships outside rolling.

Heaving and giving of the cable when both vessels are rolling is ensured by automatic tensioning cable system. When ships are not rolling, the system is in equilibrium. Hydraulic cylinder piston force which acts on the cable carrier, in this case, is equal to the tension in the cable.

## 2. THE HEIGHT OF THE CARRIER CABLE SUSPENSION POINTS CALCULATION RELATED TO THE WATER LEVEL

By analyzing the different situations of the two ships heel, we determine the worst case and minimum heights of the two suspension points of the cable. For this we will need to make the system so that subtracting from the minimum suspension height the maximum arrow and the height of the cart-box container, to obtain a sufficient height reserve enough to exclude the pull of cargo by waves. Modern ships have high superstructure and large sail area, are very stable and practical were not recorded heel angles greater than 17 ° in terms of 7 °- 8 ° storms, and in the case of storms up to 5 ° or swell, roll did not exceed 10 °. We believe that cross-vertical oscillations of the two vessels produced on wave occur in phase and therefore does not affect the height of the carrier cable suspension points. To have a sizing of the plant cover in the calculations we considered transhipment can be done in terms of vertical oscillations of ± 3m.

The two ships moving after a direction parallel to the wave axis rolling movement will be less extensive than when travelling by any other direction when pitch movement will prevail. But the angles of trim even in cases of major storms did not exceed 2 ° ... 3 °, so result almost insignificant values. In practical calculation of dimensioning the installation we chose the maximum angle of heel of each vessel as 30 ° aiming thereby to prevent the negative effects of any accidental heel than normal and to oversize the values that enhance plant safety operation, eliminating the possibility of pull and tear of the cables. To determine the height of the carrier cable suspension points in different situations of vessels heel will first

need to calculate the height of these points while the ships are not heeling. In making these calculations have to take into account the fact that at the beginning of transhipped a vessel is at minimum draft and the other at the maximum draft. To calculate the height of the carrier cable suspension point, we use the following: the freeboard (summer line) - F = 5.446 m, maximum draft - $T_M$ = 7.79 m minimum draft forward-$T_{MPv}$ = 3.80 m; minimum draft aft-$T_{MPp}$ = 40m, derrick length $I_b$= 20m, deckhouse height which is derrick mounted-$h_1$ = 3.20 m, the height of the deckhouse at the point of attachment of the derrick-$h_0$ = 2.80 m, the angle of derrick swing, θ = 30 °.
Minimum average draft (amidships) is determined as the arithmetic mean of the drafts fore and aft respectively:

$$T_{med_{\min}} = \frac{T_{mp_v} + T_{mp_p}}{2} = \frac{3{,}80 + 6{,}40}{2} = 5{,}1m \qquad (1)$$

height of carrier cable suspension point on a reefer carrier (if ship is not rolling) will be:

$$Z_{O_P} = F_M + h_1 + h_0 + I_b \cdot \cos\theta = 5{,}446 + (7{,}79 - 5{,}1) + 3{,}2 + 2{,}8 + 20 \cdot \cos 30^0 = 31{,}456508m \qquad (2)$$

To calculate the height of the carrier cable suspension point the following are useful data (assuming use of system amidships derrick): building height to main deck - $D_1$ = 9.70 m, the height of the deck on which it is derrick mounted - $h_1$ = 2.40 m, the deck height at the point of derrick attachment - $h_0$ = 1.60 m, maximum average draft -$T_{mmed}$ = 5.60 m, derrick length $I_b$= 12m, derrick swing angle θ = 75 °. With the above data the height of carrier cable suspension point for non-heeling ship will be: $Z_{0T}$=11,205829m

## 3. THE HEIGHT OF THE CARRIER CABLE SUSPENSION POINTS IN DIFFERENT CASES OF VESSELS HEELING

To calculate the height of the carrier cable suspension points when both ships are rolling out at φ = 30 °, fig. 2.

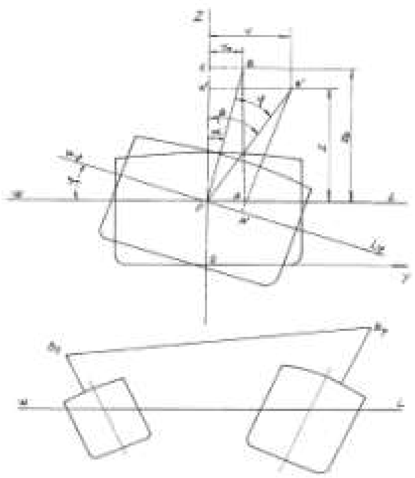

**Fig.2** Scheme for calculating the movements of the cables suspension points of the ships heeling outside

The figure notations are: F - centre of straight floating surface; B-derrick top point when the ship is heeled; B'- derrick top point position when the ship is heeled; A-perpendicular leg down from the derrick top on the waterline WL when the ship is non-heeled; A'-foot perpendicular down from the derrick top on waterline when the ship is heeled WφLφ.

Tracing supporting radiuses FB and FB ', we get two rectangular triangles (the right angles A and A') congruent. Applying the Pythagorean Theorem in triangle ABF, we get:

$$|BF| = \sqrt{|AB|^2 + |AF|^2} \qquad (3)$$

The angle α is congruent to the ABF angle of the ABF triangle (as determined by the secant internal alternate BF). In rectangular triangle ABF can express the cosine of the ABF angle. Taking into account the congruence stated above, we have the relation:

$$\cos\alpha = \frac{|AB|}{|BF|} \qquad (4)$$

From relations (3) and (4) follows:

$$\alpha = \arccos\left(\frac{|AB|}{\sqrt{|AB|^2 + |AF|^2}}\right) \qquad (5)$$

B'C'F is also a rectangular triangle with right angle at C '. It is noted in this triangle that:

$$\beta = \alpha + \varphi \qquad (6)$$

and therefore:

$$|FC'| = |FB'| \cdot COS\beta \qquad (7)$$

But from | FB | = | FB '| and relations (3) and (6) resulted:

$$|FC'| = \left(\sqrt{|AB|^2 + |AF|^2}\right) \cdot \cos\left[\varphi + \arccos\left(\frac{|AB|}{\sqrt{|AB|^2 + |AF|^2}}\right)\right] \qquad (8)$$

Substituting in (8):

$$|FC'| = z$$

$$|AB| = z^0$$

$$|AF| = Y^0, obtinem:$$

$$z^{e} = \left(\sqrt{z_{o}^{2} + y_{0}^{2}}\right) \cdot \cos\left[\varphi + \arccos\left(\frac{z_{0}}{\sqrt{z_{0} + y_{0}}}\right)\right] \qquad (9)$$

Formula (9) presents the formula for calculating the height of the cable suspension point after the ship tilted outward with φ angle. For both ships we have adopted, as we have shown, φ=30°. So, $y_0$=2m.

For the ship out heeled, the height of the cable suspension point out heel will be:

$$z_{p}^{e} = \left(\sqrt{z_{0_p}^{2} + y_{o_p}^{2}}\right) \cdot \cos\left[30^{0} + \arccos\left(\frac{z_{0_p}}{\sqrt{z_{0_p}^{2} + y_{0_p}^{2}}}\right)\right] = \sqrt{31{,}456508^{2} + 2^{2}}$$

$$\cos\left[30^{0} + \arccos\left(\frac{31{,}456508}{\sqrt{31{,}456508 + 2^{2}}}\right)\right] = 26{,}242135m \qquad (10)$$

Point of cable suspension height of the ship heeled out to be:

$$z_{t}^{e} = \left(\sqrt{z_{a_t}^{2} + y_{0_t}^{2}}\right) \cdot \cos\left[30^{0} + \arccos\left(\frac{z_{0_t}}{\sqrt{z_{0_t}^{2} + y^{2}{}_{0_t}}}\right)\right] = \left(\sqrt{11{,}205829^{2} + 2^{2}}\right) \cdot \cos\left[30^{0} + \arccos\left(\frac{11{,}205829}{\sqrt{11{,}205829^{2} + 2^{2}}}\right)\right]$$
$$= 8{,}7045326m \qquad (11)$$

The difference in level between the two suspension points of carrier cable of ship outside heeled will be:

$$\Delta_{z_e} = z_{p}^{e} - z_{t}^{e} = 26{,}242135 - 8{,}7045326 = 17{,}537602m \qquad (12)$$

We further study how varying the heights of the cable suspension points where the two vessels heels inwards by 30 °. The calculation is analogous to that presented for ship heel-out, except that in B'C'F right triangle, we have:

$$\beta = \varphi - \alpha \qquad (13)$$

With (13), relation (9) becomes in that case:

$$z^{i} = \left(\sqrt{z_{0}^{2} + y_{0}^{2}}\right) \cdot \cos\left[\varphi - \arccos\left(\frac{z_{0}}{\sqrt{z_{0}^{2} + y_{0}^{2}}}\right)\right] \qquad (14)$$

Heights of the carrier cable suspension points in this case will be:

$$z_{p}^{i} = \left(z_{0_p}^{2} + y_{0_p}^{2}\right) \cdot \cos\left[30^{0} - \arccos\left(\frac{z_{0_p}}{\sqrt{z_{0_p}^{2} + z_{0_p}^{2}}}\right)\right] = \left(\sqrt{31{,}456508^{2}} + 2^{2}\right) \cdot$$

$$\cos\left[30^{0} - \arccos\left(\frac{31{,}456508}{\sqrt{31{,}456508^{2} + 2^{2}}}\right)\right] = 28{,}242135m$$

(15)

-for receiving vessel:

$$z_i^t = \left(\sqrt{z_{a_t}^2 + y_{a_t}^2}\right)\cdot \cos\left[30^0 - \arccos\left(\frac{z_{a_t}^2}{\sqrt{z_{a_t}^2 + y_{a_t}^2}}\right)\right] = \left(\sqrt{11{,}205829^2 + 2^2}\right)\cdot$$

$$\cos\left[30^0 - \arccos\left(\frac{11{,}205829}{\sqrt{11{,}205829^2 + 2^2}}\right)\right] = 10{,}704533m$$

(16)

The difference in level between the carrier cable points of suspension when ship heeling outwards by 30 °, will be:

$$\Delta_{z_i} = z_p^i - z_t^i = 28{,}242135 - 10{,}704533 = 17{,}537602m \qquad (17)$$

If both ships heel 30 ° to starboard (the receiving ship heeled out, the other heeled inside, the difference in level between the cable suspension points will be:

$$\Delta_{Z_{Tb}} = z_p^e - z_t^i = 26{,}242135 - 10{,}704533 = 15{,}537602m \qquad (18)$$

If both vessels heels 30 ° to port level difference between the cable points of suspension will be:

$$\Delta Z_{Bb} = Z_p^i - Z_t^e = 28{,}242135 - 8{,}7045326 = 19{,}537602m \qquad (19)$$

The difference in level between the cable suspension points at baseline (non-heeled ships) will be:

$$\Delta Z_0 = Z_P^0 - Z_T^0 = 31{,}456508 - 11{,}205829 = 20.250679m \qquad (20)$$

In (12.), (17), (18), (19) and (20.) relations it is observed that the maximum difference in level between the carrier cable suspension points are recorded when the vessels are not heeled, that remark will be useful in determining the power of operating plant. It also notes that the difference in level between the cable points of suspension is the same for extreme heel positions of the two vessels, regardless of the direction of heel (inside or outside).

$$\Delta Z_i = \Delta Z_e \qquad (21)$$

We conclude that during a period of roll or while moving the ship on z axis from -30 °to +30° The worst situation for the difference in level between the cable suspension points when ships pass through normal position of equilibrium (φ = 0), and the worst situation for cable suspension heights when ships heel out at 30 ° each. Comparing (10) and (11) relationships with (15) and (16) we notice that the minimum heights of the suspension are:

$$\begin{aligned} Z_p^e &= 26{,}242135m \\ Z_t^e &= 8{,}7045326m \end{aligned} \qquad (22)$$

values that will be used in calculating the minimum reserve height from the water level to the bottom of the crate-container.

## 4. CONCLUSIONS

Proposed transhipment method provides the advantage of relative independence from the sea / weather. Transhipment can be done, in this case, for degree of agitation of the sea up to and including 8. Classical method allows transhipment at sea up to grade 3 - 4, being limited by ships friction and their poor handling in rough sea, and that the loading – unloading system can not be used at ships heeling angles greater than 50° (and for higher trim angles θ = 1,50 ... 20). Another advantage of the transhipment system presented in this paper is not necessary that the vessels are linked together and the cost of used ropes is avoided.

The method permits transhipment in open seas directly. Hence, there are two other important advantages: firstly no longer payment for any rent and operating costs, and secondly, it saves fuel, avoiding - the ship movements in ports. The long-term gain is reduced almost in half transhipment time. This leads to increased profitability and productivity.

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