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Evaluation of Boat Lifting System Using A Multiple-Drum Winch

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Abstract

Material handling equipment is designed or selected based on two factors, the aspects of technical and economic. Technical aspects of a boatlift are designated by technical specifications that can meet with the need to lift and move a boat from land to waterway and vice versa. Boatlift is a type of Rubber Tyred Gantry crane specifically designed for moving of small craft, small and medium vessels with a capacity of 10 tons to 600 tons. Boatlift with a capacity of 5 tons is very rarely to find and very different from other types of cranes such as overhead cranes that are easy to find. Boatlift with a capacity of 5 tons can be found at the Shipbuilding Institute of Polytechnic Surabaya, but it has a weakness. The boats experience an un-synchronize movement during the lifting process. This article provides the design of a boatlift pulley system with a capacity of 5 tons using a multiple-drum winch and is capable of lifting the boat at an even keel condition. The evaluation was carried out on the existing system to find the cause of the problem. The correction on the pulley system of the boatlift has been recommended without the replacement of wire rope, brakes, motor, and the multiple-drum of the winch. The weaknesses of boat lifting could be overcome by using a pulley system 8/2/2/1-DeBe + spreader.

1. Introduction

The process of lifting a ship requires accuracy on equipment selection and lifting calculation, especially in calculating the weight and center of gravity of the ship as the main lifting parameters. A careful lifting plan will result in the process of lifting the ship with a maximum level of safety and minimal risk [1]. The boatlift located at the boatyard of the Shipbuilding Institute of Polytechnic Surabaya (SHIPS) having a capacity of 5 tons is used to remove the small craft from the workshop to the test pond and vice versa.

The boatlift had a weakness which is the occurrence of trim, the un-even movement condition in the longitudinal direction of the boat. The bow and stern of small craft were unevenly lifted. If it continues will cause the ship to fall. The un-synchronous movement will increase the risk of ships falling which in turn can cause damage to ships and even fatalities to the crane operator and workers [2]. Research on boatlifts shows that all boatlifts are designed using more than one single winch, a single drum equipped with a drive. All winches with its separated pulley system work together synchronously to make the boat lifting [2,3].

This study aims to evaluate the boat lift in SHIPS that uses a winch with a double drum. This study provides the recommendation of improving the pulley system of the boatlift by using the existing crane components without the addition of another winch. In the previous research [2,3] the boatlift was driven by 2 winches that worked synchronously, while this study confirms that a simple boatlift with a pulley system driven by only one winch could be adequately used without difficulty.

2. Methods

The object of this study is a simple boatlift with a capacity of 5 tons which is driven by only a multiple-drum winch as shown in Figure 1. The problem of trim condition occurs during the lifting process. The bow and the stern cannot be lifted together evenly, although the position of lifting points located on the bow and stern has the same longitudinal distance to the center of gravity (LCG) of the small craft. Investigation on the calculation of LCG has been performed accurately, but the problem hadn't been solved. Accordingly, an analysis on the lifting force at the lifting point was carried out and the root of the problem has been found and solved.

The root cause of the problem is described in the following part of this article using the analysis of normal forces that occur at each lifting point on the pulley system of the boatlift. The lifting method that using only one double-drum as shown in Figure 1 is not commonly used on boat lifts. The crane is equipped with the 8/2/2/1 pulley system which means:

a) The lifting system has 8 suspensions of wire rope during the lifting process.
b) The system has 2 pulley system or 2 wire rope, one rope for lifting system that works on the left side and the other works on the right side, and each wire rope forms 4 suspensions on the lifting task.
c) Each pulley system has 2 lifting points.
d) This lifting system is pulled by 1 winch with a double-drum.

Figure 1. Boatlift with 1 Double-Drum Winch

The 8/2/2/1 pulley system described above is the same as 2 units of the 4/1 system. The 4/1 system is the lifting system consisted of 4 suspensions of wire rope rolled and stacked at 1 drum. In this case, the system is unique which each unit of the system has 2 lifting points and the 2 units are pulled by one winch having double-drum. Commonly, the boatlift uses more than one winch as presented in Figure 2 [4]. Figure 2 shows the lifting method using the pulley system of 16/8/1/8 described as:

a) The small craft is lifted by 16 suspensions.
b) The lifting system consists of 8 units of the pulley system or 8 wire rope, 4 units are installed on the left and 4 units on the right. Every unit has 2 suspensions of wire rope and winded by one single-drum winch.
c) Each unit of the pulley system has only one lifting point.
d) The system has 8 winches.

The 16/8/1/8 lifting system is 8 units of the 2/1 pulley system lifted by 8 winches which every unit has only 1 lifting point. The 2/1 pulley system means a pulley system with 2 suspensions and driven by 1 unit of winch or hoist. Actually, the problem on boatlift presented in Figure 1 can be solved by adopting the system applied on the crane shown in Figure 2 which is by installing 3 new units of winch but it will be high cost. Another solution is sought to minimize the cost of crane repair through the identification and analysis of crane design variables. In this case, the fixed variables are:

a) size and type of wire rope,
b) pulley size, and
c) drum size and motor power.

The changed variable is the configuration of the pulley system to achieve synchronous vertical movement. The methods used for this purpose are as follows:

a) Plan the change of system but still using only 1 unit of the existing double-drum winch.
b) Calculate the normal forces acting on each lifting point of the system and the forces should be the same. If the forces are different then the system will work un-synchronously.
c) Evaluate the capacity of wire rope, pulley, and winch.

Figure 2. Boatlift with 8 Single-Drum Winch

2.1. Alternative Design of the System

The existing pulley system is called the 8/2/2/1-KaKi which means that each unit of 4/1 system is installed on the right and left of the crane and lifts the starboard and the port side, respectively. The system is shown in Figure 3. The 2 units of 4/1 pulley system have 2 lifting points of KiDe and KiBe at the left, and 2 lifting points of KaDe and KaBe at the right of the crane.

The 2 alternatives re-design of the system are shown in Figures 4 and 5. Firstly, as shown in Figure 4, the existing pulley system is changed by removing the 2 of 4/1 system from the left and right side into the forward and rear of the crane. The change is intended to ensure that the distance of the 2 lifting points to the center of gravity of the boat is the same by assuming that the center of gravity is located at the centerline of the boat.

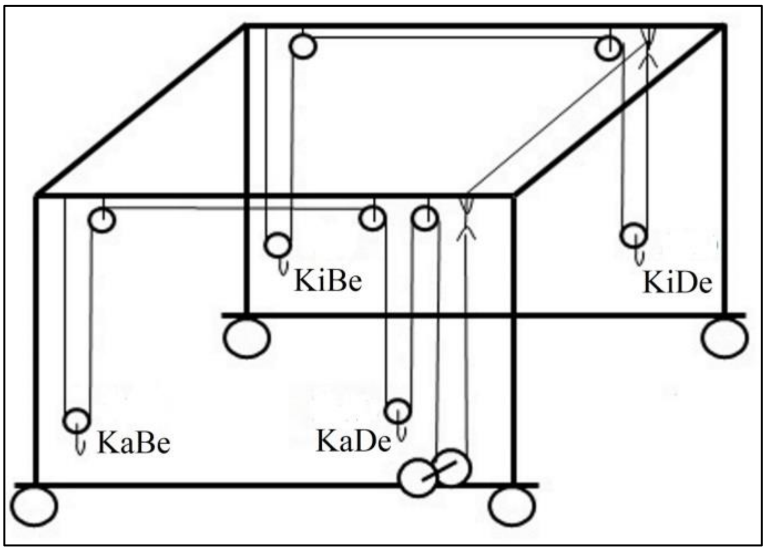

Figure 3. The of 8/2/2/1-KaKi System

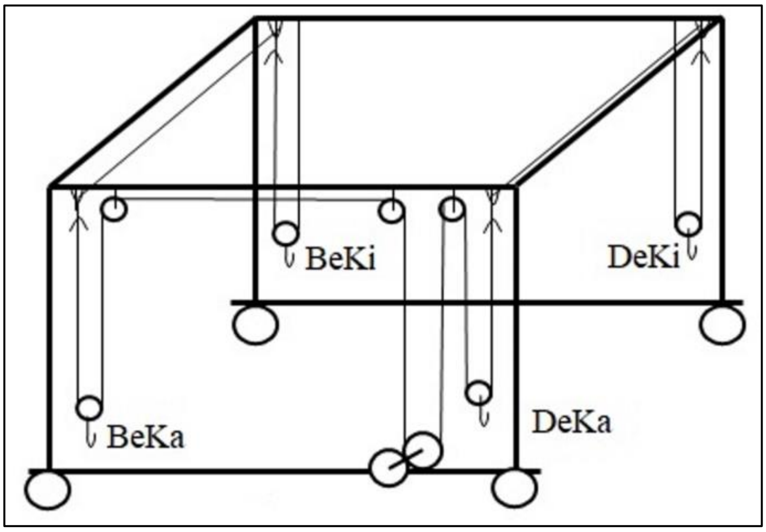

Figure 4. The of 8/2/2/1-DeBe System

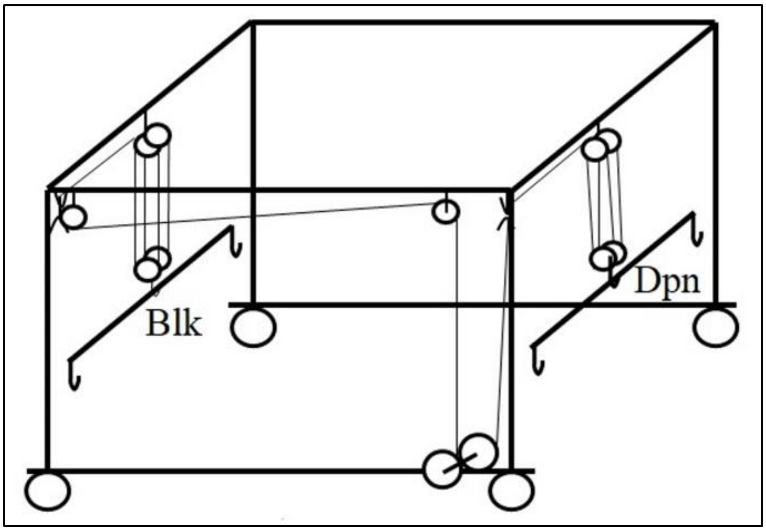

Figure 5. The 8/2/2/1+*Spreader*-DeBe System

The second change is shown in Figure 5 which also uses 2 pulley system units 4/1, but the 2 lifting points at 1 unit of the pulley system are merged into 1 point. The lifting points of KiDe and KaDe are joined to be the Dpn and their lifting points are replaced by the point of Blk. The new lifting points of Blk and Dpn are connected to two spreader bars. The spreaders make the lifting points of the boat to be 4, as same as the previous system but the 4 suspensions in the spreader system are located at the same point. The calculation of the force on each suspension can be explained in section 2.2.

2.2. Lifting Forces

The forces acting on the hanging straps (suspensions) of the system depend on the number of suspensions, load, and the friction force on each pulley. The force acting on a rope that passes through a pulley is directly proportional to the force on the rope before passing through the pulley and the resistance factor that occurs in the pulley, as shown in Eq. 1.

$$F_1 = \varepsilon F_2 \tag{1}$$

The F_1 and F_2 are suspension rope forces after and before crossing a pulley, respectively. The ε is the resistance factor of the pulley which is 1.05 for the resistance force of 0.05.

2.3. Wire Rope and Winch

Wire rope is selected based on the lifting force and the safety factor as shown in Eq. 2.

$$F_b = S_f \, F_{max} \tag{2}$$

where F_b is the minimum breaking load of the selected rope, S_f is the safety factor intended applied on the rope, and F_{max} is the maximum force acting at the rope suspensions.

Winch power is calculated based on the lifting speed and torque required to drive the winch drum as shown in Eq. 3 [7,8].

$$P = \frac{2\pi n T(1+m)}{60\eta} \tag{3}$$

where P is the power in watt, n is the drum revolution in rpm, m is the margin of safety, T is the required torque to pull the maximum suspension (F_{max}) dan η is the motor efficiency. In the case of the double-drum winch, the required torque is calculated as shown in Eq. 4.

$$T = 2F_{max} R_d \tag{4}$$

where R_d is the drum radius.

3. Results and Discussion

The results of the analysis show that the cause of asynchronous lifting between the front and the back of the ship (trim) on the pulley system installed, as shown in Figure 1, is the difference of the forces acting in between the rope suspensions. The suspension force acting at the rear lifting point (KiBe and KaBe) is higher than the force acting at the front lifting point (KiDe and KaDe) caused by the resistance force of the pulleys. The forces calculation is described in subsection 3.1.

The calculation of the center of gravity is not required on the first alternative design, but it still has the problem of unbalance lifting between the starboard and the port side of the boat. The change of the 8/2/2/1-KaKi system to the system of 8/2/2/1-DeBe will solve the trim condition, but the problem of inclining will arise. Thus the first plan of change cannot overcome the problem. The problem can only be solved by using the second plan of change, where each pulley system unit has only one lifting point, as described in subsection 3.2. An evaluation of the use of wire ropes and winch motor shows that the selection of these components is following the requirements and can be used in new systems, as described in subsection 3.3.

3.1. Nonsynchronous Lifting System

Figure 6 shows the forces acting on the pulley system that is already installed. The normal forces of rope suspension are Fmax, F1, F2, F3, and F4. The static loads acting at the lifting point of the hook, namely the points of KaBe, KaDe, KiBe, and KiDe are the same by configured the points at the same distance to the center of gravity of the boat. Thus, if the ship's weight is W, the load at each point of the lift is W / 4, as shown in Table 1. The forces acting at the rope suspensions can be calculated using Eq. 1 and the results, as in Table 2.

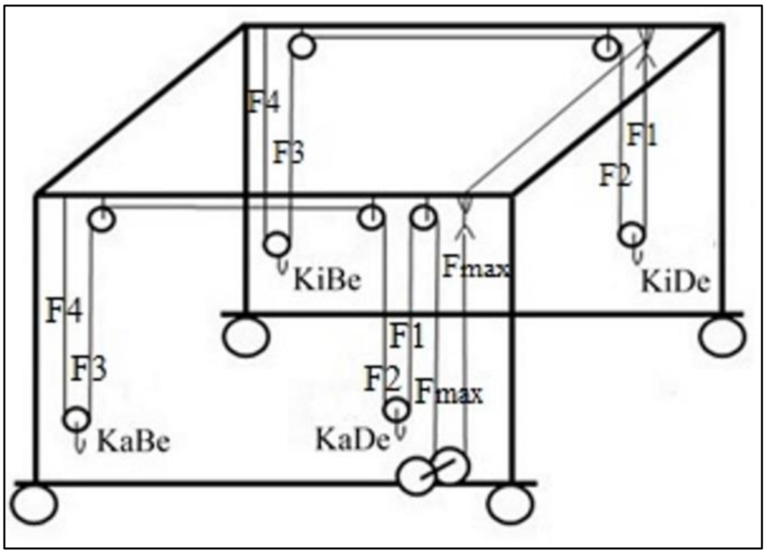

Figure 6. The Lifting Force of Existing System

Table 1. Static Load

No	Item	Weight (ton)	Load (N)
1	Boat weight	5.00	49,050.00
2	Load at the KaBe	1.25	12,262.50
3	Load at the KaDe	1.25	12,262.50
4	Load at the KiBe	1.25	12,262.50
5	Load at the KiDe	1.25	12,262.50

The lifting forces acting on the suspensions of the wire rope were calculated based on Eq. 2. The total force on the rope is equal to half the ship weight because of the 8/2/2/1-KaKi system takes only one part of the symmetrical boat weight. The half weight of the boat is also applied for the 8/2/2/1-DeBe system, if the distance of the front and rear lifting points to the boat center gravity are the same. The resultant of the forces can be formulated in Eq. 5 and simplified to Eq. 6 [5,6].

$$\begin{gathered}\frac{W}{2} = (F_1 + F_2 + F_3 + F_4)\\ \frac{W}{2} = F_1\left(1 + \frac{1}{\varepsilon} + \frac{1}{\varepsilon^2} + \frac{1}{\varepsilon^3}\right)\\ \frac{W}{2} = \frac{F_1}{\varepsilon^3}(\varepsilon^3 + \varepsilon^2 + \varepsilon + 1)\\ \frac{W}{2} = F_1\frac{1}{\varepsilon^3}\left(\frac{\varepsilon^4 - 1}{\varepsilon - 1}\right)\\ F_1 = \frac{W}{2}\varepsilon^3\left(\frac{\varepsilon - 1}{\varepsilon^4 - 1}\right)\end{gathered} \tag{5}$$

$$F_{max} = \frac{W}{2}\varepsilon^4\left(\frac{\varepsilon - 1}{\varepsilon^4 - 1}\right) \tag{6}$$

where W is the boat weight and ε is the pulley resistance factor.

Table 2. Distribution of Lifting Forces

No	Lifting Forces	Value (N)
1	F_4	5,690.09
2	F_3	5,974.59
3	F_2	6,273.32
4	F_1	6,586.99
5	F_{max}	6,916.34

Table 2 shows the results of calculating the forces on each of the suspension rope. These results indicate that there is about 10% difference between F1 and F3, where F1 is the force on the rope that comes out of the front lifting points (KiDe and KaDe) and F3 is the force on the rope that comes out of the rear points (KiBe and KaBe).

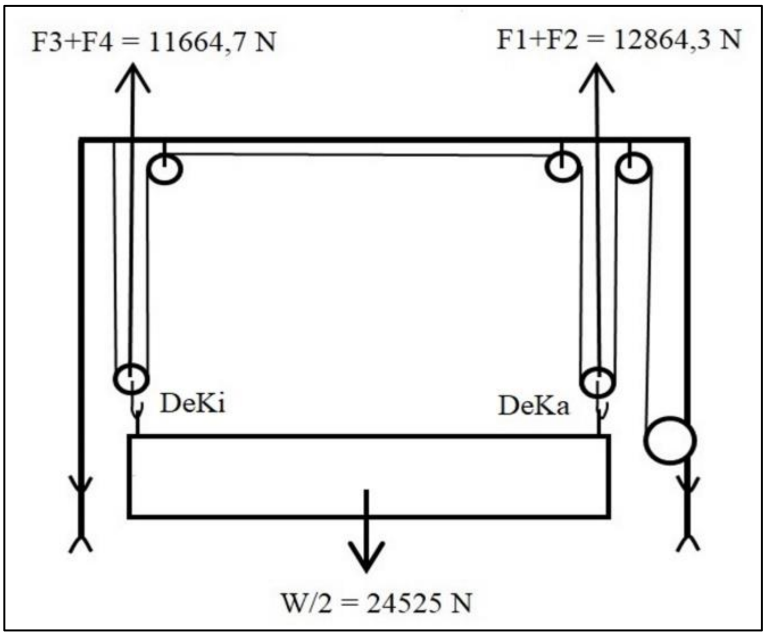

Figure 7. The Difference of Lifting Forces

This difference in force will prevent the front lifting points (KiDe and KaDe) from being lifted. The front pulley-block will only rotate at the same high position without lifting. The difference in lifting force also applies to the 8/2/2/1-DeBe system shown in Figure 7. The required force to lift the DeKa point is greater than the lifting force at the DeKi point. It is resulting in the lifting of the left pulley, while pulley at the DeKa point will be rotating without moving from a specific high position so that the ship is lifted only on the left side.

3.2. Synchronous Lifting System

The rope suspension forces on the 8/2/2/1- DeBe+Spreader pulley system, as shown in Figure 8, are the same as the force on the 8/2/2/1-KaKi and 8/2/2/1-Debe systems, but the two lifting points are joined. The lifting point is connected to the boat by the spreader beam. This system guarantees the ship to be synchronously lifted. The two lifting points on the 8/2/2/1 compound system are lifted together because the two drums are rotated synchronously by one drive motor. Spreaders at the lifting points of Dpn and Blk are lifted together. Lifting the ship using only two lifting points can cause a swing, especially when moving the ship due to the uneven surface of the wheel path. This problem can be reduced by using a controlling rope that ties the boat to the four pillars of the boat lift.

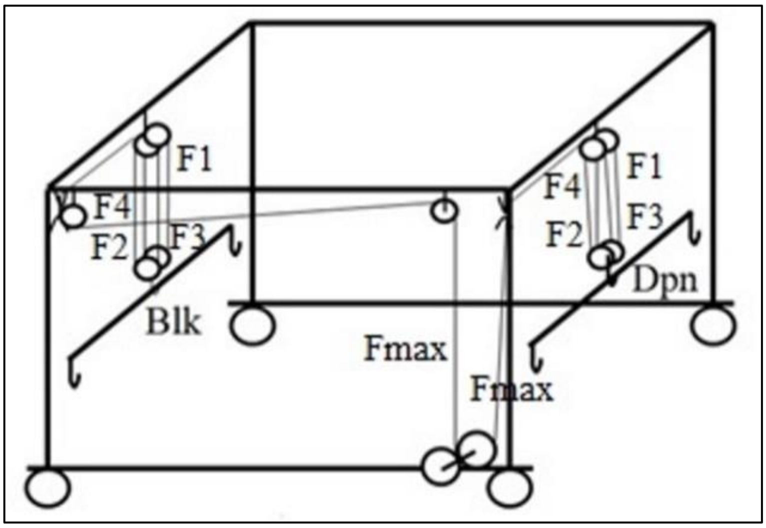

Figure 8. Synchronous Lifting System

3.3. Wire Rope, Pulley, and Motor Selection

Wire ropes used in the existing system are steel ropes with the diameter (d) of 11.1 mm and the type of 6x19 + 1FC. The rope has a breaking load of 5550 kg or 54445.5 N. Eq. 6 results in the Fmax of 6916.34 N, so the magnitude of the rope's safety factor is 7.87. The diameter of the pulleys (D) installed in the system is 300 mm or D/d is 27. The dimension of the wire rope and pulleys comply with the safety factors recommended by other researchers [9], which is 5 for static loads and 1.5 for fatigue loads. In contrast, the minimum diameter of the pulley diameter is 18 times the diameter of the steel rope [9].

The motor power used in the installed pulley system is 5.5 kW with a drum diameter of 400 mm. Based on equation 4, the torque needed to lift the ship is 2766.54 Nm. The motor efficiency is 90% and the power margin is 25% [7,8] so the maximum lifting speed of the boat lift is 4.29 m/min. Dermawan [2] planned a boat lift with a lifting rate of 5 m/min, while Vigneshwaran [10] designed a lifting speed of 36 m/min. The standard lifting speed for a crane with a capacity of 5 tons is 15 fpm [11], which is equal to 4.57 m/min. A power of 5.5 kW mounted on a boatlift has a margin of 17.5% for the lifting with a minimum standard speed.

The summary of the comparison between the existing and proposed design of the pulley system is shown in Table 3. The table shows that the proposed design only recommends the addition of a spreader bar and all other components are the same as the existing ones. The spreader makes two lifting points of two single pulleys join into one point of one block with two pulleys. Accordingly, the difference of loads at the two points (11,664.7 N and 12,864.3 N), as shown in Figure 7, are dismissed by summing the two loads into one, which is 24,529 N. The correction of two-point to be only one point can ensure that the lifting system is synchronous. This analysis is dealing with the previous design of the handling and lifting system proposed by the BOATLIFT [4].

Table 3. The comparison between the existing and proposed design

Items	Existing Design	Proposed Design
System	8/2/2/1	8/2/2/1+spreader
F_{max}	6,916.34 N	6,916.34 N
Motor	5.5 kW	5.5 kW
Drum	400 mm	400 mm
Rope type	6x19 + 1FC	6x19 + 1FC
Rope dia.	11.1 mm	11.1 mm
Pulley dia.	300 mm	300 mm
Rope SF	7.87	7.87
Motor margin	17.5%	17.5%

4. Conclusion

The evaluation of the lifting system of boatlift at Non-Metal Workshop, Politeknik Perkapalan Negeri Surabaya, concludes that the design of the pulley system is incorrect because it doesn' t result in a synchronous lifting. Synchronous lifting on the boatlift can occur if each pulley system unit on the boatlift has only one lift point and each pulley system unit is driven by each winch that works synchronously. A simple system with one double winch that uses a compound pulley system can be applied to a boatlift for synchronous lifting. A double-drum winch can only pull two pulley system units. Accordingly, to lift a boat with four lifting points, two spreader beam are required to divide the two lifting points into 4 points.

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