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***Journal of Scientific and Engineering Research*, 2017, 4(9):377-382**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

A Design and Analysis of Hydraulic System of Lattice Boom Crane

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Abstract The LBC (Lattice Boom Crane) carries a heavy freights and self-weight. In the design, the structural safety analysis under multiple loading and angle conditions is one of the mandatory processes. Since LBC is primarily used on the sea, stable motion of hull under various sea conditions and ensuring safety against outer forces under a variety of atmospheric conditions should be a priority. In the finite element analysis, the modeling for the structural analysis was designed by simplifying the unnecessary parts, and four boundary conditions were applied by selecting four cases under the condition of luffing angles and environment. Plastic deformation and fracture did not occur under all four conditions. In addition, the hydraulic system was designed to control the hoisting speed to prevent the accident caused by the overload of the crane with the safety of the structure. To control a velocity between main and auxiliary load, a hydraulic circuit was designed. As the result of structural and hydraulic analysis, LBC was satisfied of safety and evaluated its high efficiency. As a result of the structural analysis, the safety factor was derived by comparing the maximum stress with the yield strength of the material. The hydraulic system results showed that the main and auxiliary hoisting speeds could be adjusted to each other. Also from the hydraulic results, the specifications of the crane according to the hydraulic system were confirmed.

Keywords Offshore crane, Lattice boom crane, Structural analysis, Hydraulic system

1. Introduction

Korea has made rapid progress in offshore plant industry in a short term. Unfortunately, it has heavily dependent on the import of core equipment from countries such as Norway, UK or US. In order for Korea to overcome this crisis and take initiative in providing total solution, it should build robust offshore plant industry by securing competent engineering and developing high quality equipment. Offshore plant-mounted equipment accounts for as much as 40~55 % in cost structure. Korea, therefore, requires domestic production of offshore plant through technological breakthrough so that it can save cost and improve profit margins.

LBC with a truss structure rather than a box shape is installed on the topside main deck of offshore plant such as FPSO, Drillship, Rig, and Platform and is used for handling heavy materials, Raiser rack, and Pipe rack. The LBC, with its hook hung at the end of the boom, specializes at loading and unloading cargo on and off large sailing vessels or transporting small items and large drilling rig, and is widely used in offshore plant industry with a benefit of low manufacturing cost [1-5].

Main hoisting, Aux hoisting, Luffing system and Slewing system are used to transport cargo from auxiliary vessel and to transport large-scale drilling equipment such as small objects and drilling pipes.

Cranes for offshore plants are also required to have reliability in terms of basic structure, operating system, and stabilizer for rolling, pitching, and heaving movements due to waves. In other words, the crane should consider the safety of the fire and explosion due to the production of petroleum products and the operation of the crane for a long time and the quick operation, as well as the special environmental conditions of the sea directly exposed to the climatic influences such as waves and wind. Therefore, a variety of analysis techniques are required. The boom part of the crane, which is related to the actual lifting load, is composed of a truss type so receives less influence of the wind. However, in the case of the cargo, it may be affected by the wind and may affect the safety of the whole structure of the crane. [6, 7] Used in bay area, LBC requires hydraulic system, and for the prevention of its deformation or fracture, it should be equipped with overload limiter and brake gear etc. under the design requirements manual, and adjusted in advance for smooth operation. The mutual safety of the crane structure and the hydraulic system that controls the hoisting system must be taken into account when manufacturing the crane. In addition, a system device is designed to protect the crane by controlling the wire rope when the overload acts on the hydraulic system design.

The hydraulic system is analyzed considering the speed control between the hoisting and auxiliary hoisting, the speed of the luffing system and the slewing system for rotating LBC. The environmental loads are considered for the crane optimization design. And the structural analysis was carried out to confirm the safety of the whole structure.

This study aims to provide fundamental knowledge on the design of LBC used in offshore plant by assessing its safety via finite element analysis, and evaluating its operating efficiency through the development of core technology such as overload limiter [8-10].

2. Structure Analysis

2.1. 3D Modeling of LBC

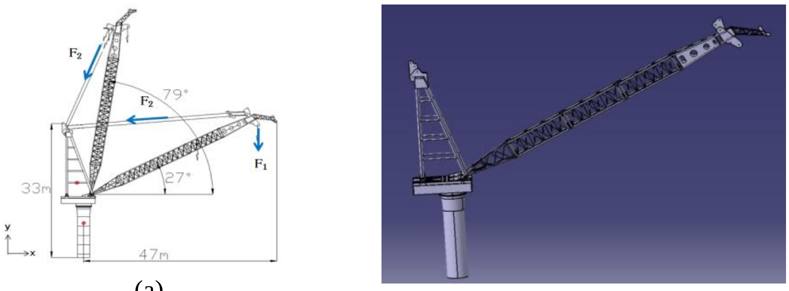
In order to create fine mesh and more precise analysis, each 9 parts were designed. To be indicated as one single structure, each parts were assembled. As shown Fig.1 (a), this study analyzed crane with a height of 33m, maximum working radius of 47m and maximum lifting capacity of 60t. Steel plates are EH36 and S355J2 which are widely used in marine structures with tensile strength of 335MPa, density of 7890kg/m³, and poisons ration of 0.3.

Fig. 1 represents 3D modeling for structural analysis. For the firm grasp of the structure analysis and to save analysis time, it did not include unnecessary equipment and auxiliary parts such as bolt joints and winch. Each parts were processed as single structure via 3D modeling and for the seamless join among the parts, crash test was conducted.[11, 12]

2.2. Boundary Conditions

LBC is also available for both loading/unloading freight on land and transporting equipment to and from auxiliary vessels, so this study was conducted under two different settings—in case of being used off board when being on the berth and the other case of being used on the sea—and different loads were applied depending on the boom angles.

Also, since crane is designed to lift materials and cargo using wire rope attached to main winch and auxiliary winch, load bearing capacity of wire should be considered when considering load limit. The load bearing capacity of the main wire connected from hook hung at the boom head to winch (F1), and the load capacity of the wire connected from auxiliary hook to gantry (F2) were calculated. F1 was calculated considering the direction of gravity, and F2 was calculated in accordance with the x and y direction. Fig.1 (a) shows how the crane appears depending on the direction of load and boom angle. Table 1 represents all of the 4 cases of conditions and load values.



(a) (b)

Figure 1: The diagram of; (a) Motion of LBC. (b) Assembly model of LBC

Table 1: Conditions for structure analysis of LBC

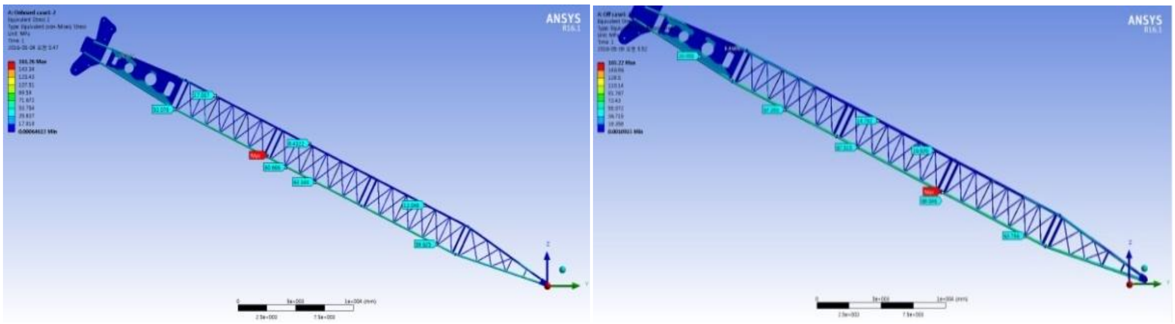
Setting	Classification	Hoisting load	Boom angle	F_1(N)	F_2(N)	
					F_x (N)	F_y (N)
On Board	Case 1	10Ton	27°	69000	25776	2255
	Case 2	60Ton	79°	299000	43810	103211
Off Board	Case 3	6Ton	27°	73333	27395	2396
	Case 4	40Ton	79°	300000	43957	103556

SWLH represents lifting load; DY.F, dynamic coefficient; Av, boom tip vertical acceleration. Under the rule of API classification class, dynamic coefficient of 1.42 and 2.0 was applied using following formula. {1}

$$\mathrm{DY.F} = 1.373 - \frac{\mathrm{SWLH}}{1173913} + A_v \qquad \{1\}$$

2.3 Results of Structural Analysis

The safety of structure was evaluated using finite element analysis. According to the finding, crane had higher stress intensity when used off board than on board. That is because environmental factors such as wave and wind have greater impact on crane when used off board. Also, the result shows the heavier each hoisting load, the higher each stress.



(a) (b)

Figure 2: The results of structural analysis; (a) Maximum stress point of Case1. (b) Maximum stress point of Case 3

Fig. 2 shows when the boom angle was adjusted to 27° as in case 1 and 3, the lower part of boom had maximum of stress. That is because boom head leaned down due to the load, compressive force on the lower part of boom, but it did not affect the structural safety at all. Also, the smaller the angle of the boom was the higher stress in the pedestal part. The smaller angle of boom was more experienced in the direction of gravity. So the stress of boom was delivered through the whole part of crane. As in case2 and 4 where the angle of the boom was adjusted to 79°, the same position of boom head experienced maximum stress. Table.2 shows maximum stress and safety factor points of all cases.

Table 2: Structure analysis results

Setting	Classification	Maximum stress	Safety factor
On Board	Case 1	161.26MPa	2.20
	Case 2	171.6MPa	2.07
Off Board	Case 3	165.22MPa	2.15
	Case 4	178.4MPa	2.0

3. Analysis of Hydraulic System

3.1. Modeling of Hydraulic System

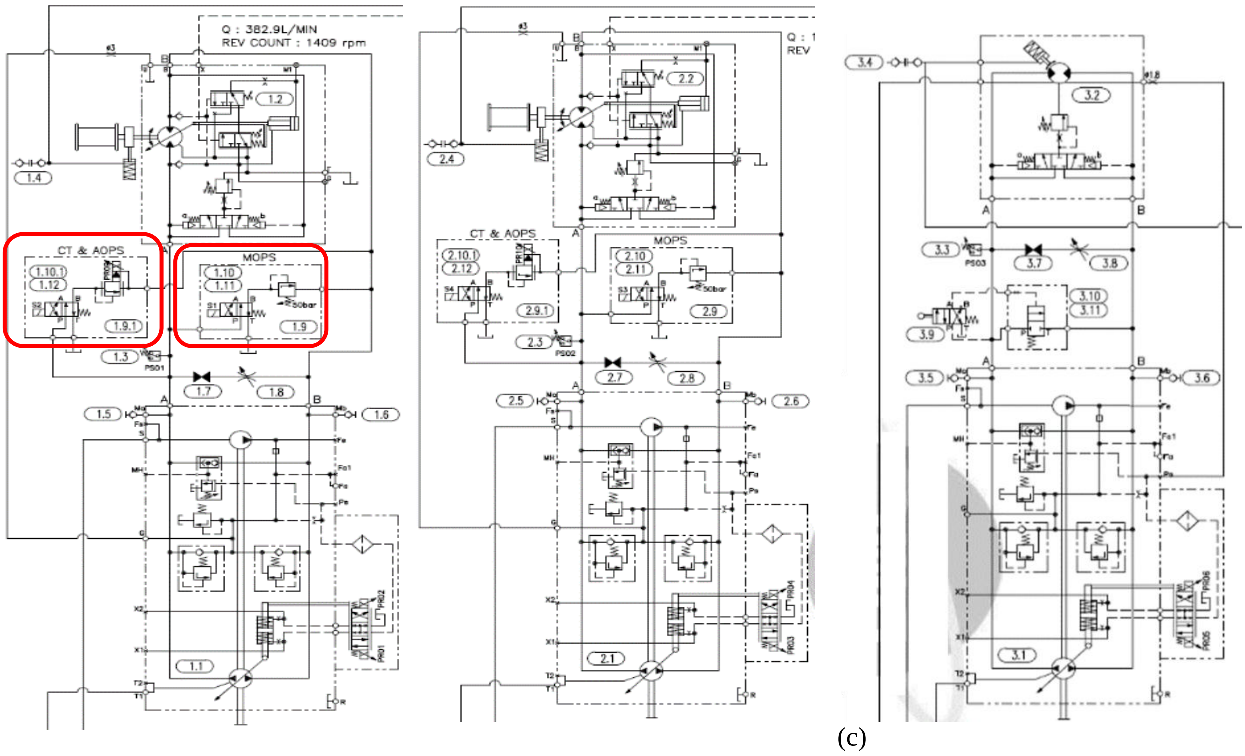
Securing safety requires MOPS (Manual Overload Protection System) manually controllable by crane driver, AOPS (Automatic Overload Protection System) preventing overload automatically, CT (Constant Tension System) keeping tension stable while lifting and lowing items. In this study, hydraulic system with MOPS, AOPS and CT was employed, and reaction velocity was calculated to evaluate its efficiency. Case 1 shows the result of correction value calculated out of interaction formula between hoisting load and pressure under the varied angle of boom. As such, this study analyzed with the condition of case 1 [13, 14].

Circuit modeling was processed with the actual application of MOPS, AOPS and CT to main hoisting system (Fig. 3a) and auxiliary hoisting system (Fig. 3b). Flushing valve was employed to luffing system (Fig. 3c) to control system pressure automatically in case of exceeding certain pressure.

3.2. Results of Hydraulic System

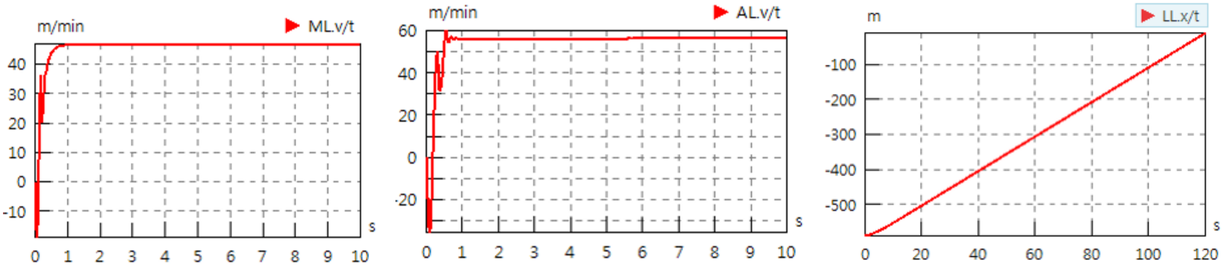
With the condition of 10t of lifting load, 1770rpm of pump and 265bar of system pressure at main hoisting system, the velocity of the system translated to 50m/min as shown in Fig.4 (a). With the same condition of pump and pressure, its velocity translated to 54m/min at auxiliary system as shown in Fig.4 (b). It is important to adjust the velocity of the main hoisting system and that of auxiliary hoisting system at the same level. That is because when lifting and lowering items using both main

Hook and auxiliary hook, main wire supports loads while auxiliary wire prevents crane from swaying. The difference of velocity of the two systems can be balanced by adjusting the input value of pump. Besides, Fig. 4 (c) graph shows that it took 125s for wire to be wounded when crane lifts items, and the velocity of luffing can be adjusted using system when operating crane.



(a) (b) (c)

Figure 3: The Hydraulic system circuit modeling; (a) Main hoisting system. (b) Auxiliary hoisting system. (c) Luffing system



(a) (b) (c)

Figure 4: The results of hydraulic system; (a) Graph of Main hoisting velocity. (b) Graph of Auxiliary hoisting velocity. (c) Graph of luffing speed

4. Conclusions

This paper evaluated the structural safety of LBC as a machine used in offshore plant, and analyzed the processing velocity of main and auxiliary hoist by utilizing overload protection system. The result of study is as follows:

- The result of the structural analysis with the 4 cases of varied boom angle and environmental setting showed that the maximum stress point varied depending on the angle of boom and lifting load. Structure turned out to be safe in that the maximum stress of all cases was below 355MPa of yield strength of materials used in structure, and that safety rate of exceeded 1.5 of the recommended safety coefficient. The result of structural safety can be utilized in providing fundamental knowledge on the initial stage of crane design.
- For the prevention of accidents due to overload, hydraulic system was developed including overload protection system and the equipment keeping tension stable. Additionally, the velocity of main hoisting and auxiliary hoisting could be balanced. Besides, maximum luffing velocity was calculated, which will enable luffing velocity to be controlled. As a result, this crane has a safe hydraulic system that can prevent overload events when used in the sea, and does not cause deformation or destruction as a robust structure when lifting the load. Also, this hydraulic system can be utilized in developing a range of crawler crane as well as LBC.

Acknowledgments

This research was supported by the Ministry of Trade, Industry & Energy (MOTIE) through the Encouragement Program for The Industries of Economic Cooperation Region(No. R0004464).

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