Design, fabrication and testing of hydraulic crane

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Abstract: In this paper, design, fabrication and testing of hydraulic crane is intended to replace the local or traditional method of lifting heavy load with hand with emphasis being laid on performance, safety and reliability. Also, hydraulic crane is capable of carrying load up to 1000kg at a time was developed using locally available materials. The crane is comprised of six primary load-carrying members that are joined together in a particular fashion, actuator, oil tank, hose, pipe and a pump that is powered by a D.C. motor. The principle of operation, fabrication details and methods were critically analyzed, calculations were clearly laid out and material selection and costing were also discussed. The machine Factor of Safety (FOS) is 2 and in the performance evaluation, it indicated 81.2% efficiency.

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1. Introduction

Hydraulic crane is a hydraulic machine that uses a system of hydraulics (which uses special fluids) to transmit forces from one point to another to lift heavy loads. These fluids are typically incompressible or at their maximum density. Most times this fluid is simply regular oil. The machines essentially work by using a piston to press down on the oil which then transmits the force to another piston, which is then driven up. So basically when one piston goes down another is raised. It uses one or more simple machines like a hoist to create mechanical advantage and thus move loads beyond the normal capability of a human (Muhammad, 2004). Cranes are commonly employed in the transport industry for the loading and unloading of freight, in the construction industry for the movement of materials and in the manufacturing industry for the assembling of heavy equipment, (Decker and Robert, 1980)

Cranes have played important part in constructing houses, buildings, cities, and nations throughout history. Structures such as the pyramids in Egypt have likely been constructed with the help of cranes to lift even the heaviest of material in what can only be described as feet's unimaginable to man. The earliest representation of a crane appeared during Ramses' regime in Egypt in 3000 B.C. a portrayal of a lifting device used to collect water- but the first "crane" appeared in ancient Greece and was used to build an entire nation in the fifth century B.C.

Cranes were made of woods until designers building dockyards decided they needed something bigger and stronger. In 1884, cranes were develop using cast iron by a firm called Hick and Rothwell in Bolten, England. This machine was able to lift up to two tons. Wire rope was added to the crane during the same year by Herr Albert Sr. an official of the German superior Board. The wire rope meant the crane was stronger and more durable, enabling cranes to have a higher capacity for lifting heavy weights. Wire ropes were weaved together to create an even more powerful capacity with the added benefit of flexibility. Germany also decided to build cranes using cast iron; the first one was built in Neuburg four years later.

Joseph Monier came up with the idea of embedding wire mesh into concrete to increase the strength of the cranes. He noticed that concrete could handle the pressure of weight but not the traction, but with his alteration he was able to create something that worked efficiently.

New project like the building of bridges and railways meant cranes needed to get with the times. William Fairbain from Great Britain came up with the idea to rivet two arch shaped jibs on a crane. His creation was successful in developing a device more stable and capable of safely lifting weights and he patented the idea shortly thereafter.

Cranes became mobile in 1868 when the firm Aveling and porter thought of mounting cranes on top of automobiles. The steam traction engine and steam roller production company named the first mobile crane "little Tom", which was produced in 1884. Little Tom had a two-ton capacity and could pick up items and carry them. The first lattice beam on a gantry crane was the result of bridges being built in Germany during 1874. It was the first time any crane had been made of iron but designers found that this material helped the crane deal with the stress.

Although cranes had come a long way, the onset of the World War II forced man to become more inventive. But it would not be until 1946 that British crane manufacturer. F. Taylor and sons would produce the first hydraulic crane. Although it was used within the company and could not luff or slew, it opened doors for a 42 and 50 series when it hydraulic crane was place on a Morris W.D operated on cylinders that were lifted and lowered as well as a boom powered by a hydraulic pump. When the company could no longer use vehicles as a chassis for the crane, production began for its very own mobile hydraulic cranes.

During the 1950s, cranes were celebrated as devices that could rebuild what bombs from the war had destroyed homes, cities, and even countries. Hydraulic systems became more and more complex with gear systems and pumps that could be powered while trucks remained immobile. The first truck to loader crane made its appearance from companies such as Hydraulic industry AB. The A2 crane was introduced in 1952. This model was essentially a crane mounted on the back of Chevrolet truck complete with hydraulic lifting cylinders and hooked winch. This loader crane started a trend Alas weyhausen, a company located in Bremen, started similar versions.

Cranes were now becoming more advanced, with companies and manufacturers making the winches more précised, developing telescopic booms, improving the hydraulic pumps, and utilizing different materials to change the way the cranes was made.

A hydraulic truck loader that consisted of a fitted winch could slew and lift up to a ton. This creation by Steinbeck Moosburg was an example of how complex designs were becoming. A company called Liebhero developed a series of cranes known as the 14A and 25A series-they were self-climbing cranes with special hydraulic embedded into fitted masts.

The more a crane could do, especially at the same time, the more popular it was. Demag Zug built a crane with a 25-ton lifting capacity but it also had hydraulic cylinders that provided rapid movement in the luffing; several different movement could be performed simultaneously.

Hydraulic mobile crane throughout the ages Gottwald's hydraulic cranes became important to their further development. The HKM 120 in 1959 was a step in another direction. By this times the bigger the crane, the better. The HKM 120 had a tower, raised cab, and a luffing jib. By the time in 1980s had arrived, cranes were everywhere and every construction company was scrambling to carry one better than the next. Equipment companies such as mounting cranes on tractors, an up-and –coming trend.

Making cranes bigger was still important as can be seen by the largest crane of this time, the Hydra Husky 36/40 TS

Perhaps the most important change was the way cranes were used and valued. Prior to the war, crane trucks were valued for how reliable they were, they had to be during a time of such strife. After the way, emphasis was placed on how comfortable the cranes were for the drivers, cranes that carry maximum results for the smallest maintenance and costs. Being able to operate the hydraulics of cranes was of paramount importance and such machines like the 65 hydraulics lattice boom crane created frenzy for their usefulness and features (www.ritchiewiki.com/wiki /index.php/Hydraulic Truck Crane, 10 Nov, 2009).

2. Design Analysis and Calculations

The crane made up of framed structure or truss is composed of several bars or rods joined together in a particular fashion; these bars are called members of the structure. A member in tension is called 'Tie' and under compression is called 'Strut' (R.K. Rajput, 1998).

There are three main types of framed structures: Efficient or perfect, deficient or imperfect and redundant. The structure is said to be 'efficient' if it satisfies the equation:

$$m = 2j - 3 \qquad (1)$$

Where, m = number of the member of the structure and j = number of the joint of the structure. When m is one number less than the required, the structure is termed 'deficient' or 'imperfect', but when it is one number greater than the required, it is termed 'redundant' structure (R. K. Rajput 1998).

In the analysis of the forces acting in each member of the crane structure, the following assumptions are made: All members are pin-jointed, the frame is loaded only at the joints, the frame structure is a perfect one and the self-weight of the members is neglected. (Rajput, 1998).

A schematic layout of the crane configuration is as shown in the fig.2.1. The members are connected to each other at joints A, B, C, D, E, F, G, H, and I. Note that this is a simplified view of the crane showing only the primary structural components and the forces in the plane of the applied load. The forces that are exerted in each load-carrying member are analyzed by the application of equilibrium or principle of statics i.e. $\sum M = 0$ (Rajput 1998).

These forces are determined using the method of moment and with a maximum load of 1 ton (or 10KN) as shown in figure 3.2 below. Note that all dimensions are in millimeters.

3. Determination of the reactions at the supports (rollers)

The rollers at A and B provide vertical support to the crane at A and B respectively. Reactions at these supports are calculated using the principle of statics (i.e. $\sum M = 0$) as follows: Summing moment about A, we find

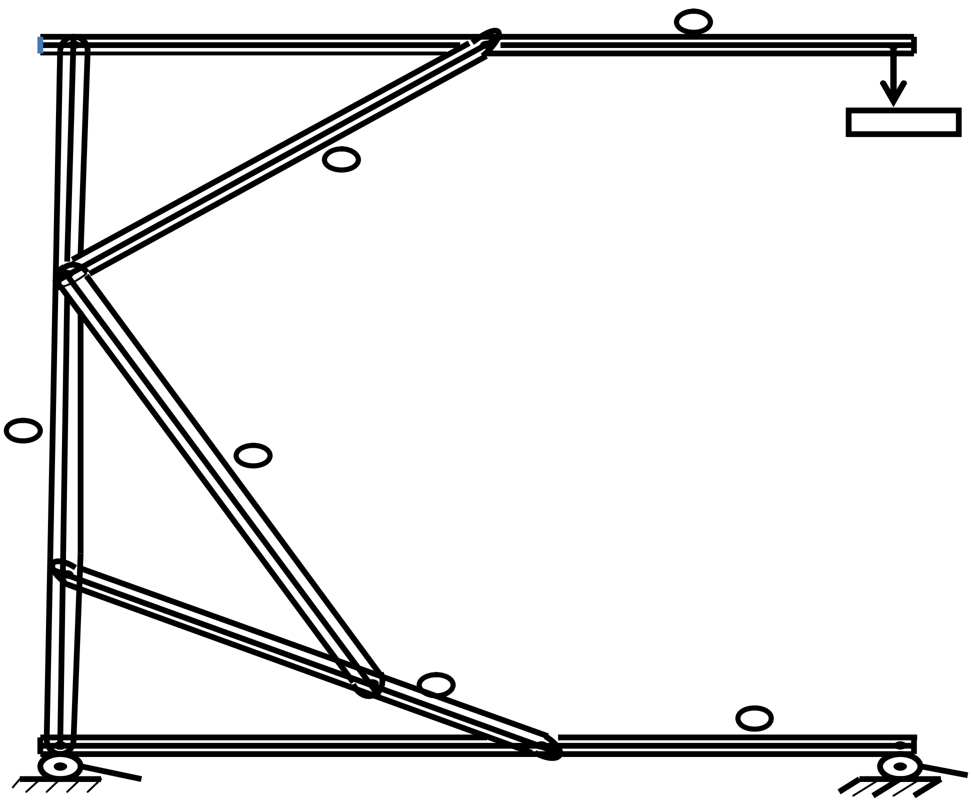
$$R_B = \frac{10\times1200}{46\ 0+7\ 00} = \frac{12000}{116\ 0} = 10.34\text{KN} \qquad (2)$$

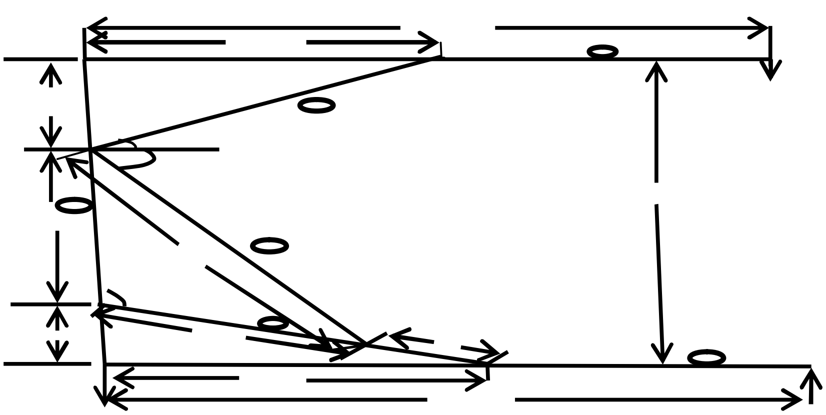
Summing forces in the vertical direction, we find

$$R_A = 10 - R_B = 10 - 10.34 = -0.34\text{KN} \qquad (3)$$

4. Determination of Forces in each of the Load Carrying Member of the Crane

Force exerted on the ram/actuator (i.e. member 5) A ram is a hydraulic cylinder designed to apply force in only one direction. It consists of a barrel, a cylinder cap, head, piston and piston rod.





The force R_H, exerted on the ram/actuator is calculated by considering the free-body diagram of member 6, as shown in figure 3.3 above.

Summing moments about G

$\sum M_G = 0 = R_{HY} \times 490 - 10 \times 1200$ and $R_{HY} = \frac{10\times1200}{490} = \frac{12000}{490} = 24.49\text{KN}$ (4)

The actuator is pin-connected at each end and carries loads only at its ends. Therefore, it is a two-force member, and the direction of the force, R_H, acts along the member itself. Then R_{HX} and R_{HY} are the rectangular components of R_H as shown in figure 3.3. We can then say that

$\tan 44.4 = \frac{R_{HY}}{R_{HX}}$, $R_{HX} = \frac{R_{HY}}{\tan 44.4} = \frac{24.49}{\tan 44.4} = 25.0\text{KN}$ (5)

Total force, R_H on the actuator is therefore,

$R_H = \sqrt{R_{HX}^2 + R_{HY}^2} = \sqrt{25^2 + 24.49^2} = 35.0\text{KN}$ (6)

We know that the forces on points F and H with respect to member 5, are equal and that they act in line with member 5, 44.4° with respect to the horizontal. The reactions to these forces, then, act at point F on the vertical support, member 4, and at point H on the horizontal boom, member 6. By considering the free-body diagram of member 6, R_H is found to be 35.0KN. It shows that member 5 is a two force member in compression.

Summing forces in the horizontal direction along member 6, we have

$R_{HX} = R_{GX} = 25.0\text{KN}$ (7)

Also, summing moments about H, to find

$\sum M_H = 0 = R_{GY} \times 490 - 10 \times (1200 - 490)$ (8)

$R_{GY} = \frac{10\times(1200-490)}{490} = \frac{7100}{490} = 14.49\text{KN}$ (9)

Considering joint F, summing forces in the horizontal direction

$R'_F \cos 71.1 + R_F \cos 44.4 = 0$ (10)

$R'_F = -\frac{R_F \cos 44.4}{\cos 71.1} = -\frac{35.0 \cos 44.4}{\cos 71.1} = -77.2\text{KN}$ (11)

Therefore, FD is in tension.

Also, considering the free-body diagram of member 1

Summing moment about A

$\sum M_A = 0 = R_{CY} \times 460 - 10.34 \times 1160$ (12)

$R_{CY} = \frac{10.34\times1160}{460} = 26.07\text{KN}$ (13)

$\tan 37.5 = \frac{R_{CY}}{R_{CX}}$ (14)

$R_{CX} = \frac{R_{CY}}{\tan 37.5} = \frac{26.07}{\tan 37.5} = 33.98\text{KN}$ (15)

Total force

$R_C = \sqrt{R_{CX}^2 + R_{CY}^2} = \sqrt{26.07^2 + 33.98^2} = 42.83\text{KN}$ (16)

Summing forces in horizontal direction, we have

$R_{CX} = R_{AX} = 33.98KN$ (Compressive) (17)

Also, summing moment about C

$\sum M_C = 0 = R_{AY} \times 460 - 0.34 \times 460 - 10.34 \times (1160 - 460)$ (18)

$R_{AY} = \frac{0.34\times460 + 10.34\times(1160-460)}{460} = 16.07\text{KN}$ (19)

5. Fabrication and testing

Although, some parts were bought from the market however, the other components were manufactured and produced to specification. The Table below shows the details and various manufacturing processes used in the production of the components.

Table 1: This shown Fabrication process

OPERATION	MACHINE TOOL USED	MATERIAL USED
Manufacture of hand lever and finishing	Welding machine, grinding machine and hack saw.	Mild steel
Cutting and grinding of the I-section column	Cutting torch, grinding machine.	Mild steel
Welding operation of joints	Welding machine	
Manufacture of oil tank	Grinding machine, welding machine, hack saw.	Aluminum alloy sheet

Assembly

The assembly of various parts of the machine follows the order stated below: Welding of the various I-Sections to produce the skeletal view of the machine, ram incorporated with bolts and fasteners, welding of chain and hook to the top plan lever arm of the machine, seating of the pump mechanism inside the hydraulic crane frame, positioning of the oil tank in the middle of the machine, lightening of the level arm to the top of the piston using M10 bolt, welding of oil tank to the frame extension and fixing of the links mechanisms, positioning of oil control valves and connection of oil pressure hose or pipe to master and actuating cylinder, incorporation of metal clips to tighten the rubber pressure hose and the copper pressure hose welding of tank cover and filling of hydraulic tank and lines with hydraulic oil respectively.

6. Finishing

The finishing operation carried out on the project to be aesthetically appealing includes the following:

removal of rough edges and surfaces using sand papers and wire brush, removal of dirt and oil from surfaces using kerosene, and spraying of the machine with paint to prevent corrosion and add to the beauty aesthetic values.

7. Testing

After the successful fabrication of the machine, performance test was carried out on the crane, this was aimed at accessing the performance and ease at which different loads could be raised and dropped by the crane. Form the calculations; if the effort is more than the calculated values hence, the following losses will occur: Frictional loss, viscous loss, leakage loss, and transmission loss.

The testing was conducted as follows:
Raise a standard weight (e.g. 100 kg, 200kg, 300kg etc.)
Lock the release valve.
Take note of the load height from the ground.
Take note of the time it takes to reach maximum height.
Allow the loads to stay at different time interval.
Then check if there is a drop in load height.
Note that drop in the loads height could be as a result of leakage in the system. This leakage could occur through: The actuating cylinder, the valves (outlet valves), the release valve and hose.

Table 2: This shown the results obtained from testing

(in lb)	Load (in kg)	Time to raise load manually. (in seconds)	Time to raise load electrically. (in seconds)	Retraction time (in seconds)
35	15.9	120	80	40
70	31.8	120	80	36
80	36.3	120	80	31
115	52.2	120	80	27
160	72.6	120	80	21

8. Mode of operation

The mode of operation of any machine or device is of great importance to its user. The system has a 2-way mode of operation, i.e. manually and electrically operated. When operating electrically, the return valve is pressed down gradually in other to bring the upper horizontal arm and the hook down. The load meant to be carried is hanged unto the hook device. It must be hanged correctly to avoid accident. Since the electric motor employed is a 12V DC motor, the crane is plugged to a 12V D.C source. This is done in two ways: by either using a 12V battery or a 12V adapter to step down the usual domestic voltage for the motor.

The motor rotates the four bar links, the links pumps the incompressible fluid from the pump to the ram and the ram in-turn lifts the upper horizontal bar of the frame carrying the hook and the load up to a certain level before the load is displaced from one position to another. This method is more convenient, energy saving and non-time consuming. It is the improved method of the work shop crane.

In the manual operating system, almost the same procedure is followed. The links to the pump is disengaged and the operator uses his hand to do the pumping until the hanged load rises to the maximum level before it is displaced from one position to another. This method is time consuming, non-energy saving and not convenient. This is the previous existing system.

Future work

In subsequent development a robotic device should be incorporated in the machine to enable it function automatically by self-maneuvering. In this way there will be work station for its mode of operation. This will save time and energy because it will be faster and more efficient. It will also help to minimize accident in the workshops and factories.

Conclusion

The design of the hydraulic crane involved analysis of forces acting in various member of the crane structure, analysis of the links mechanism, determination of pressure developed in the actuator at maximum load, material selection and cost evaluation. Its fabrication details involved some workshop operations such as marking out, cutting, machining, welding and surface treatment which was accomplished using locally available materials. Unlike the existing design that is powered manually, a motorized system was incorporated into the crane to drive the pump using electricity. This motorized system can also be detached and the pump is powered manually making the crane a two-way powered system. On performance and cost evaluation bases, the machine is efficient, reliable, and cost effective.

In the area of appearance the machine has good aesthetic value.

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