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Steel Work Design and Analysis of a Mobile Floor Crane

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OPC and OEN designed the machine and managed the analyses. Authors AOA and SJE conducted the literature searches and improved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The transportation of heavy machine parts and equipment within and outside the workshop has been a source of concern and needs urgent attention because of the hazard it exhibits. This negative effect on the health of engineers, led to the invention of the floor jib crane but research shows that contemporary designs of floor jib crane fail over time when these static load is left on it for a prolonged period of time. This project is centered on the design and fabrication of a mobile floor crane equipped with a facility to lock the load at any level as a special feature, to tackle the issue of failure due to static load. The mobile crane is designed to bear a maximum load of about 1000 kg, with a counter weight of 2.6 KN which gave the crane a 3.034 factor of safety. The materials employed are; sheet metals, angular iron, bolts, nuts, metal rollers etc. The fabrication processes involved drawing, marking out, cutting, filling, welding and assembling. For permanent joints, the arc welding process was employed. As indicated earlier, the mobile floor crane gains its significance in the transportation of heavy machine parts within and outside the workshop. It can also be used to load and unload machine parts on trucks.

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1. OVERVIEW

In our environment, it is hard to lift or transfer a heavy object from one place to another. To solve this problem, cranes are commonly employed in industries either in domestic industries or warehouse [1]. For example, crane is used in transport industry for the loading and unloading of equipment, in the construction industry for the movement of materials and in the manufacturing industry for the assembling of heavy materials [2].

A mobile floor crane is equipment with portable features which makes it admirable and recommended for both indoor (workshop/ warehouse) and outdoor purposes, for the sole aim of lifting and moving heavy materials from one place to another. Some of these features found in them include; adjustable boom, hydraulic height and balance due to rest base design. These adjustable features are to accommodate various heights and sizes of materials to be lifted. This project gains its uniqueness with the design of a dead stop incorporated in its mast, to tackle the issue of failure due to static load. There are also provisions for counter weights at the rear base for cases where the boom is extended beyond the front base wheel to balance the weight of the material to be lifted.

1.1 Mobile Floor Crane Description

A mobile floor crane has a tubular, rigid stanchion that supports a boom pivotally connected to the top end of the stanchion. The base end of the stanchion is disposed between the adjacently disposed mid portions of the tubular, rigid legs of the crane. A support member extends transversely through the mid portions of the legs and the base end of the stanchion and supports the stanchion. In an alternative embodiment, the legs have telescoping members, and a rolling member is provided on the base end of the stanchion to provide mobility for the crane when the telescoping members are detached for storage.

The crane is equipped with lift cylinders and ram that provides the upward thrust to the boom while lifting a heavy material. The lowering is effected by slacking a screw on the side bottom of the lift cylinder. The crane is hydraulically cushioned to avoid vibrations. The base frame can be wide enough to take the load between the two outstanding legs. All the four wheels have two ball bearings each. It is designed with two handles, one for lifting purpose, while the other is for pulling crane.

1.2 Significance of Mobile Floor Crane

It gains a dominant relevance in engineering workshops and warehouses for carrying, loading and unloading of heavy materials, mostly where there are no provisions for overhead crane. At times even when there are overhead cranes, space might be a limiting factor to their use which makes the portability nature of the mobile floor crane a great advantage. In repair garages, it is also used in handling engines and its parts. It is also used in industries for transporting materials from one place to another. It gains relevance also in the installation of new machine, where it is used in proper positioning of the machine. Most importantly, its simplicity reduces the cost of labour as it does not require any special skill in its operation.

2. OBJECTIVE AND SCOPE

The objective of this project is to provide a hydraulic mobile floor crane equipped with a facility to lock the load at any level, in order to tackle the issue of lift cylinder failure usually experienced when using conventional designs. The project is also concerned with the design and construction of a hydraulic mobile floor crane that can be easily disassembled for shipment and storage yet is less expensive to manufacture than a conventional crane without any reduction in the lifting capacity of comparable conventional cranes. The work focused on steel work design and fabrication of a mobile floor crane equipped with a facility that enables the locking of the load at various levels. The load locking facility forms the basis of the modification made. The mobile crane is designed with a load bearing capacity of about 1000 kg utilizing materials like sheet metals, U channels, bolts, nuts, angular irons, metal rollers, etc. which were locally sourced.

3. METHODOLOGY

The design of the machine was made with the aid of solid works showing the different views of the structure in details on which the simulation of the mechanism was done. The designed span of crane is 1.5 m making it capable to lift a load to at least 2 m for conveying of loads and light truck loading. The welding employed is arc welding.

3.1 Materials Selection

The selection of the proper material for engineering purposes is one of the most difficult problems for desired objective at a minimum cost [3]. Problems associated with pollution and recycling will have to be considered. The necessity for weight reduction to save energy will require the use of different materials [4].

In this work material selection was undertaken for the following purposes: more convenient servicing, to reduce the noise of the machinery, to produce the machinery at an economical cost, to improve and reduce dimensions, to make the machine to have a better appearance, to improve the strength of the machinery, to improve its resistance to wear, corrosion and corrosive medium.

3.2 Materials Selection for Various Parts

Several factors were considered while selecting the materials for this work. These factors include; machinability, rigidity, availability, strength and the cost of the material. The materials selected for different components and the reasons for their selection are listed in the table below.

Table 1. Material selection for different parts of the machine

S/n	Component	Material selected	Reason(s) for selection
1	Base	Mild steel	Rigidity, availability, cost and machinability
2	Mast	Mild steel	Availability, machinability and cost
3	Boom	Mild steel	Cost, machinability, availability and rigidity
4	Load locking facility	High carbon steel	High strength
5	Hook	High carbon steel	High strength and shear resistance

4. MACHINE DESCRIPTION

The mobile floor crane designed in this project consists of various parts carrying out specific functions. These parts and their functions are listed as follows;

4.1 The Boom

The boom is the part of the machine where the hook is attached and it gives the load the needed height. The boom is designed with an adjustable system giving it an adjustable length of 0.95, 1.2 and 1.5 m to enable easy loading and unloading in trucks. The boom generally can take the load to height of about 2.2 m.

4.2 The Mast

The mast is the vertical component of the machine that gives support to the boom as well as the lift cylinder. The mast is designed to a height of 1.1 m.

4.3 The Lift Cylinder

It is the most important component of the machine, a hydraulic system that does the actual lifting of the load. It comes in various capacities but the capacity used in this project is 2Tons.

4.4 The Base

This part of the machine provides the balance required by the machine whether loaded or not. It is designed in V-shape for maximum balancing of the machine. The base has a horizontal length of 1.3 m.

4.5 The Metal Rollers

This is the component of the machine that makes mobility possible.

4.6 The Load Locking Mechanism

This component is designed in the machine to hold the load in suspension as long as is required without failure (sudden dropping) due to hydraulic jack failure.

5. DESIGN CONSIDERATIONS AND ANALYSIS

Detail design analyses and calculations on the forces acting on various members as well as the bending moments and shear forces at various points of the boom for minimum and maximum boom lengths were thoroughly carried out while considering functionality, manufacturability and economic availability cost of materials and fabrication process.

5.1 System Analysis

Mathematical relationships were developed for the various parameters necessary for the implementation of this design, corresponding to the sequence of their implementation. To ease design effort, it was divided into subsystems which include: Hydraulic cylinder, Boom, Mast, Base, Load locking facility.

5.1.1 Hydraulic cylinder

The hydraulic cylinder (or the hydraulic actuator) is a mechanical actuator that is used to give a unidirectional force through a unidirectional stroke. It has many applications, notably in engineering vehicles.

5.1.2 Boom

The boom was designed to adjust into three different lengths to enable easy operation on different working conditions. As the boom bear the load, it is subjected to bending force (maximum at the horizontal position), compressive force (when the load is lifted above the horizontal position) and tensile force (when the load is below the horizontal position). Therefore, for an efficient design, these forces were adequately taken into consideration.

5.1.3 Locking device

The load locking device is actually designed to keep the load suspended even on cases of lift cylinder failure. To achieve this, a high strength member is pivoted on the boom and is designed to slot into grooves machined on the mast. This member is subjected to compressive force and thus was designed to withstand such force.

5.1.4 Mast

The being the I-section of the machine is designed fixed to the base and pivoting the boom at the top. The mast is designed to be able to withstand the force transfer from the load locking device, which will create a bending effect at the point of contact "E" between the mast and the load locking device.

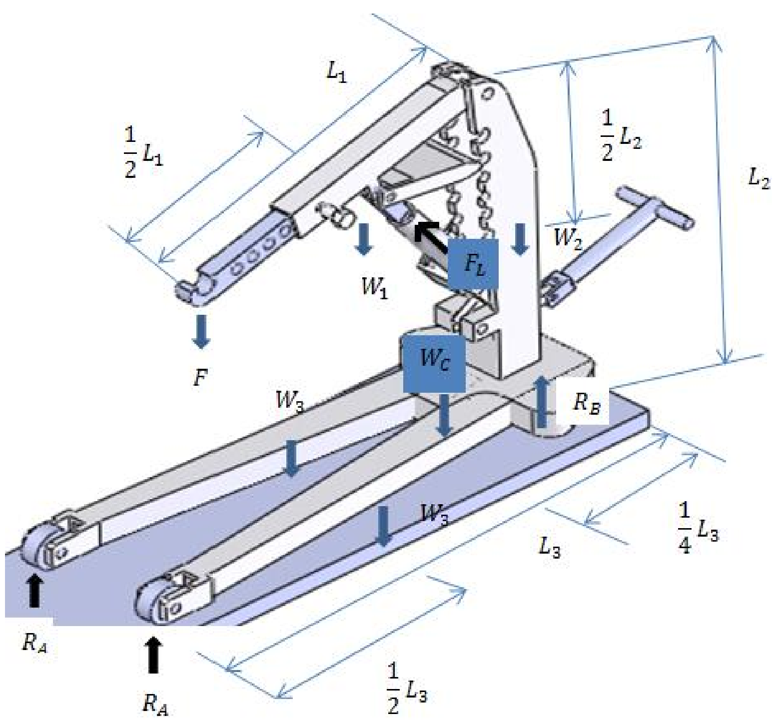

Fig. 1. Free body diagram of the crane

5.2 Determination of the Reactions at the Wheels and Factor of Safety

Reaction forces $R_A \, and \, R_B$ acting on the wheels are determined by applying conditions of equilibrium, $\sum M_Z = 0 \, at \, B \, and \sum F_y = 0$ [5], to the free-body diagram and push force equal to zero and with a counter weight W_C to prevent tipping.

$$FL_1 + \frac{1}{2}W_1L_1 + \frac{1}{2}W_3L_3 + \frac{1}{2}W_3L_3 + \frac{1}{4}W_CL_3 = 2R_AL_3 + F_L(\sin 60)\frac{L_1}{2}$$

$$R_A = \frac{1}{2}F\frac{L_1}{L_3} + \frac{W_1}{4}\frac{L_1}{L_3} + \frac{W_3}{4} + \frac{W_3}{4} + \frac{W_C}{8}L_3 - F_L(\sin 60)\frac{L_1}{4L_3}$$

From the design, $L_1 = 1.5M$, $L_2 = 2M, L_3 = 1.3M$

$w = 308.03N/M$ For mild steel of $4mm$ thickness

$\therefore W_1 = wL_1 = 462.05N$, $W_2 = 616.07N$, $W_3 = 400.44N$,

Substituting we have

$$R_A = \left(\frac{1}{2} \times 2943 \times \frac{1.5}{1.3}\right) + \left(\frac{1}{4} \times \frac{462.05 \times 1.5}{1.3}\right) + \left(\frac{400.44}{2}\right) + \left(\frac{2600}{8}\right) \times 1.3 - 17792.86(\sin 60)\frac{1.5}{4 \times 1.3}$$

$$R_A = 2091.16N$$

$$R_B = F + W_1 + W_2 + W_3 + W_3 + W_C - 2R_A - F_L(\sin 60)$$

$$= 2943 + 47.1 + 62.8 + 40.82 + 40.82 + 2600 - 2(2091.16) - 17792.86(\sin 60)$$

$$R_B = 12169.41N$$

The factor of safety is applied to tipping loads.

Considering the condition $\sum M_z = 0$[5], at point A and with a push force of $300N$ acting at a point $1M$ from the base.

$$n_1[(FL_1 - L_3) + PH] = W_1\left(L_3 - \frac{1}{2}L_1\right) + W_3L_3 + W_2L_3 + \frac{3}{4}W_CL_3$$

$$n_1 = \frac{W_1\left(L_3 - \frac{1}{2}L_1\right) + W_3L_3 + W_2L_3 + \frac{3}{4}W_CL_3}{0[(FL_1 - L_3) + PH]}$$

$$= \frac{47.1\left(1.3 - \frac{1}{2} \times 1.5\right) + (62.8 \times 1.3) + (40.82 \times 1.3) + \frac{3}{4} \times 2600 \times 1.3}{[2943(1.5 - 1.3) + 300 \times 1]}$$

$$= \frac{2695.611}{888.6}$$

$$\therefore n_1 = 3.034$$

5.3 Design for Various Parts

5.3.1 Design for mast

Since

$R_B = 12169.41N$ and $\sigma = \frac{F}{A}$ [6]

But $\sigma = 10.53 \times 10^6 N/M^2$ [7]

$$\therefore \quad 10.53 \times 10^6 = \frac{12169.41}{A}$$

i.e. Cross sectional area of mast = $1156.18mm^2$

Since the mast is designed with four similar rectangular sheets of 4mm thickness

$\therefore$ Length of each sheet

$$= \frac{1156.18}{4 \times 4} = 72.26mm$$

5.3.2 Design for boom

The expression for the reaction at the pivot of the boom will be given as;

$A_x = F_L \cos\theta = 17792.886 \ \cos 60 = 8896.443N$

Also, $\sigma = \frac{F}{A}$ [6]

$$\therefore \quad 10.53 \times 10^6 = \frac{8896.443}{A}$$

$$A = 844.87mm^2$$

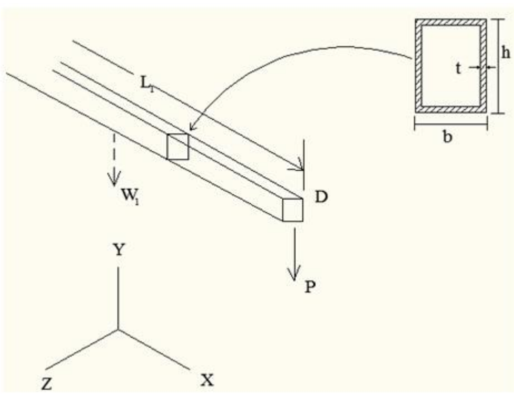

Fig. 2. Sectional view of the boom

Similarly, the boom is designed with four similar rectangular sheet of 4 mm thickness as shown above

$\therefore$ Length of each sheet $= \frac{844.87}{4\times4} = 52.80mm$

5.4 Bending Moment and Shear Force on the Boom

Taking moment about point A

$$\circlearrowleft +\sum M_A = 0 \ [5] \ \therefore \ (F_B \cos\theta \times x) - (F_C \times L) = 0$$

$$F_C = \frac{F_B \cos\theta \times x}{L} = \frac{xF_B \cos\theta}{L}$$

5.4.1 Reaction at point A

$$\uparrow +\sum F_y = 0 \qquad \therefore A_y + F_B \cos\theta - 0F_C = 0$$

$$A_y = F_C - F_B \cos\theta$$

5.4.2 Shear force at A

$$\rightarrow +\sum F_x = 0 \qquad \therefore A_x + F_B \sin\theta = 0$$

$$A_x = -F_B \sin\theta$$

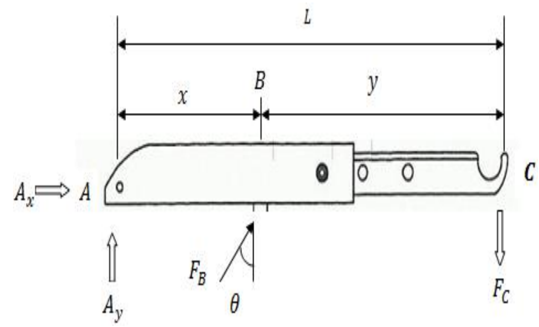

Fig. 3. Free body diagram of the boom

5.4.3 Shear force at B

$$F_{Bx} = F_B \sin\theta$$

5.4.4 Bending moment at B

$$\circlearrowleft +\sum M_B = 0 \ \therefore \left(A_y \times x\right) + M_B = 0$$
$$M_B = -xA_y$$

5.4.5 Bending moment at c

$$\circlearrowleft +\sum M_C = 0 \ \therefore \left(A_y \times L_1\right) - (F_B \cos\theta \times y) + M_C = 0$$

$$M_C = yF_B \cos\theta - A_y L$$

5.5 Bending Moment and Shear Force Diagram

The bending moment and shear force diagram of the boom is represented below.

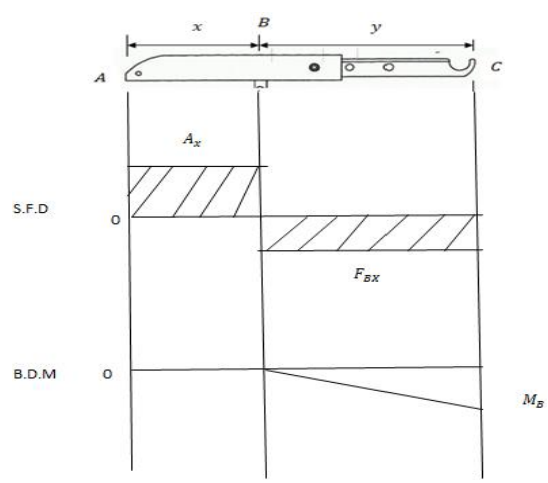

Fig. 4. Bending moment and shear force diagram of the boom

6. DESIGN FOR LOAD LOCKING DEVICE

Since the force on the load locking

$F_B = 17792.886N$, and $\sigma = \frac{F}{A}$

$$\therefore \quad 10.53 \times 10^6 = \frac{17792.886}{A}$$

I.e. Area of each groove $A = 1689.73mm^2$

But length of groove is the same as the width of mast

∴ Width of groove

$$= \frac{1689.73}{72.26} = 23.38mm$$

6.1 Stress Concentration at the Notches

$$\sigma_{max} = \sigma\left(1 + \frac{2a}{r}\right) == 10.53 \times 10^6 \left(1 + \frac{2 \times 25}{10}\right)$$
$$= 63.18 \times 10^6 N/M^2$$ [8].

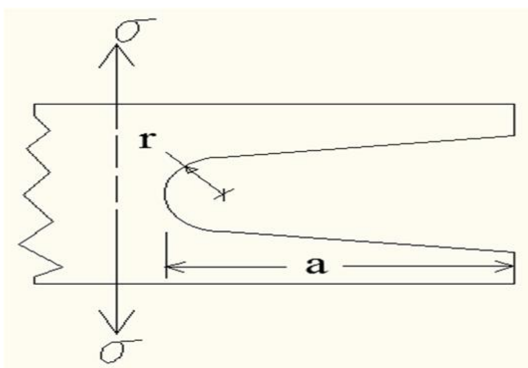

Fig. 5. Side view of the groove

7. FABRICATION PROCESSES

Although, some parts were bought from the market such as the lift cylinder, the metal rollers etc. 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.

7.1 Hand Lever

For easy grip, the hand lever was designed in Y-shape. In the fabrication of the hand lever, the first process we undertook was the marking out operation using the scriber and the measuring tape for accurate measurement and indication of cutting marks in preparation for the cutting operation. In the cutting operation being the next operation, we utilized the vice for holding the work piece firmly on the work bench and the actual cutting of the sections was done with a hacksaw. With the aid of the welding machine the two sections were joined together to form the Y-shape.

7.2 The Base

The base was designed as two different cuboid sections joined together to form a V-shape for maximum balance of the machine. These cuboid sections were made with four sheets of mild steel of about 5mm thickness, joined into a cuboid form with the aid of the of welding machine. At the ends of the two sections, mild steel sheets welding together to form cuboid similar to the sections were welded parallel to the boom where metal rollers were welded as well as on the junction where the sections were welded together for easy mobility.

7.3 The Mast

Just like the sections formed for the base for the base of the machine, four mild steel sheets of about 5mm thickness were welded together into cuboid form with the aid of the welding machine but in this case, the mild steel sheets were cut in such a way that there width are not the same throughout the length of the sheet. The part of the sheet closer to the base was wider, thus making the formed cuboid mast wider towards the base for better balancing of the mast.

Table 2. Fabrication processes

S/n	Component	Operations	Equipments used
1	Hand lever	Cutting and welding	Cutting machine and welding machine
2	The mast	Cutting and welding	Cutting machine and welding machine
3	Load locking device	Cutting, welding and drilling	Cutting machine, welding machine and drilling machine
4	Boom	Cutting, welding and drilling	Cutting machine, welding machine, drilling machine
5	The base	Cutting, welding and drilling	Welding machine, drilling machine, cutting machine

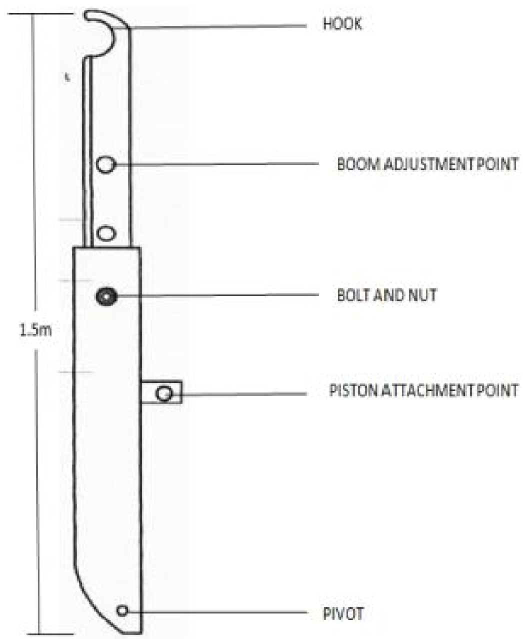

Fig. 6. The adjustable boom system

7.4 The Boom

The boom is designed into two sections, the fixed and the slider section with one of the sections designed to slot into the other so that the adjustable boom system can be achieved. The sections are cuboid in form from four sheets of mild steel welded together, with the sheets of the fixed section wider than those of the sliding section. With the aid of the drilling machine four holes were made on the boom, three on the slider section and one on the fixed section. This is to enable three different length of the boom by fixing the sliding section on the fixed section with the aid of bolt and nut.

7.5 Load Locking Device

The concept of the load locking device is actually a metal bar placed in such a way as to prevent the boom from lowering the load during the cases of cylinder failure. The fabrication processes include the cutting of the mild steel and machined. The top part of the bar is fixed to the boom with the aid of bolt and nut so as to allow free movement of the bar, at the same point where the lift cylinder is attached to the boom. The other part of the bar is designed to fit into the slots on the mast.

8. ASSEMBLY PROCESS

The assembly of various parts of the machine follows the order stated below: fixing of the metal rollers to the ends of the base with the aid of bolts and nut. The mast was welded to the base with aid of the arc welding machine. Pivoting of the boom to the mast with the aid of bolts and nuts so as to allow movement of the boom produces the skeletal view of the machine. The lift cylinder incorporated with bolts and fasteners along with load locking device. The lever handle is fixed to the rear side of the mast making the machine ready for use.

8.1 Finishing Process

The finishing operation carried out on the project to be aesthetically appealing includes the following: removal of rough edges and surfaces using emery 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.

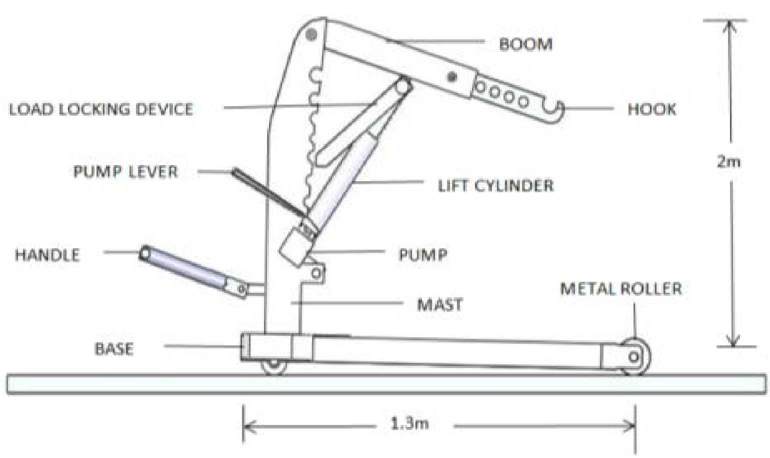

Fig. 7. Side view of the general assembly

9. TESTING AND EVALUATION

The assembled machine was then tested to evaluate function and reliability of the machine. The test was carried with various loads ranging from 50-1000 kg and the test showed that as the load is increased, the effort required for actuating of the lift cylinder increased i.e. increase in load is directly proportional to effort required. The load locking device worked perfectly, locking the load at various heights.

The effectiveness of the load locking device was ascertained by lowering the lift cylinder with the load locked at a particular height to depict the case of lift cylinder failure and the locking device was able to sustain the load at such height which is the main objective of the device.

10. CONCLUSION

The design and fabrication of a mobile floor crane equipped with a load locking device was carried out successfully meeting the required design standards. The issue of safety, which is the drive for this modification, was taken care of by equipping the device with a load locking device. The mobile floor crane is operated by hydraulic cylinder which is operated by the hand pump. The mobile floor crane can be designed for high load carrying capacity if a suitable high capacity hydraulic cylinder and stronger carbon steel is used. The mobile floor crane is simple in use and does not require routine maintenance. It can also lift heavier loads. For the present dimension we get a lift to a height of about 2 m.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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