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Design and production of a derrick crane for materials handling

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Abstract
The design and production of a derrick crane for materials in for engineering workshop was motivated by the need to ease material handling for an engineering workshop.Previous designs were reviewed and this unique design was produced.The derrick crane is hydraulicaaly operated manually. All calculations for done and the strength of the materials selected determined accordingly. The derrick designed and produced is capable of carry a maximum load of 10,000N. It has mechanical advantage of 0.5 and velocity ratio of 0.55. It has an efficiency of 91% and has special features incorporating castor wheels for easy movement and manouvarability around the engineering workshop. Future design should be anchored on using Artificial intelligence to drive the machine and its load functions in a typical engineering workshop.

***Keywords**: crane, derrick, , engineering, load, materials handling, workshop*

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I. Introduction

A crane is a machine that is capable of raising and lowering heavy loads and moving them vertically or horizontally. Cranes are different from hoist, because hoist can only lift objects but cannot move them sideways [1](Jennings, 1998). They are also different from conveyors that lift bulky materials such as grains and coal in a continuous process. The name crane is obtained from the fact that these machines have a shape with a great semblance to the long neck of the bird that bears the same name. The use of cranes is of great antiquity. But it is only since the great industrial development of the 19th century, and the introduction of the motive powers, other than manual labour, that the crane has acquired the important and indispensable position it now occupies [2](Ernest, 1995). It is however worthy of note that, in all other places here finished goods are handled, or manufactured goods or made, cranes of various forms are in universal use.

A derrick crane , which is one form of crane compreise: an upright derrick post having a hollow interior; a turning ring rotabably supported to rotate around a lower part of the derrick post about a vertical axis, a derrick boom pivotally supported at the inner proximal end thereof on the turning ring in a manner permitting up and down derrick movement of the boom, etc. A derrick crane utilizes various kinds of motive powers for its operation, namely: manual, steam, hydraulic and electric. A hydraulic driven crane for example, in addition to most of the above listed parts consists of : hydraulic damper, a chain with hook attached, a puller welded to the upright derrick post and a free rotary tyre.

A derrick has been defined as a tall machine used for moving or lifting heavy loads, especially on a ship . They also define a derrick as a tall structure over an oil well for holding the drill.

Wage (1993) [3]gives a broader definition of cranes. He sees cranes as machines by means of which heavy bodies may be lifted, and also displaced horizontally within certain defined limits. According to him, the name crane alludes to the arm or jib from which the load to be moved is suspended, but is now used in a broader sense to include the whole mechanism by which a load is raised vertically and moved horizontally. A crane has also been described as a machine that is capable of raising and lowering loads and moving them horizontally. It has also been demonstrated by[4] Banga T and Sharma s,c,(2008) that cranes are used for lifting loads-construction materials, loose materials, packages, containers, finished and semi-finished products in industries and placing them at desired place. They added that, for this purpose the crane has three motion in general namely: hoisting, derricking and slewing. A crane however comprises of an upright derrick post having the interior, a turning rotatably supported to rotate around a lower part of the derrick post about a vertical axis; a derrick boom privotally supported at the inner proximal and thereof on the turning ring in a manner permitting up-and –down derricking movement of the boom. Derrick cranes consist of a mast, a bull-wheel on which it rotates about a vertical axis, and supporting members (guys). These cranes are widely used in construction projects, industrial and multi-storey building construction, plant erection, loading and unloading of cargoes at ports, ship building etc. [5] demonstrates that the different types of motive power used to actuate cranes are manual, steam, hydraulic and electric. These also give a classification of cranes.

The derrick crane can utilize either of the afore-mentioned motive powers, but for the sake of this project, we shall be concerned with the hydraulic system as the prominent motve power for the operation of the derrick crane,

Hydraulics is based on a very simple fact of nature-you cannot compress a liquid. You compress a gas , but no matter how much pressure you apply onto a liquid, it is not possible to compress it. Now if you put a liquid in a sealed system and push on it at one end, that pressure is transmitted through the liquid to the other end of the system.

According to [6] the Greeks were among the first to understand about the use of water to provide lift and force and the name hydraulic originates from the Latin word for water-Hydra. In the middle ages, Leonado d vinvi formulated the basic principles of hydraulic called continuity and Galileo experimented with hydraulics. Today most hydraulic systems utilize oil rather than water but the principles remain the same, you cannot compress a liquid. Also a force that is applied at one point is transmitted to another point by the incompressible fluid. Because of its liquid nature, hydraulic systems can transmit force through pipes of any shape and length such that the force can be applied at one central point and transmitted efficiently to another point or multiple points far away. This is exemplified by the master cylinder in car brakes, whereby by someone stepping on the brake pedal, stopping pressure is applied on the brakes on all four wheels. Terminologies related to the hydraulic propelled derrick crane include-Hydraulic press-this is a device to lift larger load by the application of a comparatively much smaller force. It is based on Pascal’s law; hydraulic accumulator-this is a device used to store pressure energy which may be supplied to hydraulic machines such as presses, lifts and cranes; hydraulic intensifier-this is a device used to incres the intensity of pressure of water by means of energy available from a large quantity of water at a low pressure; Hydraulic damper- this is a device used for lifting heavy loads by the application of small force on a plunger, which in turn exerts a pressure to the cylinder that lifts the load.

The hydraulic system is very similar to the air pressure system in which the air on the inside exerts equal pressure on all parts of the system. And if there is no leakage, the pressure remains constant throughout the system. The hydraulic jack works on the same principle of incompressibility whereby as the jack is being compressed. But moves up to occupy another space, thereby pushing up the spindle that is in contact with the mainframe of the crane[7]

Over the years, humans have used a wide variety of devices to lift objects since ancient times. One of the earliest versions of the cranes to be developed was the shaduf, first used to move water in Egypt about four thousand years ago. The Shaduf consist of a long pivoting beam balanced on a vertical support. It is still being used in rural areas of Egypt and India.As early as the first century, cranes were built that were powered by human beings or animals operating a thres mill or large wheel. These early cranes consisted of a long wooden beam, known as boom, connected to a rotating base [8,9]

But an important development in crane design occurred during the middle ages, when a horizontal arm known as a jib was added to the boom. The jib was attached to the boom in a way which allowed it to pivot allowing for the increased range of motion. By the sixteenth century, cranes were built with two treadmills, one on each side of a rotating housing containing the boom. Cranes continued to rely on human or animal power until the middle of the 19th

Century, when steam engines were developed. By the end of the19th century internal combustion engines and electric motors were used to power cranes [1].

But sequel to the industrial revolution of the 19th century, cast iron and steel took over from wood as the major materials for taller building. Also internal combustion engines and electric motors replaced the prevailing modes of powering cranes. During the 1950’s, the availability of stronger steels, combined with an increase demand for taller buildings, led to the development of cranes with very long booms attached to small truck, or too many crawlers with caterpillar threads[9].

Modern cranes usually use internal combustion engines or electric motors and hydraulic systems to provide a much greater lifting capability than was previously possible, although manual cranes are still utilized where the provisions of power would be uneconomic.

It is worthy of note that ‘for dockslide jib cranes the use of electric power is making rapid strides. For overhead travelers in workshops, and for most of the cranes which fall into our second class (of crane types), electricity as a motive power has already displaced nearly every other method. Cranes driven by shafting or by mechanical power, have been largely superseded by electric cranes, principally on account of the much greater economy of transmission, For many years the best workshop travelers were those driven by quick running ropes; these performed admirable service, but they have given place to more modern electric traveler.

Cranes may be divided into two main classes-rovolving and non-revolving. In the first, the load can be lifted vertically, and then moved round a central pivot, so as to be deposited at anu conveneient point within the range. The first class is the ordinary jib crane. In the second class there are in addition to the lifting motion, two horizontal movements at right angles to one another. A typical example of this is the overhead craneor traveler. Jib cranes can be subdivided into fixed cranes and portable cranes; in the former, the central post or pivot or post is firmly fixed in a permanent position, while in the latter, the whole case is mounted on wheels, so that it may be transported from place to place[5].

There also exist Hand or manual cranes-These are extremely useful where the load is not excessive, and the quantities to be dealt with are not motive powers. They are also relevant where speed is not of importance and ost a vital consideration. Steam cranes is extremely useful power for all cranes that ae not operated from a central power station. The steam crane is of immense advantage since it is toally self-contained. That is, it can be moved by its own locomotive power, if desired, for long distances without requiring any complicated means of conveying power to it. It is rapid in work, faily economical and can be adapted to the most varying circumstances; where however, there are a number of cranes all belonging to the same installation, these are placed so as to be conveniently worked from a central power station. Where the work is rapid heavy and continuous, as is the case at large ports, docks and railways or other warehouses, experience has shown that it is best to produce the power in a generating station and distribut it to the cranes.

Hydraulic crane is rapid in action, very smooth and silent in working, easy to handle and not excessive in cost or upkeep. These are advantages which have ensured its adoption in every part of the world. Hydraulic cranes, as earlier noted are just one typr of hydraulic equipment that uses to provide pressure.The hydraulic crane uses a compressible fluid such as oil, allowing for a great amount of pressure and a quick release when the equipment is turned of. It is worthy of note that, while a hydraulic crane is commonly thought to be faster and more positives for materials handling, like the conventional cranes its ability to achieve true balance is limited to one specific radius. It is also note worthy that down to the closing decades of the 19th century, hydraulic power was practicaaly the only system available for making cranes from a power station. Over the years, the performance, sophistication and opertely pressure of hydraulic cranes have steadily risen causing old models to become obsolete or at the very least comparably frustrating to use.

Electric cranes as a motive power for cranes is a recent introduction. Transmission of energy by electric means can be carried out with an efficiency that is unprecedented among the other prevailing models. And, the electric motor is adaptable to any type of crane. When they are worked from a power station, great advantage is gained that, the same plant which drives them can be used for many other purposes, such as working machine tools and supplying current for lighting. For dockside jib crane, the use of electric power is making rapid strikes. For overhead cranes in workshops, and for most non-revolving cranes, electricity as a motive power has already displaced most other methods. Cranes that are driven by shafting, or by mechanical power, have been largely superseded by electric cranes, principally on account of the much greatet economy of transmission. However, cranes can also be classified into industrial and consruction cranes with particular reference to their names.

Very few machines exist in as wide a variety of designs as cranes. Before cranes are constructed, the manufacturers consider the sites whre they will be used and the weight they need to lift. In addition cranes are often modified to suit the needs of the user . For these reasons, it is not much of an exaggeration to say that no two cranes are exaxtly alike. Cranes for industrial purpose are generally designed to remain permanently in one location. Contruction cranes on the other hand are divided into mobile and tower cranes. Cranes types can be detrmined either by hteir degree of mobility or ability to caryy greater loads and reach greater heights with increased stability [10].

Cranes types according to degree of mobility include derrick crane, tueck-mounted crane, side lift crane, ough terrain crane, all terrain crane, crawler crane, railroad crane and floatimg crane.While crane types according to ability to carry greater loads and reach greater heights include but not limited to the following: tower crane, selierecting crane, telescopic crane, hammer-head crane, level luffing crane, gantry crane, overhead crane, deck drane, jib crane, etc.

Truck-mounted crane consist of crane mounted on a truck carrier. Such cranes are designed for travelling on streets and highways, thus eliminating the need for special requirement to transport the crane to worksite[11]. Great care is usually taken to avoid swinging the load sideways from the direction of travel, as most of the anti-tipping lies in the strength and stiffness of the chassis suspension. Most cranes of this type also have moving counterweights for stabilization beyond that of their outriggers.

Sidelift crane is a road going truck or semi-trailer that is able to hoist and transport IOS standard containers. Lifting of containers is achieved throough the use of parallel crane –like hoists, which can be used to lift a container from the ground, or from a railway vehicle.

Rough terrain crane is a crane mounted on an under carriage that is designed to pick and carry operations and for off road and rough terrian applications.Outriggers that extend horizontally and vertically are used to level and stabilize the cranes and simgle-engine machines where the same engine is usually mounted in the undercarriage rather than in the upper , like the crawler cranes.

All terrain crane is mobile crane which has the necessary equipment to travel with high speed on public roads/ highways and on the job siste in rough terrain with all wheel and crab steering.It combines the road ability of truck-mounted crane and the maneuverability of a rough terrain crane. All terrain cranes od ATs have 2 to 9 axels and are designed for lifting loads up to 1200 metic tones.

Crawler crane is a crane mounted on under-carriage with a set of trucks(also called crawllers) that provide for the stability and mobility of the crane. Crawler cranes range in loifting capacity from 40 US tones to 3500 US tones. The main advantage of the crawlwe cranes is that they can move around on site and then perform each lift with very little set-up, since the crane is stable on its tracts with no outtiggers. In addition a crawler crane is capable of travelling with a load. But the main disadvantage of the crawler crane is that they are very heavy and cannot be moved easily from onr job site to the next without significsnt expense. Tyipcally a large crawler must be disassembled and moves by trucks, rail cars or ships to be transported to it next location.

Railroad crane is a crane witth flanged wheels used by railroads. The simplest form is just a crane mounted on a railroad car or on a flat car. More complex devices in the crane are purpose built,

Floating crane is the type used mainly in bridge building and port construction, but are also used for occasional loading and unloading of especially heavy oe awkward loads on or off ships. Some floating cranes are mounted on a pontoon , others are specialized crane barges with a lifting capacity exceeding 10,000 tones and have been used to transport entire bridge sections. Floating cranes have been used to salvage sunken ships.

Derrick crane comprise an upright derrick post having a hollow interior , a turing ring rotatably supported to rotate around the upper part of the derrick about a vertical axix. It could be powered by either manual , steam, hydraulic or electric means. The derrick cranes are sometimes mounted on rail wagoms for quik transpotation and for woring near rail-lines and are known as whirler cranes. These cranes are available up to capacities of 49 tones with 25 meters boom length and 15 meters work radius.

The derrick cranes can be used as tower cranes for purposes of eretion of high industrial and residential buildings of heights 100 meter . They are also designed to work as port tower cranes –for use in ports for container and general cargo handling, as shipyard cranes –for use in ports for container and general cargo handling, as shipyard cranes for use in ship building and ship repairing works with longer capacities and larger working raddi[4].

This research work is focused on designing and production of a derrick crane with special features like castor wheels for use in an engineering workshop.

II. Materials and Methods

2.1 Desing Criteria

It is required to design and produce a 1000 kg derrick crane for Engineering workshop with unique features of manoevarability with castor wheels.

2.2 Theory of operation

The machines works by the application of the principle of moment by multiplication of the effort applied at the handle of the jack which pushes hydraulic fluid in an enclosed cylinder to do work. The fluid in the cylinder follows Pascal’s principle of transmissibility; which transmits the multiplied force to lift the load to the expected height.

2.3 Design Analysis

The operation of the derrick crane is based on the the operation princilple of the lever of the third class. The free body diagram of this machine is shown in Figure 1.

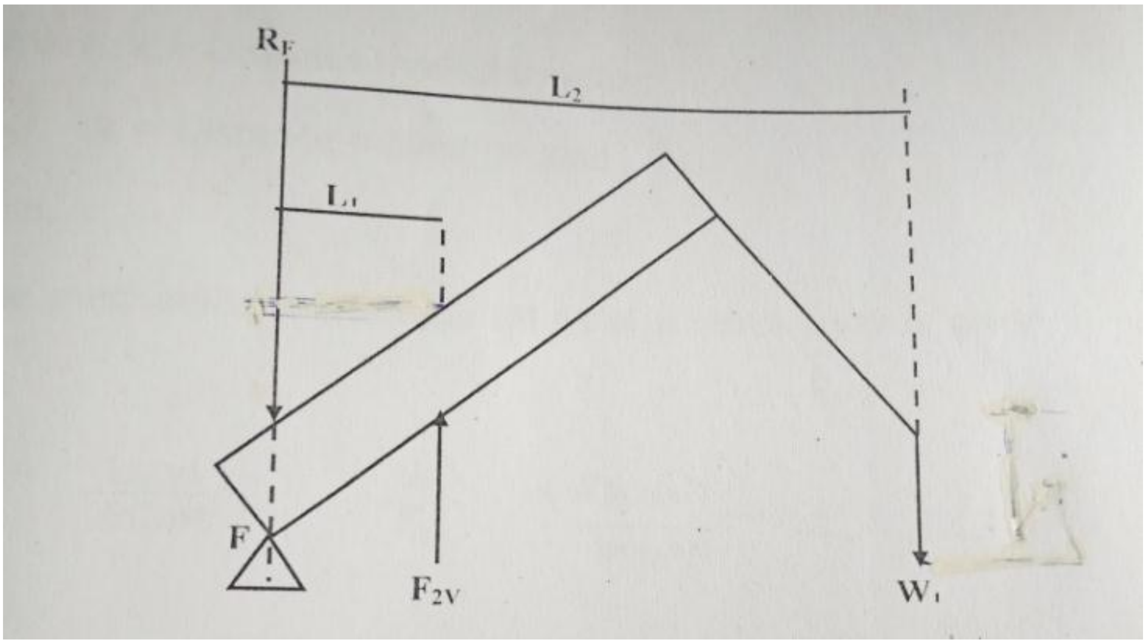


Figure 1 Simple moment of the derrick crane

Based on the principle of moment and taking the moment about the point F, Equation 1 results.
We have,

$$W_1 x L_2 = F_{2v} x L_1 \qquad \text{Equation 1}$$

where F is the Fulcrum R_F is the reaction at the fulcrum, F_{2v} is the applied force
Therefore the Mechanical Advantage (MA) is given in Equation 2 :

$$\text{MA=} MA = \frac{Load}{Effort} = \frac{W_1}{F_{2v}} \qquad \text{Equation 2}$$

Similarly the velocity ratio (V.R) in Equation 3 :

$$V.R = \frac{x}{y} \qquad \text{Equation 3}$$

where x is the distance moved by the effort and y is the distance moved by the load at the same time

The efficiency η is given in Equation 4:

$$\eta = \frac{M.A}{} V.R \qquad \text{Equation 4}$$

W_1 is the load (N), L_1, L_2 are distance of the effort and disatance of the load from the fulcrum.
For an hydraulic system which will be used as the motive force, Pascal’s principle of hydrostatics is applied. Fundamentally given in Equation 5,

$$\frac{F_1}{A_2} = \frac{W}{A_1} \qquad \text{Equation 5}$$

where F_1 is the force applied on the plunger, A_1, A_2 are the cross sectional area od the plunger and ram respectively. P_1, P_2 are the pressure intensities of the plunger and ram respectively.
Thus the Mechanical advantage of the system is presented in :

$$M.A = \frac{A_1}{A_2} \qquad \text{Equation 6}$$

The velocity ratio is the equivalent to the effort moved by the effort(hand moment) divided by the distance moved by the load.
For a simple jack this shown in Figure 2.

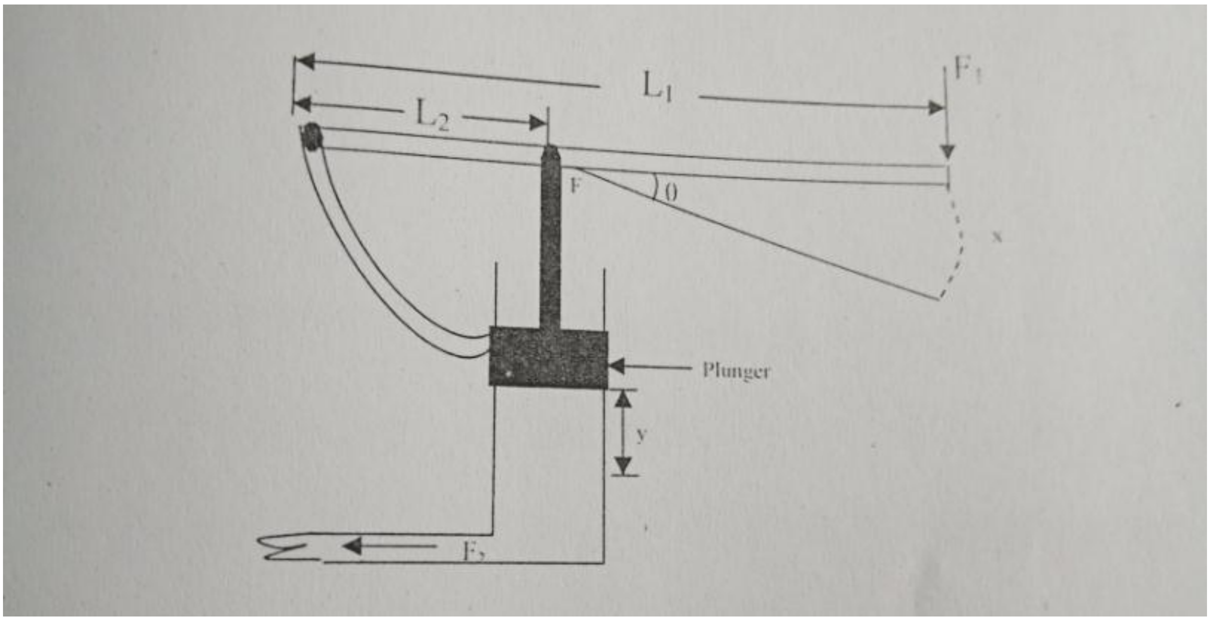


Figure 2: Effort load relationship of simple jack

F_1 is the applied load, $L_{1,}, L_2$ are the distances between fulcrum and effort and fulcrum and load at the same time, x is the vertical distance moved by load and expressed as x in Equation7:

$$x = \frac{\theta 2 \prod L_1}{360} \qquad \text{Equation 7}$$

And y is the vertical distance, E the effort given in Equation 8 as:

$$E = \frac{F_1 L}{L_2}, \qquad \text{Equation 8}$$

F is the fulcrum and θ is the inclination of the handle (applied force)

F_2 is the theoretical force on the ram, which is equal to the effort.

It can further be expressed in Equation 9; M.A in Equation 10,

$$F_2 = W = \frac{F_1 A_1}{A_2} \qquad \text{Equation 9}$$

$$M.A = \frac{L_1 A_1}{L_2 A_2}, \text{ from Equation 8} \qquad \text{Equation 10}$$

Further relationship shown in Equation 11

$$\frac{F_1}{F_2} = \frac{A_1}{A_2} = \frac{x}{y} \qquad \text{Equation 11}$$

Theoritically, the relationship between F_{2v} and the weight W from Figure 3 is presented:

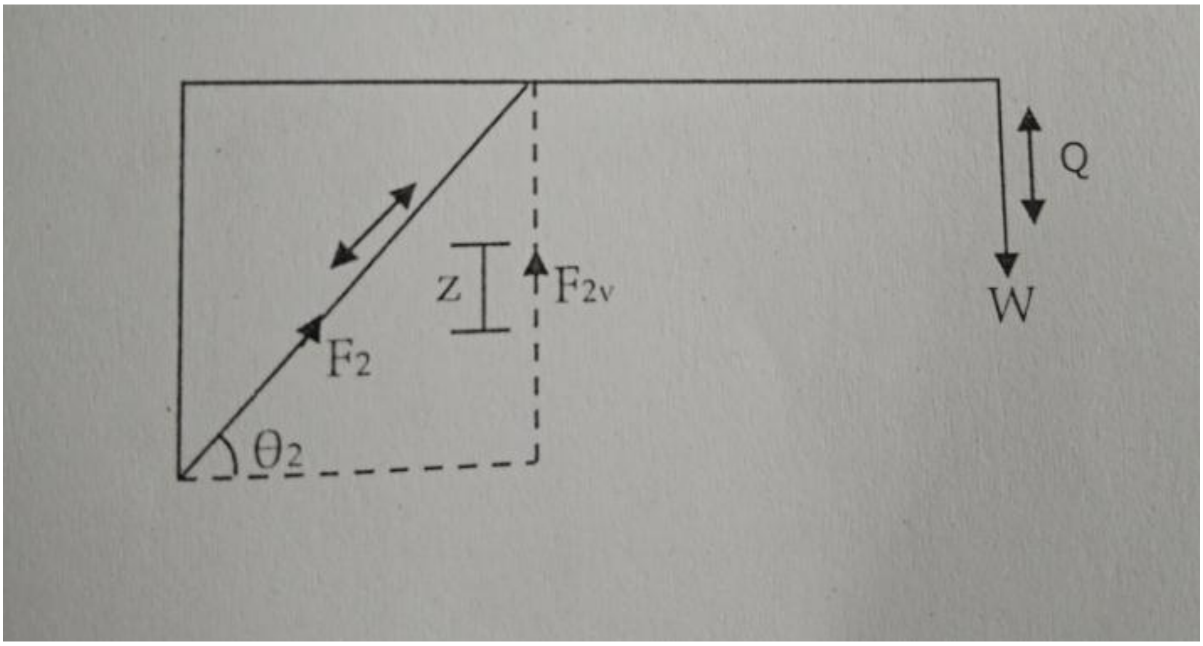


Figure 3: The relationship between F_{2v} and the weight W

The retionship between these forces and the inclination is shown is shown in Equation 12

$$\sin\theta_2 = \frac{F_{2v}}{F_2}$$ Equation 12

where θ_2 is the angle at which F_2 is inclined, and F_2 is the required fprce to lift load and F_1 is the vertical component of F_2. If we define Q, Z as thr actual vertical distance moved by the load W and the force F_2.

Figure 3 the relationship applied force and weight is shown in Equation 13

$$M.A = \frac{Load}{Effort} = \frac{W}{F_2 \sin\theta_2} = \frac{W}{F_{2v}}$$ Equation 13

And its velocity ratio in Equation 14; and efficiency in Equation 15 :

$V.R = \frac{Z}{Q}$ and the efficiency is: Equation 14

$$\eta = \frac{WQ}{F_{2v}Z}$$ Equation 15

In analyzing the stress and bending moment for a simply supported beam, Equations 16 and 17 given in apply.

$$F_x = W$$ Equation 16

where W is the weight and F_x is the shear force,

The bending moment at any section of the beam x is:

$$M_x = -Wx$$ Equation 17

For a rectangular section the moment of inertia is given in Equation 18:

$$I = \frac{bd^3}{12}$$ Equation 18

And the section modulus in Equation 19:

$$Z = \frac{bd^2}{12}$$ Equation 19

For an I section, the shear stress and maximum shear stress are given in Equation 20.

$$\tau = \frac{F_x A\bar{y}}{Ib} = \frac{F_x B\frac{(D^2-d^2)}{8} + \frac{b}{2}(\frac{d^2}{4} - y^2)}{Ib}$$ [12] Equation 20

The maximum shear occurs at the neutral axis and given in Equation 21,

$$\tau_{\max} = \frac{F_x B\frac{(D^2-d^2)}{8} + \frac{b}{2}(\frac{d^2}{4})}{Ib}$$ Equation 21

Since it is assumed that bending moment is taken by the flanges only, the flange area and depth of section, Z is given in Equation 22

$$Z = \frac{37t^4}{3t} = 12.3t^3$$ Equation 22

For the design of the Fulcrum pin(s) Equations 23 and 24 apply.

$$R_p = dLP_b$$ Equation 23

where d is the diameter, l is the length and P_b safe bearing pressure of thr pin(s).

Also since the pin is in double shear, the load on the fulcrum of the pin is given as:

$$R_F = \frac{2\prod d^2\tau}{4}$$ Equation 24

where τ is the shear stress induced in thgiven as:r fulcrum pin. The maximum bending moment is given in Equation 25 :

$$M = \frac{5WL_1}{24}$$ Equation 25

The section modulus of the pin is presented in Equation 26:

$$Z = \frac{\prod(d^3)}{32}$$ Equation 26

And the induced bending stress is expressed in Equation 27

$$\partial_x = \frac{M}{Z}$$ Equation 27

The factor of safety is given is presented in Equation 28,

$$F_S = \frac{T_U}{W_S}$$ [13] Equation 28

where $T_{U,}$ is the ultimate tensile strength of the material and W_S is the working stress

III. Results and Discussion

3.1 Results

Given :

$L_1 = 600mm$, $L_2 = 1200mm$ and $W_1 = 10{,}000N$, Therefore from Equation 1,

$F_{2v} = 20kN$

With $W_{1,}F_{2v}$ known, from Equation 2

M.A=0.5

With x= 128mm and y=232mm, from Equation 3

V.R=0.55

From Equation 4 , the the mechanical advantage and velocity ratio known:

$\eta = 91\%$

With W_1, F_{2v} known, the reaction at the fulcrum

$$RF = 10kN$$

For the hydraulic jack

Given :

$A_1 = 2026{,}83mm^2$, W_1 =10000N,

$$P_1 = P_2 = 4.93 / mm^2$$

The theorictical force acting on the ram

$$F_2 = 10000N$$

$A_2 = 176.72mm^2$,

L_1, L_2 known as 6000mm and 1200mm respectively from Equation 13 , mechanical advantage (M.A) of the jack =5.7

For the same hydraulic jack, with W_1, F_{2v} given as 10000N and 20000N, the

M.A= 0.5

And from Equation 14, the velocity ratio with x=128mm and y=232mm ($x \alpha Z, y \alpha Q)$

V.R=0.55

From Equation 15 with M.A and V.R known

$$\eta = 91\%$$

For the horizontal beam

Appying Equation 16,

$F_x = 10000N$ and $M_x = 6000Nm$

From Equation

With b=102mm, d=51 mm, from Equation 19

$$Z = 265.302mm^3$$

Thus from Equation 21

$$\tau_{\max} = 2.884N / mm^2$$

For the I section beam

Given the moment of area of an I beam,

I= 6354,82x$10^3 mm^4$, from Equation

$\tau_{\max} = 255.28N / mm^2$ and from Equationn 22

$$Z = 1{,}537.5mm^3$$

For the Design of the fulcrum pins and holes:

From Equation 24,

$$\tau = 48.73N / mm^2$$

From Equation 25

$$M = 364.58x10^3 Nmm$$

From Equation 26

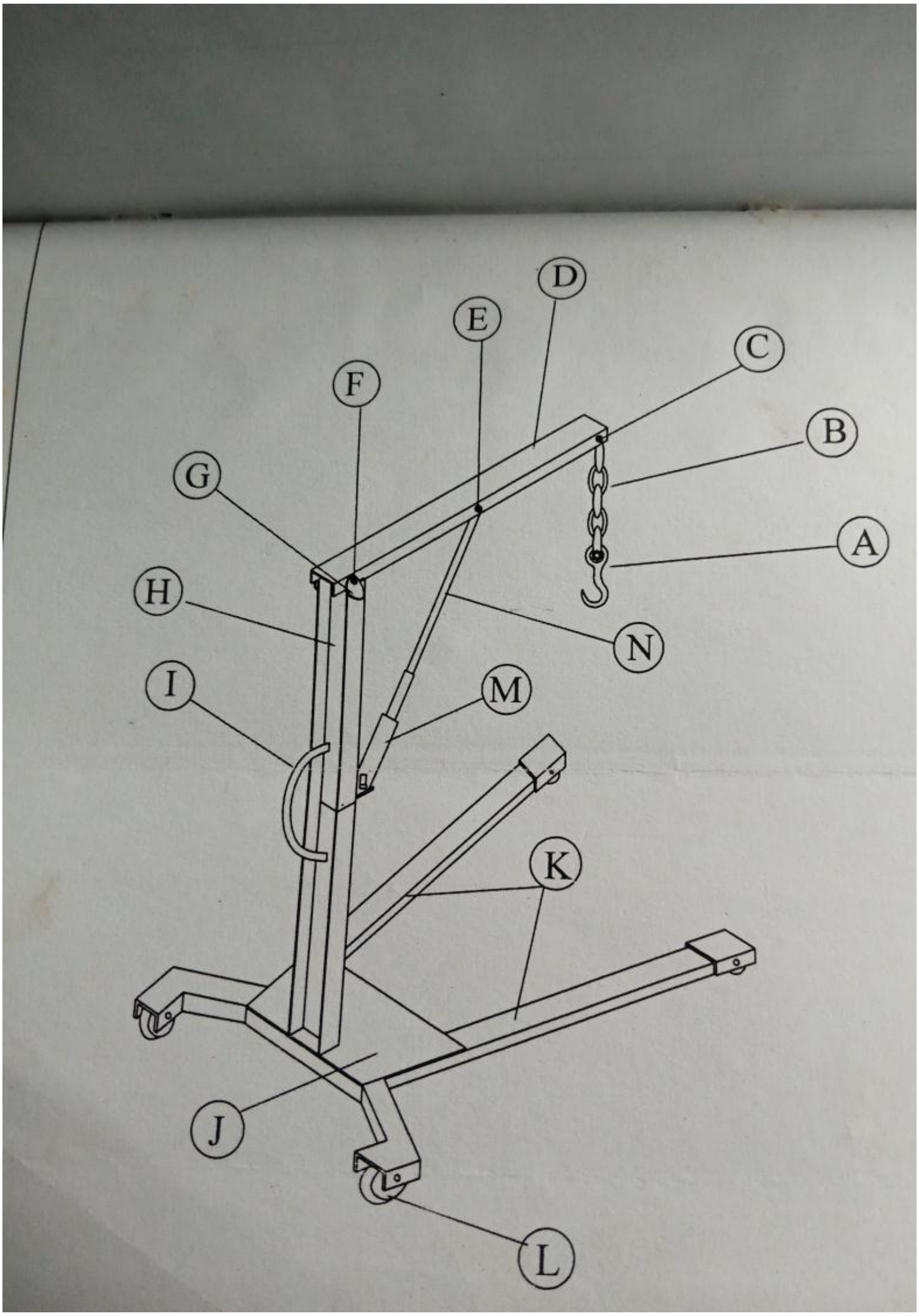
$Z = 146.6mm^3$ and from Equation 27

$$\partial_b = 2.487kN$$

From Equation 28, the factor of safety for the given material was computed.

$$F_s = 2$$

Figure 4 shows the isometric projection of the derrick crane designed and produced.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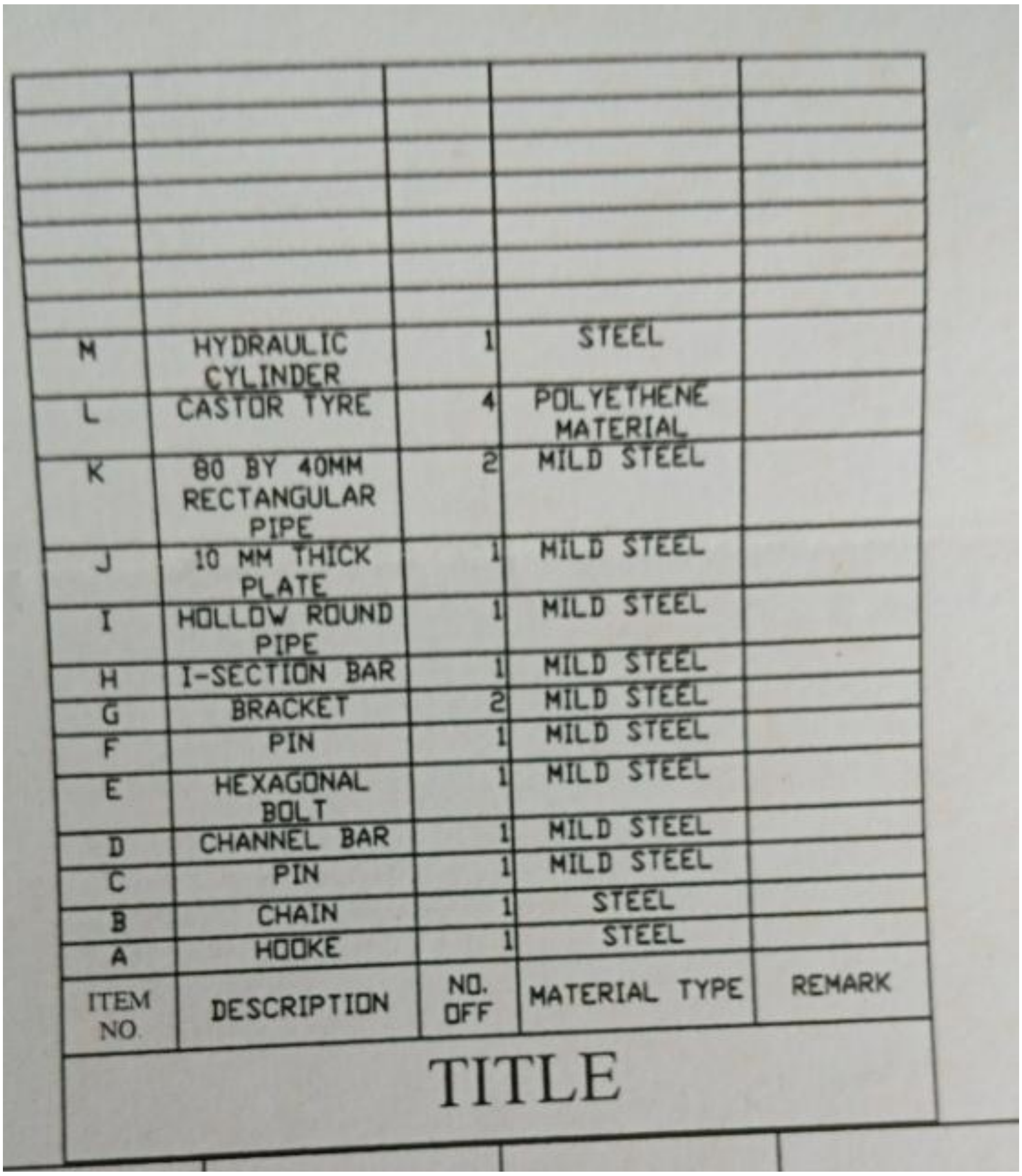

ITEM NO.	DESCRIPTION	NO. OFF	MATERIAL TYPE	REMARK
M	HYDRAULIC CYLINDER	1	STEEL	
L	CASTOR TYRE	4	POLYETHENE MATERIAL	
K	80 BY 40MM RECTANGULAR PIPE	2	MILD STEEL	
J	10 MM THICK PLATE	1	MILD STEEL	
I	HOLLOW ROUND PIPE	1	MILD STEEL	
H	I-SECTION BAR	1	MILD STEEL	
G	BRACKET	2	MILD STEEL	
F	PIN	1	MILD STEEL	
E	HEXAGONAL BOLT	1	MILD STEEL	
D	CHANNEL BAR	1	MILD STEEL	
C	PIN	1	MILD STEEL	
B	CHAIN	1	STEEL	
A	HOOKE	1	STEEL	

TITLE

Figure 4: Isometic projection of the derrick crane with part list

3.2 Discussion

The derrick designed and produced is capable of carry a maximum load of 10,000N. It has mechanical advantage of 0.5 and velocity ration of 0.55.It has an efficiency of 91% and has special features incorporating castor wheels for easy movement and manouvarability around the engineering workshop.

IV. Conclusion

The derrick crane with a maximum load carrying capacity of 10,000N was successfully done.The mechanical advantage and velocity ratio of the derrick crane was 0.5 and 0.55 respectively. The overall effieciency of the machine was 91% .Future work on using artificial intelligence to drive the machine is a good direction for reseachers.

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