Performance Analysis of Motorized Object Lifting Toggle Jack

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DOI: 10.56201/ijemt.v8.no4.2022.pg86.99

Abstract

This study seeks to develop a motorized car jack with maximum lifting capacity of 1.5 tons. The principle of the existing car jack was modified by making adjustments and using a prime mover which is the electric motor to control the lifting operation of the jack. The design incorporates an electric motor that is powered by a 12-volt battery of a small vehicle and the device is connected through a cigarette lighter adapter in the vehicle. The common challenge with the currently available car jacks on the market is that they are manually operated and need a substantial amount of physical effort is required to lift the vehicle. In this work, human effort was eliminated in raising the jack by the use of the torque generated by the motor as it rotates. The use of long cablings to control the motorized operation assists the jack to be safe to use as the operator can use the jack in a comfortable position and as far away from the vehicle as possible. The performances of the machine at different loads were calculated. The approximate values and graphical relationships were established. Using MS Excel. It was established that, the machine had efficiency of about 53%. The investigation revealed that the minimal efficiency was as a result of the great frictional forces between the screw and the threaded base required to be overcome as well as the capacity of the DC motor and gear system.

Keywords: *Toggle Jack, Design, Object lifting, Motorized, Performance*

INTRODUCTION

A screw jack is a portable device consisting of a screw mechanism used to raise or lower the load (Vijay and Singh, 2018). The principle on which the screw jack works is similar to that of an inclined plane. There are mainly two types of jacks-hydraulic and mechanical. A hydraulic jack consists of a cylinder and piston mechanism. The movement of the piston rod is used to raise or lower the load. Mechanical jacks can be either hand operated or power driven. In order to perform maintenance process in automobiles, jacks are commonly used (Ipilakyaa and Gbashi, 2012; Channaveeraiah *et al*, 2020). A screw jack is commonly used with cars but is also used in many other ways, including industrial machinery and even aeroplanes. They can be short, tall, fat, or thin depending on the amount of pressure they will be under and the space that they need to enter into. The jack is made out of various types of metal. While screw jacks are designed purposely for raising and lowering loads, they are not ideal for side loads, although some can withstand side loads depending on the diameter and size of the lifting screw. Shock loads should also be avoided or minimized. Some screw jacks are built with anti-backlash. The anti-backlash device moderates the axial backlash in the lifting screw and nut assembly to a regulated minimum. A large amount of heat is generated in the screw jack and long lifts can cause serious overheating. To retain the efficiency of the screw jack, it must be used under ambient temperatures, otherwise lubricants must be applied. Apart from proper maintenance, to optimize the capability and usefulness of a screw jack it is imperative to employ it according to its design and manufacturer's instruction. There is need to follow the speed, load capacity, temperature recommendation and other relevant factors in using the device.

In existence there are a range of car jacks that are designed to lift a vehicle from the ground. Most of these are however manually operated which implies that they require extra physical effort from the operator. For operation of these jacks, operators are required to be in prolonged squatting position for some duration which can lead to the problem of backache. During road-side emergency like tire punch, a jack is required to lift the vehicle (Noor *et al.*, 2010; Kamalakkannan, 2016; Ignatio *et al.*, 2019). Also, workshops are mostly equipped with car lifting system where vehicles are raised and lowered with electrical system. Due to the high cost, maintenance and size, such lifting devices have been found to be mostly confined to work in workshops. Survey in car lifting in several automobile garages, revealed the facts that some difficult methods are adopted in lifting vehicles for reconditioning (Manoj and Kachave, 2015; Choudhary *et al*, 2016; Kulkarni, 2017). Hence, there is need to design and fabrication of a motorized portable toggle jack that is used for lifting, using the power from a DC motor. This, does not only reduce human efforts but also save time needed to effect repairs and that is easy and safe to use. This study focuses on design of a motorized car jack that utilizes the 12-volt vehicle battery which supplies power to the motorized jack through the cigarette lighter receptacle point on the dashboard of the car. The fabrication has been considered with utmost simplicity and economy, such that this can be accommodated as one of the essential tools on automobiles garages. It consists of a D.C. motor, battery, gear arrangement and a screw jack arrangement.

METHODOLOGY

This section considers the materials and method utilized in the actualization of the work, design analysis of the motorized toggle jack, principle of operation of the system and required system assembly.

Operational Principle

Under ideal conditions, the jack is put under car body with some freedom space between top plate and skeleton. The cigarette lighter repository associated with jack will be connected to the port, consequently interfacing specifically with car battery. The car battery is used to drive the D.C motor. The D.C motor shaft is connected to the screw through coupling. If the power is driven to the D.C motor, it will run so that the screw also runs and converts rotary to translator motion. The arms of the jack move upwards, so that the vehicle lifts from the ground. The vehicle is lifted by using the lifting platform at the top of the jack. The motor draws the power from the battery. After pressing the switch, power from the battery is connected to the screw. When taping the switch to the positive pole, positive voltage is supplied to the D.C. motor in clockwise direction and the lead screw moves in downward direction. Similarly, when tapping the switch to the negative pole, negative voltage is supplied to the D.C. motor which moves in anticlockwise direction and the lead screw moves in upward direction. In this way the directions can be controlled which in turn regulates the lift load direction either upward or downward.

Design Considerations

Step I (Problem Specification): It is required to design an object lifting jack for supporting the machine parts during repair and maintenance. It should be a general-purpose jack with a load carrying capacity of 1.5tonnes and a maximum lifting height of 0.3m. The jack is so operated by means of a D.C motor.

Step II (Selection of Materials): The frame of the object lifting jack has complex shape. It is subjected to compressive stress. Thus, a material is chosen that is cheap and it can be given any complex shape without involving costly machining operations. Secondly, the screw is subjected to torsional moment, compressive force and bending moment. From strength consideration, suitable material is selected for screw. Thirdly, there is a relative motion between the screw and the nut, which results in friction. The friction causes wear at the contacting surfaces. This is thus considered in selecting material used.

Step III (Design of object lifting jack): Square threads are recommended as they have higher efficiency and provision can be made for self-locking arrangement. When the condition of self-locking is fulfilled, the load itself will not turn the screw and descend down, unless an effort in the reverse direction is applied.

Design Calculations

Design and analysis of toggle jack component were undertaken as follows:

Detail Design and Analysis of Component

In this section material are selected and computing/designing each part dimension from the given design specification.

Table 1: Jack design specification table

Parameters/Unit	Value
Weight of vehicle/object (kg)	1500
Maximum height of jack (mm)	350
Minimum height of jack (mm)	150

Toggle car jack with maximum lifting capacity of 350mm and a minimum height of 150mm, to find a suitable length of links and the degree of angle of a maximum and minimum height.

At minimum position;

In this analysis, the following equations are formulated for length L_1 and L_2 within θ_{min} and θ_{max}

$$Sin\theta_{min} = \frac{opposite}{hypotenus} \qquad 1$$

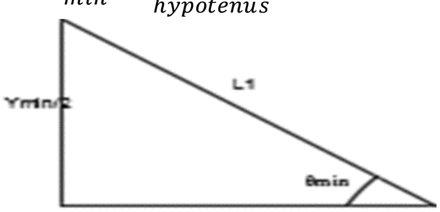


Figure 1: Angles between links.

$$L_1 = \frac{50mm}{Sin\theta_{min}} \qquad 2$$

$$L_1 = \frac{50}{Sin9}$$

$L_1 = 359.264$

At maximum position;
The length of link 1 and link 2 and within angle of θ_{max} and y_{max}

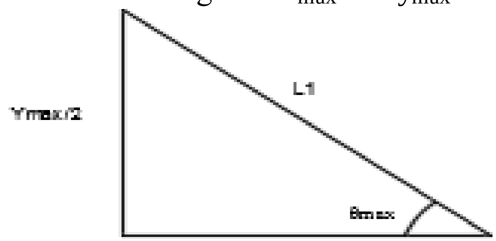


Figure 2: Angles between links.

$$Sin\theta_{max} = \frac{\frac{y_{max}}{2}}{L_2}$$

$$L_2 = \frac{150mm}{Sin\theta_{max}} \quad 3$$

$\theta_{max} = 73^O$

Therefore, we have found the values of links and angles of inclination L =360 mm, θ =9º and β=83º

The force analysis consideration is based on the assumption that, the jack holds vertically symmetrical.

Maximum mass=1500kg.

Acc. Due to gravity = 9.81m/s^2

$W = mg = 1500 \times 981 = 14715N$

At maximum raising height of the jack,

$$F = \frac{f}{\cos\theta} = \frac{7357.5}{cos\theta} = 7450 \quad 4$$

At minimum raising height of the jack,

$$F = \frac{f}{\cos\beta} = \frac{7372.37}{\cos 81^o} = 47127.5N$$

$$Design\ stress, \delta d = \frac{yield\ strength}{F.s} = \frac{360}{3} = 120MN/m^2 \quad 5$$

From the maximum distortion energy theorem (Budynas and Nisbett, 2008); where δy = 0 and τxy = 0.

$$\delta max = \sqrt{\delta x^2 + \delta y^2 - \delta x \delta y + 3\tau xy^2} \quad 6$$

$$\delta max = \sqrt{100^2 + 0 - 0 + 3(0)} = 100MN/m^2$$

The design is safe, because δd > $\delta max; i.e\ 120MN/m^2 > 100MN/m^2$

Design of the Power Screw

Power screws are used to convert rotary motion into translational motion. A screw thread is formed by cutting a continuous helical groove around a shaft (Khurmi and Gupta, 2005). These grooves are cut either left hand or right hand. The power screw is a single Acme threaded screw with collar at both ends, with one end in contact with Member and the other end having a square key way to enable the transmission of torque from a source. The collar is assumed to be frictionless and self-locking. This must have adequate strength to withstand axial load and the applied torque.

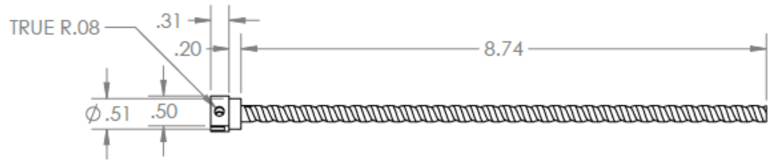


Figure 3: Power screw

$The\ design\ stress, \delta d = \frac{Tensile\ strength}{F.s}$ (Rajput, 2010) 7

$Total\ axial\ force\ in\ screw\ (F), F = \frac{w}{tan\theta};$ 8

$Hence, the\ axial\ force\ (F)\ in\ a\ screw\ is\ maximum\ when\ (\theta)\ is\ minimum.$

$$F = \frac{14715N}{tan9} = 92906N$$

$Design\ stress, \delta d = \frac{\delta yt}{F.s} = \frac{650}{3} = 217MN/m^2$ (Norton, 2000)

$$\delta d = \frac{F}{A} = \frac{92906}{A} \Longrightarrow A = \frac{92906.}{217} = 429mm^2$$

$A = \frac{\pi dc^2}{4}$ 9

$$\Longrightarrow dc = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 429}{\pi}} = 24m$$

Core diameter (dc) = 26mm, Outer diameter (do) = 32mm

$Mean\ diameter\ (d_m) = \frac{d_o + d_c}{2} = 29mm$ 10

Pitch (p) = 6mm

$Root\ diameter\ (d_r) = d_o - p$ 11

$\Longrightarrow d_r = 32 - 6 = 26mm$

$Total\ axial\ force\ in\ power\ screw, (F) = \frac{W}{tan\theta_{min}} = 92907N$ 12

$Effort\ required\ to\ raise\ the\ load, (P_r) = Wtan(9 + 3.8) = 14715 \times tan11.8 = 3127.8N$

α < ϕ, $i.e$ 3.8 < 9; $the\ load\ will\ remain\ in\ position\ after\ removal\ of\ the\ effort.$

$The\ effort\ required\ to\ lower\ the\ load\ will\ be, (Pl) = W\ tan(9 - 3.8)$

$= 14715 \times tan\ 5.2 = 1347.5N$

$Required\ torque, (Tf) = \frac{Wd_m}{2tan\theta_{min}} \times \tan(\alpha + \emptyset) = \frac{14715 \times 29}{2tan9} \times tan11.8 = 280644.1Nmm$

3.18

$Efficiency\ of\ threads, (\eta) = \frac{1 - Sin\emptyset}{1 + Sin\emptyset} = \frac{1 - Sin8}{1 + Sin8} = 0.756 = 75.6\%$ 13

$Actual\ torque\ required, (T) = \frac{Tf}{\eta} = \frac{280644.1253}{0.756} = 371222.4Nmm$ 14

Design for Cap at The Top

This cup is subjected to compressive stress and bending stress which is placed at the top of the frame and should with stand the applied load without failure.

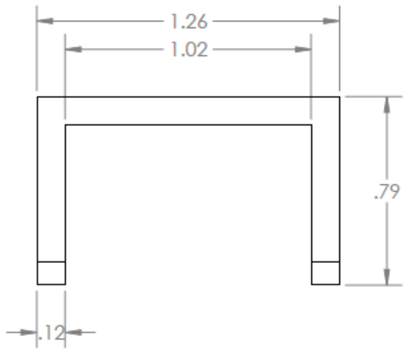


Figure 4: Cap at the top

For steel alloy used, σ_y =862Mpa, n=2.5

$$\sigma_{all} = \frac{\sigma_y}{n} = \frac{862}{2.5} = 345MPa \quad 15$$

Now axial compressive stress,

$\sigma = F / A; where\ A = bw = 50\times10 = 500mm^2 = 0.0005m^2$ 16

$\sigma = 14715/0.0005 = 29.43Mpa$

$Since\ \sigma < \sigma_{all}, it\ safe$

Design of Pins

The pins are used to joining a rotating link axis. They are used to hold parts together or limit travel of moving parts (Lokhande *et al*, 2012).

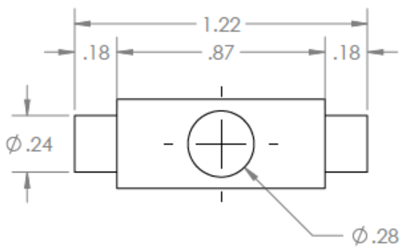


Figure 5: Pin

The material selected was 1048 grade steel.

$Diameter\ of\ head\ d_h = 1.5 \times d_{pin} = 1.5 \times 20 = 30mm$

$$\tau = \frac{F_s}{A} = \frac{F_s}{\pi d^2} = \frac{7357.5}{\pi \times 20^2} = 6MPa \quad 17$$

Hence, the material is safe.

Design of Base Plate

Here the base plate should with stand the applied load plus the whole component or linkage load by itself, the force, we have to select the material during the design process in order to resist the above all loads.

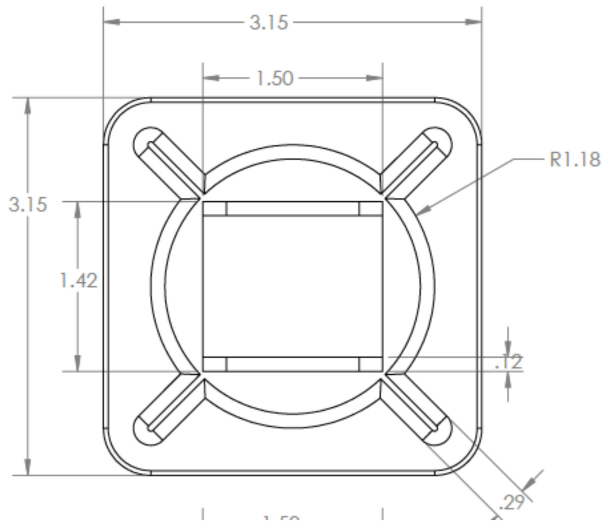


Figure 6: Upper and Lower base plates

Checking buckling since bending stress is applied on base

$$\sigma_b = \frac{F}{A} = \frac{W}{4A_{bending}} = \frac{14715}{4\times180} = 20.43MPa \qquad 18$$

$$where\ A_{bending} = t_{bending} \times d_{hole} = 9 \times 20 = 180mm^2$$

$$Since\ \sigma_b < \ yield\ strength\ it\ is\ safe$$

Design of Lifting Member (Links)

These members are made from simple U-shape metal. The web of the lifting member is cut out near the pin connections to allow proper serviceability of the toggle jack at its maximum and minimum heights (Shariff, 2010).

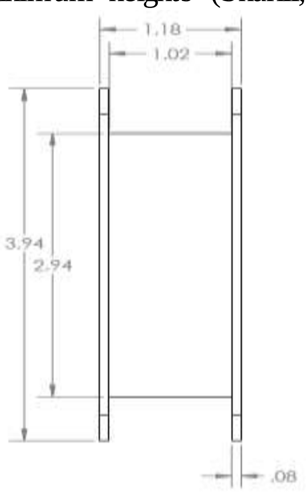


Figure 7: Lifting member

The following values are given for the steel material used: Tensile strength = 650 MN/m^2, Yield strength = 360 MN/m^2, Factor of Safety = 3

$$Design\ stress, \delta d = \frac{yield\ strength}{F.s} = \frac{360}{3} = 120MN/m^2 \qquad 19$$

For design consideration, an area of lifting member, (A) = 467mm^2 will be chosen.

$Tensile\ stress, \delta x = \frac{f}{A} = \frac{47127N}{467} = 101N/mm^2 = 101MN/m^2$ 20

From the maximum distortion energy theorem (Budynas and Nisbett, 2008);

$\delta max = \sqrt{\delta x^2 + \delta y^2 - \delta x \delta y + 3\tau xy^2}$ 21

$\delta max = \sqrt{101^2 + 0 - 0 + 3(0)} = 101MN/m^2$

The design is safe, because $\delta d > \delta max$; $i.e$ $120MN/m^2 > 101MN/m^2$

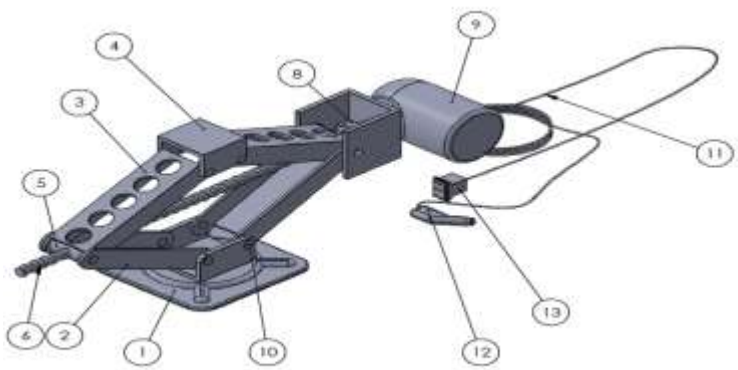
$Design\ of\ the\ links\ for\ buckling: Effective\ length\ = L \times C;$

$LC = 359.264 \times 1.0 = 359.2\ mm$

$The\ crippling\ load, = F.s \times F = 3 \times 47127.5N = 141382.5N.$ 22

Fabrication Process

Boring was done with a specific end goal to affix the bolts. Welding operation was also done. The clip is being welded to the jack keeping in mind the end goal to bolt the motor. Grinding was done to acquire a decent surface completion.



ITEM NO.	PART NUMBER	QTY.
1	base plate	1
2	Lower links	2
3	Upper links	2
4	Cap	1
5	pin	2
6	Lead screw	1
7	Part8	1
8	stud	1
9	DC Electric Motor	1
10	Rivet	8
11	Cable	1
12	Cigarette lighter plug	1
13	Switch	1

Figure 8: 3D solid drawing of motorized Jack

Components of fabricated equipment

The main parts of the automated motorized object lifting jack are: A power screw which is a mechanical device used for converting rotary motion into linear motion and transmitting power. Next is the Geared DC Motor**,** which is a DC motor and gear motor with permanent magnets known as Brushed Electrical Motors. An electric motor is a machine which converts electrical energy into mechanical energy. Batteries are other devices used. They are used for storage of excess energy which is converted into electrical energy. Control switch is used in order to start or stop the entire operation of the object lifting jack. This is designed to provide the simultaneous actuation of multiple sets of electrical contacts, or the control of large amounts of electric current or mains voltages. Electrical wires were also used in order to connect the battery to the motor and the switch. Base and Frame are where the entire set-up seats.

Experimental procedure and Performance Evaluation

Battery supplied power to the motor through the cigarrete lighter point. The DC Motor receives 12V DC current and runs accordingly. The power is transmitted to Screw Jack with the aid of Spur gear assembly. Then the Screw Jack goes upward and downward according to the operation of the switch. To study the reliability and performance of the Jack, practical tests were conducted for this analysis. The following test parameters were used to evaluate the performance of the lifting Jack:

Screw Jack Efficiency: From the geometry of figure 9,

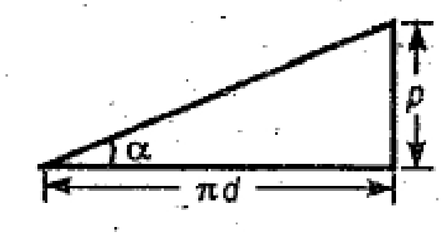


Figure 9: Geometry of the screw

$where: tan\alpha = \frac{p}{\pi d}$; $\alpha = helix\ angle; p = pitch\ of\ thread; d = mean\ diameter\ of\ the\ screw$

In a screw jack, the effort (P) required at the circumference of screw is: For raising the load, $P = Wtan(\alpha + \phi)$ and for lowering the load, $P = Wtan(\alpha - \phi)$

Note: When friction is neglected, then ϕ = 0. In that case $P_o = Wtan\alpha$; also the efficiency of a screw jack is given by

$$\eta = \frac{P_o}{P} = \frac{Wtan\alpha}{Wtan(\alpha+\phi)} = \frac{tan\alpha}{tan(\alpha+\phi)} \qquad 23$$

Process Time: Time required for maximum lift.

Comparative assessment of Developed jack and manually operated: To determine comparative advantage of the motorized object lifting equipment over the manually operated.

Cost Evaluation Analysis

This involves all cost incurred in the manufacture of the motorized toggle jack. These include cost for labour, cost of material, and other miscellaneous expenses incurred in the production process.

Total cost of scissor jack: $C_{Total} = C_{manufacture} + C_{labor} + C_{miscellaneous}$

RESULTS AND DISCUSSIONS

The fabrication of the motorized object lifting Jack was done at the Gregory University, Uturu Central Mechanical Engineering Workshop. The equipment components were fabricated and assembled. It involved the manufacturing processes of welding, drilling, boring, cutting, fastening, machining and grinding. Figure 10 shows the picture of the fabricated Object lifting Jack.

Figure 10: Fabricated Object lifting Jack

The effectiveness of the developed Jack was appraised using some performance parameters such as Jack efficiency, lifting time and comparing these parameters with manually operated Jack.

$$Jack\ Efficiency, (\eta) = \frac{Actual\ Load}{Design\ Load} = \frac{800}{1500} = 0.533 = 53.3\%$$

The efficiency of the Jack was about 53.3%, which was far less than the design efficiency of the jack which was above 70%. This is attributed to the strength of the DC electric motor and the gear system used.

Table 2: Lift Jack performance

Load (kg)	Lifting time (sec)	Lifting height (mm)
0	25.7	120
100	37.5	120
200	48.0	120
300	58.2	120
400	73.8	120
500	89.5	120

Table 2 presents the experimental result of the time take to lift loads of selected values. From the result, it is observed that the lift time increased as the load increases. This was done for a maximum height of 120mm. The trend is graphically presented in figure 11.

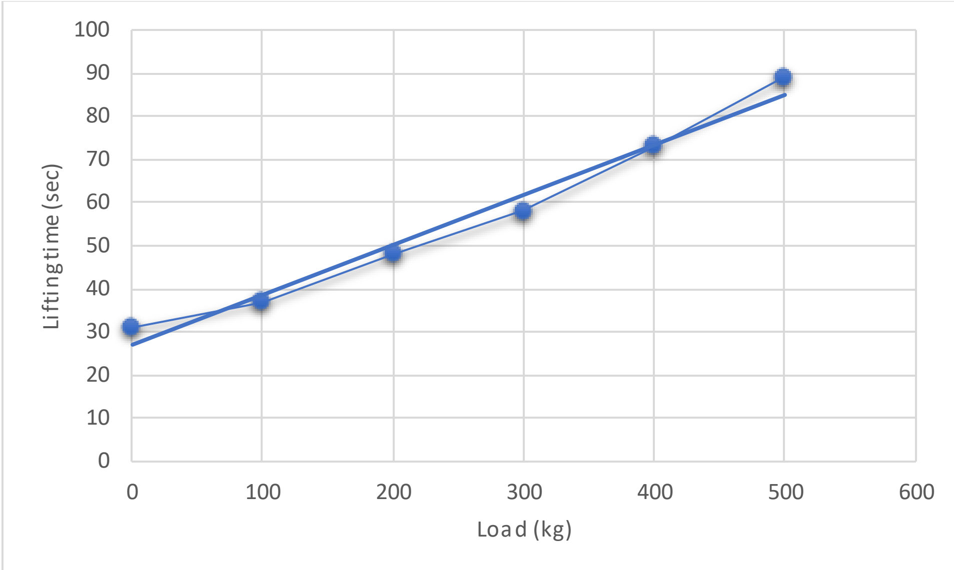


Figure 11: Comparative chart of load against Lifting time

In the performance test process, the comparison made to determine the performance advantage of the motorized Jack against the manually operated is presented in Table 3. From the data presented, the motorized system have a shorter lifting time for same amount of load against the manual operation which lifts at a longer time. In addition, the magnitude of the load is directly proportional to the lifting time (figure 12).

Table 3: Comparing Manual and Motorized operation in Object lifting

Load (kg)	Lifting time (sec)		Lifting height (mm)
	Manually operated	Motorized	
0	42.0	25.7	120
100	60.2	37.5	120
200	81.0	48.0	120
300	102.5	58.2	120
400	118.8	73.8	120
500	134.0	89.5	120

Technically also, comparing with manually operated Jack, it possess self-locking property, there is no radial thrust acting since square thread is used and higher range of speed control is obtained.

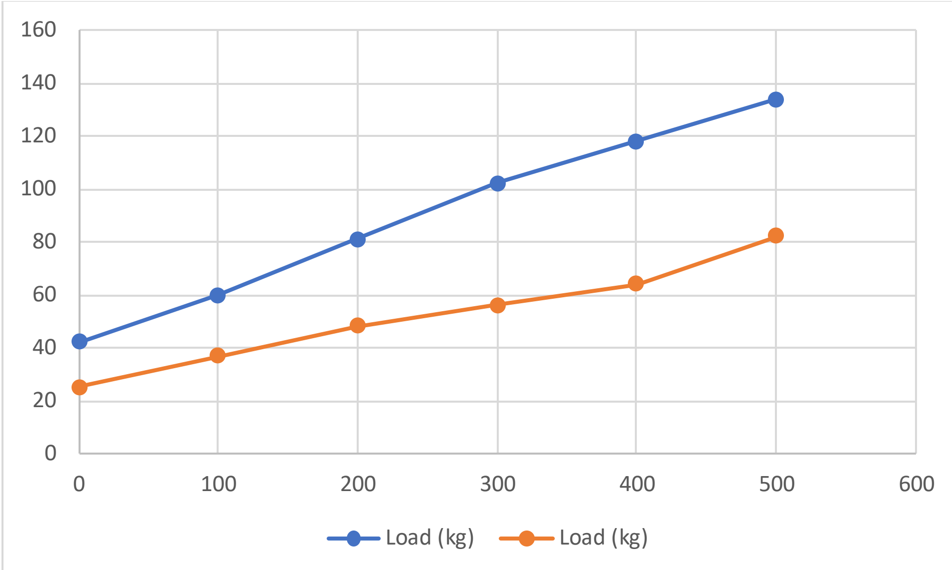


Figure 12: Comparative graph of lifting time

The costs incurred in the production of the Motorized Jack is shown in Table 4. From the cost analysis presented in Table 4, the sum required to produce the Jack is thirty eight thousand, four hundred and thirty-five naira (₦38,435.00).

Table 4: Cost Analysis of Motorized toggle Jack

S/N	Description	Unit Price (₦/Kg)	Quantity (Kg)	Amount (₦)
1	Jack production	34500	1	34500
2	Power	1000	-	1000
3	Labour Cost	-	-	2000
4	Miscellaneous	-	-	935
	Total			**38,435**

Table 5 provides the material description of the motorized screw jack components. These parts were utilized in the production of the screw jack for object lifting with general applicability in lifting loads.

Table 5: Material Specifications

Components	Qty
Power screw	1
Upper link	2
Lower link	2
Base plate	1
Cap	1
Connecting member	4
Switch	1
Pin	8
DC Motor	1

Cigarette Lighter receptacle Wire	1

CONCLUSION

This research work analyzes the screw jack by incorporating an electric motor in the screw in order to make load lifting easier. In this modified design, the power screw is rotated by connecting motor through a coupling, plugged to the automobile 12 V battery source to generate power for the prime mover (motor), which transmits its rotating speed to the power screw to be rotated with required speed reduction and increased torque to drive the power screw. The significance and purpose of this work is to modify the manually operated car jack in order to make the operation easier, safer and more reliable. The designed motorized jack will also save time and requires less human energy to operate. Based on the testing and results from the analysis with about 53% lifting efficiency, it is considered safe to use the toggle Jack. However, there are is also room for improvement on the work done. That can be applied to the gear, motor and design.

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