Design, Construction and Testing of an Electric Powered Toggle Jack Mechanism

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Abstract - *Road side emergencies such as tyre punch, is a problem commonly observed in cars. Conventional car jacks uses mechanical advantage to allow a human to lift a vehicle by manual force. This paper is a modification of the current toggle jack by incorporating a servomotor whose motion as well as torque is transmitted via gear trains to the power screw, in order to make load lifting easier for emergency use with the aid of a 12V car battery as power source. Gear ratio is used to increase the lifting power. The significance and purpose of this work is to modify the existing car jack in order to make the operation easier, safer and more reliable in order to save individual internal energy and reduce health risks especially back ache problems associated with doing work in a bent or squatting position for a long period of time. Fabrication work has been done using milling, drilling, grinding, and welding machines. The developed car jack is tested on 1400kg Toyota Camry car. Loads were increased at intervals of 50 Kg using bags of cement and it was observed that, deformation of threads began at loads beyond 1550 Kg. this implies that, the electric powered jack mechanism is capable of lifting vehicles with maximum load of 1550 Kg. The device is highly efficient with high mechanical advantage and jacking speed of 2.98 mms^{-1} more than that of the manual jack which is 1.17 mms^{-1}. Implementation of design will solve problem associated with ergonomics.*

Key Words: Toggle jack, Servomotor, Torque, Gear ratio.

1. INTRODUCTION

A toggle jack is a machine which, when a small force is applied in its horizontal plane is used to raise or lower a large load. It is usually applicable in the automobile industry for raising a side of the vehicle during tyre changing [1].

It is made up of a bolt and nut assembly and its working principle is similar to that of an inclined plane. Where a thread wound round a shaft rotates in its bearings while the nut has axial motion against the resisting axial force. In the Nigerian market today, toggle jacks abound but what they have in common is that they are all manually operated. This project is geared towards researching and developing a toggle jack that is power operated, time saving and more efficient. Thus achieving one of the goals of technology by making life easier for the end user, proper design considerations were given to the design of this project including the stresses, bending moment of the shafts, strength of materials and the maximum load it is expected to carry, thus making safety and reliability a watch word [2].

The objective of the study is to develop a mechanism in a power toggle jack that is more efficient, stress free, saves time and a reliable way to achieve lifting of the load. *Brief Review of Power Toggle Jack:* Jacks are lifting machines used to raise loads. This uses power screws which help in bearing the load. The efficiency is maximized with the use of lubrications.

Types of Jack: The various types of jacks are; Screw jack, Toggle jack and Hydraulic jack. The toggle and screw jack uses power screw to raise load. The toggle jack has link members which are arranged to a certain degree of freedom. The hydraulic jack uses fluid but no screw. This is achieved by pumping or increasing the pressure of the fluid in the cylinder to raise the loaded shaft [2].

2. COMPONENTS OF THE POWERED TOGGLE JACK

A Powered toggle jack has the following components; Upper links, Load bearing, support, the power screw shaft, 2 pins base support, Lower links, Driven gear, Driver, Gear housing, Base support, Servo motor, Alligator clips, Power switch and Connecting cable. The powered toggle jack is manufactured in such a way that a motor and gears are integrated to the jack. A motorized car jack only incorporates a motorized mechanism. The choice of D.C motor is because the power of a vehicle comes from a D.C battery. For this reason the user is able to supply the power to the motorized jack directly from the battery of the car. The powered toggle jack is ready for use whenever it is connected to the battery of the vehicle. A hand held toggle powered switch control is attached to it through which the operator is able to safely control jacking operations from some cable distance away from the vehicle. When the lift button is pressed, the jack lifts up the vehicle with a perfectly controllable speed. The down button lowers the jack in a likewise controllable manner. The controls' are made in such a way that the operator safely and comfortably lifts his vehicle to a desired height. A car jack is a device used to facilitate repairs by lifting all or part of the car. There are different types of car jack; Screw jack, Toggle jack, Hydraulic jack, Hydro-pneumatic jacks etc. Hydro-pneumatic jacks are operated by fluid pressure generated by a pump, when this jack is lifted up, it is suspended in position by pneumatically operated locks. This is used for jacking the whole vehicle up so that the underneath is accessible. Hydro-pneumatic jacks have the highest efficiency when compared with other jacks. For this reason it can be safely used to jack heavy duty vehicles [3].

3. DESIGN PROCEDURE

After the preliminary study, it was discovered that a D.C motor in combination with two gears can produce the required turning effect on the screw at less amount of time, thus eliminating the use of manually operated lever and the corresponding inconvenience that goes with it.

The next step involved choosing the appropriate servomotor (because of its ability to provide high torque) and the corresponding gear ratio to transmit the torque. However, the choice of thread on screw and nut, after calculations on appropriate internal and external diameter was chosen. Single point cutting tool was used in the cutting of the required links, while hammer and shaping machine were used to bend them to shapes.

Components assembly and balancing on roads was done while giving consideration to torsion, bending and shear forces acting on strategic point. It is important to note that iterative comparison of stress values obtained, with those required for safe operation (yield stress) was made and the cycle repeated when necessary.

Using the methodology and principle of manual jack which works on the bases of when the threaded shaft of a manual jack is turned manually using a T-handle in a clock wise direction, this causes the jack to contrast thus lifting the load and when turned anticlockwise brings the load down. So therefore, the powered toggle jacks works on this principle but the difference is that the turning of the threaded shaft in the jack is not done manually but with the aid of an electric motor. The methodology of the powered toggle jack is simply on the conversion of electric energy to mechanical energy so as to lift load [5].

3.1 Design Concepts

The jack in Figure 1 can be seen to have 8-links and 10-joints. Hence its mobility can be found to be M (degree of freedom) = 3(n – 1) – 2J [4]
i.e.,

$$M = 3(n - 1) - 2J \quad (1)$$

Where n = number of links, J = number of joints.

3.2 Design of Square Threaded Screw

A little consideration will show that the maximum load on the threaded screw occurs when the jack is in the bottom position. The position of the link, CD in the bottom position is shown in Figure 1.

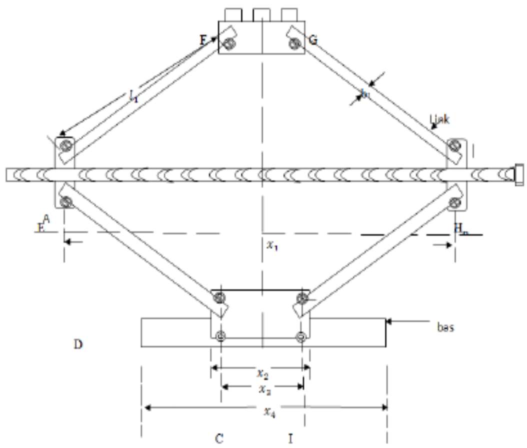

Figure 1: Schematic diagram of the powered jack

$Width\ of\ the\ link, b_1 = 36mm,$
$Length\ of\ the\ link = 185mm,$
$Length\ of\ the\ powered\ screw\ shaft, x_1 = 350mm,$
$x_2 = 50mm,$
$x_3 = 35mm$

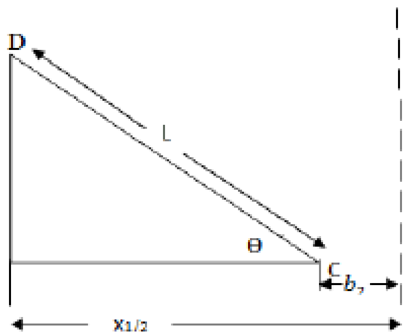

Figure 2: Free body diagram of link CD

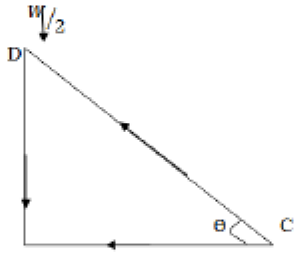

Figure 3: Diagram showing the pull of the thread

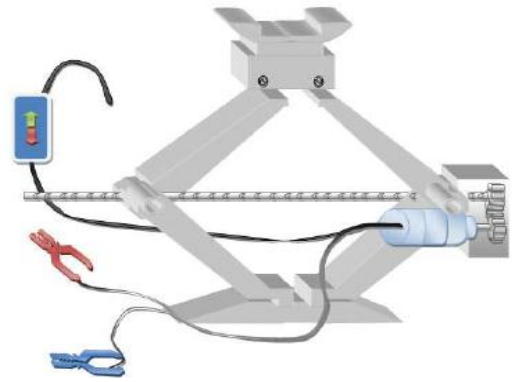

Figure 4: Assembly Diagram of a powered jack

According to Khurmi and Gupta [3], a mechanical toggle jack was considered in the following design calculation for component and other parameters as follows:

Let θ be the angle of inclination of the link CD with the horizontal. From the geometry of the Figure 3, we find that;

$$\cos\theta = \frac{\left(\frac{x_1}{2} - b_2\right)}{l_1} \qquad (2)$$

$$=> \ \theta = \cos^{-1}\frac{\left(\frac{x_1}{2} - b_2\right)}{l_1} \qquad (3)$$

Each nut in the jack carries half the total load on the jack, as a result of this, the link CD is subjected to tension while the threaded screw is under pull as shown in Figure 1 above. Thus the magnitude of the pull on the square thread screw is given by;

$$F = \frac{W}{2\tan\theta} \qquad (4)$$

Since a similar pull acts on the other nut, therefore total tensile pull on the square threaded rod is;

$$W_1 = 2F \qquad (5)$$

But load on the screw is given by:

$$W_1 = \frac{\pi}{4}(d_c)^2\sigma_t$$

Where $d_c = core\ diameter\ of\ the\ screw$

$$d_c = \frac{\sqrt{4W_1}}{\pi\sigma_t} \qquad (6)$$

Since the screw is subjected to torsional shear stress, therefore to account for this; we have to adopt the nearest value in the standard table of reference.

Therefore outer diameter of screw (d_o) is given by;

$$d_o = d_c + p \qquad (7)$$

Also mean diameter of screw is;

$$d = d_o - \frac{p}{2} \qquad (8)$$

$where\ p = pitch$

For us to check for principal stresses, we know that;

$$\tan\alpha = \frac{p}{\pi d} \qquad (9)$$

Where α is the helix angle.

The effort required to rotate the screw is given by;

$$P = W_1\tan(\alpha + \theta) = \frac{W_1(\tan\alpha + \tan\theta)}{1 - \tan\alpha . \tan\theta} \qquad (10)$$

Where $\theta = frictional\ angle$

Torque required in rotating the screw is given by,

$$T = P * \frac{d}{2} \qquad (11)$$

In the new design of this jack, the D.C servo-motor must be able to provide a torque that is above the calculated value of T above, so as to give allowances for losses during transmission by gears.

Shear stress in the screw due to torque is given by;

$$\tau = \frac{16T}{\pi(d_c)^3} \qquad (12)$$

Therefore, the direct tensile stress in the screw can be calculated as;

$$\delta t = \frac{W_1}{\frac{\pi}{4}(d_c)^2} = \frac{4W_1}{\pi d^2} \qquad (13)$$

Maximum principal (tensile) stress is thus calculated as;

$$\sigma_{t(max)} = \frac{\sigma_t}{2} + \frac{1}{2}\sqrt{[(\sigma_t)^2 + 4\tau^2]} \qquad (14)$$

Maximum shear stress is given by;

$$\tau_{max} = \frac{1}{2}\sqrt{[(\sigma_t)^2 + 4\tau^2]} \qquad (15)$$

According to basic dimensions for square threads in mm for fine series (IS 4694, 1968 (Reaffirmed 1996)), the maximum stresses are within safe limits, then the design of the square threaded screw is satisfactory.

Efficiency of a screw jack is therefore given by;

$$\eta = \frac{\tan\theta}{\tan(\alpha+\theta)} \quad (16)$$

3.3 Gear Design

Gear trains were provided at the shafts to transmit power developed at the motor to the power screw, though direction of both motion are opposite. Therefore, the design of the gear (i.e. driver and driven) of the required speed ratio of 2:1 is given as follows;

Parameters:

$x =$ *distance between the centre of the shaft*

$$= \frac{d_1+d_2}{2} \quad (17)$$

$N_1 =$ *speed of the driver*

$T_1 =$ *number of teeth on the driver*

$d_1 =$ *pitch circle diameter of the driver*

N_2, T_2 *and* d_2 $=$ *corresponding value to the driven*

P_c $=$ *circular pitch, which is the distance measured on the circumference of the pitch circle from a point of one tooth to the corresponding point on the next tooth.*

$$Speed\ ratio = \frac{N_1}{N_2} = \frac{T_2}{T_1} = \frac{d_2}{d_1} \quad (18)$$

$Required\ speed\ ratio\ = 2:1$

$$\therefore \frac{d_2}{d_1} = 2\ or\ d_2 = 2d_1 \quad (19)$$

Therefore the number of teeth on the first gear (driver) is;

$$T_1 = \frac{\pi d_1}{P_c} \quad (20)$$

A similar calculation yields T_2

Basic dimensions for square threads in mm (Fine series) according to IS 4694, 1968 [3].

4. TESTING OF THE POWER TOGGLE JACK

The jack was used to raise the left rear side of a Toyota Camry car whose total weight is 1400 kg and left suspended for about 1 hour at a maximum height lift of the jack. The terminals were connected to the battery terminals of the car while it was on. This is to avoid the battery running down while the jack is in use. The maximum height lift of the jack of 190 mm was maintained after 1 hour of suspension, indicating no thread failure or deformation. The tests were repeated for five more times and the results were compared with those obtained from equivalent number of trials with a manual screw jack. The results are as shown in Table 1.

Loads were gradually increased on the jack at intervals of 50 Kg using bags of cement and the maximum displacement of the electric jack by height was monitored after 30 minutes of every increase so as to know the maximum load that the jack can carry. Results obtained are tabulated in Table 2.

5. RESULTS AND DISCUSSIONS

The results obtained from six repeated measurements for both thread deformation and maximum carrying loads are as recorded in Tables 1 and 2 respectively.

Table 1: Thread deformation test

Number of trials	Maximum displacement of jack (mm)	Lifting time for electric jack (sec.)	Lifting time for manual jack (sec.)
1	190	63	167
2	190	66	150
3	190	61	166
4	190	65	161
5	190	66	157
6	190	62	170
Average	190	63.83	161.83

Table 2: Maximum load carrying test

S/N	Weight (Kg)	Displacement of jack (mm)
1	1450	190
2	1500	190
3	1550	190
4	1600	188
5	1650	186
6	1700	185

The average time is gotten from the formula:

$$Average\ time = \frac{t_1+t_2+t_3+t_4+t_5+t_6}{6} \quad (21)$$

While the average speed is gotten from the formula:

$$Average\ speed = \frac{maximum\ displacement\ of\ jack}{average\ time} \quad (22)$$

From the above analysis, it can be seen that the electric jack does the same amount of work as the manual did at less than half the time. The average speed of the electric jack is 2.98 mm/s while that of the manual jack is 1.17 mm/s. This difference in speed can be attributed to the human factor of 'work and rest'. The speed of the electric jack is about more than double that of the manual thus highlighting the convenience and efficiency of the electric jack.

As the load on the jack was increased, the maximum jack displacement of 190 mm was maintained then monitored within 30 minutes of every 50 Kg increase until at a load of 1600 Kg when the displacement began to drop. At this point, it means deformation of the threads began. It also means that, the applied load with which the jack will begin to fail lies between 1550 Kg and 1600 Kg. This also means that the maximum recommended load the jack can carry is 1550 Kg.

5. CONCLUSIONS

The manual toggle jack have been successfully improved by replacing the manual effort with the aid of a servomotor whose motion as well as torque is transmitted via gear trains to the power screw, thus lifting the load. This is in agreement with previous studies [6]. The design is limited to the mechanical aspects of the jack only. It does not include the manufacture of the servomotor or the construction of the electrical component. The jack is most suitable for lightweight vehicles not more than 1550 Kg. For increased performance and durability, greasing of movable parts and other services should be done on the jack regularly.

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