Proceedings of the International Conference on Industrial Engineering and Operations Management
Pilsen, Czech Republic, July 23-26, 2019

Development of a Portable Motorized Car Jack

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Abstract
This study seeks to develop a motorized car jack with maximum lifting capacity of 2 tons. The design incorporates an electric motor that is powered by a 12-volt battery of a small vehicle and the device would be 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. The authors generated three possible solution concepts based on simple engineering techniques and knowledge of existing jacks. Binary Dominance Matrix analysis was used to evaluate and determine the best solution for further development into a detailed design. Solid works 2016 software was used to simulate the operation and loading of the resultant design. The purpose of this study is to try and modify the design of the already existing car jack in use.

Key words
Jack, hydraulic, motorized, design, vehicle

1. Introduction
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. This may mean that it is not easy for elderly and handicapped to operate them. 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. World over the car jack is an essential device all car owners should possess to assist in servicing their car when need arises and normally, the need is often necessitated by flat tires that need repair or replacement. This study seeks to reduce labor in the car lifting process using a jack as most car jacks are manually operated there is need to modify them and incorporate them with a prime mover system which replaces manual handling of jacks during operation making it easier and reducing drudgery during maintenance operations. Also time consumption in the process of hoisting a vehicle will be reduced as using the available manually operated car jacks is a very time consuming process, thus there is need to design a motorized jack that improves the timeliness and efficiency in lifting. There will be reduced risk of injury as it is known that for a car jack to be hoisted, the operator has got to be near the vehicle and operating close to the vehicle during jacking is risky, so to reduce the risk of getting injury in the case of malfunctioning of the device the motorized jacking system enables operator to be at a safe distance during the jacking process.

2. Background
During road-side emergency like tire puncher, a jack is required to lift the vehicle (Choudhary 2016). It has also been noted that the roadside assistance to come and assist, is not readily available in the remote rural roads of the country. Vehicle workshops are equipped with hi-tech car lifting system where vehicles are raised and lowered using an electrically powered system. However, this is not the case for portable lifting devices. Due to the high cost, maintenance and size, such lifting devices have been found to be mostly confined to work in workshops only and such functionality can neither be placed in car nor be owned by vehicle owners. Hence there is need to design a motorized portable car jack that does not only reduce human efforts but also save time needed to repair the vehicle and that is easy and safe to use. This will be an advantage when it comes to replacing a vehicle tire on the roadside.

This study focuses on design of a motorized car jack that utilizes the12-volt vehicle battery which supplies power to the motorized jack through the cigarette lighter receptacle point on the dashboard of the car.
From the research done it was established that the process of lifting a car using an ordinary jack has become undesirable for motorists in Zimbabwe over the past few years. Motorists have been injured or stuck on the road for long periods of time.The available jacks pose a problem of drudgery and risk of getting injured during jacking process. For this reason, it is fitting to improve the later process so there is need to design and manufacture a system for the existing jacks which can ease the process and make it time-efficient.

3. Review of car jacking processes

A jack is a mechanical device that enables a relatively small force to lift heavy load. Jacks use mechanical advantage to allow the lifting of heavy loads (Patil 2014). The most common form of jacks available is the hydraulic bottle jack, screw jack and the toggle or scissor jack which is used to lift a vehicle to carry out maintenance on it (Parth 2016). The toggle of jack is commonly known as the scissor jack. Toggle jack (Figure 1) is a simple mechanism that is used to drive large loads for short distances. The toggle jack uses a power screw mechanism and also incorporate trolley mechanism. The power screw design is there to reduce amount of force that is required to drive this mechanism by the user. As with the screw jack, power screw is used to convert rotary motion into translator motion. A good example of the use of a power screw is the lead screw of a lathe machine. A toggle jack is operated simply by turning a small crank that is inserted into one end of the jack (Patil 2014).

Figure 1: Mechanical toggle Jack (Source: http://www.wikipedia.com)

A screw jack (Figure 2) is a portable device used to raise or lower the load by the use of a screw mechanism thus by using a power screw. Jacks are used frequently in raising cars so that a tire can be changed or maintenance operations that require someone going under the vehicle can be carried out. Basing on the magnitude or level of pressure they will be working with and the space they will have to fit into, screw jacks can be made to be thin, short, and tall or even fat (Kulkarni 2017). The jack is made from several types of metals but the screw is made of lead. Screw jacks normally have self-locking mechanism so that they will not fall if the power is removed, and they hold up well to the wear of repeated use.

Figure 2: Mechanical Screw Jack

The main applications of power screws are to raise the loads for example in a screw-jack (Shaikh 2015). On the contrary the hydraulic bottle jack uses a fluid to lift loads and the fluid which can be assumed to be incompressible, is forced into a cylinder by a pump plunger. The main fluid used is oil and it is used since it is self-lubricating and stable (Singh 2015). In other words, a hydraulic jack relies on hydraulic power to function and operate on the principle that fluids generate the same pressure at all points when contained in a closed system. In a hydraulic jack system, a fluid is contained in a large and small container and both these containers are linked by some form of

tubing. The phenomenon these jacks operate on is that a relatively small force is applied to the tube with a smaller diameter and the pressure on the fluid increases. In the larger tube, the same amount of pressure per square meter is applied over a larger surface area which in turn results in a significant increase in force.

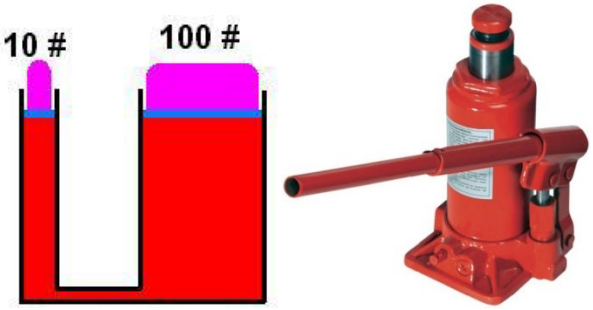


Figure 3: Pascal's Law and Hydraulic Bottle Jack (Source: http://www.edutwin.com)

A hydraulic jack basically operates on this system of two-cylinder (Muchnik 2007). This type of jack has outweighed screw jacks that were commonly used at some point in time because of its greater mechanical advantage. It generally comprises of two cylinders linked together and it operates basically on the principle of Pascal's law (Figure 3). This jack is said to be fully self-contained which means it contains its own integrated pumping units and oil reservoirs. A hand lever that is detachable is also provided for operation of plunger of the pump. Lifting handle is also provided (William 2001). The advantage of a hydraulic jack is that smaller amounts of force have the capability to lift loads which otherwise would be impossible using this jack. It can be concluded that this type of jack is capable of lifting heavier loads than the other jacks since hydraulic systems in general are associated with large load carrying capacity and this jack have got two mechanical advantages, one due to the lever system and another due to ram and plunger cylinders' hydraulic system which combine in a manner that results in a multiplying effect rather than an adding effect. This results in a much larger mechanical advantage. Since hydraulic systems are smooth and quiet in operation, vibration is minimal in these types of systems hence the hydraulic jack is relatively smooth and quiet when using it. A well-functioning motorized jack unit can bring about a whole range of benefits for the users. A motorized jack reduces drudgery (hard boring work) during maintenance operations since manual power is not required or is minimized (Asonye 2015). Motorizing the jack brings about increased timeliness and efficiency in maintenance operations on vehicles as the motor will be lifting the load faster than the manual operation. A motorized jack also reduces the risk of getting injury if malfunctioning of the device occurs during operation of the jack. Single personnel is enough to operate the motorized jack efficiently to lift the load, it does not require a skilled worker (Shaikh 2015). The motorized jack can be convenient meaning it can be accessed anywhere since it is powered by the battery on the vehicle.

4. Methodology and materials

Garage shops visits were carried out in order to attain practical information and real-life applications and problems being faced. Three possible solutions were generated, and each possible solution was evaluated with reference to its technical strengths and drawbacks. Using binary dominance matrix analysis (BDM), one solution was chosen for further detailed design development based on the simplicity of the design, cost and reliability. Solid Works Software was employed for 3D modeling of the design and related components. 2D drawings were done using AutoCAD. SPSS was also used to analyze statistical data from the questionnaires filled out by motorists.

5. Development of detailed design

Based on the Binary Dominance Matrix analysis the hydraulic based concept (Figure 4) was determined as the best option for further development. The selection was based on the following considerations such as: function, safety, ease of manufacture, ease of maintenance, efficiency, reliability, simplicity of layout, cost of manufacture, cost of maintenance, quality, weight, life span, and ergonomics. Its major components are: 1. DC motor 2. Jack Handle 3. Spur Gear system 4. Base plate 5. Crank linkage system 6. Hydraulic Bottle Jack, and 7. Lifting Platform

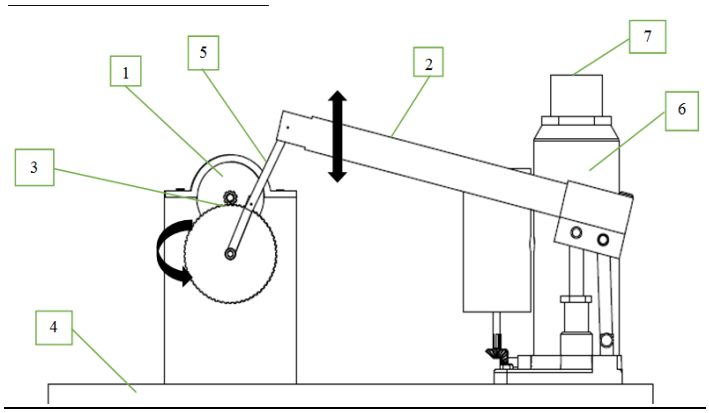


Figure 4: Motorized hydraulic car jack

The mechanism of this concept is powered by tapping into the 12V cigarette lighter socket. This serves as the source of power to drive the prime mover which in this case is the DC electric motor. The rotation of the motor generates a torque which is in turn transmitted to the meshed gear of larger diameter. This is how speed reduction is achieved, through the spur gear system. Rotary motion is then converted to rectilinear motion by the cranking system. The to and fro motion of the jack handle is produced which is necessary for actuating the hydraulic system and raising the jack. For release valve control in bottle hydraulic jack, a motor is also incorporated into the system and it is turned one way and the valve also turns to ensure one-way flow during lifting; in a closed position, lifting is carried out. In open position, a backward flow to the reservoir, which is caused by weight of load, takes place and this is how the lowering is achieved. Hydraulic systems are associated with large load carrying capacity, high efficiency with minimum friction loss keeping the cost of a power transmission at a minimum. The systems are smooth and quiet when in operation vibration is minimal in these types of systems. The oil used as a fluid cools the moving part on its own therefore this project does not require designing of any cooling mechanism of some sort.

5.1 Crank Link Gear System

Speed reduction for torque multiplication and more power are the guiding desires for the choice of the spur gear assembly for the transfer of motion of the motor to the crank link. To achieve the transfer of the motor torque to the plunger system of the jack, a gear system was adopted. The gear system effects speed reduction in the system. The spur gears are of cast steel material which has minimum tensile strength of 550 N/mm$^{2.}$ The motor rating to be used is 12 V DC motor with speed rating of 2000 revolutions per minute (rpm) and power rating of 200 Watts. The input force from the prime mover system, 237.5N which, due to the mechanical advantage of the system, results in the output force of 44.175 kN is sufficient to lift the maximum load of the jack which is 20 kN (2000 kg).

5.2 Release Valve Gear System

To connect the two shafts (motor shaft and release valve shaft) whose axes intersect at a right angle, the bevel gear system was used. Since speed reduction and torque multiplication was not imperative in this case, mitre gears were used. These are a type of bevel gears where the pinion and the gear have equal number of teeth and equal pitch angles 45^0. Basically these are equal bevel gears. The bevel gears are of cast steel material which has minimum tensile strength of 550 N/mm^2. The motor to be used will be a 12 V DC motor with speed rating of 2000 revolutions per minute (rpm) and power rating of 400 Watts. The torque that is transmitted by the gears to turn the release valve is 1.9 Nm

5.3 Crank and Linkage Mechanism

This mechanism is aimed at achieving motion conversion. Other than conversion of the rotary motion of the rotating gear to a reciprocating motion needed by the jack plunger, this also serves as a measure of additional mechanical advantage. The mechanism that was adopted was treated as a four bar chain mechanism with four links. The links in this case were taken to be the crank on the larger spur gear (r) and the connecting rod (L) and the lever/handle (L2) which makes partial rotation or oscillates represented by link 2 on diagram below and the base plate was assumed to be the fixed link 1 joining the r and L2 (Figure 5).

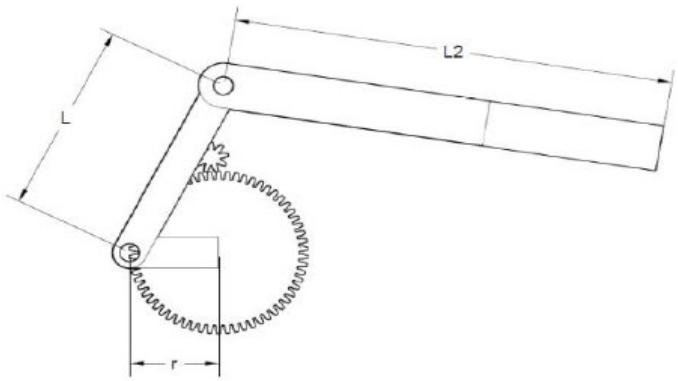


Figure 5: Crank and linkage system

After optimum consideration prioritizing compactness of the system and basing on the jack handle length (L2), the following lengths for the crank (r) and connecting rod (L): L2 = 265 mm, L = 66.25mm, and r = 40 mm

5.4 Power Supply to the Motor

The DC motor is powered using power from the car's 12V battery. The motor gets that power through the cigarette lighter socket (Figure 6) on the car dashboard. The extension socket with a simple switch is shown below(Figure 6).

Figure 6: Cigarette lighter socket and extension cable with switch

The sockets are then connected to an extension socket which has switches which will control the motor operation. The motor for the release valve will have a special motor that allows for reverse of polarity as it is imperative that this motor rotates in both directions while in use. High resistance electrical cables with coating were used for these connections from motor to socket. There is no limit on the length of the cabling connections but for the sake of keeping the system compact, the cable connections were kept at 2 m in length. This connection is enough to ensure that the jack operator is away from the vehicle during lifting or operation of the jack in general thus reducing risk of injury. Also this connection ensures that the operator can operate the jack in a more comfortable standing position thus reducing the muskuloskeletal injuries resulting from the continued manual operation of the jack.

5.5 Von Mises Stress Analysis

Von Mises stress analysis is a method that is employed by design engineers to check the strength of the component after applying a certain load. It is sometimes termed failure analysis. For a good design, the Von Misses stress should be less than the design stress. Regions with blue represents minimum Von Misses stress and regions with red represents regions with maximum Von Misses stress.

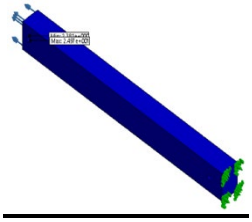
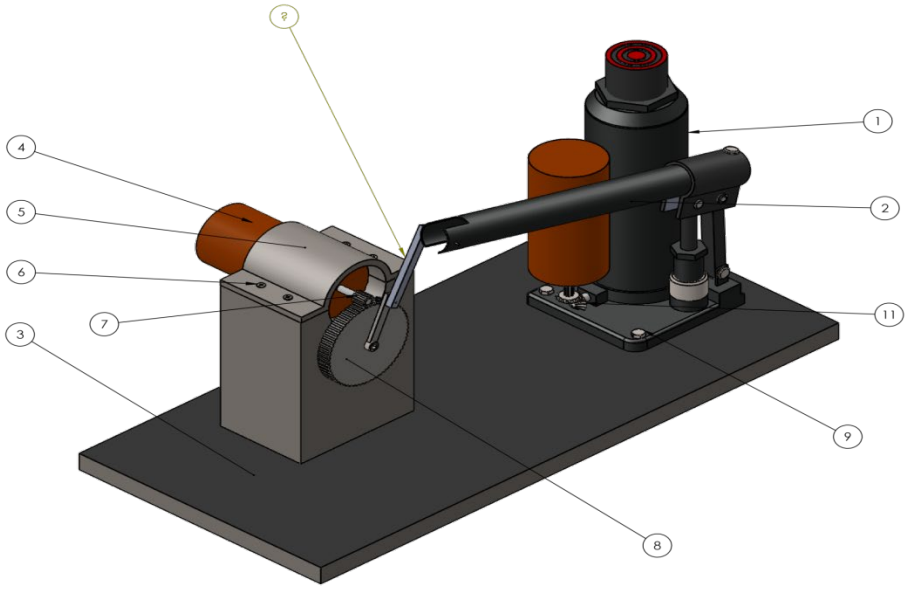


Figure 7: Von Mises stress analysis on Connecting rod

The maximum Von Misses component of 24.97 MPa is less than the value of the design stress (70,314 MPa), hence, the design is optimum and safe. The final motorized hydraulic jack will be as given in Figure 8 below.



ITEM NO.	PART NUMBER
1	Hydraulic bottle jack
2	Handle
3	Base Plate
4	Motor
5	U Brack
6	BS EN ISO 7046-1 - M3 x 16 - Z - 16N
7	Pinion Gear
8	Gear
9	M5 Stud Bolts
10	Connecting Rod
11	Straight miter gear

Figure 8: Final design of motorized jack

5.6 Cost Evaluation Analysis

The total grand cost of the finished motorized jack was estimated to be USD147, with the cost of raw finished machine constituents costing USD 127, while the costing for constituents into the chosen machine section costing USD 20.

Table 1: Summary of cost of manufacturing and raw materials

Description	**Cost/$**
Raw materials and Jack	127.00
Manufacturing and processes	20.00
GRAND TOTAL	**147.00**

6. Recommendations

The system is associated with a certain level of vibration due to the rotation of the motor and also other components like the gears and links. Therefore the system can be equipped with rubbers in the linkages since the rubbers absorb some of the vibration energy. This also reduces the noise associated with such kind of a system. A remote control system can also be incorporated to improve the compatibility of the system by limiting the amount of cabling needed for the motorized jack electrical components. Also this enhances safety of the jack and ease of use. The device can also be designed to operate using android application. An alternative power source should also be availed as part of the motorized jack kit, to avoid problems when say, the car battery is flat. This prompts future scope to also involve the development of an alternative power source to the jack. A solar and battery system can be incorporated into the device so that it can function in such a way that the solar panel is used to charge a 12V battery. A scope can be considered to look beyond a maximum of a 2-ton vehicle, and develop the jack for it to be applicable even to be used for heavy duty vehicles.

7. Conclusion

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 car battery (12V) is used to supply power source to the motor. Human effort was eliminated in raising the jack by the use of the torque generated by the motor as in rotates. The use of long cablings to control the motorized operation meant the jack would 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 torque supplied to the system is more than enough to lift a vehicle weighing around 2000 kg (2 ton). This design of the motorized carjack can considered to be a huge benefit in the lifting and lowering of 2 ton vehicles.

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Biography

Ignatio Madanhire graduated with a PhD in Engineering Management at the University of Johannesburg, South Africa, he is also a Senior Research Associate. He is also a lecturer with the Department of Mechanical Engineering at the University of Zimbabwe. He has research interests in engineering management and has published works on cleaner production in renowned journals.

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