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Design and Implementation of Automated Hydraulic Jack for Servicing and Maintenance Purposes

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Abstract –Hydraulic jack is an important device that serves numerous purposes in auto -servicing activities (e.g., as replacement of car tires). Operating the hydraulic jack is key to its vast application, but it is associated with a lot of stress, and injuries. In an attempt to ease the bottleneck in using the manual jack to raise up for servicing or tire replacement, an automatic hydraulic jack, has been designed and implemented for the purpose of maintenance of cars in Nigeria. Fabrication was done using locally available materials in other to achieve reduction in production cost, stress and injuries attributed to the use of manual operated hydraulic jack. The essential components of the automated hydraulic jack comprised of four primary sub-systems: (1) the hydraulic jack unit, (2) the transmission unit, (3) the DC motor unit, and (4) the control unit. The hydraulic jack unit of the system works based on the Pascal's law, while the transmission unit employs a kinematic linkage to transform the rotational motion of the motor's shaft into the reciprocating motion of the hydraulic jack's ram. The complete design was cased using a mild steel plate measuring 457mm x 358x110mm with thickness of 2mm. Machine performance evaluation was conducted on five models of cars of different weights (2.45, 2.25, 2.50,1.75 and 1.6 tons) in order to establish the time, the machine will lift each particular car. The results of which were 2.4 mins,3.3mins, 3.1mins,2.5 mins, and 2.4 mins respectively. The best speed of the automated hydraulic jack was obtained when operated at 2.5 tons with a speed of3.3mins. The jack is easy to handle and requires minimum operation time and maintenance. Hence making the design a user -friendly and cost-effective system.

Keywords: auto-servicing, hydraulic jack, maintenance, motor shaft, Nigeria.

1. Introduction

A jack is a widely utilized mechanical device for applying significant force to a load (Mohammed et al., 2015). The type of jack, whether mechanical, electrical, or hydraulic, depends on the method of force generation (CT, 2019). A hydraulic system is employed in a manual jack that has been modified into a hydraulic jack (Rinasa and Putri, 2020). The hydraulic jack utilizes the mechanism of a hydraulic power system, which is capable of generating substantial forces to lift heavy loads or equipment (Brian, 2006). According to Vedantu (2021), the working principle of a hydraulic jack is based on Pascal's principle. The hydraulic jacks utilize a hydraulic cylinder to apply high linear forces, while mechanical jacks utilize a screw thread. Pascal's law states that an increase in pressure at any point within a fluid substance results in an equal addition at all other points in the container (Muchnik, 2007). A force is manually applied to the pump piston to achieve efficient lifting. This force exerts pressure on the hydraulic fluid, which is inversely proportional to the piston area. The pressure exerted by the fluid against the piston generates a force proportional to the piston's area perpendicular to its direction of motion (Les, 2019). A typical diagram of a hydraulic jack is as shown in Fig. 1.

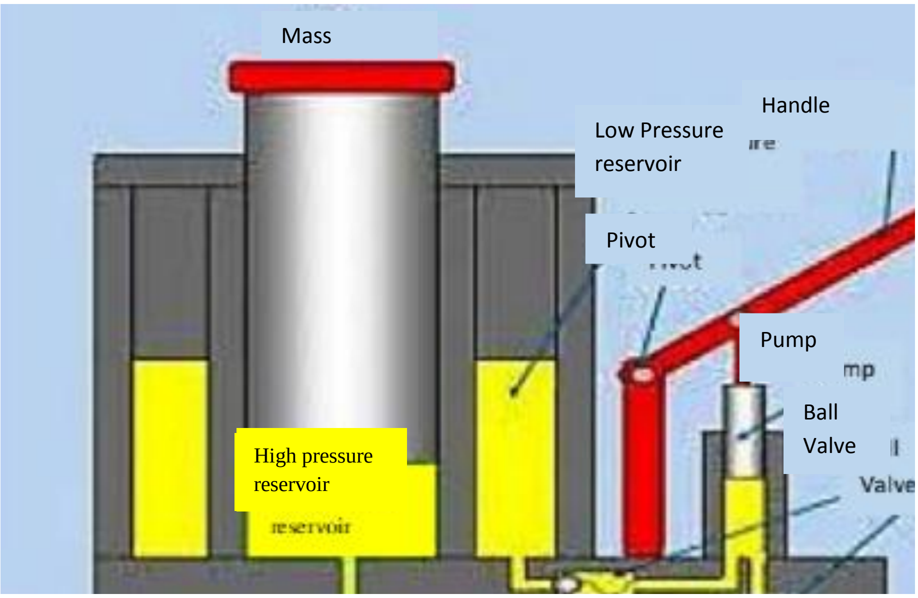


Fig. 1: Typical diagram of a hydraulic jack (Fiagbe and Amedorme , 2016)

Hydraulic jacks are highly efficient mechanical devices for lifting heavy loads (Worlifts, 2023). They consist of cylinders, a pumping system, and hydraulic fluids, typically oil (Vedantu, 2021). The most common type is the cylindrical one with a lever or pump plunger, which compresses hydraulic fluid into the jack cylinder by moving the piston (Mohammed et al., 2015). A one-way valve is often included between the reservoir and the pump, and the circuit is completed using single-acting cylinders controlled by control valves and a relief valve (Deept et al., 2021).

Conventional hydraulic jacks use hydraulic fluid as their primary power source to apply weight or exert significant forces on equipment (Sachin, 2023). They are often operated by user by allow“to’’ and “fro’’movement of the handle. However, they have been associated with ergonomic stress and potential hazards for non-professional individuals (Atuushi et al., 2022). Manual operation can cause ergonomic stress due to the application of forces, muscle activities, and working postures (Atuushi et al., 2022). Additionally, jack placement on uneven surfaces can result in load slipping off the jack, leading to injuries for the user or damage to both the car and the jack (EHS, 2023).

Automated systems have gained attention due to their ability to enhance accuracy and product/service quality, eliminate human errors, and reduce rework/defects (SL, 2023). In developing countries, new or used cars and trucks are still equipped with manual jacks (Progressive, 2023) due to their cost-effectiveness. These jacks require significant manual labour and are laborious processes (Mohan and Vinayagamoorthi, 2019). There is an increasing need for automatic control of hydraulic jack loading, which calls for the implementation of a new methodology that resolves existing issues (Shivangi et al., 2021).

Researchers have developed various automated hydraulic jacks for lifting cars in Nigeria, but there is a lack of information on safe use and local materials. Most researchers, like Akinwumi and Muhammed (2012), modified the performance of an existing design of a car jack; Ishola and Abiodun (2015) developed a performance evaluation of an operated hydraulic jack.Ikpe and Owunna (2019) worked on a remotely controlled hydraulic bottle jack for automobile Applications. The main components of the hydraulic jack were housed in a material casing of 220mm x220mmx180mm with 2mm thickness. When subjected to performance test the maximum displacement of the system was2.999x10^{-1}, and maximum equivalent stain was 3.56x10^{-3}. Althoughthese machines have helped in reducing the drudgery involved in hydraulic jackoperation, but the power supply required to operating some of them are high so it require a separate lead-cell battery for operation. The need for additional power source is extra cost for a car user.

Shoewu, et al (2020). developed, designed, analyzed and constructed a digital electronic jack. The system consistsof dc motor and the link mechanism we arrange in a way that it will allow smooth control of the jack system was designed with a dc motor actuator for controlling the up and down movement of the jack. The system control mechanism has two controls, one for achieving upward move and the other one for downward movement as controlled by an infrared transmitter. The control program/code for the system circuit was written with assembly language using MPASM compiler. However, the system is can misfunctioned due to its excess responseto sensitivity, especially ambient light, which is known to a typical problem with infra-red control system (Shoewu,2020). This complexity lapses can make the jack expensive and difficult to maintain by local technicians This study design is worth looking at because it had a better seed damage percentage, required less input power and favorable output. Electric-powered hydraulic jacks, which require DC power, are used for lifting heavy equipment, but literature is scarce on developing a prototype using a DC. motor in developing countries. This study aims to develop and evaluate a motorized hydraulic jack using a 12V DC motor, which can save money and improve the economy.

2.Methods and Materials

The fabrication process encompasses producing metal parts, such as the casing of the jack. This operation includes various steps. First, the materials are marked out and cut. In this case, a mild steel plate measuring 457mm x 358mm x 110mm with a thickness of 2mm was utilized to construct a case, as shown in Fig. 2. This case bears the entire system load, including the weight of the hydraulic jack unit, control, electric motor, and transmission component. Mild steel was chosen for its availability, strength, and affordability. The cutting process involved using a hacksaw, vice, cutting disc, and measuring rule. Next, drilling, grinding, and smoothening were carried out. The mild steel was drilled using twist drills with 14mm, 17mm, and 19mm diameters. These drills were fixed onto a hand drilling machine. Grinding operations were performed on all welded parts to achieve a smooth surface. Grinding wheels fixed onto a grinding machine were utilized for this purpose.

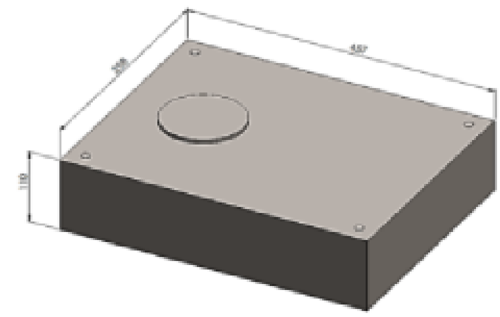
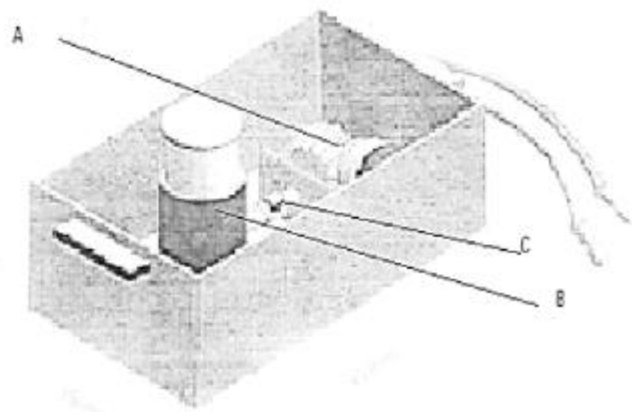


Fig. 2:Dimension of the system casing

Moving on to the fabrication of the knuckle joint, it was made using a mild steel rod through bending and welding procedures is given in Fig. 3. The welding was successfully accomplished using an electrode and an arc welding machine. A knuckle joint is a mechanical joint employed in structures to connect two cylindrical rods that are parallel to the same plane.



Key: A – electric motor; B –hydraulic cylinder; C – knuckle joint F
ig. 3: The detailed drawing of an automated jack

The work concentrates on automating an already existing hydraulic jack, which is a device that can lift heavy loads by making use of hydraulic fluid powered by the rotary power from the motor through the knuckle joint; it is shown in Fig.4. The modification of the hydraulic cylinder was done through various joining processes including: welding, fitting, as well as machining.

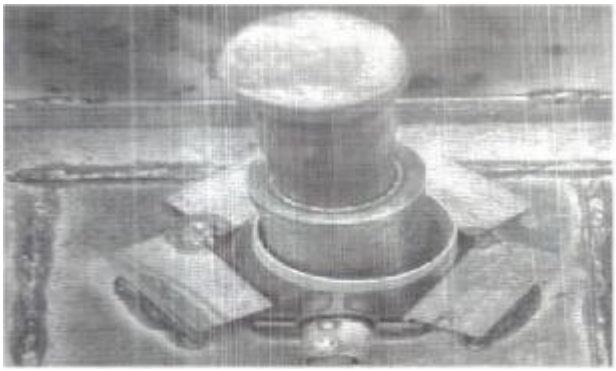
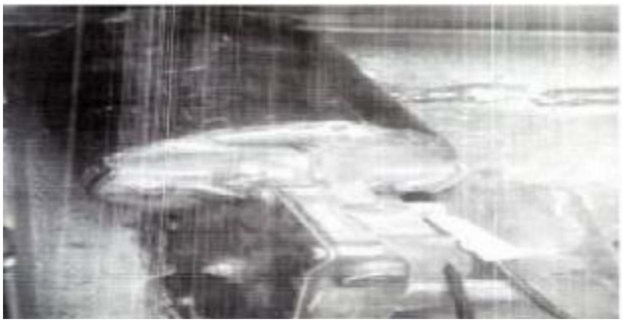


Fig. 4:Modified hydraulic cylinder

2.1 Assembly of C

A hydraulic jack is a machine that transfers hydraulic fluid from a smaller cylinder to a larger one, using Pascal's law to convert a small force on the handle into a more significant force at the lifting end (Tameson, 2021). The machine operates as a motorized system with four sub-systems: the hydraulic jack unit, transmission unit, power supply unit, and control unit. The power unit consists of a 12V DC. motor and a lead-cell battery, while the transmission unit uses a kinematic linkage to transform the rotational motion of the motor's shaft into the reciprocating motion of the hydraulic jack's ram, as shown in Fig. 5. The processing unit includes a control unit has a toggle switch that governs the direction of the DC. motor's operation. The knuckle joint (transmitter) converts the rotational motion of the electric motor into the translatory motion required for the electric jack's operation. The machine operates on the principle that any increase in pressure at a given point within a fluid substance result in an equivalent increase at all other points, while the assembled components of the automatic hydraulic jack are shown in Fig. 6.



KEY A – Terminals; B –Ram; C – Casing; D – HandleFig. 6: Assembled components of the automatic hydraulic jack

2.2 Development of an Electric Circuit

The electric circuit employed in this study consists of a parallel configuration where an electric motor is connected to a switch using a flexible wire and a jumper wire with a crocodile clip. This clip interacts with the 12V battery, which has its terminals distinguished by their respective colours. To establish the connection with the DC. motor, flexible wires were utilized. The red wire represents the positive terminals, while the negative terminal is represented by the black wire. The arrangement of this circuit is responsible for enabling the toggle switch to govern the direction of operation of the DC. motor. The representation of this arrangement and connection is shown in Fig. 7.

The circuit consists of an armature circuit made up of copper wire with resistance and inductance. A fixed coil is wounded around the stator to produce the required magnetic field the motor needs. The torque equation of the DC

motor is expressed in Eq. (1) to Eq. (10). The torque assists in producing the power required by the DC motor to operate the jack, and the higher the torque the higher the power developed by the jack in raising the load.

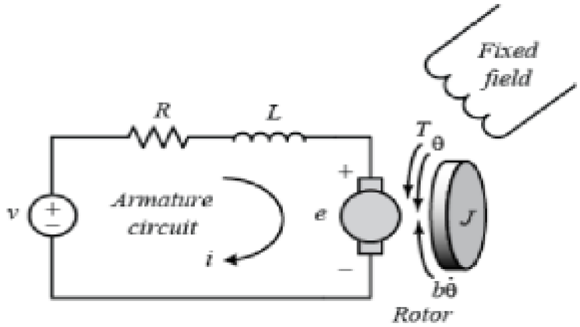


Fig. 7: The DC motor circuit schematic diagram

2.3 Derivation of Torque Equation

Work done/revolution = force × distance moved per revolution

Work done, Wd= $2\pi r.F.Nm$ Eq. (1)

$$\frac{Wd}{s} = 2\pi r.F.Nm.\frac{N}{60}$$ Eq. (2)

$$Wd = \frac{2\pi N}{60}(r.F).Nm.$$ Eq. (3)

r = radius of the armature in m.

N = speed of the armature in rpm = $\frac{N}{60}$

Tg = Gross torque (N-m) = Force × radius.

$$Wd = \frac{2\pi N\,Tg}{60}\ watt$$ Eq. (4)

The expression for voltage in dc motor is given by,

$$V = E_a + I_a R_a$$ Eq. (5)

Multiply with Ia

$$VI_a = E_a I_a + {I_a}^2 R_a$$ Eq. (6)

E_a is the back emf in the motor, I_a is the current in the motorand R_a is the resistance of the coil. Electrical input is equal to electrical power equivalent to mechanical power developed in addition to armature copper loss

Therefore, the Mechanical power

$$E_a I_a\ Watt$$ Eq. (7)

Since equation (1) = equation (2),

$$\frac{2\pi N\,Tg}{60}\ watt = E_a I_a\ Watt$$ Eq. (8)

Therefore

$$\frac{2\pi NTg}{60} = \frac{\emptyset ZN}{60} \cdot \frac{P}{A} \cdot I_a \qquad \text{Eq. (9)}$$

$$T_g = \frac{1}{2\pi} \cdot \emptyset ZI_a \cdot \frac{P}{A} \qquad \text{Eq. (10)}$$

2.3 Principle of Operation of the Jack

Typically, the operation of a hydraulic jack involves the manipulation of its handle by the user, thereby causing the transfer of hydraulic fluid from a smaller cylinder to a larger cylinder (Tameson, 2021).By adhering to Pascal's law, this action enables the conversion of a small force exerted on the handle into a larger force at the lifting end of the jack.In essence, the machine operates as a motorized system comprised of four primary sub-systems:(1) the hydraulic jack unit,(2)the transmission unit, (3) the DC motor unit, and (4) the control unit, as shown in Fig. 8.The power unit primarily consists of a 12 V DC motor and a lead-cell battery. The transmission unit employs a kinematic linkage to transform the rotational motion of the motor's shaft into the reciprocating motion of the hydraulic jack's ram. It involves a power screw connected to a prime mover (electric motor) via a universal coupling. The processing unit encompasses a stainless tank or vessel where impeller blades blend and stir the soap mixture. Lastly, the control unit comprises a toggle switch that governs the direction of operation of the DC.motor. The knuckle joint (transmitter) is utilized to convert the rotational motion of the electric motor into the translatory motion required for the electric jack's operation. The machine fundamentally relies on the principle that posits that any increase in pressure at a given point within a fluid substance results in an equivalent increase in pressure at all other points within the container (Muchnik,

2007).

Fig. 8: Complete design of the automatic jack system

3. Result and Discussion

A motorized, uncomplicated, convenient, and portable hydraulic jack was devised, constructed, and examined using Figure 4.1. The jack was engineered to be propelled by a 12-volt direct current (DC) motor, eliminating the need for manual exertion, thereby enabling the elevation of vehicles from the ground surface without the necessity of applying any impact force. Furthermore, the system comprises five primary constituents: an electrical circuit, an electric DC motor, a knuckle joint, a hydraulic jack, and the main body. These components can be conveniently procured from the local market.

The automatic hydraulic jack has a capacity of 2 tons. To evaluate the performance of the device, automobiles with varying weights were elevated, including a Toyota Camry (1.55 tons), BMWs (2.25 tons), SUVs (2.50 tons), Honda (1.75 tons), and Mazda (1.6 tons).The result of the performance test for the five different cars considered is as presented in Figure9. The minimum time required to lift a car with the jack was 2.9 minutes while a maximum of 3.3 minutes was obtained.

Efficiency tends to reduce as weight increases and there is a increase in the time for liftingas the weight reduces. Hence, there exist an inverse relationship between efficiency and speed and a direct relationship between the percentage seed damage and operating speed. It was also observed that as the weight increases, the time lifting time reduces. This is because more energy is available for agitation of the car, thereby striking them more effectively against the dead weight of the car. The recommended weigh of car to be lifted t for efficient and smooth running of the machine was found to be between 1ton and 1.5 ton.

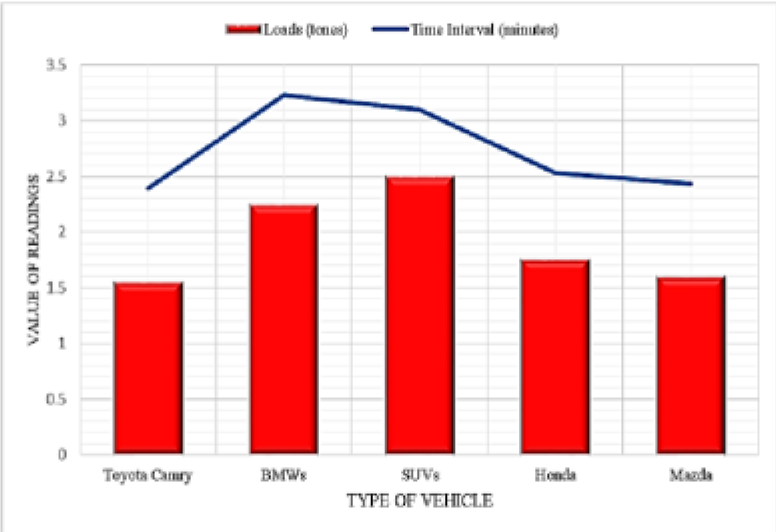


Fig.9: Plot of load and time intervals of different vehicles

5. Conclusion and Recommendation

An automated hydraulic jack was developed based on the pascal's principle of pressure and some basic of electric systems using locally available materials. The Nigeria local car users were the target recipient; hence, the machine was designed to be users friendly and at an affordable price. Its operation relies on the principle that posits that any increase in pressure at a given point within a fluid substance results in an equivalent increase in pressure at all other points within the container (Muchnik, 2007). Five time of lifting of speed were achieved by subjected to five different cars. It was observed that car weight has an effect on the performance parameters of the machine speed of time and weight of car. Operating the machine at 2.25 tons rpm produced the highest time of lifting of 3.3. There is a need for improvement on the machine in reducing the energy consumption for lifting each car. Incorporating a solar energy and its monitoring device in the designed system for the separation of reduction and management of power consumption the lifting a car fromthe base of the hydraulic systenwill to prevent sudden misfunction of the car lead cell batter in the car, and even for a safety and smooth operation should be also considered.

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