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Modification of an Existing Small Hydraulic Jack for Lifting Light Duty Vehicle

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ABSTRACT

Hydraulic jack has been used extensively in the maintenance, servicing and repairing of motor vehicles. Although the hydraulic jack serves a wide range of purpose, it has one major problem of unexpected hydraulic failure. This has called for the use of a mechanism or an axle stand when the hydraulic jack is in use. Most often, drivers carry the jack forgetting to go along with the stand. And in the event of any repairs on the road have to use incorrect undersigned or unprescribed supports to assist the jack. This paper highlights on the modification of an existing small hydraulic jack for lifting light duty vehicle. The modified jack has been incorporated with reasonable clutch top, simple locking mechanism and sizable base to support the weight of the vehicle in the event of any hydraulic failure. The distortion energy theory (DET) is used to predict failure and check the factor of safety. The new modification makes the jack serves multi-purpose function of lifting and acting as supporting unit. It also prevents the frustrations the drivers go through in search for undersigned lifting supports between trips when they encounter a flat tyre as well as eliminates the burden mechanics go through in fixing an axle stand.

Key words: *Modified Hydraulic Jack, Hydraulic Failure, Failure Prediction, Von Mises*

1. INTRODUCTION

An automotive jack is a device used to raise all or part of a vehicle into the air in order to facilitate vehicle maintenances or breakdown repairs. The use of jack is not new. It has developed to its present sophisticated state over many years. There are two main types of automotive jacks: Hydraulic and screw jacks. These two categories also have many subcategories of jacks. A screw jack is a type of jack which is operated by turning a lead screw. In this jack, a small force applied in the horizontal plane is used to raise or lower large load [1, 2]. Of the screw-type mechanisms, there are scissor jacks, common in newer cars, and bumper jacks, common in older cars [3, 4]. Hydraulic jacks have the shape of a bottle, or built into a trolley (the floor jack), friction jack and racketing jack [1].The hydraulic jack has all the advantages of producing tons of closer controlled torque-free power for minimum effort by the operator. The hydraulic jack is ideally suitable for repair work because it could be operated in any plane and controlled from outside the car. A large percentage of work will require the use of hydraulic jack for lifting, pulling, pushing and alignment. It is not only used in automobile industries for repairs but warehousing establishments, storage establishments, distributors, service stations and couriers also use hydraulic jacks for a range of high pressure and heavy-duty lifting procedures. The device itself is light, compact and portable, but is capable of exerting great force [5, 7]. Hydraulics is the science of transmitting force or motion through the medium of a confined liquid. In

a hydraulic device, power is transmitted by pushing on a confined liquid. The transfer of energy takes place because a quantity of liquid is subject to pressure [8]. The device pushes liquid against a piston; pressure is built in the jack's container. This is based on Pascal's law which states that the pressure of a liquid in a container is the same at all points. Pressure on a confined liquid is transmitted undiminished and acts with equal force on equal areas and at 90 degrees to the container wall. A liquid, such as oil, is displaced when either piston is pushed inward. The small piston, for a given distance of movement, displaces a smaller amount of volume than the large piston, which is proportional to the ratio of areas of the heads of the pistons. Therefore, the small piston must be moved a large distance to get the large piston to move significantly. The distance the large piston will move is the distance that the small piston is moved divided by the ratio of the areas of the heads of the pistons. This is how energy, in the form of work in this case is conserved and the law of conservation of energy is satisfied in the hydraulic jack. Work is force times distance, and since the force is increased on the larger piston, the distance the force is applied over must be decreased [9, 10]. A hydraulic jack uses a liquid, which is incompressible, that is forced into a cylinder by a pump plunger. Oil is used since it is self-lubricating and stable. When the plunger pulls back, it draws oil out of the reservoir through a suction check valve into the pump chamber. When the plunger moves forward, it pushes the oil through a discharge check valve into the cylinder. The suction valve ball is within the chamber and opens with each draw of the plunger. The discharge valve ball is outside the chamber and opens when the oil is pushed into the cylinder. At this point the suction ball within the chamber is forced shut and oil pressure builds in the cylinder. Although the hydraulic jack has all the above advantages, it has one major problem of an unexpected hydraulic failure. This, therefore, needs further research in order to overcome such a problem. On average, 160 injuries are associated with car jacks each year. Injuries have ranged from amputation to fractures and crush injuries. Improvement and the correct use of jacks can prevent death or injury. Improvement in automotive car jack is really needed to make the tool more efficient, user-friendly, practical to use, changes in industry direction and most importantly high safety features [11, 12]. The modification of small hydraulic jack is intended to be of value to the automobile industries, private and especially the commercial vehicle users. The mechanism added will support the existing jack after it has lifted the load so that it will act as an additional support to strengthen the effort of the jack even when there is failure. More specifically when moving along the road and a punctured tire or a tire is to be changed, it will serve as an axle stand and a jack at the same time i.e. it will have multi-purpose function of lifting and acting as a supporting unit. In addition, to ensure the safety of the hydraulic jack during unexpected hydraulic failure the improved mechanism will act as a locking stand.

2. THEORY OF HYDRAULIC JACK AND FAILURE PREDICTION FOR THE ADDITIONAL MECHANISM

The working principle of a hydraulic jack may be explained with the aid of Fig.1. Consider a ram and plunger, operating in two cylinders of different diameters, which are interconnected at the bottom, through a chamber, which is filled with some liquid [13].

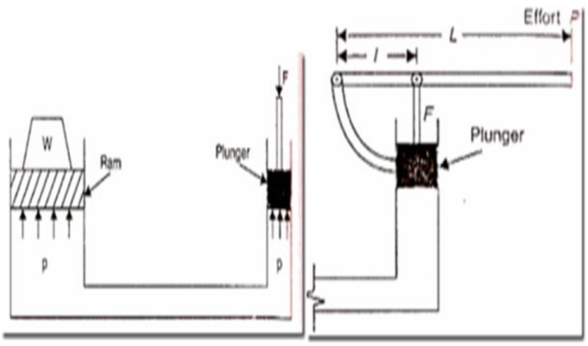


Figure 1: Principle of hydraulic jack

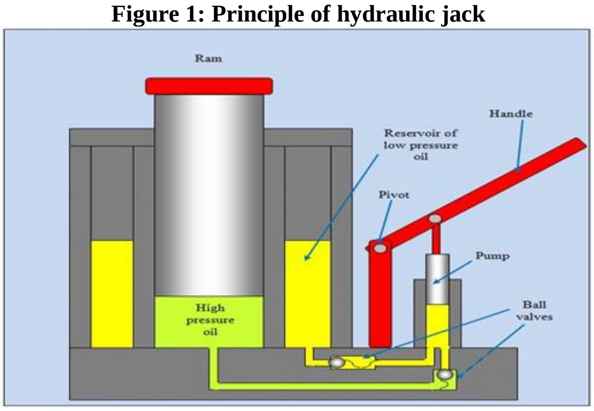


Figure 2: Features of hydraulic jack

Let

W =Weight to be lifted, $F =$ Force applied on the plunger, $A =$ Area of ram, and $a =$ Area of plunger.
Pressure intensity produced by the force F,
$P = F/Area\ of\ plunger = F/a$

As per Pascal's law, the above intensity p will be equally transmitted in all directions.
Therefore, the pressure intensity on ram
$P = F/a = W/A$ or $W = F(A/a)$
Above equation indicates that by applying a small force F on the plunger, a large force W may be developed by the ram.
Mechanical advantage of jack $= A/a$
If the force in the plunger is applied by a lever which has a mechanical advantage (L/I) then the total mechanical advantage of jack = $(L/I)(A/a)$. The ratio $L/I)$ is known as leverage of jack.

In operating or working with the hydraulic jack from a user's perspective, the release valve is tightly closed by turning it clockwise. The metal pumping bar shown on the main features in Fig.2 is inserted into the handle socket and the pumping is carried out up and down which pushes the ram up and raises the load attached to the end. In order to lower a load the bleed or release valve located on the base of the jack is open by turning it counterclockwise. The reservoir is not overfilled with oil. The jack's maximum lift stroke is determined by the amount of oil in its reservoir. Thus, if too much oil is added, the piston can extend beyond its length causing it to fall out of the jack. The greatest single cause of failure in hydraulic units is dirt. Therefore, the jack should be kept clean and well lubricated to prevent foreign matter from entering the system.

Generally two criteria are used to predict the likelihood of failure in a ductile material. These are maximum shear stress theory (MSST) and distortion energy theory (DET). The maximum shear stress theory (MSST) states that a component will fail when the shear stress exceeds a critical value. This critical stress is determined from standard uniaxial tensile tests. On the other hand, the distortion energy theory (DET) which is also called von Mises yield criterion and predicts failure with greater accuracy than MSST states that failure is caused by the elastic energy associated with shear deformation [14].
The von Mises stress σ_e for triaxial stress state:

$$\sigma_e = \frac{1}{\sqrt{2}}[(\sigma_2 - \sigma_1)^2 + (\sigma_3 - \sigma_1)^2 + (\sigma_3 - \sigma_2)^2]^{\frac{1}{2}}$$

For the biaxial stress state, the von Mises stress reduces

$$\sigma_e = (\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2)^{\frac{1}{2}}$$

Failure occurs if

$$\sigma_e \geq \frac{S_y}{n_s}$$

where S_y = Yield stress of material, n_s = Factor of safety.

3. METHODS AND MATERIAL

The performance and life span of the additional mechanism incorporated into hydraulic jack will depend greatly on the type of materials used for each component. Table 1 shows the parts list of the modified hydraulic jack. The clutch top, connecting members, locking pins and the main base were all made from medium carbon steel with 45 ksi (310 MPa) minimum yield point, 81.9 ksi (565 MPa) minimum tensile strength and 16 % elongation) due to the following reasons: Good machinability, good ductility, high strength, wear resistance and ease of producing complicated parts [15].

Table 1: Parts List of the Modified Hydraulic Jack

ITEM	DESCRIPTION	NO. OFF	MATERIAL
1	Main clutch top	1	Medium carbon steel
2	Inner bar	2	Medium carbon steel
3	Outer bar	2	Medium carbon steel
4	Main base	1	Medium carbon steel
5	Spring	2	Medium carbon steel
6	Spring holder	4	Medium carbon steel
7	Locking pin	2	Medium carbon steel
8	Locking pin spring	1	Medium carbon steel

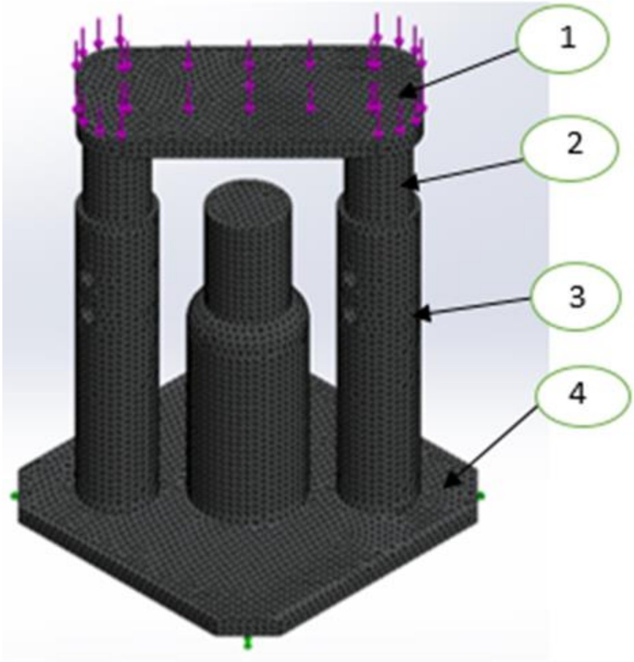
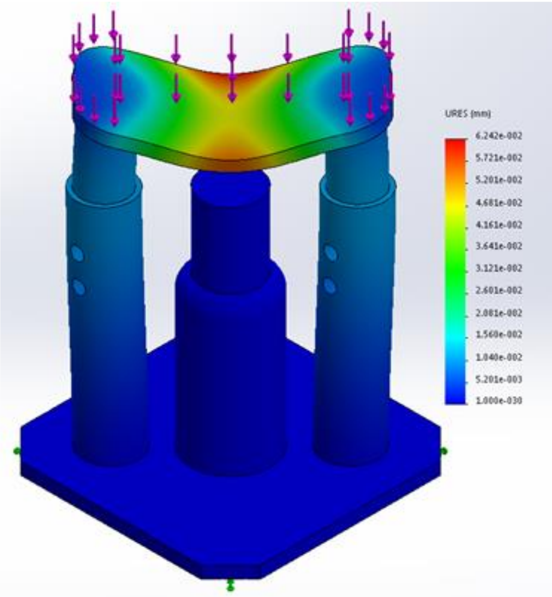


Figure 3: Mesh on modified hydraulic jack

The mesh shows in Fig.3 was generated using finite element analysis in Solidworks and it is used to determine whether or not the additional mechanism could support the weight of the vehicle in the event of hydraulic failure. The optimum force is applied on the clutch top because that is where the vehicle will sit and the main base fixed. The force directions are indicated by the arrows on the main clutch top of the mechanism and the forces become distribution loads. In the analysis of the additional mechanism to the jack, the force should have been a variable factor and the conditions of additional supports assessed. But because the weight of the vehicle is known in this case 1000kg (10kN) the simulation is performed only with this critical force.

4. RESULTS AND DISCUSSION



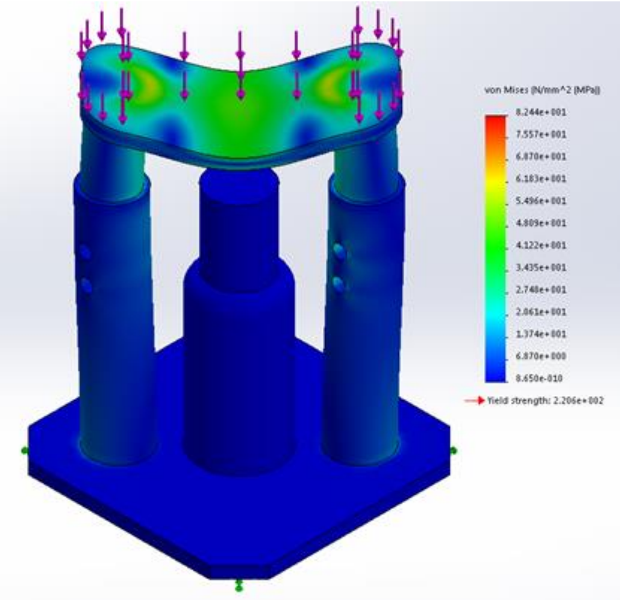
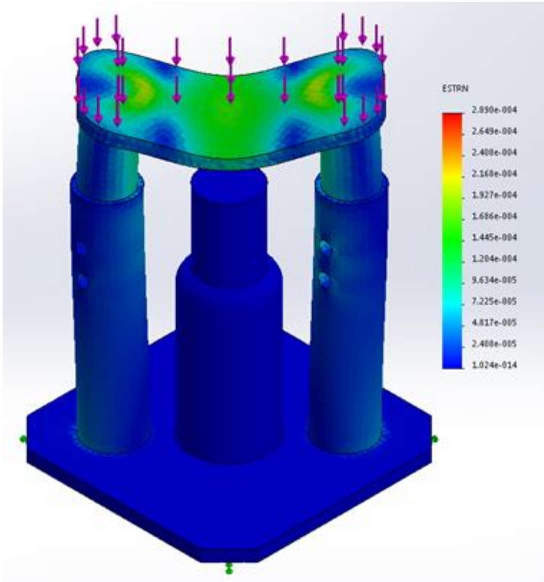


Figure 4: Stress distribution **Figure 4 Displacement on the modified hydraulic jack**
on the modified hydraulic jack



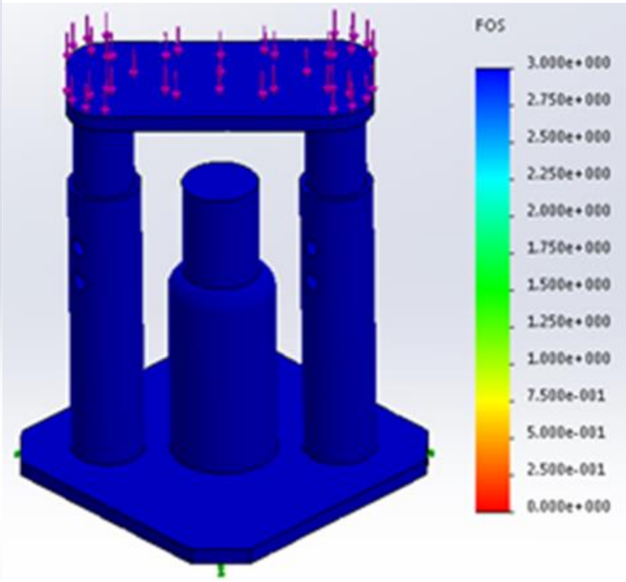


Figure 6: Strain distribution of the **Figure 7: Factor of safety for the modified hydraulic jack**
modified hydraulic jack

The modified hydraulic jack was developed utilizing the Solidworks and analysed using Finite Element Analysis to check safety factor and a failure. Based on the analysis on Finite Element Analysis, the results show that the maximum nodal displacement magnitude on the additional support to the jack in event of hydraulic failure is around 0.062mm as shown in Fig. 5 when the maximum load (10000 N) was applied. Furthermore, it can be observed from Figs. 4 and 6 that the maximum Von Misses stress and strain stand at 82.44MPa and 0.00029 respectively, and this indicates the stress values in safe point because $\sigma_e < S_y$ since the minimum yield strength for medium carbon steel is 310 MPa. The modified jack was tested on real car and it proven it can be used commercially.

5. DESCRIPTION OF PARTS OF MODIFIED HYDRAULIC JACK

The Figs. 8 and 9 show the constructed modified hydraulic jack and the description of the main components.

The outer bar

The outer bar has a height of 220mm and the diameter of 36mm. Two holes are provided for the locking mechanism and has diameter of 9mm. The distance from the bottom of the bar to the centre of the first hole is 160mm and the distance between the centre of the holes is 30mm. The medium carbon steel bar has a thickness of 3mm.

The inner bar

The inner bar is made of medium carbon steel and has a diameter of 30mm and a height of 220mm. The distance from the top of the bar to the centre of the first hole is 75mm. The spacing between the holes is 30mm and the thickness of the bar is 3mm

Main clutch top

The main clutch which supports the weight of the vehicle is octagonal in shape and made of medium carbon steel. The thickness is 8mm and has dimension of 140mm x 90mm. The side of the octagon is 50mm and 40mm.

Main base

The main base has the specification of 160mm x 160mm and the thickness of 8mm. it is made of medium carbon steel.

Figure 8: Modified hydraulic jack

Figure 9: Modified hydraulic jack in use

6. CONCLUSION

This research paper sought to find the solution to unexpected hydraulic failure in the hydraulic jack. The new design has been incorporated with main clutch top, locking pins and sizable base to ensure safety and prevent vehicle uses from using unprescribed lifting supports. The modification has been made simple and not too complicated and can be used by any mechanic without any difficulty. Based on the testing and results from the analysis, it is considered safe to use the modified jack under certain specification.

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