# DESIGN AND DEVELOPMENT OF A SOLAR POWERED MOTORISED HYDRAULIC JACK FOR INDUSTRIAL AND DOMESTIC APPLICATIONS

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**F. I. Ashiedu[1]* and T. C. Nwaoha[2]**
[1,]Mechanical Engineering Department, Federal University of Petroleum Resources, Delta State, Nigeria
[2]Marine Engineering Department, Federal University of Petroleum Resources, Delta State, Nigeria
*Correspondent author: ashiedu.ifeanyi@fupre.edu.ng

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**Abstract:** The huge cost associated with rehabilitating workers suffering from epidemiological conditions as a result of performing daily repetitive tasks that involves awkward postures in lifting low lying heavy loads in our workplace has been on the increase, as shown by records available in our health institutions. To address this problem in our workplaces, it becomes imperative that a simple device that can automatically lift and lower heavy objects powered by solar energy was conceived, designed and developed using available local materials and technology. This device was designed in such a way as to reduce the man-machine interface to the least minimum. Test carried out using the developed five tone solar powered hydraulic screw jack showed that the device can lift or lower heavy loads within its design limit to or from a height of four hundred 400 mm) in less than two minutes 2 min). It is our view that this cost effective lifting device be commercialized to eliminate these ugly health challenges among our workforce, thus encouraging more youths to become engaged as lifters in our industrial settings. This will in turn create employment among the youths, improve the already low standard of living and increase our national gross domestic product as a nation.

**Keywords:** Solar power, screw jack, hydraulic, epidemiology, industry

## Introduction

Records available in our national and local health rehabilitation centers showed that majority of our youths and young men in their productive age surfers from epidemiological conditions ranging from serious spinal cord injuries; back pains disorders and sometimes rheumatic pains. Further studies revealed that these health challenges are caused mostly by repetitive task involving the lifting of heavy low lying objects in our industrial settings while maintaining awkward posture (Igboanugo *et al*., 2010). This work is therefore aimed at providing a lasting solution to these problems by incorporating mechanisms that will automate the use of mechanical jacks to lift heavy low lying objects without compromising ergonomic potentials of workers in our work places. This work is therefore important, interesting and relevant in that it uses available local material to design and develop a solar powered motorized hydraulic jack capable of lifting all forms of heavy loads in our factories. To this end, extensive works have been done at the local and the international levels with regards to different kinds of jacks for lifting light weight vehicles in case of emergencies or repairs that involve lifting to the desired height. Some of these works include Ademola and Sunday (2008).

This paper incorporated a wedge in the development of a vehicle jack that can lift any light weight vehicle to a height of about 160 mm. in addition to this, was the provision of a self locking device to the 4 Kg weight mechanical jack while cost of production was kept as low as possible. In consideration of the energy requirement involved in lifting cars using manual jacks and the frustrations encountered all the time Jayesh *et al*. (2017) developed an electric jack capable of lifting any small, medium and light weight vehicles to its desired height using electric current. The paper recommended 12 volts batteries or any other direct current source. Similarly, a design for an integrated jack for lifting automobiles whose weight ranges from 1000 to 2200 Kg to a height of about 200 mm was developed by Musa *et al*. (2016). The paper added that a performance evaluation conducted on this jack showed that the jack was able to lift a load of 2.2 tones to a height of 200 mm within 1.6 minutes. In an attempt to make life more meaningful, easy, comfortable and convenient for vehicle operators, Gaurav *et al*. (2014) incorporated a direct, current device into its design to automatically raise light weight vehicle to their desired height. According to the paper, the power source is derived from the battery source used by the vehicle. The design is simplified in such a way that it can be attached to the existing manual jack when and where the need arose. In the same way, Benjamin and Okwu (2017) modified a scissors screw jack by incorporating series of gears arranged in definite pattern to increase efficiency, functionality, availability and reliability of the system. The paper added that the new jack when used properly will eliminate the ergonomic constraint experienced in the use of other manual jacks. The modified jack is capable of handling vehicular and non vehicular loads in our work environment. In a sharp contrast, Sainath *et al.* (2014) applied the principle of pressures acting in cylinders filled with fluids preferably hydraulics to generate forces on application of little effort. The paper added that the forces so created by applying little effort to the plunger can lift both heavy and light loads to a height of about 180 mm within a short period of time.

The design and development of a remote censored hydraulic jack for use in lifting both Vehicles and other light loads was conceived and executed by Asonye *et al.* (2015). The paper reported that the problems associated with manual methods of lifting can be addressed using this design that is easy to use. Again, Mohamed *et al.* (2015) designed and developed a mechanism that will enable workers stand erect and pedal the plunger of a jack to lift a low lying objects to its desired h height. This method of lifting according to the paper will create room for industrial safety and at the same time reduce and or eliminate all or most of the ergonomic constraint associated with lifting heavy loads in awkward position. A performance evaluation test was carried out on a developed electric powered toggle jack developed by Ipilakyaa *et al.* (2017). The paper reported that this the jack can only lift a load of about 1550 Kg at an average speed of 2.98 $mm/s^{-1}$. Akshay *et al*. (2018) and Aditya *et al.* (2018) considered the option of having a separate mechanical screw jack for four wheelers. These jack according to the papers can conveniently lift the entire vehicle up to the desired height to aid underneath routine maintenance as at when due. Again, Balkeshwar and Anil (2015) designed and fabricated an automatic remote controlled device to assist in lifting various forms of loads to their desired heights for easy accessibility to some vital components that requires attention periodically.

The paper recommended a near zero level of human machine interface in the use and operation of this remote controlled screw jack. From the literature reviewed, the underlying factor among others necessary for the re- construction, analysis, re-design, incorporation of new systems and ideas remained to improve the work place. This again is not different from Kamalakkannan *et al*. (2016) and Akinwonmi and Mohammed *et al*. (2012). This current work therefore, is aimed at using a solar powered device to operate a motorized hydraulic jack by eliminating the man – machine interface responsible for most industrial accidents and other health challenges recorded over time.

**Materials and Methods**

The design model used for the fabrication of the motorized solar powered hydraulic bottle jack is for a jack that has a maximum weight carrying capacity of 5 tonnes.The parts of the hydraulic bottle jack like the bottle was formed from steel. A steel metal of 8mm thickness which acts as the foundation upon which all other parts are mounted was used. All other formed parts were welded to the foundation plate. The handle of the jack was formed from steel rod which comprise of provision made for the locking of the cam. When the system is turn on, the solar power charges the car battery and this in turn cause the electric motor to rotate. The rotation of the motor causes the cam to rotate thereby converting the rotational motion of the motor into a linear motion i.e. up and down motion of the jack handle. This motion pressurizes the hydraulic oil used and this enables the lifting of the weight. The materials used for the actualization of the work include; Hydraulic oil, Electric motor, Car battery, Wires, Bolts and nuts, Steel plate, Steel rods, Solar panel and Paints

***Design calculations***

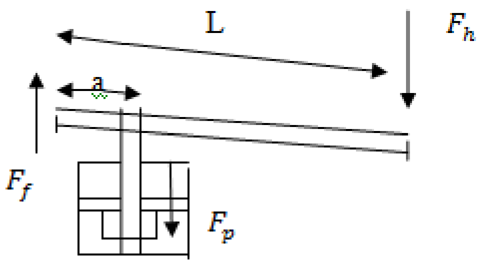
For the given design, the maximum load to be lifted is 5 tonnes. 1 tonne = 1000 Kg, Hence 5 tonnes = 5000 Kg.

Therefore $F_l = Mg$

***w□ere*** *$F_l$ is the load or weight to be lifted,* M is the mass of the weight in kilogram, G is acceleration due to gravity.

$F_l = 5000 * 10 = 50000N = 50KN$

Analysis of force system




**Where** L is the handle length, a is the pin to pin length

$F_p$ is the force acting on the pin or plunger

$F_h$is the force applied to the handle of the jack

$F_f$is the force acting at the fulcrum

Applying the principle of equilibrium of forces and moment

For moment

$$\sum Mx = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Hence analyzing the structure

$$(F_h * L) + (F_p * 0) - (F_f * a) = 0$$

$$(F_h * L) - (F_f * a) = 0$$

$$F_f = \frac{F_h * L}{a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For forces

$$\sum F = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (3)$$

Hence

$$F_f = F_p + F_h$$

$$F_p = \frac{F_h * L}{a} - F_h \ldots\ldots\ldots\ldots\ldots\ldots\ldots . . (4)$$

$$F_p = F_h\left(\frac{L}{a} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

To determine value for $F_p$ and $F_f$, the values of L, a

L=350 mm from a range of 300-500 mm

a=35 mm from a range of 30-50 mm

$F_h$=300N

$$F_p = 300\left(\frac{350}{35} - 1\right) = 2700N$$

I.e. $F_p = 2.7KN$

Recall $F_f = F_p + F_h$

Therefore $F_f = 2700 + 300 = 3000N = 3KN$

***Pressure analysis***

In order to design the bottle jack, the minimum pressure required to lift the desired load must be determined.

Hence the minimum pressure will be represented as;

$$P_{cm} = \frac{F_l}{A_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ..(6)$$

$$A_c = \frac{\pi D_{hr}{}^2}{4} \text{ or } \frac{\pi D_{ci}{}^2}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

**Where:** $P_{cm}$ is the minimum cylinder pressure; $A_c$ is the cylinder area; $D_{ci}$ is the internal cylinder diameter; $D_{hr}$is the hollow ram diameter;

$$P_p = \frac{F_p}{A_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (8)$$

**Where:** $P_p$is the plunger or pumping force; $A_p$ is the plunger area

Base on Pascal's law, the pressure at every point in an enclosed fluid is equal

Hence $P_p = P_r = P_c$

Therefore

$$\frac{F_p}{A_p} = \frac{F_r}{A_r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$\frac{F_p}{D_p} = \frac{F_r}{D_r} \quad \text{since } A_p = \frac{\pi D_p{}^2}{4} \text{ and } A_r = \frac{\pi D_r{}^2}{4}$$

**Where:**$P_c$ is the cylinder pressure, $P_r$ is the ram pressure, $P_r$ is the ram pressure, $D_p$ is the plunger diameter, $D_r$is the ram diameter and $A_r$ is the ram area.

To determine the value of $P_{cm} = \frac{F_l}{A_c}$

The hollow ram diameter is assumed to be 64 mm.

$$A_c = \frac{\pi * 64^2}{4} = 3217.408\, mm^2$$

Recall $F_l = 50KN$

$$P_{cm} = \frac{50000}{3217.408} = 15.54MPa$$

To determine the value of $P_p = \frac{F_p}{A_p}$

The plunger diameter is assumed to be 14 mm from a range of 10-16 mm

$$A_p = \frac{\pi * 14^2}{4} = 153.958mm^2$$

Recall $F_p = 2.7KN$

$$P_p = \frac{2700}{153.958} = 17.54MPa$$

Applying Pascal's law $P_p = P_c$.

Thread design

$F_l = 50KN$ $\quad$ $S_y = 480MPa$

$$\sigma_t = 0.65S_y \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots ... (10)$$

$$\sigma_t = 0.65 * 480 = 312MPa$$

$$\sigma_t = \frac{F_l}{A_t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$A_t = \frac{\pi {d_c}^2}{4} \ldots\ldots\ldots\ldots\ldots (12)$$

$$d_c = \sqrt{\frac{4F_l}{\pi \sigma_t}} \ldots\ldots\ldots\ldots\ldots (13)$$

Where $\sigma_t$ is the tensile stress of the screw thread

$A_t$ is the core area of the thread, and $d_c$ is the core diameter of the thread

Hence $d_c = \sqrt{\frac{4*50000}{\pi*312*10^6}} = 0.0143m = 14.3\ mm$

From table for fine series of square thread $d_c = 16\ mm$

Pitch (p)=2 mm, nominal diameter $(D_N) = 18\ mm$, Depth of thread for nut (H)=1.25 mm and constants (a and b)=0.25

Nut diameter $(D_n) = D_N + 2a$…………………(14)

$D_n$=18+0.5=18.5 mm

$A_t = \frac{\pi*16^2}{4}$=201.088 $mm^2$

mean diameter $(D_m) = \frac{D_N+d_c}{2}$……………..(15)

$$D_m = \frac{18+16}{2} = \frac{34}{2} = 17mm$$

Considering the load bearing capacity, frictional torque and efficiency of the thread, The helix angle (∝) and frictional angle (∅) must be determined.

$tan \propto = \frac{lead}{\pi D_m}$………………………………. (16)

Since the design involves the use of a single start thread, the pitch of the thread is equal to its lead.

So $tan \propto = \frac{p}{\pi D_m}$

$$\propto = tan^{-1} \frac{2}{\pi * 17} = 2.14°$$

For frictional angle

$\emptyset = tan^{-1}\mu$…………………………………. (17)

**Where** $\mu$ is the coefficient of friction.

Using a hardened steel on cast iron (starting), $\mu = 0.15$

Therefore

$\emptyset = tan^{-1}0.15 = 8.53°$

Since the frictional angle is greater than the helix angle, the arrangement of the screw thread is a self-locking type.

For lowering of load

$W_l = F_l * \tan(\emptyset - \propto) \ldots\ldots\ldots (18)$

$W_l = 50000 * \tan(8.53 - 2.14) = 5599N$

For raising of load

$W_R = F_l * \tan(\emptyset + \propto) \ldots\ldots\ldots (19)$

$W_{RR} = 50000 * \tan(8.53 + 2.14) = 9424N$

Frictional torque $(T_\mu) = \frac{F_l * D_m * \tan(\emptyset+\propto)}{2}$

$$T_\mu = \frac{W_R * D_m}{2} \ldots\ldots\ldots\ldots (20)$$

$$T_\mu = \frac{9424*17}{2} = 80.104Nm$$

Efficiency of the square screw thread $(\eta)$

$\eta = \frac{ideal\ effort}{actual\ effort} = \frac{W_o}{W_R}$…………………… (21)

$W_o = F_l tan \propto$……………………………………… (22)

$$\eta = \frac{tan\ 2.14}{\tan(2.14+8.53)} * 100 = 19.86\%$$

$\eta_m = \frac{1-sin\emptyset}{1+sin\emptyset}$…………………………… (23)

Where $\eta_m$ is the maximum thread efficiency

$$\eta_m = \frac{1-sin8.53}{1+sin8.53} = 0.742 = 74.2\%$$

Stress analysis for the thread

$$\sigma_c = \frac{4F_l}{\pi {d_c}^2} \ldots\ldots\ldots\ldots (24)$$

$\sigma_c$ is compressive stress

$$\sigma_c = \frac{4*50000}{\pi * 16^2} = 248.65MPa$$

$$\tau_m = \frac{16T_\mu}{\pi {d_c}^3} \ldots\ldots\ldots\ldots (25)$$

$\tau_m$ is the maximum shear stress

$$\tau_m = \frac{16*80.104}{\pi * 16^3} = 99.59MPa$$

When the thread is subjected to axial loading, it experiences axial shear stress.

Therefore

$$\tau_A = \frac{F_l}{\pi n d_c t_t} \ldots\ldots\ldots\ldots (26)$$

**Where** n is the number of thread t is the thickness of the thread

$$n = \frac{H}{p} \ldots\ldots\ldots\ldots (27)$$

$$n = \frac{1.25}{2} = 0.625$$

$$t_t = \frac{p}{2} \ldots\ldots\ldots\ldots (28)$$

$$t_t = \frac{2}{2} = 1$$

Hence $\tau_A = \frac{50000}{\pi*1*0.625*16} = 1591.34MPa$

Checking for occurrence of buckling

$$W_{cr} = \frac{W_{crushing}}{1 + a(\frac{L_e}{K})^2} \ldots\ldots\ldots\ldots (29)$$

Where $W_{crushing}$ is the crushing load

a is the Rankine constant

$L_e$is the equivalent length, and K is the radius of gyration

$$K = \sqrt{\frac{I}{A}} \ldots\ldots\ldots\ldots (30)$$

**Where** I is the moment of inertia

$$I = \sqrt{\frac{\pi {d_c}^2}{64}} \ldots\ldots\ldots\ldots (31)$$

$$W_{crushing} = \sigma_{crushing} * A_c \ldots\ldots\ldots (32)$$

$$K = \sqrt{\frac{\frac{\pi {d_c}^4}{64}}{\frac{\pi {d_c}^2}{4}}}$$

$$K = \sqrt{\frac{{d_c}^2}{16}} = \sqrt{\frac{16^2}{16}} = 4mm$$

From a table of standard, cast iron was selected.

$\sigma_{crushing} = 550MPa$

$$a = \frac{1}{1600}$$

Assuming $L_e = 80mm$

Recall $A_c = 201.008mm^2$

$$W_{cr} = \frac{550 * 201.088}{1 + (\frac{1}{1600} * (\frac{80}{4})^2)} = 88.478KN$$

$P_b = \frac{W_{cr}}{factor\ of\ safety\ (n_d)}$………………………… (33)

**Where** $P_b$is the buckling load of the system? Using a factor of safety of 1.5

$$P_b = \frac{88.478}{1.5} = 58985.8N$$

Since $P_b > F_l$ the square screw thread is safe from buckling.

***Design of a solid ram***

In the solid ram, both shearing and crushing stresses occur. This is because the solid ram is pushed by the cylinder pressure until it hits the hollow ram at its neck. Hence the force that is exerted at the neck either causes a shear or crushing.

Recall $D_{hr} = D_{ci} = 64mm$

$F_l = 50KN$
$P_c = 17.54MPa$
Alloy steel AISI 1015 is the material used
$S_{ut} = 420.6MPa$
$S_y = 313.7MPa$

$$\sigma_i \ or \ \tau_i = \frac{S_y}{n_d} \dots \dots \dots \dots \dots \dots \dots \dots (34)$$

Where $\sigma_i and \tau_i$ are induced crushing and shear stresses, respectively

$$\sigma_i \ or \ \tau_i = \frac{313.7}{2} = 156.85MPa$$

$$F_N = P_c * A_c \dots \dots \dots \dots \dots \dots \dots \dots (35)$$

$F_N$ is the force at the neck of the ram

$$A_c = \frac{\pi * 64^2}{4} = 3217.408mm^2$$

$$F_N = 17.54 * 3217.408 = 56.433KN$$

For shearing to occur in the solid ram, the induced shear stress must be greater than the maximum shear shear.

$$\tau_i = \frac{F_N}{A_s} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (36)$$

$$A_s = \pi D_c t \dots \dots \dots \dots \dots \dots \dots (37)$$

Where $A_s$ is the area of shear, t is the thickness

$$A_s = \pi * 32 * 12 = 1206.528mm^2$$

$$\tau_i = \frac{56.433 * 10^3}{1206.528} = 46.77MPa$$

**Results and Discussion**

Having gone through the detailed design calculations, it becomes necessary to put the respective elements together to form a system represented in Fig. 1. Similarly, Fig. 2 shows the engineering drawing of the solar powered hydraulic jack as conceived and fabricated.

The design and development of a solar powered hydraulic jack useful in lifting and lowering heavy objects in our industries has been done using available local materials as seen in the Figures.

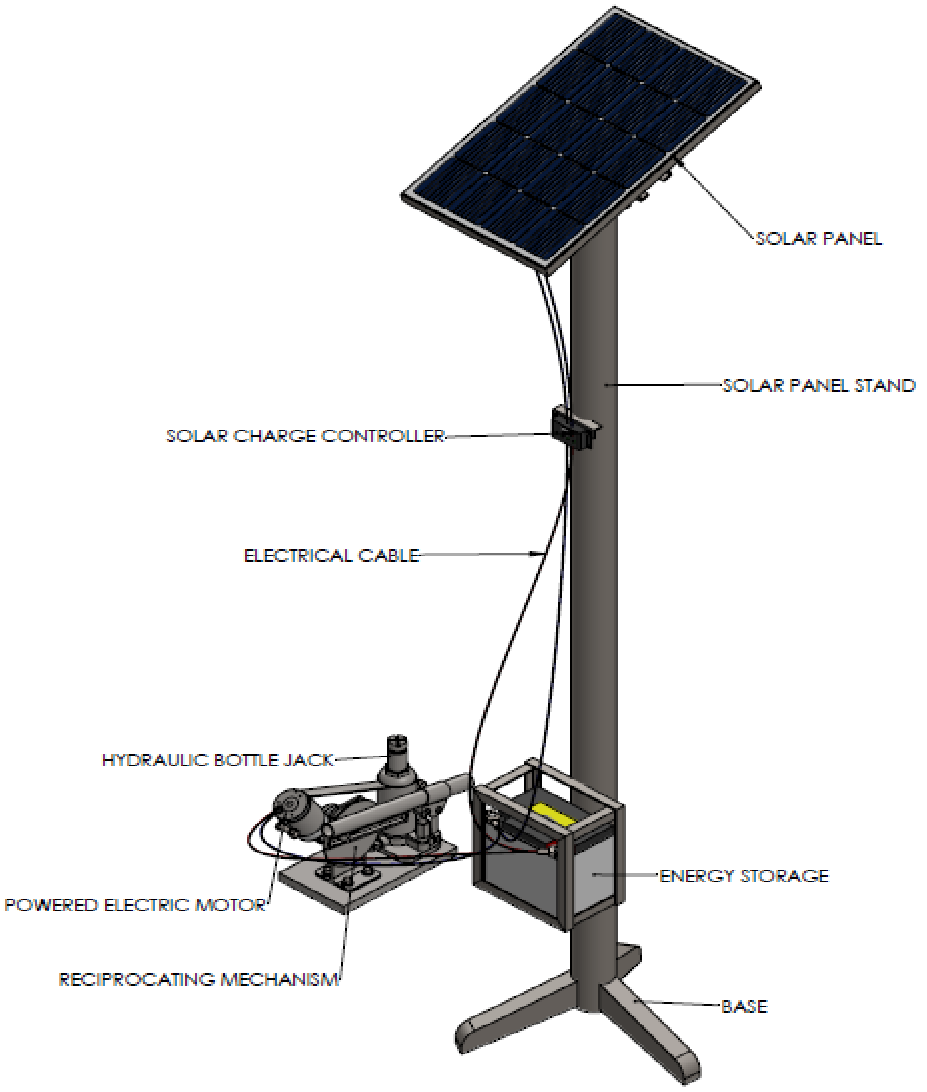



**Fig. 1: Diagramme of the assembled solar powered hydraulic jack**

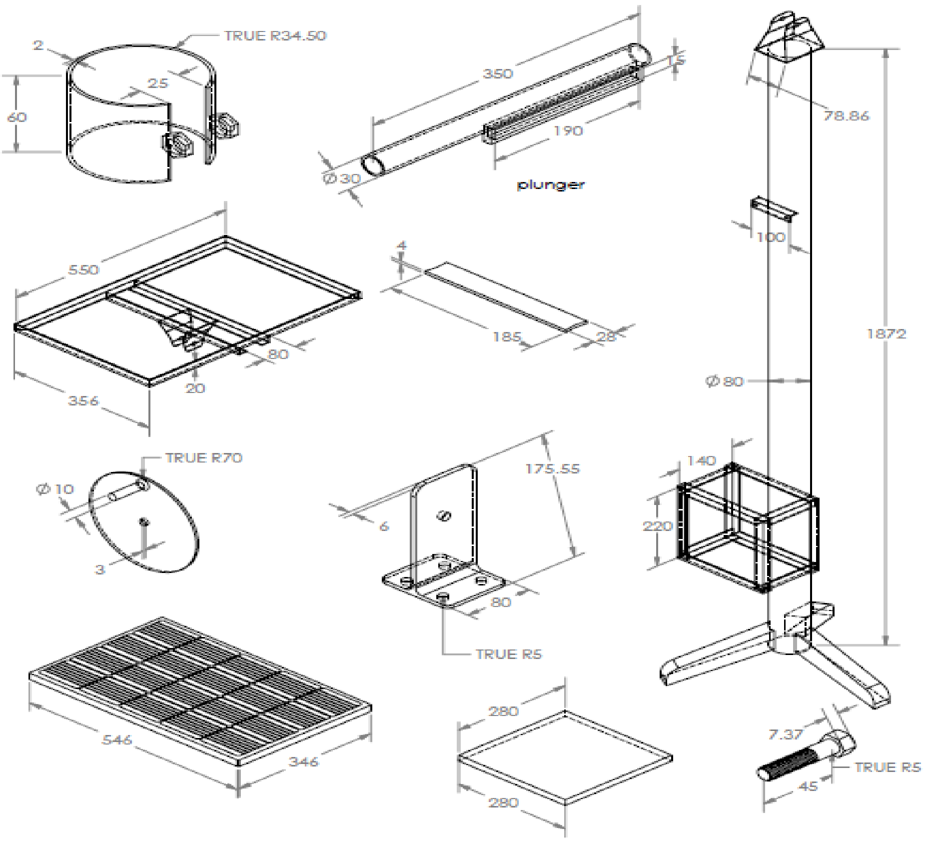



**Fig. 2: Dimensional details of the used components for the developed jack**


**Fig. 3: Exploded views of some components used in the fabrication of the solar powered jack**

**Conclusion**

A five tone capacity hydraulic screw solar powered jack has been conceived, designed, fabricated and tested. The ergonomic attributes, the little initial set up time, the availability and reliability makes the industrial jack stand out high among other types of hydraulic jacks available in the market as at the time of this report. The solar powered hydraulic jack on performance evaluation in terms of efficiency, availability, reliability, ease of use and cost effectiveness in terms of maintenance proved to be a novel in its class of lifting equipment. The jack so developed is suitable for bringing, pushing, pulling and lowering loads from a perceived location to the desired position within a time of 2 min. The most interesting thing about this developed jack is that it is very easy to operate; secondly, it can be moved from one place to another because of its light weight. Other important characteristics of the device include but not limited to its near zero human machine interface which in a way brings down significantly the epidemiological conditions suffered by users of manual jacks. It is therefore our view that this industrial jack will be utilized maximally in our industries; again create employment for our unemployed youths who may get involved in entrepreneurial training that require the use of this cost effective device.

**Conflict of Interest**

The authors declare that there is no conflict of interest related to this study.

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