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DEVELOPMENT OF AN INDIGENOUSLY MADE DIESEL INJECTOR TESTER

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ABSTRACT

This work entails the design and construction of a diesel injector tester for proper spray pattern, leakages and pressure inspection. The mechanism is important as the injection system requires greater manufacturing precision and tight tolerance for the system to function efficiently. A diesel injector tester was designed with CREO Parametric CAD software after which the real hardware prototype was developed. The machine was tested and its performance was evaluated through the spray, pressure and leakage tests, respectively, as it worked perfectly. Conclusively, the machine was successfully completed having a unique ability of being modified as it can be utilized in any automobile workshop for proper diagnosis. Necessary recommendations were later made.

KEYWORDS: Diesel engine, Injection system, Injector tester, CREO parametric, Evaluation.

1. INTRODUCTION

The automotive industry is constantly challenged to overcome the demands of lower engine emission level, more efficient fuel economy, and quicker vehicle response time with innovative designs and technologies. These demands are especially critical in the area of the internal combustion engine, with the use of diesel fuel as the driving agent criticized for loud noise and dirty emissions (Chiu, 2008).

Fuel injection is a technology used in internal combustion engines to mix the fuel with air prior to combustion. As in a traditional carburettor, fuel is converted to a fine spray and mixed with air through a venture to pull the fuel into the air stream. A fuel injection system forces the fuel through nozzle under pressure to inject the fuel into the air stream without requiring a venture. Thus, fuel injection can increase fuel efficiency and reduce pollution (Dhaval, 2016).

During the compression stroke in a four-stroke diesel engine, air is compressed in the engine cylinder. The pressure of the air is increased and its temperature is also increased. The diesel fuel is injected at the end of the compression stroke and the fuel is ignited. The fuel feed system popularly called injector ensures that the diesel oil is injected into the cylinders at the correct time (Praveen *et al.*, 2015).

The function of the injector is to disperse the fuel through compressed charge of air in the engine cylinder. Proper functioning of injector should be ensured for proper functioning of the diesel engine as fuel injector has to spray fuel uniformly through a diesel fuel injection tester (Ashish, 2016).

However, diesel fuel injectors tester demands a certain degree of fuel thermal oxidative stability to maintain proper and expected spray quality. Injector nozzle deposits have adverse effects on engine fuel consumption, performance, efficiency, and endurance. This stability requirement becomes more demanding as the injector is operated at higher temperatures.

Also, the performance of diesel engines is heavily influenced by their injection system design. In fact, the most notable advances achieved in diesel engines resulted from superior fuel injection system designs. It is therefore necessary to develop a machine that would help to deliver fuel into the engine cylinders optimally which in turns affect the engine performance, emissions, and noise characteristics positively, as it would precisely control the injection timing, fuel atomization, and other parameters thereby reducing the problems affecting the diesel injector system.

Sirsat *et al.*, (2016) carried out a review on a fuel injection testing equipment and suggested three different tests (pressure, leak-off and spray) to be carried out on it to ascertain the functionality of the injector.

In another research carried out by Ashish *et al.*, (2016), a fuel injection testing equipment consisting of storage of fuel tank, pressure gauge for measuring pressure, non-return valve to prevent backward flow of fuel, ON/OFF valve for controlling fuel supply trough PU tube to the injector, timer circuit and stand. In the pressure test, the standard pressure was (35pa to 60pa) but (35 to 40pa) as reported is good i.e. injector spray is good. In leak-off test, there was no accurately rounded spot on the paper therefore fuel injector nozzle utilized was not good. In spray test, during the performing test the authors discovered accurately rounded spot on the paper confirming that fuel injector nozzle is good.

Dongre *et al.*, 2018 proposed an automatically controlled mechanical unit injector tester machine in order to reduce the human efforts and minimizes errors during inspection. The paper gave detailed plan about implementation of mechanical unit injector testing machine.

2. METHODOLOGY

CREO parametric was the main software used in the design. The performance and reliability of the machine depends on the system designs and specifications, which in turn affect the designed parameter to conform with the operating conditions of the system.

2.1 MATERIALS

A large number of materials are available for engineering applications. The following were considered in this work: cost effectiveness, availability, high or low tensile, strength as may be required, rigidity and/or flexibility, corrosion resistance, ductility, fatigue, toughness, weldability etc. The mild steel plate used for the base of the machine is ductile, thus making it possible for it to be rolled, folded and bent without cracks or fractures.

Table 2.1: Materials Selection.

S/N	Part	Materials	Selection
1	Bottle jack	Steel	Steel is very strong material and can withstand wear and tear
2	Pressure gauge		(0-10bar)
3	Coupler	Bronze metal	Good formability and have good resistance to corrosion
4	Tank	Plastic	This is where the diesel would be held, plastic is best because it cannot be subjected to corrosion or rust. 1 Litre capacity
5	Injector	Aluminium	12 volts multi point injector
6	Base	Steel	Steel is very strong material and can withstand wear and tear
7	Metallic fuel line	Seamless pipe	High ability to withstand pressure and strong as there is no welding involved

2.2 METHODS

2.2.1 Description of the work

Figure 2.1 includes blocks diagram of components used in making the injector tester functional, the various components involved includes; the fuel tank with rubber hose, bottle jack with a lever, pressure gauge, coupler, metallic fuel line, injectors as well the diesel injector tester stand with the base. With the aid of the diagram above the mode of operation of this machine is described.

Figure 2.1: Block diagram.

a. **Fuel tank:** A 0.001 m^3 capacity cylindrical fuel tank made of plastic is to store diesel meant for testing the injectors. A rubber hose of 355.6 mm long is connected to the base of the tank to ease the supply of oil to the fuel line.

b. **Bottle jack:** It is a short stroke hydraulic lift which is fed from hand pump. The hydraulic jack may be portable. This is extensively used for lifting automobiles usually to facilitate and repair and for replacing the punctured wheels. It is also a mechanical device used as a lifting device to lift heavy loads or to apply great forces. But in this case, it was used as a means to pump the diesel through the system at a high pressure. This is possible by disposing the oil in it, and drilling a hole in the piston, this allows the oil to flow through the piston instead of pushing the piston like the regular jack. The bottle jack utilized here is of 50 tons capacity.

c. **Coupler:** a connector between two mechanical components or systems. It is short length of pipe with two female threads in which other parts can be attached. It is bored through, thereby continuing the flow of the diesel through it to the different parts attached to it (the pressure gauge, the metallic line and the valve) from the newly improvised pump. The coupler utilized here was made o bronze.

Figure 2.2: Coupler.

d. **Pressure gauge:** This is instruments used to measure and display pressure in an integral unit is called pressure gauges the diesel flowing through the system is measured to observe the output at different stages. A pressure gauge of 0 to 10 bar capacity was used.

Figure 2.3: Pressure Gauge.

e. **Metallic fuel line:** A fuel line is a hose used to bring fuel from one point in a vehicle to another the fuel line transfers the diesel from the mechanism to the injector at constant pressure. The fuel line utilized was 635 mm long.

Figure 2.4: Metallic fuel lines.

f. **Injector tester stand with Base:** This is meant to accommodate all other components of the machine. It consists of four-side poles (stand) with a 381 mm x 241.3 mm x 50.8 mm base.

2.2.2 Working Principles

This diesel injector tester is meant for diesel engine four-wheel vehicles. When the injector is energized, an electromagnet moves a plunger that opens the valve, allowing the pressurized fuel to squirt out through a tiny nozzle. The nozzle is designed to atomize the fuel-to make as fine a mist as possible so that it can burn easily. The bottle jack (as reciprocating pump) serves as a means to pressurize the diesel oil through the system; the upward movement of the lever draws in diesel from the tank, then the downward movement of the lever pumps the diesel (pressurized) through the piston to the coupler assembly. The pressurized diesel passes through the coupler which at one end has the pressure gauge taking the readings of the pressure at which the diesel is supplied (this occurs only when the valve is open), and at the other end the metallic fuel line is connected. This metallic fuel line holds the injector, so the diesel is passed through the line to the injector nozzle.

2.2.3 Design Calculation

The following were considered in the development of the diesel injector tester: Availability of the materials and parts; cost; workability of the project and safety.

Design of Reservoir/Fuel tank: The tank was filled according to design consideration to the full capacity.

$$V = \pi r^2 h$$

Where, *r* is the radius of the tank; and h is the depth of the tank.

Therefore, the volume of the oil in the tank: $V = 1000\ cm^3 = 1\ litre$

Diesel Injector Tester Base: The base was calculated using

$$V = lwh$$

Where, *l* is the length of the base; w is the width of the base and h is the depth of the base.

Bottle jack: The hydraulic jack is perhaps, one of the simplest forms of a fluid power system. By moving the handle of a small device, an individual can lift a load weighing several tons. A small initial force exerted on the handle is transmitted by a fluid to a much larger area. The operation of hydraulic jack depends on Pascal 's law which says that 'the intensity of pressure in a fluid at rest is the same in all direction'. Mechanical advantage is obtained by a practical application of Pascal 's law of transmission of fluid pressure. Two pistons of different sizes operate inside two cylinders suitably connected with a pipe so that pressure in each is the same.

$$P_1 = P_2$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

Where, F_1 and F_2 are the force applied of the small plunger and the load lifted on the ram, respectively. Then, A_1 and A_2 are the cross-sectional area of the small cylinder (plunger) and the big cylinder (ram), respectively. If the volume of liquid is constant. The displacement of large piston will be proportionately to smaller plunger. According to Pascal Law, force applied to the plunger F_p = Load × Gravity; F_p = 397.6974 N.

The lever: A lever is made up of mild steel and is used to apply load on the plunger. It is attached to the plunger with the help of pivot (Sainath *et al.*, 2014). According to Chavan *et al.* (2017),

a. Length of the lever

1. The required fulcrum length = 4 cm
2. Effort put on lever by man = 10 kg
3. Load acting on plunger = 40.54 kg (5 tons)
4. Velocity ratio of lever, $V_R = \frac{effort\ distance}{Load\ distance} = 4.54$
5. Required distance from fulcrum to load = 15 cm
6. Total length of lever = velocity ratio x Load distance= 4.54× 15 = 68.10 cm. The length of lever taken without extended bar = 70 cm

b. Diameter of the lever: This was obtained from the bending equation

$$\frac{M}{I} = \frac{\sigma_t}{Y} = \frac{E}{R}$$

$$\sigma_t = \frac{MY}{I} = \frac{M}{Z}$$

$$d = \sqrt[3]{\frac{32 \times M}{\sigma_t \times \pi}}$$

Where

M = maximum bending moment

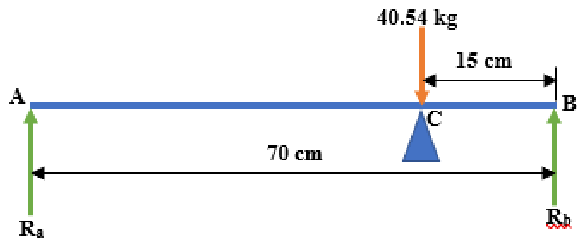
I = moment of inertia, $\pi d^4/64$

σ_t = permissible tensile strength of mild steel (σ_t) = 120 N/mm^2 (Sainath *et al.*, 2014)

Y = distance between outer most layer to neutral layer, $d/2$

Z = section modulus

d = diameter of the lever;



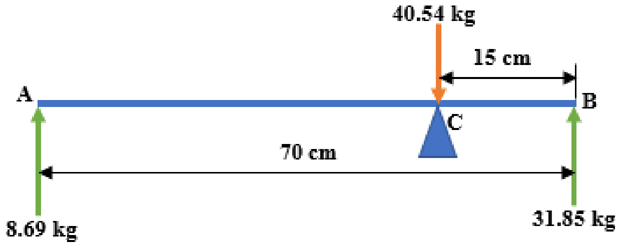
Taken moment about B, $\sum M_B = 0$; $(R_a \times 70) - (40.54 \times 15) = 0$

$$R_a = \frac{(40.54 \times 15)}{70} = 8.69\ kg$$

Then, $\sum f_v = 0$; $R_a + R_b = 40.54\ kg$

$R_b = 40.54 - 8.69 = 31.85\ kg$

From the bending moment analysis;



Bending moment at C = 0

Bending moment at A = 8.69 × 9.81× 0.55 = 46.89 N-m

Bending moment at B = (8.69× 9.81× 0.70) – (40.54× 9.81× 0.15) = 0

Thus, the maximum bending moment = 46.89 N-m

Then, the diameter of the lever

$$d = \sqrt[3]{\frac{32 \times 46.89}{120 \times 10^6 \times \pi}} = 0.01585\ m = 15.85\ mm$$

The diameter of lever adopted = 20 mm

Design of plunger and plunger cylinder

According to design catalogue standard value of plunger (Chavan *et al*., 2017)

Diameter of the plunger, D_p = 20 mm,

$$Area\ of\ the\ plunger, A_p = \frac{\pi}{4} \times D_p{}^2 = 314.15\ mm^2$$

The diameter of plunger cylinder (D_{pc})

$$\sigma_t = \frac{pd}{2 \times t_{pc}}$$

Where t_{pc} is the thickness of the plunger cylinder

P is the operating pressure 10 bar (1 MPa)

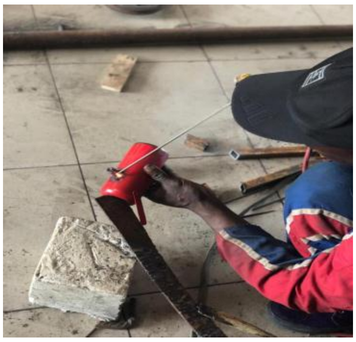
Approx. t_{pc} = 5 mm

$$D_{pc} = D_p + 2t_{pc} = 30\ mm$$

2.2.4 Construction of the machine

The diesel injector tester was designed majorly to test injectors. Some of the equipment used in fabricating the various parts of the machine is as follows: Centre lathe, drilling machine, welding machine, cutting tools and marking/Measuring tools etc. The components were firstly made available in the workshop which serves as a platform for carrying out the fabrication. A systematic approach was used in achieving the major goal of the work from start to completion. The bottle jack was exploded to take out the piston to be drilled as shown in figure 2.5 (a) before an external orifice was welded to the jack housing (figure 2.2 b). The piston was later taken to the centre lathe for drilling (figure 2.2 c). The piston was threaded and connected to the coupler (figure 2.2 d). The pressure gauge in figure 2.2 (e) was also connected to one end of the coupler. The exploded bottle, valve and pressure gauge were later connected through the coupler and then mounted on the base while the tank was mounted on the tank stand (figure 2.2 f). The complete assembly of the machine shown in figure 2.2 (g) was coated against corrosion.

(a) Exploded bottle jack



(b) welding the external orifice

(c) Drilling the piston



(d) Threading the piston (e) Pressure gauges after coupling (f) Mounting on the base

(g) Complete assembly

Fig. 2.2

3. TESTING AND EVALUATION

3.1. Testing

This machine is a prototype which is aimed at developing a diesel injector tester and tests its effectiveness in the engineering laboratory of Elizade University Ondo State, Nigeria. Three different injectors were tested on the diesel injector tester. The system is designed in such a way that three tests were taken on the diesel injector tester. These include pressure test, spray test and leakage test.

1. **Pressure Test:** The reservoir tank was filled with a diesel to the peak and covered with the lid. The lever was pumped continuously and the pressure at which the injector nozzle opens was observed; The reading in the pressure gauge shows atmospheric pressure and the pressure of two of the injectors is equal to the pressure specified by the manufacturer which indicate that the injectors are functioning. The pressure of the third injector is more or less then the specified then the spring is adjusted according to the size of shim in the

injector. The process was repeated until the correct pressure reading is obtained. Finally, the lock nut was tightened.

2. **Spray Test:** The second test that was carried out was the spray test. The reservoir tank was filled with a diesel to the peak and covered with the lid. During the test, diesel was sprayed from the injector, therefore a suitable receptacle was placed to capture the spray. The nozzle of the injector should not be pointed towards the operator or anyone else. Upon nozzle opening, the spray pattern/atomization was compared to the manufacturer specification to described correct spray pattern. Two of the injectors satisfy this and that is the indication that only two of the three are functioning.
3. **Leak Test:** Leak test was the third test carried out on the three samples. The reservoir tank was filled with a diesel to the peak and covered with the lid. The lever on the tester was pumped to build up pressure to the injector. Once some pressure has built up, the pressure drop was checked to know if there are obvious leaks. There could be a leak between the supplied pipe and the injector or tester. Necessary connections were later checked and tightened. In the third injector, a pressure drop was still noticed after checking and tightening the connections which is an indication that the third injector nozzle was leaking**.** Sometimes the leak is visible once pressure starts to build up in the injector. The other two passed the leak test.

Figure 4.1: Testing preparation.

3.2. Performance Evaluation

The performance of this project was thoroughly evaluated after the assembly; the mechanism was subjected to test observation in comparison to the predicted output. When the diesel injector tester was constructed it was tested with different injectors to ensure efficient result and observe errors and leakage.

3.3 Applications

The Diesel injector tester is very important in engineering of today as it has found numerous applications in different spheres of life, its applications include but are not limited to;

1. Automobile quality control unit
2. Commercial generator
3. Automobile workshop for proper diagnosis and servicing of injectors.

4. CONCLUSION

The fuel injection equipment which is meant is to disperse the fuel through compressed charge of air in the engine cylinder is the essential component for the proper working of the diesel engine. This is to ensure proper functioning of engine as fuel injector has to spray fuel uniformly. The work which is the design and implementation of a diesel injector tester has met its objectives which is to design a diesel injector tester using computer aided design, implementation of the designed diesel injector tester on a hardware prototype considering factors like economy, availability of components and research materials, efficiency, compatibility, portability and also durability. The machine was tested and its performance was evaluated through the spray test, pressure test and leakage test. In conclusion, the machine was successfully completed having a unique ability of being modified with few changes required as would be highlighted in subsequent sections of this write-up. It is suggested that more research can be carried out towards the improvement of the work. Thus, the following recommendations should be strictly taken for future enhancement of this work and also for technological advancement:

1. More techniques should be carried out in implementing the diesel injector tester
2. This work should be modified and developed according to its application
3. Techniques on the development of a tester that can work for both gasoline and diesel injectors should be considered.
4. If required, carry out any repairs or remedial work to the injector as detailed in the manufacturer's technical service documentation, before re-testing. Note: when disconnecting the injector, be aware that care needs to be taken to depressurize.

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