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Research Article

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Design Analysis of a Locally Fabricated Compressed Air Engine

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Abstract The problems created by the current world energy program such as emission of green-house gases can be associated with the recent climatic changes, flooding, and paranormal heat waves and so on. This is majorly due to the lack of political will by world leaders to develop and invest in renewable energy that is sustainable and efficient. The need for the immediate move to save our planet from extinction is the reason behind the development of a technology that would generate energy using atmospheric air. This paper presents the design analysis of a compressed air engine for energy generation. A 2.75 KW, 2100 rpm compressed air engine was designed and analysed. The compressed air engine was designed and run on air whose pressure is as low as 5 bar and flow at a flow-rate of 0.0035846 m^3/s.

Keywords Compressed Air Engine, Pressure, Speed, Efficiency, Brake Power, Velocity, Torque

1. Introduction

Today fossil fuels are widely used as a source of energy in many applications e.g. internal & external combustion engines, as heat source in manufacturing industries, etc. but its stock is very limited and due to this tremendous use, fossil fuels are depleting at faster rate [1]. So, in this world of energy crisis, it is inevitable to develop alternative technologies to use renewable energy sources, so that fossil fuels can be conserved. One of the major fields in which fossil fuels are used is Internal Combustion Engine (IC) [2]. An alternative of IC Engine is "Compressed Air Engine". It is an engine which uses compressed air to run the engine. It is cheap as it uses air as fuel, which is available abundantly in atmosphere. There are several technical benefits of using this engine, as no combustion takes place inside the cylinder; working temperature of engine is very close to ambient temperature [2-3]. This helps in reducing wear and tear of the engine components. Also there is no possibility of knocking. This in turn results in smooth working of engine. One more technical benefit is that there will not be any need for installing cooling system or complex fuel injection systems. This makes the design simpler. Thus compressed air powered car has the capacity to satisfy present demand and can prove to be the future vehicles [1]

Compressed air is a gas, or a combination of gases, that has been put under greater pressure than the air in the general environment [4]. The first compressed air vehicles were built by Andraud and Tessié du Motay in Paris between 1838 and 1840 [5]. A compressed air engine does mechanical work by expanding compressed air; its convert the compressed air energy to mechanical work through either linear or rotary motion. Linear motion can come from either a diaphragm or piston actuator, while rotary motion is supplied by either a vane type air motor, piston air motor, air turbine or gear type motor [6]. In recent years more advanced compressed air vehicles have been demonstrated [7].

An air compressor does most of its work during the compression stroke. This adds energy to the air by increasing its pressure. Compression also generates heat, however, and the amount of work required to compress a quantity of air to a given pressure depends on how fast this heat is removed. The compression work done will lie between the theoretical work requirements of two processes [8]. Our environment must be protected against various contaminations produced by fossil fuel engine which produces some of the most adverse environmental effects. These emissions, which are above all caused by road traffic damage the flora and fauna and deteriorate human health. For instance, Nitrogen Oxide (NOx) after oxidation forming nitric acid, which contributes to the acid rain which has caused severe forest damage in the past decades. Compressed air engine are zero emission engines [9-11]. This is so because air is used as fuel and exhaust is also in the form of air. Hence, these vehicles does not release any CO, NOx, hydrocarbons, soot etc. and hence do not damage the environment. Thus compressed air powered car can prove to be the environment friendly vehicle of 21st century [1].

2. Materials and Methods

2.1. Materials

During the course of this research work, the following are the various machine parts that were employed:

- Cylinder Block and the cylinder head.
- Pistons and piston pins.
- Connecting rods.
- Crankshaft
- Gears
- Hoses
- Timing shaft and Intake manifold tube
- Engine Frame

The design method employed was similar to that of the Internal Combustion Engine (ICE) and it involves the following steps:

- Design calculations
- Isometric design drawings
- AutoCAD design
- Fabrication of components
- Assembly of components
- Testing

In order to reduce the overall inertia forces that would be accumulated in the force system of the engine, the moving parts like the pistons, the connecting rods, the timing-shaft, the gears and the crankshaft of the compressed air engine were reduced in size by a very minute fraction.

2.2. Methods

2.2.1. Engine Parts Description

Cylinder Block and the Cylinder Head

The cylinder block houses the piston that moves vertically in the cylinder at a distance that is known as the length of stroke of the engine. The uniqueness of the compressed air engine makes the cylinder head different from that of conventional engines because of the nature of the energy source (air) for compressed air engines.

Piston and Piston Pin

The pistons are of cylindrical form in the cylinder block. The diameter of the piston directly affects the power of the engine, and its length helps reduces air leakages in the cylinder. The pistons are directly impacted by the pressure force of the highly pressurized air flowing from the tank. Piston pins are small cylindrical bars that horizontally hold the connecting rods in the piston.

Connecting Rods

The connecting rod is a machined piece that links the piston with the crankshaft in order to conveniently transform the reciprocating motion of the piston to the rotational motion required to drive the crankshaft. The length of the connecting rod was measured in the engineering drawing from the piston pin centre to the crank centre. A factor of safety of 5.5 was used to determine the buckle load experienced by the connecting rod.

Crankshaft

This is a major part of the compressed air engine that is involved in the conversion process from pressure energy to mechanical energy. The overall power of the engine is dependent on a major characteristic of the crankshaft known as the crank radius. The torque of the compressed air engine is also described by the crank radius, which enables the engine drive a load at a specific speed and the generated torque.

Gears

The meshing gears found in the compressed air engine are major parts of the valve-gear mechanism whose function is to ensure that the mechanical energy is transmitted from the crankshaft to the timing shaft to regulate the volume of air that would flow into the cylinders.

Timing Shaft and Intake Manifold Tube

Timing shaft is another major component of the valve system that controls and regulates the volume of air (which was designed to receive air from a pipe of 11mm internal diameter, so as to maintain the minimum flow-rate required by the engine to run at 2100 rpm, which is 0.0035846 m^3/s) and chooses the cylinder in which to deliver air at intervals. The timing shaft is force-fitted into a gear that is meshed with another gear (crankshaft) both gears have a transmission ratio equal to unity. The Intake manifold tube houses the continuously rotating timing shaft which is connected by hose to the tank and always filled with air at every point in time. The intake manifold tube has projected ports through which air flows from the timing shaft to and from the cylinders without leakages.

Engine Frame

The vertical frame support houses the two journal bearings in which the timing shaft and the crankshaft rotates. The horizontal support functions as a bed for the engine to dissipate its minute vibrations.

Design Calculations

The Engine Power was calculated according to [12] as shown below:

$$\boldsymbol{F = PA} \quad (1)$$

Computing the Engine speed;

$$\mathbf{N} = \frac{\mathbf{Q}}{\mathbf{ALn}} \text{ (rps), [13]} \quad (2)$$

Where,

Q = flow rate of the air into the engine

A = cross sectional area of the piston.

n= number of pistons.

L= length of stroke = 1.5D, [13]

The Flow rate of the engine may be obtained as follows [14];

$$\boldsymbol{Q = Av} \ (m^3/s) \quad (3)$$

Where,

A = cross sectional area of the outlet area of the pipe/hose

v = velocity of fluid.

The Dynamic Pressure, P_d, of a fluid is obtained by [14];

$$\boldsymbol{P_d = \frac{1}{2}\rho v^2} \quad (N/m^2) \quad (4)$$

Where,

v = velocity of fluid. (m^3)

ρ = density of air at a particular temperature and pressure (kg/m^3)

This is obtained as follows;

$$\boldsymbol{\rho = \frac{2.7(P_{psig}+14.7)}{T_f+459.7}} \ (lb/ft^3) \quad (5)$$

$$T_f = (T_c \times 1.8) + 32 \quad (6)$$

Where,

P_{psig} = gauge pressure (psi)

T_f = temperature (^oF)

T_c = temperature (^oC)
Taking gauge pressure to be 5bar and assuming a room temperature of 25^{o}C,
$T_f = 77^oF$
At 5bar and 1 atm

$$\rho = \frac{2.7(72.518872 + 14.7)}{77 + 459.7}$$

ρ = 0.438776 lb/ft^3
Obtaining the velocity of the fluid, while taking the dynamic pressure into consideration at 5bar;
From eqn. 4

$$P_d = \frac{1}{2}\rho v^2$$

$P_d = 5 \times 10^5 N/m^2$
$\rho = 7.02831 Kg/m^3$
$v^2 = 142281.71$
v = 377.20249m/s
The diameter of the hose to be used was measured to be 11mm. Hence, the flow rate Q is calculated from eqn. 3 as follows,

$$Q = Av = \frac{\pi d^2}{4} v$$

Q= 0.035846m^3/s
For the aerodynamic efficiency of air in and out of the rotary valve mechanism, the flow rate is 10 times the mean effective flow rate of air flowing into the cylinders,

$$Q = 10Q_m \quad (7)$$

$Q_m = 0.0035846\ m^3/s$
Recall that, the engine speed N, from eqn 2

$$N = \frac{Q}{Aln}(rps)$$

Calculating for $A=\frac{\pi d^2}{4}$; (m^2) [Area of piston]
For the piston diameter calculation, for a small engine d = 35mm

$$A = \frac{\pi \times 0.035^2}{4} = 9.6211 \times 10^{-4}\ m^2$$

n = 2 (for 2 piston engine)
l = 1.5d = 1.5 x 0.035 = 0.0525 m

$$\text{Therefore, } N = \frac{0.0035846}{9.6211 \times 10{-}4 \times 0.0525 \times 2}\ (rps)$$

N = 2100 rpm
The Engine Torque is obtained as follows;

$$T = F \times r \quad (8)$$

Where,
F = maximum air force on piston (N)
r = crank radius (m)
From eqn. 1,

$$F = P \times A$$

Where,
P = air pressure = 5bar = $5 \times 10^5\ N/m^2$
A = area of piston = $9.6211 \times 10^{-4}\ m^2$
$F = 5 \times 10^5 \times 9.6211 \times 10^{-4}$
F = 481.055 N
The crank radius, r, is obtained from the length of stroke as follows;

$$l = 2r \quad (9)$$

From internal combustion engine (ICE) design, the length of stroke is given by [14]
T = 12.6277 Nm

The Power that would be transmitted at any point in time through the crankshaft is also known as the engine power. It is given by:

$$P = \frac{2\pi NT}{60} \quad (10)$$

Where,

N = engine speed (rpm)

T = engine torque (Nm)

$$P = \frac{2\pi \; x \; 2100 \; x \; 12.6277}{60}$$

P = 2776.97489 W

P = 2.7 kW

3. Results and Discussion

The result of the calculations made and the AUTOCAD drawings with the exploded compressed air engine is shown in the Table 1, Fig. 1 and Fig. 2 respectively:

Table 1: Calculated Parameters

Parameters	Symbol	Value	Unit
Dynamic Pressure	P_d	5 x 10^5	N/m^2
Density of Air	P	0.438776	lb/ft^3
Velocity of Fluid	V	377.20249	m/s
Flow Rate	Q	0.035846	m^3/s
Aerodynamic Efficiency of Air	Q_m	0.0035846	m^3/s
Engine Speed	N	2100	rpm
Maximum Air Force on Piston	F	481.055	N
Engine Torque	T	12.6277	Nm
Engine Power	P	2.7	kW

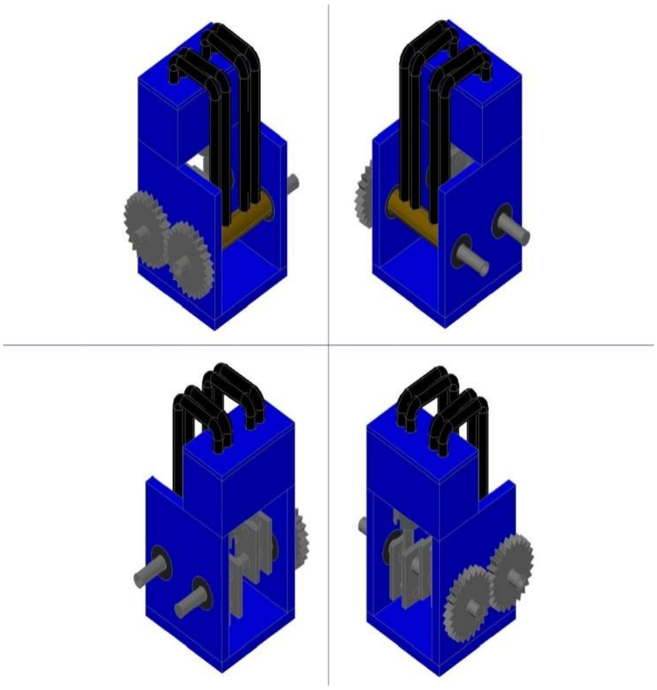

Figure 1: Isometric Views of the Compressed Air Engine

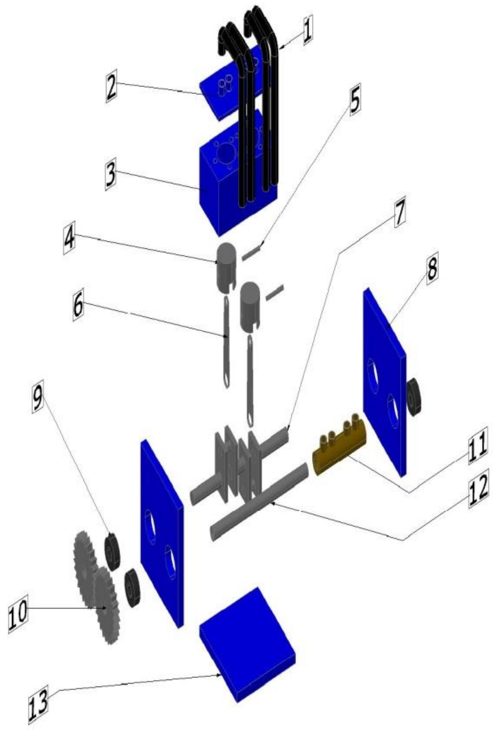

Figure 2: The Exploded View of the Compressed Air Engine

Table 2: Parts of the Exploded View of the Engine

Part Number	Part Description
1	Hose
2	Cylinder Head
3	Cylinder
4	Piston
5	Piston Pin
6	Connecting Rod
7	Crankshaft
8	Frame
9	Bearings
10	Gears
11	Manifold tube
12	Intake Valve
13	Base

The fabricated compressed air engine using locally available materials is shown in fig. 3 below:

Figure 3: The Fabricated Compressed Air Engine

Experimental analysis were carried out on the fabricated compressed air engine to find out its performance characteristics like brake power, mechanical efficiency, indicated power, torque etc. The observed value for each parameter is shown in Table 3.

Table 3: Experimental Analysis Values

Parameters	Values
Engine Speed (rpm)	**2100 rpm**
Output shaft speed (rpm)	**710 rpm**
Weight (kg)	**24 kg**
Torque (Nm)	**4.35 Nm**
Break Power (KW)	**0.327 KW**
Indicated Power (KW)	**1.43 KW**
Constant Pressure from Tank (bar)	**5.5 bar**
Efficiency (%)	**22.86%**

4. Discussion of Results

In this research work, an air compressed engine was design and fabricated with locally available materials. The test results show that, the fabricated air compressed engine has satisfactory performance; the engine has a speed of 2100 rpm, operates at a pressure of 5 bar, torque of 12.6277 Nm and fluid velocity of 377.20249 m/s^2. To select the right materials for the fabrication work, the service condition of every part was taking into considerations which guild in the selection of appropriate materials. From Table 1, it can be seen that the compressed air engine is design to operate on a flow rate of 0.035846 m^3/s and engine power of 2.7 kW. The experimental analysis carried out on the fabricated air compressed engine shows that the fabricated air compressed engine has an output shaft speed of 710 rpm, brake power of 0.327 kW and mechanical efficiency of 22.86 %. It is clear from the observed data and efficiency as enumerated above that, the performance of the machine is excellent. From the design consideration and analysis; reliability, safety, serviceability and cost of construction were given due consideration.

5. Conclusion

The design and fabrication of the compressed air engine was borne out of the need to develop indigenous technology for a cleaner energy engine to save our planet. Detailed calculations made and the use of locally available raw materials for the fabrication of the machine has significant technological benefit. From the design consideration and analysis; reliability, safety, serviceability and cost of construction were given due consideration. From the design analysis on the fabricated compressed air engine the following can be established:

i. Tank pressure = 5 bar
ii. Speed =20-25 km/hrs.
iii. Time to fill tank/reservoir =3 min. (7 bar)
iv. Exhaust temperature =150 ^oC
v. Distance travelled per refill =200 m

The ability of the compressed air engine to work on a pressure of 5 bar was a great achievement and base on the above, the design analysis was successfully carried out.

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