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Design and Fabrication of a 4 Bar Air Compressor

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Abstract- Though air is free, making it available in the right conditions cost quite a fortune and requires mechanical work to be done on the air via compressors. Hence, the purchase price and operating cost of compressors however makes it difficult for the advantages of air based technologies to be appreciated. This study focuses on the design and fabrication of a 4 bar mechanical compressor using a 6.5 Hp fuel engine. An air pump with operating torque of 20Nm to 34Nm is used to move the air from the atmosphere into a 100 psi (6.8 bar) capacity steel tank obtained from a diesel truck. The performance evaluation of the air compressor is done using the pressure gauge to obtain pressures of the air in the tank and how much work was done on the air by the compressor as it was run by the 6.5 Hp fuel engine. From the data obtained and processed during experimentation, it can be inferred that useful amount of energy can be stored in the form of pressured air using an air compressor. The process is however not 100% efficient and this is evident in the fluctuations of the pressure read by the use of the pressure gauge. Also, the efficiency and cost benefit of the air compressor was done by comparing the useful work of the air in the tank using the values form the attached pressure gauge to the work done on the air by the compressor as it is moved by the engine. Conclusively, it is shown that air is a good source of energy for useful mechanical work.

Keywords- Air compressors, Compressed air, High pressure air, Air pressure, 4 Bar Air Compressor.

I. INTRODUCTION

From tackling unusual phenomenon in space exploration where man has to survive in places devoid of air and lacking atmospheric pressure exerted by air molecules, to the working mechanisms of automatic rifles which use the pressure from the air within the barrel to operate firing mechanisms, pressurized air finds application in a wide variety of aspects in homes and industries[1].

The earliest tool used to compress and direct airflow is the lung. However, artificial air compressors in the form of bellows were invented around 3000 B.C. when metallurgy became prevalent. Bellows were used for fanning fires used in melting various ores and were either operated by hand or foot. In recent years, modern air compressors have become more sophisticated and automatically run by power systems that can produce variations in pressures and air compressor forces more and more air into a storage tank, increasing the pressure. When tank pressure reaches its engineered upper limit the air compressor shuts off. The compressed air, then, is held in the tank until called into use.

This is possible due to the compressibility of air. Valves are used to control, dampen and amplify the energy derived from releasing the compressed air[3]. Some popular applications of compressors are in spray painting, compressed air engine, supercharging surface cleaning, refrigeration, and air conditioning, chemical industry, etc. Air compressors are also for driving pneumatic tools and air operated equipment in industries such as grinders, automatic punch, pneumatic press, pneumatic actuator, etc. They are also used to propel air conditioning, heating, refrigeration, and air-purification equipment. Also, air compressors, as air pumps, are widely used to create pressurized air for flushing airlines in buildings and canals for conduction fluids [3]. The design of air compressors can vary according to the type of application. A standard air compressor design usually comprises a blower (generator) and a compressor (or air compressor pump). The blower consists of a duct that raises and lowers the volume of air from the compressor. This is a relatively simple design but with some limitations in the volume of air that can be compressed, such as the power of the blower motor. Although many variations of the air compressor have been developed, most air compressors use a compressor-driven air pump which uses a mechanical pump motor to pump pressurized air through an air compressor or air compressor pump. While the mechanical pumps are still in use, some air compressors are driven by an electric motor. The aim of this study is to design, fabricate, and evaluate the performance of a 4-bar air compressor while conducting a detailed 3D model and simulation of the machine using SolidWorks, with a focus on achieving high efficiency, cost-effectiveness, and versatility, ensuring its functionality and efficiency for use in various industrial applications.

1. Justification of Study

Air compressors are essential in various industrial and commercial applications, including manufacturing, construction, and automotive industries. In manufacturing, for instance, compressed air is used for operating pneumatic tools, conveying materials, and even controlling processes. In the construction industry, air compressors are employed to power pneumatic hammers and drills [4], [5]. Additionally, they are essential in the automotive sector for tasks like painting and inflating tires.

Hence, the study is justified because the design of an efficient air compressor can significantly enhance productivity in various sectors. In manufacturing, efficient air compressors ensure that pneumatic tools operate optimally, reducing downtime due to tool malfunctions or inconsistent performance. In construction, pneumatic tools like jackhammers and drills powered by air compressors are essential for excavation and other tasks. An efficient air compressor design ensures that these tools work consistently, allowing construction projects to progress smoothly and meet deadlines. In automotive painting applications, a consistent and high-quality supply of compressed air is critical for achieving uniform paint finishes, while reducing the likelihood of defects, thus improving the overall production process.

Also, energy efficiency isn't just about cost savings; it's also about reducing the environmental footprint. Many industrial processes have a significant impact on the environment due to energy consumption and emissions [6], [7]. An energy-efficient air compressor design aligns with sustainability goals and regulatory requirements. It can help companies reduce their carbon footprint and demonstrate environmental responsibility, which is increasingly important in today's global market. Additionally, the cost of acquiring and running traditional air compressors is often high making it difficult for many industries to adopt the technology.

However, the 4 Bar compressor, with its innovative design and efficient operation, can reduce the cost of production and make it more affordable to acquire. As a result, more industries can benefit from the advantages of air compressors, ultimately leading to increased productivity and profitability. Similarly, because traditional air compressors are known to break down easily, they are prone to costly repairs and maintenance. However, the innovative design approach adopted will make it more robust and durable, thus reducing the likelihood of breakdowns and the need for frequent maintenance, ultimately saving time and resources [8]. Moreover, the study provides the opportunity to explore modern design techniques and fabrication procedures that align with the current trends in manufacturing and mechanical engineering industry. This study would also contribute innovative and valuable knowledge to the field of mechanical engineering, specifically with respect to compressor design and fabrication.

II. LITERATURE REVIEWS

“Air is free, but compressed high pressure air is not”. This phrase is true because generating high pressure compressed air is not such as an economic and energy efficient process. There is the challenge of high initial and maintenance costs. However, once a person is able to get a good and well maintained air compressor, such person can reduce energy consumption from 30-50% [9]. This section discusses some literature studies on Air Compressor, including the historical background of the air compressor, its classification and applications, etc.

1. Historical Background

The historical background of air compressor date as far back as the origin of mankind: the human lungs. Since the human body can exhale air, primitive people used their own breath to blow on cinders and create fire. But healthy lungs can only produce 0.02 to 0.08 bar of air pressure. Hence, as people began melting metals tin, copper and even gold, higher temperatures and a more powerful source of air was needed. The bid to solve this problem began the evolution of the air compressor, starting with the use of wind and blowpipes by Egyptian and Sumerian metallurgists [10].

Hence, it can be said that, the earliest documented use of the compressor dates back to around 4th century B.C. In those times, the compressor was regarded as a "water organ". The water organ was invented by Ctesibius of Alexandria. The design comprised of a chamber filled with air and water, a water pump, collection of pipes of various dimensions and connecting tubes and valves. The mechanism of operation was relatively simple; by pumping water into the chamber, the air gets compressed. But as time went on, and with the advancement of technology, very important improvements and innovations were needed, and thus made to the water organ.

An example of this is seen in 1808 when the Multi Stage Axial Compressor, designed by John Dumball, brought an industrial application of the modified design. However, this design did not achieve wide-spread popularity because the compressor comprised of moving blades without stationary blades to transfer the air flow into the successive compression stage.

To better this innovation, another design was needed. During the 19th century, the invention of the Roots Blower was a huge step leading to invention of modern air compressor systems. Philander and Francis Roots designed the Roots blower, while devising a suitable replacement for the water wheel at their woolen mill. The roots blower consisted of numerous impeller pairs rotating in opposite directions. Dr. Franze Stolze designed the modern compressor in 1900; which comprised of a multi stage axial flow compressor with a combustion chamber, multi-stage axial turbine along with a regenerator to heat the discharged air utilizing exhaust waste gases [9]. During the turn of the century, portable compressors on wheels were introduced and by 1910 most commonly had one large, single-stage compression cylinder driven horizontally by a steam or oil engine. Portable compressor development was quickly stimulated by the invention of the lightweight air drill which would aid in the development of city skyscrapers and suburban communities. With the help of portable compressed air, the Industrial Revolution saw road construction, bridgework, and railroad development open new economic opportunities for farmers, factory owners and various businesses to expand market potential and profitability. This period of prosperity was also filled with inventors and manufacturers seeking ways to improve the daily lives of American families by quickly developing and distributing modern appliances and devices, mass producing and packaging processed foods, and much more – all thanks to the help of compressed air and pneumatic tools.

Furthermore, in 1933, the first two-stage air-cooled portable compressor was manufactured and in no distant time, standard sizes and ratings on actual free air delivery were established. Later, a Swedish professor named Alf Lysholm designed the first twin screw compressor while working on steam and gas turbines. The screw compressor was patented in Sweden in 1935, and then found its way around the world including the Americas [10]. As global development continued, people began to conceptualize more ways to utilize this technology such as the mining industry, especially in the United States, where compressed air not only powered drills, but other machines such as hauling, pumping and stamping machines.

Well, although arguably inefficient and unreliable until the 20th century, air compressors have withstood the test of time and are vital to the productivity of almost every industry and the overall global economy. Today, air compressors continue to advance in technology and diversify offerings to keep up with the ever-changing needs and demands of business [9].

2. Classification of Air Compressors

Compressors are broadly classified as Positive displacement compressor and Dynamic compressor[11].

1) Positive displacement compressorslowers the volume of the gas to raise the pressure within it.

They can also be divided into rotary and reciprocating compressors.

2) Dynamic compressors speed up the air, which results in more pressure being applied at the outlet. Centrifugal compressors are the basis for dynamic compressors, which are further divided into axial and radial flow types. A certain type of compressor is suitable for a given application depending on the flow and pressure requirements.

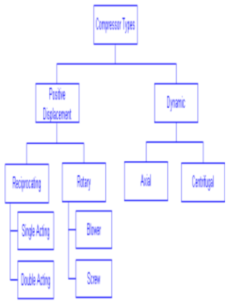

Figure 1 Compressor types based on operating principles

2.1 Positive-Displacement Compressor

Positive displacement compressors, which may be broadly categorized into two types—rotary compressors and reciprocating compressors—deliver a fixed amount of air at high pressures. A certain incoming volume of gas is constrained in a particular space in all positive displacement machines, and it is then compressed by shrinking this constrained area or volume. The gas is then released into the discharge pipe or vessel system at this high pressure [11].

2.2. Reciprocating compressors

The reciprocating, or piston, compressor is a positive displacement compressor that transfers gas from one pressure level to a higher pressure level by moving a piston inside a cylinder. Table 1 lists several reciprocating compressor benefits and drawbacks [11].

Table 1: Advantages and disadvantages of reciprocating compressor

SN	Advantages	Disadvantages
1.	Simple design, easy to install	Higher maintenance cost
2.	Lower initial cost	Many moving parts
3.	Large range of horsepower	Potential for vibration problems
4.	Special machines can reach extremely high Pressure	Foundation may be required depending on Size
5.	Two stages models offer the highest efficiency	Many are not designed to run at full capacity

2.3 Rotary Compressors

Rotary compressor is a set of positive displacement devices which has many vanes and a center rotating rotor. This device uses a rotating component to generate pressure. The devices are small, reasonably priced, and need very little running care and upkeep. Table 2 displays the benefits and drawbacks of rotary compressors [11].

Table 2 Advantages and disadvantages of rotary compressor

SN	Advantages	Disadvantages
1	Simple design	High rotational speed
2	Low to medium initial and maintenance Cost	Shorter life expectancy than any other designs
3	Two-stages design provide good efficiencies	Single-stage designs have lower efficiency
4	Two-stages design provide good efficiencies	Difficulty with dirty environment
5	Few moving parts	

2.5 Dynamic Compressor

Dynamic compressor also called a continuous-flow compressor combines an axial and centrifugal compressor. It is frequently utilized for certain services in the chemical and petroleum refinery industries. They are also utilized in various fields, including the production of iron and steel, pipeline boosters, and reinjection compressors on offshore platforms. The revolving impeller of a dynamic compressor increases the fluid's velocity and pressure. The dynamic compressor is substantially smaller and produces far less vibration than the positive displacement type [11].

2.6 Centrifugal Compressor

A dynamic device, the centrifugal compressor compresses gas by imparting inertial forces (acceleration, deceleration, and rotation) by the use of rotating impellers. It is composed of one or more stages, each of which has a diffuser as the fixed component and an impeller acting as the spinning component. Diffusers come in two varieties: vane less diffusers and vaned diffusers. While the vane less diffuser is utilized in situations where a high pressure ratio or high efficiency are required, it is frequently employed in applications with a wide working range. Those parts of centrifugal compressor are simply pictured in Figure 2 [11].

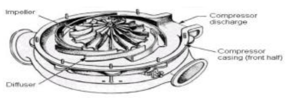

Figure 2 Centrifugal Compressors

The fluid flow enters the impeller of a centrifugal compressor in an axial direction, and it exits the impeller radially at a right angle to the axis of rotation. Impeller blades rotate quickly, forcing the gas fluid through the impeller. The gas then travels in a spiral around a circular chamber (the diffuser), losing speed and gaining pressure. Table 3 provides a summary of the centrifugal compressor's benefits and drawbacks.

Table 3 Advantages and disadvantages of centrifugal compressor

SN	Advantages	Disadvantages
1	High efficiency approaching two stages reciprocating compressor	High initial cost
2	Can reach pressure up to 1200 psi	Complicated monitoring and control systems
3	Completely package for plant or instrument air up through 500 hp	Limited capacity control modulation, requiring unloading for reduced capacities
4	Relatives first cost improves as size Increase	High rotational speed require special bearings and sophisticated vibration and clearance monitoring Specialized maintenance considerations
5	Designed to give lubricant free air	
6	Does not require special foundations	

2.7 Axial Flow Compressor

Gas turbine compressors are the major application for axial flow compressors. They are utilized in huge nitric acid facilities and blast furnace blowers in the chemical and steel industries, respectively. Axial flow compressors, in contrast to other types of compressors, are typically utilized in situations where a low necessary head and a high intake volume of flow are present. An axial flow compressor has a better efficiency than a centrifugal compressor. They come in sizes that can generate pressures greater than 100 psi with input volumes ranging from 23,500 to 588,500 acfm. The direction of the flow stream is not greatly changed by axial flow compressors; the fluid stream enters the compressor and exits the gas turbine in an axial direction (parallel with the axis of rotation). Here are the advantages and disadvantages of axial flow compressor as in table 4 [11].

Table 4 Advantages and disadvantages of Axial flow compressor

SN	Advantages	Disadvantages
1	High peak efficiency	Good efficiency over narrow rotational speed range
2	Small frontal area for given airflow	Difficulty of manufacture and high cost
3	Straight-through flow, allowing high ram efficiency	Relatively high weight
4	Increased pressure rise due to increased number	High starting power

	of stages with negligible losses	requirements

III. DESIGN THEORY AND CALCULATIONS

1. Design Concept

The aim of this study is to design, fabricate, and evaluate the performance of a 4-bar air compressor while conducting a detailed 3D model and simulation of the machine using SolidWorks. Below is an isometric view of the Design.

Figure 3 Isometric View of the Air Compressor Model using SolidWorks

2. Components

The 6.5Hp Air Compressor consists of the following components;

1. Pump
2. Engine
3. Belt
4. Tank.
5. Tank Drain
6. Frame and Support
7. Hose
8. Pipes
9. Fittings
10. Shock absorber
11. Control shaft
12. Pressure spring
13. Outlet pipe
14. Bolts
15. Belt Guard
16. Discharge Tube
17. Pressure Gauge
18. Tyre rollers

3. The Air Pump

The pump is a mechanical device that moves air by mechanical action, thus converting the mechanical energy transmitted via the belt into hydraulic energy. The power conveyed into the liquid increases the energy of the liquid per unit volume. Thus, the power relationship is between the change of mechanical energy of the pump mechanism and the air molecules within the pump.

A 4-bar air pump requires a torque of about 20Nm to 34Nm depending on the pump efficiency to operate well[12]. The pump selected for the design of the air compressor is the centrifugal pump with an operating pressure of about 4 bars which is best suited for the specification required.

4.The Pump Efficiency

The efficiency defines the percentage of energy supplied to the pump that is converted into useful work.

$$efficency = \frac{P_{out}}{P_{in}} \quad - \quad - \quad - \quad - \quad - \quad (1)$$

3.2.2 The Engine

A 6.5 HP engine is used as the prime mover for the compressor pump. The power generated by the engine is transmitted to the pump via the belt system. The Engine meets the torque and speed requirements of the pump were selected using the results of the pump specifications from above.

The Engine specification

Marketing Gross Power (Rated Power) = 6.5 HP
Number of Cylinders = Single-Cylinder Machine
Engine Type = Air-cooled 4-stroke OHV single Cylinder
Maximum Torque = 24.8 Nm
Speed N_2 = 1700 (+/- 150) rpm
Height = 330 mm
Width = 370 mm
Length = 291 mm
Weight = 15 kg
Fuel tank Capacity = 3.6 Litres

3.2.3The Transmission System

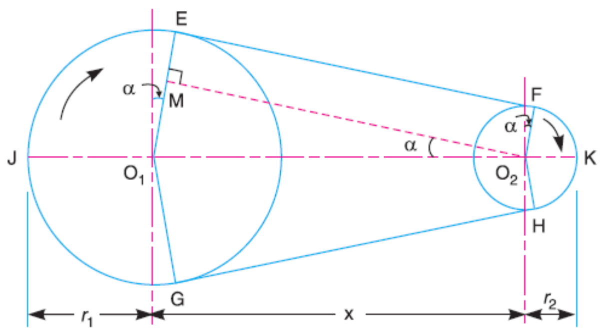

Figure 4: Belt drive system[13].

The belt system transmits the power from the engine to the air pump.

The pulley EGJ is the driven pulley (pump) and the pulley FKH is the driving pulley (engine).

Where;

d_1, d_2, r_1 and r_2 = Diameters and Radii of the larger and smaller pulleys,

x = Distance between the centers of two pulleys (*i.e.* $\overline{O_1 O_2}$), and

L = Total length of the belt.

N_1 and N_2 are the speeds of the larger and smaller pulleys respectively

- **Diameters of the pulleys**

From the speeds specified, the diameter of the larger pulley can be determined by the velocity ratio $\frac{N_2}{N_1} = \frac{d_1}{d_2}$ - - - - - - - - - (2)

$N_1 = 1752$ rpm

$N_2 = 1700$ (+/- 150) rpm

d_2 from its design is 100 mm and $r_2 = 50$ mm

$d_1 = \frac{N_2 \; x \; d_2}{N_1}$

$d_1 = \frac{1850 \; x \; 100}{1752}$

$d_1 = 105.59$ say 110 mm and $r_1 = 55$ mm

- **Speed of the belt drive**

$v = \frac{\pi d N}{60}$ - - - - - - - - - (3)

$= \frac{\pi(0.110)(1850)}{60}$

= 10.65 m/s

- **Length of belt required**

$L = \pi(r_1 + r_2) + 2x + \frac{(r_1+r_2)^2}{x}$ - - - - - (4)

$= \pi(55 + 50) + 2(500) + \frac{(55+50)^2}{500}$

= 1351.9 mm

- **The angle of Contact, β**

Angle of contact β = 180° + 2α - - - - - - (5)

$\text{Sin } \alpha = \frac{r_1+r_2}{x}$

$\text{Sin } \alpha = \frac{55+50}{500}$

$\alpha = Sin^{-1}(0.21)$ - - - - - - - (6)

$\alpha = 12.12$ °

Thus θ = 180° + 212.21° = 204.42° = 3.57 rad

- **Tensions in the belt**

The coefficient of friction, μ between leather and cast iron is 0.25 [14].

Also, the maximum tension, T_1 on the belt is 1484N [15].

Using $2.3\log\left(\frac{T_1}{T_2}\right) = \mu \cdot \theta$ - - - - - - (7)

$T_2 = \frac{T_1}{antilog\left(\frac{\mu \cdot \beta}{2.3}\right)}$

$T_2 = \frac{1484}{antilog(\frac{(0.25x3.57)}{2.3})}$

= 607.2 N

Required initial belt tension, $T_0 = \frac{T_1+T_2}{2}$ - - - - (8)

$= \frac{1484 + 607.2}{2}$

= 1227.6 N

- **Power Transmitted**

Thus power transmitted is

$P = (T_1 – T_2)v$ - - - - - - - - (9)

Thus the power is

P = (1484 - 607.2) x 10.65

= 9337.9 W

= 9.3 kW

3.2.4 The Tank

The compressed air tank functions as a reservoir for the compressed air. An air tank gotten out of a heavy-duty truck was used as the air reservoir. The air reservoir is the component that stores the air. As the compressor pushes high-pressure air, it is stored in the air tank or compressed into the air tank up to 100 to 150 psi (6 to 8 Bars), so that it can be used to inflate a car tire or to inflate a balloon or drive power tools.

Tank Specifications

The tank was completely sealed to avoid any air leakage when the air is under pressure. This action was made possible by a type of welding called arc welding. After which a fitting was welded at the tie end of the tank so that the rollers can be fixed on the sitting, and by so doing, it will make easy transportation of the machine around the work area possible. Still, on the tank, a 2 inches angle iron is welded to the tank to create a base or provide a base for other components to sit on. For example, a 2inches angle iron was cut and welded into a 7.5inches.

3.2.5 Cylinder design

(a) Longitudinal stress in the cylinder tank

The cylinder is subjected to the same internal pressure which tends to split the cylinder into two

Maximum Pressure = 4 bars = 58 psi = 400 kPa = 0.4 N/mm^2, Cylinder diameter d = 550 mm, thickness = 4 mm

Therefore Longitudinal stress, σ_L is given by:

$\sigma_L = \frac{Total\ pressure}{resisting\ section}` = \frac{pd}{4t}$ - - - - - - (10)

$$\sigma_L = \frac{0.4 \text{ x } 550}{4 \text{ x } 4}$$

= 13.75 N/mm^2

(b) Circumferential stress in the cylinder tank

The cylinder is subjected to internal pressure that will tend to split the cylinder into two troughs.

Therefore circumferential stress, σ_C is given by:

$$\sigma_C = \frac{Total\ pressure}{resisting\ section} = \frac{pd}{2t} \quad (11)$$

$$\sigma_C = \frac{0.4 \text{ x } 550}{2 \text{ x } 4}$$

= 27.5 N/mm^2

3.2.6 The Frame

The air compressor assembly is mounted on an angle iron frame.

3.2.7 The Hose

A high-pressure hose capable of withstanding 6 to 8 bars is suitable for this design.

The dimension of the hose is uniform throughout its length. The diameter of the hose is greater than that of the delivery pipe and is given by:

$$d = \sqrt{\frac{4Q_{max}}{\pi v}} \quad (12)$$

where d = Hose inner diameter (m)

Q_{max} = Maximum flow rate m^3/s

v = Fluid mean velocity, m/s

Flow rate through the hose is

$\dot{Q}$is flow rate in m^3/s = $\frac{\Delta P \pi D^4}{128 \mu L}$ = $\frac{(P_1 - P_0) \ x\ \pi\ x\ (d)}{128\ x\ \mu\ x\ L}$

Where

$$\dot{Q} = Flow\ rate\ in\ m^3/s$$

$\Delta P\ pressure\ differenciatial$ = $P_1 - P_0$

P_1 = Operating tank pressure

P_0 = Pressure at end of the hose

D = diameter of hose

L = Length of hose

μ = Dynamic viscosity of air

The delivery hose is connected to the rotating, however, there is a little pressure difference from the tank outlet to the end of the hose. This is due to the pressure used to do some work in moving the air from the tank to the end of the hose.

According to theoretical considerations, there are two types of losses during the flow of fluid through pipes;

1. Minor losses
2. Major losses

Minor losses: these are losses that occur whenever there is a change in the cross-section of the pipe. They are caused by the disruption of the flow due to the installation of appurtenances, such as bends and other fittings in the piping system.

Major losses: these are losses that occur in the pipe because of friction. It is termed a major loss because there is a significant loss of energy because of friction.

During the flow of fluid through the pipe unit, Bernoulli's equation and Darcy-Weisbach equation are needed to calculate power in the system and also losses in the system.

3.2.8 Fittings

Fittings or adapters are used in the systems to connect straight sections of pipes or tubes, adapt to different sizes, and shapes, and change the direction of flow.

Due to the presence of leakages, fitting which can effectively connect the hose to the compressor and the tank is used. 17mm nut welded will be used on the tank to allow for the air pressure gauge to fit into the tank and read the air pressure inside the tank when the machine is in operation. The fitting will be made out of a 4mm sheet metal and a ½ inches steel pipe.

These fittings were made such that there were no leakages at the joints by use of water-proof glue.

3.2.9 The Shock Absorber

A shock absorbing system was placed in between the angle iron on the tank and the angle iron constructed into 7 and ½ inches by 20 and ½ inches. The shock absorber that is in between serves as a means of removing unwanted vibrations from the machine when in operation.

3.2.10Pressure spring

In other to avoid excessive pressure and stress in the tank and the system, a pressure regulator is constructed, the regulator is constructed with a 2 and ½ inches pipe and a piece of 2 mm sheet metal, and some high-pressure spring. The spring presses down on round sheet metal of 2 inches in diameter, and under neat the 2 inches 2 mm round sheet metal is a hole of 10 mm. In between the sheet metal and the hole is a rubber sheet. The spring presses down on the round sheet and the rubber sheet against the hole leading into the interior of the air tank as the compressor compresses air into the air tank, when the air reaches 100 psi, the air pressure will lift the round sheet metal and the rubber upward, thereby allowing some air to escape through the air exit on the pressure regulator, hence putting under control any catastrophic damage that can result from excess pressure from the machine when in operation.

3.3Design Theory and Analysis

This design is intended to be mounted on a variety of applications requiring the use of compressed air. An attempt will now be made to state and apply relevant equations which govern the operation of the air compressor and the energy interactions at various points.

3.3.1 Energy interaction of the air

One of the most common problems in fluid flows is to determine the relationship between velocity, pressure, and elevation of a flowing fluid in a pipe or other duct. To do this, we enforce conservation of energy on the fluid, i.e. the energy contained by the fluid at one point in the flow is the same as any other, but the energy may be transformed from one form to another. Moreover, it is more convenient to work with power (rate of change of energy) rather than energy itself.

3 types of power must be considered, and their sum conserved. In words, the conservation of energy can be stated as:

(Power needed to push fluid into the tube inlet - power extracted at the tube outlet) + (kinetic power of the fluid flowing into the tube - kinetic power of the fluid flowing out of the tube) + (power associated with the change of gravitational potential energy of fluid) = 0

The power needed to push fluid into the tube inlet or power extracted at the tube outlet:

$$\text{Power} = \text{force} \times \text{velocity}\left(\frac{force}{area}\right)(velocity \times area) \quad (13)$$

$$= \text{pressure x (volume/time)} = \text{pressure x } \frac{mass/time}{mass/volume} = \frac{P\dot{m}}{\rho}$$

Where;

$\dot{m}$ is the mass flow rate (units kg/sec)?

ρ is the density of the fluid (kg/m^3)

Kinetic power of the fluid

$$\text{Power} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right) = \frac{1}{2}\frac{dm}{dt}v^2 = \frac{1}{2}\dot{m}v^2 \quad (14)$$

3.3.2. Conservation of Mass

For a steady flow in a pipe, the mass flow rate $\dot{m}$ (kg/s) has to be uniform throughout the flow system. The mass flow rate is the product of the fluid density (ρ), velocity (v), and the cross-sectional area of the pipe through which the fluid flow;

$$\dot{m} = \rho_1 v_1 A_1 = \rho_2 v_2 A_2 \quad (15)$$

3.3.3. Losses of Energy in the Piping System

- Minor losses
- Sudden expansion losses:

$$(h_l)_{exp} = \frac{(v_1 - v_2)^2}{2g}$$

- Exit loss:

$$(h_l)_{exit} = \frac{{v_1}^2}{2g} \quad (16)$$

- Sudden contraction loss:

$$(h_l)_{con} = \frac{(v_c - v_2)^2}{2g} \quad (17)$$

Where v_c= velocity at vena contracta

- Entrance loss:

$$(h_l)_{ent} = \frac{0.5 \times {v_2}^2}{2g} \quad (18)$$

- Bend loss:

$$(h_l)_{bend} = \frac{kv^2}{2g} \quad (19)$$

The value of k depends on the angle of the bend and the radius of the curvature of the bend.

- Major loss:

The major loss is the head loss due to friction. According to Darcy's Weisbach equation:

$$h_l = \frac{flv^2}{2gD} \quad (20)$$

Where;

F = friction factor

L = length of pipe

V= velocity of flow

D = diameter of the pipe.

3.4 Working Principle of the Machine

The air compressor works by converting rotational force from the 6.5 Hp multipurpose engine into an up and down motion inside the air compressor pump. The air pump has about 8 cylinders. Each cylinder has a piston and the rotation from the engine is transferred to the air compressor with the help of a fan belt. The piston inside the compressor moves downward, this downward motion of the piston inside the compressor makes the cylinder suck air from the atmosphere, and also, a valve is opened inside the compressor to allow air into the cylinder. As the rotation of the compressor continues, the piston moves back inside the cylinder. The valve through which air goes into the piston is closed. As the piston moves back up immediately, another valve is opened to direct the air into the air output of the compressor. The air output of the compressor is linked to the air inlet of the air tank. The valve that opens for the air to come into the cylinder is linked to the air inlet of the compressor. The air compressor is thereafter able to pump air at every revolution of the speed. If the multipurpose engine is increased to its highest level of 3000 rpm, the air compressor pump will rotate at 2000 rpm, thereby making the compressor pump air faster. The speed at which the compressor can pump air faster to high pressure inside the air tank is proportional to the speed and the power of the multipurpose engine driving it. As the multipurpose engine is in operation, along with every other component in the machine, the crankshaft of, the multipurpose engine makes the engine vibrate. This vibration has to be compensated so that the vibration doesn't affect the bolt and the nut on the machine and make them loose. With the help of a shock absorber present in the machine, the vibration and the shock are absorbed by the shock absorber, thereby making the machine run for a long time and smoothly without any need for repair caused by vibration because the machine runs on gasoline, it is safe to use and operate this machine in a well-ventilated environment to prevent carbon dioxide poison.

IV. RESULTS

1. Bill of Engineering Measurement and Evaluation

The commercial success or failure of any product depends largely on the profit made from sales of the product which is equally a function of the integral performance of the individual components. The bill of engineering measurement and evaluation includes expenses directly associated with the production of the air compressor. These include material cost, transportation cost, labour cost, and procurement cost.

Table 5: Evaluating Bill of Engineering Measurement

SN	ITEM	QUANTITY	UNIT PRICE	COST (N)
1	Heavy duty truck air tank	1	8000	8000
2	Air compressor (pump)	1	9500	9500
3	6.5hp Multipurpose engine	1	35000	35000
4	Flexible hose	2	4750	9500
5	High pressure hose	1	3000	3000
6	17mm bolts and nuts	4	150	600
7	10mm bolt and nut	4	175	700
8	Zip tie (packet)	1	700	700
9	Cup of car paint	3	3000	9000
10	Cup of car paint	3	3000	9000
11	Length of 2 inches angle iron	2	8000	16000
12	Sheet of 4mm sheet metal	1	15000	15000
13	Engine shock absorbers	4	700	2800
14	13mm Bolt and nut	8	75	600
15	Tyre rollers	2	3500	7000
16	Length of 1 and ½ inches pipe	1	8000	8000
17	Pressure gauge	1	5000	5000
18	Pressure regulator	1	5000	5000
19	Clip for the pressure hose	4	200	800
	Total Material			145,200

4.1.1 Total Cost

Total Material Cost ₦145,200

Labor cost is based on 75% of the material cost

$$\frac{40}{100} \times 145{,}200 = ₦58{,}000$$

Transportation cost is based on 10% of the material cost

$$\frac{10}{100} \times 145{,}200 = ₦14{,}520$$

miscellaneous expenses is based on 5% of the material cost

$$\frac{5}{100} \times 145{,}200 = ₦7260$$

Overall cost = 145200 + 58,000 + 14520 + 7260
= ₦ 224,980

4.2. Material Selection

The materials used for the design was selected by taking factors like availability of materials, cost, Weight, resistance to corrosion and strength into consideration. Some of the important materials Selected include; Steel for the air tank, galvanized iron for the support and thick engine sitting-rubber for then shock absorber spring.

4.3. Performance Evaluation

4.3.1 Apparatus

The apparatus used in carrying out the performance test of the machine is described below:

i. Pressure Gauge: For measuring the internal pressure of the compressed in the air tank of the machine.

ii. A stop watch: A stop watch was used to measure the time taken for the air compressor to attain 75% of the safe operating pressure of 45 psi of the machine. The results obtained when the machine was tested are as shown

4.4. Results of readings

Table 6: Table of results readings

SN	Pressure (psi)	Volume (Litres)	Time
1	14.6	60	00
2	25.8	60	120
3	35.7	60	240
4	45.6	60	120

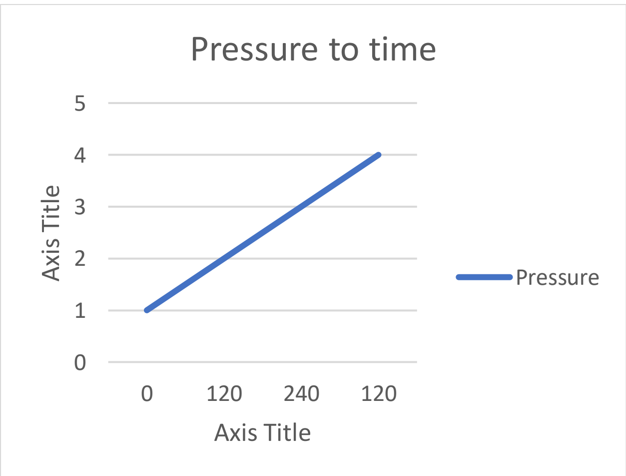

Figure 5: Graph of pressure to time

Efficiency

$$\eta = \frac{Power_{hydr}}{Power_{Mech}}$$

Work Input

Formular for input and conditions

$Power_{Mech}$ = Wattage x time

The engine produces 6.5 Hp = 4847 W

Since the engine was run for 2 minutes (120 seconds) before the pressure relief valve triggered off

$Power_{Mech}$ = 4847 x 120
= 581,640 W
= 581 kW

Work Output

Formular for input and conditions

$$Power_{hydr} = P_1 x\, \dot{Q}_1 x \left(\frac{P_4}{P_1}\right)$$

Volume = constant = 60 Litres = 0.060567 m^3

Where P_1 and P_4 are final and initial pressures in Pa,

P_1 = 45.6 psi = 314 kPa

P_4 = 14.6 = 100 kPa

$\dot{Q}$is flow rate in m^3/s = $\frac{\Delta P \pi D^4}{128 \mu L}$ = $\frac{(P_1 - P_0)\, x\, \pi\, x\, (d)^4}{128\, x\, \mu\, x\, L}$

Where

$$\dot{Q} = Flow\ rate\ in\ m^3/s$$

$\Delta P\ pressure\ differenciatial$ = $P_1 - P_0$

P_1 = Operating tank pressure

P_0 = Pressure at end of the hose

D = diameter of hose

L = Length of hose

μ = Dynamic viscosity of air

= $\frac{(314 - 282.6) kPa\, x\, \pi\, x\, (0.01\, m)^4}{128\, x\, 4.5\, x\, 10^{-5} x\, (1.5\, m)}$

= 0.114 m^3/s

$Power_{hydr}$ is hydraulic power

$$Power_{hydr} = P_1 x\, \dot{Q}_1 x \left(\frac{P_4}{P_1}\right)$$

= 314 x 10^3x 0.114 x $\left(\frac{100\, x\, 10^3}{314\, x\, 10^3}\right)$

= 114 kW

The efficiency is:

$$\eta = \frac{Power_{hydr}}{Power_{Mech}}$$

= $\frac{114\, kW}{581\, kW}$

= 0.19 say 19%

4.5 Cost Evaluation

Table 7: Cost of air compressors by popular vendors

SN	Rating	Price (N)
1	**50 Litres, 4 bar**	**202,637.50**
2	**100 litres, 10 bar**	**336,561**

Comparing the costs to get the cost efficiency;

$$= \frac{Cost\ of\ designed\ air\ compressor}{Cost\ of\ commercial\ air\ compressor}$$

$$= \frac{202637.50}{224980}$$

= 90%

Thus the design is economically considerable.

V. CONCLUSION

The performance evaluation of the air compressor is done using the pressure gauge to obtain pressures of the air in the tank and how much work was done on the air by the compressor as it was run by the 6.5 Hp fuel engine. From the data obtained and processed during experimentation, it can be inferred that useful amount of energy can be stored in the form of pressured air using an air compressor. The process is however not 100% efficient and this is evident in the fluctuations of the pressure read by the use of the pressure gauge. To ensure safety of operators and the equipment's a pressure relief valve was set to about 70% of the maximum pressure (60 psi). The efficiency got by using the direct work comparison method was about 19% showing the 81% of work done on the system was lost to heat and friction without doing useful work. The cost of design and fabrication of the air compressor was also compared to the cost of purchasing compressors of similar rating. It was found to be economically reasonable.

RECOMMENDATIONS

This design project presents the following recommendations:

1. Since the cost of fuel is on the increase, an alternative energy source, say an electric motor, can be used in place of the fuel engine.
2. More work can be done to analyses the flow characteristics and heat interactions of the compressed air during compression, after compression and during use.

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