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Pneumatic Operated Engine

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Abstract

The increasing awareness of fossil fuel depletion and environmental pollution has accelerated the need for the development of sustainable and eco-friendly alternatives to traditional internal combustion engines. Pneumatically operated engines have been identified as a potential alternative for small-scale mechanical power generation owing to their advantages of zero exhaust emissions, noise reduction, and operational safety. This paper describes the design, development, and performance analysis of a pneumatically operated engine, which uses compressed air as a carrier energy to generate mechanical motion without combustion. The proposed system uses a double-acting pneumatic actuator controlled by a directional control valve that converts the energy of compressed air into a reciprocating piston motion. The linear motion is then converted into rotary motion using a crank-pulley and belt transmission mechanism along with a flywheel for smooth and continuous operation. The engine was designed to work at a pressure range of 3 to 6 bar, and the calculations were performed to find the required piston diameter and air consumption for a force output of 2000 N. Experimental testing and graphical representation were carried out to analyze the effect of supply pressure, actuator speed, and stroke time. The results show that an increase in operating pressure results in a corresponding increase in piston speed and a decrease in cycle time. At 6 bar pressure, the system performed optimally, making it suitable for driving light mechanical loads up to 200 kg. A comparative analysis with conventional internal combustion engines reveals the benefits of the new technology, which include zero emissions, reduced thermal losses, low maintenance, and suitability for use in hazardous environments. Despite the limitations of the technology, including the need for a compressed air supply and lower energy density, this research has shown that pneumatically operated engines are feasible for use in light vehicles, automation systems, and auxiliary power units. The results of this study have confirmed the potential of pneumatic engines as a sustainable alternative for specific low-power applications, thus encouraging further research in this area.

Keywords: Pneumatic engines, compressed air technology, sustainable engineering, zero emissions, green technology

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INTRODUCTION

The growing pace of industrialization and urbanization in today's world has resulted in a substantial rise in the demand for energy on a global scale, which is being met to a large extent by fossil fuels [1]. However, the widespread use of internal combustion (IC) engines has caused severe environmental issues, such as greenhouse gas emissions, noise pollution, and exhaustion of non-renewable energy resources, which have encouraged researchers and engineers to look for alternative and sustainable energy resources [2, 3].

One such promising alternative energy source is the pneumatic operated engine, which uses compressed air as the working fluid to produce mechanical energy without involving any combustion process [4]. In a pneumatic engine, high-pressure compressed air is supplied to a cylinder, which generates a force on the piston to produce linear motion. This linear motion is then converted into rotary motion by a crank and shaft mechanism, similar to that of an IC engine [5].

Unlike gasoline or diesel engines, pneumatic engines run solely on the power of compressed air, making fuel combustion and subsequent exhaust emissions obsolete. Consequently, the process of operating vehicles has become greener, cleaner, and more environmentally sustainable [6]. Moreover, pneumatic engines provide enhanced safety during operation owing to the absence of flammable fuels, making them ideal for use in hazardous and environmentally sensitive settings [7].

Research Question

Can a Pneumatic Engine be Developed to Replace IC Engines in Small-Scale Applications in a Cost-Effective, Efficient and Sustainable Manner?

To answer the research question, the current study aims to design, develop, and manufacture a functional prototype of a pneumatic engine. The prototype was then tested to examine its performance, efficiency, and usability for small-scale applications [8].

The purpose of this research is to contribute to sustainable engineering solutions by investigating alternative emission-free power generation methods. The pneumatic engine has many benefits, including its compact design, low maintenance costs, and ability to operate safely in oxygen-sensitive or flammable environments [9]. This technology has the potential to reduce the use of fossil fuels such as diesel, petrol, and kerosene if it is developed and utilized properly, which can help mitigate climate change [10].

LITERATURE REVIEW

Pneumatically driven engines have also gained attention in recent years as an alternative to the recent year's working conventional IC engines and eco-friendly driving systems.

Majumdar (1996) laid out the principles of pneumatic system knowledge, detailing the concepts, components, and maintenance routines necessary for proper air-operated equipment design [1].

Similarly, Parr (2011) hypothesized the comparative performance of pneumatic and hydraulic systems, stating that although pneumatics are good for cleaner and safer operations, they have limitations in terms of energy density and accuracy of control factors influencing the efficiency and usability of pneumatic engines [2].

Thakker et al. (2015) created and developed a basic pneumatic engine model, which proved its feasibility of running on compressed air. In their research, it was proven that with suitable mechanical design and control, engines can produce adequate torque to drive light loads as an alternative source of fuel instead of fossil fuel [3].

Kurien et al. (2014) performed a theoretical analysis of the system configuration, storage requirements, and performance restrictions of a compressed air-powered car. They presented concerns about poor energy density and steep pressure decay but emphasized the zero-emission green benefit and noise elimination [4].

Noronha et al. (2019) employed MATLAB Simulink to model the pneumatic cylinder performance, providing insight into dynamic performance parameters such as pressure build-up, response time, and actuation delay. Such a simulation-based strategy is easily transferable to pneumatic engine design, as it allows for accurate modeling and optimization of the airflow and timing mechanisms [5].

Patel et al. (2016) surveyed various pneumatic systems used in the industry, noting their reliability and ease of integration with automation. While not directly involving engines, their notes on system efficiency, component selection, and maintenance practices are of immense utility for the long-term application of air-powered mechanisms [6].

ISO 6431:1992 standardizes the mounting and dimensional requirements for single rod pneumatic cylinders to be interchangeable and compatible. These requirements play a significant role in modular engine designs, where consistency and interchangeability are required [7].

Doughty et al. (2018) discussed energy use in compressed air systems and suggested ways to maximize energy efficiency by curtailing compressor use, leakage detection, and air storage regulation. They conserve energy, especially in pneumatic engine systems, where compressed air is the source of energy with the widest influence [8].

METHODOLOGY

This study illustrates an experimental approach to designing and testing the functioning of a pneumatically operated engine. The timeline of crafting a step-by-step process from the design, fabrication, and prototype testing to scientific data collection and analysis to measure its operational values and feasibility towards small-scale implementation.

STUDY DESIGN

An experimental approach was employed to establish the functional efficiency of a compressed air-powered pneumatic engine. The study involved constructing a functional or working model and testing it by performance measurement through quantitative and qualitative analyses under different levels of pressure.

MATERIALS AND COMPONENTS

- The following components are used in the system:
- Double-acting pneumatic cylinder (actuator)
- Air compressor with a regulated storage tank
- Directional control valve (5/2 valve)
- Drive pulley mounted on the actuator crankshaft
- Driven pulley attached to wheel shaft
- V-belt for mechanical power transmission
- Flywheel for inertia and stability
- Steel base frame for mounting
- Pressure gauges, tachometer, and safety fittings

PROTOTYPE DEVELOPMENT

The fabrication was carried out in the following phases (Figure 1).

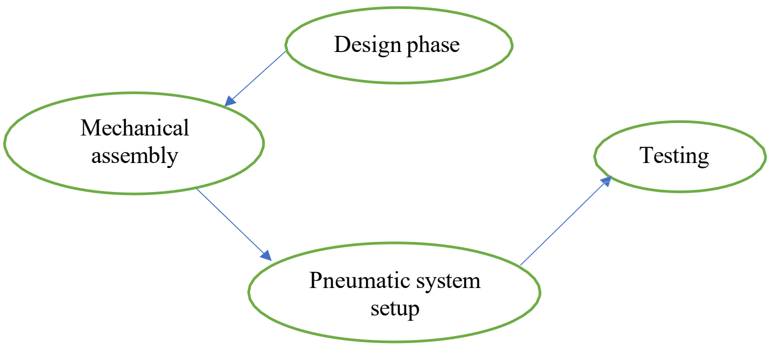

Figure 1. Prototype development.

POWER TRANSMISSION MECHANISM

The pneumatic actuator pushes and pulls its piston rod under alternate air inputs from the directional control valve. This reciprocating movement rotates the drive pulley back and forth owing to the offset bolted connection. A V-belt links the drive pulley to the driven pulley attached to the wheel axle, converting the oscillating input into rotational wheel motion. The flywheel inertia helps to smooth the motion and maintain continuity between the strokes.

Safety Measures

Safety protocols included:

- Relief valves and emergency shutoffs on the air tank.
- PPE (goggles and gloves) during testing.
- Secured frame and shielded pulley system to prevent accidents from moving parts.
- Leak and vibration checks before each test run.

CALCULATIONS

Known Parameters

- *Required Force (F):* 2000 N
- *Working Pressure (P):* 6 bar = 600,000 Pa

  Formula: $F = P \times A$

  $\Rightarrow A = F / P$

- Calculate Required Piston Area (A)

  $A = 2000 / 600000 = 0.00333\ m^2$

- *Calculate Required Diameter*

  $A = \pi d^2 / 4$

  $\Rightarrow d = \sqrt{(4A / \pi)}$

  $= \sqrt{(4 \times 0.00333 / 3.1416)}$

  $\approx \sqrt{(0.00424)}$

  ≈ 0.065

So, the required piston diameter is ~65 mm.

SUMMARY FOR 2000 N

The calculated design parameters required to achieve a force output of 2000 N at a pressure of 6 bar are summarized in Table 1.

Table 1. Summary of design parameters for 2000 N force output.

Parameter	Value
Required force (F)	2000 N
Working pressure (P)	6 bar (600,000 Pa)
Required area (A)	0.00333 m²
Piston diameter (d)	~65 mm
Stroke length (assumed)	150 mm
Air volume per stroke	0.00333 × 0.15
= 0.0005 m³ = 0.5 L	

Table 2. Effect of supply pressure on engine speed.

Pressure	Force	Output speed (approx.)
3 bar low	(~50%)	Slow
4 bar medium	(~66%)	Moderate
5 bar good	(~83%)	Fast
6 bar full	(100%)	Max speed

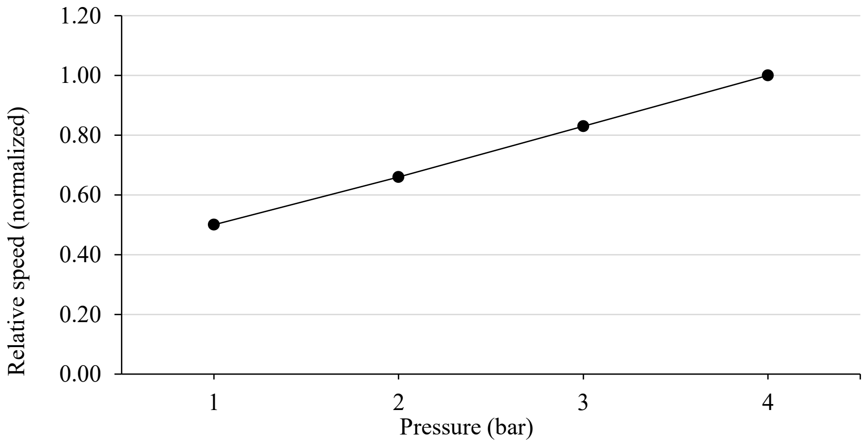

Figure 2. Actuator speed versus pressure.

APPROXIMATE EFFECT OF PRESSURE ON SPEED

Assuming a constant load and airflow, increasing the pressure generally increases the initial force, thereby accelerating the piston. The qualitative effects of the supply pressure on the actuator force and output speed are presented in Table 2.

Graphical analysis: The graph illustrates the variation of normalized piston speed with respect to input pressure ranging from 3 to 6 bar. A clear linear trend is observed, indicating that the speed of the pneumatic engine increases proportionally with the supplied pressure. This is due to the direct relationship between pressure and force output as per the equation:

Force = Pressure × Area

This increased force led to higher acceleration and hence speed, validating the suitability of pneumatic systems for variable-speed applications depending on input pressure control (Figures 2–4).

CAD MODEL

Figure 4 illustrates the chassis construction.

FUTURE EXPLORATION

Automation and Control Integration

Incorporating programmable logic controllers (PLCs) or microcontroller-based systems can enable the real-time control of stroke length, speed, and pressure regulation, thereby improving precision and adaptability.

Hybrid Actuation Systems

Exploring hybrid systems that combine pneumatic and electric or hydraulic drives could enhance the torque, energy efficiency, and flexibility across different load conditions.

Energy Efficiency Optimization

Advanced flow control valves, pressure sensors, and regenerative systems can be integrated to minimize air consumption and energy losses, particularly for continuous or cyclic operations.

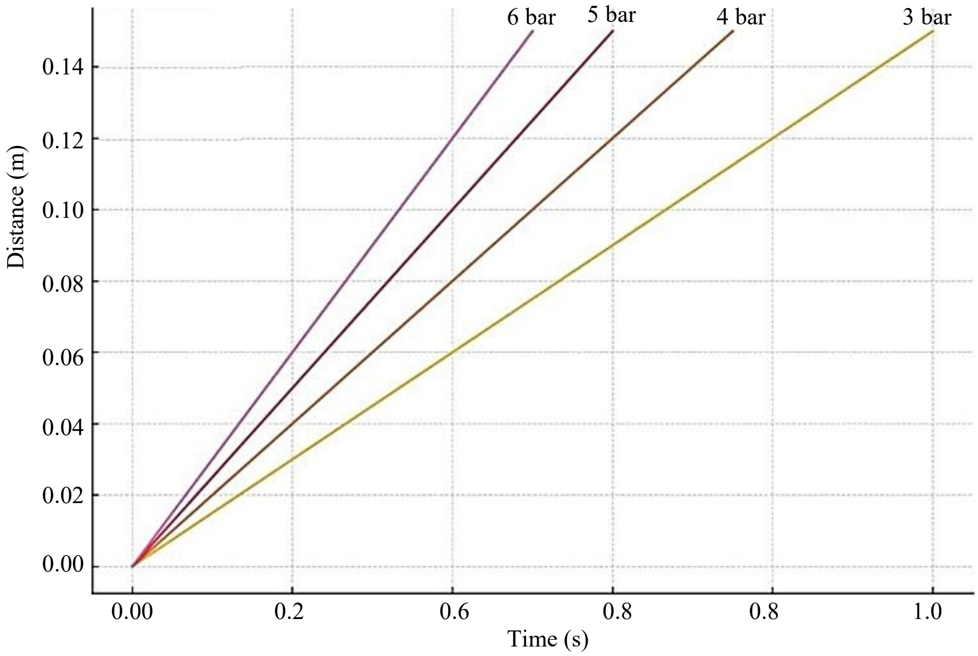

Figure 3. Piston stroke distance versus time at different pressures.

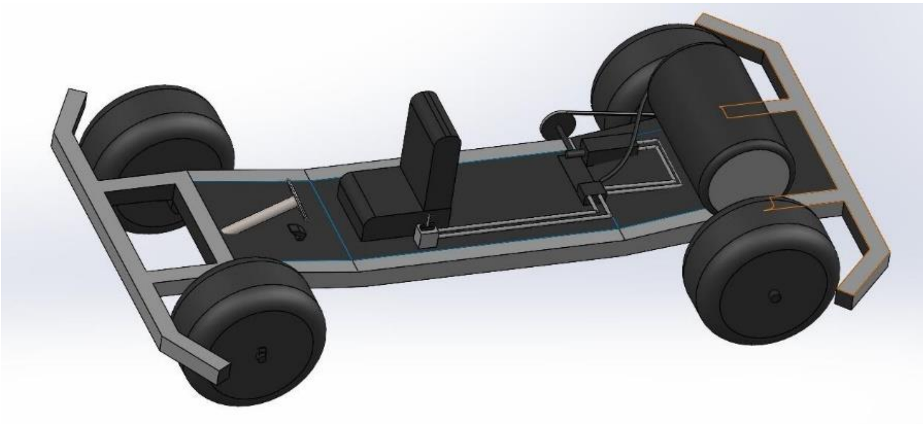

Figure 4. Chassis construction.

CONCLUSION

This study successfully demonstrated the design and functional performance of a pneumatically operated engine that utilizes a linear actuator coupled with a pulley-belt transmission system. Through experimentation and theoretical analysis, it was established that the actuator can deliver an adequate force output of up to 2000 N when operated within a pressure range of 3 to 6 bar, making it suitable for driving mechanical systems with moderate loads, such as 200 kg.

Graphical analyses of the pressure versus actuator speed and time-distance behaviors under varying pressures provided insights into the dynamic performance of the system. The actuator speed increased with pressure, resulting in reduced cycle times and enhanced responsiveness. At 6 bars, the actuator achieved an optimal speed, completing a 150 mm stroke in the shortest time, which is critical in applications requiring rapid actuation.

Despite the promising results, certain limitations exist, such as dependency on continuous air supply, sensitivity to pressure fluctuations, and relatively lower energy efficiency compared to electrical systems. These limitations suggest the need for further optimization of system design and control strategies.

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