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NOVEL I.C. ENGINE DESIGN

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Abstract

The key innovation of this new spark ignition (SI) engine design is the achievement of a quasi-constant volume (QCV) during the combustion phase. The proposed mechanism is developed to realize a specific motion profile aimed at enhancing fuel efficiency in internal combustion (IC) engines. These improvements compared to conventional engines are made possible by the integration of a non-standard piston mechanism. Numerical simulations were conducted across various scenarios, altering piston mechanism parameters, compression ratios, and engine speeds. The resulting efficiency and power curves were generated and benchmarked against those of a conventional SI engine. Findings indicate that maintaining combustion under quasi-constant volume conditions significantly boosts efficiency.

***Keywords**: concept,IC engine, efficiency*

1. INTRODUCTION

Since the inception of the spark-ignition internal combustion engine, enhancing its performance has been a major driving force behind both experimental and theoretical investigations. Over the centuries, significant progress has been made in practice and theory; however, most technological advancements have relied on intuition or trial-and-error experimentation rather than strict derivations rooted in fundamental principles. Issues such as fuel consumption, emissions from the transport sector, and overall vehicle efficiency have become critical topics, with increasing regulatory pressure to limit fleet-average CO_2 emissions. Traditional IC engines employ relatively straightforward mechanisms to convert a thermodynamic cycle into mechanical work. While engine performance, emissions, and reliability have improved substantially over time, the core principle of the crank-rod-piston slider mechanism has largely remained unchanged. Theoretically, the Otto cycle represents the most efficient thermodynamic cycle for IC engines [1], consisting of isentropic compression and expansion processes along with heat addition and rejection at constant volum. In practice, neither conventional spark-ignition engines, compression-ignition engines, nor advanced combustion strategies such as homogeneous charge compression ignition (HCCI) or controlled auto-ignition (CAI) can reach the efficiency predicted by ideal thermodynamic cycles. Only the ideal Otto cycle achieves the theoretical maximum thermal efficiency [2]. The conventional slide-crank design limits the time available for constant-volume combustion, which significantly reduces cycle efficiency.

Considerable research has been devoted to determining optimal piston trajectories for internal combustion engine cycles under different design objectives. Studies have shown that optimized piston motion can lead to improved engine performance. Various works have investigated optimal motion paths for diesel cycles, as well as thermodynamic conditions for maximizing cycle efficiency and minimizing entropy generation. Other research has analyzed optimal piston motion for diesel engines and examined the irreversible Otto cycle. Additionally, efforts have been made to optimize piston velocity profiles to achieve maximum work output, demonstrating that controlled piston motion can significantly enhance engine performance.Significant research has been conducted on the performance optimization of internal combustion engines through variations in thermodynamic cycles, kinematic parameters, and intake system design. Thermodynamic modeling of irreversible heat engines has explored the performance limits of various cycles, providing insights into optimum efficiency conditions [3]. Specifically, the effects of heat transfer and variable specific heats on the Otto cycle have been analyzed, highlighting their impact on engine performance and exergy efficiency [4,5].

Further studies have investigated the influence of variable stroke length and compression ratio on both conventional and alternative-fuel engines, demonstrating improvements in output performance and reductions in emissions under optimized kinematic conditions [6,7]. Collectively, these studies underscore the importance of integrating thermodynamic analysis, kinematic optimization, and simulation-based design for enhancing engine efficiency and performance.Modeling IC engine performance has long been a key focus, with numerous predictive models developed. Zero-dimensional (0-D) models are among the most commonly used analytical tools for IC engine analysis, as they provide averaged properties over the cylinder volume without spatial resolution. Building on established 0-D modeling techniques for SI engines, this paper explores a novel engine concept that allows for an extended piston dwell near top dead center (TDC). The proposed quasi-constant volume (QCV) IC engine can maintain a longer dwell angle at TDC compared to conventional engines. This work provides a basic description of the new engine concept, which aims to realize a thermodynamic cycle with higher efficiency. Optimal design criteria for heat engines may vary depending on operational goals. If the objective is maximum energy utilization rather than peak power, the design should prioritize thermal efficiency.

2.NOVEL I.C. ENGINE DESIGN

In reality, no engine is capable of performing heat addition strictly at constant volume. During operation, the piston continuously reciprocates between top dead center (TDC) and bottom dead center (BDC) at a frequency directly proportional to engine speed. In contrast, the chemical reactions associated with combustion occur over a relatively fixed duration, largely independent of the piston’s motion or engine speed.

To maximize the work extracted from the energy released during combustion, the air-fuel mixture must be ignited before the piston reaches TDC, and the ignition timing must be carefully adjusted according to engine speed and the mixture quality. However, the early portion of heat release before TDC contributes negatively to the work output. Because piston movement is entirely determined by crank rotation, achieving truly constant-volume heat release is impossible. Ideally, combustion would start and finish while the piston remains stationary at TDC.

One practical approach to approximate this condition is to reduce the crank rotation velocity near TDC, allowing more time for combustion to complete. This leads to a modified combustion cycle “the quasi-constant volume (QCV) cycle” which lies between the conventional IC engine cycle and the ideal Otto cycle with constant-volume combustion. A schematic of the QCV SI engine is shown in Figure 1.

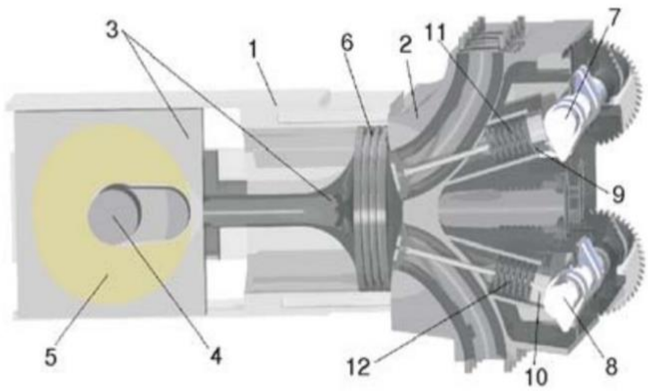

Fig. 1_Basic parts of novel I.C. engine_

The engine shown in Figure 1 consists of the following components: 1 – engine block, 2 – engine head, 3 – piston, 4 – crankshaft, 5 – connecting disc, 6 – piston rings, 7 – intake camshaft, 8 – exhaust camshaft, 9 – intake valve, 10 – exhaust valve, 11 – intake valve spring, 12 – exhaust valve spring. As illustrated, the pistons move according to a mechanism involving a crankshaft and connecting disc. A detailed kinematic analysis of this new engine design is beyond the scope of this work; the focus here is on thermodynamic characteristics and advantages relative to conventional SI engines.

The previous figure shows only the basic layout of the engine and its main components. The engine can be designed in various ways, with a greater number of cylinders and pistons. Some of the possible configurations are shown in Figures 2 and 3, where the engine in this case consists of three cylinders/pistons.

Fig. 2_The crankshaft of the engine with three pistons_

Fig. 3_The crankshaft of the engine with three pistons_

Dwell time, or dwell angle, is an important factor during combustion. In conventional engines, variations in the ratio between the connecting rod length and crank radius can slightly alter the dwell angle. While references are often made to piston dwell at TDC and BDC, it should be noted that, strictly speaking, there is no true dwell period in ordinary mechanisms.

The piston only momentarily comes to rest when the crank and rod are aligned (at TDC or BDC) and is in motion at all other crank angles. Near TDC and BDC, the piston moves very slowly, and this slow motion is what gives rise to the term “piston dwell.” In the QCV concept, classical piston dwell is also absent. Instead, there are only minimal changes in cylinder volume near TDC, especially for engines with a high length-to-radius (L/R) ratio. By extending the piston’s dwell near TDC and initiating ignition appropriately, the combustion-generated pressure has a longer time to act on the piston, improving work extraction. However, if the dwell period is excessively long, it may lead to undesirable energy conversion and reduced efficiency.

3. PISTON MOTION

This piston mechanism represents a specific variation of the conventional piston linkage commonly used in internal combustion engines, but it includes several distinctive features that will be discussed in this section. It should be noted that the kinematic configuration of this mechanism closely resembles that of a standard piston system. Kinematics scheme of unconventional piston mechanism is presented on the following Fig. 4.

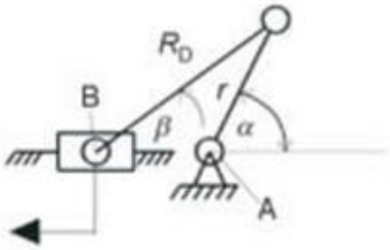

Fig. 4*Kinematics scheme of unconventional piston mechanism*

For the piston path s(α), it follows from fig. 4, where R_D is radius of connecting disc, r – the radius of crankshaft, and λ_k – r/R_d ratio:

$$s(\alpha) = r\left\{[R_D - \cos(\alpha)] + \frac{1}{\lambda_k}[1 - \sqrt{R_D - \lambda_k^2 \sin^2(\alpha)}]\right\} \qquad (1)$$

In theory, the ideal situation would be to initiate and complete the combustion process while the piston remains stationary at TDC. However, in practice, an excessively long piston dwell at TDC can result in significant heat losses through the cylinder walls.

Therefore, in real engines, maintaining the piston at TDC for extended periods is not necessarily the optimal strategy for efficient energy conversion. Only by optimizing the dwell duration or equivalently, the crank angle range near TD can higher combustion efficiency be achieved.Several additional benefits arise from carefully controlling the piston dwell near TDC. Small variations in piston position at this stage allow the engine to harness maximum thermal potential while minimizing negative work caused by early ignition during the compression stroke, which is a common limitation in conventional engine strategies. Furthermore, extending the dwell near TDC can help prevent backflow through valve overlap.

Completing combustion close to TDC also enables the effective expansion stroke to be fully utilized, maximizing conversion of thermal energy into work and providing sufficient time for post-combustion reactions, thereby reducing partially burned emissions. Finally, we can observe the piston motion for different kinematic parameters, as illustrated in the Figure 5.

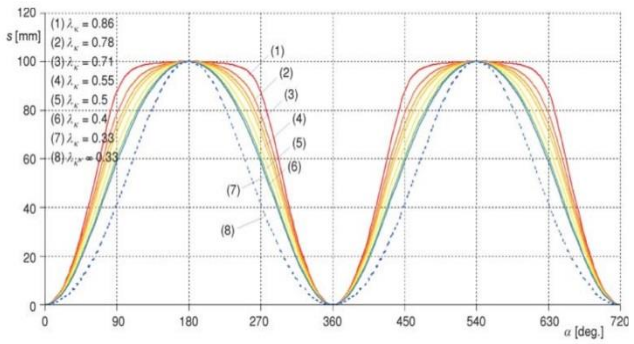

Fig. 5*Piston motion in relation to crank angle and λ_k ratio*

4. RESULTS

For the present study, a zero-dimensional (0-D) combustion model is utilized. Several assumptions were made to facilitate the numerical analysis. Firstly, the specific heats of the working fluid are assumed to remain constant. The cylinder gas is modeled as air, behaving according to the ideal gas law. Another key assumption is that the crankshaft rotates at a uniform speed throughout the cycle.For simplification, gas leakage through the valves or piston rings is neglected, implying that the mass within the cylinder remains constant. The cylinder contents are considered fully mixed and spatially homogeneous, with uniform composition and properties during the intake, compression, expansion, and exhaust processes. Finally, the gas is assumed to move through a sequence of quasi-equilibrium states during the entire cycle. Now, we can observe how the modified kinematics affects the output efficiency of the engine. For the purposes of this study, two diagrams will be presented. The first one, shown in Figure 6, displays a graph illustrating the efficiency as a function of the compression ratio and engine speed for a selected kinematic ratio.

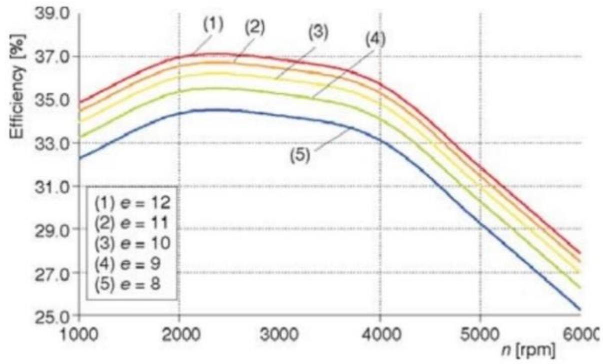

Fig. 6 *Efficiency of unconventional engine for λ_k = 0.5 in relation of engine speed and compression ratio*

In the second figure, Figure 7, a diagram is presented showing the difference in efficiency between the proposed concept and the conventional engine.

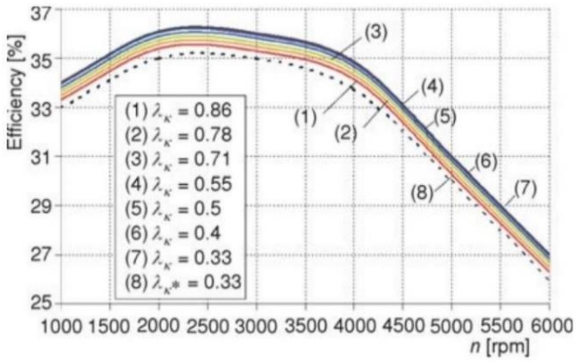

Fig. 7*Efficiency comparison between ordinary SI engine and unconventional engine concept*

4 CONCLUSION

This work introduces a novel Otto cycle engine concept, where intake and compression are achieved through an unconventional piston mechanism. Numerical simulations were conducted to optimize the cranking mechanism in order to maximize thermal efficiency. The performance of this unconventional Otto heat engine was analyzed using 0-D modeling. Results indicate the existence of optimal piston dwell values at which both power output and efficiency reach their respective peaks. The thermal efficiency of the cycle depend not only on temperature and thermal conductance between the working fluid and cylinder walls but also on the engine's geometric and operational parameters, which are detailed in this study. The proposed system allows a significant reduction in piston velocity near the top dead center (TDC) compared to conventional engines operating at a constant crankshaft speed. Consequently, quasi-constant volume (QCV) combustion is effectively achieved, leading to notable improvements in fuel consumption, which are discussed in this paper.This article presents a potential approach to enhancing SI engine efficiency. The described concept offers multiple advantages over conventional SI engines. Notably, it enables heat addition at nearly constant volume, which allows for reduced spark advance angles. Additionally, this design eliminates the need for valve overlap. Collectively, these benefits indicate that the efficiency potential of SI engines has not yet been fully exploited. As shown in the study, during the constant volume combustion cycle, piston motion is considerably slower near both TDC and bottom dead center (BDC). Overall, the pressure integral for the QCV combustion cycle is approximately 4% higher than that of a conventional cycle at full load.

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