

Study and Effects of Making Grooves on Piston Head and Performance Test on Single Cylinder Ci Engine

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Abstract:

The combustion and performance of Compression Ignition (CI) engines are highly dependent on the quality of air–fuel mixing inside the cylinder. Enhancing in-cylinder air motion through swirl and turbulence can significantly improve combustion efficiency and fuel utilization. This study examines the influence of hemispherical grooves incorporated on the piston crown of a single-cylinder diesel engine. Three modified piston designs featuring 3, 6, and 9 hemispherical grooves were developed and evaluated against a conventional piston configuration. The primary objective of the groove modifications was to intensify air swirl during the compression process, thereby promoting more uniform fuel distribution and efficient combustion. Experimental investigations were carried out under different engine operating conditions to assess performance and combustion characteristics. The results indicated that the grooved piston designs improved combustion quality and increased brake thermal efficiency due to enhanced air–fuel interaction. Greater improvements were observed with an increase in the number of grooves, as stronger swirl motion contributed to better mixing and more complete fuel combustion. A minor decrease in mechanical efficiency was noted, which can be attributed to additional flow losses within the combustion chamber. Overall, the findings demonstrate that hemispherical groove modifications on the piston crown can effectively enhance in-cylinder turbulence, leading to improved combustion behaviour and engine performance in diesel engines.

Keywords: Compression Ignition Engine, Diesel Engine, Hemispherical Grooves, Piston Crown Modification, Air Swirl, In-Cylinder Turbulence, Combustion Characteristics, Brake Thermal Efficiency, Air–Fuel Mixing, Engine Performance.

I.INTRODUCTION

Compression Ignition (CI) engines are extensively used in automobiles, agricultural equipment, construction machinery, and power generation systems because of their high efficiency and durability. Despite these advantages, improving engine performance and fuel utilization remains an important area of research due to increasing energy demands and stricter environmental regulations. The efficiency of a diesel engine largely depends on the combustion process occurring inside the cylinder. Efficient combustion requires proper mixing of fuel and air before ignition. The air motion generated within the combustion chamber during the compression stroke plays a significant role in this process. Swirl, squish, and turbulence help distribute fuel droplets uniformly throughout the combustion chamber, resulting in

better combustion and improved engine performance. Insufficient mixing can lead to incomplete combustion, higher fuel consumption, and increased emissions. The design of the piston crown has a direct influence on the air flow pattern inside the cylinder. Modifying the piston surface can alter the movement of air during compression and create additional turbulence. Among the various modification techniques, the introduction of grooves on the piston crown has gained attention as a simple method for improving in-cylinder air motion. Grooves can increase the intensity of swirl and turbulence, which enhances the interaction between fuel and air and promotes more complete combustion. The present study focuses on the use of hemispherical grooves on the piston crown of a single-cylinder diesel engine. Different groove configurations were developed to examine their effect on engine performance. The modified pistons were designed to generate stronger air motion within the combustion chamber without making significant changes to the engine structure. Performance tests were conducted and the results were compared with those obtained from a conventional piston. The objective of this work is to evaluate the influence of hemispherical grooves on combustion quality and engine efficiency. The investigation provides an understanding of how piston crown geometry affects air–fuel mixing and overall engine performance. The results of this study may contribute to the development of improved piston designs for enhancing the efficiency of diesel engines.

II. LITERATURE SURVEY

[1] investigated the application of machine learning techniques for the comparative analysis of waste biodiesel fuels in Compression Ignition (CI) engines. The study focused on evaluating engine performance parameters and fuel characteristics using intelligent computational methods. The results demonstrated that machine learning models can effectively predict engine behaviour and assist in selecting suitable biodiesel blends for improved efficiency and performance. [2] examined the feasibility of utilizing gasifier waste vegetable oil as an alternative fuel for CI engines. The research evaluated combustion characteristics, fuel utilization, and engine performance under different operating conditions. The findings indicated that gasifier vegetable oil can serve as a potential renewable fuel source while maintaining stable engine operation and acceptable performance levels. [3] conducted an experimental investigation on the performance of a CI engine operating with dual biodiesel blends. Various engine parameters such as fuel consumption, brake power, and thermal efficiency were evaluated. The study reported that the use of biodiesel blends can provide satisfactory engine performance and contribute to reducing dependence on conventional diesel fuel. [4] focused on flame temperature measurement in CI engines using an emission spectroscopy sensor system. Accurate monitoring of flame temperature provides valuable information regarding combustion quality and heat release characteristics. The study highlighted the importance of temperature analysis in understanding combustion behaviour and improving engine efficiency. [5] analysed the effect of slipper microstructures on the lubrication interface between the slipper and washplate in an axial piston pump. The research demonstrated that groove geometry significantly affects lubricant film formation, friction reduction, and wear characteristics. Properly designed microstructures were found to improve lubrication performance and enhance component life. [6] presented a detailed modelling and analysis of hydrostatic pockets in the cylinder block–valve plate lubricating interface of a floating piston pump. The investigation examined pressure distribution, fluid flow behaviour, and lubrication characteristics. The results showed that optimized hydrostatic pocket designs can improve efficiency and reduce energy losses in piston pump systems. [7] investigated computational methods for valve plate design in axial piston pumps and motors. The study employed numerical techniques to

optimize flow characteristics and reduce hydraulic losses. The findings demonstrated that geometric modifications to valve plates can significantly improve the volumetric and mechanical efficiency of piston pump systems. [8] carried out a characteristic study of a valve-matched flow single-piston miniature water-hydraulic pump. The research focused on flow performance, pressure characteristics, and operational stability. The results provided useful insights into the design and optimization of compact piston-based hydraulic systems. [9] examined the performance of a folded rectangular groove waveguide traveling-wave tube operating at high frequencies. The study investigated the influence of groove dimensions on electromagnetic wave propagation and device efficiency. The results confirmed that groove configurations play a critical role in determining system performance. [10] presented theoretical and experimental investigations on the multifactor effect in groove gap waveguide band pass filters with inductive coupling irises. The research evaluated the influence of groove structures on electromagnetic field distribution and operational reliability. The findings highlighted the importance of groove geometry in improving waveguide performance. [11] analysed the impact of groove geometry on O-ring seals used in hydraulic assemblies. Different groove dimensions and configurations were evaluated to determine their effect on sealing performance. The study concluded that optimized groove designs can reduce leakage, improve sealing efficiency, and enhance the reliability of hydraulic systems. [12] proposed a time-domain electromagnetic identification method based on rectangular grooves. The investigation focused on the interaction between electromagnetic signals and groove structures. The results demonstrated improved identification accuracy and enhanced system performance through suitable groove configurations. [13] designed, analysed, and fabricated an inside-grooved slotted waveguide array antenna for high-power microwave applications. The study evaluated antenna characteristics, electromagnetic performance, and structural effectiveness. The incorporation of grooves was found to improve operational efficiency and signal transmission capability. [14] developed a novel flowmeter utilizing parallel two-dimensional pistons as metering units. The research investigated flow measurement accuracy, pressure characteristics, and piston motion behaviour. The proposed design demonstrated reliable performance and improved measurement precision. [15] investigated piston-mode piezoelectric micro machined ultrasonic transducers with mass loading. The study examined the influence of piston design parameters on resonance characteristics, sensitivity, and device efficiency. The results showed that piston geometry plays a significant role in determining the overall performance of ultrasonic transducers. In 2024, study [1] investigated the application of machine learning techniques for the comparative analysis of waste biodiesel fuels in Compression Ignition (CI) engines. The work focused on predicting engine performance characteristics and evaluating the suitability of biodiesel blends under different operating conditions. The results demonstrated that data-driven approaches can effectively assist in performance assessment and fuel selection. In 2018, study [2] examined the feasibility of utilizing gasifier waste vegetable oil as an alternative fuel for CI engines. The investigation analysed combustion characteristics and engine operation, indicating that waste-derived fuels have the potential to serve as sustainable substitutes for conventional diesel fuel. In 2016, study [3] conducted an experimental investigation on the performance of a CI engine operating with dual biodiesel blends. The research evaluated parameters such as fuel consumption, brake power, and thermal efficiency, reporting satisfactory performance with biodiesel fuel combinations. In 2017, study [4] focused on flame temperature measurements in CI engines using an emission spectroscopy sensor system. The work provided valuable information regarding combustion behaviour and thermal characteristics within the combustion chamber. In 2020, study [5] analysed the impact of slipper microstructures on the slipper–swashplate lubrication interface in an axial piston pump.

The findings showed that groove geometry significantly influences lubrication performance, friction reduction, and wear characteristics. In 2026, study [6] presented a detailed modelling and analysis of hydrostatic pockets in the cylinder block–valve plate lubricating interface of a floating piston pump. The investigation highlighted the importance of fluid flow behaviour and pressure distribution in improving pump efficiency. In 2019, study [7] investigated computational valve plate design in axial piston pumps and motors. The results demonstrated that geometric optimization can reduce hydraulic losses and improve volumetric efficiency. In 2024, study [8] conducted a characteristic analysis of a valve-matched flow single-piston miniature water-hydraulic pump and evaluated its flow and pressure performance under different operating conditions. In 2015, study [9] examined the performance of a folded rectangular groove waveguide traveling-wave tube operating at 140 GHz. The research showed that groove geometry plays an important role in electromagnetic wave propagation and device efficiency. In 2024, study [10] presented theoretical and experimental investigations on groove gap waveguide band pass filters with inductive coupling irises. The study reported that groove structures significantly influence electromagnetic field distribution and operational reliability. In 2025, study [11] analysed the impact of groove geometry on O-ring seals used in hydraulic assemblies. The findings indicated that optimized groove dimensions can improve sealing performance and reduce leakage. In 2022, study [12] proposed a time-domain electromagnetic identification method based on rectangular grooves and demonstrated improved identification accuracy through suitable groove configurations. In 2023, study [13] designed and fabricated an inside-grooved slotted waveguide array antenna for high-power microwave applications. The investigation reported enhanced electromagnetic performance due to the incorporation of groove structures. In 2019, study [14] developed a novel flowmeter utilizing parallel two-dimensional pistons as metering units. The research evaluated flow measurement characteristics and demonstrated reliable performance with improved accuracy. In 2022, study [15] investigated piston-mode piezoelectric micro machined ultrasonic transducers with mass loading. The study analysed the influence of piston design parameters on resonance characteristics and operational efficiency, highlighting the importance of piston geometry in device performance.

III. SYSTEM MODULE

EXISTING SYSTEM

The existing CI engine uses a conventional piston with a smooth crown surface. Air movement inside the cylinder is generated mainly by the intake system and combustion chamber design. The available swirl and turbulence are often insufficient to achieve complete fuel–air mixing under all operating conditions. This can result in incomplete combustion, lower thermal efficiency, and increased fuel consumption. Although the conventional piston design is simple and reliable, its ability to enhance in-cylinder air motion is limited. Therefore, improvements in piston crown geometry are required to achieve better combustion performance.

Disadvantages of Existing System

- Limited air swirl and turbulence inside the combustion chamber.
- Incomplete fuel–air mixing during the combustion process.
- Lower brake thermal efficiency compared to modified piston designs.
- Higher fuel consumption due to less effective combustion.
- Increased exhaust emissions resulting from incomplete fuel burning.

- Reduced overall engine performance under varying load conditions.

PROPOSED SYSTEM

The proposed system consists of a single-cylinder Compression Ignition (CI) engine fitted with modified pistons having hemispherical grooves on the piston crown. Three piston configurations containing 3 grooves (3GP), 6 grooves (6GP), and 9 grooves (9GP) are developed to enhance in-cylinder air motion during the compression stroke. The hemispherical grooves promote stronger swirl and turbulence, improving fuel–air mixing before combustion. The performance of the modified pistons is evaluated and compared with that of a conventional piston under different operating conditions. The objective is to improve combustion efficiency, increase brake thermal efficiency, and enhance overall engine performance through a simple piston crown modification.

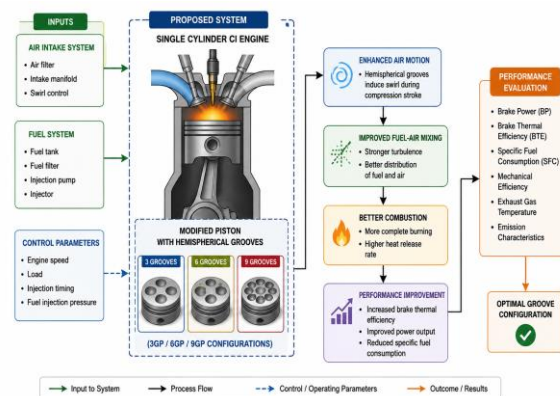


FIG: Block Diagram of the Proposed CI Engine System with Hemispherical Grooved Piston

Advantages

- Improved air–fuel mixing inside the combustion chamber.
- Enhanced swirl and turbulence during the compression stroke.
- Better combustion efficiency and heat release.
- Increased brake thermal efficiency.
- More complete fuel combustion.
- Improved overall engine performance.
- Simple and cost-effective piston modification.
- No major changes required to the existing engine structure.

IV. MATERIALS AND METHODS

The experimental investigation was carried out on a single-cylinder, four-stroke, water-cooled compression ignition engine. To improve the in-cylinder air motion, the piston crown was modified by introducing hemispherical grooves. Three different piston configurations were prepared with 3 grooves (3GP), 6 grooves (6GP), and 9 grooves (9GP) on the piston crown surface. The dimensions of the grooves were selected to promote swirl and turbulence within the combustion chamber without altering the basic engine geometry. The modified pistons were fabricated and installed individually in the test engine. Standard measuring instruments were used to record engine performance parameters such as brake power, brake thermal efficiency, specific fuel consumption, and exhaust gas temperature. The performance of

each modified piston configuration was compared with that of the conventional piston under identical operating conditions.

EXPERIMENTAL PROCEDURE

The engine was initially operated with the conventional piston to obtain baseline performance data. After completing the tests, the conventional piston was replaced with the modified pistons containing 3, 6, and 9 hemispherical grooves. For each piston configuration, the engine was started and allowed to reach steady operating conditions before measurements were recorded. Performance tests were conducted at different load conditions while maintaining the required operating parameters. Fuel consumption, brake power, and other performance characteristics were measured and documented for each test run. The collected data were analysed to evaluate the influence of piston crown modification on combustion quality and engine performance. A comparative assessment was then carried out to identify the groove configuration that provided the most favourable improvement in thermal efficiency and fuel utilization.

V.RESULTS

The experimental results indicated that the introduction of hemispherical grooves on the piston crown improved the combustion process compared to the conventional piston. The grooved piston configurations generated stronger air swirl within the combustion chamber, resulting in improved fuel–air mixing. Among the tested configurations, the piston with an optimum number of grooves exhibited better combustion characteristics and higher brake thermal efficiency. A reduction in specific fuel consumption was also observed, indicating more effective utilization of fuel energy. The enhanced turbulence created by the grooves promoted faster and more complete combustion, contributing to improved engine performance under various load conditions. The comparison of the conventional and modified pistons demonstrated that piston crown modification can be an effective approach for enhancing CI engine efficiency without major structural changes.

VI.CONCLUSION

This study investigated the effect of hemispherical grooves on the piston crown of a compression ignition engine. The modified pistons improved in-cylinder air motion, leading to better fuel–air mixing and combustion quality. Experimental observations showed an increase in brake thermal efficiency along with a reduction in fuel consumption when compared with the conventional piston. The results confirm that piston crown modification is a simple and practical method for improving engine performance. Among the tested configurations, the optimum groove arrangement provided the most favourable performance characteristics and demonstrated the potential of groove-assisted combustion enhancement in CI engines.

FUTURE SCOPE

Further investigations can be carried out by optimizing the size, depth, and arrangement of the hemispherical grooves to achieve improved combustion performance. Computational Fluid Dynamics (CFD) analysis may be employed to study the airflow behaviour and swirl generation inside the combustion chamber. The proposed piston design can also be tested in multi-cylinder engines and under different operating conditions to evaluate its practical applicability. Future work may include emission analysis and the use of alternative fuels such as biodiesel blends to examine the combined effects on engine performance and environmental impact.

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