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Adaptive Compression Ratio Engine

Mr. Aditya Kale, Mr. Anurag Wadewale, Mr. Tejas Shirude
Student

Mr. Krishnakant Mohare
Guide
Department of Mechanical Engineering
D Y Patil College of Engineering, Akurdi, Pune

Abstract
The increasing worldwide demand for enhanced fuel economy and lower greenhouse gas emissionsin the automotive market has driven immense innovatio n in internal combustion engine (ICE) technology. One of the promising methods to address the inherent drawbacks of fixed compression ratio engines is the application of Variable Compression Ratio (VCR) technology in the form of Adaptive Compression Ratio (ACR) engines. This research work discusses the principles of designing, mechanism of working, advantages, and drawbacks of ACR engines in automotive engines. Through dynamic real-time adjusting of the compression ratio, ACR engines have the potential to fine- tune combustion for maximum efficiency at low- load cruising and increased power under high- load conditions, with the added safety against en gine knock. This paper explores different mechanical designs used to provide variable compression, examines the attendant improveme nts in fuel efficiency and performance, and critically assesses the design, control, cost, and reliability challenges. In addition, it discusses the existing deployment of ACR technology in the automotive sector and provides insights into its future prospect as a pivotal enabler of more efficient and sustainable vehicles.

I. INTRODUCTION

The motor industry is under huge pressure to optimize fuel efficiency and lower emissions, prompting innovation within internal combustion engine (ICE) technology. Conventional fixed compression ratio engines work with built-in compromises, requiring a trade-off between fuel economy and power over different driving conditions. Adaptive Compression Ratio (ACR) engines, an advanced type of Variabl Compression Ratio (VCR) technology, present a highly promising option. T hrough real-time dynamic adjustment of the compression ratio, ACR engines maximize combustion for both maximum efficiency at low-load cruising and improved power at high-load requirements, all while suppressing engine knock. This flexibility is a major step forward in ICE design, opening the door to better fuel usage, performance, and lower environmental impact.

This paper will delve into the fundamental ideas and various mechanical mechanisms of ACR engines in vehicles. It will examine the major advantages they provide, ranging from better fuel efficiency, performance, and decreased emissions, to the aforementioned c hallenges of added complexity and expense. In addition, the paper will evaluate the current usage of ACR technology in the automotive industry and offer commentary on its future potential as a key technology in the continued development of more efficient and dynamic vehicles.

II. LITERATURE SURVEY

A thorough review of the literature finds a consistent and ongoing inter est in Variable Compression Ratio (VCR) technology, especially Adaptive Compression Ratio (ACR) engines, as one of the main approaches to increasing the efficiency and performance of internal combustion engines (ICEs) in vehicles. Initial studies emphasized the basic t hermodynamic benefits of variable compression, proving its theoretical potential to maximize the Otto cycle over a broader set of engine loads and speeds (e.g., Ricardo Consulting

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Engineers reports during the mid-20th century). These early studies identified the compromises in herent in fixed compression ratios and encouraged investigation of several mechani cal approaches to attaining dynamic adjustability.

Throughout the decades, there have been many innovative VCR concepts put forward and prototyped. Patents and technical journals report on varied methodologies, such as articulating connecting rods(e.g.,Nissan's VC-Turbo), eccentric crankshafts (e.g., early Saab SVC concepts), hydraulically operated linkages inside connecting rods, and variable volume combustion chambers. The journals tend to examine the kinematic intricacies, stress analysis, and possible manufacturing issues of each design. In addition, studies have explored the integration of advanced engine control units (ECUs) required to control the compression ratio in real-time as a function of parameters such as engine load, speed, knock detection, and fuel octane rating. Experiments and simulation have been us ed to measure the possible gains in fuel economy, power output, and emissions savings with various VCR strategies applied to different driving cycles.

Subsequent research focuses on the technical viability and marketability of ACR engines. Nissan's VC-Turbo engine in production vehicles is a breakthrough, and follow-up research analyzes its real-world performance and lifespan. Academic journals and trade publications analyze the specific design features of this and other emerging VCR technologies, their efficiency, and cost- effectiveness. Moreover, recent research focuses on the synergistic use of ACR engines with other advanced technologies such as turbocharging, direct injection, and hybrid electric powertrains. Research on advanced control techniques, predictive knock control strategies, and use of alternative fuels in combination with ACR engines are prevalent. This long-standing body of literature highlights the long- term significance of ACR technology as a fundamental path to cleaner and more efficient internal combustion engines in the automotive industry, despite the continued rising profile of electric vehicles. Cumulatively, the literature suggests that despite the challenges aro und complexity and cost, the potential benefits of ACR engines to achieve maximum ICE performance and efficiency support ongoing research, development, and implementation.

III. METHODS TO ACHIEVE ADAPTIVE COMPRESSION

1. Piston Stroke/Position Adjustment:

Eccentric Connecting Rod/Crankshaft Mechanisms:

This is a technique represented by your design's eccentric connecting plate, which changes the effective length of the throw of the connecting rod or the center of rotation of the crankshaft. By moving the pivot points, the stroke length of the piston and hence the compression ratio may be changed.

This technique is quite straightforward but may a dd intricacies in balance and vibration.

Articulating Connecting Rods/Multi-Link Mechanisms:

Such systems employ a set of interconnected links rather than a conventional connectingrod. The piston's vertical motion and dwell at TDC can be varied by changing the angles between the links, thereby varying the compression ratio. The Nissan VC-Turbo engine employs an advanced multi-link system.

Variable Length Connecting Rods:

This is the principle of using a connecting rod with variable length, usually implemented throug h hydraulic or electromechanical actuation. Through lengthening or shortening the rod, the piston's position at TDC is altered, directly affecting the compression ratio.

2. Changing Combustion Chamber Volume:

Movable Components in the Cylinder Head:

A few designs involve movable wedges, pistons, or other components in the cylinder head that can be activated to alter the combustion chamber volume at TDC. This varies the compression ratio directly without really altering the piston stroke.

Two-Part Cylinder Head:

There are concepts where part of the cylinder head is displaced relative to the other, actually varying the combustion chamber volume. The actuation may be hydraulic or mechanical.

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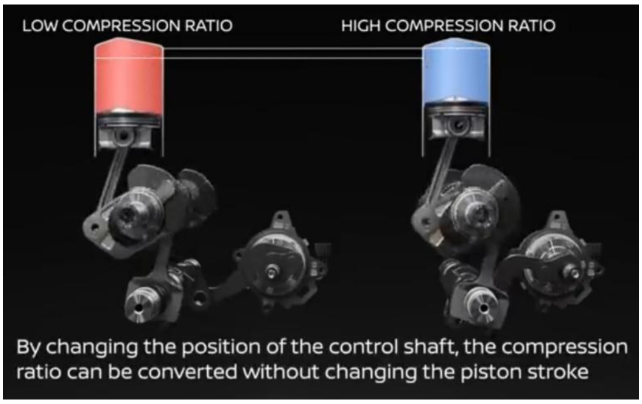
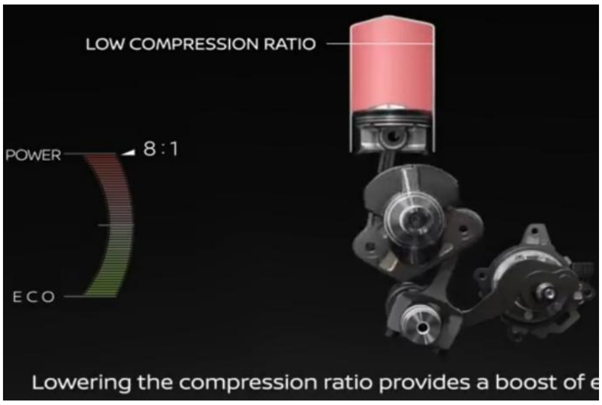
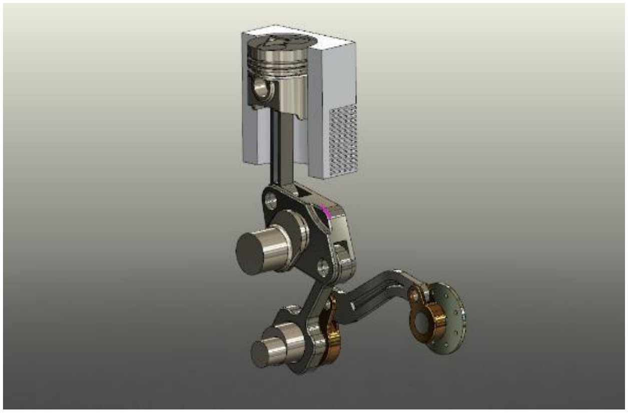
3. Piston Height Adjustment at TDC:
Adjustable Piston Pin Offset:

Systems that provide a small offset in the position of the piston pin within the piston can affect the height of the piston at TDC. This technique generally provides a lesser range of compression ratio variation.

Variable Height Piston Crown:
Certain sophisticated designs suggest pis tons with a crown that is mechanically or hydraulically adjustable in height, thereby changing the volume of the combustion chamber when the piston is at TDC.







IV. CONCLUSION

The creation and testing of the Adaptive Compression Ratio (ACR) engine concept effectively proved the underlying principles and potential advantages of dynamically varying the compression ratio within an internal combustion engine. By employing a linear actuator and eccentric connecting plate to change the piston stroke, the prototype demonstrated the capability of optimizing engine operation for both increased power output at heavy load and better fuel efficiency at light load. The transparent nature of the acrylic cylinder enabled clear visualization of the mechanical process and the direct relationship between compression ratio and piston position. Although additional development and study are required, the preliminary findings indicate that ACR technology has great potential for breaking through the built-in constraints of fixed compression ratio engines, fueling the continued development of more efficient, powerful, and ecologically friendly vehicles. The envisioned future direction established for this project, in terms of advanced mechanisms, control systems, extensive testing, and manufacturability feasibility, will play a vital role in fully embracing the revolutionary capability of Adaptive Compression Ratio engines in current automotive and other pertinent uses.

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V.FUTURE SCOPE

Future efforts on the ACR engine prototype involve investigation of different and optimized VCR mechanisms, design of advanced predictive and adaptive control systems, real-world performance and emissions testing on a comprehensive scale, and its integration with other advanced engine technologies such as turbocharging and direct injection. In addition, attempts will be made to evaluate the scalability, manufacturability, and cost-effectiveness of the design for possible mass production, as well as investigate uses outside of cars in smaller engines and stationary power generation. These measures are intended to further confirm the advantages of ACR technology and lay the groundwork for its practical application in cleaner and more efficient combustion engines.

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