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ADVANCED RESEARCH ON INTERNAL COMBUSTION ENGINE AND ITS TECHNICAL ASPECTS

Ram Priye Kumar Sahu[*1], Semin[*2], Dipamjyoti Das[*3]

[*1,2,3]Dept. Of Mechanical Engineering, Institute Technology Sepuluh Nopember (ITS), India.

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ABSTRACT

Internal combustion engines (ICEs) remain a crucial technology powering transportation and industry worldwide. This paper provides a comprehensive overview of the technical aspects of ICEs, covering their thermodynamics, combustion processes, design and analysis, control systems, emissions, fuels and lubricants, and applications. We highlight the key research areas and technological advancements within each domain, focusing on improving efficiency, reducing emissions, and exploring alternative fuels. Additionally, we discuss the future trends in ICE technology. This paper aims to provide a critical analysis of the current state of ICE technology and its prospects in shaping a cleaner and more sustainable future for transportation and energy.

I. INTRODUCTION

An Internal Combustion Engine (IC engine) is a type of heat engine where the combustion of fuel occurs within the engine itself, generating high-pressure gases that act on a moving component, such as a piston, to produce mechanical work. These engines are widely used in various applications, including automobiles, motorcycles, airplanes, and power generators.

Classification of IC Engines:

IC engines can be classified based on several criteria, including the working cycle, fuel used, number of strokes, and the arrangement of cylinders. Here are the primary classifications:

1. Based on Working Cycle

- Otto Cycle Engines: These engines operate on the Otto cycle, which involves constant volume heat addition during combustion. Most gasoline engines in automobiles follow the Otto cycle.
- Diesel Cycle Engines: Diesel engines operate on the Diesel cycle, characterized by constant pressure heat addition during combustion. These engines are commonly found in diesel-powered vehicles and industrial applications.

2. Based on Fuel Used:

- Gasoline Engines: These engines use gasoline (petrol) as the primary fuel. They are prevalent in passenger cars and motorcycles.
- Diesel Engines: Diesel engines utilize diesel fuel, known for its high energy density. These engines are commonly used in trucks, buses, and some cars.

3. Based on Number of Strokes:

- Two-Stroke Engines: These engines complete a power cycle in two strokes of the piston (one upstroke and one downstroke). Two-stroke engines are often found in smaller vehicles, motorcycles, and certain handheld power tools.
- Four-Stroke Engines: In four-stroke engines, the power cycle is completed in four strokes of the piston (two upstrokes and two downstrokes). Most automobile engines and larger industrial engines follow the four-stroke cycle.

4. Based on Cylinder Arrangement:

- Inline Engines: Cylinders are arranged in a straight line. Common configurations include inline-4 and inline-6 engines.
- V-Type Engines: Cylinders are arranged in two banks in a V shape. V6 and V8 engines are common examples.
- Boxer Engines: Cylinders are horizontally opposed, with a flat configuration. This design is often found in some automobile engines.

Each classification has its advantages and disadvantages, making different types of IC engines suitable for specific applications based on factors such as efficiency, power output, and operational characteristics.

1.1. Historical development of Internal Combustion Engines

The historical development of Internal Combustion Engines (IC engines) is a fascinating journey that spans several centuries. Here is an overview of key milestones in the evolution of IC engines:

1. Early Concepts (17th-18th Century):

- The concept of internal combustion can be traced back to the 17th century, with early experiments by figures like Christian Huygens and Robert Boyle.
- In the 18th century, the idea of using explosive gases for propulsion gained attention, but practical implementations were lacking.

2. Development of Early Engines (Late 19th Century):

- The mid-19th century saw the first practical developments in IC engines. Étienne Lenoir patented one of the earliest commercially successful engines in 1860, which ran on illuminating gas.
- Nikolaus Otto, in collaboration with Eugen Langen, developed the first practical four-stroke engine, known as the Otto engine, in 1876. This design laid the foundation for modern gasoline engines.

3. Rudolf Diesel and the Diesel Engine (Late 19th Century):

- Rudolf Diesel patented the Diesel engine in the late 19th century. Unlike the Otto engine, Diesel's design relied on high compression rather than a spark plug for ignition. This led to greater efficiency and fuel economy.

4. Mass Production and Automobiles (Early 20th Century):

- The early 20th century witnessed the mass production of automobiles. Companies like Ford played a pivotal role in making automobiles accessible to the general public.
- The development of the electric starter by Charles Kettering in 1911 eliminated the need for hand cranking, making automobiles more user-friendly.

5. World War II and Advancements (Mid-20th Century):

- World War II accelerated advancements in aviation and automotive technology. Jet engines and more efficient aircraft engines were developed.
- The post-war period saw the rise of turbocharged engines, improving power output and efficiency.

6. Environmental Concerns and Emission Regulations (Late 20th Century):

- Concerns about air pollution and environmental impact led to the implementation of emission regulations in the late 20th century.
- The development of catalytic converters and other technologies helped reduce harmful emissions from IC engines.

7. Advances in Electronics and Computerization (Late 20th Century Onward):

- The late 20th century and beyond witnessed significant advancements in engine control through electronic systems.
- Electronic Fuel Injection (EFI) systems replaced traditional carburetors, providing more precise control over the fuel-air mixture.

8. Hybrid and Electric Technologies (21st Century):

- The 21st century has seen a growing emphasis on hybrid and electric propulsion technologies as the automotive industry responds to environmental concerns and seeks sustainable alternatives.

The historical development of IC engines reflects a continuous quest for improved efficiency, reduced emissions, and innovative solutions to meet the evolving needs of transportation and industrial applications.

1.2. Application of I.C. Engines

Internal Combustion Engines (IC engines) find widespread applications across various industries and sectors due to their versatility and ability to convert chemical energy into mechanical work. Here are some key applications of IC engines:

1. Automobiles:

- IC engines power the majority of vehicles on roads, including cars, trucks, motorcycles, and buses.
- Gasoline engines are common in passenger cars, while diesel engines are prevalent in trucks and buses.

2. Aircraft:

- Aviation relies on IC engines for propulsion in both commercial and military aircraft.
- Jet engines, a type of IC engine, are widely used in modern aviation for their high power-to-weight ratio.

3. Marine:

- IC engines are employed in various marine vessels, including ships, boats, and submarines.
- Diesel engines are commonly used in marine applications due to their fuel efficiency and reliability.

4. Power Generation:

- IC engines are utilized for power generation in stationary applications, such as electricity generators.
- They are often employed in areas with limited access to the electrical grid or as backup power sources.

5. Industrial Equipment:

- IC engines power a range of industrial equipment, including construction machinery, agricultural tractors, and mining equipment.
- Diesel engines are preferred in these applications due to their durability and torque characteristics.

6. Rail Transportation:

- Some trains and locomotives are equipped with IC engines for propulsion.
- Diesel-electric locomotives, for example, use diesel engines to generate electricity for electric traction motors.

7. Off-Road Vehicles:

- IC engines are commonly found in off-road vehicles such as all-terrain vehicles (ATVs), dirt bikes, and dune buggies.
- These engines provide the necessary power and mobility for various recreational and utility purposes.

8. Small Engines and Equipment:

- Small IC engines power a wide range of equipment, including lawnmowers, chainsaws, and portable generators.
- Two-stroke engines are often used in these applications due to their simplicity and lightweight design.

9. Military Applications:

- IC engines are integral to military vehicles, including tanks, armored personnel carriers, and military trucks.
- Portable generators powered by IC engines are used in field operations.

10. Pumps and Compressors:

- IC engines are employed to drive pumps and compressors in various industrial processes, such as water pumping and gas compression.

11. Recreational Vehicles:

- Motorhomes, RVs (Recreational Vehicles), and boats often use IC engines for both propulsion and onboard power generation.

12. Emergency Services:

- Fire trucks, ambulances, and other emergency service vehicles commonly rely on IC engines for quick response and mobility.

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II. THERMODYNAMIC CYCLES OF IC ENGINES

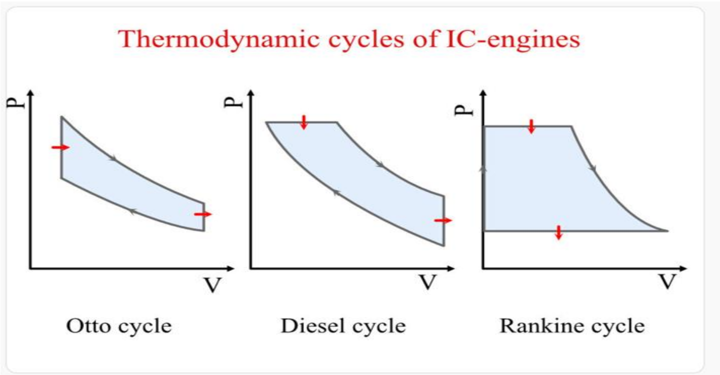

Figure 1: Various Thermodynamics Cycles

Internal Combustion Engines (IC engines) operate on thermodynamic cycles that describe the sequence of processes involved in converting chemical energy from fuel into mechanical work. The two primary cycles are:

1. Otto Cycle:

- Used in gasoline engines, the Otto cycle consists of four processes: isentropic compression, constant volume heat addition (combustion), isentropic expansion, and constant volume heat rejection (exhaust).
- The cycle is characterized by a spark ignition, and it is more fuel-efficient than alternative cycles at partial loads.

2. Diesel Cycle:

- Diesel engines operate on the Diesel cycle, which involves isentropic compression, constant pressure heat addition (combustion), isentropic expansion, and constant volume heat rejection.
- Diesel engines use compression ignition, where air is compressed to a temperature sufficient for spontaneous ignition of the fuel.

3. Dual Combustion Cycle (or Dual Cycle):

- Combines elements of both Otto and Diesel cycles. It includes two constant volume processes and one constant pressure process.
- This cycle is often used for theoretical analyses due to its ability to represent aspects of both gasoline and diesel engine operation.

A. Combustion Processes in IC Engines:

Combustion in IC engines involves the rapid chemical reaction between fuel and oxidizer (usually air) to release energy. The combustion process in gasoline and diesel engines differs:

1. Gasoline Engines:

- Combustion in gasoline engines is initiated by a spark plug. The air-fuel mixture is ignited, and a flame front propagates through the mixture, leading to a rapid increase in pressure.
- Flame propagation speed is a critical factor influencing combustion efficiency and performance.

2. Diesel Engines:

- Diesel combustion is initiated by the high temperature resulting from the compression of air in the cylinder. Diesel fuel is injected into the hot, compressed air, leading to spontaneous ignition.
- Diesel combustion is characterized by a longer ignition delay and a more gradual pressure rise compared to gasoline engines.

3. Combustion Phases:

- Ignition Delay: The time between the start of injection (diesel) or spark ignition (gasoline) and the commencement of significant combustion.
- Flame Propagation: The rapid increase in pressure due to the flame front moving through the combustion chamber.
- Burnout: The completion of combustion where almost all the fuel is consumed.

III. FACTORS AFFECTING COMBUSTION EFFICIENCY AND EMISSIONS

1. Air-Fuel Ratio: The ratio of air to fuel in the combustion mixture affects combustion efficiency and emissions. Stoichiometric (chemically balanced) ratios are critical for optimal performance.
2. Ignition Timing: The timing of spark ignition (gasoline engines) or fuel injection (diesel engines) influences combustion efficiency. Proper timing ensures maximum pressure is achieved at the right crankshaft angle.
3. Compression Ratio: The compression ratio affects the efficiency of the combustion process. Higher compression ratios in diesel engines contribute to increased efficiency.
4. In-Cylinder Turbulence: Enhanced turbulence promotes better mixing of air and fuel, facilitating more complete combustion and reducing emissions.
5. Combustion Chamber Design: The shape and design of the combustion chamber influence the combustion process. Efficient combustion chamber designs promote better fuel atomization and mixing.
6. EGR (Exhaust Gas Recirculation): Introducing a portion of exhaust gas back into the combustion chamber helps control peak temperatures and reduce NOx emissions.
7. Fuel Quality: The quality of the fuel, including its octane or cetane rating, influences combustion characteristics and emissions.
8. Cylinder Pressure and Temperature: Higher cylinder pressures and temperatures generally lead to more complete combustion and improved efficiency.
9. Turbocharging and Supercharging: Forced induction systems increase air intake, promoting better combustion efficiency and power output.
10. After treatment Systems: Exhaust after treatment systems, such as catalytic converters and particulate filters, play a crucial role in reducing harmful emissions.

IV. ENGINE COMPONENTS AND THEIR FUNCTIONS

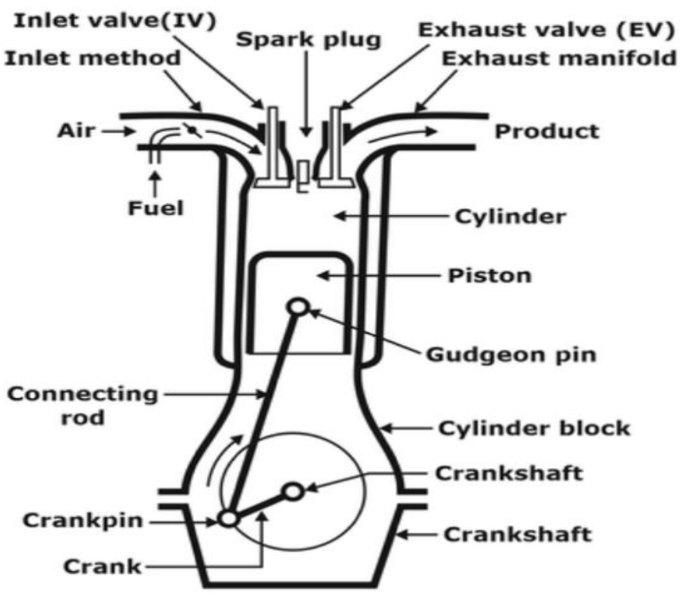

Figure 2: IC Engine Components

1. Piston: Converts reciprocating motion into rotary motion. The piston moves up and down within the cylinder, transferring force to the crankshaft.
2. Cylinder: Provides a sealed chamber for the combustion process to take place. The piston moves inside the cylinder, and the cylinder is part of the engine block.
3. Crankshaft: Converts the reciprocating motion of the piston into rotary motion. It is connected to the piston through a connecting rod and transfers power to the drivetrain.
4. Connecting Rod: Connects the piston to the crankshaft, transmitting the linear motion of the piston to the rotary motion of the crankshaft.
5. Camshaft: Controls the opening and closing of the engine's valves. The camshaft is synchronized with the crankshaft to ensure precise valve timing.

6. Valves (Intake and Exhaust): Control the flow of air and exhaust gases into and out of the combustion chamber. The opening and closing of valves are timed to optimize combustion.
7. Cylinder Head: Forms the top of the combustion chamber and houses the valves and, in some cases, the camshaft. It plays crucial role in sealing the combustion chamber.
8. Piston Rings: Seal the gap between the piston and cylinder walls, preventing excessive oil from entering the combustion chamber and helping with heat transfer.
9. Timing Belt/Chain: Synchronizes the rotation of the crankshaft and camshaft, ensuring proper valve timing.
10. Engine Block: Houses the cylinders, crankshaft, and other major components. It provides structural support and serves as the main body of the engine.
11. Fuel Injector: Atomizes and injects fuel into the combustion chamber for combustion.
12. Exhaust Manifold: Collects and directs exhaust gases from the cylinders to the exhaust system.
13. Oil Pump: Circulates engine oil to lubricate moving parts and cool components.
14. Coolant Pump: Circulates coolant through the engine to regulate temperature and prevent overheating.
15. Flywheel: Stores rotational energy and smoothens out fluctuations in engine speed.

V. ENGINE DESIGN PARAMETERS AND THEIR IMPACT ON PERFORMANCE

1. Bore and Stroke: Affects the engine's displacement and its torque and power characteristics.
2. Compression Ratio: Influences efficiency, power output, and thermal efficiency. Higher ratios can improve efficiency but may require higher-octane fuel.
3. Valve Timing and Lift: Affects the efficiency of the combustion process, power delivery, and overall performance.
4. Fuel Injection System: Direct injection, port injection, or a combination can affect combustion efficiency, emissions, and power output.
5. Turbocharging/Supercharging: Increases air intake, allowing for more efficient combustion and increased power output.
6. Engine Cooling System: Influences the engine's operating temperature, efficiency, and durability.
7. Exhaust System Design: Affects the scavenging of exhaust gases, backpressure, and emissions.
8. Materials and Weight: The choice of materials influences the engine's weight, durability, and thermal characteristics.
9. Cylinder Arrangement (Inline, V, Boxer): Affects the engine's packaging, balance, and overall vehicle design.

VI. ENGINE CONTROL SYSTEMS AND THEIR ROLE IN PERFORMANCE AND EMISSIONS OPTIMIZATION

1. Electronic Control Unit (ECU):

- The ECU is the brain of the engine control system, monitoring and managing various parameters to optimize performance and emissions.
- Controls fuel injection timing, spark timing, and other critical engine parameters.

2. Sensors:

- Sensors provide real-time data to the ECU, allowing it to make adjustments for optimal engine operation.
- Include sensors for measuring engine speed, throttle position, air intake temperature, coolant temperature, oxygen levels in exhaust gases, and more.

3. Actuators:

- Actuators respond to signals from the ECU to adjust various components and systems in the engine.
- Actuators control fuel injectors, throttle position, exhaust gas recirculation (EGR), and variable valve timing.

4. Fuel Injection Systems:

- Precisely controls the amount and timing of fuel injection for efficient combustion.
- Direct Injection (DI) and Port Fuel Injection (PFI) systems contribute to optimizing the air-fuel mixture.

5. Ignition Systems:

- Controls the timing of spark ignition in gasoline engines.
- Optimizes ignition timing for efficient combustion, power output, and emissions control.

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6. Variable Valve Timing (VVT) Systems:

- Adjusts the timing of the opening and closing of engine valves for optimal performance at different engine speeds.
- Enhances torque, fuel efficiency, and reduces emissions.

7. Turbocharger and Supercharger Control:

- Manages forced induction systems to optimize air intake and combustion efficiency.
- Adjusts boost levels for improved power output and fuel efficiency.

8. Exhaust Gas Recirculation (EGR) Systems:

- Reduces NOx emissions by recirculating a portion of exhaust gases back into the combustion chamber.
- Controlled by the ECU based on operating conditions.

9. Transmission Control Systems (for Automatic Transmissions):

- Coordinates engine and transmission operation for optimal performance and fuel efficiency.
- Manages gear shifts, torque converter lock-up, and other transmission parameters.

10. Idle Speed Control:

- Maintains a stable and efficient idle speed when the vehicle is stationary.
- Adjusts air-fuel mixture and throttle position during idling.

VII. EMISSIONS FORMATION MECHANISMS AND CONTROL STRATEGIES

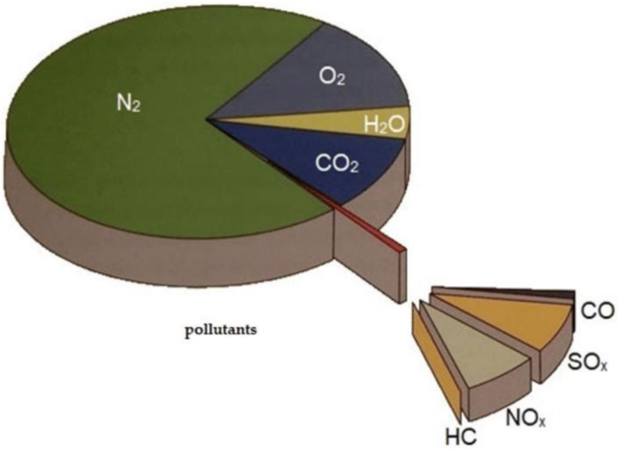

Figure 3: Emission emitted by Marine Engines

1. Nitrogen Oxides (NOx) Formation:

- High temperatures during combustion lead to nitrogen and oxygen reacting to form NOx.
- EGR systems, lean-burn combustion, and selective catalytic reduction (SCR) reduce NOx emissions.

2. Carbon Monoxide (CO) Formation:

- Incomplete combustion of fuel leads to the production of CO.
- Optimizing combustion through precise fuel injection and air-fuel ratio control.

3. Hydrocarbons (HC) Formation:

- Unburned fuel and incomplete combustion contribute to HC emissions.
- Efficient combustion, catalytic converters, and vapor recovery systems help reduce HC emissions.

4. Particulate Matter (PM) Formation:

- Incomplete combustion and the breakdown of hydrocarbons lead to the formation of particulates.
- Diesel particulate filters (DPF), advanced combustion systems, and fuel additives mitigate PM emissions.

5. Carbon Dioxide (CO2) Emissions:

- Produced during complete combustion of carbon-based fuels.
- Improving fuel efficiency and exploring alternative fuels to reduce CO2 emissions

VIII. ADVANCED IC ENGINE TECHNOLOGIES FOR IMPROVED EFFICIENCY AND EMISSIONS

1. Variable Compression Ratio (VCR) Technology: Allows the adjustment of the compression ratio during operation, optimizing efficiency under different driving conditions.
2. Homogeneous Charge Compression Ignition (HCCI): Combines the benefits of spark ignition and compression ignition, improving fuel efficiency and reducing emissions.
3. Gasoline Direct Injection (GDI) and Direct Diesel Injection: Precision fuel injection directly into the combustion chamber for better control over combustion, leading to improved efficiency and reduced emissions.
4. Advanced Combustion Modes: Research into innovative combustion modes, such as stratified charge and lean-burn combustion, to achieve higher thermal efficiency and lower emissions.
5. Advanced Turbocharging and Supercharging: Integration of electrically-assisted turbocharging, twin-scroll turbochargers, and other technologies to enhance engine performance and efficiency.
6. Waste Heat Recovery (WHR): Utilizing waste heat from the exhaust gases or engine coolant to drive additional power-producing systems, improving overall efficiency.
7. Cylinder Deactivation and Variable Valve Timing: Enhanced systems that deactivate specific cylinders or adjust valve timing to optimize engine performance and fuel efficiency during partial loads.
8. Advanced Materials and Coatings: Implementation of lightweight materials and advanced coatings to reduce friction, enhance durability, and improve overall engine efficiency.

The future of internal combustion engines involves a combination of advanced technologies to enhance efficiency, reduce emissions, and integrate with electrification. These trends reflect the industry's commitment to meeting stringent environmental standards and addressing the evolving demands of sustainable transportation.

IX. CONCLUSION

Internal combustion engines (ICEs) have played a significant role in driving transportation and powering various industries for over a century. Despite their remarkable achievements, they face challenges related to efficiency, emissions, and resource depletion. This necessitates ongoing research and development to improve their performance while minimizing their environmental impact.

Advances in thermodynamics, combustion processes, materials science, and control systems hold immense potential for improving ICE efficiency and reducing emissions. Additionally, electrification, hybridization, and exploration of alternative fuels offer promising avenues for cleaner and more sustainable transportation solutions.

The future of IC engines lies in embracing technological innovation and embracing alternative powertrains. By leveraging advancements in various fields and pursuing a multi-pronged approach, we can ensure that IC engines continue to contribute to societal progress while minimizing their ecological footprint.

The continued development and improvement of IC engines will be crucial for maintaining the mobility and economic growth that we rely upon while transitioning towards a more sustainable future.

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