Performance Comparison Between Traditional Internal Combustion Engines and Hybrid Powertrains

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Abstract. This paper explores the performance differences between traditional internal combustion engines (ICEs) and hybrid engines. Traditional ICEs have been the cornerstone of automotive technology for over a century, operating by converting chemical energy from burning fuel into mechanical energy. Despite their widespread use, traditional ICEs are significant contributors to air pollution and global warming. In contrast, hybrid engines combine one or more electric motors with a traditional ICE, utilizing battery packs and regenerative braking to enhance fuel efficiency and reduce emissions. As society increasingly adopts hybrid vehicles due to their environmental benefits, understanding the advantages and disadvantages of both engine types is crucial. This study evaluates the energy efficiency, emissions, and power output of traditional and hybrid engines. By analyzing common driving scenarios, this paper provides a comprehensive comparison to inform consumer choices, manufacturing trends, and policies aimed at reducing the automotive industry's carbon footprint and improving economic factors related to fuel consumption. Ultimately, this research aims to contribute to the ongoing dialogue on sustainable transportation and the future of automotive engineering.

Keywords: Traditional engine, internal combustion engine, hybrid engine, emissions reduction, fuel efficiency.

1. Introduction

ICEs primarily traditional engines, have played a crucial role over a century [1]. These engines operate by burning fuel, such as gasoline or diesel, in a combustion chamber, creating a high-pressure gas that drives pistons, creating a large movement of these pistons in order to convert chemical engines into mechanical energy. Hybrid engines represent the combinations of one or more electric motors and a traditional ICE. The electric motors can either assist the combustion engine (mild hybrids) or drive the vehicle independently (full hybrids). Hybrid systems typically include a battery pack that stores energy, which is either generated during braking (regenerative braking) or supplied by the engine. By integrating electric power, hybrid engines offer the advantage of reduced fuel consumption and lower emissions, making them a more environmentally friendly alternative to traditional engines. As society develops, more and more hybrid engine vehicles are used in modern cities, competing and replacing vehicles with traditional engines. Society needs to know the advantages and disadvantages of both types of engines. Due to the growing concern about environmental issues, the study of engine performance has become crucial.

Traditional ICEs contribute significantly to air pollution and global warming by emitting large amounts of carbon dioxide (CO_2), nitrogen oxides (NO_x) and particulate matter. In contrast, hybrid engines promise to reduce emissions and minimize their impact on the environment. Understanding the performance of these two engines can help develop more sustainable automotive technologies and policies aimed at reducing the carbon footprint of the automotive industry. Economic factors have also driven the study of engine performance. Fuel efficiency directly affects the operating costs of vehicles, and more efficient engines can reduce fuel bills for consumers. In addition, advances in hybrid technology could reduce reliance on fossil fuels, potentially leading to greater energy security and stable fuel prices. Analyzing the performance of conventional and hybrid engines can inform consumer choices, influence manufacturing trends, and ultimately influence the global economy. In this paper, the authors focus on the Performance Difference Between Traditional Engines and Hybrid

Engines in the aspects of energy efficiency, emissions and power output. For a fuller comparison, the authors also include two different common driving cases to seek subtle advantages and disadvantages.

1.1. Traditional Engine

Traditional engine, primarily ICEs, stands for Internal Combustion Engines. These engines generate power by burning fuel within the engine itself. The combustion process occurs inside the engine's cylinders, where the fuel-air mixture is ignited, causing an explosion that drives the pistons. This process converts the chemical energy of the fuel into mechanical energy, which can then be used to power vehicles, machinery, and other equipment. ICEs are commonly used in cars, motorcycles, trucks, aircraft, and many other types of machinery [1]. Traditional engines focus on efficiency, but their crankshaft linkage mechanism leads to significant mechanical loss, leading to reduce in thermal efficiency. The energy (thermal) efficiency of an engine is the product of its indicated thermal efficiency and mechanical efficiency. Therefore, the author aims to highlight both aspects of efficiency.

1.2. Thermal Efficiency

To indicate thermal efficiency, traditional engines require the maximum combustion pressure to be between 12 and 15 crankshaft angles. Fig. 1 shows that if the maximum combustion pressure is near the top stop point, the maximum piston force at 0 degrees is greater than at 13.5 degrees. Fuel combustion duration requires 50 to 60 crankshaft angles [1].

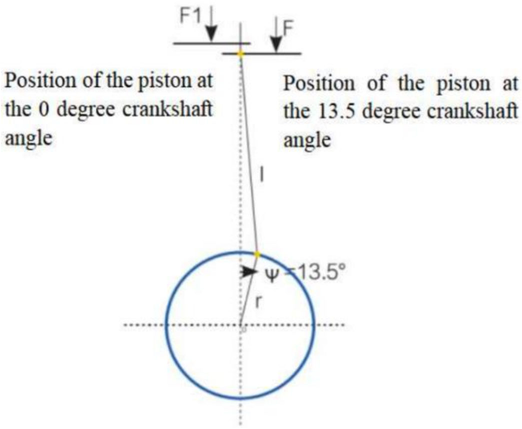

Figure 1. Maximum combustion pressure loss [2]

Furthermore, to reveal the truth of the disadvantage of energy inefficiency of fuel engines, the diagram below shows the energy efficiency is low no matter which type of fuel energy is used and what speed (rpm) the engine is working at (Fig. 2).

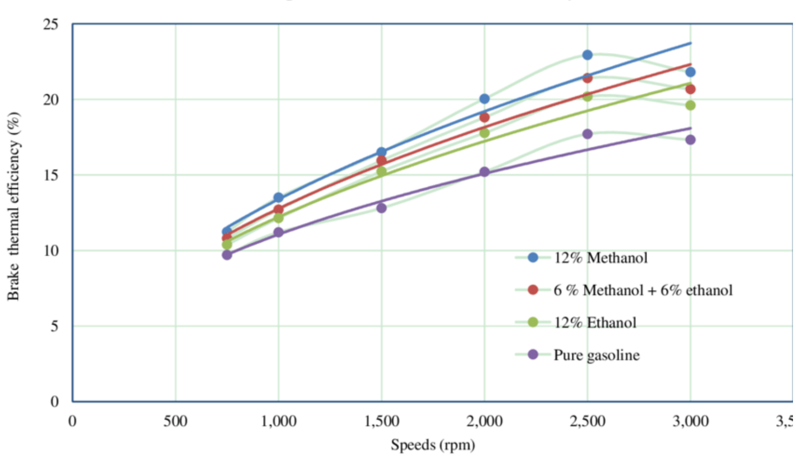

Figure 2. Speeds with thermal efficiency (Photo/Picture credit: Original)

1.3. Mechanical Efficiency

In traditional engines, mechanical efficiency is affected by two primary mechanical losses. The first is friction loss, which is the energy loss due to resistance between the moving parts of the engine. The second is mechanical conversion loss, which includes the sum of friction losses and other mechanical losses related to converting energy into useful work [2]. These combined losses reduce the overall efficiency of traditional engines, as they waste energy that could otherwise be used for propulsion [3]. The distribution of mechanical efficiency loss in a fuel engine has been shown in Fig. 3 [2].

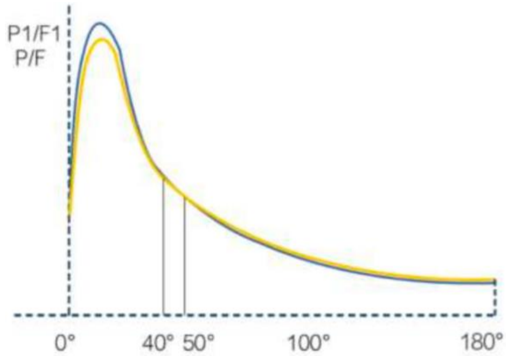

Figure 3. Combustion duration of time loss [2]

2. Hybrid Engines

A hybrid engine is a system that combines two power sources: an ICE and an electric motor. This system is designed to optimize fuel efficiency and reduce emissions while providing the performance advantages of traditional ICE vehicles.

2.1. Parallel Hybrid System

Structure and Working Principle: In a parallel system, both the ICE and the electric motor can independently or collaboratively drive the vehicle. Both can be directly connected to the vehicle's drive shaft. This means the vehicle can be powered by the ICE, the electric motor, or both together. Flexibility and Efficiency: This configuration allows the vehicle to choose the power source under different driving conditions flexibly. For example, during high-speed driving or when greater power output is needed, the ICE can primarily provide power. During low-speed driving, starting, or short trips, the electric motor can be primarily used, thereby saving fuel and reducing emissions. Regenerative Braking: The parallel hybrid system is usually equipped with regenerative braking technology, which converts the energy generated during braking into electrical energy and stores it in the battery, further enhancing energy utilization efficiency. Hybrid engines combine one or several ICEs with an electric motor to optimize fuel efficiency and reduce emissions [4]. In this case, we are analyzing the combination of an ICE and a relevant smaller power output electric motor, which combination is the broadest usage for vehicles with hybrid engines in the city.

2.2. Idling Performance

While idling, all the energy of the engine is consumed by mechanical losses. Hybrid engines perfectly solve this issue during parking idles by separating energy and power management. Electric motors have a significant advantage in energy efficiency compared to traditional heat engines. When the electric motor can be used, it significantly increases the overall energy efficiency of the vehicle, benefiting efficiency, the environment, and energy savings. The electric motor's ultra-high energy efficiency advantage is further amplified when the vehicle is idling [2]. The diagram below shows the significant advantage of hybrid engines under idling conditions (Fig. 4). Hybrid engines can reward idling while maintaining idle stability [1]. As the frequency and duration of idling increase, the economic performance advantages of hybrid engine vehicles become more apparent.

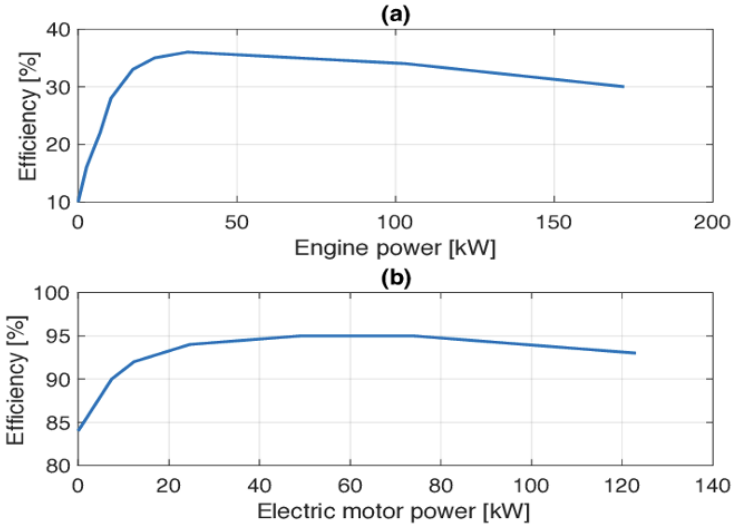

Figure 4. Power comparison [1]

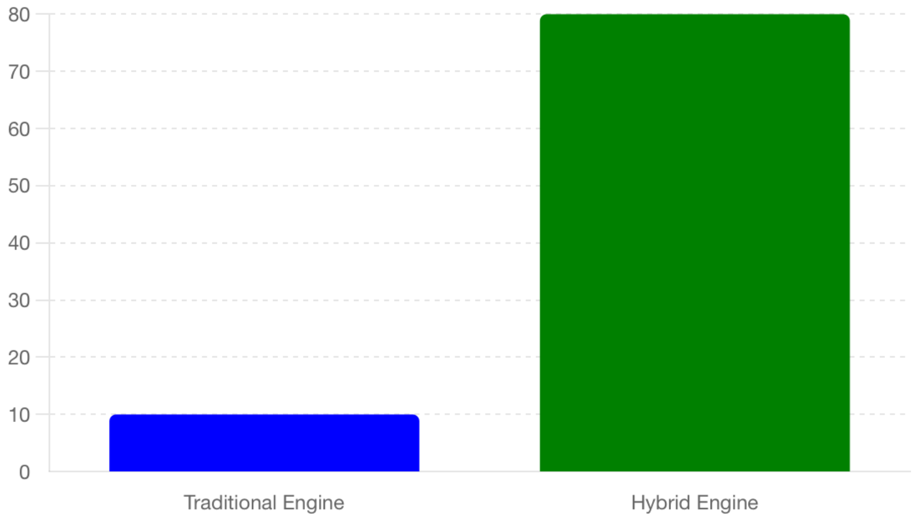

Figure 5. Power output (Photo/Picture credit: Original)

2.3. Working Efficiency

The power sources of hybrid electric vehicles are the engine and motor, and the smaller power engines are selected through the control strategy so that most of the working points can fall in the efficient range of the engine (Fig. 5) [5]. At low speed and low load, if the motor can meet the required power, then the motor is driven alone to achieve pure electric mode; if the motor cannot meet the required power, then start the engine and control the engine in the efficient working area, the remaining power for the battery, to improve fuel utilization [6, 7]. When the car accelerates and climbs sharply, and the engine cannot meet the needs of the whole vehicle, the motor will participate in the work so as to realize the motor power combined drive mode. Controlling the engine works in the efficient spare time while controlling the engine works in the efficient area can improve the economy by 5% to 10% [5]. The diagram below shows the power range of both engines to illustrate their different active ranges (Fig. 6).

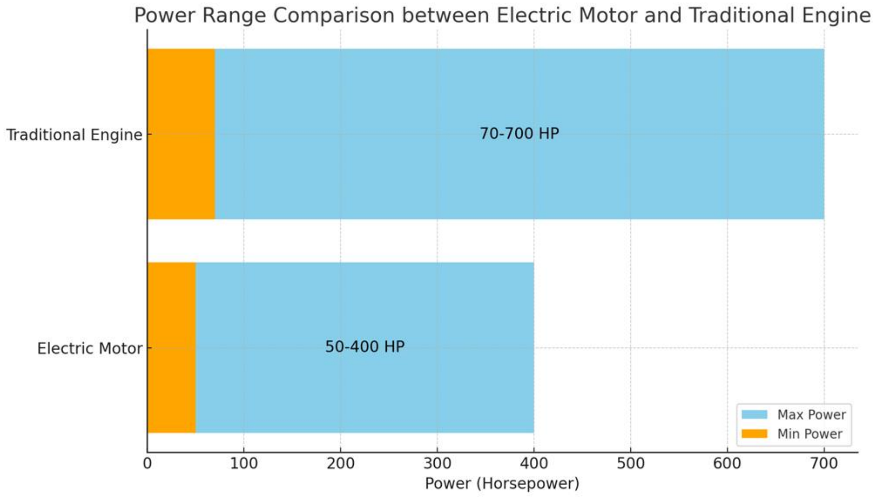

Figure 6. Power range between the electric motor and traditional engine (Photo/Picture credit: Original)

3. Comparative Analysis

Traditional engines pay attention to efficiency, but the crankshaft linkage mechanism has a large mechanical loss, which reduces the thermal efficiency of the engine. The total energy efficiency of an engine is the product of its indicated thermal efficiency and mechanical efficiency. Conventional engines require maximum combustion pressure to occur between 12 and 15 crankshaft angles for optimal thermal efficiency.

Energy efficiency across fuel types and engine speeds remains low. The mechanical efficiency of these engines is mainly affected by two kinds of losses: friction loss, which is the loss of energy due to the resistance between moving parts, and the sum of mechanical conversion losses, including friction losses and other losses associated with the conversion of energy to useful work [7]. These combined losses greatly reduce the overall efficiency of conventional engines, wasting energy that could otherwise be used for propulsion [8]. As a result, conventional engines are less efficient overall compared to more modern alternatives, highlighting the need for technological advances in engines to reduce mechanical and heat losses and increase energy efficiency.

In the case of idling, traditional ICE vehicles idle only through fuel consumption, resulting in a large amount of fuel consumption, while hybrid vehicles can separate energy and power management with superior economic performance. In terms of work efficiency, traditional vehicles rely entirely on traditional engines and often operate under low load conditions, resulting in poor fuel economy and high emissions. Hybrid cars, by contrast, use less powerful engines. At low speed and low load, the motor can meet the power demand, allowing pure electric mode.

4. Social Impact

The findings of this study have significant implications for the automotive industry. Hybrid engines offer higher fuel efficiency and lower emissions compared to conventional ICE highlighting the need for manufacturers to prioritize the development and production of hybrid vehicles. With increasing demand from governments and consumers for environmentally friendly vehicles, automakers that invest in hybrid technology may gain a competitive advantage. In addition, hybrid engines can save money in the long run due to improved fuel efficiency, which is a selling point for consumers looking to reduce their vehicle expenses in the long run.

The environmental impact of adopting hybrid engines is profound. Traditional ICEs are a major source of air pollution and greenhouse gas emissions, which have adverse effects on global warming and public health [9]. Switching to hybrid engines could significantly reduce the automotive industry's carbon footprint, as these engines emit fewer pollutants and use energy more efficiently

[10]. By reducing reliance on fossil fuels and lowering emissions, hybrid vehicles contribute to improving air quality and environmental health, in line with the global Sustainable Development Goals and efforts to combat climate change.

One limitation of this study is the variability of the data sources. Conventional and hybrid engines from different manufacturers and models vary in specifications, performance metrics and efficiency levels. This variability may affect the generalizability of the findings. In addition, real-world driving conditions, such as traffic patterns, weather, and driving habits, can significantly affect engine performance. Although these factors were controlled for as much as possible, inherent differences in data sources may have affected the results.

Potential bias in the study may also limit the results. Data selection and analysis methods may inadvertently favor one type of engine over another. For example, if the data mainly represents new models with advanced technology, the performance of hybrid engines may appear more favorable. Conversely, if the older model is too representative of the traditional engine, its efficiency may appear less. Despite efforts to ensure balanced representation, bias may still exist due to differences in available data and research focus. Future research should address these biases by including a wider range of engine models and richer driving scenarios.

5. Conclusion

This study compares traditional ICEs and hybrid engines, highlighting differences in performance, efficiency, and environmental impact. Traditional ICEs, despite their long-standing dominance, suffer from mechanical and thermal inefficiencies due to friction losses and suboptimal combustion processes, resulting in higher fuel consumption and emissions of CO_2 and NOx. These engines significantly contribute to air pollution and global warming. In contrast, hybrid engines combine electric motors with traditional ICEs, optimizing fuel efficiency and reducing emissions. Features like regenerative braking, idle-stop systems, and pure electric mode operation enhance fuel economy and decrease harmful emissions, addressing critical environmental issues. This shift towards hybrid technology marks a significant step in the automotive industry's evolution towards more sustainable and economically viable alternatives.

The growing popularity of hybrid vehicles, driven by consumer demand for eco-friendly options and regulatory pressures, is prompting manufacturers to invest more in developing hybrid systems. This trend is expected to drive advancements in hybrid technology, further improving performance and efficiency. Environmentally, the widespread adoption of hybrid engines could reduce the automotive sector's carbon footprint and mitigate climate change effects by lowering fossil fuel dependence, improving air quality, and enhancing public health. However, the study acknowledges limitations due to data variability and potential biases, as different manufacturers and models exhibit varying specifications and performance metrics. Real-world driving conditions, such as traffic patterns, weather, and driving habits, also impact engine performance. Future research should include a broader range of engine models and diverse driving scenarios for comprehensive evaluations. In conclusion, while traditional ICEs have been foundational in automotive technology, hybrid engines represent a significant advancement toward more efficient and environmentally responsible vehicles. As the automotive industry transitions, ongoing innovation and investment in hybrid technology will be crucial for achieving sustainable mobility and addressing global environmental challenges, marking a necessary shift towards a more sustainable future.

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