

IMPROVING THE ENERGY EFFICIENCY OF A GASOLINE INTERNAL COMBUSTION ENGINE THROUGH ADVANCED FUEL INJECTION SYSTEM OPTIMIZATION

Ergasheva Dilorom Burxon kizi

Warranty Engineer, Quality Control and Warranty Department
LLC “ADM Jizzakh”, Uzbekistan

Abstract

This paper presents an analysis of improving the energy efficiency of gasoline internal combustion engines (ICE) through the optimization of modern fuel injection systems. Internal combustion engines remain widely used in the automotive industry; however, their efficiency is limited by incomplete combustion, fuel losses, and non-optimal air–fuel mixture formation. The study investigates advanced fuel injection technologies, including multi-point fuel injection (MPFI) and gasoline direct injection (GDI), which provide precise fuel metering, improved atomization, and enhanced combustion control. A comparative analysis with conventional carburetor systems demonstrates that modern electronic fuel injection significantly improves fuel economy, thermal efficiency, and emission characteristics. The results confirm that fuel injection modernization is a key factor in enhancing engine performance and environmental sustainability.

Keywords: Internal combustion engine, fuel injection system, energy efficiency, gasoline engine, MPFI, GDI, combustion optimization, emissions reduction

Introduction

The internal combustion engine (ICE) remains one of the most important power sources in transportation systems worldwide. Despite the rapid development of electric mobility, gasoline engines continue to dominate due to their affordability, reliability, and established infrastructure. However, improving their energy efficiency remains a critical engineering challenge.

A significant portion of fuel energy in ICEs is lost due to incomplete combustion, heat transfer, pumping losses, and friction. Among these factors, inefficient fuel-air mixture formation plays a crucial role in limiting engine

efficiency. Therefore, the fuel delivery system becomes a key element in determining overall engine performance.

Traditional carburetor systems are unable to provide precise fuel control under varying operating conditions. This leads to non-optimal combustion and increased emissions. In contrast, modern fuel injection systems, controlled electronically via an engine control unit (ECU), allow accurate fuel metering based on real-time engine parameters.

Technologies such as multi-point fuel injection (MPFI) and gasoline direct injection (GDI) have significantly improved combustion efficiency, fuel economy, and emission performance. This paper aims to analyze the impact of these systems on engine energy efficiency and evaluate their advantages over conventional systems.

Fuel Injection System Technologies

Modern fuel injection systems operate through electronic control mechanisms that adjust fuel delivery based on engine load, speed, temperature, and air intake conditions.

In MPFI systems, fuel is injected into each cylinder's intake port, ensuring uniform air-fuel mixture distribution. This improves combustion stability and reduces fuel consumption.

In GDI systems, fuel is injected directly into the combustion chamber at high pressure. This enables better atomization, higher compression ratios, and improved thermal efficiency.

Key advantages of modern systems include:

- Precise fuel metering
- Improved atomization
- Optimized combustion timing
- Reduced fuel wastage
- Adaptive engine control

These features significantly enhance engine efficiency and reduce harmful emissions such as CO, HC, and NO_x.

Efficiency and Performance Analysis

Modern fuel injection systems improve engine performance through better control of combustion processes. The following improvements are typically observed:

A. Fuel Economy Improvement

Fuel consumption is reduced by approximately 10–25% compared to carburetor systems due to optimized fuel delivery.

B. Combustion Efficiency

Better fuel atomization leads to more complete combustion, increasing thermal efficiency and reducing unburned fuel residues.

C. Emission Reduction

More efficient combustion significantly reduces carbon monoxide, hydrocarbons, and nitrogen oxide emissions.

D. Engine Performance Enhancement

Improved torque characteristics, smoother acceleration, and higher power output are achieved due to precise fuel control.

IV. Discussion

The transition from mechanical fuel systems to electronic fuel injection represents a major advancement in internal combustion engine technology. The integration of sensors and ECU-based control allows real-time optimization of engine operation.

Although modern injection systems are more complex and require higher manufacturing costs, their benefits in terms of efficiency, performance, and environmental compliance outweigh these limitations.

Furthermore, these systems support global emission regulations and contribute to sustainable automotive development.

V. Conclusion

This study demonstrates that modern fuel injection systems significantly improve the energy efficiency of gasoline internal combustion engines. Technologies such as MPFI and GDI ensure precise fuel delivery, enhanced combustion quality, and reduced emissions.

The results confirm that fuel injection system modernization is one of the most effective approaches to improving ICE performance. Future developments in injection technology will further increase efficiency and support environmentally friendly transportation systems.

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