Design and construction of a fault emulator for the electronic control of an internal combustion engine via wireless interface

Diseño y construcción de un emulador de fallas para el control electrónico de un motor de combustión interna mediante interfaz inalámbrica

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ABSTRACT

Electronic fuel injection systems have replaced carburetors due to their precise control of the air-fuel mixture, optimizing combustion and reducing emissions. These systems, which include sensors, actuators and the ECU, are essential to engine performance. The complexity of these systems requires advanced diagnostic tools and specialized training for automotive technicians. Emulators are crucial for training, allowing practice in safe environments. Injection systems use sensors to measure airflow, pressure, temperature and crankshaft position, sending signals to the ECU to adjust injection and ignition. Some key sensors are the MAF, MAP, IAT, CKP, KS and the oxygen sensor. The ECU analyzes these signals to adjust the amount of fuel needed, improving efficiency and

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reducing consumption and emissions. Therefore, this document details the design and construction of a fault emulator for the electronic injection system for an internal combustion engine, through the application of electronic components, PCB design in Protel 99 SE and use of Iocomp commands which will allow the identification of faults, engine behavior and training for automotive technicians. Fault emulation allowed the identification of faults and erroneous behavior of the internal combustion engine.

Keywords: actuators, emulator, faults, sensors.

RESUMEN

Los sistemas de inyección electrónica de combustible han reemplazado a los carburadores debido a su control preciso de la mezcla aire-combustible, optimizando la combustión y reduciendo emisiones. Estos sistemas, que incluyen sensores, actuadores y la ECU, son esenciales para el rendimiento del motor. La complejidad de estos sistemas requiere herramientas de diagnóstico avanzadas y capacitación especializada para los técnicos automotrices. Los emuladores son cruciales para la formación, permitiendo practicar en entornos seguros.

Los sistemas de inyección usan sensores para medir flujo de aire, presión, temperatura y posición del cigüeñal, enviando señales a la ECU para ajustar la inyección y el encendido. Algunos sensores clave son el MAF, MAP, IAT, CKP, KS y el sensor de oxígeno. La ECU analiza estas señales para ajustar la cantidad de combustible necesaria, mejorando la eficiencia y reduciendo el consumo y las emisiones. Por lo tanto, en este documento se detalla el diseño y construcción de un emulador de fallas para el sistema de inyección electrónico para un motor de combustión interna, mediante la aplicación de componentes electrónicos, diseño de PCB en Protel 99 SE y uso de commandos Iocomp con lo cual permitirá la identificación de fallas, comportamiento del motor y entrenamiento a técnicos automotrices. La emulación de fallas permitió la identificación de fallas y comportamiento errado del motor de combustión interna.

Palabras clave: actuadores, emulador, fallas, sensores.

INTRODUCTION

Electronic fuel injection (EFI) systems have largely replaced carburetors in modern vehicles due to their ability to precisely control the air-fuel mixture, resulting in more efficient combustion and reduced pollutant emissions (Aguilar, Gallo, Calero, & Guerra, 2022) (González, 2012). Electronic fuel injection management, which involves sensors, actuators, and an electronic control unit (ECU), is critical for optimal engine performance (Aguilar et al., 2022) (González, 2012) (Sandovalin, Correa, Guasumba, & Calero, 2022).

The increasing complexity of electronic injection systems requires advanced diagnostic tools and specialized training for automotive technicians (Alonso & Dos Reis Filho, 1999) (Gómez Iaconcha, 2020) (Almachi Oñate, Mena Villamarin, Ordoñez Vivero, & Reigosa Lara, 2024). Emulators have become an essential training tool, as they allow technicians to practice diagnosis and troubleshooting in a safe and controlled environment (González, 2012) (Byron, Borja, Isaac, & Cruz, 2023). These emulators allow common faults in sensors and actuators to be recreated, thus facilitating practical learning (Aguilar et al., 2022) (González, 2012) (Almachi Oñate et al., 2024) (Fuentes Covarrubias & Fuentes Covarrubias, 2013) (Almachi Oñate et al., 2024).

This document explores the operation of sensors in electronic injection systems, their importance in controlling fuel consumption, and methodologies for their diagnosis and emulation. Electronic injection systems use a variety of sensors to measure parameters such as air flow, pressure, temperature, and crankshaft position, among others (Sandovalin et al., 2022) (Aguilar et al., 2022) (González, 2012) (Fuentes Covarrubias & Fuentes Covarrubias, 2013) These sensors send electrical signals to the ECU, which processes this information and adjusts fuel injection and ignition to achieve optimal combustion (Aguilar et al., 2022) (Sandovalin et al., 2022) (Fernando Galeano-Vergara III, Vinicio Vergara-Hidalgo, & Edison Guasumba-Maila, 2021).

Practical training with fault emulators is an effective method for teaching technicians to identify and solve problems in electronic injection systems. This article details the design, construction, and validation of a fault emulator for the electronic injection system of an internal combustion engine, developed for the technical training of automotive technicians in Ecuador. The emulator was designed to recreate common faults in the system's sensors and actuators, allowing technicians to practice diagnosis and troubleshooting in a safe and controlled environment [

To this end, the relevant emulations were performed on the CMP, MAF, TPS, IAT, ECT sensors, clutch switch, neutral switch, and actuators such as injectors and IAC valve of an internal combustion engine. This study included the identification of their operating principles, connection pins, control tests, operating values and adjustment specifications, and diagrams of the engine control circuits and diagnostic connector (DLC). The injection time was analyzed in relation to the lambda probe signal.

Key sensors in electronic injection systems:

Mass air flow (MAF) sensor: Measures the amount of air entering the engine (Aguilar et al., 2022) (González, 2012).

Manifold absolute pressure (MAP) sensor: Measures the pressure inside the intake manifold (González, 2012).

Intake air temperature (IAT) sensor: Measures the temperature of the air entering the engine (Fernando Galeano-Vergara III et al., 2021).

Crankshaft position sensor (CKP): Detects the position and speed of the crankshaft for ignition and injection timing (Fernando Galeano-Vergara III et al., 2021)(Aguilar et al., 2022).

Knock sensor (KS): Detects abnormal combustion in the engine (Aguilar et al., 2022).

Oxygen sensor (Lambda): Measures the amount of oxygen in the exhaust gases (Aguilar et al., 2022) (Sandovalin et al., 2022)

The operation of an engine depends on the electrical signals sent by these sensors to the ECU, which analyzes the information and adjusts the actuators for optimal performance (Aguilar et al., 2022). Unlike carburetors, electronic fuel injection systems allow the exact amount of fuel needed for combustion to be determined, resulting in greater engine efficiency, lower fuel consumption, and reduced emissions (González, 2012) (Aguilar et al., 2022) (Sandovalin et al., 2022) (Sandovalin et al., 2022).
Electronic fuel injection systems can be classified according to several criteria:
Number of injectors: they can be single-point or multi-point, with one injector per cylinder (Aguilar et al., 2022).
Injector location: they can be direct or indirect injection, where the fuel is injected directly into the combustion chamber or into the intake manifold, respectively (Aguilar et al., 2022) (Sandovalin et al., 2022).
Injector timing: They can be sequential, where each injector is activated at the precise moment, or simultaneous, where several injectors are activated at the same time (Aguilar et al., 2022).

MATERIALS AND METHODS

The methodology used in this project was divided into several stages, such as: study of sensors and actuators, design and construction of the emulator, software development, and validation testing. The main phases of this process are described below:

Printed Circuit Board Design

The printed circuit board (PCB) was designed using Protel 99 SE software. This software enabled the creation of electronic schematics, layout design, and the generation of files for PCB manufacturing. The PCB included: 12 relays for switching sensors and actuators (ECT, IAT, TPS, injectors, IAC, PCM power and ground, ignition, start), 3 BJT transistors to simulate the clutch pedal position switches, power steering switches, and neutral switch, 3 digital potentiometers for varying the signals from the ECT, IAT, and TPS sensors, 1 MOSFET for the IAC valve flicker signal, 2 PIC 16F877A microcontrollers for simulation control and management, 2 transmitters for wireless communication with the control software on the PC, and regulators, capacitors, oscillators, resistors, diodes, and other support components. Figure 1 shows the emulation circuits for each of the sensors and actuators. Figure 2 shows the electronic circuit design in Protel 99 SE. Figure 3 shows the track design for the Main Board and Transmission.

Figure 1. Circuits for emulating faults in the main sensors and actuators a) CMP, b) MAF, Neutral Switch, i) Inyectores

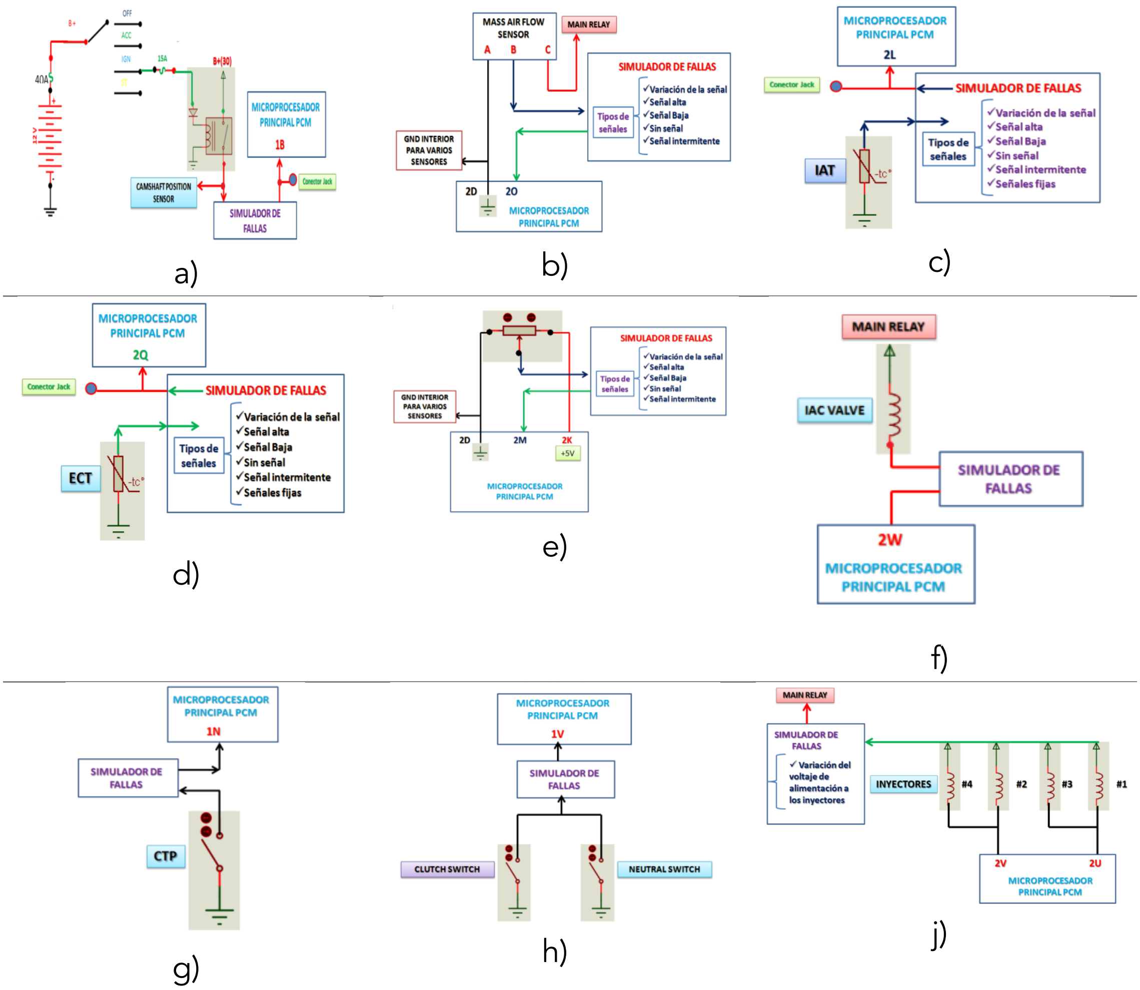
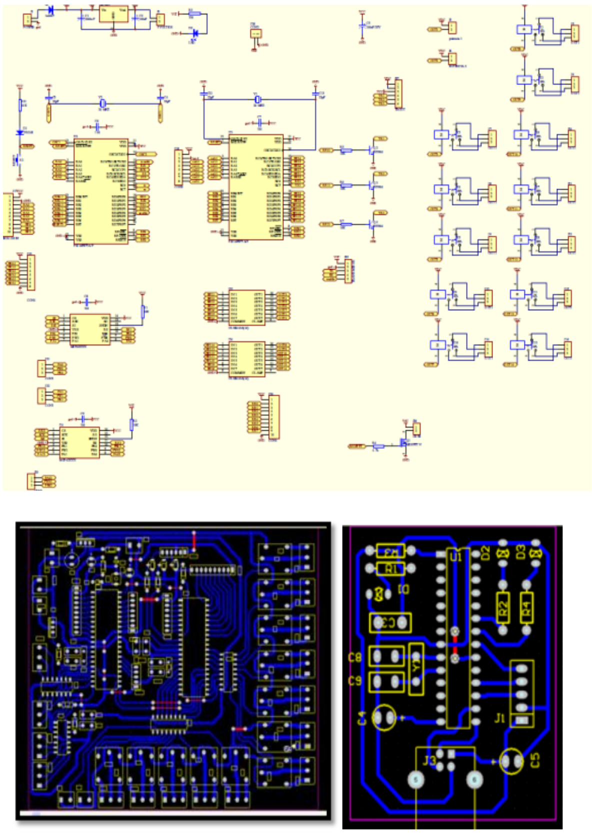


Figure 2. Electronic Circuit Design



Microcontroller Programming

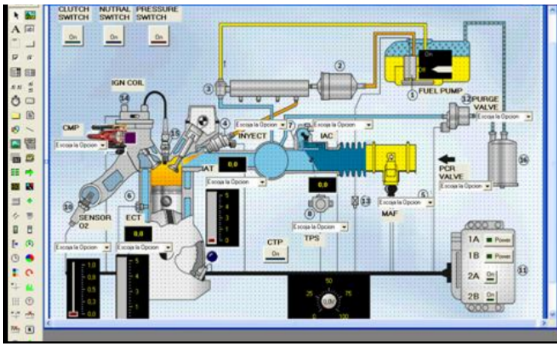
Two PIC 16F877A microcontrollers were programmed using a specific programming language for microcontrollers. The first microcontroller acted as the master, receiving commands from the software and sending signals to the second microcontroller, which controls the relays, potentiometers, and transistors in the power stage. The main microcontroller reads the sensor signals and sends the data to the slave microcontroller, which controls the relays and transistors to simulate the faults.

Software Development

Software was developed in Visual Basic Studio to control the simulator. This software included two main windows:

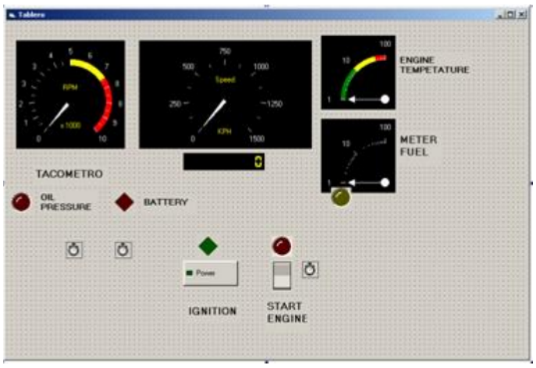
“Engine” window: For selecting the simulations to be performed on the sensors and actuators, with the help of combo boxes. Figure 3 shows the “Engine” window.

Figure 3. “Engine” window



‘Dashboard’ window: For viewing the engine status in terms of parameters such as revolutions, temperature, fuel level, among others, using Iocomp commands to create indicators and gauges. Figure 4 shows the “Dashboard” window.

Figure 4. “Dashboard” window



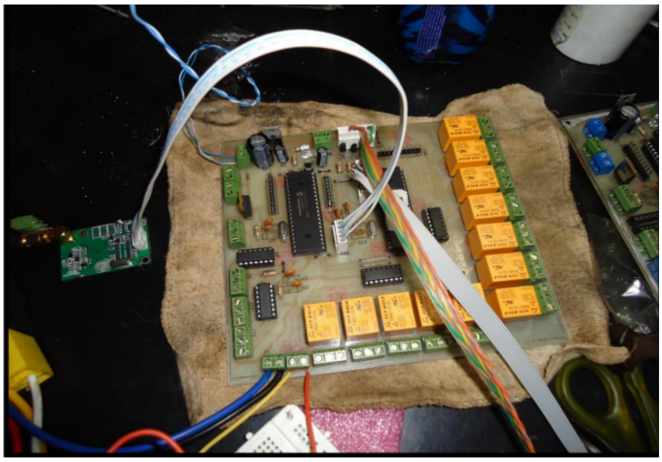
“Main” window: For selecting the communication port and accessing the “Engine” and “Dashboard” windows. Figure 5 shows the ‘Main’ window.

Figure 5. “Main” window

Control Circuit Adaptation

The necessary connections were made between the PCB and the engine sensors and actuators. Relays were used to simulate signal interruptions, and digital potentiometers were used to vary the analog signals from the resistive sensors (ECT, IAT, TPS). Figure 6 shows the PCB prior to installation with the sensors, actuators, and PCM.

Figure 6. Finished PCB board



Simulator operation

1. The instructor selects a specific simulation from the software on the computer.
2. The software sends the command to the microcontroller via radio frequency.
3. The microcontroller on the PCB activates the corresponding circuit (relays, transistors, potentiometers).
4. The circuit simulates the failure in the sensor or actuator, sending an altered signal to the PCM.
5. The technician can analyze the engine's response and diagnose the fault using diagnostic tools.

Figure 8 shows a general diagram of how the emulator works.

RESULTS

Extensive testing was conducted to validate the simulator's operation. Different types of sensor and actuator failures were simulated, and the control system's response and the generation of the corresponding fault codes were verified using an automotive multimeter and an automotive scanner.

Validation with Diagnostic Equipment

The voltage values of the sensors and actuators were measured with an automotive multimeter, and the fault codes were verified with an automotive scanner.

The fault generation equipment built allowed the emulation of different fault scenarios in the Mazda G6 engine injection system. Some of the simulations performed are shown below:

Sensor Fault Simulation

MAF Sensor: The sensor disconnection was simulated, obtaining a reading of 0.05 V, which resulted in fault code P0100 (MAF CIRCUIT FAULT). Figure 7 shows the voltage presented by the fault.

Figure 7. Voltage obtained by disconnecting the MAF sensor

IAT Sensor: Intermittent faults, disconnection (with a reading of 5.01 V), and temperature signal variation were simulated. Fault code P1110 (TEMPERATURE AIR INTAKE CIRCUIT – OPEN/SHORT) was obtained. Figure 8 shows the voltage presented by the fault.

Figure 8. Voltage obtained by disconnecting the IAT sensor

ECT sensor: Intermittent faults, disconnection, and temperature signal variation were simulated.

The latter varied the voltage outside the upper range, with a fault code of P0118 and a voltage value of 4.96 V. Figure 9 shows the voltage presented by the fault.

Figure 9. Voltage outside the upper range of the ECT sensor

TPS Sensor: Intermittent faults, disconnection, and variation of the throttle position signal were simulated. The latter varied the voltage outside the minimum range, with a fault code of P0122 and a voltage value of 0.03 V. Figure 10 shows the voltage presented by the fault.

Figure 10. Voltage out of lower range TPS sensor

Switches: The closing and opening signals of the clutch, neutral, and CTP switches were simulated, showing changes in engine speed and, therefore, engine load.

CMP sensor: The cut-off and closure of the camshaft position sensor signal was emulated, which showed the engine shutting down during this simulation.

Actuator Failure Simulation

Injectors: A power supply defect was simulated by reducing the input voltage to the injectors to 11.7 V, which generated a delay in the opening of the injector of 0.53 ms, implying a loss of injection of 26.5%. Figure 10 shows the variation in the voltage supply to the injectors.

IAC valve: Valve activation and deactivation were simulated, allowing changes in the idle speed to be observed. The figure simulates the IAC at low load, generating a voltage of 7.27 V, evidencing an unstable idle speed.

Benefits of the emulator

Hands-on training: Allows technicians to experiment with simulated faults in a safe environment.

Improved reasoning: Encourages logical reasoning in fault diagnosis.

Reduced maintenance time: Allows faults to be identified more quickly and efficiently.

Fault database: Allows the creation of a database of faults and their respective solutions.

Adaptability: The simulator can be adapted to other Mazda engines with software modifications.

DISCUSSION

The fault simulator developed in this project proved to be an effective tool for technical training on the Mazda G6 BT-50 engine's electronic injection system. The results obtained validated the simulator's design, construction, and operation. The main conclusions are:

A simulator was successfully designed and built that accurately recreates common faults in the electronic injection systems of the Mazda G6 BT-50 engine.

The PCB designed and implemented worked correctly, managing the switching and variation of sensor and actuator signals.

The control software developed in Visual Basic allowed intuitive interaction with the simulator, facilitating the selection and execution of simulations.

The use of microcontrollers and wireless communication allowed for efficient management of the simulator.

The emulator was built to the actual scale of the Mazda BT-50 pickup truck engine compartment, providing a realistic learning environment.

The simulator facilitates the identification of error codes using an automotive scanner, simulating electrical faults such as high, low, no, and intermittent signals, allowing for an understanding of the possible causes of engine faults.

The simulator can be adapted to other electronic injection engines by reprogramming the software.

The validation of sensor and actuator signals with real diagnostic equipment (multimeter, scanner) ensured the accuracy of the simulations.

REFERENCES

Aguilar, C. D., Gallo, E. M., Calero, D. A., & Guerra, J. I. (2022). Análisis del funcionamiento en los sensores de inyección electrónica para controlar el consumo de combustible. Dominio de las Ciencias, 8(2), 451–769. https://www.dominiodelasciencias.com/ojs/index.php/es/article/view/2673

Almachi Oñate, R. R., Mena Villamarín, D. A., Ordóñez Vivero, R. E., & Reigosa Lara, A. (2024). Aplicación del simulador ELECTUDE y el rendimiento académico en la figura profesional electromecánica automotriz. Tesla Revista Científica, 4(1), e387. https://doi.org/10.55204/trc.v4i1.e387

Alonso, G. C. M. B., & Dos Reis Filho, C. A. (1999). Automotive simulator for electronic fuel injections. SAE Technical Papers. https://doi.org/10.4271/1999-01-3053

Byron, A., Borja, A., Isaac, W., & Cruz, M. (2023). Ricardo Andrés Vera Indio (Vol. 10, pp. 1552–1567). (Nota: referencia incompleta; se recomienda revisar nombre de la revista o editorial).

Galeano-Vergara III, H. F., Vergara-Hidalgo, E. I. V., & Guasumba-Maila, J. I. E. (2021). El control y la gestión de la inyección electrónica de combustible para los motores de encendido provocado. Dominio de las Ciencias, 7, 1869–1887. http://dominiodelasciencias.com/ojs/index.php/es/index

Fuentes Covarrubias, R., & Fuentes Covarrubias, A. (2013). Desarrollo de un sistema experto para el diagnóstico de fallas automotrices. TE & ET: Revista Iberoamericana de Tecnología en Educación y Educación en Tecnología, (11), 83–91.

Gómez Iaconcha, J. R. (2020). Sistema de emulación fuera del vehículo de ECUs de control del motor para su diagnóstico posterior. Tknika, 3. https://www.ni.com/es/innovations/case-studies/19/system-of-emulation-outside-the-vehicle-of-engine-control-ecus-for-their-subsequent-diagnosis.html

González, H. E. C. (2012). Diseño de un simulador de señales básicas para un sistema de inyección electrónica de gasolina [Trabajo de titulación].

Sandovalin, J., Correa, E., Guasumba, J., & Calero, D. (2022). Los sistemas de inyección electrónicos y el control de gases. Polo del Conocimiento, 7(69), 344–361. https://doi.org/10.23857/pc.v7i4.3828