Adama Science and Technology University

School of Mechanical, Chemical and Materials Engineering

Development of Manifold Electronic Fuel Injector Tester for Liquid Fuels (Petrol)

A Project Submitted in Partial Fulfillment of the requirements for the award of degree of

Master of Science

in

Automotive Technology Teachers Education

by

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CANDIDATE'S DECLARATION

We hereby declare that the study project work which is being presented in this paper entitled "**Development of manifold electronic fuel injector tester for liquid fuels (petrol)**" in partial fulfillment of the requirements for the award of the degree of master of science in automotive technology is an authentic record of our own work carried out from March 2015 to June 2015 under the supervision of N. Ramesh Babu (Associate Professor) and Ato Hilemariam Nigus (MSc), Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this paper has not been submitted by us for the award of any other degree or diploma. All relevant resources of information used in this paper have been duly acknowledged.

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This is to certify that the declaration made by the candidate is correct to the best of my knowledge and belief. This project has been submitted with our approval.

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List of acronyms, abbreviations and symbols

SI	Spark ignition
CO	Carbon monoxide
HC	Hydrocarbon
CO_2	Carbon dioxide
PFI	Port Fuel injection
DI	Direct injection
EFI	Electronic fuel injection
ETA	Ethiopian Transport Authority
EEPA	Ethiopian Environmental Protection Authority
Kg	Kilograms
Mi	Milliliter
SAE	Society of Automotive Engineers
A/F Air-	Fuel Ratio
ROM	Random Access Memory
TVET	Technical and Vocational Education Training
Vbr	Maximum reverses voltage
Vf	Maximum forward voltage
DIL	Dual – in – line
ECU	Electronic Control Unit
IG	Ignition switch
SW	Switch
Ewd	Electrical wiring diagram
LED	Light Emitting Diode
V	Voltage
R	Resistance
I	Current
MIL	Malfunction Indicator light
PPE	Personal Protective Equipment

OHS	Occupational Health and Safety
AC	Alternating Current
DC	Direct Current
A	Unit for Current
PFC	Power Factor Correction
VOM	Volt-Ohm-Millimeter
Ni	Nickel
Ch	Chromium
Mg	Magnesium
lb	Pound
Ω	Ohm

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ABSTRACT

In the present Technology, all manufacturers of Automotive (Small to Light duties) and related machines are producing their products with Computer controlled Fuel Management system, for the simple reasons that as compared to the carburetor engine: better engine performance, best fuel economy, better cold starting, better drivability and above all the meeting of the emission standards are the features of this design. Computer controlled fuel system, popularly known as EFI uses a solenoid injector to inject the required amount of fuel as per the requirement of the engine as determined by the computer from the signals sent by various sensors from around the key operating variables of the engine. The computer controlling is as per the predetermined instruction stored in the ROM (read only memory) of the ECU (electronic control unit) for different operating conditions of the engines so it is generally perfect as long as the injectors are in good electrical and mechanical order. The objective of this project was to develop (fabricate) external device that tests the performance of all Electronic Fuel Injection injectors for Injection Volume, Injection Variation, Injection Pattern and no Injector Leakage tests for port injection and throttle body injection to determine whether it was as per the recommendation by manufacturers or not, as required after some kilometers/years' service of the vehicle. The methodology for standardization was proved by making the design considerations for the components, lines pressure, and voltage across injectors, injection duration/ pulse time using timer and flasher, in general by maintaining the tester to have accuracy and reliability as expected. The methodology used to design the frame structure that was used to support and host the system components was using AUTO-CAD technique. The result of the developed tester was perfect as to the standard due to the above mentioned methodologies and the tester was able to measure the performances of electrical solenoid injectors in the case of port and throttle body injections as mentioned above. In conclusion the developed tester was perfect or to the standard of a similar tester and found to be used perfectly to test the performances of electrical solenoid injectors. Generally, it was found to have economic and social advantages.

Key-words: Fabrication and Installation, Testing Injection Volume, Injection Variation, Injection Pattern and no Injector Leakage.

1. INTRODUCTION

1.1 Background of the study

During the last 30 years, reduction in tail pipe exhaust emissions of more than 90% have been demanded of and achieved by the automobile industry with one of the most important enabling technologies being low cost, series production EFI (Electronic Fuel Injection).[3]

Relative to carbureted fuel systems, the main mechanisms by which EFI has helped to reduce exhaust emissions are as follows: reduced wall wetting, improved fuel admission, greater flexibility in Air/Fuel ratio control, and improved unit to unit repeatability.

In addition to reduced exhaust emissions, EFI has also introduced other benefits such as engine performance, less fuel consumptions, better cold start ability, reduced noise, improved drivability and so on. Such technology is now often smaller to light duty vehicles and related machineries as the research study has shown. Automotive engineering researchers and the worldwide society of the field are behind this rapidly changing development in automotive history.

As mentioned above, in terms of engine performance and emission characteristics as a major in computer controlled engine management system where the fuel controlling as per the demand of the engine for all operating ranges in all the vehicles we see on the roads nowadays. A research study in Ethiopia has shown that with such engine management system the number of vehicles are rapidly increasing from year to year. It will go on increasing in more refined development in the future as well.

Ethiopian Energy and Environment Protection Agency Policy take the measure to reduce net carbon emissions, therefore, the old carburetor vehicles are almost on the boarder to leave according to the plan of this concerned body, the vehicle with fuel management systems are close to fulfill the requirement and as long as the electronic injector is in its right order both mechanically, electrically and electronically.

The manuals of all manufacturers have clearly stated that the solenoid injectors need to be checked based on certain kilometer or months service time whichever occurs first for performance check and replace as needed to meet the standard by the maker as well as Ethiopian Energy and Environments protection Agency.

To execute the above measurement for performance standard solenoid injector tester are used in developed countries. However, in Ethiopia the instrument or device used for checking the performance is available only in one garage in Addis Ababa city administration; when it should have been available in each and every standard garage in the country the reasons are may be one it is costly; second the lack of awareness of the drawbacks of the injector failure after some service time and hence affecting the amount of injection, or missing of injection which directly reduces engine performance , increase of carbon emissions, poor starting, poor drivability and so on. In this study we will develop a standard device for testing the performance of all EFI-injectors [3, 2].

The introduction of these technology will have significant advantages like: creating job for the unemployment urban poor, reducing dependence on imported technologies and hence reducing hard currency in the future as the device soon becomes important for the benchmark standards as it is the case in the developed countries , transferring the technology to each and every TVET institutions for training purpose and above all exercising these tests regularly as per the instructions and recommendations of all makers to keep engine performance and emissions result to the standard of the Ethiopian energy and environment protection agency.

As transport levels are expected to rise substantially, especially in Addis Ababa city and Regional capital towns; fairly drastic political decisions may have to be taken to address this in the future. An important step in efforts to solve in the country to make all EFI vehicles checked as per the instruction and recommendation of all makers so as to keep at least emissions free Environment like as the case now a days with all the developed countries [5,11].

1.2 Statement of the Problem

When we study this problem, the major is that on the one hand the development of EFI has solved the problem with a carburetor version such as carbon emissions and engine performance but as stated earlier on the other hand the fuel controlling management is perfect as long as the solenoid fuel injector is in the right order as indicated in the manuals of all makers for all EFI-injector designs, therefore, our project focuses on the development of manifold electronic fuel injector tester for liquid fuels(petrol),to test the performance of all solenoid injectors periodically as specified in the makers manual and replace as needed to make the least emission and best performance of the engine as per the standard of EFI management. The other main problem for the study is, in the case of Ethiopia such device is available only at one garage and nowhere else in the country.

1.3 Objectives

1.3.1 General objective

The General objective of this project is to develop manifold electronic fuel injector tester for liquid fuels (petrol) which will be used for testing the performance of all solenoid injectors.

Specific objectives

The specific objectives of the project are:

- to obtain and prepare the necessary items for the device development
- to develop the device as per the design intended
- to test and verify the device
- to conduct test on solenoid injectors to determine the amount of fuel it delivers in the specific time or injection duration, injection variation, injection pattern and injector leakage.

1.4 Significance of the study

The project will indicate how and why the performance measurements of solenoid is used using the device, it will keep the standards of the manufacturers in the case of emission result and engine performance, fuel economy and the like so it is helpful to meet the legislation released by the country to keep the environment pure, and the car owners will be benefited by this performance measurements as it corrects any miss match from the makers specification and recommendation.

After the accomplishment and implementation of the device, the system is expected to have the following basic significance:-

- Minimize the need for import and reduce foreign currency
- Cars will meet the standard and hence minimum emission and good engine performance as expected by manufactures
- Improves environment from pollution
- Enhanced car owners' Satisfaction

So in general, the significance of the study will have economic and social benefits.

1.5 Delimitation of the study

The developed device will be used for checking the performance of four injectors and above due to its nature but for small cars with two injectors another two standard injectors are installed together to check the performance of the two injectors and there is no other way to check the performance small cars with less than four injectors. The device works with common rail pressure of 2.5bar and 3bar, therefore, the device cannot be used with direct injection injectors since this requires a high pressure pump.

1.6 Limitations of the study

It has been found out that poor project workshop facility at the department of mechanical and vehicle engineering of Adama Science and Technology University is believed to have a negative effect on the project development, installation, and testing as we have expected according to the work plan of the study. Had all the needed equipment and tools and other update resources were available here at the university for the purpose of research work some of the parts would have been made in the workshop of the university or in the research center workshop the accuracy of the device would have been exact as to the standard, further time, cost and energy minimized. The finding of some items for the development of the device even in the country was another challenge which consumes our time.

2. LITERATURE REVIEW

2.1 Introduction

The basic goals of the automotive industry is to have a high power, low specific fuel consumption, low emission, low noise and better drive comfort. With increasing the vehicle number, the role of the vehicles in air pollution has been increasing significantly day to day. The environment protection agencies have drawn down the emission limits annually. Furthermore, continuously increasing price of the fuel necessitates improving the engine efficiency. Since the engines with carburetor do not hold the air fuel ration close to the stoichiometric at different working conditions, catalytic converter cannot be used in these engines. Therefore these engines have high emission values and low efficiency. Electronic controlled Port Fuel Injection (PFI) systems instead of fuel system with carburetor have been used since 1980's. In fuel injection systems, induced air can be metered precisely and the fuel is injected in the main fold to air amount. By using the lambda sensor in exhaust system, air/fuel ratio is held of stable value. Fuel systems without electronic controlled it is impossible to comply with the increasingly emissions legislation [3].

If port fuel injection system is compared with carburetor system, it has some advantages. Some of them are as follows:

1. Lower exhaust emissions.
2. Increased volumetric efficiency and therefore increased output power and torque. The carburetor venturi prevents air and, in turn, volumetric efficiency decrease.
3. Low specific fuel consumption. In the engine with carburetor, fuel cannot be delivered the same amount and the same air/fuel ratio per cycle, for each cylinder.
4. More rapid engine response to changes in throttle position.This increases the drive comfort.
5. Less rotating components in fuel injection system, the noise decreases [3,2].

Though the port fuelinjection system has some advantages, it cannot bemeet continuouslyincreased the demands about performance, emission legislation and fuel economy, at the presentday.The controlled gasoline direct injection systems were started to be used instead of port fuel injectionsystem since 1990's. Applications of Electronic fuel Injections types of Fuel Injections Schemes are:

Early designs:

- Mono Jetronic
- D-Jetronic
- K-Jetronic
- Ke-jetronic
- L-Jetronics

Current designs:

- Motronic
- L-type EFI
- D-Type EFI
- K-Type EFI,DI

In addition, some small vehicles are using solenoid injectors in the current design to achieve the same purpose as the above cases [8, 9].

In general, the arrangements of the device to be developed are made in such a way that it is able to determine the conditions of all the injectors as per the instructions and recommendations of all makers of the cars to meet the standards desired. So more or less the device will be more practical to solve the problems in determining the condition of all solenoid injectors as per the instruction and recommendation of the makers [6].

2.2 Fuel injection system

The purpose of the fuel injection system is to precisely inject a metered amount of fuel at the correct time. Based on the input sensor signals, the ECUs programming will decide when to turn each injector on and off. The next page figure shows the overview the overall fuel injection system component parts [1, 2].

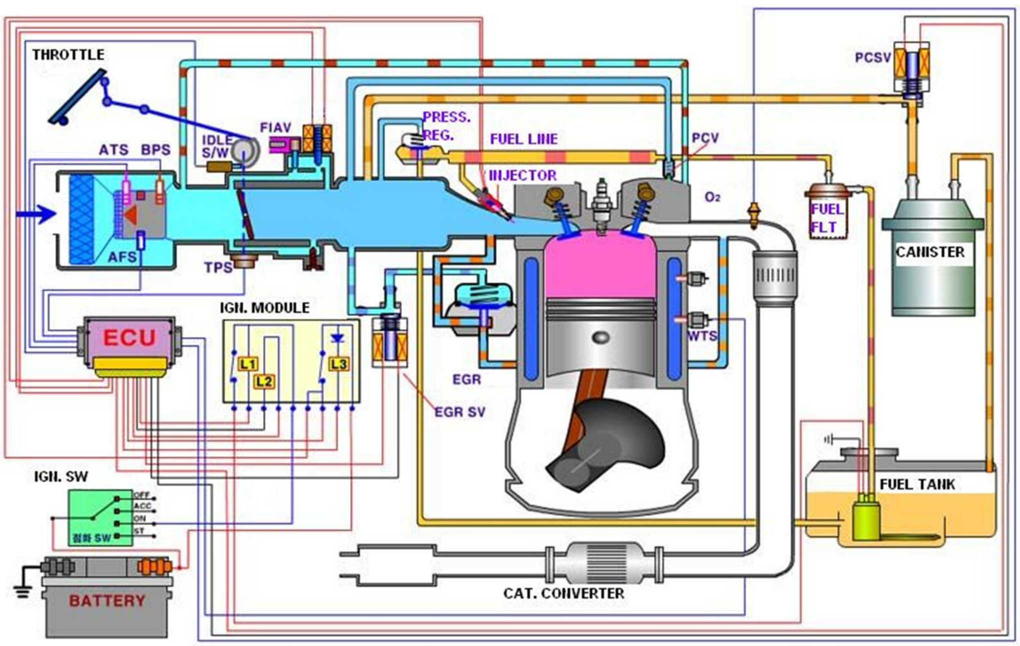

Figure 1: Overview gasoline fuel injection

Fuel Delivery System

The purpose of the fuel delivery system is to quietly deliver the proper volume of fuel at the correct pressure. The fuel delivery system must also meet emission and safety regulations. Major components are as shown the below figure 2.

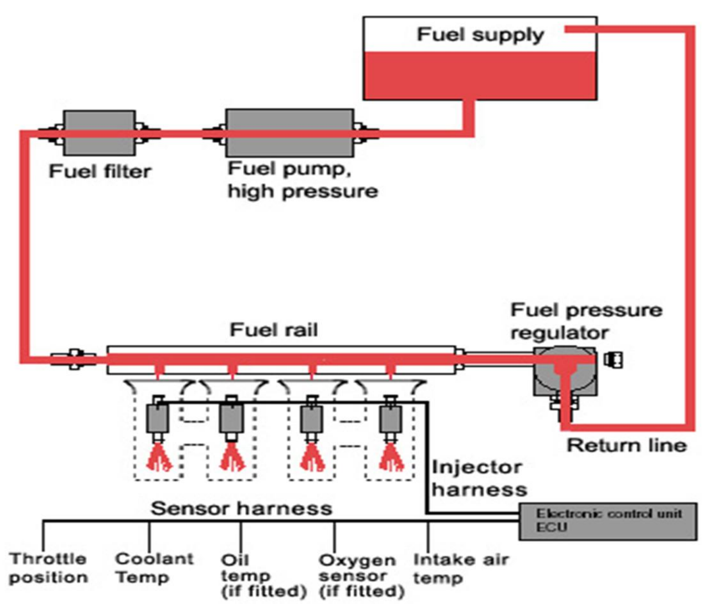

Figure 2: components of fuel injection system

Return Fuel Delivery System

As we can see figure 3, when the fuel pump is activated by the ECU, pressurized fuel flows out of the tank, through the fuel filter to the fuel rail and up to the pressure regulator. The pressure regulator maintains fuel pressure in the rail at a specified value. Fuel in excess of that consumed by engine operation is returned to the tank by a fuel return line. A pulsation damper, mounted on the fuel rail, is used on many engines to dampen pressure variations in the fuel rail. The injectors, when turned on by the ECU, deliver fuel into the intake manifold. When the fuel pump is turned off by the ECU, a check valve in the fuel pump closes maintaining a residual pressure in the fuel system [1, 2].

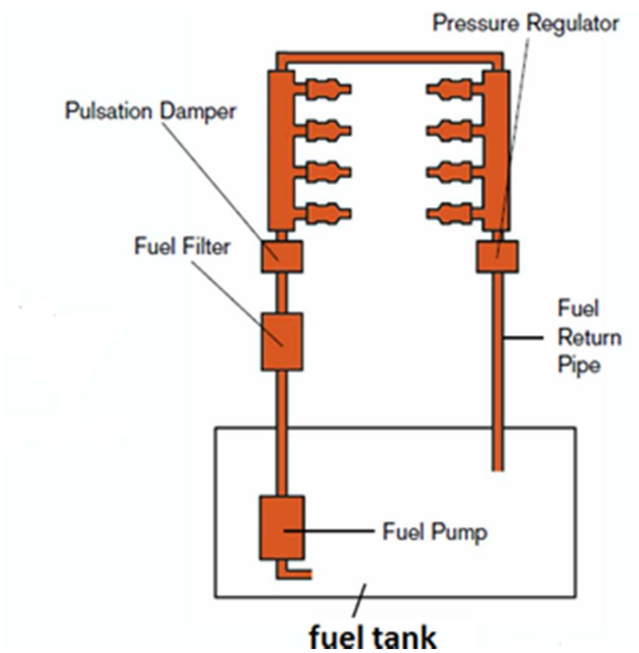

Figure 3: Return fuel delivery system

Return less Fuel Delivery System

As we can see figure 4, when the fuel pump is activated by the ECU, pressurized fuel flows from the pump to the pressure regulator. At the pressure regulator excess fuel is directed to the bottom of the fuel tank and pressurized fuel is sent out of the fuel tank, through the fuel filter, pulsation damper, and into the fuel rail. When the ECU turns on the injectors fuel is delivered into the intake manifold. Fuel pressure in this system is maintained at a constant and higher pressure, 44-50 psi. than the return fuel system. ECU programming and a higher fuel pressure eliminates the need for a vacuum modulated pressure regulator.

The return less fuel delivery system was adopted because it lowers evaporative emissions since no heated fuel is returned to the fuel tank. On the return fuel delivery system, fuel heated by the engine returns to the fuel tank and has warmer fuel creating more fuel vapors [7, 8].

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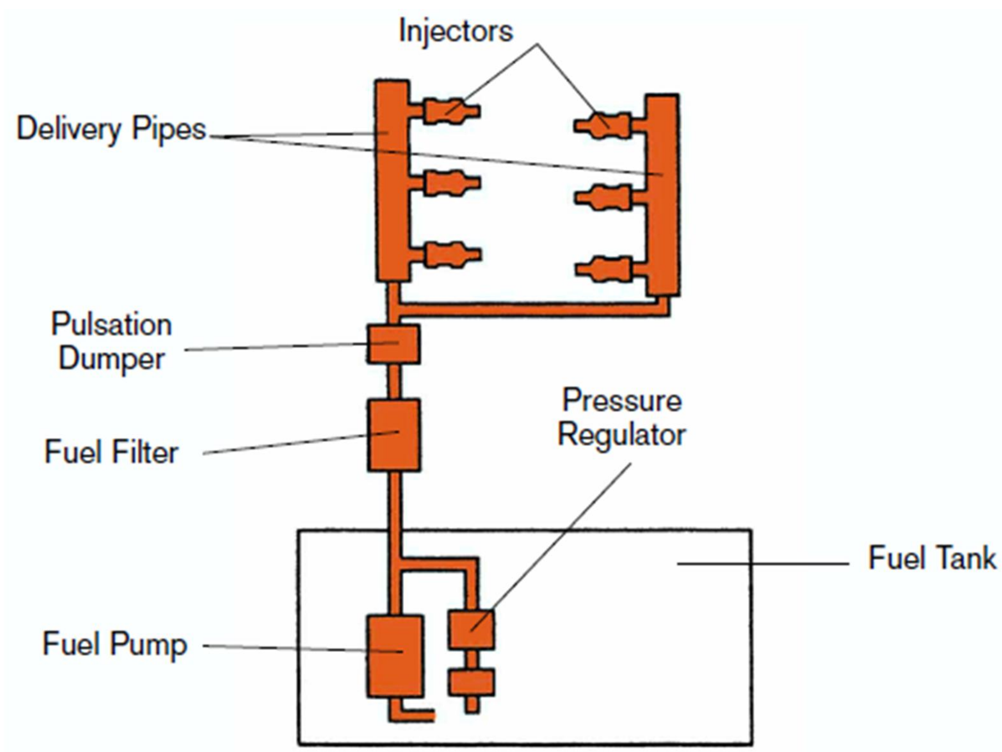

Figure 4: Return-less fuel delivery system

Fuel Pump

The fuel pump is mounted in the tank and immersed in fuel. The fuel cools and lubricates the pump. When current flows through the motor, the armature and impeller rotate. The impeller draws fuel in through a filter and discharges pressurized fuel through the outlet port. (See figure 5) The fuel pump's pumping capacity is designed to exceed engine requirements. This insures that there will always be enough fuel to meet engine demands. An outlet check valve, located in the discharge outlet, maintains a residual fuel pressure in the fuel system when the engine is off. This improves starting characteristics and reduces vapor-lock. Without residual fuel pressure, the system would have to be pressurized each time the engine was started and this would increase engine starting (cranking) time. When a hot engine is shut off, fuel temperature in the lines around the engine increases. Keeping the system pressurized increases the boiling point of the fuel and prevents the fuel from vaporizing. A pressure relief valve will open if the fuel system becomes restricted. This is a safety device to prevent the fuel lines from rupturing and damage to the pump on many models the fuel pump is part of the fuel pump assembly. This assembly contains the filters, pressure regulator (return less fuel system only), sending unit, and fuel pump. Many of the components can be serviced separately [7].

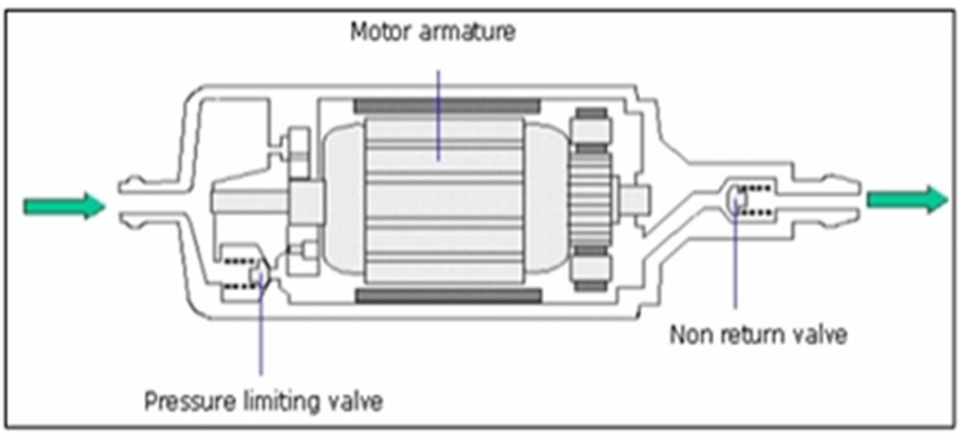

Figure 5: Electrical fuel pump

Fuel Pump Controls

A variety of fuel pump control circuits and controls have been used over the years. The following basic methods are:

• ON/OFF Control by ECU.

• ON/OFF Control by Fuel Pump Switch.

• ON/OFF Two Speed Control with a Resistor.

• ON/OFF Two Speed Control with Fuel Pump ECU.

• ON/OFF Three Speed Control with Fuel Pump ECU.

The most accurate way of determining the type of fuel control circuit is to look up the circuit in the appropriate EWD.

The following describes the basic methods of fuel pump control. An essential point to remember is that the fuel pump operates only when the engine is cranking or running.

ON/OFF Control by ECU: - The following is an explanation of how the fuel pump circuit is activated.

Engine Start:- When the engine is cranking, current flows from the IG terminal of the ignition switch to the L1 coil of the EFI main relay, turning the relay on. At the same time, current flows from the ST terminal of the ignition switch to the L3 coil of the circuit opening relay, turning it on to operate the fuel pump. The fuel pump is now supplying fuel to the fuel injection system [1, 2].

NOTE The circuit opening relay in this example is ground side switched. The figure below shows the electrical circuit of ON/OFF control by ECU operation.

Engine Running: - Once the engine starts and the ignition key is moved to the ON (IG) position, Current to the L3 coil is shut off, but the ECU will keep the fuel pump on through coil L2 as long as the ECU receives an NE signal. If the NE signal is lost at any time after starting, the ECU turns the fuel pump off.

Engine Stopped:-When the engine stops, the NE signal to the ECU stops. This turns off the transistor, thereby cutting off the flow of current to the L2 coil of the circuit opening relay. As a result, the circuit opening relay opens turning off the fuel pump [1, 2].

NOTE :- The resistor R and the capacitor C in the circuit-opening relay are for the purpose of preventing the relay contacts from opening when current stops flowing in coil L2 due to electrical noise (fuel pumps controlled by the ECU) or to sudden drops in the intake air volume (fuel pumps controlled by fuel pump switch). They also serve to prevent sparks from being generated at the relay contacts. On some models, an L3 coil is not provided in the circuit-opening relay [1, 2, 4].

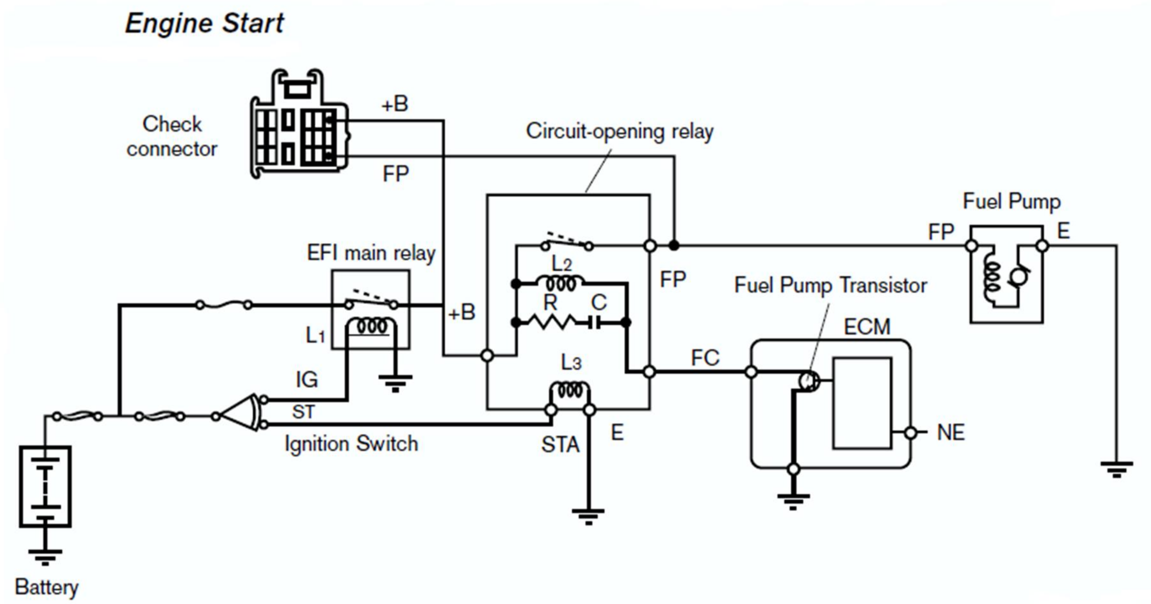

Figure 6: ON/OFF Control by ECU

ON/OFF Control by Fuel Pump Switch

The fuel pump switch is found on older vehicles using a Vane Air Flow Meter. The air moves the vane when the engine is running closing the fuel pump switch. The following is an explanation of circuit operation.

Engine Start:- When the engine is cranking, current flows from the IG terminal of the ignition switch to the L1 coil of the EFI main relay, turning the relay on. Current also flows from the ST terminal of the ignition switch to the L3coil of the circuit-opening relay, turning it on to operate the fuel pump. After the engine starts, the cylinders begin drawing in air, causing the measuring plate inside the air flow meter to open. This turns on the fuel pump switch, which is connected to the measuring plate, and current flows to the L2 coil of the circuit-opening relay.

Engine Running:- After the engine starts and the ignition switch is turned from ST back to IG, current flowing to the L3 coil of the circuit-opening relay is cut off. However, current continues to flow to the L2 coil while the engine is running due to the fuel pump switch inside the air flow meter being on. As a result, the circuit-opening relay stays on, allowing the fuel pump to continue operating [1, 4, 5].

Engine Stopped:-When the engine stops, the measuring plate completely closes and the fuel pump switch is turned off. This cuts off the flow of current to the L2 coil of the circuit-opening relay. As a result, the circuit-opening relay goes off and the fuel pump stops operating. (See figure 7)

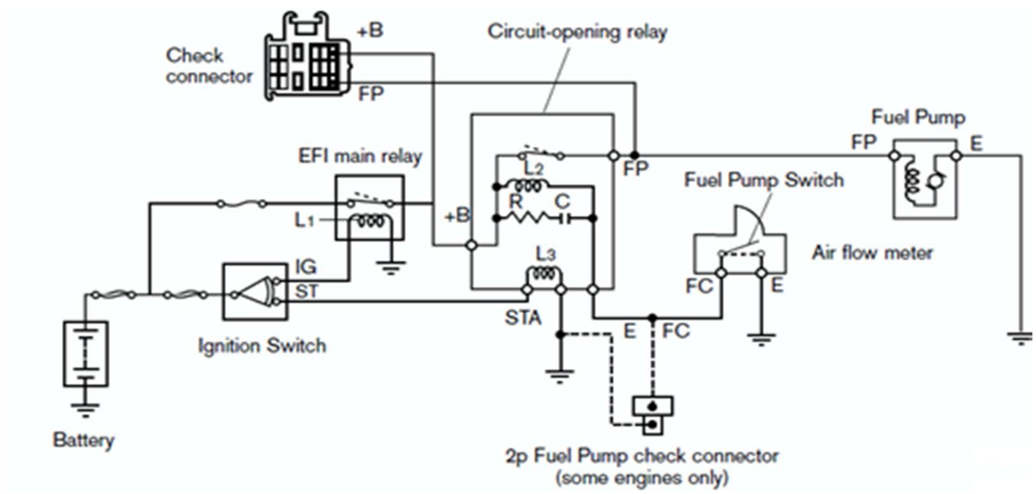

Figure 7: ON/OFF Control by Fuel Pump Switch

Pressure Regulators: - The pressure regulator must consistently and accurately maintain the correct fuel pressure. This is important because the ECU does not measure fuel system pressure. It assumes the pressure is correct. There are two basic types of pressure regulators.

1. Modulated Pressure Regulators
2. Vacuum Modulated Pressure Regulator [3, 4].

1. Modulated Pressure Regulators

The return fuel delivery system uses a pressure regulator located on the fuel pressure rail between the fuel pressure rail and the return line to the fuel tank. There are two types of pressure regulators. One type is modulated by vacuum, the other by atmospheric pressure. Figure 8 shows Modulated pressure regulator type of pressure regulator [1, 2].

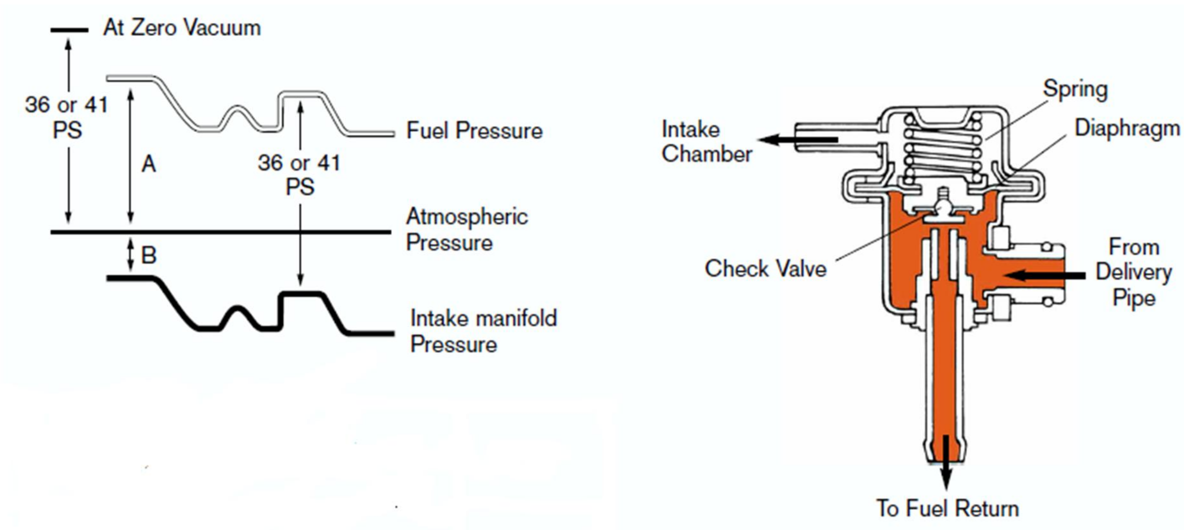

Figure 8: Modulated pressure regulator

2. **Vacuum Modulated Pressure Regulator**

To maintain precise fuel metering, the vacuum modulated pressure regulator maintains a constant pressure differential across the fuel injector. This means that fuel rail pressure will always be at a constant value above manifold absolute pressure. See figure 9 the construction of vacuum modulated pressure regulator.

Low intake manifold pressure (idle for example) pulls on the diaphragm decreasing spring pressure. This allows more fuel to return to the fuel tank decreasing pressure in the fuel rail. Opening the throttle increases manifold pressure. With less vacuums on the diaphragm spring pressure will increase restricting fuel flow to the fuel tank. This increases pressure in the fuel rail [9, 11].

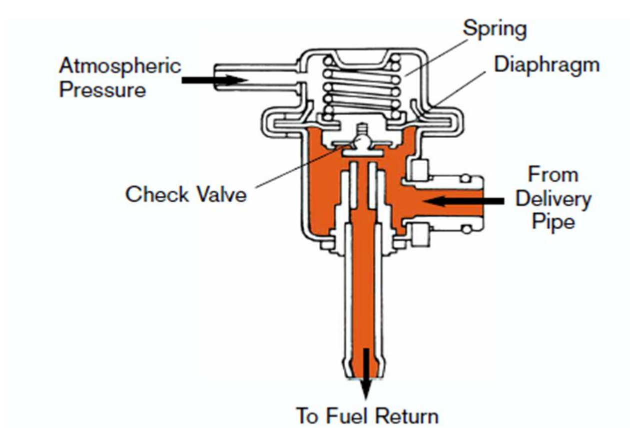

Figure 9: Vacuum Modulated Pressure Regulator

Pulsation Damper:-The rapid opening and closing of the fuel injectors cause pressure fluctuations in the fuel rail. The result is that the amount of injected fuel will be more or less than the desired amount. Mounted on the fuel rail, the pulsation damper reduces these pressure fluctuations. When pressure suddenly begins to increase the spring loaded diaphragm retracts slightly increasing fuel rail volume. This will momentarily prevent fuel pressure from becoming too high. When pressure suddenly begins to drop, the spring loaded diaphragm extends, slightly decreasing effective fuel rail volume. This will momentarily prevent fuel pressure from becoming too low. Not all engines require the use of a pulsation damper. The screw mounted at the top of the damper provides an easy check for fuel system pressure. See figure 10, when the screw is up it means the fuel rail is pressurized. Under most conditions, this check is adequate. The screw is nonadjustable and it is used to calibrate the damper at the factory [9, 11].

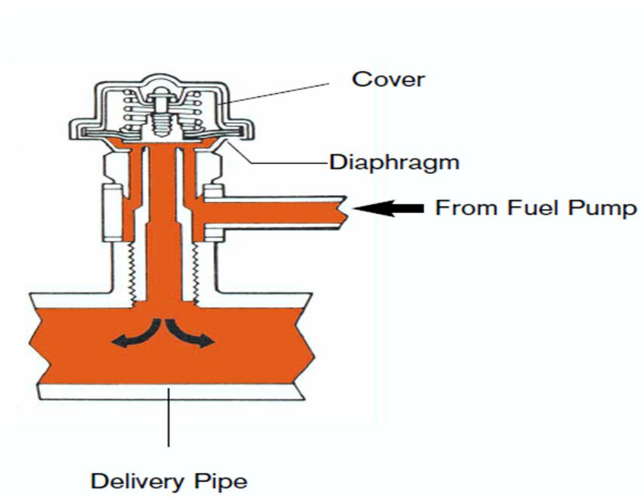

Figure 10: Pulsation damper

Fuel Lines and Connectors:-Today's vehicles use a variety of materials and connectors for fuel lines. Steel and synthetic materials are used, depending on location and model year. It is critical that the correct procedures be followed when servicing the fuel lines. Connectors can be the threaded type or the quick connector style.

Fuel Tank:-The fuel tank is designed to safely contain the fuel and evaporative emissions. Typically, it houses the fuel pump assembly and rollover protection valves.

Fuel Injectors: -The fuel injector is an electrically operated spring-loaded solenoid, which delivers a metered amount of fuel into the intake manifold runner, just ahead of the intake valve.

The injectors are electrically charged as the key switch is set to the “RUN” position. The ECU controls the injection by completing the ground circuit, lifting the solenoid, which allows high-pressure fuel to flow. The ECU then opens the ground circuit allowing the spring to close the injector and stop the fuel flow [4, 7].

The fall of carburetor

For most of the existence of the internal combustion engine, the carburetor has been the device that supplied fuel to the engine. On many other machines, such as lawnmowers and chainsaws, it still is. But as the automobile evolved, the carburetor got more and more complicated trying to handle all of the operating requirements. For instance, to handle some of these tasks, carburetors had five different circuits:

- Main circuit - Provides just enough fuel for fuel-efficient cruising;
- Idle circuit - Provides just enough fuel to keep the engine idling;
- Accelerator pump - Provides an extra burst of fuel when the accelerator pedal is first depressed, reducing hesitation before the engine speeds up;
- Power enrichment circuit - Provides extra fuel when the car is going up a hill or towing a trailer; and
- Choke - Provides extra fuel when the engine is cold so that it will start [7, 8].

In order to meet stricter emissions requirements, catalytic converters were introduced. Very careful control of the air-to-fuel ratio was required for the catalytic converter to be effective. Oxygen sensors monitor the amount of oxygen in the exhaust, and the engine control unit (ECU) uses this information to adjust the air-to-fuel ratio in real-time. This is called closed loop control it was not feasible to achieve this control with carburetors. There was a brief period of electrically controlled carburetors before fuel injection systems took over, but these electrical cars were even more complicated than the purely mechanical ones[7,9].

At first, carburetors were replaced with throttle body fuel injection systems (also known as single point or central fuel injection systems) that incorporated electrically controlled fuel-injector valves into the throttle body. These were almost a bolt-in replacement for the carburetor, so the automakers didn't have to make any drastic changes to their engine designs. Gradually, as new engines were designed, throttle body fuel injection was replaced by multi-port fuel injection (also known as port, multi-point or sequential fuel injection). These systems have a fuel injector for each cylinder, usually located so that they spray right at the intake valve. These systems provide more accurate fuel metering and quicker response.

2.3 Terms used with EFI

Terms used to classify/categories petrol fuel injection systems e.g. single-point injection (throttle-body or central fuel injection), multipoint injection (indirect/port injection), continuous injection, intermittent injection (sub-divided into simultaneous and sequential injection) and direct injection [11].

2.4 Types of Gasoline Electronic Fuel Injection

- Mechanical(K-Jetronic)
- Electromechanical fuel injection system (KE Jetronic)
- Electronic fuel injection

  K and KE- Jetronic

K and KE –jetronic systems are the most common of the Bosch injection continuous injection systems, used on European makes at different times.

K comes from the German word for continuous," Kontinuerlich" because the fuel flows continuously from that system's injectors as long as the engine is running based on the way of sensing amount of intake air. The below figures shows the injection method

- D-Type EFI
- L-Type EFI

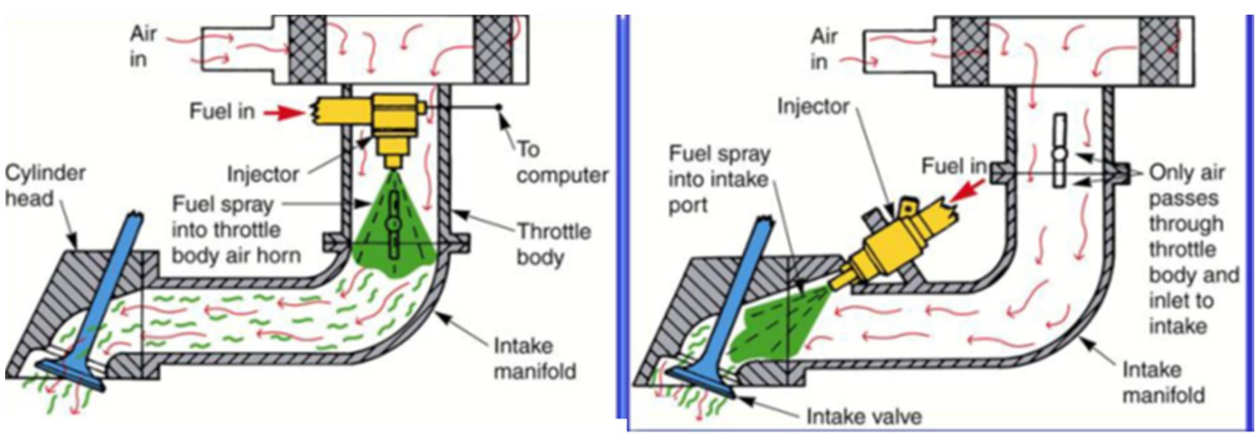

Figure 11: throttle body and port injection

Based on mixture formation

- External (manifold/indirect injection)
- Internal (direct injection)

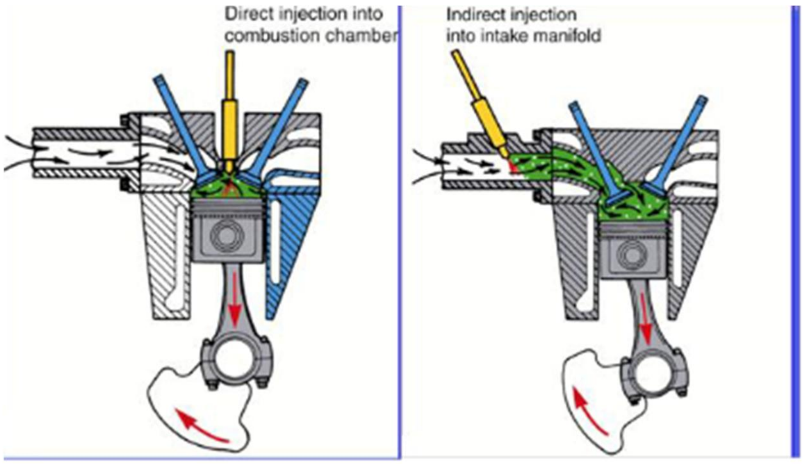

Figure 12: Direct and indirect injection

In general the basic components of Gasoline Electronic fuel injection components are

- **Sensor:-** Converts a physical/chemical condition into an electrical signal
- **ECU:-** the electronic control unit evaluates the data delivered by various sensors concerning the engine operating condition, and from the status generates a control signal for the actuators (injectors)
- **Actuators (injectors):-** the injectors are controlled by an electronic module (a single function computer systems) [11, 13].

2.5 Types of Injection Strategy

In general there are six types of Fuel Injections there are:

1. Single-point, central fuel injection or throttle body injection (TBI)
2. Multi-point fuel injection (MPFI)
3. Continuous injection
4. Sequential fuel injection (SFI)
5. Simultaneous injection
6. Direct injection [2,3]

1. Single-Point, Central Fuel Injection or Throttle Body Injection (TBI)

The earliest and simplest type of fuel injection, Electronic throttle body injection was introduced in the early 1980s as a transition technology to fully-electronic port injection. Single-point simply replaces the carburetor with one or two fuel-injector nozzles in the throttle body, which is the throat of the engine's air intake manifold.

2. Multi-Point Fuel Injection (MPFI)

Multi-point fuel injection devotes a separate injector nozzle to each cylinder, right outside its intake port, which is why the system is sometimes called Port injection. Shooting the fuel vapor this close to the Intake port almost ensures that it will be drawn completely into the cylinder. The main advantage is that MPFI meters fuel more precisely than do TBI designs, better achieving the desired air/fuel ratio and improving all related aspects. Also, it virtually eliminates the possibility that fuel will condense or collect in the intake manifold. With TBI and carburetors, the intake manifold must be designed to conduct the engine's heat, a measure to vaporize liquid fuel. This is unnecessary on engines equipped with MPFI, so the intake manifold can be formed from lighter-weight material, even plastic.

3. Continuous Fuel Injection System (This is a mode of injection)

Continuous fuel injection systems provide a continuous spray of fuel from each injector at a point in the intake port located just before the intake valve. The entrance of the fuel into the cylinder is controlled by the intake valve.

4. Sequential Fuel Injection (SFI) (This is a mode of injection)

Sequential fuel injection, also called sequential port fuel injection (SPFI) or timed injection, is a type of multi-port injection. Though basic MPFI employs multiple injectors; they all spray their fuel at the same time or in groups. As a result, the fuel may" hang- around" a port for as long as 150 milliseconds when the engine is idling. This may not seem like much, but it's enough of a shortcoming that engineers addressed it: Sequential fuel injection triggers each injector nozzle independently. Timed like Spark Plugs, they spray the fuel immediately before or as their intake valve opens. It seems a minor step, but efficiency and emissions improvements come in very small doses.

5. **Simultaneous Injection (This is a mode of injection)**

In multi-point injection, the injectors can all be triggered simultaneously, twice per cycle. In a throttle-body system, the central injector is normally triggered on each ignition pulse. With 2 injectors, alternate triggering may be used

6. **Direct Injections**

Direct injection takes the fuel injection concept about as far as we can go, injecting fuel directly into the combustion chambers, past the valves. More common in diesel engines, direct Injection is starting to pop up in petrol engine designs, sometimes called DIG for direct injection gasoline or GDI for Gasoline Direct Injection. Again, fuel metering is even more precise than in the other injection schemes and the direct injection gives engineers yet another variable to influence precisely how combustion occurs in the cylinders. The science of engine design scrutinizes how the fuel –air mixture swirls around in the cylinders and how the explosion travels from the ignition point. Things such as the shape of cylinders and pistons; port and spark plug locations; timing, duration and Intensity of the spark; and number of spark plugs per cylinder (more than one is possible) all affect how evenly and completely fuel combusts in a petrol engine[3].

2.6 Fuel injector and its operation

Different engines require different injectors. Injectors are designed to pass a specified amount of fuel when opened. In addition, the number of holes at the tip of the injector varies with engines and model years. When replacing an injector it is critical that the correct injector be used.

The injectors are mounted in the intake manifold so that they spray fuel directly at the intake valves. A pipe called the fuel rail supplies pressurized fuel to all of the injectors.

When the injector is energized, an electromagnet moves a plunger that opens the valve, allowing the pressurized fuel to squirt out through a tiny nozzle. The nozzle is designed to atomize the fuel to make as fine a mist as possible so that it can burn easily [11, 13].

2.6.1 Types of injectors

The amount of fuel supplied to the engine is determined by the amount of time the fuel injector stays open. This is called the pulse width, and it is controlled by the ECU.The below figure shows different types of injector. The figure below shows different types of injectors [13,14].

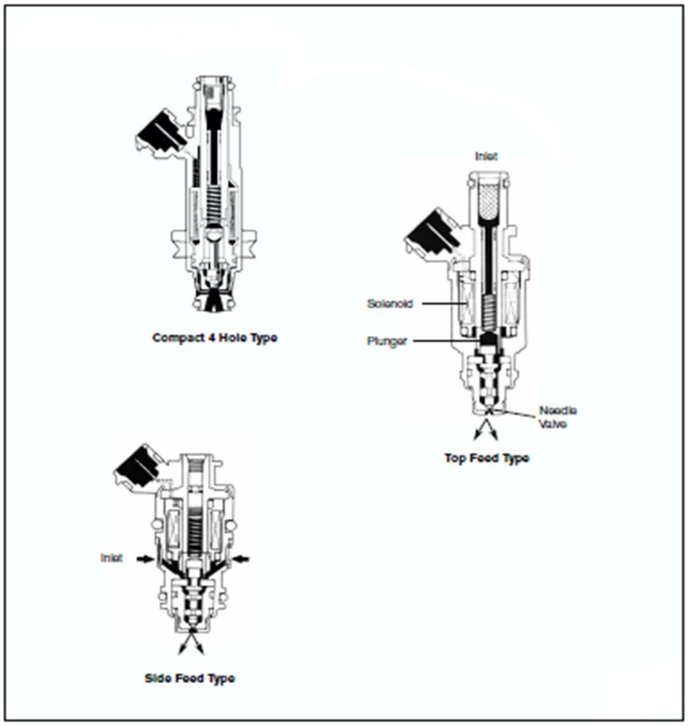

Figure 13: Types of injector

2.6.2 Injector component

- O" Ring seals
- Solenoid
- Pintle

2.6.3 Injector operation

The exact injector open time depends on the data the sensors give the ECU. The injector is supplied with constant live via the fuel pump relay. The engine control operates the injector by the means of turning off and on the earth circuit in quick succession. It provides pulses of a set duration, so that the injector valve opens and closes, or pulses, very quickly. Electrical pulses pass through the injector winding and set up a magnetic field that draws the plunger and valve away from the nozzle seat. This function is known as pulse with modulation (PWM). The PWM is responsible for the amount of fuel injected. Fuel held under pressure in the fuel rail can now pass through the filter and the center of the injector and enter the inlet port. When fitting injectors it is important to fit a new “o” ring (seal) at the base of the injector [8, 9].

Injector pulse width

- The injector pulse width indicates the amount of time each injector is energized and kept open.
- The computer controls the injector pulse width.
- Under full acceleration, the computer will sense a wide-open throttle, high intake manifold pressure, and high inlet airflow.
- The computer would then increase injector pulse width to enrich the mixture for more power
- Under low load conditions, the computer will shorten the injector pulse width. With the injectors being closed a large percentage of time, the air-fuel mixture will be leaner for better fuel economy [3].

The figure 14 shows the operation of injector compare with the injection pulse width,

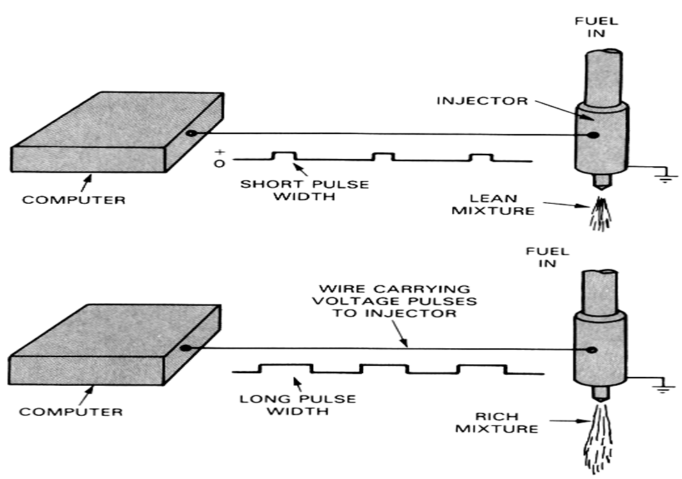

Figure 14: operation of injector

2.7 Injector timing or drive circuit

The design of the injector drive circuit and ECU programming determines when each injector delivers fuel in relation to the operating cycle of the engine. If the injectors are turned on according to the crankshaft position angle, it is called synchronous injection. That is, the injectors are timed to turn on according to crankshaft position. Depending on engine application, the three main types of synchronous injection designs are: Simultaneous, Grouped, or Sequential. In all these types, voltage is supplied to the injectors from the ignition switch or EFI main relay and the ECU controls injector operation by turning on the driver transistor grounding the injector circuit. Simultaneous and grouped are the oldest styles, and are no longer used. On simultaneous, all injectors are pulsed at the same time by a common driver circuit. Injection occurs once per engine revolution, just prior to TDC No. 1 cylinder. Twice per engine cycle, one-half of the calculated fuel is delivered by the injectors. With grouped drive circuits, injectors are grouped in combinations. There is a transistor driver for each group of injectors. On sequential drive circuits, each injector is controlled separately and is timed to pulse just before the intake valve opens. There are times when the ECU needs to inject extra fuel into the engine regardless of crankshaft position and this is called asynchronous injection. Asynchronous injection is when fuel is injected into all cylinders simultaneously when predetermined conditions exist without relation to the crankshaft angle. Two common conditions are starting and acceleration[5.6]

NOTE: - The EWD injector circuit can identify if the injection system is a grouped or sequential. A sequential system will have one injector per injector driver.

2.8 Injector control methods

There are two types of transistor driver circuits used to operate electric fuel injectors: voltage controlled and current controlled. The voltage controlled type is sometimes called a "saturated switch" driver, while the current controlled type is sometimes known as a "peak and hold" driver. The basic difference between the two is the total resistance of the injector circuit. Roughly speaking, if a particular leg in an injector circuit has total resistance of 12 or more ohms, a voltage control driver is used. If less than 12 ohms, a current control driver
is used. It is a question of what is going to do the job of limiting the current flow in the injector circuit; the inherent "high" resistance in the injector circuit, or the transistor driver. Without some form of control, the current flow through the injector would cause the solenoid coil to overheat and result in a damaged injector [9, 12].

2.8.1 Voltage controlled circuit ("saturated switch")

The voltage controlled driver inside the computer operates much like a simple switch because it does not need to worry about limiting current flow. Recall, this driver typically requires injector circuits with a total leg resistance of 12 or more ohms. The driver is either ON, closing/completing the circuit (eliminating the voltage-drop), or OFF, opening the circuit (causing a total voltage drop). Some manufacturers call it a "saturated switch" driver. This is because when switched ON, the driver allows the magnetic field in the injector to build to saturation. This is the same "saturation" property that you are familiar with for an ignition coil.

There are two ways "high" resistance can be built into an injector circuit to limit current flow. One method uses an external solenoid resistor and a low resistance injector, while the other uses a high resistance injector without the solenoid resistor. (See figure 15). In terms of injection opening time, the external resistor voltage controlled circuit is somewhat faster than the voltage controlled high resistance injector circuit. The trend, however, seems to be moving toward use of this latter type of circuit due to its lower cost and reliability. The ECU can compensate for slower opening times by increasing injector pulse width accordingly.

NOTE: Never apply battery voltage directly across a low resistance injector. This will cause injector damage from solenoid coil overheating

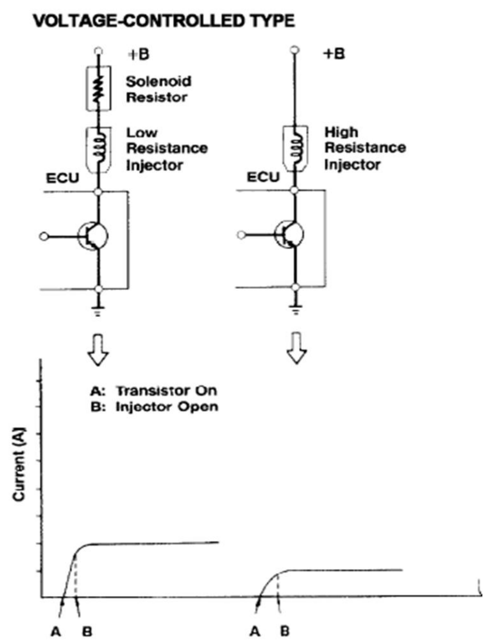

Figure 15: voltage controlled type

2.8.2 Current controlled circuit ("peak & hold")

The current controlled driver inside the computer is more complex than a voltage controlled driver because as the name implies, it has to limit current flow in addition to its ON-OFF switching function. Recall, this driver typically requires injector circuits with a total leg resistance of less than 12 ohms. Once the driver is turned ON, it will not limit current flow until enough time has passed for the injector pintle to open. This period is preset by the particular manufacturer/system based on the amount of current flow needed to open their injector. This is typically between two and six amps. Some manufacturers refer to this as the "peak" time, referring to the fact that current flow is allowed to "peak" (to open the injector). Once the injector pintail is open, the amp flow is considerably reduced for the rest of the pulse duration to protect the injector from overheating. This is okay because very little amperage is needed to hold the injector open, typically in the area of one amp or less. Some manufacturers refer to this as the "hold" time, meaning that just enough current is allowed through the circuit to "hold" the already-open injector open. There are a couple methods of reducing the current. The most common trims back the available voltage for the circuit, similar to turning down a light at home with a dimmer. The other method involves repeatedly cycling the circuit ON/OFF. It does this so fast that the magnetic field never collapses and the pintail stays open, but the current is still significantly reduced. See Fig.16 for an illustration. The advantage to the current controlled driver circuit is the short time period from when the driver transistor goes ON to when the injector actually opens. This is a function of the speed with which current flow reaches its peak due to the low circuit resistance. Also, the injector closes faster when the driver turns OFF because of the lower holding current [7, 8].

NOTE: Never apply battery voltage directly across a low resistance injector. This will cause injector damage from solenoid coil overheating.

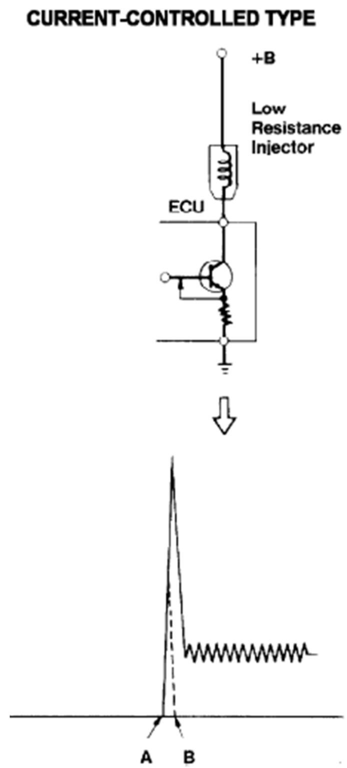

Figure 16: Current Controlled type

2.9 Diagnosis of injector on vehicle

1. Inspect injector operation
   (a) With the engine running or cranking, use a sound scope to check that there is normal operating noise in proportion to engine speed.
   (b) If there is no sound scope, check the injector transmission operation with finger.
   (c) If no sound or unusual sound is heard, check the wiring connector, injector or injection signal from ECU [8, 10].
2. Inspect injector resistance
   (a) Disconnect the injector connector.
   (b) Using an Ohmmeter, measure the resistance between the terminals
   Resistance: 13.4Ω-14.2Ω at 20^0C (68^0F)
   If the resistance is not as specified, replace the injector.
   (c) Reconnect the injector connector.

Inspect the following points visually

- Fuel leaks.

- Vacuum leaks.
- Kinked lines
- Sensor problems.
- Loose or corroded electrical connections.

NOTE: Do not disconnect EFI harness terminal when ignition in "on" position

OBD (*On Board Diagnostics)* & OBD II

- Most EFI systems have on-board diagnostic abilities.
- ECM can detect and record possible faults.
- Figure below shows MIL (*Malfunction Indicator Light)* in the dash-board glows when any abnormality is sensed. [2,4,5]

Figure 17: Malfunctioning indicator light

- Scan tool will find and display many problems.

Figure 18: scan tool

Pressure Regulator Testing

Caution – Relieve fuel pressure (up to 60 psi) before disconnecting line.

- Bleed Relief Valve or Fuse
- Check fuel pressure with fuel pressure gauge and match readings against the specs.

Fuel Pressure Too Low

- Check clogged fuel filter or bad electric pump.

Fuel Pressure Too High

Usually bad pressure regulator.

Maximum Fuel Pressure Test

- Pinch the return line with engine running (*line with smaller diameter)*
- Check the gauge just like the below figure, if pressure too low, Fuel Pump, not the pressure regulator is at fault.

Figure 19: pressure regulator testing

Injector Testing

Bad injector can cause

- Rough Idle
- Hard Starting
- Poor Fuel Economy
- Engine Miss

Leaky Injectors will richen the fuel mixture

Dirty Injectors restricts the air- flow, causing a lean mixture.

Inoperative EFI Injectors

- no action (*Miss Fire*) [2,4,5]

Figure 20: injector testing

The above figure shows the following points:

1. FAIR - but weak
2. BAD - split spray pattern
3. BAD - split spray pattern
4. BAD - jetting on left side
5. GOOD
6. BAD - feathering at top of spray

TBI Diagnosis

- Check Pressure.
- Fuel spray pattern can be seen into the horn.
- If current and fuel pressure present, injector may be bad [3, 5].

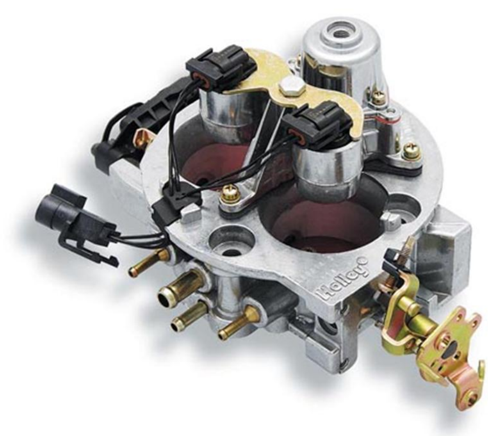

Figure 21TBI Diagnosis

Multi-port Diagnosis

- Listen for “clicking” sound at each injector with a stethoscope

Figure 22: Stethoscope

- Locate the bad injector.
- Using an ohm meter check for resistance across coil and short to ground.

Infinite Resistance = Open coil

Zero resistance to ground = shorted

The below figure shows the fuel rail with injector wire harness

Figure 23: fuel rail assembly with jumper wire harness

Injector noid light

- Special test lights to check EFI feed circuit. As we can see figure 24.
- Injector cleaning kit can clean partially clogged injectors [2, 4, 5].

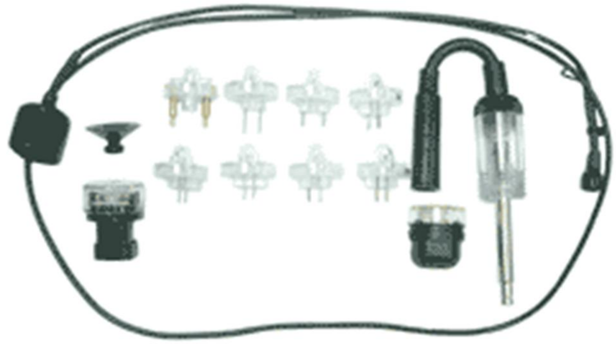

Figure 24: EFI feed circuit test light

2.10 Solenoid injector performance testes on the tester

As intended by all EFI in the case of petrol the performance of the injector needs to be tested on vehicle and off vehicle as instructed and recommended by petrol EFI manufacturers after some kilometers/miles or months service of the vehicles whichever occurs first to check the condition of the injectors for their performance on the vehicle and as well as off vehicle the reason beyond is that in the case of petrol EFI unless the injector is in proper condition the controlling of the ECU for the fuel injection becomes somewhat meaningless therefore the injectors are to be tested not only on vehicle but also off vehicle on the tester known as solenoid off vehicle tester for checking the performance of the injector for its correct volume delivery, injection variation as intended by makers, injection pattern, non-leakage testes, and sticky injectors. So the tester developed in this study made sure that all the above said testes can be ensured to check whether the injectors are working proper or not and decision will be made accordingly [12].

Thus, the different testes to be executed on the tester are as recommended by makers after some kilometer services are:

- The volume of fuel delivered by all injectors of the vehicle in a given time as given in the makers manual
- The variation of the fuel delivery by all injectors of the vehicle as the engine speed increases
- The fuel delivery pattern by all injectors, this also should be as given in the makers manual
- Non- leakage and non-sticky injectors checking

Therefore, all the above mentioned tests were executed by the tester for any solenoid injectors of petrol EFI except for the direct injection petrol EFI

[References: Injector Tester Documents from BOSCH Company, Guangzhou Automotive LTD Company].

2.11Arrangement of the tester

The arrangement of the system has a complete of the system lay out as it is used in the vehicle except for the injectors now facing a graduating after the injectors are installed on the tester for the performance tests, in which the injectors of vehicles will be tested against the recommendations and specifications of the maker's manual

[References: Injector Tester Documents from BOSCH Company, Guangzhou Automotive LTD Company].

2.11.1The promise of the Tester

If used properly it will help the country in solving the problems that will occur on the Environment due to Exhaust Emissions, and also the problems of the engine power loss, fuel consumption that will result due to the malfunctioning of injectors. Again the problems of the customers will decrease hence their satisfaction becomes great.

2.11.2 Advantages of the device

Enables to reduce emission results, improves engine performance, reduces noise, improve cold starting, and improves customer satisfaction and so on.

2.12 Methods of injection

As stated in the literature review EFI petrol designs employ of different injection strategies such as depending on the type of design there may be continuous injection, simultaneous injection, sequential injection, and group injection but for the purposes of the tester in our tester cases and similar tester which are used so far and still in use either sequential injection tester method or simultaneous injection method. For this project development we employed simultaneous injection strategy because of its simplicity in the circuit diagram and decreased test time especially as the number of vehicles whose injectors condition are to be tested increases [5, 7, 12].

2.13 Features of the tester

- Solves emission problems and hence purer environment
- Engine performances restored properly
- Fuel economy is maintained
- Problem or trouble on the customer side minimized
- Easily portable
- Solves country as well as customers problems in solving the above mentioned problems, and hence it will have social and economic benefits and so on and so forth

2.14 Manufacturer instruction and recommendation

In the case of automotive petrol EFI it is instructed and recommended to check the condition of the solenoid injectors with all the different tastes like resistance test, power test etc. on the vehicle while the injector is still on the vehicle these all are stated in the maker's manual after some service time of solenoid injectors but that will give only whether there would be continuity or clicking sound is there or not but in the general case vehicle manufacturers recommend to have the injectors removed and tested on such type of tester to check the general performance of the injectors like for the amount of fuel delivered in a given time, delivery variation as needed, spray pattern, leakage test, and non-sticky injector and so on these are the strict cases given in the makers manual of all petrol EFI, therefore, here with as such tester is not available as such in the country this study would solve the technological gap in this regard thus contributing to the extent of social, economic, and environmental benefits [4, 6].

3. MATERIALS AND METHODS

3.1 Research Design

The study was conducted at Kefitegna 20 TVET College in the Departments of Automotive Technology, manufacturing Technology and electrical electronics workshop. A frame structure was designed, fabricated as per the design intended and made ready first to support and host all the system components to be developed, next as per the design plan all the necessary design considerations were conducted on each and every component as well as at each critical points while developing the system of the tester to make it up to the standard. The standard tester should fulfill three points:

- The system pressure should be the same as the constant pressure at which the solenoid injectors injects fuel while they are on the engine vehicle.
- The voltage across each and every injector should be exactly the voltage across solenoid injectors while they are on the engine vehicle.
- The pulse width or injection duration should be as specified by the maker

Together with the right design consideration of each component of the system tester and the right connection the tester developed will be as to the standard with similar tester manufactured by companies.

With the developed tester we will check the performance of electrical solenoid injectors for:

- No-leakage test
- Volume delivered for a certain injection duration specified by maker
- Variation of injection and
- Injection Pattern

So the promise of the tester is that it will enable us to make the engine of EFI systems perform as expected if regular performance checks are made and the necessary corrections taken as recommended by makers.

This research study involved the following tasks:

After developing the tester and checked for its accuracy and reliability according to a standard tester testing of a new standard solenoid injectors four in number and next a used solenoid injectors for a reasonable service time or kilometers four in number will be tested for performance and the result of both categories will be evaluated, decided and compiled according to the data given in the makers manual.

The different taste and evaluations to be made on electrical solenoid injectors of EFI systems in the case of Port and TBI injections according to makers manual are:

- No-leakage test and evaluation
- Volume delivered for a certain injection duration specified by maker and evaluation
- Variation of injection and evaluation
- Injection Pattern

Finally conclusion, recommendation, and educational implications based on the developed tester will be given in detail.

3.2 Materials

- Raw materials for the frame fabrications together with all the necessary items to fabricate the frame- this supports and hosts the developed system components everything will be considered according to the engineering requirement.
- With all the design considerations, components and lines will be correctly procured for the development of tester system design.
- New standard solenoid injectors four in number, maker’s manual are required. Figure 25 shows new standard solenoid injectors.
- Vehicle whose injectors condition are to be tested with makers manual

Figure 25: A standard electrical solenoid injector new

Table 1: Manufacturer specifications for the new injector

s/n	Perfect Measurement	Injector 1	Injector 2	Injector 3	Injector 4
1.	No-leakage test				
2.	Volume delivery				
3.	Volume variation				
4.	Injection pattern				

Figure 26: A test vehicle all injectors condition to be tested

Table 2: Manufacturer specification for the test vehicle

s/n	Perfect Measurement	Injector 1	Injector 2	Injector 3	Injector 4
1.	No-leakage test				
2.	Volume delivery				
3.	Volume variation				
4.	Injection pattern				

[References: TOYOTA carina E vehicles manual]

Table 3: Materials required for the development of the developed tester

Material required for the modification of fuel supply and raw material for the frame	Materials required for the modification of electrical and electronics cont. circuit	Materials required for performance test of the tester comp. and system
Fuel Tank	Power Supply	Pressure gauge
Fuel lines	Toggle Switch	Multi-meter
Fuel Filter	Timer	
Fuel rail	Flasher Unit	
Fuel Pressure regulator	Variable Resistors	
Vibration Damper	Main switch	
Fuel Return Lines	Resistors	
Solenoid injectors(to be tested- New	Diodes	
Graduating cylinder	Light Emitting Diodes	
Solenoid Switch	Capacitors	
Low Pressure lines	Transistors	
Square Tube	Control board	
Sheet Metal	Cable and wires	
Electrodes, Paint	Control switch	

3.3 Methodology

It is mostly a developmental process as indicated in the title and includes the following stages respectively: the procedure of each stage is given below

3.3.1 Fabrication of the frame structure and development of the tester system

Before and after mounting the components and hence the tester system the performance of each component and the system have been determined to the standard of a similar tester. (See figure 27)

Figure 27: developed tester

3.3.2 Preparing the test injectors for performance evaluation

i. A new standard electrical solenoid injectors- Four in number

ii. An old or used electrical solenoid injectors properly removed from the vehicle

iii. An old solenoid injectors are prepared well

iv. The developed tester is prepared for testing

v. And first the new injectors are installed, tested, value recorded and evaluated

vi. And next the old injectors are installed, tested, value recorded and evaluated

Test Procedure

Fuel injectors need to be maintained or checked for proper functioning. They are vulnerable to specific kinds of wear and generally will not last forever. When to check fuel injectors to make sure they are working properly, here are some of the most common basic steps.

Step1. As we can see the figure below, Remove fuel injectors or lead wires if necessary**:** For some types of testing, it's necessary to remove the fuel injectors from their housings. For checking with an ohmmeter, just take the wire off of the fuel injector.

Figure 28: Remove fuel injector lead wires

[References: TOYOTA carina E vehicle manual]

Step2. Check fuel injectors with electronic tools**:** using a multi-meter or an ohmmeter, we can check the electrical resistance of the fuel injector just like the figure as we can see the figure below to make sure it's working properly.

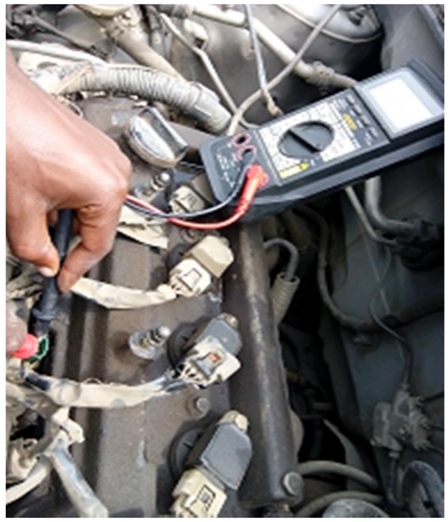

Figure 29: measure the resistance of injectors

Step 3 Decipher sounds: Along with checking a fuel injector electronically, we can listen for certain kinds of sounds that will tell us when a fuel injector might not be working correctly. A clunking sounds or similar warning sound may show that the fuel injector is not functioning the way it should.

Steps 4 remove fuel injector from the vehicle

Step 5 test fuel injectors

Using the gasoline electronic fuel injector tester, can check the fuel injector is actually delivering the spray or mist that it is supposed to into the fuel air mix.

- How much fuel the fuel injectors are delivering into the system,
- Analyze spray patterns, fuel injectors get clogged, the original spray can be decreased. Testing of fuel injectors can help to determine if this has occurred by pressurizing the fuel injectors and measuring spray patterns.
- And also check whether it has leakage the injectors

[References: TOYOTA carina E vehicle manual]

3.4 Experimental Procedure

3.4.1 Data Acquisition

As mentioned above once the developed tester is to the standard, that can be achieved when the system pressure, voltage across the injectors, and pulse width or duration are to the standard as it is exactly when the injectors are installed on the engine during its operation, the point here is to measure the performance of the injectors by removing it from the engines and evaluate its performance.

Removal of injectors from the engine whose solenoid injectors condition is to be tested, evaluated (see figure 30).

1. before servicing the vehicle, refer to the precautions section
2. release the fuel system pressure
3. remove or disconnect the following:

- negative battery cable
- fuel injection supply manifold
- retaining clips and gently twists the fuel injector out of the manifold

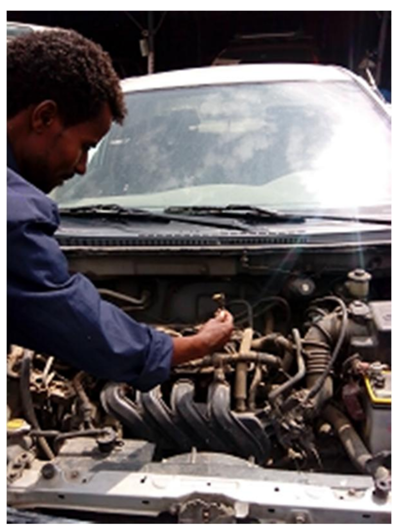

Figure 30: disconnecting electrical connections to remove from the injector

[References: TOYOTA carina E vehicles manual]

To do this generally four performance measurements were to be conducted as per the steps given below:

Step 1.prepare the injectors (like cleaning, voltage checking and the like) whose performance condition is to be tested and evaluated

Step2.prepare the developed tester system for injectors testing and evaluation

Step3.install injectors one at a time on the tester using the proper tools

Step4.check all the connections are proper

Step 5.start the pump and bring first the system pressure to the standard

Step6.while executing the test makes sure the injectors voltages are to the expected value of Injector's voltage

Step 7, execute all the performance tests and record the actual value

The different tests are executed in the order as follows:

i. No leakage test for all injectors and the results recorded
ii. Volume delivery test for all and the results injectors recorded
iii. Volume variations delivery test for all injectors and the results recorded
iv. Injection pattern test for all injectors and the results recorded

Then the test results, evaluated according to the makers specification and recommendation, and based on this the decision will be made.

Note: - for the test procedure Occupational health and safety (OHS) were observed, personal protective equipment(PPE) were used and all the testes were performed on the same date, and the type of fuel used is exactly the same as the fuel used by the vehicle whose injectors condition has to be tested and evaluated

3.5 Additional data collection

During the development process of the project, the team members collected data using the data gathering through observation, interview. Different techniques could be utilized for collecting data and relevant information. Both primary and secondary data were collected using the following techniques:

3.5.1 Primary data collection

Primary data was collected through interviews.

Interviews (refer on the appendix A)

Primary data was collected through formal interviews with various stakeholders and experts who involve directly or indirectly in working around the major EFI systems and it are testing the interviewees are mainly selected by contacting first the concerned body who directly involve in the profession. The interview with the various company stakeholders and workers helped in our views points on the study topics. Before each interview, the team members designed a goal points on which the concerned body is to give his/her ideas on each and every points designed by members.

The following are the key informants with whom the interview was conducted. The names of people, organizations they work for and the date to be collected are clearly identified.

1. MOENCO- Motor Engineering Corporation commonly known as Toyota Company: Bole
2. NMC- National Motors Company: Mexico Temama foke
3. EBG- Equatorial Business Group: Saries

3.5.2 Secondary data collection

Secondary data was gathered through literature review, literature review was under taken during the formulation of the problem. Similarly it has been under taken during the various phases: presentation of the theoretical background information needed, during the study of design considerations for the study in all phases from the very beginning of the development up to the final installation and testing and so on. Both printed and electronic sources were utilized: these include strategic documents and journals, reports, newspaper articles relevant to this research study, books, internet or various web pages, workshop papers, committee proposals, research papers and so on. Moreover policy document and proclamations were reviewed.

4. DEVELOPMENT PROCESS

4.1 Introduction

The system as the whole was developed to accurately measure the performance condition of solenoid injectors. The system measures the various performance aspects of solenoid injectors of TBI and PI EFI systems, based on the manuals of the makers. The detail developing process of each component in the system was given below. All the necessary design considerations together with all the necessary testing for the correct specification and matching of the system components were made perfectly using the necessary design steps, in addition the necessary modifications carried out in developing the tester to adopt the fuel injection system along with measuring instruments. The frame Structure was also designed and fabricated to support the system components, actually it was made to the standard as much as possible, then an installation and system testing for standardization was performed. As the study carried out another feature was added to make the tester system to clean all the injectors as needed [8,9].

4.2 Layout and Components of the Tester (fuel supply system components) – with test Injector installed

The electrical solenoid tester fuel supply system incorporates the following components: Fuel tank, electrical Fuel pump, Fuel pipe and filter, Fuel delivery pipe (rail),Fuel pressure regulator, Fuel return pipe, Fuel injectors, Graduating Cylinder, and fuel return .(see figure 31)

[Reference TEXAS INSTRUMENTS, 2015 “LM1949 Injector Drive Controllers”]

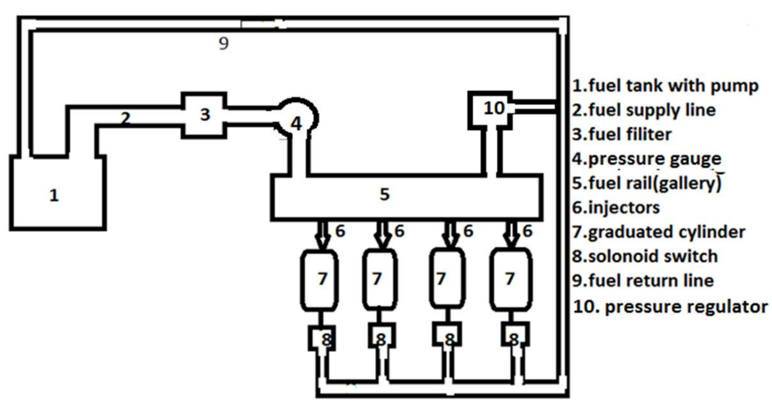

Figure 31: Schematic diagram of fuel supply system components of the developed tester

4.3 Electrical and Electronic Circuit Diagram

The diagram below shows the components of electrical and electronics used to control the tester operations as desired in checking the performance conditions of the solenoid injectors the design consideration of each components in the diagram for their proper selection in terms of the necessity, capacity, materials, all the necessary testing for their correctness, reliability and so on were discussed in the last section of this study material.

The electrical solenoid tester system incorporates the following electrical and electronics components:

Main input supply, Power supply, Toggle switch, Timer, flasher, and all the necessary wires and cables that are used to connect all the components together**.**

[Reference: TEXAS INSTRUMENTS, 2015 "LM1949 Injector Drive Controllers"]

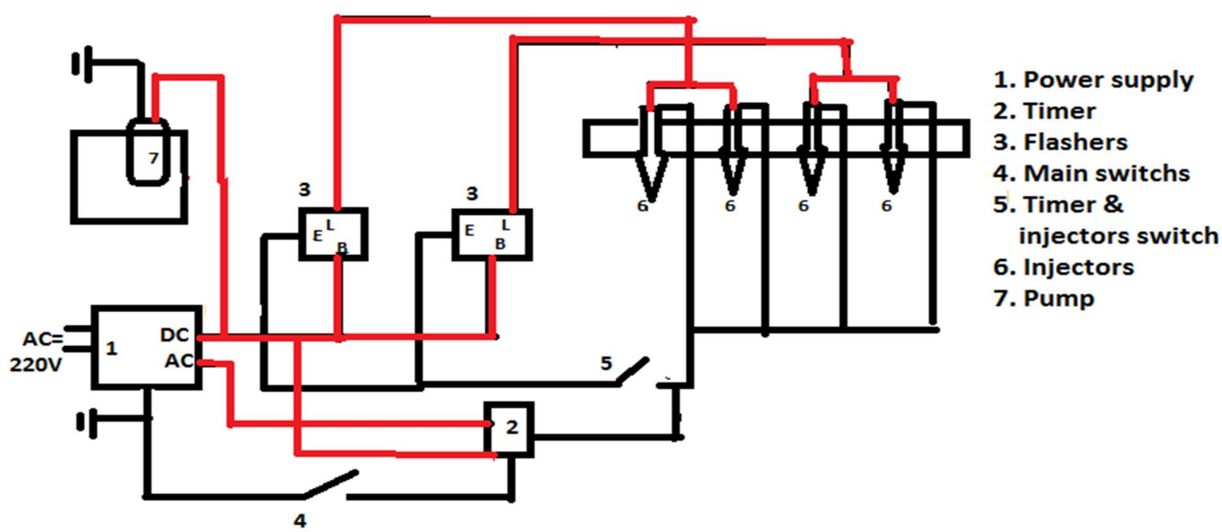

Figure 32: Schematic Diagram of Electrical and electronics circuit of the developed tester

4.4 Complete components diagram for the tester

The all components of the tester both the fuel supply together with the connection of injectors lines assembly and the electrical and electronics circuit components are shown below to give the overall circuit diagram of the tester system as mentioned above in the fuel supply and injector assembly and electrical and electronics circuit. The design consideration of each components for their proper necessity, design specification, material selection, all the necessary testing for their reliability and so on were carried out and the details for such arrangement were discussed in the first part of this study after the design consideration for the frame structure is completed as this part is needed to support and host all the above mentioned components in the circuit diagram for the tester.

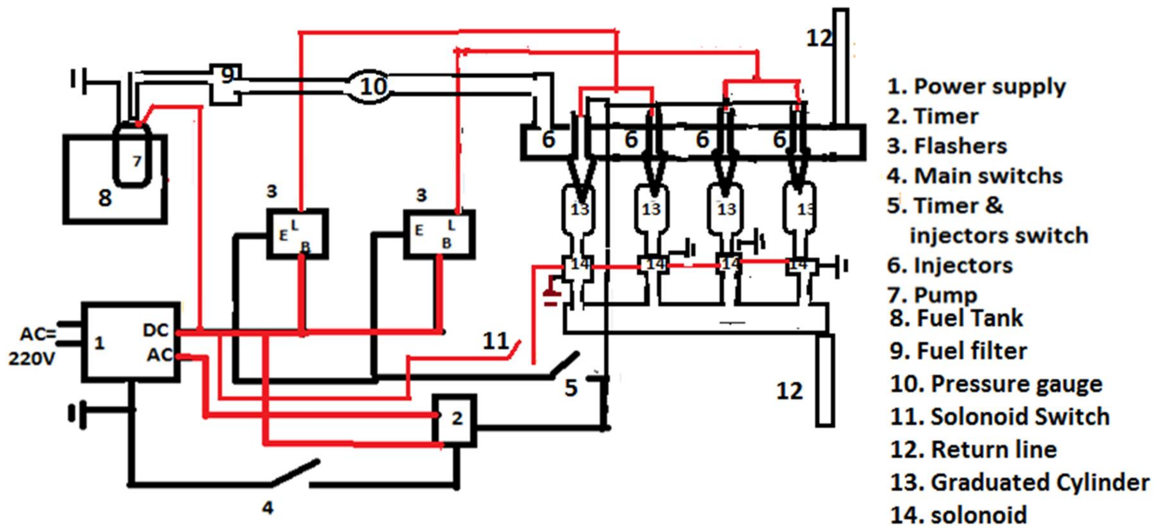

Figure 33 complete schematic diagram of developed tester

[Reference: TEXAS INSTRUMENTS, 2015 “LM1949 Injector Drive Controllers”]

4.5 Design Consideration for the Frame Structure

The design of frame structure has been made to the standard required to give support and host to all the components of the tester. The necessary raw materials such as square tube of dimension 1.5 *2.0*100mm and sheet metal of dimension 1mm with thickness 2*3 width together with other necessary items to process and complete the frame structure as per the expected final design or form. Below is the auto cad design for how the frame structure should look like.

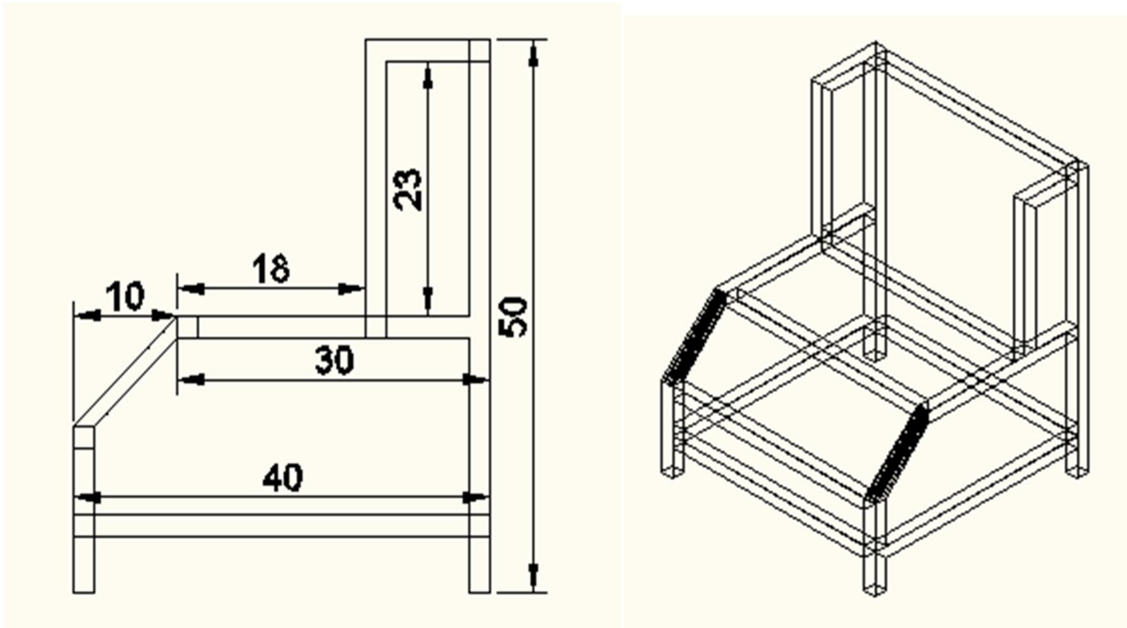

Figure 34: AUTO CAD design for the frame structure

Steps in the fabrication of the frame structure

Step1. Below are the raw materials together with all the necessary items for processing

Figure 35: necessary raw materials and tools

Step2. The next is the preparation of the raw material to the correct dimension to give the desired frame structure.

The group member prepares the sheet metal and square tube, measure the dimensions and cutting according to the measurement.

Figure 36: the group member at work in the preparation of materials to the correct dimensions

Step3. Frame structure formation under process:

The group member makes the frame structure by using welding.

Figure 37: the group members at work in the making of the frame structure

Step 4. Finalizing the frame structure including painting

Figure 38: the group member at work in finalizing the making of the frame structure

Step5. The final frame structure

Figure 39: final frame structure

4.6 Design Considerations for the Tester Components-Fuel supply side

The function of the fuel system is to store and supply fuel to the fuel rail and injector to be tested where it can be pressurized to the system pressure for which most EFI system pressure functions. The fuel, petrol, is stored in a fuel tank. A fuel pump draws the fuel from the tank through fuel lines and delivers it through a fuel filter to both fuel rail and the installed injectors, then delivered to the graduated cylinders when the system is activated for a certain time for the fuel delivery from injectors to the graduated cylinder, this way the performance conditions of the injectors are checked.

4.6.1 Fuel Tank and Lines

This is the obvious place to start in any fuel system explanation. The tank is a sealed unit that allows the natural gas of the fuel to aid delivery to the pump by slightly pressurizing the system. When the filler cap is removed, pressure is heard to escape because the fuel filler caps are no longer vented. Tank location and design are always a compromise with available space for the type of tester. Most testers have a single tank located in the back of the frame structure. All tanks have a fuel filler pipe, a fuel outlet line to the fuel rail through fuel filter and a vent system. Fuel tank of the tester was vented to the atmosphere, emitting hydrocarbon emissions but that much air pollution does not occur and also wherever the tester is used for testing the injectors it is highly advisable to ventilate the area if the tester is to be used extensively.

Fuel lines are developed in such a way that it is highly secured to let properly the fuel that is driven through it to the fuel rail by the fuel pump. Steel lines and flexible hoses carry the fuel from the tank to the fuel rail and injectors. As this part is very sensitive we recommend that when servicing or replacing the steel lines in the future, copper or aluminum must never be used. Steel lines must be replaced with steel. When replacing flexible rubber hoses, proper hose must be used. Ordinary rubber such as used in vacuum or water hose will soften and deteriorate. All the necessary testes are made and as required all the corrections are applied to make it free of leakage and reliable the below figure shows the tank construction [18, 20].

Figure 40: plastic fuel tank and fuel pump used for the tester fabrication

4.6.2 Electric Fuel Pump

Most electronic fuel pumps as they are used for the tester are rated for flow at 12 volts @ 40 psi. Most tester small to medium sized operate anywhere from 12.6 V to 13.2 V. Within limits, the more voltage you feed a pump (for a given current), the faster it spins, resulting in a higher output of fuel from the same fuel pump. Rating a fuel pump at 12 V should offer a fairly conservative fuel flow rating allowing you to safely determine the pump's ability to supply an adequate amount of fuel for a particular application to the tester, assuming the gauge of wire feeding power to the pump is sufficient to carry the current required from the battery side this is also checked for the pump tester and found out perfect according to the design.

As previously mentioned, testers actually required to deliver a certain volume of fuel at a certain pressure, NOT a certain mass of fuel per the capacity of the system pressure. This cannot offer a bit of confusion since most fuel pumps are rated by volume, and not by mass. To determine the proper fuel pump required, a few mathematical conversions were needed to determine the exact pump we wanted for the tester we used the following information: There are 3.785 liters in 1 U.S. gallon, and 1 gallon of gasoline (0.72 specific gravity @ 65° F) weighs 6.009 lb.

An additional fact to consider is that the specific gravity of the fuel that we are using is very important. The fuel that we put in our car should be put in the tester also and should only be obtained from a source which supplies fuel intended for an automobile. Some people make the mistake of using aviation fuel for the tester other than using the same type of fuel used by the engine whose injectors' condition is to be checked (Sometimes referred to as "Av Gas"), thinking that the higher octane of this fuel may offer a performance gain. The problem is that TRUE aviation fuel has a much lower specific gravity (commonly as low as 0.62 to 0.65) than automotive grade fuel (0.72 to 0.76). Therefore much care has been taken to take the specific gravity of our desired fuel into consideration when sizing the fuel pump. As it is always the case in engineering application a safety factor has been taken to account for things such as pump-to-pump variability, voltage loss between the pump and the battery, etc., so it is always recommended in engineering to multiply the final output of the fuel pump by 0.90 to determine the capacity of the fuel pump at 90% output to be on the safe side, that has been done perfectly for the pump chosen for the tester. See figure 41 that is used to that our developed tester [14, 15].

Figure 41: in tank type electrical fuel pump used for the developed tester

4.6.2.1 Types of Pump

Generally in design there are two types of electronic fuel injection based on the locations of pumps one is in tank type (i.e. submerged in the fuel tank) and the other is in line type(i.e. the fuel pump is placed outside the tank just in the line at suitable location the same is used in the design of the solenoid injector testers as far as pump is concerned, in many ways in tank pump is preferred to in line because of pump protection, reduction of noise as usually occurred while the pump operates and so on, in the design considerations of the tester in tank pump has been chosen because of the above mentioned benefits and also most similar testers manufactured these time are also in this category [10,11].

4.6.2.2 How Pump Works

Normally the pump in use in the tester starts as soon as the pump control switched is made on immediately it pumps fuel to the rail and test injectors through fuel filter, when the fuel pressure is above the predetermined value fuel pressure regulator returns excess fuel back to the tank through fuel return line. And also while executing the performance test of the injector it still runs to keep the system pressure to the value at which the system is designed to inject fuels when activated therefore the system is kept always at the exact pressure value.

4.6.2.3 Modification of Pump Electrical Circuit Control

The pump electrical circuit is modified in such a way that the controlling of the pump is possible before starting the measurement to bring the system pressure to the desired working pressure and also it keeps running as the test is made on the tester for the purpose of maintaining the system pressure to the desired value. The normal electrical circuit of electronic fuel injection pump control circuit is modified to suit for controlling the tester pump as desired. When it is time to operate the tester closing the switch simply connects the circuit of the pump to the power side so it immediately starts operating. (See figure 32 electrical circuit of developed tester)

4.6.3 Fuel Filters

It is very important to supply clean fuel to the fuel rail in the injector tester system. Small particles of dirt can block an injection nozzle and cause an irregular spray pattern then causing to take the wrong measurement for the injectors under examination. Any water in the fuel will corrode the inside of the supply components - especially if the tester stands unused for long periods. The first filtering occurs with a strainer or fine gauze in the fuel tank. The next filtering occurs at the in-line filter, on the high-pressure side of the pump. This is a large-capacity filter encased, in a steel shell or aluminum housing. This housing must be rigid, to withstand the high pressures in the tester system so in our fabrication or development of the tester the right capacity together with the right filtering quality has been selected as this part of the tester system is also crucial like the other parts of the tester. The filter is a pleated paper type with pore size of about 10 microns. A fluted support plate keeps the filter stable in the housing. The filter is directional and it has been fitted in the direction of fuel flow. Due to the pressure in the system it is important to depressurize the system before changing fuel filters. Generally like the other parts installing fuel filters were carried out according to manufactures specifications. Final filtering occurs with a small conical filter at the fuel entry to the injector but this part of the injectors to be tested. As this is more important for the lives of the tester components as well as the injectors to be tested, much care has been taken in selecting the right capacity of fuel filter for the tester [13, 19]. The below figure shows the fuel filter that used to our developed tester

Figure 42: fuel filter used for the developed tester

4.6.3.1 Types of fuel filter

Inline and spin-on filters: Inline and spin-on filters are located between the fuel pump and fuel metering components. They are connected to fuel lines either by clamps, banjo bolts, flare fittings or quick-disconnect fittings. Some have a clear plastic housing that allows you to view the amount of dirt trapped in the filter. Some filters consist of a replaceable pleated paper cartridge installed in permanent filter housing [13, 19].

4.6.3.2 Determining Filter Capacity

According to the design of the filter for the tester or the filter used for the tester, the capacity of the tester is selected according to the filtering capacity list of manufacturers or the capacity of the filter used for the tester the top list has been selected from the list of the company according to the working condition of our country.

The filtering quality of the tester fuel filter is the highest rank. This selection is just to keep the injectors to be tested free of foreign particles.

The fuel rail is a large diameter pipe used to carry the high pressure fuel to the individual injectors of multi-point injection systems. All injectors are attached to this ‘rail’ and therefore all have equal fuel line pressure. A fuel pressure ‘damper’ may be fitted to the ‘rail’ to steady out the small pressure oscillations in the fuel due to the pump and injector actions. Single point systems have the fuel delivered from the filter directly to the single or central injector.

4.6.4 Fuel Rail

To avoid the leakage the assembly of the fuel rail was carried out with all the necessary cautions. The required pressure test on the fuel rail was made before starting the test for injectors.

The fuel rail (or ring) acts as a manifold supplying fuel to each injector. See figure 43, It also acts as a mounting point for the fuel-pressure regulator. Some domestic vehicles have the regulator riveted to the fuel rail; both are supplied if either needs replacing. The fuel injectors are sealed with O rings where they mount to the rail; the O rings should be replaced whenever the rail is removed from the injectors. Some testers of fuel rails usually have a fuel-pressure test fitting (Schrader valve) mounted on the rail, but the one we used does not have such facility which makes servicing much easier. Many imported vehicles do not use Schrader valves and require special adaptors to test system pressures and injectors fuel volume using the tester.

Figure 43: Fuel rail used in the tester

4.6.5 Pressure Regulator

The pressure regulator in port injection systems is similar to the regulator used in TBI systems. A diaphragm and valve assembly is positioned on the center of the regulator, and a diaphragm spring seats the valve on the fuel outlet. When fuel pressure reaches the setting of the regulator, the diaphragm moves against the spring tension, and the valve opens. This action allows fuel to flow through the return line to the fuel tank. Port systems present a problem for fuel regulation because the injectors have their tips located in the intake manifold below the throttle plate where constant changes in vacuum would affect the amount of fuel injected (at a given pulse width increased vacuum would allow more fuel to be pulled from the injector tip). To compensate for these fluctuations port injection systems are equipped with fuel pressure regulators that have manifold vacuum acting on the regulator diaphragm. This vacuum works with the fuel pressure to move the diaphragm and open the valve. When the engine is running at idle speed, high manifold vacuum is supplied to the regulator. Under this condition, relatively low fuel pressure can open the regulator valve. When the engine is running under heavy load and/or wide-open throttle, a very low vacuum is supplied to the regulator. During these times, the vacuum does not help open the regulator valve and a relatively high fuel pressure is required to open the valve. Therefore when engine vacuum is high fuel pressure is low and when engine vacuum is low fuel pressure is high. This change in fuel pressure allows the computer to control fuelling precisely based on pulse width or on time of the injector alone, in other words the regulator strives to maintain a constant pressure drop across the injector tips so that a 10 millisecond on time would deliver the same amount of fuel regardless of the pressure/vacuum present in the manifold. But that is what is actually happening while the injector is on the engine but here on the tester there is no need to have such connection since there is no manifold vacuum problem. Figure below shows pressure regulator that is used to our developed tester.

Figure 44: fuel pressure regulator used in the developed tester

4.6.5.1 How Pressure Regulator Works

The fuel pressure as it is used in the tester controls the system pressure at a predetermined value for which the system is designed to operate when the system pressure goes above 3/2.5 bar the regulator spring compresses as the result of the excess pressure then excess fuel returns back to the this way the pressure regulator keeps the system pressure at a predetermined value hence the performance of the injectors are always checked at a pressure for which they are designed initially so the measurement result shows their exact performance inside the manifold [21,22].

4.6.5.2 Modification of Vacuum Connection

In electronic fuel injection system for most designs vacuum connection are installed to compensate for the drop of pressure at the tip of injectors while the engine is running, on the latest design of electronic fuel injections since a sensor is used to measure the intake manifold pressure drop then the electronic control unit calculates from the information fed to it through this sensor to determine the exact pulse width time for the correct amount of fuel injection. But it the case of this and the like testers manifold compensation is not needed since the injection is made under normal condition, therefore the vacuum connection is modified to be closed as we can see figure 45 [21, 22].

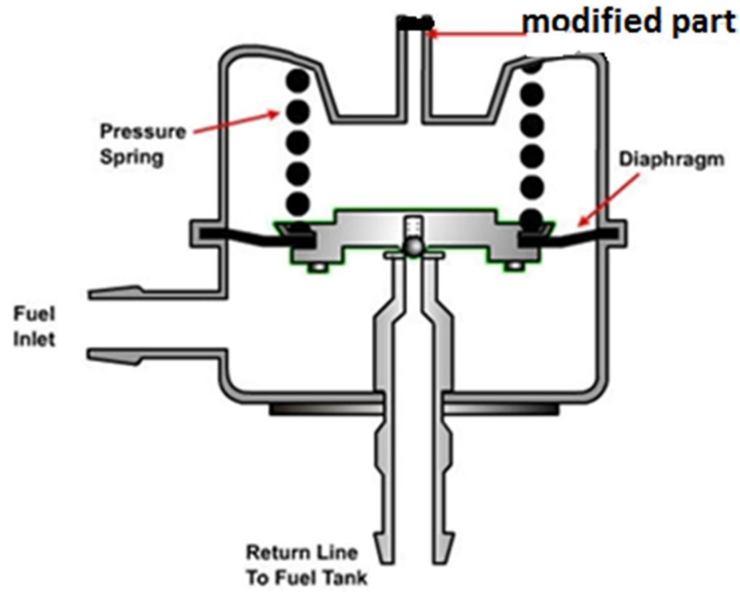

Figure 45: modified Vacuum Connection of the regulator used in the developed tester

4.6.6 Injectors test background as injectors are installed on the tester

Fuel injectors last a long time but, like everything else, are eventually subject to failure. They can fail in various ways, some of which can be fixed and others not. Just to give an idea of the kind of tests on injectors on the tester designed by this group, here is a list of things that were tested to measure the performance that cannot be tested while the injector is on the vehicle, these tests are included as part of the tester design and discussed below

- Flow for an equivalent of 1 and 5 seconds pulsed operation. Rate of flow is critical because the ECU depends upon the specified flow during an energizing pulse of particular duration while the injector is on the vehicle in the same way the value obtained is to be compared. Since injectors are designed for pulsed rather than continuous operation they are tested by pulsing, but the results are expressed in terms of "equivalent continuous operation." Dirty injectors have lower flow rates. Flow rate volume is checked accordingly.
- Leaks (OK or Leaks). Leakage can be either through the tip or internal. Tip leakage is caused by the valve not closing completely, perhaps due to dirt particles at the seat, which can't be seen without removing the injector from the car. Sometimes cleaning will resolve tip leaks. Internal leaks are when the casing breaks or something so that fuel goes where it shouldn't be. Sometimes this results in visible leakage from the plastic part of the injector body, so they can be seen

without removing the injector. However, the testers rejected two of my injectors for internal leakage and I don't remember seeing any external signs, so I don't fully understand this failure mode. At any rate, cleaning won't fix this.

- Spray pattern (OK, stringy, or plugged), before and after cleaning. Even if the flow rate is OK and there are no leaks an injector can develop a poor spray pattern, possible affecting combustion. I have heard of shops servicing the racers that give actual spray patterns recorded on a blotter for each injector.
- Injection variation to measure how the injector varies the injection when changing the pulse width of the injectors
- Coil resistance (Ohms), cool and hot. The resistance of the solenoid coil is one measure of electrical soundness of an injector. We don't know everything that can happen in this category, but coil burn out is possible we suppose, in which case the resistance would be infinite. Perhaps internal leakage could result in corrosion, leading to higher than normal resistance. The injectors have already been taken off the engine and installed on the tester for performance measurements [21, 22].

4.6.6.1 Injector Voltage

Here in this as a complete jig for the tester two different types of injectors in terms of voltage category are there, therefore when the injector is to be checked before operating the injector its voltage to be determined either it is 5V or 12V accordingly the right voltage need to be used to operate the injector [12, 18].

4.6.6.2 Injector Sizes and Adapter

To make the tester to be used for all sizes of injectors different adapters are used with tester therefore, as we measure the voltage category to identify whether it 5v or 12v the, the size is also to be checked and the right size of adapter is to be used before installing the injector on the tester [12, 18].

4.6.6.3 Injector Electrical Circuit Modification

Like the circuit for the electric pump the circuit for the injectors are modified to give simultaneous injections while the test is being executed, this is a simplified circuited and also saves time as all injectors inject fuel simultaneously say if number of cars to be tested are many this is preferred to a sequential one, we assumed the number of cars whose conditions are to be tested in our country are many that is why this type of circuit modification we used for this tester. (See figure 32 electrical circuit of developed tester).

4.6.6.4 Injector Installation

With all the personal protection equipment and occupational health and safety procedure after removing the injectors from the vehicle using the proper procedure injectors are installed on the tester the below shows while installing the injector on the tester.

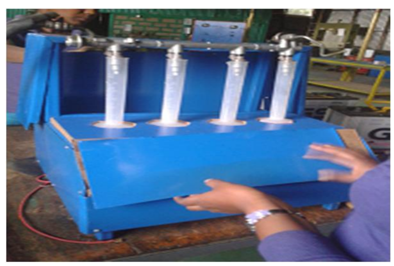

Figure 46: shows while the injector installed on the tester

4.6.7 Fuel Return Lines

Generally the return lines are used to let fuel back to the fuel tank in design there are two types one returns the excess fuel due to a pressure above the predetermined (high pressure side) value therefore maintaining the system to the desired pressure and the other returns the fuel in the graduating (low pressure side) cylinder back to the fuel tank.

4.6.8 Graduated Cylinder

The graduating cylinder is used to indicate the level of fuel as it is being injected in with the graduation scale the level of the fuel injected can be measured for each cylinder. The below figure shows the graduated cylinder that used to made developed tester.

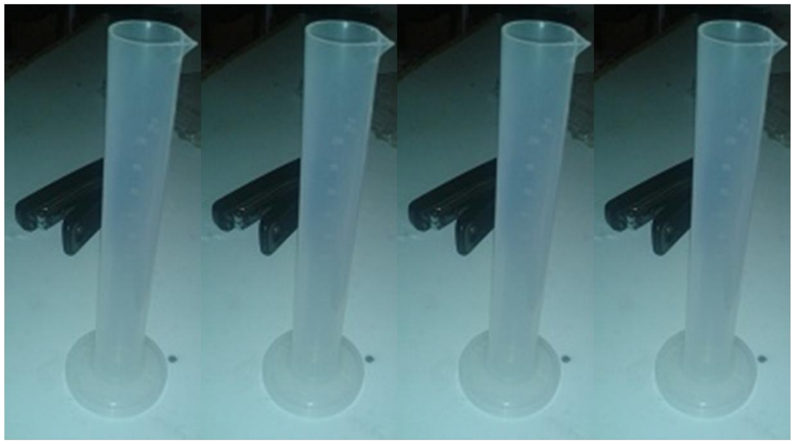

Figure 47: Graduated Cylinder used to the tester

4.6.9 Solenoid Switch

The solenoid switch is located below each and every graduated cylinder, when the fuel is being injected and the measurement it is in a closed position then it is opened to let the fuel back to the tank. The figure below shows solenoid switch that used to make the developed tester as a return switch.

Figure 48: shows solenoid switch used in the tester

4.6.10 Type of Fuel Used

The type fuel used in the tester is exactly the same as that of fuel used or experienced in the vehicle in our country because the aim of the tester is to find out exactly how the solenoid injectors function inside the engine whether it is as intended or not, therefore to exactly determine how the injectors behaves it is a must to check the injector under the same fuel condition, otherwise due to viscosity, quality and so on error will be induced [15].

Design Considerations for the Tester Components- Electrical and Electronics components side

In the designing of electrical and electronic circuit in our research study the three most important considerations are:

(i) Power sources like dc power supplies

(ii)Circuit components like resistors, Capacitors, Transistors, Diodes and so on.

(iii) Measurement and analysis instruments like multi-meters.

This Unit deals with familiarization of basic components like resistors, Capacitors and diodes, followed by introduction to a few instruments like multi-meters.

Basic Components: Basic components used in the design of the tester controlling units are capacitors, resistors, inductors, diodes, light emitting diode (led) and transistors can be divided into 2 categories: (i) Passive components like resistors and capacitors and (ii) Active components like diodes and transistors. The difference between the above two categories is that active components can generate energy whereas passive components cannot generate energy. In other words active components can increase power of a signal whereas passive components often cause the power to be lost.

Some components like resistors have their values marked on them whereas others like transistors do not have any value marking but have a type number on them. One has to refer to datasheets to get to know the value of the unmarked component. Besides component values, they are also characterized by their ratings for e.g. maximum current value that a component can stand without being burnt out all these considerations were taken into account to select the right type of component and design specification. Below are the details of design considerations for each and every component as they are used in the tester [22].

4.6.11 Power Supply

A simplified consideration of the electrical design of power supplies allows considering them as a device with an input side and an output side. The input side and the output side are electrically isolated against each other. The type of power supply used in the tester is linearly regulated power supplies with 220V input and an output of 5V and 12Vto be used by tester according to the type of injector to be tested. Below is the type of power supply used by tester with all the electrical diagram and input/output characteristics, below it the actual power supply used is see fig 49 [15.16].

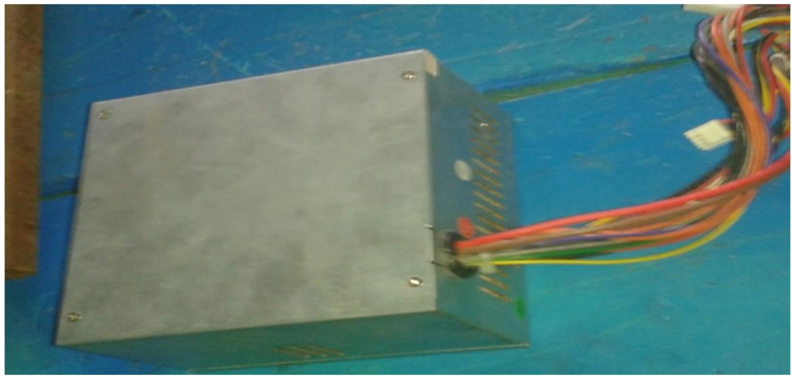

Figure 49: power supply used in the developed tester

The following table lists the most important terms regarding the input side and the output side.

Table 4 : Terms regarding input and output side

Input side	Output side
Primary side	Secondary side
Input voltage	Output voltage
Primary grounding	Secondary grounding
Current consumption	Short-circuit current
Inrush current	Residual ripple
Input fuse	Output characteristics
Frequency	Output current
AC supply	DC out put
Power failure buffering	Power factor correction (PFC)

Linearly regulated power supply

The AC mains voltage is transformed to a lower level, rectified and smoothed by capacitor C1. Then, voltage regulation is performed, typically using a power transistor. The power transistor acts as a variable resistor, controlled to keep the output voltage constant. The efficiency of linearly regulated power supplies is only approx. 50 % due to the high losses inside the power transistor. The remaining energy is emitted in the form of heat. Due to this, sufficient ventilation is required to cool the power supply. Compared with unregulated power supplies, linearly regulated power supplies have a very small residual ripple of the output volt-age (in the dimension of milli volts). Linearly regulated power supplies are used for all applications that require a very exact output voltage, e.g. For the tester for highly precise medical devices [15, 16].

Table 5: Linearly regulated power supplies as used in the tester

Advantages	Disadvantages
Short regulation times	Poor efficiency
Small residual ripple	Large size
Simple circuitry	No DC supply

4.6.12electrical cable and Switches

Used to connect and control the electrical and electronic circuit. The figure below shows different switch that used to our developed tester.

Figure 50: different Switches used in the tester

4.6.13The LM 555 Timers

The 555 timer is a very versatile 8-pin, which can be configured with a few external components and to build many circuits involving timing. The NE 555, used in this design is a popular version that is suitable in most cases where a 555 timer is needed. It is a dual-In -line (DIL) package. The 555 timer configuration can be done in three modes but for the purpose of this design, two of them are required namely: Astable and Monostable mode. Astable circuit produces a square wave with sharp transitions between low and high. It is called as table because it is not stable in any state since the output is continually changing between “low” and “high” therefore such design is not applicable for the design of the tester. A mono stable circuit produces a single output pulse when triggered. It is stable in just one state; the “output low” state. This is also known as the triggered pulse producer. Once the timer relay used in the tester circuit depending on the type of injector suit uses timing variations configurable with RC elements the specifications of this timer are: 12v voltage operation, manual programming done with a dip switch, the output has a 5v or 12v to suit to the two different voltages used in injectors, mode of operation monostable and this type is applicable for our tester [21].

The working principle of the timer

Programming the timing intervals was done by operating the dip switch that has three switches and with a potentiometer. Depending on the position of SW1 1 and 2 contacts the timer can be configured for the 4 time ranges. We used flasher for setting the timing period within these intervals. This way the timer is used to switch the injectors for different pulse width in this tester design according to the manuals of all the makers for solenoid injectors the condition of the injectors are checked under 1s and 2s pulse width the tester was made to work according to this standard the below figure shows the timer that used to our developed tester. [21].

Figure 51: shows the Timer used in the tester

4.6.14 Flasher

The flasher of the developed tester used as like a switch that controls injector pulse width. The below figure shows the flasher that used to our developed tester.

Figure 52: Flasher used in the tester

4.6.15 Resistor

Resistors can be of two types: fixed value resistors or variable resistors. The formula for resistance is given by: $R = \rho\, l / A$ where ρ is resistivity, l is length and A is area of cross section. Different value resistors can be manufactured by changing the length and area of cross-section or the material itself which changes the resistivity. Materials generally used for fabrication of resistors are nichrome (80 % Ni and 20 % Cr), constatntan (55% cu and 45 % Ni) and Manmganin (85 % Cu and 10 % Mn and < 5 % Ni). Metals are not used as they have a very high temperature coefficient of resistance. Three main methods of fabrication are (i) a slab or a rod of suitable resistivity, (ii) Material using thinner cross section and longer length. The length is doubled and then wound in such a way that inductance effects are cancelled out. (iii) Thin films of material on insulating substrate. Each resistor has a current carrying capacity, with this knowledge the right type of resistor value has been used for the design of the tester but in addition to show that there are different sizes from which the desired value is to be selected the figure below shows different sizes of resistor [15, 16].

Figure 53: Different sizes of the resistor

4.6.16 Variable Resistor

Variable resistors besides the fixed value resistors have been used in the development of the tester. The resistance of variable resistors can vary in steps or continuously. Potentiometer is also an example of continuously varying resistor the main function of this in a tester is to vary the amount of the current to solenoid injectors' fig. below shows the variable resistors that can be used in the development of such testers see below figure [15,16].

Figure 54: variable resistor used in the tester

Light Emitting Diode (LED)

Led's are pn junction devices which emit light radiation when biased in the forward direction. The semiconductor material used for these junctions is a compound semiconductor whose band gap corresponds to a particular wavelength according to equation $Eg = 1.24 / \lambda$ where Eg is the band gap in ev and λ is the wavelength in microns. (e.g. red ~ 0.7 μ hence corresponding $E g = 1.24 / 0.7 = 1.77$ ev). A very important precaution while using an led is the amount of current being passed through it. For most LEDs the maximum allowable current is 20 mA beyond which the led can burn out. Hence in most of the circuits a resistor is used to limit the current. Some important specifications before using an led are: LED color, peak wavelength, viewing angle, optical power output, luminous intensity, forward current and forward voltage. For the development of the tester the red and yellow LED have been used. See figure 55.

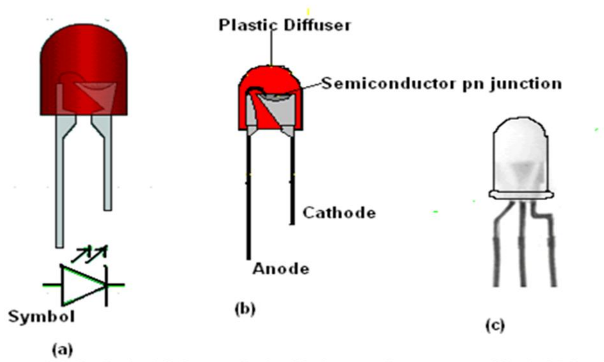

Figure 55: types of LED

4.6.17MeasuringInstruments

Multi-meters: A multi-meter is an instrument which measures electrical parameters such as AC or DC voltage, current, and resistance. See figure 56, Rather than having separate meters, a multi-meter combines a voltmeter, an ammeter, and an ohmmeter. The two main kinds of a multi-meter are analog and digital. A digital multi-meter has an LCD screen that displays the value of the parameter being measured. While in an analog multi-meter display, a needle moves through a graduated scale. Topmost scale is usually for resistance and the readings increases from right to left while other scales readings increase from left to right. Another name for an analog multi-meter is Volt-Ohm-Millimeter (VOM). Each type of meter has its advantages and disadvantaged. When used as a voltmeter, a digital meter is usually better because its resistance is much higher, 1 M or 10 M, compared to 200 Ω for an analogue multi-meter for a similar range. On the other hand, it is easier to follow a slowly changing voltage by watching the needle on an analogue display. Most modern multi-meters are digital and traditional analogue types are becoming obsolete [15, 16].

Figure 56 Automotive multi-meter

Components installation on the frame and checking the developed tester against the standard

The components location design, installation and test have been made according to the standard of similar tester and finally the tester is checked for standard with new injectors and found out that the tester is to the standard (the test result of standard injector on the tester is given at the end of this chapter)

Steps of installation: In the case of Fuel Supply System from tank to low pressure line

Step 1.The fuel tank and fuel pump are both checked and installed on the frame.

Step 2.The fuel line and filter are both checked and installed.

Step 3.The fuel rail assembly checked (including pressure regulator, injectors and return line) and installed.

Step 4.The graduating cylinder, solenoid switch and low pressure return line checked and installed to complete the fuel system components**.**

Steps of installation: In the case of electrical and Electronic Circuit components

Step 1 Power supply is checked and installed first

Step 2.Flasher and Timer is check and installed

Step 3.Variable resistor/potentiometer is checked and installed

Step 4.Connect terminals and switches

5. RESULT AND DISCUSSION

5.1 Testing the Functionality of the Developed Tester

As mentioned in the last part of Chapter 4.0, each component of the developed tester was tested and at each and every points necessary during the development period of the tester system and found out correct plus corrected as required to bring the tester system to the standard tester system available for the same purpose at which this study aims.

Next the functionality of the developed tester was again further checked with four new standard solenoid injectors of Toyota Make, Carina Model, E Series car together with a manual in which the specification and recommendation is given regarding performance determination of those injectors in terms of volume delivery, injection variation, spray pattern and no leakage test. This manual specifies what a normally working solenoid injector's performance should be.

To execute all the above performance measurements the new four standard solenoid injectors are installed properly on the tester and the tester system is checked, prepared and made ready as a precondition steps (that means making ready the tester) to make solenoid performance measurement. At each and every part during testing the tester system pressure, voltage across the injectors are checked against standard to make the result correct and reliable.

5.2 Solenoid Injectors Performance Measurement and Evaluation-New Standard Solenoid Injector

5.2.1 No Leakage Test and Evaluation

First the tips of all the injectors wiped dry, then the electrical pump circuit was made on to run the pump till the system pressure reached to the standard fuel rail or tester system pressure 3 bars- this is the normal pressure at which the solenoid injectors inject fuel when activated. But for no leakage test the solenoid injector was not activated only the system pressure is to be maintained for a certain time 1 min. as recommended by the makers and then the tip of the injectors were checked and all proved to be free of leakage or showed no leakage. The summary was given in Table 1 and Table 2 summarizes the standard condition of the injectors as given in the Manufacturer's manual.

Table 6: Shows standard condition for the no- leakage test as given in the manufacturer manual

s/n	Injectors	No leakage test	Performance condition	Remarks
1.	Injector 1	No leakage	ok	-
2.	Injector 2	No leakage	ok	-
3.	Injector 3	No leakage	ok	-
4.	Injector 4	No leakage	ok	-

Table 7: shows actual condition for the No-leakage test as tested by the developed tester

s/n	Injectors	No leakage test	Performance condition	Remarks
1.	Injector 1	No leakage	ok	-
2.	Injector 2	No leakage	ok	-
3.	Injector 3	No leakage	ok	-
4.	Injector 4	No leakage	ok	-

When this test was made the electrical circuit of injector control was disabled in order to make the injectors not to be activated.

As for this test, the tips of the solenoid were checked by observation and hand touch.

In conclusion as far as this test is concerned the test result from the developed tester was found out exactly as recommended by the maker for the good performance condition of solenoid injectors from this it was concluded that the developed tester is showing good functionality in the case of no leakage test result.

5.2.2 Volume Delivery Test and Evaluation

As mentioned before the injection strategy of the tester is simultaneous that is for simplicity purpose all the injectors are activated to inject fuel once the solenoid injectors control circuit is made on, therefore once the tester is ready for such test, as recommended by the maker of injectors two tests were made separately the first test was for 1 second volume delivery test and then the volume delivered reading was taken from the graduating cylinder and recorded for each cylinder in the Table 9 below, the second was for 5 seconds injection volume delivery test was made and in a similar fashion the volume delivered reading from the graduating cylinder and recorded in the same Table. In both tests the system pressure at which the fuel is injected is 3 bar and the voltage across each and every solenoid injector was 12V. In Table 9 below for a comparison purpose the volume of fuel the injectors should deliver for 1 second and 5 seconds were taken from the manuals and filed in the table.

Table 8: Shows Standard condition of solenoid injectors for the volume delivery test as the given maker manual

s/n	Injectors	Volume(1sec)	Volume (5sec)	Performance condition	Remark
1.	Injector 1	0.5 ml	2 ml	Nice	-
2.	Injector 2	0.5 ml	2 ml	Nice	-
3.	Injector 3	0.5 ml	2 ml	Nice	-
4.	Injector 4	0.5 ml	2 ml	Nice	-

Table 9: shows the actual condition of solenoid injectors for the volume delivery test as tested by the developed tester

s/n	Injectors	Volume(1sec)	Volume (5sec)	Performance condition	Remark
1.	Injector 1	0.5 ml	2 ml	Nice	-
2.	Injector 2	0.5 ml	2 ml	Nice	-
3.	Injector 3	0.5 ml	2 ml	Nice	-
4.	Injector 4	0.5 ml	2 ml	Nice	-

In conclusion as far as this test is also concerned the test result from the developed tester was found out exactly as recommended by the maker for the good performance condition of solenoid injectors injection volume delivery, hence from this it was concluded that the developed tester is showing good functionality as far as injection volume delivery test is concerned.

When this particular test was performed the system pressure was at the standard and the voltage at each and every injector was 12 V this was also the standard voltage at which the injectors were to operate.

5.2.3 Injection Pattern Test and Evaluation

The third operation on the tester was to check injection pattern here the injection pattern of all injectors were observed one at a time for five consecutive injection operations and it was exactly observed that the injection patterns of all injectors are all the same and alike, but here it is not because all are the same and alike we are concluding but the atomized pattern shown by all the injectors are as per the pattern expected of solenoid injectors in the makers manual, below are the two Tables the first one summarizes the performance condition of good solenoid injectors under test and the second one summarizes the test result from the developed solenoid injector tester.

Table 10: Shows the standard condition for the Injection Pattern test as given in the maker manual

s/n	Injectors	Injection Pattern	Performance condition	Remarks
1.	Injector 1	Conical	ok	-
2.	Injector 2	Conical	ok	-
3.	Injector 3	Conical	ok	-
4.	Injector 4	Conical	ok	-

Table 11: Shows the actual condition for the Injection Pattern test as tested by the developed tester

s/n	Injectors	Injection Pattern	Performance condition	Remarks
1.	Injector 1	Conical	ok	-
2.	Injector 2	Conical	ok	-
3.	Injector 3	Conical	ok	-
4.	Injector 4	Conical	ok	-

In conclusion as far as this test is also concerned the test result from the developed tester was found out exactly as recommended by the maker for the good performance condition of solenoid injectors injection pattern, hence from this it was concluded that the developed tester is showing good functionality as far as injection volume delivery test is concerned.

When this particular test was performed the system pressure was at the standard and the voltage at each and every injector was 12 V this was also the standard voltage at which the injectors were to operate.

5.2.4 Injection Variation Delivery Test and Evaluation

The tester was made to function in order to test variation of injection delivery for all injectors at the same time under the same condition and then the injection delivery variation was observed at each and every injector and recorded in the table that follows, and finally the total volume delivered reading was taken from the graduating cylinders and recorded in the same table after the test operation, it was found out that the total volume delivered by each solenoid was the same.

Table 12: 7shows the standard condition for the Injection Variation test as given in the maker manual

s/n	Injectors	Variation-in Injection	Performance condition	Remarks
1.	Injector 1	Variation observed	ok	-
2.	Injector 2	Variation observed	ok	-
3.	Injector 3	Variation observed	ok	-
4.	Injector 4	Variation observed	ok	-

Table 13: Shows the actual condition for the Injection Variation Delivery test as tested by the developed tester

s/n	Injectors	Variation-in Injection	Performance condition	Remarks
1.	Injector 1	Variation observed	ok	-
2.	Injector 2	Variation observed	ok	-
3.	Injector 3	Variation observed	ok	-
4.	Injector 4	Variation observed	ok	-

When this particular test was performed the system pressure was at the standard and the voltage at each and every injector was 12 V this was also the standard voltage at which the injectors were to operate.

In conclusion as far as this test is also concerned the test result from the developed tester was found out exactly as recommended by the maker for the good performance condition of solenoid injector's injection variations, hence from this it was concluded that the developed tester is showing good functionality as far as injection volume delivery test is concerned.

In the final conclusion of the functionality of the developed tester system it has been found out that the tester developed functions in the same standard to that of a similar standard solenoid injector test machine that are now a day's used worldwide. As seen in the test results above from the developed tester, the tester is able to function as desired from the very beginning; therefore the tester will solve all the problems stated earlier in the proposal of this study.

5.3 Solenoid Injectors Performance Measurement and Evaluation-Used Solenoid Injector

A vehicle whose solenoid injectors condition is to be checked, was identified and with all the steps, procedures, occupational health and safety and all the personnel protective equipment stated in chapter 3.0, the injectors were removed from the vehicle, prepared for test and the tester machine was prepared and all four injectors installed on the tester and with all the final preparation for testing on the machine, the testes were made and below are tables with a standard value in the makers manual in each firs Table and an actual value test results in each second Table.

5.3.1No-Leakage Test and Evaluation

Table 14: The standard condition for no-leakage as given in the maker manual

s/n	Injectors	No leakage test	Performance condition	Remarks
1.	Injector 1	No leakage	Ok	-
2.	Injector 2	No leakage	Ok	-
3.	Injector 3	No leakage	Ok	-
4.	Injector 4	No leakage	Ok	-

Table 15: The actual condition for the no-leakage test as tested by the developed tester

s/n	Injectors	No leakage test	Performance condition	Remarks
1.	Injector 1	No leakage	Ok	replace
2.	Injector 2	leakage	Bad	replace
3.	Injector 3	leakage	Bad	replace
4.	Injector 4	leakage	Bad	replace

When this test was made the electrical circuit of injector control was disabled in order to make the injectors not to be activated.

As for this test, the tips of the solenoid injectors were checked by observation and hand touch and three of the injectors are found out to be leaky.

5.3.2 Volume Delivery Test and Evaluation

Table 16: the standard condition of solenoid injectors for the volume delivery test as given in the maker manual for 1 second and 5 seconds

s/n	Injectors	Volume(1sec)	Volume (5sec)	Performance condition	Remark
1.	Injector 1	0.5 ml	2 ml	Nice	-
2.	Injector 2	0.5 ml	2 ml	Nice	-
3.	Injector 3	0.5 ml	2 ml	Nice	-
4.	Injector 4	0.5 ml	2 ml	Nice	-

Table 17: the actual condition of solenoid injectors for the volume delivery test as tested by the developed tester

s/n	Injectors	Volume(1sec)	Volume (5sec)	Performance condition	Remark
1.	Injector 1	0.45 ml	1.98 ml	Bad	replace
2.	Injector 2	0.6 ml	2.7 ml	Bad	replace
3.	Injector 3	0.611 ml	2.4 ml	Bad	replace
4.	Injector 4	0.65 ml	2.45ml	Bad	replace

In conclusion as far as this test is concerned the test results from all injectors for both measurements are bad from this it was concluded that since all the actual value results are below the recommended standard value by the maker therefore all injectors needed to be replaced.

When this particular test was performed the system pressure was at the standard and the voltage at each and every injector was 12 V this was also the standard voltage at which the injectors were to operate.

5.3.3 Injection Pattern Test and Evaluation

Table 18: shows the standard condition for the Injection Pattern test as given in the maker manual

s/n	Injectors	Injection Pattern	Performance condition	Remarks
1.	Injector 1	Conical	ok	-
2.	Injector 2	Conical	ok	-
3.	Injector 3	Conical	ok	-
4.	Injector 4	Conical	ok	-

Table 19: shows the actual condition for the Injection Pattern test as tested by the developed tester

s/n	**Injectors**	**Injection Pattern**	**Performance condition**	**Remarks**
1.	Injector 1	disorder	bad	Replace
2.	Injector 2	disorder	bad	Replace
3.	Injector 3	disorder	bad	Replace
4.	Injector 4	disorder	bad	Replace

When this particular test was performed the system pressure was at the standard and the voltage at each and every injector was 12 V this was also the standard voltage at which the injectors were to operate.

5.3.4 Injection Variation Delivery Test and Evaluation

The tester was made to function in order to test variation of injection delivery for all injectors at the same time under the same condition and then the injection delivery variation was observed at each and every injector and recorded ***(having bad value as compared to the makers manual)*** in the table that follows, and finally the total volume delivered reading was taken from the graduating cylinders and recorded in the same table after the test operation, it was found out that the total volume delivered by each solenoid was the same.

Table 20: Shows the standard condition for the Injection Variation test as given in the maker manual

s/n	Injectors	Variation-in Injection	Performance condition	Remarks
1.	Injector 1	Variation observed	ok	-
2.	Injector 2	Variation observed	ok	-
3.	Injector 3	Variation observed	ok	-
4.	Injector 4	Variation observed	ok	-

Table 21: Shows the actual condition for the Injection Variation Delivery test as tested by the developed tester

s/n	Injectors	Variation-in Injection	Performance condition	Remarks
1.	Injector 1	Variation observed, Ng	bad	-
2.	Injector 2	Variation observed, Ng	bad	-
3.	Injector 3	Variation observed, Ng	bad	-
4.	Injector 4	Variation observed, Ng	bad	-

When this particular test was performed the system pressure was at the standard and the voltage at each and every injector was 12 V this was also the standard voltage at which the injectors were to operate **Ng = means not good.**

In conclusion as far as this test is also concerned the test result from the developed tester was found out bad as compared to the specification and recommendation given in the maker manual.

In the final conclusion of all the injectors according to the actual test result of each and every solenoid injector as we compare to the standard value given in the maker manual for these injectors all are found to be defective or have bad result and should be replaced by genuine standard solenoid injectors

6. CONCLUSION, RECOMMENDATION AND EDUCATIONAL IMPLICATIONS

6.1 Summary

The main objective of this project study was the "**Development of manifold electronic solenoid injector tester for liquid fuels (petrol)** " the result of the research study showed that the developed tester was proved to be to the standard since during the development according to similar standard tester or to simulate the system under the same situation while the injectors are on the vehicle the following considerations were to be given: to have correct components, connecting lines both for the fuel supply and electrical and electronic system, maintaining the system pressure to standard pressure, maintaining the voltage across injectors to the right injector voltage according to the type, and maintaining the pulse duration or pulse time by timer and flasher these all modifications were made to bring the developed tester to the standard, in addition, the tester was used to test a new four standard injectors and the actual readings of all tests were compared to the standard value in the manufacturers manual and the actual value were to be the same as the standard values given in the manual. Therefore, the team members proved that the developed tester can perfectly be used for the performance measurements of electrical solenoid injectors, such as for no-leakage test, volume delivery test, injection pattern test, and injection variation tests.

6.2 Conclusions

The main aim of this research study was to develop a standard Electrical Solenoid Injector Tester, which is used to test electrical solenoid injectors of Electronic Fuel Injections in the case of Port and throttle body injections. The developed tester system measures no-leakage test, volume delivery test, injection pattern, and variation of injections of all injectors and then the actual result can be compared and evaluated against the standard values given in the maker's manual from which a conclusion is made about the performance of the injectors according to the standard.

Below are the conclusions given on two injectors categories as tested on the developed standard tester system by the research team members: one category was a new standard solenoid injectors, another category was a used solenoid injectors.

6.2.1 Based on the no-leakage testes

According to the test result from the developed tester system all the new standard injectors were according to the data specification given in the makers manual, no- leakage was shown at each tip of the injectors during the test, this showed that all the injectors are perfectly good as specified by the makers in the manual. In the case of used injectors, those removed from the car only the injector for the first cylinder was found to be correct and all other were showed a leaking signs at the tip of injectors.

6.2.2 Based on the volume delivery testes

This test was executed for 10 second volume delivery and 60 second volume delivery testes, according to the test result from the developed tester system again for these two durations test all the new standard solenoid injectors were found to deliver the right amount for according to the duration when compared with the amount of volume delivery in each case it was exactly as the data in the maker manual of these new injectors where as for both durations all injectors of the used one found to be excess volume than the volume specified by the maker in the manual.

6.2.3 Based on the injection pattern testes

This test was executed for 60 second duration for both injectors categories and the patterns of injection as seen on the new injectors are perfect band to the shape of pattern in the manual but used all injectors have shown distorted pattern for which the manual specifies bad pattern.

6.2.4 Based on the injection volume variations testes

As tested on the developed tester system in general all the new standard solenoid injectors have shown variations and finally the total volume measured from all graduating cylinders are all exactly the same and as specified in the makers manual but in the case of all used injectors the variations are great between injectors when finally the total volume was read and also not the same as compared to the specified value in the makers manual.

Note: for this test the variations and the final total volume are specified in the manuals.

6.2.5 General conclusions based on the test result and evaluation

All the new standard electrical solenoid injectors have shown the excellent performance condition, this also indicates that the developed tester system is to the standard. All the used solenoid injectors have shown bad performance condition, this also shows how the developed tester system is able to show as defective injectors. All injectors of the car should be replaced to re store all the benefits of the EFI systems for this car otherwise in short the engine of this car will give poor performance, less fuel economy, poor starting, high emission and so on.

6.3 Recommendations

The project forms the foundation for various works, one as discussed above it is an issue of the country, as the device if used to test and evaluate based on certain kilometers or months whichever occurs first for the measurements of performance on electrical solenoid injectors as used by all developed countries,

- to protect the environment
- to keep the performance of the engine as intended
- to improve fuel economy
- to enhance the satisfaction of the car owners and so on such tester is used for measuring the general performance of injectors. As it was proved by this project study result the tester can be produced easily here in the country.

As the vehicles with the EFI systems are now in the country is more than enough

- by having such very portable machine without the need of a large work area it can create a job opportunity for youngsters and the mass production of such tester can easily be made here in the country.
- the tester can even be used as a teaching aid in the universities and TVET colleges all over the country. The only thing needed from the Government side is to create awareness in all the concerned bodies and the car owners on the benefits of making such performance measurements as specified by manufacturers and take the necessary

corrections to be all the time to the correct tune in this regard as intended by manufacturers.

The tester developed is to the standard of a similar tester, therefore having this project as one input ASTU shall transfer this technology

- to micro enterprises and
- to TVET to accelerate our countries technological advancement or development like the developed countries at least in protecting the environment, saving car owners money, time and energy by bringing the vehicles all the time to the standard and so on.
- In conclusion, we sincerely wish that all our effort in trying to bring changes will soon become practical in this country.

6.3 Educational Implications

The objective of the national TVET strategy is to create a competent, motivated, adaptable and innovative work force in Ethiopia contributing to poverty reduction, social and economic development through facilitating demand driven, high quality technical and vocational education and training, relevant to all sectors of the economy, at all levels and to all people in need of skill development transferring new technologies (National TVET strategy, MOE, 2006).

- ❖ Technical and vocational education is of great relevance to the technological and economic status of nation. Such as:

- ❖ Technological advance and progression, which naturally lead to economic release and independence
- ❖ Evaluate new instructional program and draw lessons for further Improvement
- ❖ To improve and develop the teaching and learning process
- ❖ Gain educational decision makers in making decisions and take action
- ❖ Effective handling the issue of transfer of technology and its attendant problems Reduction of over dependence on imported products
- ❖ Conservations of the resource that could have spent in engaging the service of foreign experts

The objective of this project is to show how education can play a great role in introduce and transferring **Electrical Solenoid Injectors Tester technologies** to the country and also to enrich understanding and create ability of University and TVET trainees through education. Accordingly, the findings of this project could have an impact in TVET education, and training in the following area:

- It can help to transfer **Electrical Solenoid Injectors Tester technology** into TVET training
- It can initiate TVET experts to introduce new instructional programs
- It can develop the potential of TVET trainees to create job opportunities with minimum initial cost

FUTURE PLAN

The tester designed can also be used for cleaning, if all the injectors tested are found to be correct according to the specification of the manufacture recommendation. The design for the cleaning of injectors within the specification or sometimes as needed customer's may come for the cleaning of injectors.

Most fuel injectors can be cleaned on the vehicle by feeding injector-cleaning liquid into the fuel rail, or TBI/CFI test port while the engine is running. One common piece of equipment is shown in Figure below. Liquid cleaner, which may require diluting with gasoline, is poured into the container after the top has been unscrewed. The top, containing an adjustable air pressure regulator, is re-installed and a shop air hose is attached to the regulator. Ensure that the shut-off valve is closed and adjust the container pressure to 35 kPa (5 psi) lower than the fuel-injection-

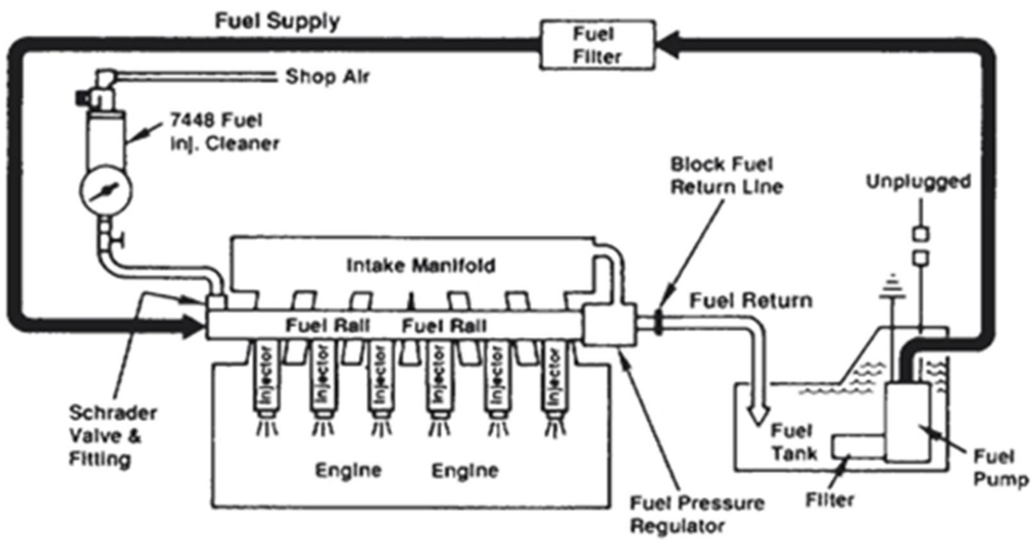

Figure 57: Fuel-injectors cleaner is fed into the fuel system with this cleaning unit

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APPENDEX -A

Some questions are prepared to collect the necessary information for conducting a study on the topic **"Development of manifold electronic solenoid injector tester for liquid fuels (petrol)"** since the success of the research significantly depend on your information contribution the researchers will kindly re request you to honestly response the questions:

Personal information of the interviewer

Sex______________

Age_____________

Educational level_____________________

Qualification_________________________

Position in the organization____________

Experience_________________________

Questions to be asked

1. Do you have electrical solenoid fuel injector tester?
2. How do you measure the performance of the electrical injectors solenoid fuel tester in terms of:
   No-leakage test?
   Injection volume delivery?
   Spray pattern?
   Injection volume variation?
3. If not? How do you measure such performances? While the injectors are still on the mounted on the engine?
4. When do you change the injection nozzle for petrol Electronic Fuel Injection system/EFI/
5. How do you evaluate the performances of EFI system cars after a kilometers or years drive?
6. Do you have any information where Electrical solenoid injector tester is found?
7. Do you know that other developed countries use this tester to test and evaluate the performance of solenoid injectors?

APPENDIX-B

Cost analysis

Conversion cost

Below are list of the costs incurred while developing of manifold electronic fuel injector tester liquid fuels (petrol)

Square tube	=180 Birr
Sheet metal	= 400 Birr
Rivet	= 50 Birr
Electrode	= 75Birr
Fuel tank	= 500 Birr
Fuel line	= 100 Birr
Fuel filter	= 60 Birr
Pressure gauge	= 950 Birr
Fuel Rail	= 2050 Birr
Pressure regulator	= 700 Birr
Injectors	= 1600 Birr
Fuel pump	= 800 Birr
Graduated cylinders	=320 Birr
Solenoid switch	= 2360 Birr
Toggle Switch	= 800 Birr
Power supply	= 600 Birr
Timer	= 850 Birr
Connectors	= 75 Birr
Flasher	= 100 Birr
Variable resistor	= 800 Birr
Petrol fuel (2lit)	= 45 Birr
Resistor	= 80 Birr
Diodes	= 100 Birr
Transport cost	=500 Birr
Electrical wire	=75 Birr
Paint	=80 Birr

Fitting and square rubber	= 50 Birr
Kerosene (2lit)	=26 Birr
Total cost	=14, 476 Birr

Running Cost

As mentioned above the total amount to develop the tester system is 14, 476 Birr (fourteen thousand four hundred seventy six) whereas once the tester is developed the running cost is only fuels to be replaced after sometime but the other components of the system will give longer service time.

If transferred to small and micro enterprise, it does not require spaces for investments but professionally the researcher recommends ASTU , Adama Science and Technology University this study result to be transferred because of the following reasons:

- It has a market every where
- The profit is high
- Low initial investment
- The environment is protected
- The performance of the cars will be maintained
- Enhances customer satisfaction
- If training for is given small enterprise it can be easily managed, and fills the gap of the unemployed poor of the country and so on and so forth.