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Design and Fabrication of an Electronic Fuel Injection Kit for a Conventional Small Capacity SI Engine

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Abstract- Port Fuel Injection (PFI) was developed in 1980s for automotive industry in order to improve engine performance and control emission effectively. It is now used widely in modern cars and some kind of sport motorcycles. To take advantage of electronic, the premix of air-fuel and combustion process can be programmed and controlled very precisely. Therefore, the emission and performance of the engine can be improved significantly for different working conditions. One of the main reasons for remote use of PFI technology in motorcycle is its complexity added with high cost. This paper reports on the design, development and fabrication of a new and compact PFI system that can replace an in-used carburetor easily with minimum modifications.

Index Terms— Automotive; Four stroke; Gasoline; fuel retrofit kit; Spark ignition Engine.

I. INTRODUCTION

Carburetor is used widely in spark ignited engine to control the fuel flow rate applied to combustion chamber. It also partly mixes fuel with air to be a combustible mixture inside intake manifold before leading to engine. The air –fuel ratio (AFR) is adjusted depend on load and working condition of engine (cold start, idle, cruise, etc.) by different venturi systems.

Carburetor works on the principle of difference pressure between cross sectional area that air flows through and float chamber (atmospheric pressure). The choke is often shaped like a tube with a converging –diverging venture section. In this restricted section, the air flow's velocity becomes higher (Bernoulli's principle), therefore the air pressure will be lower, causing the influx of fuel upwards through the jets and orifices.

Carburetors are mechanical systems that mix fuel with air. To accomplish this, carburetors use (what is known as) the venturi-effect. Carburetor works on the principle of pressure difference for sucking the fuel through a miniature tube, which releases small droplets of fuel into the air.

The deficiencies of the elementary carburetor can be summarized as follows [10]:

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1. At low loads the mixture becomes leaner; the engine requires the mixture to be enriched at low loads.
2. At intermediate loads, the mixture equivalence ratio increases slightly as the air flow increases. The engine requires an almost constant equivalence ratio.
3. As the air flow approaches the maximum wide-open throttle value, the equivalence ratio remains essentially constant. However, the mixture equivalence ratio should increase to 1.1 or greater to provide maximum engine power.
4. The elementary carburetor cannot compensate for transient phenomena in the intake manifold. Nor can it enrich the mixture during engine starting and warm-up.
5. The elementary carburetor cannot adjust to changes in ambient air density (due primarily to changes in altitude).

Regulating bodies in major countries have come up with stringent emission regulations, which will be enforced in the near future. There are three ways to reduce emissions form spark-ignition engines which are; changes in engine design, combustion conditions, and catalytic after-treatment.

Some of the variables of the engines and combustions that affect emissions are the air-fuel ratio, ignition timing, and turbulence in combustion chamber. And among these variables, air-fuel ratio is the most importance variable that needs to be focused on. Air-fuel ratios for the internal combustion engine are controlled by fueling system which is either by using carburetor system or fuel injection system.

For small gasoline-fuelled engines (below 250cc), a carburetor system is still favorable. It is proven for many years that such system is cheap and easy to maintain. However, Komuro et al. [1] and Latey et al. [2] have shown that there are much improvement can be made by converting the carburetor system to a fuel injection (FI) system alone.

The engine is the first major sub system of the vehicle to be turned over from mechanical to electronic control. Engine electronics was introduced in the 1970s for the control of ignition and exhaust gas recirculation (EGR) in gasoline engines. In the 70's, engines relied on mechanically generated signals to ignite the fuel/air mixture.

Since that time, engine electronic controller (EEC) system has developed and changed greatly. In 1977, EEC II was introduced by Delco Remy. It gave accuracy and flexibility and offered other advantages such as a reduced part count and a lower maintenance burden than its mechanical forebears. It was also as a response to the oil crisis and promised marginally better fuel economy.

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Electronic controls have significantly improved engine performances relative to mechanical controls. The use of digital electronic control has also enabled this engine to meet the government regulations on exhaust emission and fuel economy by controlling the system accurately with excellent tolerance and flexibility.

EEC III was introduced in 1979 on the Lincoln Continental. The most significant single change for EEC IV, 1982-1985, is the introduction of the diagnostic requirements. The implementation of these requirements is estimated to have doubled the use of resources, measured in memory usage and processor throughput. The type of microcomputer is significantly different. A complex instruction set computer (CISC) 8 bit micro-computer has given way to a 32 bit reduced instruction set computer (RISC) device. The increasing demand for functions and the legislative requirement have driven the pace of change and have forced changes in the system architecture.

II. FUEL INJECTION SYSTEM

Fuel injection system can substantially lower consumption and emissions when compared to conventional vehicles, no matter what fuel they use. Fuel injection for gasoline engines can be defined by its fuel-injection location such as direct in-cylinder injection (DI) and port-fuel injection (PFI).

There are two types of fuel injection system [10]:

i. Direct Injection

Fuel is injected directly into the main combustion chamber. The engines would have either one main combustion chamber or a divided combustion chamber made up of a primary and secondary chamber.

ii. Indirect Injection

Fuel is injected into the secondary chamber of engine with a divided combustion. The fuel injection arrangement can either be based on the throttle body injection (TBI) or multi-port injection (MPI). A TBI system uses the same intake manifold as a carbureted engine, where the TBI replaces the carburetor. By injecting the fuel into the intake air stream, the fuel is better atomized than if it were drawn through with a venturi. TBI has the drawback of potentially large cylinder-to cylinder variations. Like a carburetor, TBI injects the fuel into the intake air at a single location upstream of all the cylinders and this long and different travelling routes cause discrepancies in the amount of fuel that reaches each cylinder. Manufacturers account for this variation in their design and may make compromises such as injecting extra fuel to ensure that the cylinder with the leanest mixture will not misfire. These will eventually compromises combustion and fuel consumption.

MPI allocates a fuel injector at each of the intake port. A quantity of fuel is injected each time the intake valve opens for each cylinder. This allows manufacturers to more precisely control the amount of fuel injected for each combustion event, as well as optimising the air-fuel ratio for combustion. Due to these advantages, MPI system has been widely used in automotive applications for over 15 years.

One of the approaches being used to improve injector performance is air-assisted fuel injection, which injects high-pressure air along with the fuel spray to produce greater atomization of the fuel droplets can be achieved. This technology aids the improvement on engine performance and reduction of emissions at low engine speeds. In addition, industrial studies have shown that the short burst of additional fuel needed for responsive, smooth transient maneuvers can be reduced significantly with air-assisted fuel injection due to a decrease in wall wetting in the intake manifold.

DI fuel-injection system is more complicated and requires much more sophisticated control over the fuel-injection, air-fuel mixing and combustion processes compared to PFI system [9].

PFI system was selected in developing fuel injection retrofit kit in order to replace the current fueling system – carburetor due to its simplified system.

In this study, An effort to develop a new and compact PFI system that can replace an in-used carburetor easily with less extra modifications and an EEC for controlling the fuel injection is purposed and this is called as electronic fuel injection (EFI) controller. Basically, this electronic controller design is similar for gasoline, diesel, natural gas (NG), and alcohol powered engines, as well as hybrid-powered engines, a variety of cylinder, and fuel-delivery configurations effort to develop a new and compact PFI system that can replace an in-used carburetor easily with less extra modifications.

III. ISSUES: FUEL INJECTION IN SI ENGINES

However, in dealing with small gasoline-fuelled engines, the application of a fuel injection kit still poses several interesting challenges, among others:

i) The added cost for an EFI system must not considerably increase the total vehicle cost [3].
ii) The fuel pump must have low power consumption [4].
iii) Obtaining accurate load detection at small throttle opening [5] and [6].
iv) The EFI system must be able to operate only by kick-start when the battery is completely discharged [7].
v) The integration of software and hardware requirements of electronic control unit (ECU) development process caters for the complexity of engine control strategy [8].

IV. MATERIALS AND METHODS

The proposed prototype for fuel system retrofit has components similar to that of a conventional fuel injection system and the main parts are fuel supply system, fuel injector and electronic control unit (ECU). A schematic representation of this fuel injection system test bench is shown in figure 1.

A conventional fuel pump is used to supply pressurized fuel to the injector, the pressure being controlled by a control value positioned in the bye pass line. The mass flow rate of fuel injected is controlled by a microcontroller. To minimize the loss of injected fuel by evaporation, an ice bath is used in the test bench.

Using the test bench, the operating characteristic curves for different fuel injectors are experimentally determined, and the injector which suits the need of the test engine can then be selected.

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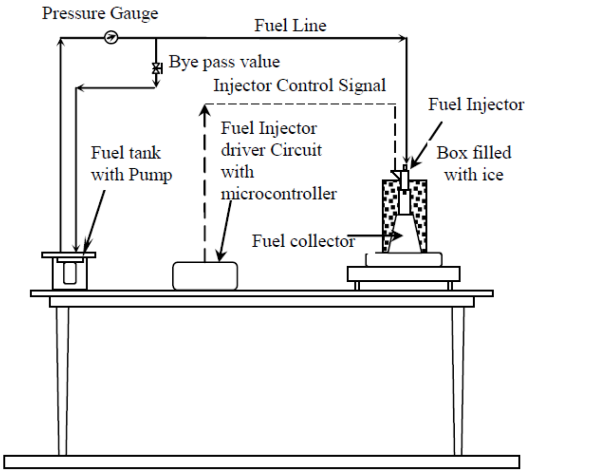

Figure 1 Schematic representation of fuel injection test bench

A. Fuel Supply System

The fuel supply system provides a constant pressure resource for the injector. Basically, the fuel supply system is similar to the conventional design of gasoline Port Fuel injection (PFI) engine contained by high-pressure fuel pump, pressure regulating bypass value and fuel line. The fuel pump that supplies fuel to the rail at the pressure of 5-10 MPa. The pressure regulating bypass value maintains the pressure in the rail at the required level by regulating its fuel flow.

B. Electronic control unit (ECU)

The ECU controls the injection quantity and injection timing of the injector by special programs according to calculation and analysis of analogue and digital inputs of various sensors. During operation the ECU collects signals such as engine speed, TDC, throttle position and air flow. These signals are be processed and then used to control engine operation.
An electronic control unit (ECU) contains the hardware and software. The hardware consists of electronic components on a printed circuit board (PCB), ceramic substrate or a thin laminate substrate. The main component on this circuit board is a microcontroller chip (CPU). The software is stored in the microcontroller on the PCB, typically in EPROMs or flash memory so the CPU can be re-programmed by uploading updated code. This is also referred to as an (electronic) Engine Management System (EMS).

C. Fuel injector

Fuel Injector is a solenoid operated electromagnetic valve, which atomizes the fuel by forcing it through a small nozzle under high pressure. The injection system used is a timed injection system and the injection is done close to the inlet valve. The injector operates based on the pulse width signal given by the ECU. The fuel injector is assembled in the inlet manifold located between the inlet port on the cylinder head and air filter. It is placed at an angle in the intake manifold so as to give maximum fuel spray and minimum wall wetting.

D. Fuel Injector Driver Circuit

The injector driver circuit convert the +5VDC signal from the microcontroller to +12VDC signal to operate the fuel injector. The typical pulse width obtained from the microcontroller and pulse width obtained from the injector driver circuit is shown in the below figure 2 and 3.

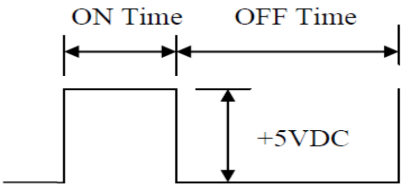

Figure 2. Pulse form microcontroller

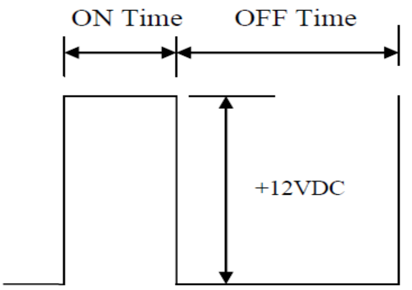

Figure 3. Pulse form fuel injector driver circuit

The schematic representation of the experimental setup is as shown in figure 4. The major components of the setup are (i) the engine, (ii) fuel injection system and (iii) the sensors.

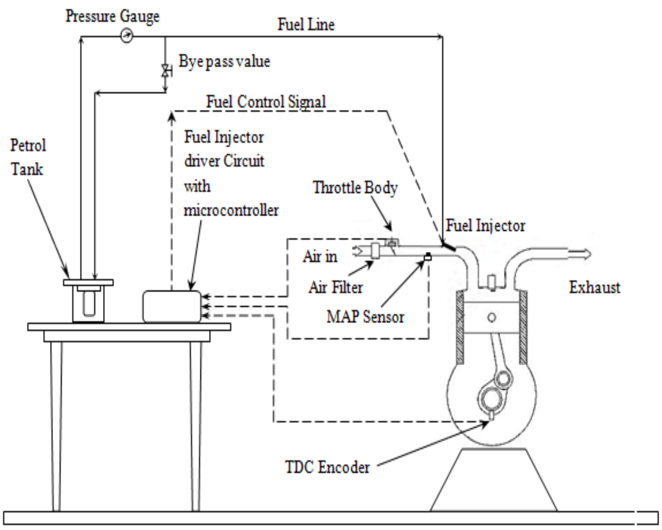

Figure 4 Schematic representation of experimental setup

A conventional 350cc, single cylinder, four stroke, air cooled Royal Enfield engine was used in this experimental study and the existing carburetor fueling system was removed and is retrofitted with the proposed Electronic Port fuel injection system. The fuel injection system having a configuration similar to the one shown in the test bench is used. To have a better control over the fuel air mixture supplied to the engine, sensors like throttle position sensor, TDC encoder and manifold pressure sensor are used. Throttle Position Sensor (TPS) is used to monitor the position of the throttle and is located on the butterfly spindle so that it can directly monitor the position of the butterfly throttle valve. The sensor is usually a potentiometer and therefore provides a variable resistance depending upon the position of the butterfly valve and hence throttle position can be sensed by the ECU. The sensor signal is used by the ECU as an input to its control system.

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The Manifold Pressure Sensor (MAP) provides instantaneous manifold pressure information to ECU. This is necessary to calculate air density and determine the engine's air mass flow rate, which in turn used to calculate the appropriate fuel flow rate to the engine through the injector.

TDC Encoder used in this study was an absolute rotary encoder. The optical encoder's disc is made of glass or plastic with transparent and opaque areas. A light source and photo detector array reads the optical pattern those results from the disc's position at any one time. This code can be read by a controlling device, such as a microprocessor or microcontroller to determine the angle of the shaft. The absolute analog type produces a unique dual analog code that can be translated into an absolute angle of the shaft. The TDC encoder provides point of injection signal to ECU.

E. Experimental Procedure

Experiments are conducted in the test bench to determine the effect of pulse width and speed on the rate of injected for different injectors. While the fuel pressure is maintained at 2 kg/cm^2, the pulse width was varied from 12 to 60 ms, to a maximum of 50 % duty cycle, in steps of 5 ms. Duty cycle is the amount of time that the fuel injectors are switched on. A duty cycle of 0% means that the injector is not ON at all, a duty cycle of 100% means the injector is ON constantly.

Initially the MAP sensor is connected to a pressure source and the MAP output (in volts) is measured for the various pressures in the range of 10 – 100 kPa.

Test are also conducted to establish a relationship between Throttle Position Sensor output (in voltage) versus Throttle plate angle (in Degrees). While the throttle plate angle is varied in the range of 0 to 80^o, corresponding to fully open and closed positions, the throttle position output over this range was from 0.6 (± 0.02V) to 3.86 volts (±0.1V).

Since the objective of this work was to run the engine with a simplified electronic fuel injection system with minimum number of sensors, the following was used. Initially, the engine was fitted with both the throttle body and carburetor. While the fuel is supplied through the carburetor, the air is supplied through the throttle body. Using suitable instruments, the mass flow rate of air is measured. From the mass flow rate of air, the mass flow rate of fuel is calculated using the stoichiometric conditions.

The engine is then fine tuned for a particular speed, after removing the carburetor, by supplying the fuel using the designed fuel injection system. The flow rate of fuel injected is controlled by varying the pulse width of injection which in turn is controlled by the output of throttle position sensor. The same procedure is for various speed of the engine in the range of 1000 to 5000 rpm.

V. RESULT ANALYSIS

Figure 5,6 and 7 shows the effect of pulse width on the rate of fuel injection, for various speeds in the range of 1000 to 5000 rpm in steps of 500 rpm, for three different injectors. From these diagrams, it could be concluded that

i) As the pulse width is increased, the rate of fuel injection also increased in a linear manner.

ii) As the speed is increased (at constant "ON" time pulse width of 5, 10 and 15 ms), the rate of fuel injection also increased in a linear manner as shown in the figure 8.

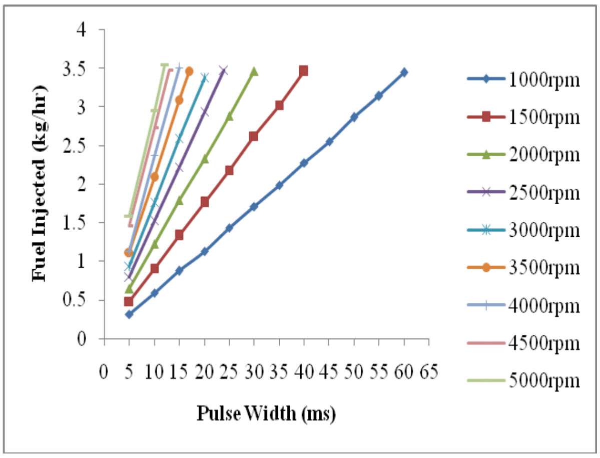

Figure 5 Effect of pulse width on fuel injected for a fuel injected with four holes (Denso Make)

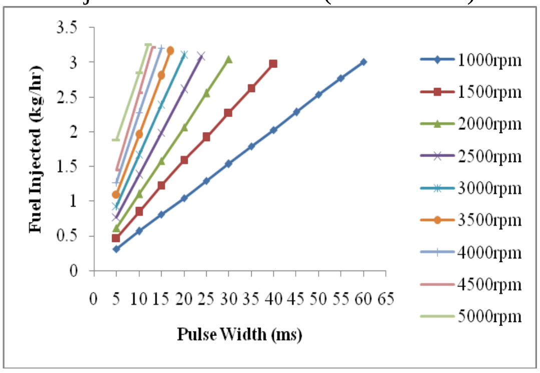

Figure 6 Effect of pulse width on fuel injected for a fuel injected with four holes (Bosch Make)

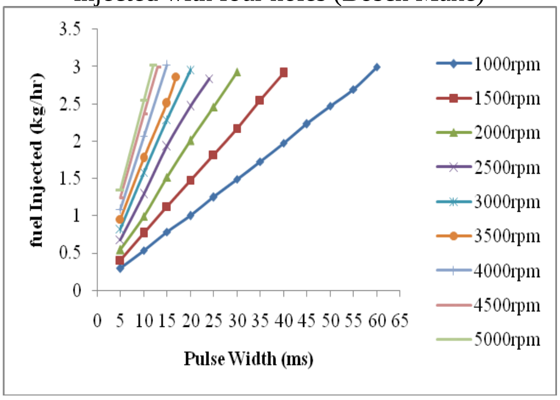

Figure 7 Effect of pulse width on fuel injected for a fuel injected with two holes (Denso Make)

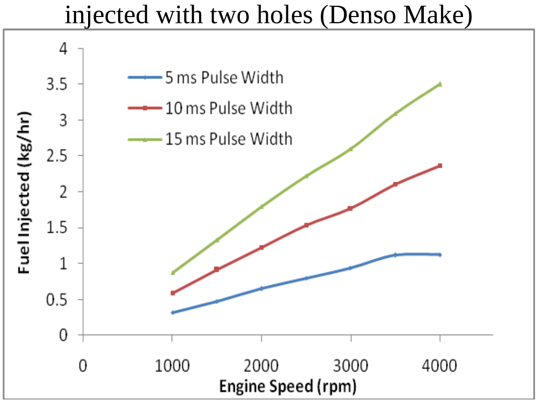

Figure 8 Effect of engine speed on mass flow rate of fuel injected with four holes (Denso make)

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Based on the test results the variation in pressure in (Kpa) versus MAP output voltage is shown in the figure 9 and the variation in throttle plate angle in degrees versus throttle position sensor output voltage is shown in the figure 10.

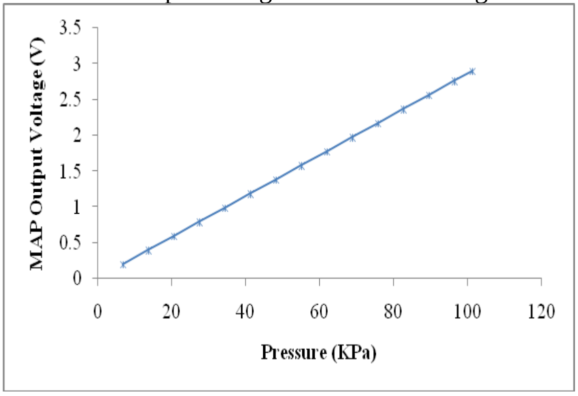

Figure 9 Effect of manifold pressure on the MAP sensor output

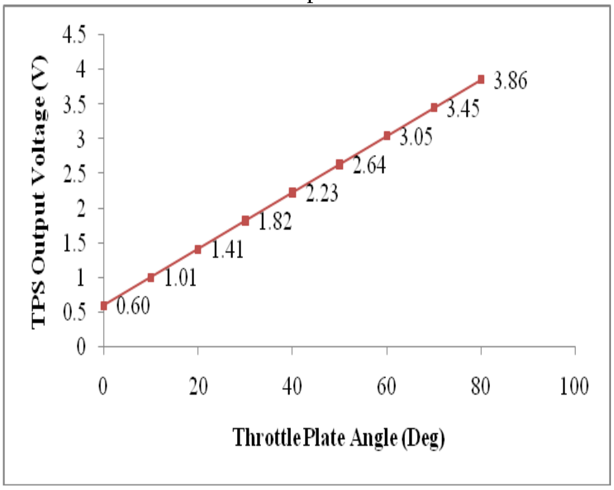

Figure 10 Effect of throttle plate angle on the TPS sensor output

From the above two graph we have concluded that results the variation in pressure in (Kpa) versus MAP output voltage and the variation in throttle plate angle in degrees versus throttle position sensor output voltage was linear.

Based on the test result the variation of throttle position sensor in voltage versus fuel injected is shown in figure 11.

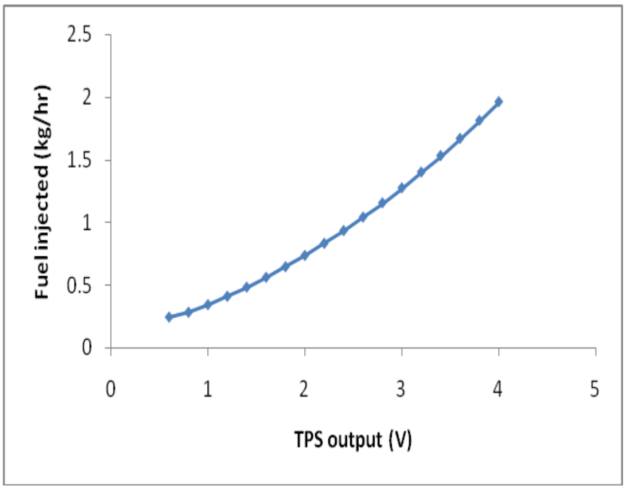

Figure 11 Effect of TPS output on the mass flow rate of fuel injected

VI. CONCLUSION & FUTURE WORK

While a electronic fuel injection (EFI) system for an engine is complicated due to the presence of a number of sensors like Air flow meter, Engine rpm sensor, Crank angle sensor, Intake air sensor, Water temperature sensor, Throttle position sensor, Vehicle speed sensor, and oxygen sensor, the system developed was simple involving least number of sensors and is effective.

In this work an effort is made to design and develop a electronic fuel injection kit for a small capacity engine to run it at various speeds (in the range of 1000 to 5000 rpm) and at no load. In future, the kit is to be further (developed) modified to take care of transient conditions that occurs during variations in speed and for loaded conditions of the engine.

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