IN THEORY IT'S BETTER THAN A CARBURETOR

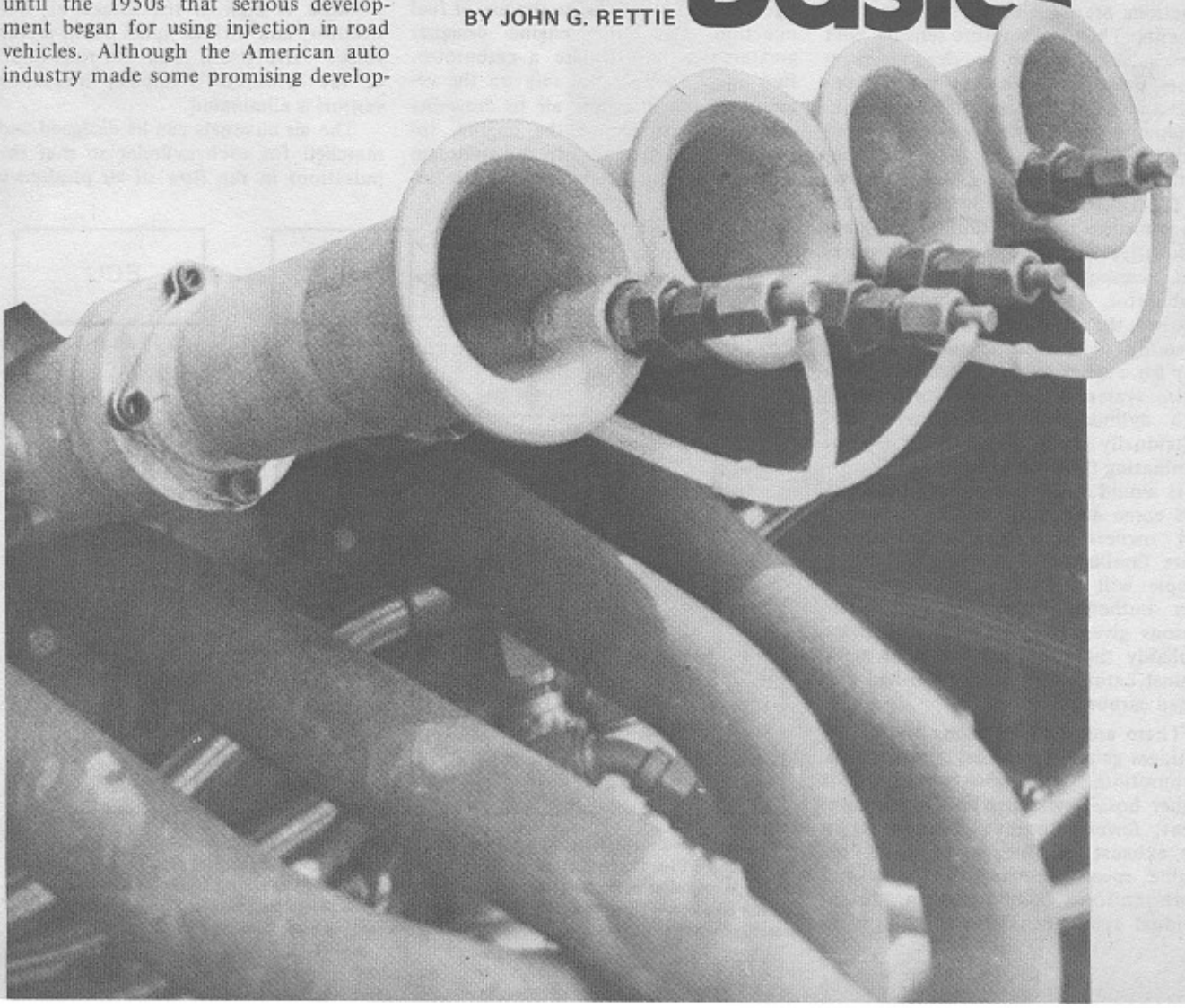
Fuel Injection Basics

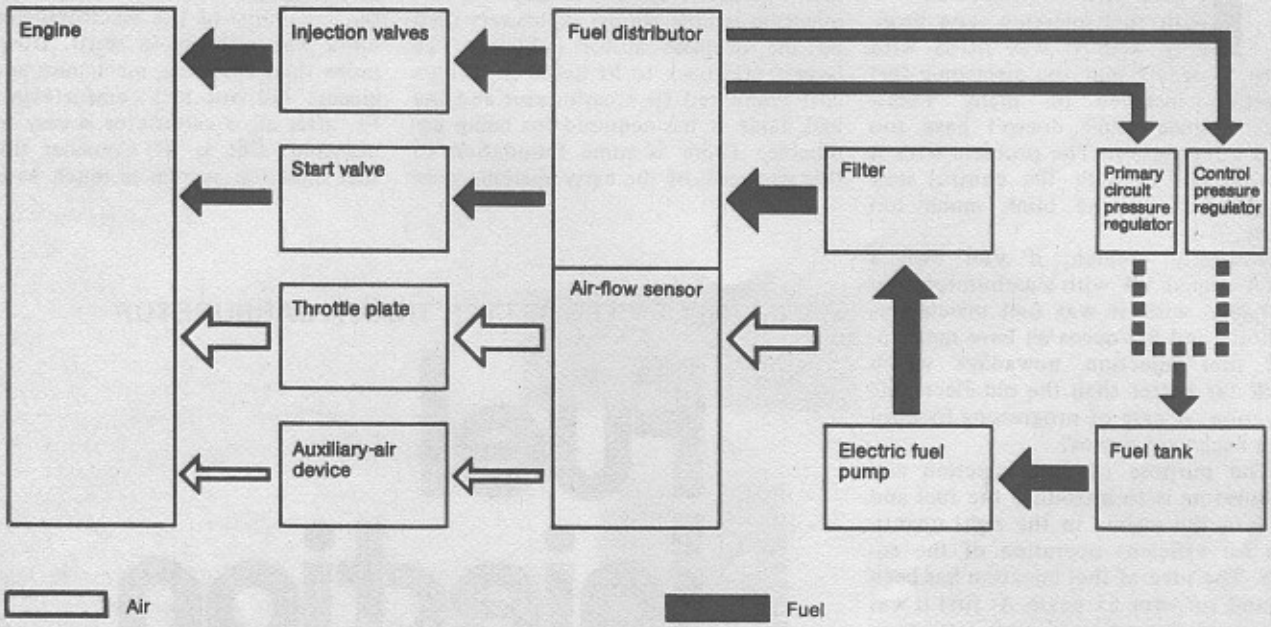
BY JOHN G. RETTIE

If you own an air-cooled VW with fuel injection, you probably wish it was fitted with carbs. It seems that the electronic fuel injection installed on many Volkswagens since 1967 doesn't have too good a reputation. The problem with it appears to be with the control unit which goes on the blink much too often.

Strangely enough, if you own a water-cooled VW with a carburetor, you probably wish it was fuel injected as Rabbits and Sciroccos all have mechanical fuel injection nowadays which work far better than the old electronic injection. A case of progressing forward with backward moves?

The purpose of fuel injection and carburetors is to introduce the fuel and air into the engine in the right quantities for efficient operation of the engine. The idea of fuel injection has been around for over 65 years. At first it was developed for use in aircraft engines in the 1930s and enabled planes to become much more reliable as well as allowing them to fly at far higher altitudes. Fuel injection was in use in race car engines at much the same time, but it was not until the 1950s that serious development began for using injection in road vehicles. Although the American auto industry made some promising developments in the late 50s and early 60s, fuel injection is now almost exclusively used by the overseas motor industry. The largest drawback to FI has been its high cost compared to a carburetor and the bad name it has acquired for being unreliable. There is some foundation to this as many of the early systems were more complicated than necessary, and the reliability of the electronic control units was not up to snuff. However, more than anything, mechanics and engineers did not feel comfortable with FI, after all, a carburetor is easy to understand. But is it? Consider this! A fuel injection system is much easier to





Block diagram showing the operating principles of the Bosch Continuous Injection System. The fuel distributor is mechanically controlled by the air-flow sensor; this metering unit is the nerve center of the system.

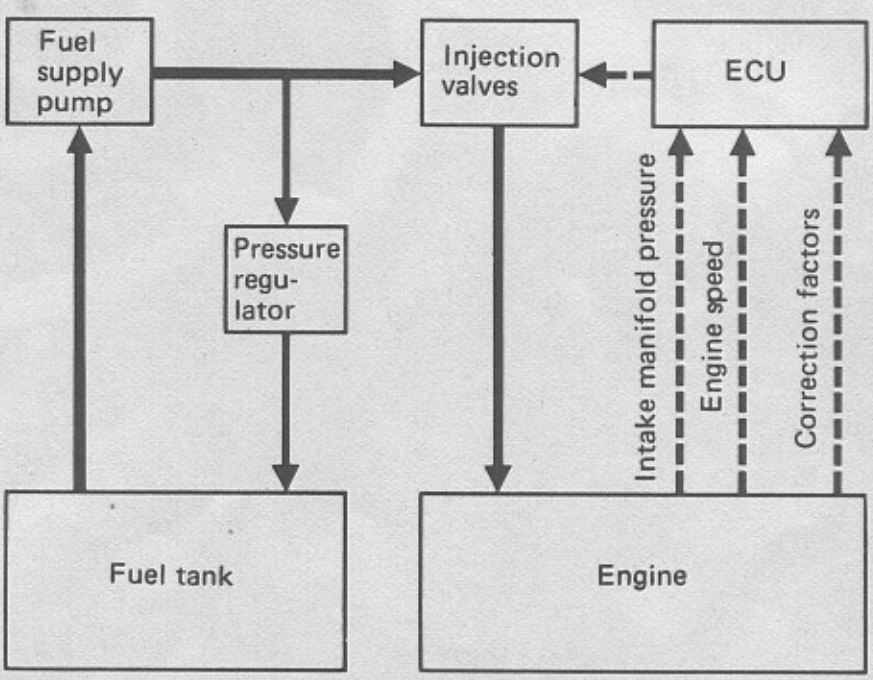
troubleshoot or repair because different functions are handled by separate components. Thus temperature sensors, cold start valves, injector nozzles, air regulators, pressure regulators, mixture controls and other devices can be tested individually and faulty parts replaced without disturbing the whole system.

On the other hand, a carburetor has all functions confined in one unit that has countless minute drillings, air bleeds and orifices controlled by jets and valves that cannot be tested separately. Carburetor troubleshooting usually requires the removal, cleaning and reassembly of the whole unit. Also, it's easy for a speck of dirt to knock out the entire system in a carburetor whereas each cylinder is supplied with fuel individually in a FI system, all but eliminating the problem of dirt.

It would seem that as more and more cars come equipped with fuel injection and owners and mechanics become more familiar with the way it works, people will begin to wonder why we ever bothered with carburetors. The reasons given against fuel injection are probably the same that would be made against carburetors if injection had preceded carburetors!

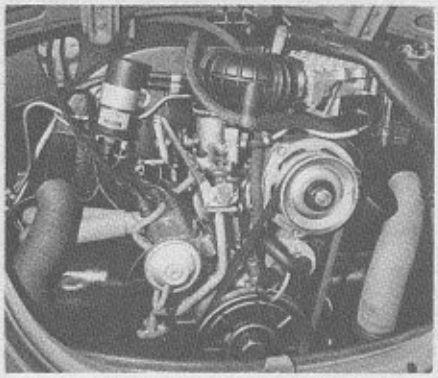
There are several reasons for the advantages gained from fuel injection over carburetion. The most important is higher horsepower per unit of displacement, fewer unburned components in the exhaust gas, higher torque at low engine speeds, greater flexibility and more uniform combustion in the individual cylinders. These advantages do not rise only from the fact the fuel is injected, but also because the use of fuel injection gives the engine designer greater freedom. Unlike a carburetor, fuel injection does not rely on the velocity of the incoming air to draw the fuel air mixture into the engine. Instead, fuel is injected into the airstream under pressure. Therefore the air intake channels can be designed so that air pressure is high in the intake air distributor, and airflow most rapid at the intake valve itself. Also the restriction of the carburetor's velocity increasing venturi is eliminated.

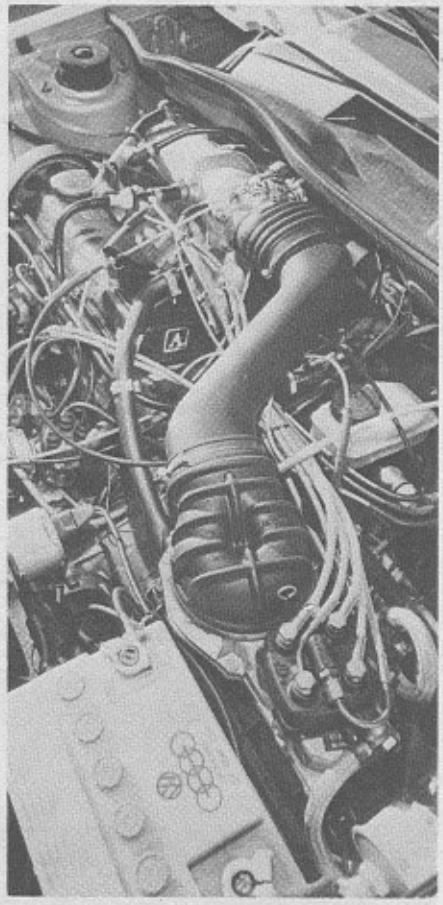
The air channels can be designed and matched for each cylinder so that the pulsations in the flow of air produce a



Block diagram showing the operating principles of the electronically controlled Bosch EFI-D and EFI-L fuel injection systems. In the EFI-L system, the intake manifold pressure sensor is replaced by an air-flow sensor. The correction factors are information received by the electronic control unit (ECU) about conditions in the environment, such as air temperature and humidity, and conditions in the engine, such as temperature.

BELOW LEFT, the electronically controlled fuel injection system installed in a Beetle does not leave much room for maintenance, whereas (BELOW RIGHT) the mechanically controlled Continuous Injection System as used in all water-cooled VWs fits in place beautifully. The fuel distributor and air-flow sensor is the unit at the bottom of the picture.





supercharging effect which results in improved volumetric efficiency. Additionally, various possibilities exist for matching the quantity of fuel injected to the many different operating conditions that the engine is subjected to.

Early fuel injection systems sprayed the fuel directly into the cylinders just as in the diesel engine. But, today, most FI systems spray the fuel into the intake manifold or intake port.

In gasoline engines the air-fuel mixture is compressed to a ratio suitable for ignition and combustion, and is then ignited by an electric spark. Formation of the air-fuel mixture starts when the fuel is added to the air being drawn into the engine. The amount of this mixture is determined by the operating characteristics of the engine.

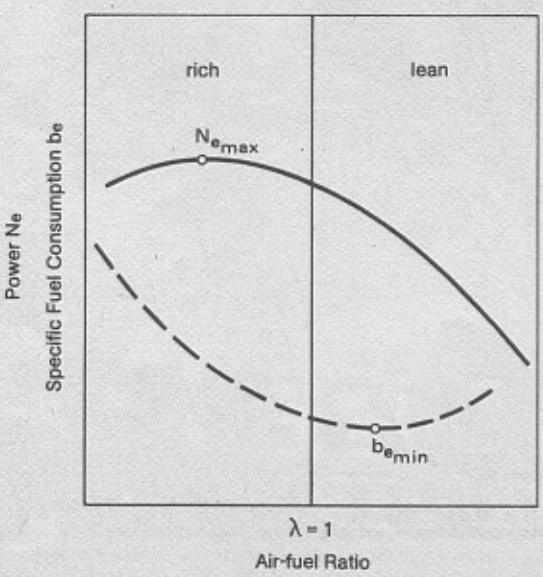
Perfect ignition and combustion of the air-fuel mixture can only take place within a certain range of air-fuel ratios. With gasoline, the average ratio for full combustion is 14:1, i.e. 14 lb. of air are required for complete combustion of 1 lb. of gasoline. Or put another way, 9800 gallons of air are required for complete combustion of 1 gallon of gasoline. With this air-fuel ratio the air factor is 1. This value, λ (Lambda) is determined as follows:

$$\lambda = \frac{\text{actual volume of air drawn into engine}}{\text{theoretical requirement of air}}$$

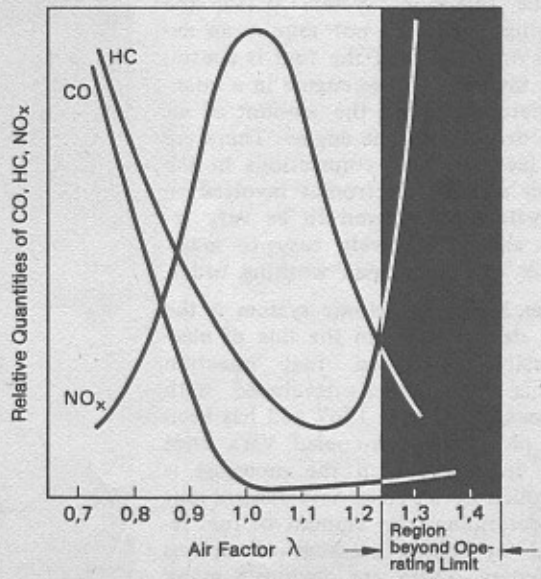
When the mixture is rich, i.e. a deficiency of air, λ is less than 1 and likewise if the mixture is lean, λ is greater than 1. Spark-ignition engines develop the greatest power at about 10% air deficiency ($\lambda = 0.9$) and consume the least fuel at about 10% air surplus ($\lambda = 1.1$). When there is an air deficiency the fuel is not utilized adequately and the concentration of unburned components in the gas is higher. With a surplus of air the power developed by the engine is lower and the temperatures of the engine and the exhaust gases are higher. The air factor of the engine must lie between 0.7 and 1.3, otherwise the engine will not operate.

The accompanying graphs show that the most important toxic components in the exhaust, namely carbon monoxide (CO), hydrocarbons (HC) and nitrous oxide (NOx) vary to a certain extent in opposite directions as the air factor changes. It is easy to see why modern engines tend to operate with an air factor of around 1.1 to 1.2. It is also easy to see how it is much easier to find a favorable compromise, with regard to the factors mentioned, when a fuel injection system is used instead of a carburetor.

Graph shows how the fuel consumption and power vary according to the air-fuel ratio.



Graph shows the influence of the air-fuel ratio on the exhaust gas emission from an engine at full load.



Simply put, a fuel injection system consists of a fuel pump that pumps fuel under pressure from the fuel tank to a metering unit that distributes the fuel to the injection nozzles on each cylinder in the correct amount. Excess fuel is released through a pressure relief valve back to the fuel tank. For cold starting, an additional cold start injector is located in the intake manifold that sprays additional fuel, acting rather like a choke on a carburetor. Obviously there are many more components in the system required to keep it running efficiently and reliably through different conditions.

The metering unit of a fuel injection system is the most important component. There are basically three different ways of metering the fuel, two by mechanical means and one electronically. The Robert Bosch Company of Germany has probably done more development work on fuel injection than any other company in the world, and they supply more systems for mass-produced cars than anybody else, including the entire range of modern VWs. In the October issue of DB& HVWs we took an indepth look at the mechanically operated Bosch fuel injection system as used on race cars. This system is similar to the Lucas race system that is used in so many of the top race cars around the world including nearly all Formula One cars. The mechanically operated metering unit is powered by the engine, either by direct drive or by a belt driven from the engine. Obviously a race fuel injection system is different from one used on a passenger car due to the different requirements.

In the mechanically operated Bosch K-Jetronic system, also called the Continuous Injection System (CIS), the metering unit does not require an external drive. Instead the fuel is continuosly metered to the engine in a quantity determined by the amount of air being drawn into the engine. There are very few electrical connections in the system and no electronics involved so the system has proven to be very reliable and is relatively easy to maintain in good efficient working order.

The Bosch L-Jetronic system is the latest development in the line of electronically controlled fuel injection systems that Bosch developed with Volkswagen back in 1967 and has been used on various air-cooled VWs since then. In this system the metering is controlled by an electronic control unit that determines the amount of fuel required by taking readings of various parameters. There are obviously many electrical and electronic components in the system which of course means there is much more to go wrong. However, as the state of the art in electronics progresses, we can expect to see more and more electronic fuel injection systems.

There are two versions of the electronic system, one the EFI-D which is controlled primarily by the intake manifold pressure and the engine speed, and the EFI-L which is controlled by the amount of air being drawn into the engine. The EFI-L is the latest and is really an electronic version of the mechanical K-Jetronic. In both of these systems, the fuel is injected in a uniform quantity but in pulses of varying duration fed by the solenoid operated injectors which are controlled by a computer.

In the next two issues we will look at both the mechanical and the electronic fuel injection systems in detail as they are applied to the air-cooled and water-cooled range of VWs.

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BELOW, the Rabbit and the Scirocco proudly display the fact they are fuel injected as the mechanically controlled system works so much better than a carburetor providing more power, lower fuel consumption and less emissions.