D-Jetronic History and Fundamentals

History

The D-Jetronic system developed by Bosch in the early 1960's was the first mass-production electronic fuel injection system. It was primarily based on patents that Bosch licensed from the Bendix corporation. Bendix developed the basic idea of using an inductive element coupled to manifold vacuum as a component in a loop circuit ("multivibrator") to develop the basic injection pulse width. The system was first used on the 1967 VW Type 3 motors. Bosch continued development of the system, and it was last used in the D-Jetronic form in about 1976. Variants of D-Jetronic were used by other manufacturers (Ford, Toyota, etc.) for many years, and various forms of "speed-density" injection systems similar to D-Jetronic are still in use today. Bosch developed many more types of electronic fuel injection after D-Jetronic (L-Jetronic, K-Jetronic, etc.) that had improved characteristics, and still is a dominant force in fuel injection systems today.

D-Jetronic References

Two papers were published in the Bosch Technical Journal that gave overall descriptions of the D-Jetronic system, components, and operation. I have recently secured these documents from the Bosch archivist and there are links below to the PDF files. Both articles are in German. I have done a rough translation of the Scholl article that is in text file format. The system as described in the Scholl article is very similar to the implementation of D-Jetronic on the Porsche 914 1.7 and 2.0L motors.

"An Electronic Fuel Injection System for Automobiles", Von Gunther Baumann, Bosch Technical Journal, 1967.

"Electronic Fuel Injection - Jetronic", Von Hermann Scholl, Bosch Technical Journal, 1969 (part 1)
"Electronic Fuel Injection - Jetronic", Von Hermann Scholl, Bosch Technical Journal, 1969 (part 2)
English Translation

D-Jetronic Patents

Thanks to Dirk Wright, 914 owner and USPTO employee, I have a good list of fundamental D-Jetronic related patents, and I've found quite a few using those as a starting point. Here are links to the patents at the USPTO web site, along with a short description of the gist of each patent. NOTE - you may have to load the TIFF file applet to be able to view and print the patents, click on any of the patents below and follow the "Help" link for more information. If anyone can dig up patents on other D-Jetronic components, please let me know and I'll include the numbers here.

...for each URL below, click on the "Images" button at the top of the page to see the patent....

- 2,948,272 - 9/2/1960: Bendix FI system patent that D-Jetronic is based on.
- 2,992,640 - 7/18/1961: Early Bosch EFI patent. Note the use of the loop circuit and inductive pressure sensor.
- 3,005,447 - 10/24/1961: Much more evolved Bosch EFI patent by Gunther Baumann. Note dual-coil pressure sensor, speed correction, loop circuit, etc., very much like D-Jetronic.
- 3,338,221 - 9/29/1967: Fundamental D-Jetronic patent by Hermann Scholl of Bosch. Similar to the Baumann patent, but with full ECU for mixture control, temperature compensation, speed correction, starting enrichment, etc.

- 3,463,130 - 9/26/1969: D-Jetronic with over-run shut-off circuit from Bosch.
- 3,464,396 - 9/2/1969: D-Jetronic variant with a differential MPS
- 3,483,851 - 12/16/1969: Another D-Jetronic variant from Bosch.
- 3,521,606 - 7/28/1970: Overall structure of the ECU, with focus on the speed control circuit
- 3,570,460 - 3/16/1971: Improved over-run shut-off circuit. Used on the 1975-1976 Porsche 914 2.0L ECU (0 280 000 051)
- 3,583,374 - 6/8/1971: Full-load diaphragm version of the MPS
- 3,593,692 - 6/20/1971: TPS and ECU acceleration circuits
- 3,620,196 - 11/16/1971: Speed control circuit of the ECU
- 3,623,461 - 11/30/1971: Pulse multiplier circuit of the ECU? Speed control? (needs review)
- 3,678,904 - 7/25/1972: Injector driver circuit of the ECU
- 3,734,067 - 5/22/1973: Starting enrichment circuit of the ECU
- 3,747,575 - 7/24/1973 Load-dependent speed control circuit of the ECU (adaptation)

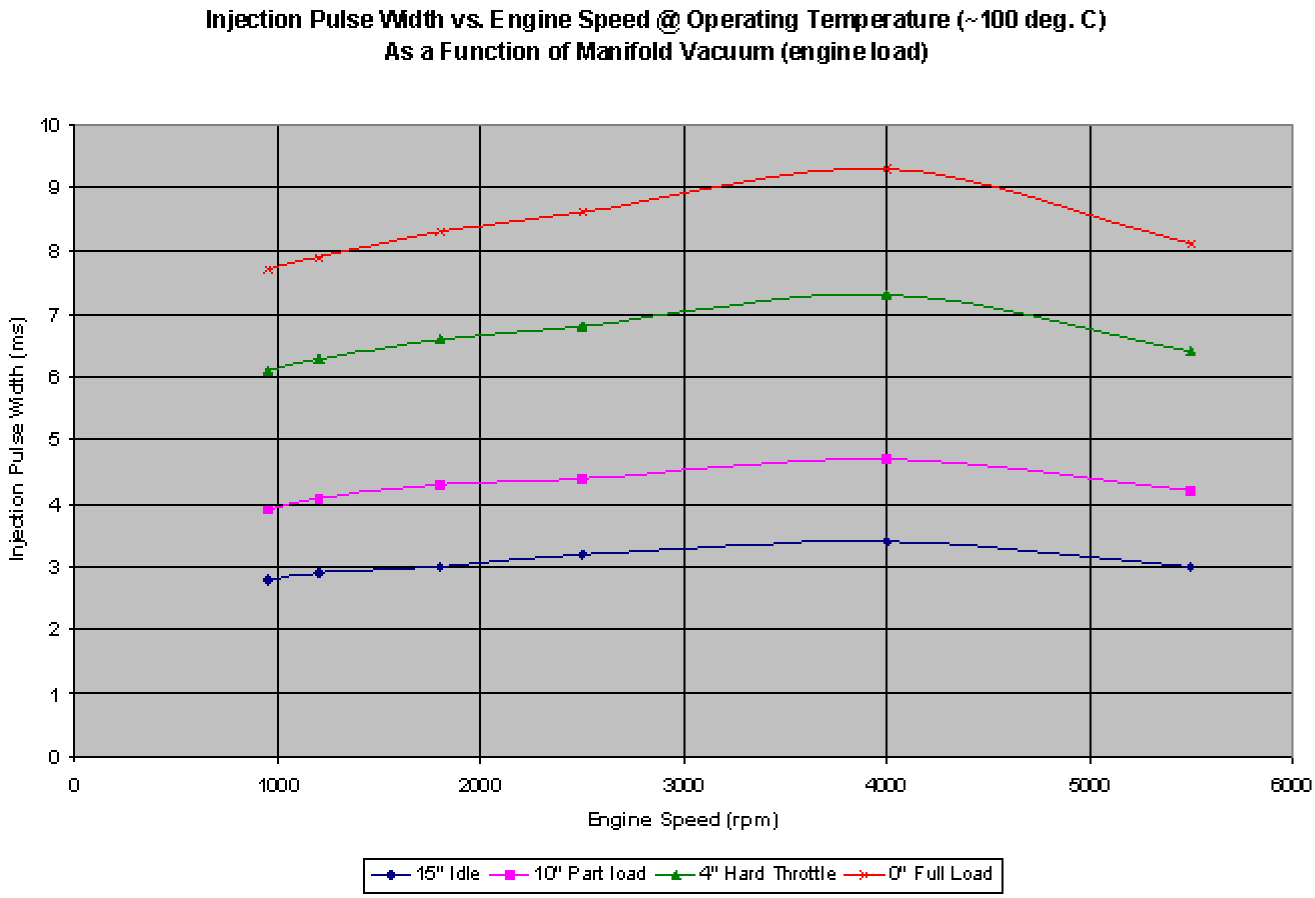
"Speed-Density" Fuel Injection

NOTE: The discussion here is limited to constant fuel pressure, multi-port, pulsed injection systems.

The primary function of any injection system is to control the mass air/fuel (A/F) ratio of a specific engine over all expected operating conditions. The desired A/F value for a specific operating condition depends on the optimization of fuel economy, performance, emissions, and other factors. The parameter that is to be controlled is the mass of fuel to be injected, so the problem is to determine the mass of the air in the cylinder. A "speed-density" system does this by measuring the **density** of air in the intake manifold (via a pressure or vacuum sensor), correcting for the pumping efficiency of the engine (which is a function of engine **speed**). The result gives the density of air in the cylinder. If the cylinder volume is known, then the mass of the air in the cylinder can be determined. Since the fuel pressure and flow rate of the injector is also known and constant, the exact pulse duration to deliver a fuel mass needed to produce the desired A/F value can be determined.

In the D-Jetronic system, the manifold pressure sensor senses the intake manifold vacuum, and engine speed is sensed by the trigger contact points in the base of the distributor. The contact trigger points also determine the timing of the injection pulses. D-Jetronic is a grouped injection system, where half of the injectors are in a group that are pulsed simultaneously. In four-cylinder implementations, there are two cylinders per group. There is one injection pulse per power cycle. With grouped injection, one cylinder gets the injection pulse right before the intake valve opens, the other cylinder gets the injection pulse about 180 degrees before the intake valve opens.

Below is a plot of data taken on a 2.0L Porsche 914 D-Jetronic system under simulated operating temperature, engine load, and engine speed conditions using an EFI Model 1401 Electronic Analyzer, a D-Jetronic tester:



The speed-density nature of the system is obvious from this plot. As engine load increases (decreasing manifold vacuum), the injection pulse width increases (the "density" part). At a constant load, injection pulse width varies with the pumping efficiency of the motor (the "speed" part).

The total pulse duration described above determines the "basic injection quantity", or Tb. Other factors must be accounted for to determine the actual injection pulse, Tinj. These factors include:

1. **Air Temperature:** The density of air is a function of temperature and the basic injection quantity must be corrected for the effect. In the D-Jetronic system, the TS1 sensor is a negative-temperature-coefficient resistor (resistance goes down as temperature goes up), mounted on the intake plenum. The ECU uses the value of the TS1 resistance to correct the injection quantity for the effect of temperature.
2. **Acceleration:** Due to the finite response time of the pressure sensor and the ECU, and the inertia of the air mass in the intake manifold, there is a delay between the opening of the throttle and the response of the system to the need for added fuel. To reduce this response time, a separate acceleration system is required for good engine response. D-Jetronic uses a set of contacts in the throttle position switch to provide both immediate injection pulses and a delayed acceleration enrichment effect when the throttle is opened.

3. **Idle:** For good transition when accelerating from a stop, and for smooth and stable idle while powering accessories (e.g. lights, cooling fan, a/c, etc.), control over the idle mixture is required. In D-Jetronic, an idle switch on the throttle position switch sends a signal to the ECU when the throttle is closed. A separate idle mixture control circuit in the ECU sets the idle mixture, which is adjustable via an external potentiometer.
4. **Cold Starting:** When the engine is cold, additional fuel is required for starting due to poor mixing and condensation. The ECU senses the cold start using data from the TS2 or cylinder head temperature sensor, and provides additional fuel when cranking. At very low temperatures (below 32 deg. F) , a separate thermo-switch and cold-start valve (CSV) in the intake manifold are activated. This injector sprays an extremely fine mist of fuel that mixes better with the cold air than the injector spray, and helps make cold starting easier. Some later D-Jetronic systems used a thermo-time switch which limited the duration the CSV would remain open, to prevent flooding and spark plug fouling.
5. **Warm-Up Transition:** When the engine is below its normal operating temperature, more fuel is needed to account for condensation and incomplete mixing until the engine is fully warmed up. The TS2 sensor is a negative-temperature-coefficient resistor (resistance goes down as temperature goes up), mounted on the cylinder head. The ECU has a warm-up enrichment circuit that senses the resistance of the TS2 sensor and corrects the mixture for the engine temperature.
6. **Over-Run:** When the throttle is closed while the car is moving and in gear, there is a high vacuum in the intake manifold while the engine is at a fairly high speed. For lower emissions, early D-Jet system shut off the fuel supply until the engine had dropped below some target speed (1300 rpm or so). Over time, this was found to increase HC emissions when the fuel supply was restarted, due to cooling of the cylinder walls, and the over-run circuit was deleted from the ECU. Surprisingly, later cars (1975-1976 2.0L) have ECU's where this circuit was restored, possibly to reduce unburned fuel from being passed through the exhaust to the catalytic converter, which can cause the temperature of the converter to rise to dangerous levels. On cars without the over-run circuit, an air bypass valve (deceleration valve) was incorporated that passes additional air past the throttle plate when closed, to provide better combustion during over-run.
7. **Full-Load:** When the engine is under full-load (wide open throttle) conditions, maximum power is desired and an enriched mixture is needed. Additionally, air cooled engines under full-load conditions need the additional fuel for a secondary concern, cooling. A full-load diaphragm is incorporated into the manifold pressure sensor to enrich the mixture under full-load conditions. This diaphragm is activated when the pressure differential between the intake manifold and the atmospheric pressure drops below 100 mTorr. The diaphragm moves more per unit pressure difference than the part-load aneroid cells, causing an abrupt increase in the injection duration.

For a detailed description of how the ECU operates and accommodates the various operation conditions, see my ECU web page. For a detailed description of how the manifold pressure sensor responds to part-load and full-load conditions, see my manifold pressure sensor web page.

D-Jet System Engineering - My Conjectures...

Bosch used D-Jetronic on many different applications. Here are a few conjectures of mine as to how they made the system manufacturable by using standard components and customization:

- **General** - Three components were customized for each engine application:

  1. ECU daughter card - engine speed correction and start enrichment
  2. MPS - Full load enrichment

3. Injector flow rate - matched to cylinder size and application

Each of these customizations and why I think they were done is discussed below...

- **ECU** - From my analysis of a number of ECU's, and from what I've read from Bosch on the subject, the main board of the ECU is essentially identical across most D-Jet applications with a few exceptions. Late ECU main boards incorporated the advanced fuel shut-off circuit described in the last patent listed above. By keeping the main boards the same, tooling and inventory costs were minimized. Customization of the ECU was accomplished with the daughter card. This card had the specific speed correction for the engine application, and any tweaking of the start enrichment.
- **Injectors** - Since D-Jetronic fuel pressure is the same for all applications, and the ECU main board circuit is essentially the same, and engine vacuum levels are roughly the same for all applications in the various operation modes (idle, part-load, full-load), then variations fuel needs as a function of the cylinder volume for each application can be accommodated by sizing the injector flow rate. This also means that the injector duty cycle would remain essentially the same for all applications, simplifying engineering of the injectors. Note that it doesn't directly scale by cylinder volume - for example the 1.7L injector flows 265 cc/min, and the 2.0L flows 380 cc/min. If the scaling from 1.7L to 2.0L was the only factor, then the 2.0L injector would flow about 312 cc/min, so there must be other factors at play here (cam? intake? compression?).
- **Intake Air Temperature Sensor**- Same part for all D-Jetronic applications.
- **Cylinder Head Temperature Sensor**- For all air cooled applications, essentially the same sensor resistance range across the board with some exceptions (see below). Same is true for water cooled, but to a different value, as water cooled and air cooled engines have different fuel needs during their warmup. There are different physical configurations for each application as necessary (e.g. longer/shorter pigtail, different mounting, design, etc.).
- **MPS**: From my measurements, most MPS's have the same part-load response, which makes sense. Some have a long "nose" and different coil spring for early onset of the movement of the full-load diaphragm - I assume this is a tuning selection. The main difference in MPS's is the setting of the full-load mixture, which varies by engine application. This parameter is easily settable when the MPS is essentially complete, allowing customization at the last step in the manufacturing process.
- **Throttle Switch**: With some variation over the years in the presence or absence of a full-throttle switch, essentially the same across all applications.
- **Special Cases**: I only have one specific case, the introduction of the 2.0L motor for the 914 in 1973. It's clear that this motor had a different speed correction curve than the 1.7L, but the motor was introduced using the 1.7L's ECU. My conjecture is that Bosch and/or VW-Porsche had not completed the development and design of the 2.0L ECU, so they had to go with the 1.7L's. Higher flow rate injectors were used to account for the basic mixture difference, but that still didn't handle the changes in the Ve curve. To accommodate, Bosch made a slight change in the MPS - they tweaked it to have a richer full-load response, and they changed the resistance characteristics of the head temperature sensor. First, they changed the set-point of the sensor at 20 C from 2.5 K ohms to 1.3 K ohms, and added a ballast (static) resistor of 270 ohms in series. This brought the cold engine (sitting overnight, ambient temp 20 C) resistance to 1.57 K ohms, considerably leaner than before - this was usually dealt with by running the idle mixture richer,but '73's were always a bit harder to get going when cold. When hot, however, the ballast resistance kept the hot resistance value considerably higher (richer) than would the standard sensor. The richer mixture produced good part-load and full-load response, even with the more choked-off Ve response of the 1.7L ECU. Note that Automobile Atlanta has sold a "hot European setup" for many years - a '73 MPS, temp sensor, and ballast resistor. Gives you a richer part-load mixture for more power - oh, and more emissions and higher fuel consumption, too.

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