Fuel Injection Fundamentals

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Let’s put the Fun back in Fundamentals!
Agenda – What you can expect

• Welcome & personal introduction
• Start with the basics: Not the why nor necessarily the how, primarily the what
• Fuel Injection Theory
• Brief Overview of Porsche Fuel Injection systems
• Along the way, we’ll look into the functions of the parts themselves
  – Injectors
  – Fuel pump
  – Pressure regulators/dampers
  – Oxygen sensor
  – Other fuel-related systems like evaporative emission controls and catalytic converters
• Model-specific questions & answers!
We’re NOT going to get into the chemistry or the thermodynamics, we’ll stick mainly to car parts and what they do.

But first …
Let’s start by looking at how SIMPLE fuel injection is

\[ V = P \times T \times A \]

**V** = Volume of fuel through the injector  
**P** = Fuel pressure behind the injector  
**T** = Time the injector is open  
**A** = Area of the injector orifice

- CIS (K-Jetronic)  
- MPI (D-Jetronic)  
- AFC (L-Jetronic)  
- DME (Motronic)
Fuel Fundamentals

Which inputs are most important?

- Engine speed & throttle position
- Engine speed & throttle position
- Engine speed & throttle position
- Engine speed, TDC & throttle position
- Engine speed, TDC & throttle position
- Engine speed, TDC & throttle position

What are the outputs?

- Metered fuel through a mechanical injector, pulsed flow
- Metered fuel through a mechanical injector, continuous flow
- Ground pulse to an electric injector
- Ground pulse to an electric injector
- Ground pulse to an electric injector
- Ground pulse to a high pressure electric injector

Note: All systems use an electric fuel pump!
Fuel Controller Inputs / Outputs

Here's an example from the 928S4

North American 928S4

European 928S4
Now here’s a blast from the past but the same basic idea, this time they’re focusing on the inputs to a mechanical rod.
Q: If the fundamentals are covered by engine speed and throttle position, why is Bosch adding other controls?
A: Because the engine doesn’t perform they way they want it to under certain conditions.
Mechanical Fuel Injection
MFI
Bosch Mechanical
Bosch Mechanical Fuel Injection
Bosch Mechanical Fuel Injection

Diagram showing the stages of fuel injection:
1. **FILLING**
   - Barrel
   - Fill Port
   - Plunger
   - Sleeve
   - Spill Port

2. **BEGIN INJECTION**
3. **CONTINUE INJECTION**
4. **END INJECTION**

Additional component details:
- Compenating Lever
- Barometric Cell
- Connecting Link
- Pivot
- Fuel Inlet
- Oil Return To Engine
- Oil Inlet
- Shut Off Solenoid
- Roller Tappet
- Camshaft
- Pump Drive Wheel

Post 1970 MFI Injection Pump
NEW refurbished Bosch MFI Pump Porsche 911 2,4S - Mechanical Fuel Injection

www.eisenbrandt.eu - Made in Germany, with warranty!

$6,700.00
Buy It Now

🔥 13 watching

Up for sale is a Bosch MFI Pump Porsche 911 2,4S. This MFI Pump is in new condition. Made in Germany, with warranty! The pump meets in all respects the manufacturer’s specification.
Continuous Injection System
CIS
Bosch K-Jetronic
CIS Injector Type

Fig. 11: Bosch CIS Injector
Bosch CIS (K-Jetronic)
Bosch CIS (K–Jetronic)
Bosch CIS (K-Jetronic)
Bosch CIS (K-Jetronic)
Bosch CIS (K–Jetronic)

Rube would be proud.
A first-generation electro-magnetic fuel injector is used to add additional fuel for start-up. This proved problematic for some 911 air boxes as fuel would pool at the bottom of the intake plenum.
Bosch CIS (K-Jetronic)
Bosch CIS (K-Jetronic)

We’re introduced to a combination of simple sensors that use resistors and bi-metallic strips to sense temperature and activate cold starting and cold running cycles.

1: contacts
2: heater coil wrapped around bi-metallic strip
G: heater wire to (smaller) G terminal and ignition switch circuit
W: contact wire to (larger) W terminal and CSV circuit

<35 °C closed
>35 °C open
Bi-metal strips can open and close contacts, and can even be leveraged to perform work, as in the aux. air valve and warmup regulator.
Let’s recognize other fuel-related components

Auxiliary Air Injection (even Thermo Reactors!)
Catalytic Converters
Oxygen Sensors (non-heated, heated, pre- and post-catalyst)
Fuel Vapor Recovery including the Charcoal Canister & Expansion Tanks
Crankcase ventilation, including air/oil separators
Time Out!

Let’s recognize other fuel-related components:

Auxiliary Air Injection with Thermo Reactors
Think About It

“Blind” fuel injection systems vs. “Smart(er)” fuel injection systems:
Q: What’s the difference?
A: Some level of feedback.
Bosch CIS with Lambda Control

Vacuum line and emission control component layout of 1980 through 1983 models

A  Fuel lines
B  Vacuum lines
1  Throttle housing
2  Mixture control unit
3  Fuel injector
4  (Warm-up) control pressure regulator
5  Cold start valve
6  Auxiliary air valve
7  Auxiliary air regulator
8  Frequency valve
9  Distributor
10 Fuel pump
11 Fuel reservoir
12 Fuel filter
13 Deceleration valve
14 Vacuum booster
15 Cruise control servo

“Lambda Control”
Catalytic Converters Introduced

Oxygen sensors are used not only to keep the engine running properly, they also help prevent the catalyst from overheating by limiting hydrocarbons.
The oxygen sensor serves multiple functions today, targeting the best running condition of the engine, and evaluating the health of the catalyst.
Fundamental Challenges with K-Jetronic

As good as the fuel distributor/fuel injector setup was, there tended to be differences in fuel delivery to each cylinder.
Bosch CIS (K-Jetronic)

- to top of control pressure regulator
- to lid of oil filler
- to evaporative emissions control valve
- to distributor vacuum retard
- to control pressure regulator (side)
- to vacuum control; tees to blowoff switching valve
- to vacuum source on intake plenum
- to throttle bypass circuit (incl auxiliary air regulator)

- electrical plug for fuel consumption meter (MY82)

Air Distribution Housing Hose Connections (K-Jetronic)
Time Out!

Let’s focus on a component: Fuel Pump

Q: What cools the pump?
A: Gasoline!

Porsche 911 Turbo S 01-05 Fuel Pump In Tank
And you want the fuel pump to run?
I’m going to completely baffle them by disconnecting this vacuum line right here ...
Manifold Pressure Injection
MPI
Bosch D-Jetronic
Fundamentally different than CIS and much closer to our current generation fuel systems:

- Uses a microprocessor control unit to activate the injectors
- Solenoid-style electric injectors
- Utilizes a throttle switch with multiple internal contacts
- The big news is that it determines engine load by means of a vacuum sensing unit.
Bosch MPI (D-Jetronic)

Rube hasn’t left the building yet.

**NOTES for Fig. 10: Typical 4-Cyl. Bosch D-Jetronic Fuel Injection Wiring Diagram**

1. ECU Connector
2. MPC Sensor
3. Cylinder Head Temp. Sensor
4. Intake Manifold Temp. Sensor
5. Injector
6. Throttling Switch
7. Cold Start Valve
8. Distributor/Trigger Contacts
9. Engine Speed Relay (1972 models)
10. EGR Switch Unit (Some models)
11. Throttle Valve Switch
12. Vacuum Advance Disconnection 2-Way Valve
13. EGR Valve
14. Air Valve for Auxiliary Air Supply (1972 models)
15. From Starter Terminal No. 50
16. EGR Thermoswitch
17. A/T Oil Pressure Switch (1972 models)
18. Fuel Pump
19. Auxiliary Air Valve (If Equipped)
20. To Fuse Box Terminal No. 30
21. Fuel Pump Relay
22. To Battery
23. Main Relay
24. To Ignition Switch Terminal No. 15 or Ignition Coil Terminal No. 15
The system will determine engine speed AND trigger the injectors by means of mechanical contacts in the distributor in a compartment below the ignition points.
Star of the show is the electro-magnetic fuel injector, a solenoid that opens and shuts fully when activated.
Bosch MPI (D-Jetronic)

A rather simple layout, introduced on the 914
The typical Bosch cylinder head sensor is a variable resistor that lowers its resistance value as the temperature goes up. They’re called Negative Temperature Coefficient resistors (NTC).

Bosch MPI (D-Jetronic)

The throttle switch provided idle and part-throttle information to the electronic control unit.
The manifold pressure sensor sensed absolute pressure by means of a single vacuum line to the intake manifold.
This was Bosch’s initial attempt at a modern fuel system controller. They even supplied a shop tester to dealers.
Let’s focus on a component: Electric Fuel Injectors

The duty cycle is always determined by the electronic control unit.
Time Out!

Let’s focus on a component: Electric Fuel Injectors

Q: What’s the difference between each of these aftermarket applications?
A: The flow rate.
Air Flow Control
AFC
Bosch L-Jetronic
Air Flow Control (L-Jetronic)
Air Flow Control (L-Jetronic)

The fundamental change from D- to L-Jetronic is the way engine load is measured.
Air Flow Control (L–Jetronic)

As the air flap moves, a sweeper arm draws across a carbon track with increasing resistance value. This value is understood by the control unit to be the amount of air being pulled into the intake.

A factory-preset steel spring can be seen at the bottom of the assembly.
We’ll find that the L-Jetronic airflow meter will carry over to the DME System.
Digital Motor Electronic
DME
Bosch Motronic
Bosch DME (Motronic)
Bosch DME (Motronic)
Bosch DME (Motronic)
The DME control unit is going to use magnetic sensors to determine engine speed, relationship to Top Dead Center (TDC), and in later versions a cam sensor to determine which cylinder is firing. All injectors activate at the same time.
As usual, there are model-by-model differences. On the 3.2 liter Carrera there will be a separate idle and full throttle switch. On the 944 the two switches will be integrated into the same housing.
Bosch DME (Motronic)

- Idle speed regulation is also introduced with DME
DME continued to evolve by adding electronic control inputs like engine oil temperature in addition to coolant temperature.
Q: What are two motivating factors for fuel injection engineers to make changes to a functional system?
A: Legislation & Cost Reduction.
Hot Wire (Air Mass Sensor)
Bosch LH-Jetronic
While fundamentally the same as L-Jetronic, LH-Jetronic successfully introduced the idea of measuring air mass instead of air flow.
Bosch LH-Jetronic

The air mass sensor uses a voltage usage theory to determine how much air is flowing across a wire that is kept at constant temperature; this compensates for intake air temperature and altitude. The wire must be maintained (cleaned) by burning off impurities picked up from the atmosphere after each drive cycle.
LH technology was introduced on the 928S4 as a standalone fueling system. Ignition was handled by EZF/EZK Ignition Control.
Let’s focus on a largely passive, often misunderstood system, fuel vapor recovery.
Time Out!

Fuel vapor recovery
Gasoline Direct Injection
GDI
Bosch Motronic
The injectors themselves require higher pressures and a modified injector profile fitted to the center of the combustion chamber.
Gasoline Direct Injection (GDI Motronic)

Injectors

The central position of the 7-hole injector in the cylinder head promotes a homogeneous, symmetrical fuel distribution in the cylinder.

Voltage boosters with flexible drivers are installed in the DME control unit for activation of the injectors.

1. Electrical connection
2. O-ring (high-pressure side)
3. Holding-down device
4. Recess seal
5. Spacer ring
6. Circlip
7. Teflon sealing ring (to combustion chamber)
8. 7-hole injector
9. Central injector position

997.2
Injector orientation and spray pattern can be optimized for best atomization, resulting in both power and efficiency.
So what could possibly be next?

Now in development: water injection
So, what should I take away from all this?
Two Final Takeaways

1. Fuel Injection is fundamentally simple.

   Fuel injection volume = Fuel pressure x Fuel timing x Fuel Injector Size

2. Don’t believe everything you read.
Thanks for your attention!

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