DEKA VII Multipoint Fuel Injector Application Study

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Abstract: Injectors must be capable of metering and delivering the fuel in the form of an optimized spray into the engine. That is to meet increasing requirements of emission related legislations and better engine running conditions. Every engine has unique requirements, technical background, parameters, etc. In order to determine the optimized injector characteristics, communications and joint efforts are necessary between the customer system engineering and the DEKA VII injector application. The study will provide general technical guidance

1. Product Description

1.1 General Description

The purpose of a fuel injector is to deliver metered and predictable, controlled quantities of atomized fuel to the intake system of a gasoline engine. To accomplish this, current flows through the coil to create a magnetic force. This magnetic force pulls the armature into an open position (overcoming fuel pressure, spring load and friction). This allows fuel to flow through the injector and out of the orifice disc holes. When the current input stops, the magnetic field decays and the armature moves back to the closed position by the combination of spring force and fuel pressure. An injector is basically an on and off valve: An injector is either open or closed. It is a normally closed valve. The coil controls the condition of that valve. The injector is open when current flows through the coil; the injector is closed when current does not flow through the coil. The size of the orifice at the tip (bottom) of the injector determines how much fuel flows out while the injector is open. In reality, the injector takes time to open and it takes time to close. These opening and closing times add an element of variability to the on and off nature of the injection valve. Shown as figure 1

![Figure 1](https://example.com/figure1.png)

**Figure 1.** DEKA VII profile & Fuel Path
1.2. Injector Flow Characteristics

As explained above, an injector is basically an on and off valve. Once the injector opening and closing times have stabilized, the fuel flow (dynamic flow) is a linear function of the injection duration (\(T_i\)). The dynamic flow is measured in grams per injection pulse at that injection duration. The graph below shows that relationship between dynamic flow and injection durations. The slope of the line (as shown on the graph next page) is called the static flow. It is measured in grams per second. It is primarily a function of the flow restrictions located inside of the injector, and of the pressure of the fuel to be injected.

- The size of the orifice installed at the tip of the injector is the main factor defining that static flow.
- Other internal flow restrictions can weaken the relationship between the size of the orifice and the static flow. Such restrictions are to be avoided if at all possible.
  - The static flow is proportional to the square root of the fuel pressure.
  - The static flow is also affected by parameters influencing the density and viscosity of the fuel, such as its nature, and temperature.

Finally, the injector characteristics (and the resulting fuel flows) are affected by the design of the electronic injector driver. Different injector driver designs will result in slightly different dynamic flow performance. Injector drivers should not affect the injector slope. As shown on the graphs next page, three injection duration ranges divide the scale\(^{(1)}\):

- Between the start of the injection pulse and the start of needle motion, the injector does not have time to open. No fuel flows out of the injector.
- The second range, called the ballistic range, is the range during which the injector does not have time to fully open before the injector pulse is shut-off. The dynamic flow increases very quickly with the injection duration, but does so in a non-linear and often unpredictable way.
- The third range, called the linear range, is the useful range. Opening and closing times for the injector have stabilized, and the flow is linear with injection duration. This is the only range where injector to injector distribution (flow differences between injectors for the same injection duration) can be closely controlled.
- There is a fourth range, not shown here, which is that where the period between injections (on the same injector) becomes so short that it interferes with the injector's closing time (the injector does not have time to close before it is re-energized). This results in non-linearity and will be discussed under the LFR section of this report.
- In production, the injector is calibrated at a chosen set point, at a pulse width usually located well within the "linear range", generally at 2.5 milliseconds of duration\(^{[2]}\).

![Flow graph](image1)

![Driver Pulse](image2)

Opening times are usually between 1.2 milliseconds and 1.8 milliseconds.
Closing times are usually between 0.75 milliseconds and 1.15 milliseconds.

1.3 Components
An injector's most critical components are:

- The coil, which energizes on or off the moving parts of the injector to control their motion. The coil is energized through the electrical connector.
- The armature and needle assembly, made of the armature, which is the upper part of the assembly and is attracted up by the magnetic forces generated in the coil, and of the needle, which seats on the injector seat, and controls the flow of fuel out of the injector. The needle is guided in its up and down motion by the seat guide at the bottom, and by the eyelet at the top.
- The spring, which pushes down on the top of the armature, and forces the armature needle assembly closed until the magnetic force generated in the coil overcomes the spring force and pulls the injector open. The spring force is responsible for the injector delay to open and for the injector's closing time. It also aids in controlling fuel leakage in the close injector position.
- The adjusting tube, located on top of the spring, inside the inlet connector tube, which is moved during the calibration process to set and lock the spring force at the value required for the specific dynamic calibration (dynamic flow) of the specific injector.
- The lower screen, which is a fine mesh filter sitting on top of the lower guide. The lower screen prevents any contamination particle from interfering with the needle motion, and creating a fuel leak or a major injector failure.
- The orifice disk[^1], which is a thin disk into which the spray holes (or hole) are punched. The geometry of the disk defines the injector's static flow.

2. Injector Targeting
   a. Aim

   A primary objective of a port fuel injector is to deliver fuel to the intake valves at the proper time with the proper quantity. For this reason, the injector is located in a manner to enable directing the fuel toward the inlet valve(s). Therefore, the first aspect of spray targeting is to understand the manifold geometry and determine the best possible spray to avoid the wetting of surfaces that will be cold and build wall film. Based on the manifold configuration, the number of inlet valves, the injector location, distance from the inlet valve and other concerns a type of spray will be chosen to most aptly target the fuel toward the valve.

   b. Geometrical Pattern

   The pattern of a spray can be described by the geometry of the fuel streams exiting the injector. The standard terms used by the industry include:
   - pencil spray: a narrow, well defined stream useful in applications with the injector tip a long distance from the inlet valve
   - cone spray: a conical spray of fuel that may be further defined as hollow or solid and has been the standard pattern in the industry for many years
- bent stream: introduced by Siemens to aim a cone spray pattern off the center axis of the injector
- split stream: introduced for 4 valve engine applications where two cones are individually targeted to the two inlet valves
- bent/split stream: a combination of the split stream that also provides an off axis dimension allowing the targeting of two inlet valves with packaging flexibility

Figure 5. Spray profile

The Pencil Stream spray pattern has a narrow conical shape with a cone angle. This spray pattern gives excellent targeting and penetration, and is used for applications where the injector is a long distance from the intake valve. It does not, however, provide a good atomization because the spray is too concentrated.

Cone Spray injectors have a wider conical shape with cone angles from 10° to 30. The spray cone angle is defined as the included angle where 95% of the fuel is contained. This spray pattern is used for applications where the injector can be positioned close to the valve. The injector has improved atomization as compared to the pencil stream injector.

Figure 6. Pencil & Cone & Split Stream

A Split Stream is used for engines having two intake valves per cylinder. The split angle is generally between 15° and 30. Atomization is better than a pencil stream, but not as good as a cone spray.

Another spray pattern configuration is the Bent Stream or Bent/Split Stream. These configurations are used for applications where it is not possible to position the centerline of the injector in line with the intake valve. The bend angle is generally between 5 and 25°.

Figure 7. Bent Stream

Variations on these patterns are being introduced as the applications are designed. However, all of
these can be described geometrically by referencing the included angle of the individual streams and the angle of the stream relative to the center axis of the injector.

The area of largest variation in pattern description is in the included angle of an individual stream. A cone spray is always documented by the included angle of the spray, however, the angle may be defined by several techniques. A hollow cone may state the included angle at which the maximum density of fuel is distributed. Either a solid or a hollow cone may state the included angle at which all fuel is contained or at which a given percentage of the fuel is contained. Any of the techniques is valid, however, the technique must be known to adequately determine the targeting of a spray for an application [4]. Furthermore, only one descriptive angle is not enough to adequately determine the proper targeting, only a starting point. Most all data acquisition of spray parameters is accomplished in ambient atmospheric conditions. Addition of manifold vacuum, temperature, proximity of manifold walls, etc. can significantly alter the geometric pattern of the spray. The geometrical description of a spray is the most useful information in determining the ideal targeting of an application. In addition, the pattern is the most often used parameter to measure compliance to a specification. Typically, compliance is judged in terms of percentage of fuel in defined location.

3. Conclusion

The best way to define the injector spray pattern is to visualize the fuel spray geometry with a CAD system, using the customer’s intake manifold geometry as the base. Customers send a CAD drawing with the manifold, intake port, and fuel rail geometry; from this, the design engineers develop an initial spray pattern. The CAD drawing and the spray model are used to visualize the spray pattern inside the manifold and the port. With a series of cross sections it is possible to identify wall-wetting issues. This information is used to confirm or to correct the initial spray pattern. The targeting study can also give the customers information required to improve the engine layout [5].

Targeting and atomization are influenced by a number of engine and injector characteristics. In order to select an optimized injector spray pattern for their engine, customers should take into account targeting considerations while designing an intake system. The laboratory performance of an injector as well as installation differences in the application can impact overall performance. Accuracy in injector mounting (and/or the fuel rail design) can impact the final targeting performance, with the resulting impact on engine emissions and performance [6].

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