DEKA VII Multipoint Fuel Injector Characteristics Study

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Abstract: A saturated injector driver is a power transistor driver circuit that turns fully on, and electrically saturates for the entire duration of the injector pulse width. This type of driver is better used with injectors having high resistance coils (12–16 Ohm). The advantage of this type of injector driver is that electrically generated heat is dissipated through the injector and not through the power transistor of the driver circuit. The circuitry is simplified compared to a peak-and-hold type driver (which requires heat sinks to dissipate the electrical load).

1. Introduction

1.1 Minimum Operating Voltages (MOV)

1) SMOV (Static Minimum Operating Voltage)

SMOV is the minimum voltage, measured across the injector coil, at which the injector actually opens (as detected by an accelerometer or by sensing device capable of detecting the initiation of fluid flow). It is a measure of the injector capability to operate under low voltage conditions. It is measured in Volts. Fuel pressure is applied during the test.

2) DMOV (Dynamic Minimum Operating Voltage)

DMOV is the minimum voltage supplied to the injector driver, at which the injector flow exceeds 50% of nominal dynamic flow. It is a measure of the fuel injection system’s response to low voltage conditions. It is measured in Volts. It is typically performed at a pulse width of 10 milliseconds. The driver circuit has a significant effect on the injector response characteristics; therefore, the actual driver circuit used in the vehicle must be used for this measurement.

1.2 Injector Flow Sizing

If the maximum fuel flow required by the engine is known, the static flow is simply:

Max. flow (g/sec) * 1.15 (safety factor) / no. of cylinders. The safety factor is added to ensure that the injector is cycling (not fully open) and linear through its operating range. An alternative method can be used in preliminary investigations before the fuel requirements of the application are fully identified. The static flow is calculated by three different theoretical methods:

- The Thermal Energy Calculation model,
- The Airflow Equilibrium Calculation model
- The Specific Fuel Consumption Calculation

The estimate of static flow is obtained by averaging the three results obtained.
1.3 Determining Dynamic Flow Calibration

For this calibration point two values are needed:

\[ \text{MinimumInjectorFlow}(\frac{mg}{pulse}) = \frac{\text{MinimumEngineFuelFlow}(g/\text{sec})}{(\text{RPM} \times 120 \times \text{No.Cylinders})} \]

\[ \text{IdleInjectorFlow}(\frac{mg}{pulse}) = \frac{\text{IdleEngineFuelFlow}(g/\text{sec})}{(\text{RPM} \times 120 \times \text{No.Cylinders})} \]

The dynamic flow set-point is specified such that the minimum fuel flow is within the 5% linearity range. Additionally, the flow offset is calculated to verify that the LFR and MOV requirements can be met\[^1\]. Typical flow offsets are between 0.5 and 0.9 msec. From the dynamic flow set-point value, idle and minimum pulse widths can be calculated as follows: The coil, which energizes on or off, is the moving part of the injector to control their motion. The coil is energized through the electrical connector.

\[ P\text{Widle}(ms) = 2.5(ms) + \frac{Q\text{idle}(mg/pulse) - Q\text{dset}(mg/pulse)}{Qs(g/s)} \]

\[ P\text{Wmin}(ms) = 2.5(ms) + \frac{Qd\text{ min}(mg/pulse) - Q\text{dset}(mg/pulse)}{Qs(g/s)} \]

dynamic set-point pulse width of 2.5 ms is used for most DEKA injectors\[^2\].

2. Pulse-Width Limits

a. Minimum Pulse-Width (MPW)

Minimum pulse width is the shortest injection time at which linearly controllable fuel flow is achieved. It is related to minimum injector flow.

b. Tail-biting

Rich flow shift of injector occurs when pulse width becomes close to the pulse period. The phenomenon is caused when armature starts an opening stroke before the closing stroke is finished. To avoid this effect, the injector needs to have properly dimensioned static flow.

3. Linear and Working Flow Range

a) Linear Flow Range (LFR)

The LFR is a ratio based on the linearized flow curve of a single injector. It is used to compare the linear range between injectors of different design or manufacture. The LFR ratio is defined as the maximum linearized flow point LFR (max) divided by the minimum linearized flow point LFR (min) at their respective pulse widths where the measured flows deviate +/-5.0% from the theoretical, and not actual, linearized flow curve. i.e., \( \text{LFR} = \frac{\text{LFR (max)}}{\text{LFR (min)}} \). The higher LFR is better for low fueling controllability\[^3\].

b) Working Flow Range

WFR is a ratio based on the mean flow curve of a population (24 minimum) of injectors representative of a normal production distribution. This ratio provides a relative measure of production injector-to-injector variability: that is, the flow range where a population of injectors will be within a specified tolerance. The WFR ratio is defined as the maximum working flow point WFR (max) divided by the minimum working flow point WFR (min) where all injectors are within +/-5.0% of the mean theoretical, not actual, flow curve at three standard deviations\[^4\].

i.e. \( \text{WFR} = \frac{\text{WFR (max)}}{\text{WFR (min)}} \).
4. **Dynamic or Static Fuel Flow Specifications**

a) **Static Flow $Q_s$**

The static flow is the rate of fuel delivered (measured in grams/second) by an injector when energized in the fully open position. It is the maximum flow rate of the injector and is important to meet the maximum fuelling requirements of the engine. This flow is also used to calculate the dynamic flow at all points away from the set point pulse. The static flow rate of an injector is dependent upon the system pressure and restrictions in the injector. The main restrictions in the injector are the orifice area and seat area. The orifice area is controlled by the size and number of orifice holes; the seat area is controlled by the needle lift\(^5\).

b) **Dynamic Flow $Q_d$**

The fuel delivered per pulse when the injector is energized at a specified pulse width (measured in mg/pulse). The dynamic flow is typically tested at a pulse width of 2.5ms at a 10ms period\(^6\). That is because we can assume that the injector flow at 2.5ms pulse width is well within the linear range. The dynamic flow of an injector is dependent upon the system pressure and upon the opening and closing response times of the injector, as well as on the injector's static flow.

![Figure 1 linearized flow curve and flow range calculations](image)
5. Conclusion

The flow from an injector should be linear and directly proportional to pulse width over the full flow range of the injector. This is not the actual case, for significant deviation from linearity occurs at the extremities of the flow curve. In order to measure the deviation from linearity, a least squares regression analysis is performed on five intermediate flow points at 3, 4, 5, 6, and 7ms PW with a period of 10 ms/pulse. Qd and PW are, respectively, the dependent and independent variables. The resulting curve is referred to as the linearized flow curve. Deviation from linearity is then defined as the percent difference between the measured or actual flow (Qd) taken at a given pulse width divided by the calculated flow.

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