

Dosing Performance of Piezo Injectors and Sensorless Closed-Loop Controlled Solenoid Injectors for Gasoline Direct Injection

Sebastian Skiba and Joachim Melbert
Ruhr-University of Bochum

ABSTRACT

Advanced combustion strategies for direct injection gasoline engines require high performance fuel injectors. They must perform precise fuel metering, enhanced linear flow range and multi-pulse injection cycles in order to meet tight emission limits and low fuel consumption. Cold start is the most critical phase concerning emission levels. The performance of outwardly opening piezo-electric actuated fuel injectors is compared with conventional inwardly opening solenoid injectors. The investigation focuses on dosing performance, temperature influence and the impact of production tolerances. Besides full valve needle lift, both types of injectors are also analyzed in ballistic operating mode for minimum injection quantities. Compared to piezo injectors solenoid injectors show a much larger tolerance band at low fuel quantities. A new sensorless closed-loop control system results in substantial improvement of the dosing performance of solenoid injectors. Information about the valve needle motion is gathered from the electrical injector signals in the electronic control unit by utilizing the solenoid injector itself as a sensor. By this approach, standard cost effective solenoid injectors equal or even exceed the performance of piezo injectors.

CITATION: Skiba, S. and Melbert, J., "Dosing Performance of Piezo Injectors and Sensorless Closed-Loop Controlled Solenoid Injectors for Gasoline Direct Injection," *SAE Int. J. Engines* 5(2):2012, doi:10.4271/2012-01-0394.

INTRODUCTION

Direct fuel injection for gasoline engines is a key component to comply with future emission limits. Besides a significant reduction in fuel consumption and pollutant emissions, gasoline direct injection also leads to an optimization of engine performance and driving dynamics. Precise fuel metering is mandatory for optimal mixture formation and combustion quality. Recently, solenoid injectors have been substituted by piezo injectors in order to meet the growing demands of spray-guided stratified combustion. The advantages of better dynamics and variable valve lift result in higher production costs and more complex electronic control systems compared to solenoid systems. The increased requirements of advanced injection strategies cannot be fulfilled with solenoid injectors conventionally used as pure passive actuators.

Most recent injection systems for gasoline engines with second and third generation spray-guided combustion processes use piezo injectors for precise fuel metering. Stable spray generation under all engine operating conditions and reliable ignition of the mixture are the advantages of piezo injectors [1, 2]. Current investigations on spray-guided direct-

injected engines demonstrate that combustion stability and emissions of outwardly-opening piezo injectors and multi-hole solenoid injectors are comparable [3].

During cold start and warm-up the highest particulate emission levels occur. Optimized injection strategies apply multi-pulse operation for improved spray preparation and minimization of the particulate number [4]. Multiple injections with very small fuel quantities require the ballistic operating mode of the valve needle.

In the ballistic range, known solenoid injectors show unacceptable spread of the injected fuel quantity due to manufacturing tolerances. Outwardly-opening piezo injectors provide fast valve opening and flexible valve lift and show a better performance in ballistic operating mode. Production costs of piezo injectors are much higher compared to solenoid injectors and they require more complex electronic control units.

Figure 1 shows the typical characteristic of solenoid injectors. In linear operating range acceptable fuel quantity dosing tolerances of less than 10 percent due to production spread are found for many samples from different manufacturers. In ballistic operating mode even small tolerances lead to large fuel quantity spread, which can

exceed a factor of two. During changeover from linear to ballistic operation the injected fuel quantity even increases while the driving current pulse width decreases, which disturbs proper operation of the lambda control loop.

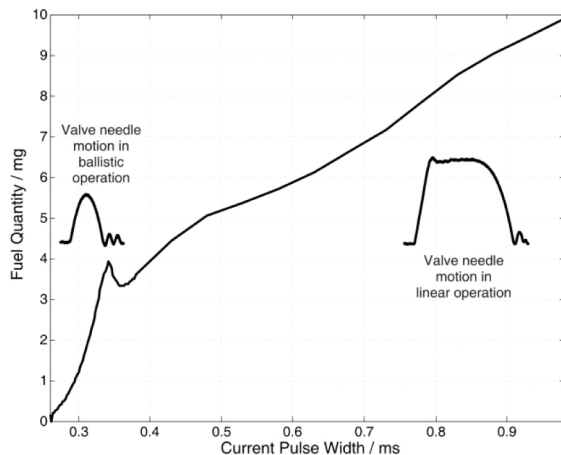


Figure 1. Solenoid injector characteristic and valve needle motion in ballistic and linear operating mode

Various improvements for solenoid injectors are currently ongoing, such as enhanced linear flow range, shorter closing time, less bouncing at injector closing and even outwardly opening nozzles [5]. Different approaches for acquisition of the injection rate of solenoid injectors have been presented, for example the utilization of pressure sensors, knock sensors and seat contact switches [6].

Knowledge of characteristic injection timing parameters such as begin and end of injection (BOI, EOI) allows for adjusting the driving signals. Relevant events during the valve needle motion can be derived from the injector voltage and current [7, 8]. In this case the solenoid injector itself acts as a sensor, with minimum additional effort [9].

Variation of dosing performance of piezo and solenoid injectors from large-scale production is presented. Influences of production spread and temperature are discussed by evaluation of valve needle motion and injected fuel quantity. The results of closed-loop controlled solenoid injectors are compared with conventionally driven solenoid injectors and piezo injectors.

TEST BENCH

The test bench, as shown in Figure 2, can generate arbitrary current profiles. Data acquisition includes the precise measurement of single injected fuel quantities, valve needle motion and all relevant operating parameters such as fuel pressure, voltages and temperature. This permits the stimulation of all individual operating and environmental conditions.

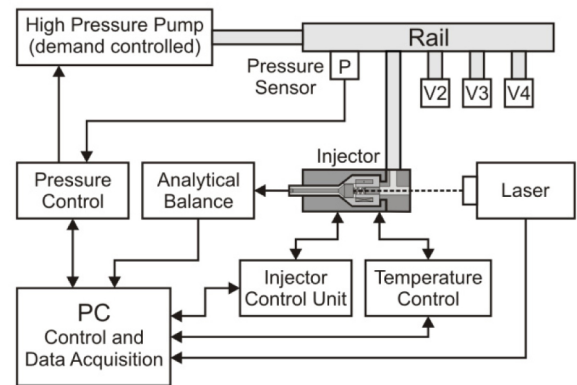


Figure 2. Test bench for solenoid and piezo injectors

The test bench contains components of state of the art injection systems applied in gasoline direct injection engines such as fuel rail, high-pressure fuel pump and pressure sensor. An electronic control unit keeps the rail pressure at constant values between 50 and 200 bar. The demand controlled high-pressure fuel pump ensures constant pressure delivery with fluctuations lower than one percent.

A separate control system is used for temperature control of the fuel injectors. The heating system provides constant ambient temperatures for the investigated injectors between room temperature and 125 °C with an accuracy of one percent.

Valve needle motion of the outwardly opening piezo injector nozzle is captured with a laser interferometer on the fuel outlet. For inwardly opening solenoid injectors a fiber optics on the fuel feeding connector provides online observation of valve needle motion. In order to measure single shot-fuel quantities an analytical balance with a resolution of 0.02 mg is used. Control of the whole test bench and data acquisition is achieved by a graphical user interface (GUI) developed in MATLAB.

INJECTOR CONTROL UNIT

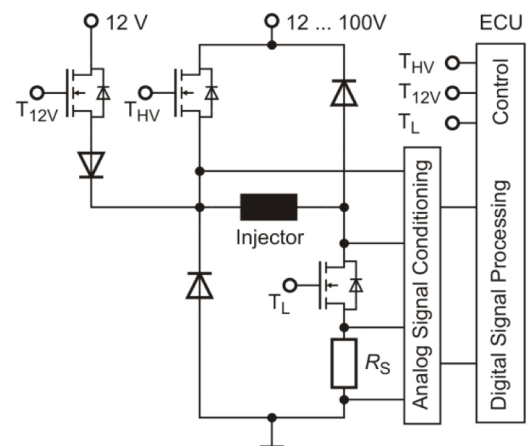


Figure 3. Solenoid injector drive circuitry