The Challenge: Developing a flexible test system for nonintrusive analysis of fuel spray characteristics in a car fuel injector.

The Solution: Creating a system based on LabVIEW and IMAQ with data acquisition (DAQ) boards to acquire and elaborate fuel spray images.

A Suitable, Non-Intrusive Test Bench
The study of fuel spray characteristics represents one of the most important research areas in the field of internal combustion engines. With recent developments in direct-injection engines, we made refinements to our spray shape control methods and analysis tools.

Penetration, cone angle, and bend angle are fundamental parameters for correct engine operation. For gasoline ICEs, these geometrical characteristics strictly link to sparkplug position and combustion chamber shape. Carefully matching injection features with cylinder design and flow patterns contributes to correct fuel charge structure and good combustion evolution. Additionally, this matching enhances efficiency and reduces exhaust gas emissions. Because of the primary importance of these parameters, engineers include spray shape tests in audit stations on injector production lines.

We used National Instruments LabVIEW software and IMAQ hardware to decrease development time and simplify maintainability of the source code.

Our experimental line required nonintrusive methodologies, injector-type flexibility and mounting capability. The system must operate at high pressures, store results, and have a high testing potential for raw analysis of multiple prototypes.

Finally, we required refined and detailed fine tuning analysis for selected samples, and a bench room designed for further expansion of our diagnostic tools.

Capturing Images with a Precise Delay
A PC controls our test bench operation and works as a mass storage system for the results the image analysis tool acquires. The test bench’s shadow graphic spray analysis technique of the test bench employs a stroboscopic lamp, generating a spotlight with a maximum frequency of 60 Hz.

We use a PC equipped with an NI PCI-6035E data acquisition board, a PCI-DIO96 digital I/O board, and an NI PCI-1422 board acquiring images from a DALSA CA-D8-512w digital camera.

Our bench operates at fuel injection pressures up to 280 bar and regulates main parameters associated with injector functioning, such as period and pulse width. Every injector family links to a specific control driver. The bench also can configure and regulate the correct driver-feed voltage.

With this system, we can choose delays from the start of injection to the image acquisition and analyze the spray shape during its evolution. To correctly acquire the injector spray images, the system must synchronize the injection, the charge-coupled device (CCD) acquisition, and the spray illumination. The system performs event synchronization through the TTL digital line of the NI PCI-1422 and the NI PCI-6035E and uses a RTSI bus cable to synchronize the two boards.

A fiber bundle guide in the same camera optic line conveys light from a stroboscopic lamp. By positioning the nozzle of the injector between the lens and the CCD, we can acquire the spray images. The short bright spot from the stroboscopic lamp synchronized with the reduced camera exposure time helps
us acquire clear images of the spray as it appears dark on a white background. For the measurement systems, the 60 Hz output of the light source limits the image acquisition frequency. As a result, the system carries out spray behavior analysis through “common averages.” A study on the evolution of the single-event injection requires a high-acquisition frequency of thousands of frames per second. To characterize the spray average behavior, we acquire different images with a precise delay respective to a fixed event. For example, we consider the signal arriving at the injector’s control driver as the start of the trigger chain. After image acquisition, the PC converts them to a digital format and calculates the intensity average value of each pixel, resulting in an average image with a precise delay. By repeating the procedure for different delays, we receive a complete characterization of the spray average evolution.

Once the system acquires the images, we extract the spray geometrical characteristics. The system then:
- Sharply separates the image of the spray from the background using the binarization procedure
- Coordinates computation
- Measures the geometrical parameters

Full Control with LabVIEW and IMAQ

The system software gives us control of the test bench functions. We can change the test bench parameters through interactive screens. The system software manages the various measurement setups and verifies the hardware bench status with the software utilities.

We used National Instruments LabVIEW software and IMAQ hardware to decrease development time and simplify maintainability of the source code. We separated the bench management from the acquisition and elaboration of the spray images with modular software. With the NI PCI-1422 frame grabber and NI-IMAQ driver, we can separate the CCD software from the hardware, so we can replace the CCD camera, now a DALSA CA-D8, with another model to improve the image characteristics.

The modularity of the software eases the development of new types of analysis and measurements, so we can adapt to the market’s demands.

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