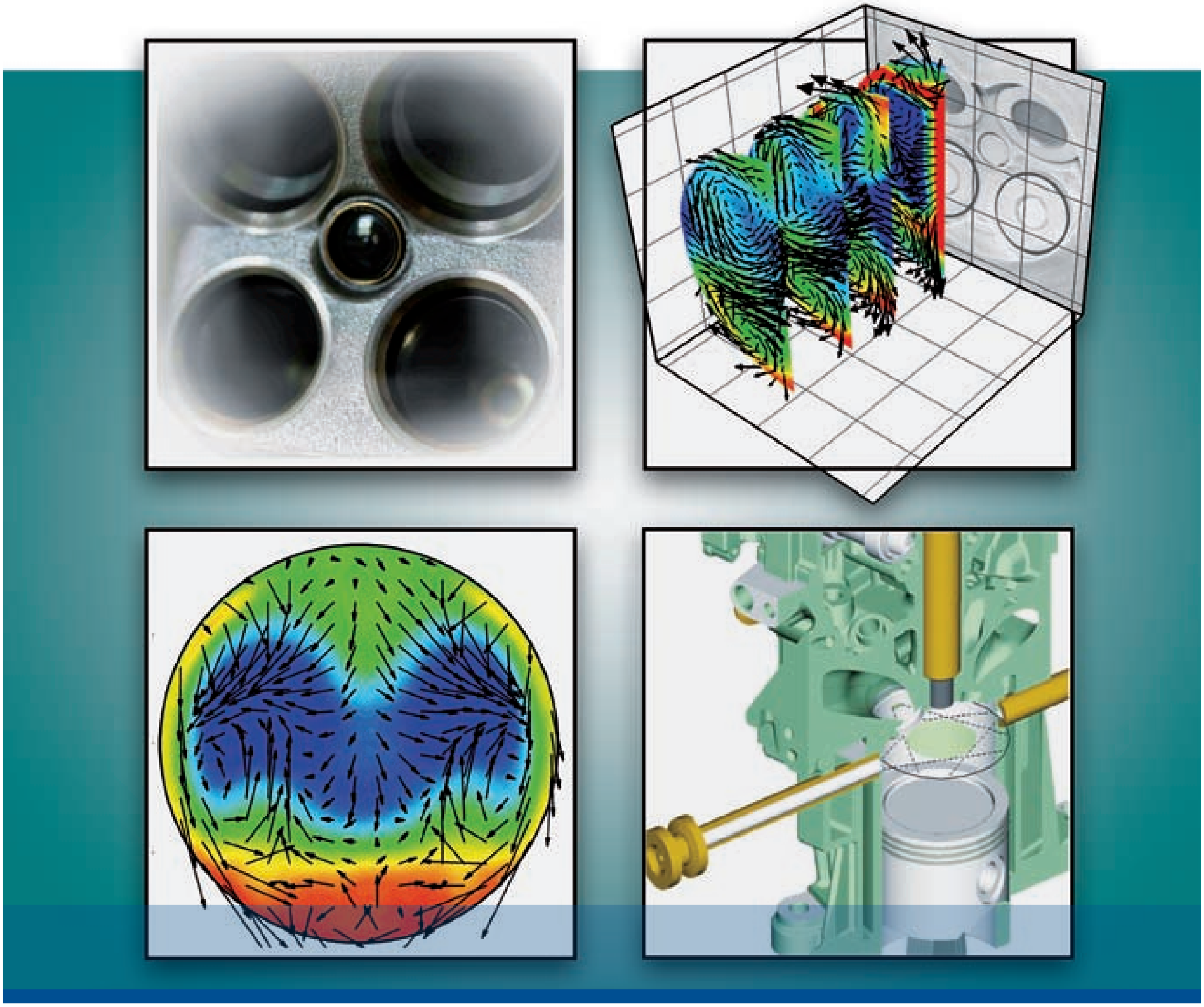

Doppler Global Velocimetry

Measurement of Flow Inside Cylinders of DI SI Engines

Optical methods for measuring flow inside the cylinder chamber have become widely accepted in the process of developing engine combustion systems. At IAV GmbH, Doppler Global Velocimetry (DGV) has been used for this purpose since 2000. Flexible endoscopes and Powell lenses developed in cooperation with DLR e.V. (German Aerospace Center) permit measurement in situations where optical access is complicated [1]. This makes it possible, for example, to conduct measurements in direct-injection spark-ignition engines. The measurement technique can be adapted to production engines with little effort.

1 Introduction

The use of Doppler Global Velocimetry began in steady-state flow testing on flow boxes and cylinder heads [2]. To visualize charge motion while the engine is operating and investigate its effect on specific mixture-formation and combustion-profile parameters, the technique was improved for measuring in-cylinder flow in the intake and compression phase of a reciprocating engine. Doing so, particular importance was attached to making the measurement technique as easy as possible to calibrate, also on production engines. In addition, an approach was sought which, on the basis of the fast and cost-effective results that can be achieved from steady-state flow, provided the means to derive statements on charge motion in relation to engine speed and load while the engine is running. The solution found was able to demonstrate its suitability, as shown by comparisons with the measurement results obtained from the motored engine. In this way, it was possible to close a further piece of the gap in the development process between steady-state flow results and actual course of combustion [3].

DGV measurement results hitherto published for in-cylinder flow, however, have been obtained without fuel injection. The following discourse shows that Doppler Global Velocimetry is also suitable for measurement with spark-ignition engine injection.

2 Measurement Setup

2.1 Physical Principle

Doppler Global Velocimetry belongs to the laser-optical light-sheet methods. Using the Doppler effect, all three spatial velocity components of the flow field are measured in one plane on a spatially resolved basis [4]. It is possible to combine various options for generating light sheets and recording images independently of each other. **Figure 1** shows two typical examples (left: use of parallel light sheets and camera lens, right: use of Powell lenses and endoscope) [5].

2.2 Test Engine

The test engine selected for demonstrating the measurement capability in DI SI engines was a four-cylinder four-stroke spark-ignition engine with homogeneous direct injection and displacement per cylinder of approx. 500cc. The engine is provided with a variable tumble system through which a charge motion can be generated.

To make the interaction visible between injection spray and surrounding flow, two different test setups were used:

- Measurement with steady-state flow through the intake ports, pulsed injection and unimpeded outflow (without pistons)
- measurement on the motored engine.

2.3 Measurement Setup with Steady-state Flow through the Intake Ports

Figure 2 shows the schematic test setup with steady-state flow through the intake ports.

Flow is illuminated using parallel light sheets that are generated with rotating prisms. Droplets of paraffin introduced into the intake flow, together with the fluid droplets produced at the time of direct injection, provide the seeding neces-

Authors

Dr.-Ing.
Thomas Seidel
is technical specialist flow measurement at the IAV GmbH in Chemnitz (Germany).

Dipl.-Ing.
Henry Steuker
is test engineer flow measurement at the IAV GmbH in Chemnitz (Germany).

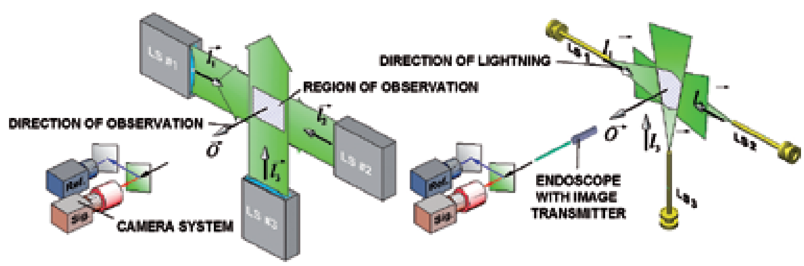

Figure 1: Options for generating light sheets and taking photographs for DGV measurement of all three velocity components in one plane

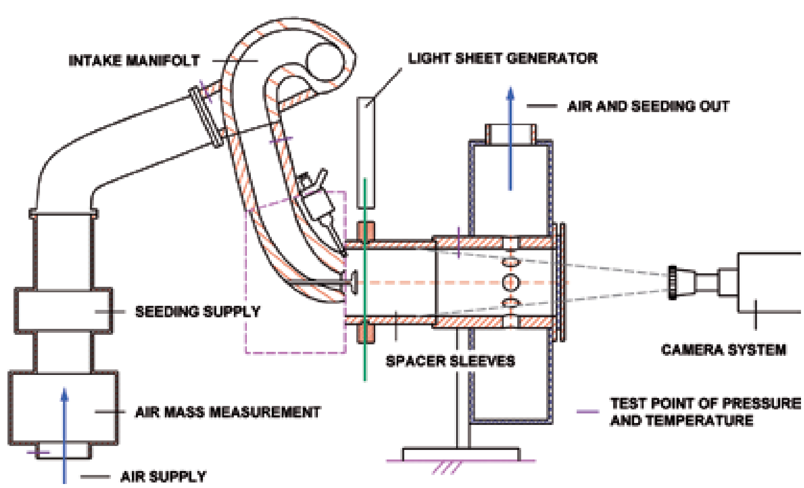

Figure 2: Schematic diagram of the test setup with steady-stage flow through the intake ports

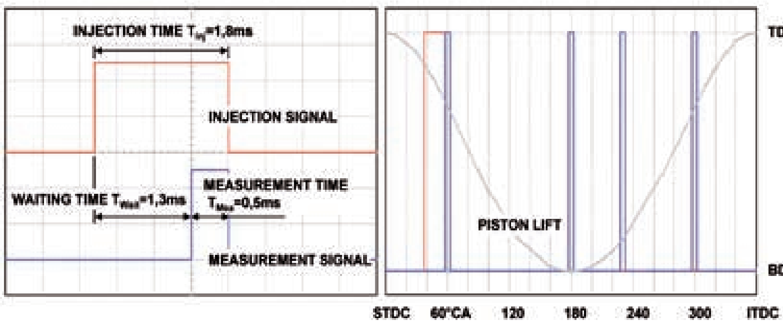

Figure 3: Triggering of injection and measurement

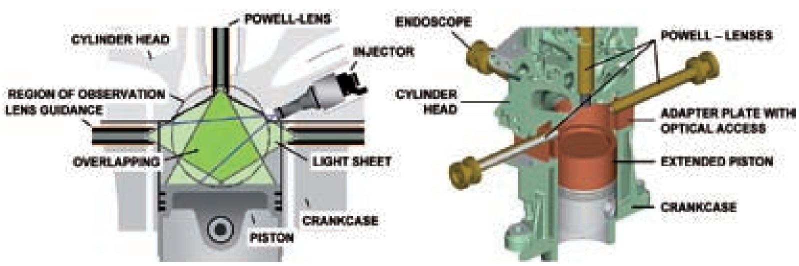

Figure 4: Schematic diagram of the test setup for measuring flow in the motored engine

sary for the measurement process, i.e. the velocity is measured at which these seeding particles flow.

The flow field is observed with a camera system. Individual measurements were conducted on a total of eight measurement planes arranged perpendicular to the cylinder axis, and volume data sets were generated for the flow fields with and without injection.

On the basis of an engine speed of 1200 rpm and part-load operation, injection was pulsed at a frequency of 10 Hz with an intake valve lift of 2 mm. Pulse duration was used to set the global air/fuel ratio of λ=1, **Figure 3** (left).

2.4 Measurement Setup for Motored Engine Operation

Flow measurement in the motored direct-injection spark-ignition engine was conducted using the Powell lenses and an endoscope with flexible image conductor. To obtain a good view of injection spray, a vertical light-sheet arrangement was selected in the example. The endoscope is arranged at right angles to the cylinder axis, with one of three Powell lenses being positioned in the spark-plug bore. The resultant measuring plane that is produced by superimposing the three light bands from the various directions of illumination is shown in **Figure 4**. The area observed extends into the spark-plug region. Figure 4 also shows the use of an intermediate plate to secure the position of the other two Powell lenses and endoscope, and an extended piston for restoring compression. This has the advantage of requiring hardly any mechanical work to the production engine and of allowing it to be re-used for engine tests after DGV measurement.

Multiple exposure of the camera system, combined with stroboscopic illumination (crank-angle resolution 5°), results in an averaging of the flow fields over approx. 500 cycles. Figure 3 (right) shows the triggering used for injection and measuring.

3 Measurement Results for In-cylinder Flow in the DI SI Engine

3.1 Measurement Results for Steady-state Flow through the Intake Ports

As several measurement planes were measured, any position can be selected for the sheet plane for graphically displaying the steady-state flow fields measured. **Figure 5** shows examples of flow fields measured with and without injection in a vertical and a horizontal sheet plane.

The color scale in the vertical display corresponds to the amount of velocity and, in the horizontal display, to the velocity component in the direction of the cylinder axis. The vector components in each plane are shown as arrows. The direction of injection spray is marked schematically in the figure.

As the DGV measurement technique is not sensitive to fluctuations in droplet concentration, the flow field can be measured simultaneously within injection spray and the surrounding intake air. The effect of injection on the flow field can be clearly seen. As a result of injection, the flow velocity is high, particularly in valve proximity, and has a pronounced influence on the flow field. High flow velocities occur in the direction of the cylinder wall that prevent centrally aligned inflow of the air.

However, the information content of these flow fields is limited as no allowance is made for the influence of the piston and dynamic effects. For the purpose of better adapting the boundary conditions to those prevailing with the engine running, measurements were also conducted on the motored engine.

3.2 Measurement Results for Motored Engine Operation

Figure 6 shows examples of relevant measurement results. The first two flow images show a comparison of flow with and without injection at an engine speed of 3000 rpm, with injection taking place during the inflow cycle at 37 °CA after CC-TDC and measured at bottom dead center. Velocity componets rectangular to the view are color scaled. Both flow fields show the formation of tumble flow that was generated by the activated tumble system. The swirl center lies below the measurement area. In spite of the strong influence on the flow field during injection, reflected in the measurements of steady-state flow, no significant difference is shown to exist in the flow field at the time of measurement. By changing the injection parameters, the influence of injection could be altogether greater. However, it must be noted that flow between individual injection cycles in the steady-state case has probably not stabilized sufficiently. As a result of these boundary conditions, taking measurements during motored engine operation must be given preference over steady-state measurement.

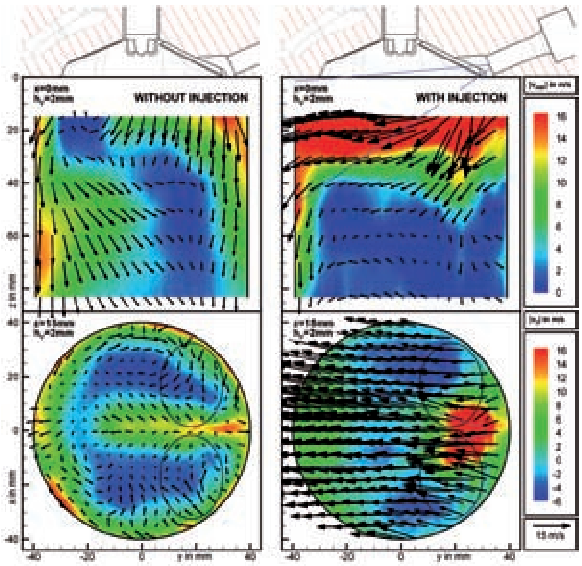

Figure 5: Comparison of flow fields during steady-state flow through the intake pistons

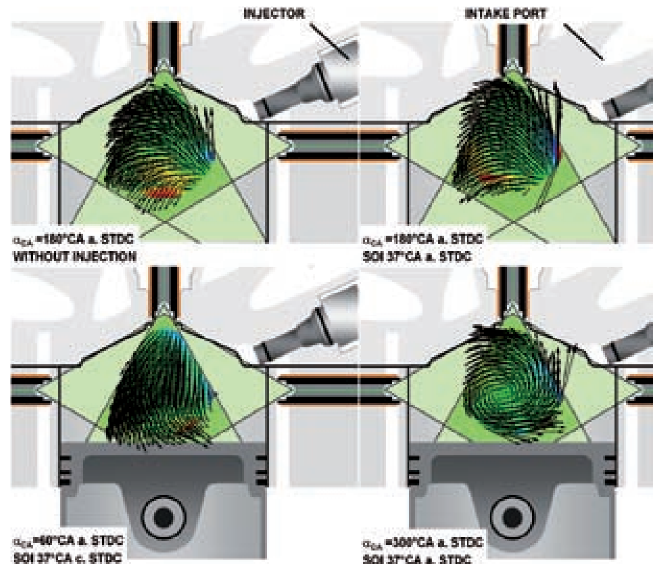

Figure 6: Comparison of flow fields in the motored engine

Figure 6 also contains measurement results aimed to demonstrate that it is also possible to carry out measurement during inflow and injection. This opens up scope for further-reaching investigations.

4 Summary

The article demonstrates the use of Doppler Global Velocimetry for measuring flow inside the cylinder chamber of DI SI engines. For this purpose, measurements were conducted with steady-state intake-port flow-through as well as on the motored engine.

The results prove the ability to use Doppler Global Velocimetry for measurement in both cases, with it being possible to measure the flow field in the injection spray and in the surrounding area simultaneously since the measurement technique is relatively insensitive to differences in the concentration of droplets contained in the flow (seeding).

It is shown that the information content of measurement results for steady-state flow through the intake ports is limited from the aspect of investigating injection because the influence of piston and dynamic effects must be left out of consideration. By way of example, measurement was carried out in the steady-state flow test at a trigger frequency of 10 Hz, i.e. flow was unable to stabilize between individual injection cycles.

It was established that, under the given boundary conditions, injection only has any significant influence on global charge motion in the short term. The DGV measurement technique permits further-reaching injection-related studies in the spark-ignition engine process while varying the injection parameters.

5 Other Applications

Given the velocity and high level of resolution with which flow fields can be measured, the use of Doppler Global Velocimetry has developed into one of IAV GmbH's standard services. In addition to measuring in-cylinder flow, the application area also extends as far as measuring flow in exhaust-gas catalysts and other components. For instance, scavenging flows were measured in two-stroke engines with steady-state through-flow and also in the motored engine at up to 8500 rpm. It has also be used for performing activities involved in measuring the flow field in the exhaust tract, e.g. outflow from a turbocharger turbine at up to 120,000 rpm as well as flow fields upstream and downstream of honeycomb catalysts. In this context, CFD simulation is supported by the provision of measurement data.

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