Correlation Velocimeter for Dense Sprays

H. Chaves¹, C. Kirmse², Ch. Brucker³, F. Obermeier⁴

1: Inst. Mech. and Fluid Dyn., Freiberg Univ. of Mining and Tech., Germany, Humberto.Chaves@imfd.tu-freiberg.de
2: Institute for Mechanics, Tech. University, Chemnitz, Germany, Clemens.kirmse@mb.tu-chemnitz.de
3: Inst. of Mech. and Fluid Dyn., Freiberg Univ. of Mining and Tech., Ger., Christoph.Bruecker@imfd.tu-freiberg.de
4: Inst. of Mech. and Fluid Dyn., Freiberg Univ. of Mining and Tech., Germany, Frank.Obermeier@imfd.tu-freiberg.de

Keywords: Velocimetry, Correlation, Spray

The knowledge of the temporal and spatial variations of the spray velocity at or close to the nozzle exit is a necessary requirement for the understanding of atomization, for the development of models and of CFD codes simulating the atomization process. However, standard methods for velocity measurement as Laser Doppler Anemometry can not work well in this region due to the high optical density of the spray. Furthermore, for modern common rail fuel injection systems the spray velocity can reach levels (~600 m/s) that impose stringent requirements on the bandwidth of the detection system and on the capabilities of the burst analyser. At the same time, the injection duration of these sprays ranges between 0.3 to 2 ms. Therefore, a method of measuring the spray velocity is needed that is insensitive to a low signal to noise ratio, that needs no assumptions about the tracers that are used and that has the spatial resolution to resolve flow velocity profiles of span wise dimensions of the order of 100 µm as well as a temporal resolution in the order of 10 µs. The method presented here is essentially a modified laser-two-focus (L2F) velocimeter where the evaluation of the signals is performed by cross-correlation and not by time of flight analysis. This allows to measure even when the signal to noise ratio is low as is the case for dense sprays and where not only one structure occurs within the cross-correlation window. When a drop or ligament or any structure that obscures the light moves past the foci and it has a velocity vector that is aligned with the separation plane of the foci the corresponding signals show a temporal shift that is used together with the separation distance of the foci to calculate the velocity. Basically the same limitations that are valid for L2F, are valid here, i.e. the flow should have a preferential flow direction, so that a tracer that crosses one measuring volume will cross the other volume with a high probability.

The optical set-up of the method is shown in Figure 1. Light from a laser diode (LD, spot size ~10 µm) is split into two beam bundles (green and red lines) by the Wollaston prism (WP1). The two bundles are characterized by their plane of polarisation. For the optics behind the Wollaston prism it appears as if two point sources are present. They are imaged onto the measurement plane by the lenses L1 and L2 with a magnification of about 1. The resulting two foci have then a size comparable to the source and are separated by a distance that depends on the focal length of the combination of L1 and L2, on the splitting angle of the Wollaston prism and on its position relative to the laser. In our case the separation was set at 104 µm. Light coming from the foci is collected by lens L3 and split according to its plane of polarisation by a second Wollaston prism (WP2) with a large splitting angle. Lens L4 focuses the light on the ends of two light fibres. At the other end of the fibres the light is converted into a voltage by two photodiodes and corresponding trans-impedance amplifiers. The complete optical set-up is compact. It is mounted on a 3-d traverse that allows positioning of the measuring volumes relative to the nozzle.

The measurements were performed on a common rail injection system equipped with a single axial one-hole nozzle. The spray was injected into a pressurized chamber that allowed varying the gas density. Exemplarily, the results of velocity measurements along the spray axis for different chamber pressures and injection pressures are shown in Figure 2. The ordinate of this plot is the product of the distance from the nozzle normalized by its diameter and the density ratio. This allows collapsing the data in a rough manner. The abscissa is the ratio of the mean of the velocity measured during the quasi-steady period of injection to the product of the discharge coefficient times the Bernoulli velocity for each pressure difference.

The limitations and measurement errors of the method are discussed.

Fig. 1 Optical set-up of the correlation velocimeter

Fig. 2 Decay of the mean velocity along the jet axis