Chapter 4
LDA Systems

4.1 Hardware and Optical Components

Based on advanced development of laser and computer technologies as well as on extended requirements in high quality flow measurements, LDA systems have become commercially well available and state of the art products. The hardware of an LDA system consists of transmitting and receiving units. The optical component in the transmitting unit commonly counts the laser, the laser beam transmitter including the Bragg cells and splitters, the fiber and the LDA-head, as shown in Fig. 4.1a for a system of Dantec Dynamics. The laser that is mostly used in LDA measurements is the argon-ion laser that basically provides three selectable wavelengths of 514.5, 488 and 476.5 nm. An LDA system is usually configured to use the laser light of the wavelength 514.5 (green) and 488 (blue) nanometers. After getting into the transmitter, the laser is separated and split into a pair of green and a pair of blue beams. For the purpose of resolving velocity directions, the light frequencies respectively in one green and one blue beams are shifted by Bragg cells, typically for 40 MHz. In some optical configurations, the Bragg cell also serves as the beam splitter. Four laser beams are then conducted into four fibers that are bundled and connected to the LDA head. A two-component LDA head is usually configured such that the plane of two green beams is perpendicular to the plane of two blue beams. This arrangement ensures the measurements of two perpendicular velocity components. The front lens on the LDA head enables all four laser beams to be focused at a unique point for forming the LDA measurement volume. By changing this front lens for different focal lengths the distance of the measurement volume to the LDA head can be changed. Corresponding geometrical and optical properties of the measurement volume in using the lens of different focal lengths will be described in Sect. 4.2.

Because of the use of fiber techniques, LDA optics is sometimes also called the fiber-optic LDA.

The receiving unit of a LDA system commonly includes the components such as the receiving optics, photodetectors like photomultipliers (PM), the signal processor and a computer for both controlling measurements and evaluating measurement data. In the act of using two pair of laser beams, the backward scattered laser light

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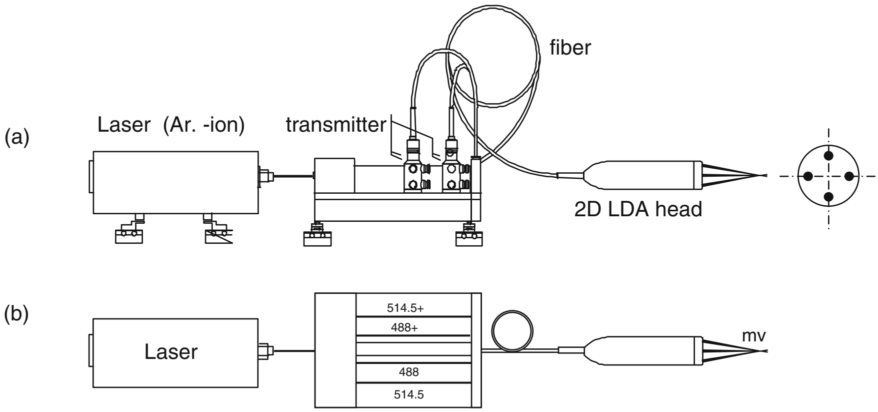

Fig. 4.1 Transmitting optics of an LDA system (Dantec Dynamics)

contains two sequences of light signals and hence is informative of two-component flow velocities. As shown in Fig. 4.2 for the most common case, the LDA head with the corresponding front lens also serves as the receiving unit. The scattered laser light is collected and focused onto the plane end of a supplementary fiber. At another end of the fiber which is usually integrated into the transmitter, the light is firstly separated into two parts of wavelengths 514.5 and 488 nm. These are then guided to respective photomultipliers which convert the light signals into electronic signals. The signal processor and the computer finally work out signals involving the flow velocities and the velocity-time relations.

The LDA system, as shown in Fig. 4.2, is called the backward scattering system. The most relevant advantage of such a system is the consistency of the optical alignment between the transmitting and the receiving units. The LDA head can thus be placed mobile for flow measurements, without realignment each time. In contrast, the forward scattering system necessitates a separate optical receiver for receiving the forward scattered laser light. The background of sometimes configuring such

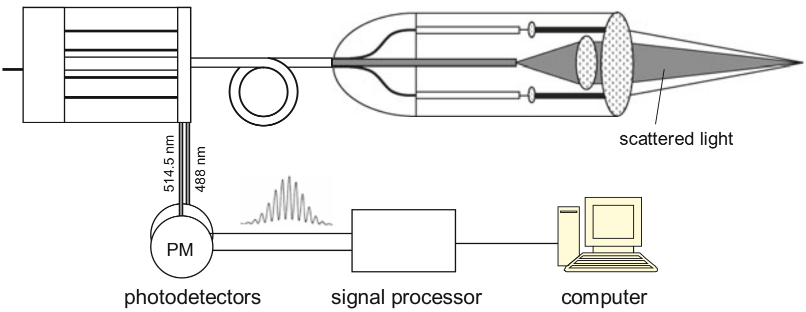

Fig. 4.2 Receiving optics of a backward scattering LDA system

a system is the utilization of high intensity of the forward scattered laser light. Because of the separation between the transmitting and the receiving units an optical realignment is usually always indispensable when the measurement point i.e. the measurement volume in the flow is changed. The realignment of the measurement volume will be very time-consuming, if it deals with measurements of internal flows. All refractions of both the transmitting light beams and the scattering light on diverse medium interfaces (as air-glass and glass-flow) have to be concerned.

LDA systems that use other laser lights (e.g. diode laser) rather than the argon-ion lasers have also been found in the practical applications.

In some few other applications with special optical configurations, coincident measurements of three particular velocity components have been carried out (Hüttmann et al. 2007, Richter and Leder 2006). In these applications, the additional laser light of the wavelength of 476.5 nm has usually been used. As demonstrated in Fig. 4.3 for instance, usually it deals with the measurements of non-orthogonal velocity components. The complete flow information including all three velocity components and the turbulence quantities in the Cartesian coordinate system can be obtained through the appropriate coordinate transformation. More about this technique will be presented in Chap. 6.

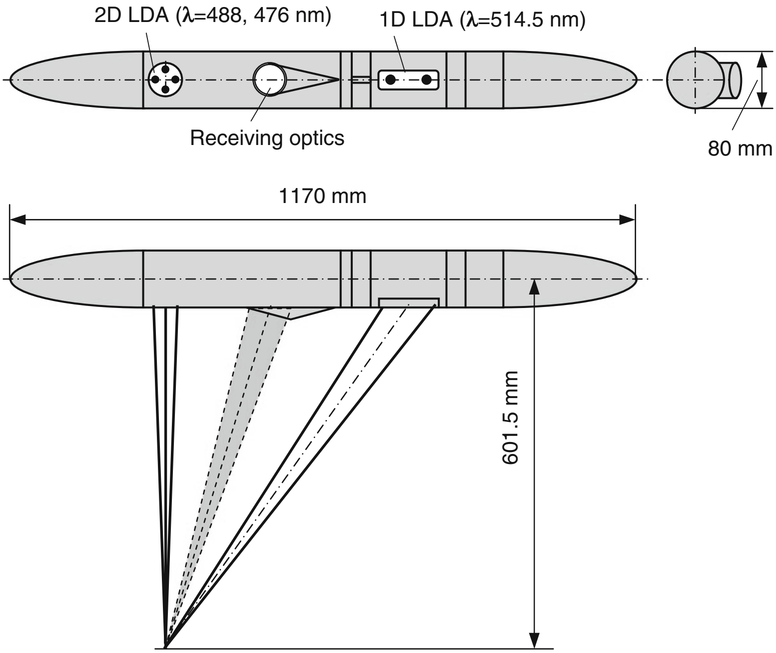

Fig. 4.3 Integrated three-component LDA head, applied for in-water measurements (Richter and Leder 2006)

4.2 Specification of LDA Measurement Volumes

It has been indicated in Sect. 3.8 that the measurement volume size depends on the optical configuration and the used optical lens which determines both the beam crossing angle and the waist thickness of each laser beam. In all LDA configurations, the laser beam crossing is achieved by the lens on the LDA head. Usually each laser beam prior to the lens is configured to be a nearly parallel light bundle. The diameter of such a light bundle is of about $2w_0' = 1 \sim 2$ mm. By considering this thickness as the waist diameter of a light bundle and according to Eq. (3.74) for the laser light with a wavelength $\lambda = 500$ nm, the divergence angle of the light bundle of a diameter $2w_0' = 2$ mm is only about 0.009°. Correspondingly the Rayleigh length is calculated from Eq. (3.66) to be $z_R' = 6283$ mm. In all commercial LDA systems, the laser beam thickness $2w_0'$ prior to the lens is configured to be a fixed value. Another fixed value is the distance $2d$ between two laser beams of a beam pair (Fig. 4.4). By changing the lens on the LDA head, both the geometrical dimensions and the optical properties (brightness, fringe spacing etc.) of the measurement volume will get updated. Applying Eq. (3.76) with respect to $f << z_R'$ i.e. $f/z_R' << 1$ yields

$$s = f \tag{4.1}$$

The waist of the laser beam thus coincides with the focal point of the lens on the LDA head. The crossing of two laser beams in a beam pair at the beam waists has been thus ensured.

The waist thickness of each laser beam at the beam crossing point (measurement volume) can be calculated from Eq. (3.75) with respect to $\left(s' - f\right)/z_R' << 1$ as

$$w_0 = \frac{f}{z_R'} w_0' \tag{4.2}$$

It is thus directly proportional to the focal length of the lens used on the LDA head. The corresponding thickness of the measurement volume is then given from Eq. (3.77) as

$$d_{mv} = \frac{2f}{z_R' \cos\alpha} w_0' \tag{4.3}$$

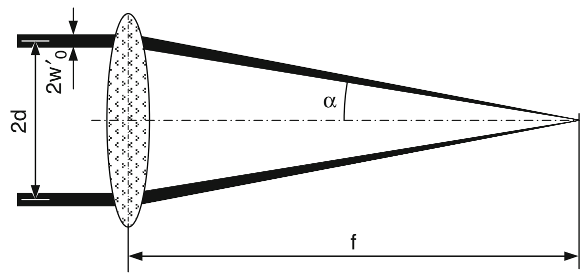

Fig. 4.4 Creation of LDA measurement volume and basic parameters determining the measurement volume size

In using the lens with a small focal length, for instance, small thickness and thus high brightness of the measurement volume can be achieved. This could be very meaningful for LDA measurements at which small natural particles in the flow should be used.

Furthermore, the focal length of the lens simply determines the crossing angle between two laser beams and thus the fringe spacing in the measurement volume. This determination relation is given from Eq. (3.46) as

$$\Delta x = \frac{\lambda_0}{2\sin\alpha} = \frac{\lambda_0}{2}\sqrt{1+\frac{f^2}{d^2}} \tag{4.4}$$

The number of fringes in the measurement volume can be calculated by Eq. (3.78). As it can be confirmed with respect to $\tan\alpha = d/f$ and Eq. (4.2), the number of fringes remains unchanged while changing the lens for another focal length:

$$N = 4\frac{w_0}{\lambda_0}\frac{d}{f} = 4\frac{d}{\lambda_0}\frac{w_0'}{z_R'} \tag{4.5}$$

The length of the measurement volume, according to Eq. (3.79) with respect to Eq. (4.2), is calculated as

$$2a = \frac{2f}{\sin\alpha}\frac{w_0'}{z_R'} = 2f\frac{w_0'}{z_R'}\sqrt{1+\frac{f^2}{d^2}} \tag{4.6}$$

It largely depends on the focal length of used front lens on the LDA head.

In Table 4.1 considering the optical configuration of a standard LDA head manufactured by Dantec Dynamics, calculation examples of geometrical properties of the measurement volume have been shown. While the thickness of the measurement volume is usually in the order of about 0.1 mm, the measurement volume length varies between 0.5 and 5 mm. It should be mentioned that the use of the lens with a long focal length will reduce both the brightness of the measurement volume and the spatial resolution in velocity measurements. In addition, the effective aperture of the receiving optics to the measurement volume decreases too, leading to weakening of signals to be detected.

Table 4.1 Optical configurations and geometrical properties of the measurement volume, example of a standard LDA head ϕ60 of Dantec Dynamics

$\lambda_0 = 514.5$ nm, $2w_0' = 2.2$ mm, 2d = 38 mm				
Focal length of the lens f	mm	160	400	600
Beam intersection angle $2\alpha_0$	deg	13.54	5.44	3.63
Beam waist radius w_0	mm	0.024	0.060	0.089
Measurement volume diameter d_{mv}	mm	0.05	0.12	0.18
Measurement volume length 2a	mm	0.40	2.51	5.65
Fringe spacing Δx	µm	2.18	5.42	8.13
Number of fringes N	–	22	22	22