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Adjustable focus laser sheet module for generating constant maximum width sheets for use in optical flow diagnostics

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Abstract

A general design of a laser light sheet module with adjustable focus is presented, where the maximum sheet width is preserved over a fixed region. In contrast, conventional focusing designs are associated with a variation in maximum sheet width with focal position. A four lens design is proposed here, where the first three lenses are employed for focusing, and the last for sheet expansion. A maximum sheet width of 1100 μm was maintained over a 50 mm long distance, for focal distances ranging from 75 to 500 mm, when a 532 nm laser beam with a beam quality factor $M^2 = 29$ was used for illumination.

Keywords: laser sheet, flow diagnostics, flow visualization, combustion diagnostics, laser diagnostics, particle image velocimetry, PIV, laser induced fluorescence, LIF

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Optical diagnostics of flows and flames quite often employs laser sheets for illumination, in order to obtain data in a thin cross section through the measurement object. The signal generated by the laser sheet is then captured using a two-dimensional detector, such as a CCD camera. Through the use of diagnostic techniques such as Mie scattering, particle image velocimetry (PIV), laser induced fluorescence (LIF), Rayleigh scattering and laser induced incandescence (LII) information on flow velocities, species concentrations, temperatures, droplet and particle characteristics can be obtained [1–3].

Laser sheets are normally generated by combinations of spherical and cylindrical lenses [1], even though more advanced designs have also been explored [4–6]. For many applications fixed optical components mounted on optical tables, breadboards or rails are employed. For increased ease of use or for applications requiring compact and adjustable sheet generation, light sheet optics integrated into a single module are also commonly used. Common fields of use include PIV and industrial applications where optical access is limited. Such modules often feature a focusing ability, through translation of one of the lens elements, or adjustments based on interchangeable lenses. For access through small apertures laser sheet borescopes have even been demonstrated, e.g. for in-cylinder engine diagnostics [7].

Ideally a light sheet optics module should feature a wide range of focusing, with a reasonably small translation of a single lens element, in order to allow for a compact and simple mechanical design. Furthermore, it should generate a sheet with similar characteristics over the entire range of focusing. In particular, variations in sheet width at focus and at a certain distance from the focus, determined by the size of the region to be imaged, should be minimized. This would ensure a similar illumination over the measurement region at all focal lengths and control of the illumination parameters, such as maximum sheet width over the illuminated region. Knowledge of illumination parameters can be crucial for controlling the spatial resolution or optical flux in sheet-based diagnostics.

Normally a combination of a negative and a positive lens, one of which can be translated, is used for the focusing of the sheet. When the separation between the lenses is decreased the focal length is increased—and the beam diameter at the second, positive, lens decreases. As a consequence the beam waist at the focus will increase, and thus vary as a function of focal length. Furthermore, this variation in beam waist is also

