HYDROGEN DETECTION: VISUALISATION OF HYDROGEN USING NON INVASIVE OPTICAL SCHLIEREN TECHNIQUE BOS

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ABSTRACT

The detection of hydrogen after its accidental release is not only important for research purposes but will be much more important under safety aspects for future applications when hydrogen should be a standard energy resource. At Fraunhofer ICT two principally different approaches were made: first the new optical background-oriented schlieren method (BOS) is used for the visualization of hydrogen distribution and mixing processes at a rate of up to 1000 frames per second. The results from experiments with small scale injection of hydrogen/air–mixtures into air flows and free jets of hydrogen and hydrogen/air–mixtures emerging from 1" hoses simulating exhaust pipes will be discussed and interpreted with support from selected high speed videos. Finally mixing zones and safety distances can be determined by this powerful method.

1.0 INTRODUCTION

In the area of experimental safety technology research and development concerning hydrogen as an energy carrier several activities of Fraunhofer ICT are addressing the development and use of measurement systems. Basic studies are performed on the physical and chemical properties of hydrogen under different conditions and extensive risk assessment studies on vehicles but also on facilities and systems where hydrogen is used.

Under certain conditions hydrogen reacts very severe because of its physical and chemical properties and therefore different types of safety problems occur in technical use. Either constructive as well as unintentional release of hydrogen in accidental or malfunction cases of technical facilities, vehicles and system components raise questions concerning spatial and temporal expansion, explosion capability and mixing behaviour of hydrogen with ambient air. Traditional gas measurement techniques to measure and characterize hydrogen distributions and mixing processes work on the base of sampling sensors but there are specific disadvantages like the limitation of the number of single sensors, disturbance of the flow field and small time resolution.

Goal of the presented experimental work is the application of the non intrusive optical BOS measurement principle (Background Oriented Schlieren Technique) for the visualisation of hydrogen free jet flows and mixing processes of hydrogen injection flows inside a piping. Further applications of the system allow the visualisation of pressure pulses of a well defined hydrogen air explosion.

2.0 THEORY

The BOS method is based on the measurement principle that light beams are deviated while passing through transparent objects with density gradients. The BOS System only needs one digital camera focussed on a background pattern of statistical distributed dots and records this pattern through the area of interest. Density gradients within the observed area between camera and background pattern produce virtual local displacements of the background pattern recorded by the camera. The magnitudes of these local displacements (Δy) are proportional to the integral density gradient along the specific line of sight (Fig. 1). In order to evaluate the displacements for the whole visual field of the camera and for each single picture, computerized PIV algorithms (Particle Image Velocimetry) are used [1,2].

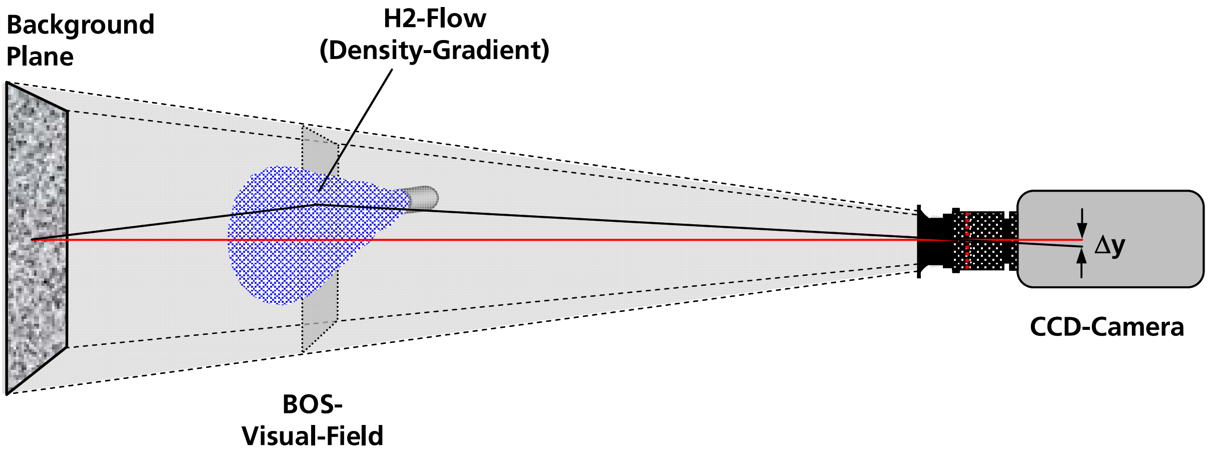

Fig.1: Ray tracing for density gradient measurement by the BOS Method

For an optimized set-up the background pattern is adapted to the specific viewing area and the optical resolution of the camera. To perform a BOS measurement initially a reference picture is recorded with absence of flow and PIV-processed with all pictures recorded later with flow. Caused by the 14.4 times lower density of gaseous hydrogen related to air, high density gradients occur at the border- and mixing zones between the two media. For this reason, the BOS Method is very well suited to visualize these otherwise invisible hydrogen flows. Highly dynamic processes can be recorded and characterized this way with very high time resolution using modern high speed cameras.

3.0 EXPERIMENTAL SETUP

3.1 Test Facility

The presented measurements were obtained using a digital high speed camera Phantom V5 of Vision Research whose CCD-Chip has an optical resolution of 1024x1024 pixels. This camera is usable for picture frequencies up to 1000 frames/s at full resolution. The necessary randomly distributed background patters with different grey steps were digitally produced and adapted to the specific viewing area of the camera. Best resolution can be obtained if each dot of the randomly distributed background structure is imaged by 2-3 pixels [3]

3.2 Free Jet Flows

In order to visualize hydrogen free jet flows a vertical and a horizontal scenario was built-up with a 1“ steel tube (Fig.2/3).

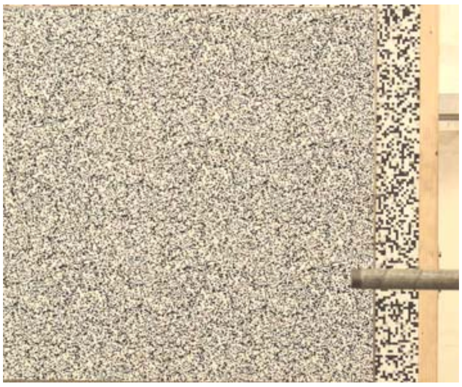

Fig.2/3: Vertical and horizontal setup (1“- steel tube)

The needed hydrogen mass flows were delivered by a gas supply system, based on a remote controlled multi channel gas mixing system with integrated mass flow controllers and transmitted by a tube to the free jet pipe. For the vertical pipe, the hydrogen mass flow was 2.1 g/s (1400 l/min) and for the horizontal arrangement 0.375 g/s (250 l/min). The selected time resolution was for both set-ups 1000 fps at full optical resolution of 1024x1024 pixels. The internal camera memory has a capacity of 1019 frames at full resolution, wherefrom measurement duration of 1.019 s arises and a frame rate of 1 ms respectively.

Figure 4 shows the resulting BOS pictures after PIV processing for the vertical free jet flow. Two single pictures from different points of view, which had a vertical distance of 60 cm above the tube mouth, were put together.

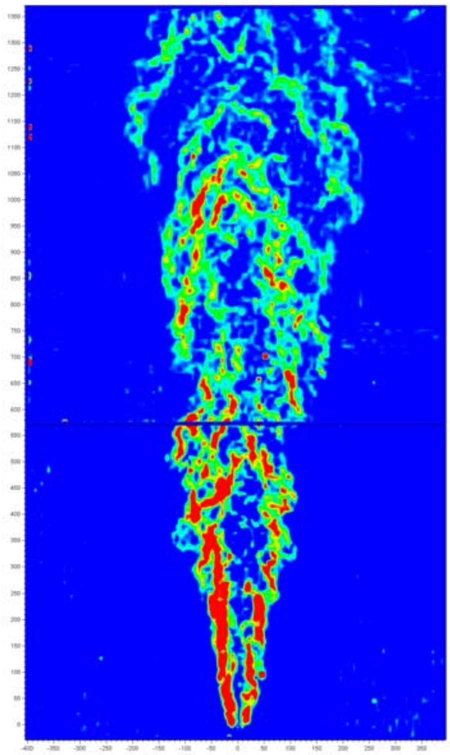

Fig.4: BOS visualisation of the density gradients in the case of vertical release

Figure 5 shows, as result of the BOS density gradient visualization of a horizontal free jet flow, a sequence of 3 single images with time step of 15 ms between each other.

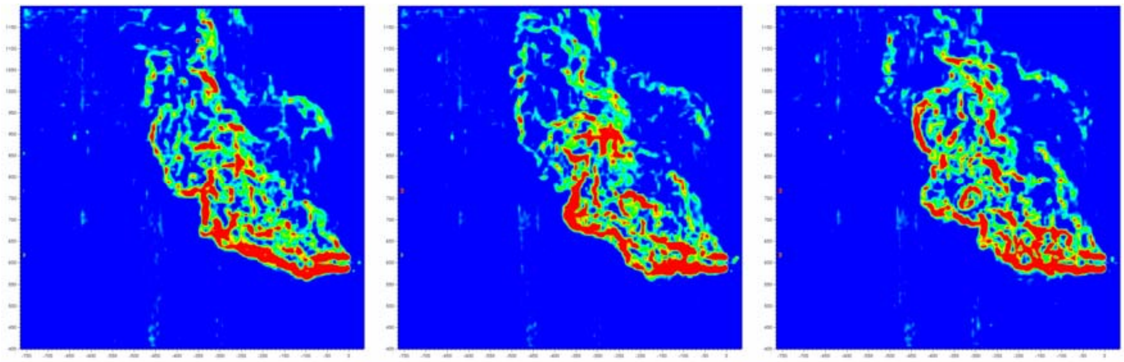

Fig.5: BOS visualisation of the density gradients in the case of horizontal release

3.3 Injection flow

In order to visualise the mixing process of a hydrogen flow into a pipe with a defined air flow a setup consisting of a rectangular steel tube (20x20x2 mm) was constructed including inspection windows. These windows were applied with a background pattern and illuminated by a halogen light source (Fig.6). On the topside of the tube a borehole (Ø 8 mm) allowed the injection of hydrogen gas 0.6 g/s (404.5 l/min) into the airflow of the same velocity of 0.6 g/s (27.8 l/min).

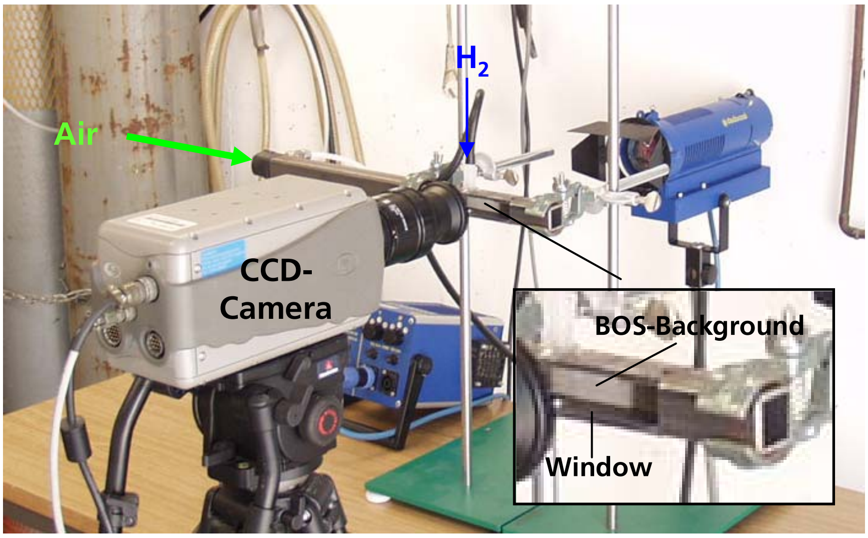

Fig.6: Experimental setup for the visualisation of injection flows

Again a time resolution for both set-ups of 1000 fps at full optical resolution of 1024x1024 pixels was selected. The result of the BOS-Visualisation of the mixing process regarding the density gradients is depicted in Fig. 7 in a sequence of 5 single shots with an interval of 20 ms.

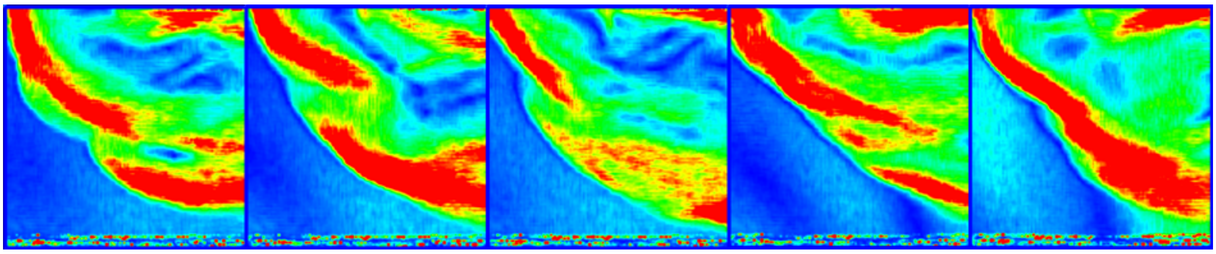

Fig.7: BOS-visualisation of the mixing process of H2 in a pipe flow

3.4 Pressure pulse

Another advantage of the BOS-method is the possibility to visualise the expansion of the pressure pulse resulting from a gas explosion. Therefore a plastic container of 1000 l volume has been filled with a stoichiometric hydrogen-air mixture (29.6 %vol.). To guarantee a homogeneous distribution the mixture was stirred by means of a ventilator inside the container. The ignition of the mixture took place in the centre of the containment.

Fig. 8 shows the pictures of the high-speed-camera with a frame rate of 1000 fps. Only the first two pictures are divided by 15 ms, the following difference is 1 ms.

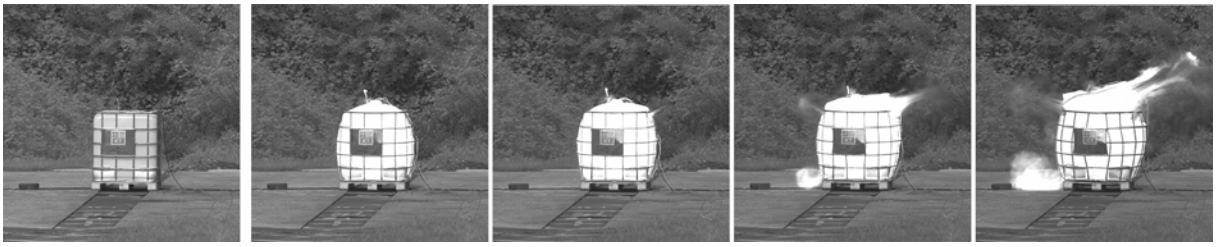

Fig.8: High-speed pictures of a H2-explosion

As a background pattern for the BOS-evaluation of the single pictures the natural background of the viewing area was taken. Due to the dimension of the interesting area this irregular structure of the background is sufficient to detect the virtual displacement. The pressure impulse of the hydrogen explosion leads to density gradients at the transition of compressed to ambient air which allow the evaluation with the PIV-Algorithm. The results are depicted in Fig. 9 relating to the original pictures of Fig. 8.

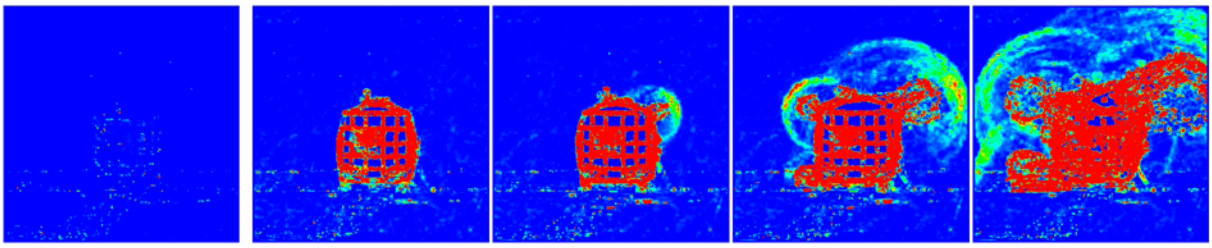

Fig.9: BOS-Visualisation of pressure pulses of a H2-explosion (ref. fig. 8)

The selected time resolution was for both set-ups 1000 fps at full optical resolution of 1024x1024 pixels.

4.0 CONCLUSIONS

Several investigations were performed at Fraunhofer ICT, concerning the non-intrusive optical BOS-measuring system to visualize free jet flows, the mixing phenomena of hydrogen-air-mixtures in piping but also to determine the expansion of pressure waves resulting from gas explosions.

It was shown that this method delivers a good tool due to the great differences in density between hydrogen and air to depict hydrogen flows with a high time resolution. This could also be stated for different H_2 free jets and mixing configurations in flow tubes. Especially the visualisation of the pressure waves of explosions in combination with pressure measurements permits a better risk evaluation in respect of the hazard impact to environment.

The time resolution of the system is limited by the maximal time resolution of the digital camera used. As a result of these measurements one obtains single frames resp. video sequences which show the density gradients of different compressed gaseous media and derived the lateral and temporal expansion.

Caused by the integral measuring principle of the BOS-method in direction of recording quantitative statements on the predominant hydrogen concentration are limited. Further experiments showed that the differences in density below the lower explosion limit (4 %vol.) are too small to be detected by the BOS-system which means a minimum density difference of ~3.9% approximately.

Due to the results of the BOS-system regarding the spatial and temporal expansion of the hydrogen flow it is possible to discover the regions of ignition. A main advantage despite the high time resolution compared to standard sampling sensors is, that the hydrogen flow to be observed is not disturbed in its development and local expansion and that the measured values are not falsified through the extraction of gas.

These results deliver a wide range of applications of the BOS-system in the investigation of safety aspects concerning hydrogen as an energy carrier as well as in the basic determination and characterisation of hydrogen flows, -mixing processes and distribution. The visualisation of the spatial and temporal distribution of hydrogen flows in vehicles, facilities and components caused by releases allows the detection of ignitable regions and thereby safety margins or counter measures can be defined. Furthermore this visualisation technique provides insight into H_2 mixing to optimize the mixing process, to adjust the geometries and to detect and correct insufficient mixing.

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