APPLICATION OF A DIGITAL HIGH-SPEED CAMERASYSTEM FOR COMBUSTION RESEARCH BY USING UV LASERDIAGNOSTIC UNDER MICROGRAVITY AT BREMEN DROP TOWER

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ABSTRACT

This paper describes a digital high-speed camera- and recording system that will be used primary for combustion research under microgravity (µg) at Bremen drop tower. To study the reaction zones during the process of combustion particularly OH-radicals are detected two-dimensional by using the method of laser induced predissociation fluorescence (LIPF). A pulsed high-energy excimer laser system combined with a two-staged intensified CCD-camera allows a repetition rate of 250 images (256 x 256 pixels) per second, according to the maximum laser pulse repetition. The laser system is integrated at the top of the 110 m high evacuatable drop tube. Motorized mirrors are necessary to achieve a stable beam position within the area of interest during the drop of the experiment-capsule. The duration of 1 drop will be 4.7 seconds (microgravity conditions). About 1500 images are captured and stored onboard the drop capsule 96 MByte RAM image storage system. After saving capsule and data, a special PC-based image processing software visualizes the movies and extracts physical information out of the images. Now, after two and a half year of developments the system is working operational and capable of high temporal two-dimensional LIPF-measuring of OH, H_2O, O_2, and CO concentrations and two-dimensional temperature distribution of these species.

1. INTRODUCTION

The drop tower located in Bremen, Germany, is a European unique facility to provide ground based short term microgravity experiments. The duration of microgravity is 4.7 seconds and depends on the drop distance of 110 m inside the tower (fig. 1). To minimize any outer disturbances the inside of the inner steel drop tube can be evacuated down to 10 Pa, so the remaining acceleration is less than 10^{-6} g. The drop capsule reaches the breaking unit with 167 km/h final speed and stops inside the deceleration container, filled with fine polystyrene pellets. The internal equipment of each drop capsule is design in such a way to stay undamaged during the breaking phase with $30g_0$ deceleration in average. The facility delivers 3 drops per day. In order to double the microgravity time it is planned to install a catapult system at the base of the shaft.

The ZARM-institute is working on the scientific fields of hydrodynamic stability, rotating fluids, interfacial dynamics, space technology, hypersonic and combustion to study phenomena under reduced gravity. The objective of the combustion research is to collect data about physical and chemical processes during combustion. In contrast to terrestrial conditions, in the microgravity environment of Bremen drop tower convective mass transport can be totally suppressed. Without the overlapping and masking effects of natural convection driven buoyancy the purely diffusion controlled microstructures of combustion can be examined. So the high-pressure combustion project analyzes the behavior of single fuel droplets during heating, evaporation, auto ignition and combustion under varied ambient conditions [1]. Inside a static high pressure cell, the developing of concentration- and temperature profiles around the fuel-droplets like methanol or n-heptane were investigated by applied thermocouples, video cameras, high-speed cine and interferometric methods. By comparing these experiments with attending 1g-experiments and theoretical considerations a combustion model of single droplets and droplet sprays under µg-conditions can be defined.

While the UV-laser diagnostic as a non-intrusive diagnostic system is well established in terrestrial combustion, at drop tower Bremen now exists an excimer laser based two-dimensional spectroscopic measurement technique for examination under short weightlessness conditions [2] [3]. The beam of an excimer laser system (KrF^+ at 248 nm) mounted in the top of the tower is mirrored into the vacuum tube and follows the track of the falling capsule. After entering the capsule positioning sensors and motorized mirrors compensate deviations, so a well defined beam position is available. Formed to a 30 mm wide sheet the beam passes the reaction zone for 25 ns and induces two-dimensional the characteristic optical effects which are detected by the image intensified CCD-camera up to 250 images per second. First experiments have been carried in 1995 on the chemical structure of diffusion flames burning around single fuelled spheres (methanol, n-heptane). Physical background is the electronic $A^2\Sigma \rightarrow X^2\Pi$ transition of OH-radicals.

2. DESIGN BENCHMARKS OF THE LASERSYSTEM AND BEAM GUIDE

Two UV-excimer lasers are used in an oscillator-amplifier configuration (*Lambda Physik LPX 120i, LPX 220i*) and equipped with an external narrowband unit using a tunable Littrow grating. The laser enables high pulse repetition rates of 250 Hz and provides high output energy up to 600 mJ per pulse. The pulse duration of 25 ns and the narrowband properties (2 pm) obtain high temporal and spectral resolutions. Because of the variability of the laser wavelength spectroscopic investigations are possible within a band of 1 nm at 248 nm. In order to minimize the divergence of the laser beam over the operation distance range of 5 to 120 m the beam is expanded to about 30 x 30 mm^2 by means of a telescope and formed to a thin sheet later inside the drop capsule.

The laser system itself is integrated at the top of the tower, mounted directly to the inner vacuum tube to prevent from relative movements. The widened beam enters the tube through an inlet window and follows the falling capsule via a mirror (fig. 1).

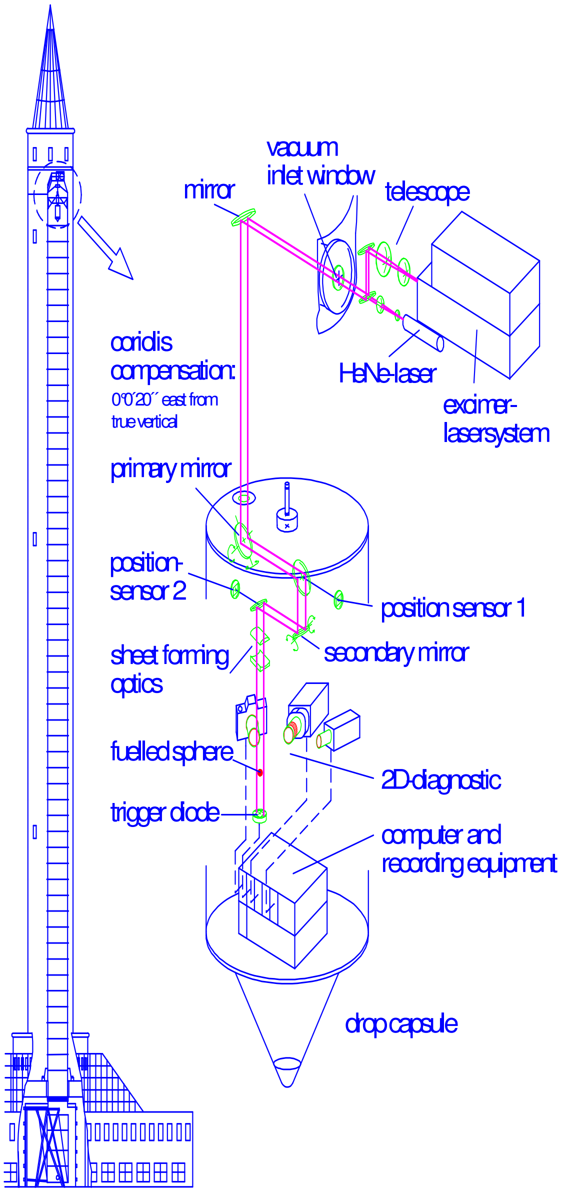

Fig. 1: Drop tower with drop capsule and beam guide of UV-laser system

Inside the drop capsule a so-called pointing assembly and cylindrical lenses shape the beam to a light sheet of suitable height and achieves a stable beam position within the area of interest. The beam traveling derives from small wind induced oscillations of the tube and thus lateral or rotational deviations of the capsule relative to the tube from the moments of release on. The pointing assembly is based on two positioning sensing detectors (PSD) measuring the position of a confocal continuous HeNe-beam and two motorized mirrors, all connected together by a real time control unit.

The laser system at the top of the tower is completely remote controlled from the drop tower control room. The position of the laser beam can be easily adapted to different experimental arrangements. For training as well as calibration and 1g-experiments a second comparable system is available in a laboratory.

3. DESIGN BENCHMARKS OF THE HIGH-SPEED CAMERA- AND RECORDINGSYSTEM

Ignition and burning of the fuel are recorded by ordinary video and photo camera within the integral light and by a special digital high speed camera- and recording system to watch the narrow banded (2 pm) laser induced predissociation fluorescence (LIPF) of the fuel respectively OH-radicals at 248 nm (fig. 2). The sensor for the two-dimensional LIPF-spectroscopy is designed as a high-speed CCD-camera. The 256 x 256 pixel camera is equipped with a two-staged proxifier in *Chevron*-arrangement. The laser beam also triggers the camera control unit. So the camera is only sensitive during the phase of LIPF by switching the gain of the phosphorized micro channel plates (MCP). Additional optical interference filters prevents the sensor from saturation by scattered laser light. High temporal resolution is necessary because of costs and limited time of the µg-phase and on the other hand to study possible turbulent structures in a better way. So up to 250 images per second are taken, according to the maximum laser pulse repetition. The onboard digital image storage system includes an analog-/digital converter and has a memory of 96 MByte RAM to captures about 1500 images at 18 MHz pixel clock and 8 bits per pixel dynamic range.

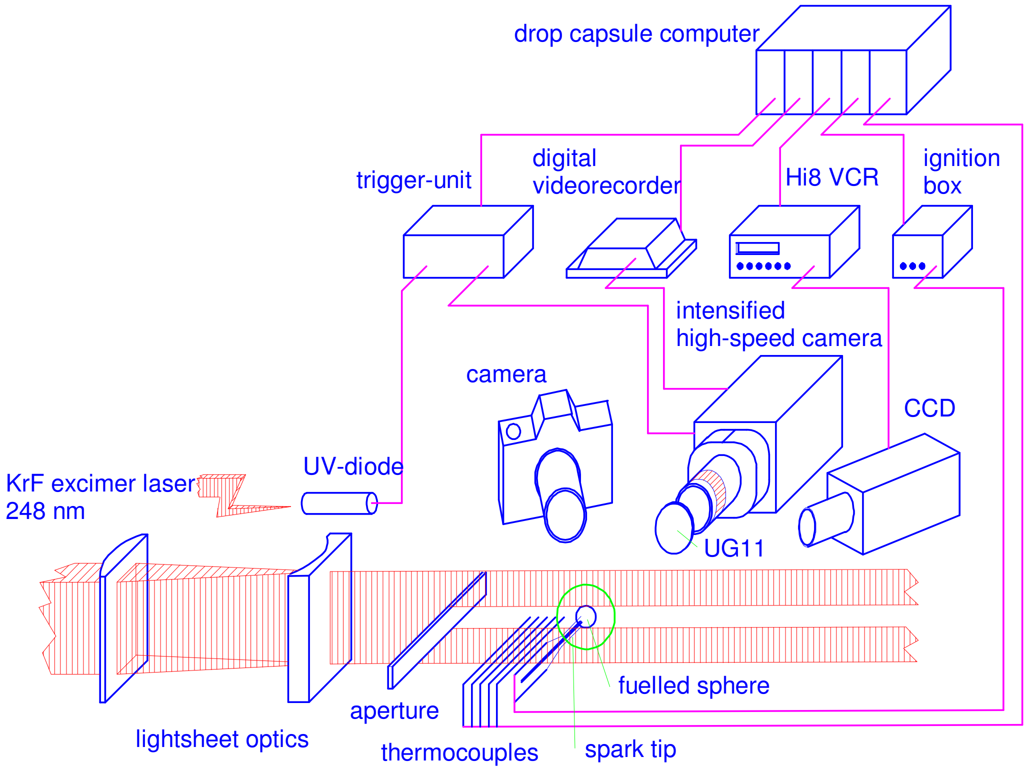

Fig. 2: Experimental setup with camera arrangement inside the drop capsule

4. DROP CAPSULE AND DROP TOWER OPERATION

The microgravity laboratory system itself is a cylindrical capsule with a diameter of 800 mm and a length of 2.4 meters. Inserted platforms, held in aluminium profiles, form a flexible drop capsule structure. The standard equipment of a drop capsule includes a computer platform as well as the accumulator platform necessary for internal power supply. The computer of the capsule will facilitate experimental control, housekeeping data storage and interactive experimental guidance by means of telemetry during pre-test and microgravity phase. The middle of the capsule is reserved for the experiment to be applied. The whole capsule will be closed pressure tight with an aluminium cover after the integration of the experiment.

The 1.700 cubic meters capacity of the steel drop tube and the deceleration chamber is then evacuated to minimize the air drag acting to the falling capsule. A system of 18 pumps with a nominal capacity of 32.000 cubic meters per hour will require about 1.5 hours for the evacuation. The capsule is then released in accordance with the scientists and their experiments at a residual pressure of 10 Pa by the control station of the drop tower.

After the damping of disturbances caused by the release, merely residual accelerations of 10^{-6} g will be detected during the free fall of 110 meters. As mentioned within the introduction chapter, the drop capsule arrives at the breaking zone with 167 km/h final speed and is gently stopped inside the deceleration container, filled with fine polystyrene pellets. The nose cone of the capsule reduces the entry peak, stabilizes the vertical axis during the breaking and houses the antenna of the telemetry system. For retrieval, the vacuum chamber is reflowed with preconditioned air within 20 min.

5. IMAGE DATA-HANDLING AND -PROCESSING

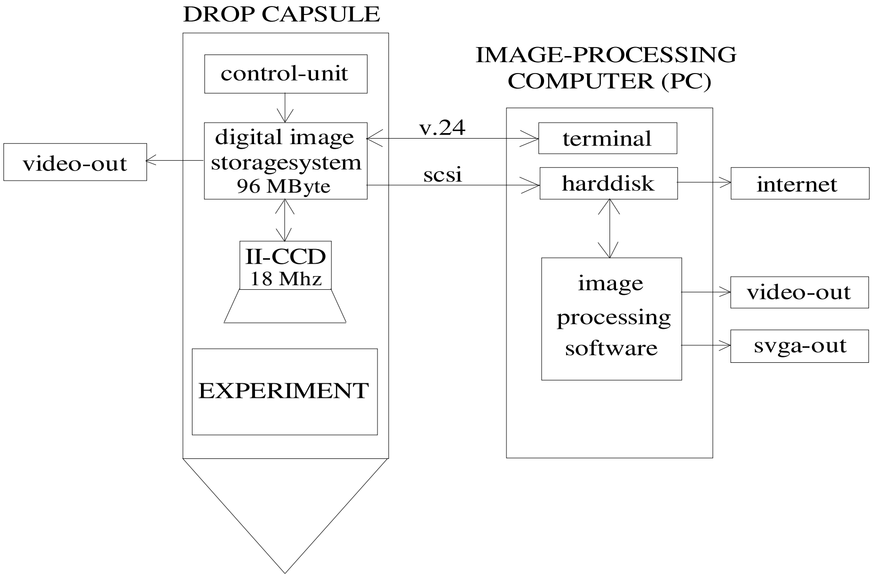

Fig. 3: Image data acquisition, -handling and -processing

After recovery of the drop capsule from the breaking chamber, the digital image data and other housekeeping data can be transmitted by telemetry to computer network or saved directly on PC hard disk via SCSI-link. Also video output is available for first monitoring.

To analyze the image data a special PC-based image processing software was implemented (*Borland Pascal*). Software tools like contrast enhancements, smoothing, calibration with background images, filtering, etc. are important to improve the image quality. Special tools extract physical and chemical information automatically out of the images (species concentration, geometry of combustion zone, etc.). Later the processed data can be watched like a movie with a rate of 25 images per second on the svga-screen, respectively video-transferred on TV-screen or VCR (fig. 3).

6. FIRST RESULTS

To verify the capability of the whole system a demonstration drop tower experiment was carried out. An experimental image sequence (fig. 4a-4i, grayscale inverted) at 250 Hz shows the transition of an OH-radial field around a burning methanol porous sphere (fig. 5) during the transition from normal gravity (1g, present convection flow) to microgravity (µg, no convection flow). The silica fiber sphere has a diameter of 6.75 mm and is fuelled by a movable needle-pump system briefly the drop capsule released. The ignition is realized by pulsed high-voltage via thin wires. The porosity of the sphere is about 80 % to keep the influence of the matrix on the heat capacity and heat conductivity compared with an all-fuel droplet as low as possible [4]. An aperture is necessary to prevent laser light scattering from the sphere.

fig. 4a: 1g flame fig. 4b: $t_d + 16$ ms fig. 4c: $t_d + 32$ ms

fig. 4d: $t_d + 48$ ms fig. 4e: $t_d + 64$ ms fig. 4f: $t_d + 80$ ms

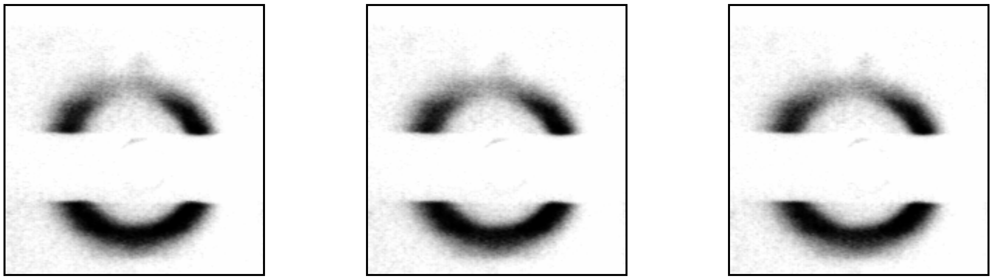

fig. 4g: $t_d + 96$ ms fig. 4h: $t_d + 112$ ms fig. 4i: $t_d + 128$ ms

Fig. 4a-4i: Image sequence with 1g → µg transition at 250 Hz (each 4th image is shown)

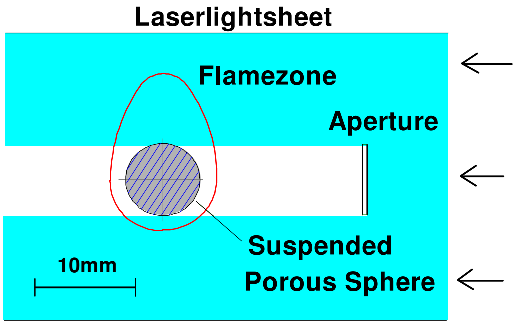

Fig. 5: Flame within the laser light sheet →

7. CONCLUSIONS

After two and a half years of design and construction the two-dimensional UV-diagnostic system at Bremen drop tower is operational. High temporal and spectral resolution are provided under microgravity conditions. To demonstrate the capability of the system, OH concentration fields were measured in a burning methanol soaked porous sphere.

At the moment the system is capable of:

- 2-dimensional LIPF measuring of OH, H_2O, O_2 and CO concentrations.
- 2-dimensional temperature measurements can be performed via Rayleigh-scattering or differential LIF.
- Mie-scattered signal of soot-aggregates or seeded tracers can simultaneously be used for particle-image velocimetry (PIV).

Further planning includes:

- 1-dimensional Raman-spectroscopy for simultaneous measurement of different major species by implementing a polychromator in the drop capsule.
- Raman shift to 226 nm by implementing a Raman-cell in the capsule will enable 2-dimensional-LIF of NO and O.
- Adaptation of a Dye-cell for 2-dimensional-LIF of aldehydes at 353 nm is planned.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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