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## LASER - DOPPLER VELOCIMETRY IN IONIZED GASES : A REVIEW PAPER.

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Abstract

A review of plasmas velocities measurements by means of Laser-Doppler velocimetry is presented. Specific difficulties are pointed out. Although such experiments are until now very scarce, there is no doubt that the future will see a tremendous increase of LDV-applications to plasmas owing to its great potential.

The reader is assumed to be well aware of the LDV general theory and applications. Basic books are available (1, 2, 3).

LDV-measurements have been successively made in liquids (4), cold gases, then combustion devices. Plasmas investigations started more lately, owing to the expected difficulties : high temperatures giving rise to noise problems due to plasma and seeding particles radiations ; electromagnetic saturation of the electronic devices (r.f. torches) or electrical interference from the large current supplied to arcs ; fast evaporation of the scatter centers, coupled with difficulties to be sure that they are small enough to follow the fluid when they reach the optical probe ; thermophoresis phenomenon producing a very slow rate of data acquisition when some critical zones are studied ; sensitivity of the plasma state to the presence of possible artificial seeding particles, etc. Nevertheless, workers attempted to solve these problems in order for instance to provide a better understanding of the heat and mass transfer processes between a plasma flow and suspended particles, with emphasis on plasma chemistry.

S.A.SELF started experiments in a MHD boundary layer (5, 6, 7) with additional problems due to restricted optical access, high velocities (> 500 m/s), high spatial resolution requirements, refractive index inhomogeneity, scatter from the wall. On the other hand, temperatures were rather low ( $\sim 2\ 700\ K$ ), and the fluid was more a flame than strictly speaking a plasma. Furthermore the detection used an optical Fabry-Perot system, so

without heterodyning. It was then spectroscopic measurements rather than classical LDV-ones. A laserline filter is used (10 Å bandwidth) to remove thermal radiation and ambient light. Experiments have been then carried out with a differential-forward scatter method for sidewall measurements (8, 9). Processing was achieved through a high-speed counter linked to an P-2100 computer. Mean velocities, turbulence intensities and spectrum of velocity fluctuations have been measured.

M.R.BARRAULT et al reported about LDV-experiments in a transient (12 ms) arc circuit breaker(10). Specific problems arose plus the extra problems of transient nature of the arc, high velocities (up to  $3\ 000\ ms^{-1}$ ) and drastic seeding problems. The real fringe mode optical set-up was used and forward scattering from an  $Ar^+$ , 1.5 W, laser. The parasitic radiation was removed with a 10 Å interference filter and associated polariser, plus a Fabry-Perot filter of 0.5 Å bandwidth. Signal processing was achieved through an oscillographic raster display. Then improvements were made in order to cover the entire arcing period (11). But problems of interpretation remained due to the unknown size of scatter centers which did not always follow the fluid. An approximate correlation was used between signal frequencies (particle velocities) and signal amplitudes (particle sizes) in order to deduce the plasma velocity from the particle one. Such a correlation is not very reliable : as a matter of fact, big particles passing through the edges of the control volume give rise to the same signal amplitudes than small ones passing through its center. Effectively, the authors consider that the accuracy is not better than about 40 %. Then, IRIE and BARRAULT carried out measurements using the Doppler shift of a Q-switched ruby laser radiation without foreign elements. Again, there was no heterodyne detection, so that it was spectroscopy measurements rather than LDV ones (12).

GOUESBET reported LDV-mean velocities measurements in a 4 MHz, rf torch, by means of a 5 mW

He-Ne forward real fringe system with oscillographic display of the signals (13, 14). But the exact fluid velocity was not measured due to the too large sizes of the used particles, although the disagreement was further found to be less than typically 20 %. Further experiments were carried out with a more powerful laser (Krypton, 800 mW on the 647,1 nm line) and an automatic data acquisition and processing system using a single counter (15, 16, 17, 18). The parasitic emitted light was removed by means of a monochromator (2 Å bandwidth). Seeding was achieved by means of a counter-current system supplying the plasma in  $\sim 5 \mu\text{m}$ ,  $\text{Al}_2\text{O}_3$ -particles, at a rate sufficiently small for not disturbing the flow. The beam was expanded before focusing to improve the S/N ratio and the spatial resolution. The spatial resolution was again increased by collecting the scattered light off-axis. The effect of the parasitic rf radiation was decreased by means of a Faraday cage and filtering the signal through rejectors. Mean velocities and 'fluctuations' have been successfully carried out. Furthermore, the atom temperatures were measured by coupling LDV- and dynamic pressures measurements.

Mme THI HIEN HO attempted measurements in a 4 MHz rf torch with a 5 mW He-Ne laser, using a real fringe mode set-up (19). Processing was achieved through a frequency tracker and a frequency analyser. Measurements were not really successful. It is suggested that a frequency tracker could be difficult to work properly owing to the small rate of particles arrival. The frequency analyser probably picked up the radio frequency of the plasma generator. Furthermore, GOUESBET's experiments showed that a 5 mW power is too critical for 'comfortable' measurements in such a situation. The photon correlation technique could be possibly successfully used.

LDV-measurements are reported from the Imperial College (London) in a DC transferred arc heater at the National Physical Laboratory (20,21). Real fringe systems were tested in forward and backward scatterings. A spectrum analyser, a frequency tracker and a frequency counter have been tested. The seeding particles were Nickel ( $\sim 50 \mu\text{m}$ ) and alumina ones ( $\sim 1 \mu\text{m}$ ). Velocity histograms were recorded. Alumina particles exhibit much higher velocities than nickel ones, as it could be expected from drag arguments.

The author is aware of experiments carried out in Limoges but no report has been received at time to discuss about them. Let us also mention Tiller's paper (22). Finally, preliminary plasma experiments have been made at the ONERA in 1975. A plasma work is actually now planned (Boutier, ONERA, Châtillon/Bâgneux).

#### CONCLUSION

The previous reported experiments show that LDV can be successfully used for plasma diagnostics. The difficulties remain important, but there is now no doubt that such techniques will become a very popular tool for such experiments owing to the tremendous versatility and potential of LDV-systems.

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