THE IMAGING OF A SCHOCK WAVE WITHIN A SUPER-SONIC LOW-PRESSURE GAS FLOW USING OPTICAL METHODS

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Abstract: Using Environmental Scanning Electron Microscope (ESEM), which uses high gas pressure within the specimen chamber instead of vacuum, allows us to study samples containing water, samples with high capacity and live biological samples. It is because of the lack of the need to freeze the sample to sublimate the water from it. However, the behavior of the pumped gas in low pressures is not well mapped to be the low-pressure gas flow simulations considered adequately precise for applying on ESEM. To increase the precision of simulations, it is possible to use optical methods for imaging the shock wave within the differentially pumped chamber because of its uniqueness.

Keywords: ANSYS Fluent, Electron microscopy, Environmental scanning electron microscope, ESEM, Optical methods, Shadowgraph, Schlieren method, Shock wave, SolidWorks

1 INTRODUCTION

Not only because of high gas pressure difference between its tube (1 mPa – 1nPa) and specimen chamber (up to 3 kPa) that can be achieved, but also because of its ability to compensate the charging of the specimen, the Environmental scanning electron microscope is the most suitable for studying many kinds of samples we were not able to study before, such as biological samples, samples containing liquid water, dielectric samples with high capacity and even chemical reaction [1].

To be able to achieve and maintain such high gas pressure difference there is a built-in differentially pumped chamber between the tube and the specimen chamber. This chamber or more precisely the gas flow running through it was a subject of many simulations and experiments aiming to precisely describe the behavior of supersonic low-pressure gas flow which could help to make the microscope more accurate and to get more insight into simulations of stochastic effects.

One of possible ways to gain insight into the behavior of this gas flow is by using optical methods to get an image of a shock wave which forms on a boundary between supersonic and subsonic flow and which is the most specific area of every single supersonic gas flow.

2 OPTICAL METHODS

There are three methods that can be used to display the shock wave formed within the chamber, the Shadowgraph, the Schlieren method and Mach-Zehnder interferometer. These methods are based on the refractive index change caused by the density change of the fluid, which affects the refraction angle of the light beam that goes through the fluid. This principle can be described with Clausius-Mosotti equation:

$$n - 1 = K\rho \tag{1}$$

where n is the refractive index, ρ is the densify of fluid and K is the Gladston-Dale constant (refractivity) of the fluid [3]. The principle of these methods can be seen of Figure 3.

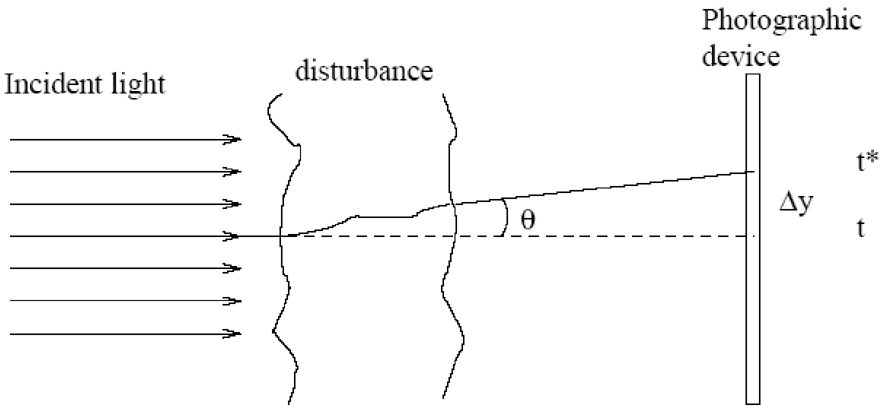

Figure 1: Fundamental scheme of optical methods

2.1 SHADOWGRAPH

Shadowgraph is the fundamentally simplest of the three optical methods that can be used to determine the density change within a fluids' flow. It is qualitative method which gives the second derivation of density (the speed of density change) as a result image on a photographic device. The principle of the Shadowgraph can be seen on Figure 4.

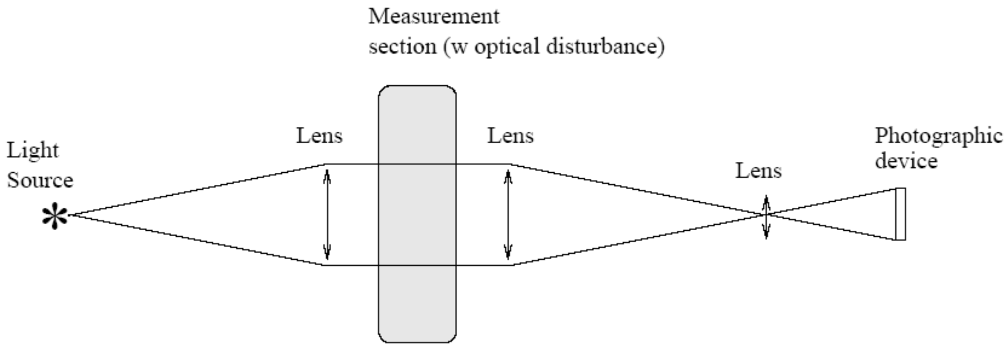

Figure 2: The scheme of the Shadowgraph

2.2 SCHLIEREN METHOD

Schlieren method is also qualitative method and it is very similar to the Shadowgraph, except there is an optical knife in the focal point of the beam, which removes the diffraction of the beam downwards (dark areas) and keeps the diffraction upwards (light areas) unchanged, thus instead of the second derivation it gives the first derivation (the gradient) of the density of the fluid as a result. The principle of this method can be seen on Figure 5.

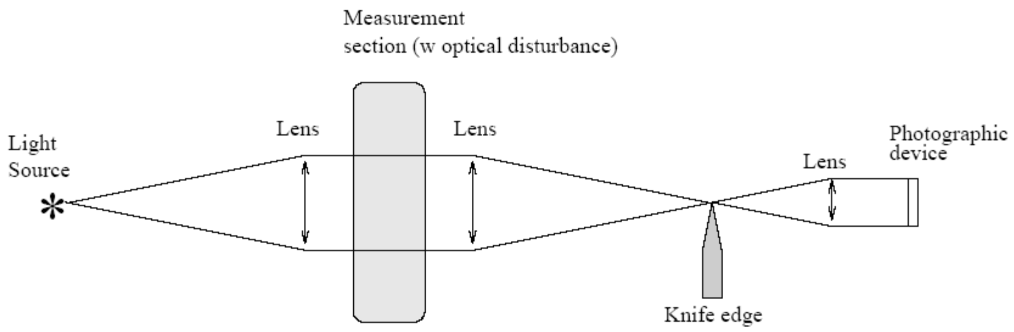

Figure 3: The scheme of the Schlieren method

2.3 MACH-ZEHNDER INTERFEROMETER

This method is the most complex of the three optical methods described. Unlike the two previous methods, it is a quantitative method and it gives directly the density of the fluid as a result. Using Mach-Zehnder interferometer requires the use of two chambers that will be compared. One chamber through which the fluid will flow and the second one which will serve as a compensating chamber containing the same fluid with comparable static pressure to the one within the first chamber. The principle of the interferometric method can be seen on Figure 6.

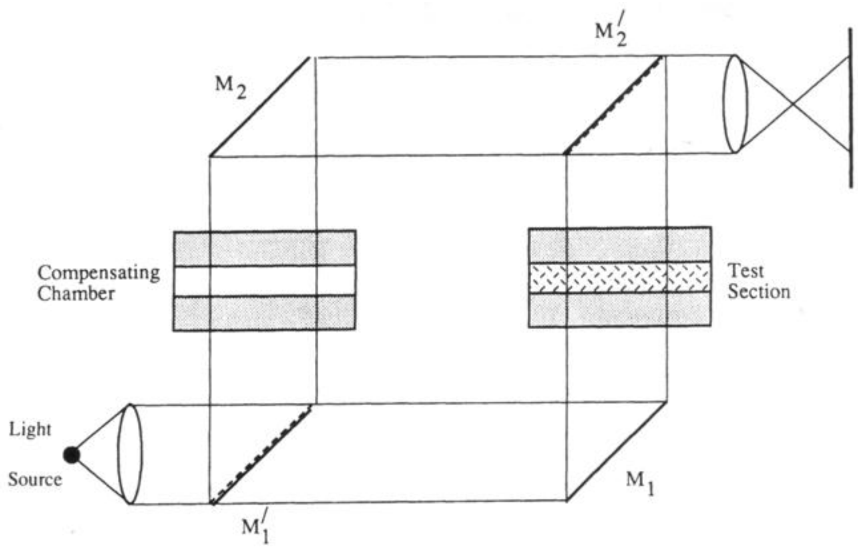

Figure 4: Mach-Zehnder interferometer

3 SIMULATION MODEL

To be able to create a clearly visible supersonic shock wave in such small area like the differentially pumped chamber and which can also be displayed using optical methods, we needed to modify the chambers' construction.

As a base construction of the differentially pumped chamber for further modifications we used a simplified model G. D. Danilatos used for calculations with Monte Carlo method and that you can see on Figure 1.

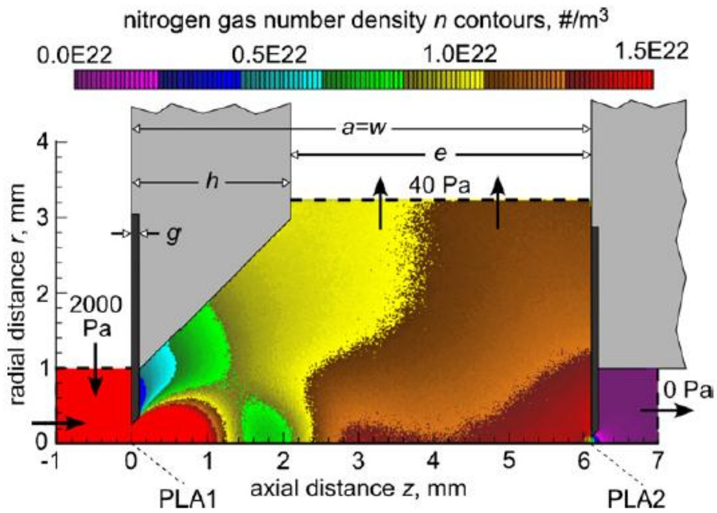

Figure 5: Sectional view of simplified differentially pumped chamber from G. D. Danilatos [2]

In this version of differentially pumped chamber the shock wave forms blurred (the green area on X axis 1,8 mm right of PLA1). We modified the inner shape of the chamber, as shown on Figure 2, to intensify the shock wave and its shape and to be able to display it using optical methods.

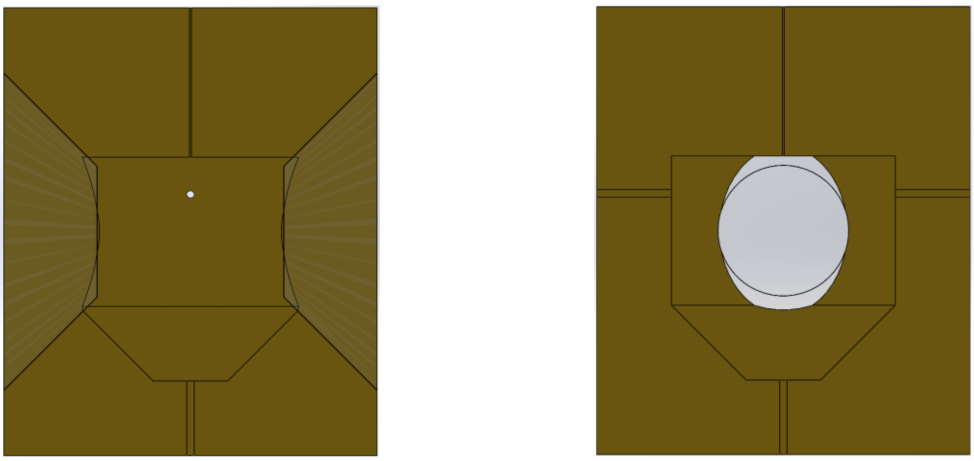

Figure 6: Sectional view of modified chamber with glass apertures

4 CONCLUSION

Contribution of this work to the current progress in mapping a behavior of a low-pressure fluid flow is in the use of supersonic flow and in the mapping of the shock wave formed within it. Currently this work is in the stage of checking the simulation results so the shock wave is properly formed and displayable using the optical methods. Next step will be the manufacturing of the chamber based on the 3D model used in the simulations. Then we will apply the optical methods on the manufactured chamber followed by the finish tuning of the mathematical model and simulation settings so the next simulations of low pressure supersonic fluid flows can be more accurate.

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