A Computational Fluid Dynamics Model of a Spinning Pipe Gas Lens

C Mafusire[1,2*], A. Forbes[1,2,3], G Snedden[4]
[1]CSIR National Laser Centre, PO Box 395, Pretoria, 0001, South Africa
[2]School of Physics, University of KwaZulu–Natal, Private Bag X54001, Durban 4000, South Africa
[3]Stellenbosch University, Private Bag X1, Matieland 7602, South Africa
[4]CSIR Defence Peace Safety Security, P. O. Box 395, Pretoria 0001, South Africa
*email: cmafusire@csir.co.za,www.csir.co.za

Abstract:

When a metal horizontal pipe is heated and rotated along its axis, a graded refractive index distribution is generated which can be used as a lens, hence the name, the spinning pipe gas lens (SPGL). Experimental results showed that though increase in rotation speed and/or temperature resulted in a stronger lens and removed distortions due to gravity, it also increased the size of higher order aberrations resulting in an increase in the beam quality factor (M^2). A computational fluid dynamics (CFD) model was prepared to simulate the aerodynamics that show how it operates and, in the process shed some light on the experimental results.

Introduction:

When a metal pipe is heated and rotated along its axis, the heat causes a lower density to occur near the walls which forces the cold air along the axis. Since density of a gas is directly proportional to its refractive index, this implies the refractive index along the axis is higher than near the walls, a graded index medium. Hence if a laser beam is propagated along the axis, it can be focused. This device is called a spinning pipe gas lens (SPGL). The effect is increased by rotating the pipe which causes exchange of gas with the surroundings which means the axis is always kept at room temperature. The rotation also removes distortions due to gravity.

However, the temperature field causes gases of different temperatures to mix randomly, causing turbulence, the process which is accelerated by increasing the rotation speed. A higher wall temperature increases the temperature gradient and a higher rotation speed increases the gas mixing. This means the conditions which make it possible for lensing are also responsible for the turbulence. The spinning pipe gas lens can be referred to as a lensing medium which introduces beam 'tremble' thereby causing deterioration in beam quality. Therefore, the SPGL can be referred to as a generator of turbulence, since by changing the temperature and/or rotation speed, one can, effectively, 'control' the turbulence.

The randomness of the gas lens medium can be characterized by aberrations generated by the medium onto a laser beam. In this case, the aberrations are expressed using Zernike polynomial set at selected rotation speeds and wall temperatures.

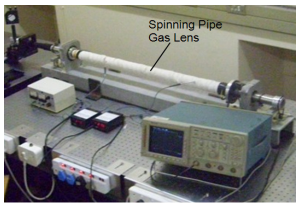

Figure 1 *Spinning pipe gas lens*

A computational fluid dynamics model:

A computational fluid dynamics (CFD) model of the pipe show the density distribution in a pipe rotating at 20 Hz with a wall temperature of 100˚C. The diagrams show that there are gas exchanges which take place with the surroundings (Figure 2) which is responsible for the gas lens's ability to focus effectively since it creates a more degraded density distribution which makes the lens stronger. A cross–section of a SPGL showing (top left) the velocity and (top right) the density distribution of the gases as the warmer gas near the wall escapes, and is replaced by the cool air which enters along the axis.). A closer profile shows the cyclic nature of the localised velocity distributions (bottom). The results are confirmed in Figure 3 which shows that rotational symmetry is achieved during rotation. The density and temperature distribution for the entire SPGL (Figure 4) illustrate the fact that focusing in the SPGL occurs at two sections along its length making it imperative that it must be aligned properly.

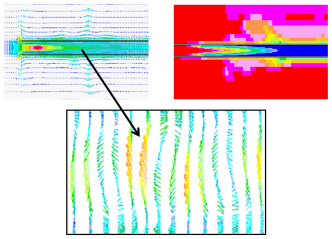

Figure 2 *Velocity and density profiles*

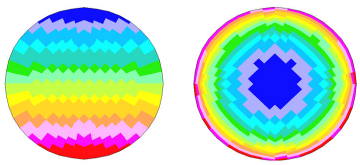

Figure 3 *Density cross-sections before (left) and during (right) rotation*

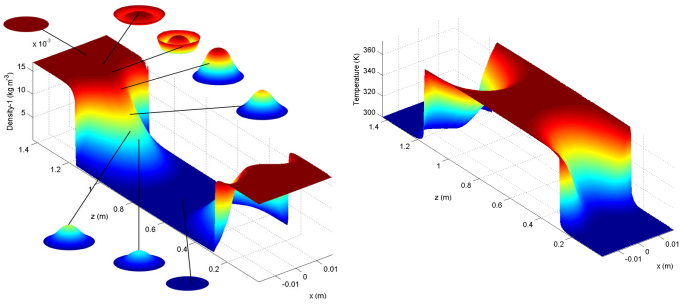

Figure 4 *Density with cross-section profiles (left) and temperature (right) inside an SPGL*

Experimental verification:

The experimental set-up showing the position of the Shack-Hartmann wavefront sensor after the SPGL to measure focal length, beam quality and Zernike coefficients is shown in Figure 5.

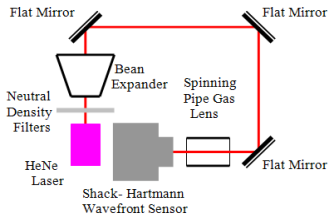

Figure 5 *Experimental Setup*

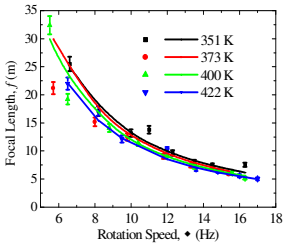

Figure 6 *The focal length of the SPGL as calculated from the optical wavefront*

(a) (b) (c)

Figure 7 *The phase distribution of the laser beam with: (a) no rotation but heated to 422 K, showing tilt; (b) after rotating the SPGL at 17 Hz, showing significant curvature on the wavefront; and (c) same conditions as in (b) but with defocus and tilt removed, revealing the higher order aberrations.*

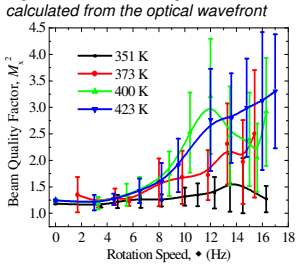

Figure 8 *Increase in M^2 with rotation speed, at selected wall temperatures, as a direct result of the aberrations*

The results show how the SPGL can focus a laser beam, the conditions suitable for this effect are responsible for a side-effect, creation of a turbulent medium which can be controlled for experiments in lab-generated optical turbulence studies. This might explain why other aberrations, other than defocus as expected from theory, are observed. It is cheap and easy to make which makes it an instrument of choice in such work.

References

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