our future through science

Gas Lensing in a Heated Spinning Pipe

C MAFUSIRE[1,2], A FORBES[2], G SNEDDEN[3], C MAHLASE[3], MM MICHAELIS[4] & M MATHUTHU[1]
[1]University of Zimbabwe, Mount Pleasant, Harare, Zimbabwe
[2]CSIR National Laser Centre, PO Box 395, Pretoria 0001, South Africa
[3]CSIR Defence Peace Safety and Security, PO Box 395, Pretoria 0001, South Africa
[4]University of KwaZulu-Natal, Durban 4041, South Africa

ABSTRACT

When a heated pipe is rotated, the dynamics of the gas inside exhibit properties reminiscent of a solid-state positive lens. The properties are a result of a parabolic distribution of refractive index in the pipe which is caused by mixing of hot and cold gases. When a laser beam was propagated along the pipe's axis a focal spot was observed. Experimental data to demonstrate how the lensing properties depend on pipe rotation speed and pipe temperature is presented. A numerical model using the basic equations of a Graded Refractive INdex (GRIN) lens provides a further tool to analyse the propagation of laser beams through this system.

BEAM PROPAGATION THROUGH GAS LENSES

The heated spinning pipe acts as a GRIN lens where the refractive index variation inside the pipe is given by

$$n(r) = n_o - \tfrac{1}{2}\gamma^2 r^2 \qquad (1)$$

The variable parameters of the gas lens in this work were the rotation speed ω and temperature T, and thus γ = γ (ω,T). Assuming no=1, the ABCD matrix of a beam propagating in the lens is given by

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(\gamma z) & \sin(\gamma z)/\gamma \\ -\sin(\gamma z)/\gamma & \cos(\gamma z) \end{bmatrix} \qquad (2)$$

where z is the beam propagation distance. An equation showing the variation of the beam size, ω(z), in the lens, which can only be presented in terms of the A and B components, is given by the equation:

$$\omega^2 = A^2\omega_o^2 + B^2\theta_o^2 \qquad (3)$$

where ω_o and θ_o are the input beam waist and divergence respectively. After substituting we find that

$$\omega^2(z) = \omega_o^2\cos^2(\gamma z) + \frac{M^4\lambda^2}{\pi^2\omega_o^2}\frac{\sin^2(\gamma z)}{\gamma^2} \qquad (4)$$

If the parameter γ(ω,T) is chosen correctly by selecting appropriate values for the speed of rotation and the pipe temperature, then the system will have only one focus outside the pipe, leading to the view that the pipe acts as a lens.

EXPERIMENTAL SETUP

The spinning pipe gas lens (SPGL) used was made of stainless steel and was fitted on a stand. It was 1.43 m long with an internal diameter of 3.66 cm. The pipe was rotated along its axis at frequencies up to 1200 rpm. The rotation speed of the pipe was determined by using an optical switch to monitor the time for each complete rotation of the pipe. The pipe had a heating tape wound around an 88 cm section of the pipe, with almost equal uncovered portions on each side. The tape was made up of a heat- resistant fibre intertwined with electrical wiring. Heat was generated when an electric current was passed through these wires. A special heat-resistant tape, made of asbestos, was wound on top of the heating tape, to reduce heat losses. The temperature measurement system used in the investigation consisted of three WIKA model 3503 temperature monitors, each with a dynamic range -50°C to 200°C. Thermocouples, made of platinum and titanium, were attached to each of the monitors and a value was displayed on the digital monitor. The focal length was measured from the exit of the pipe to a moveable screen, where the waist position was determined visually. The difference between the focal plane and the waist plane was found to be negligible.

Figure 1: (a) Experimental setup with gas lens

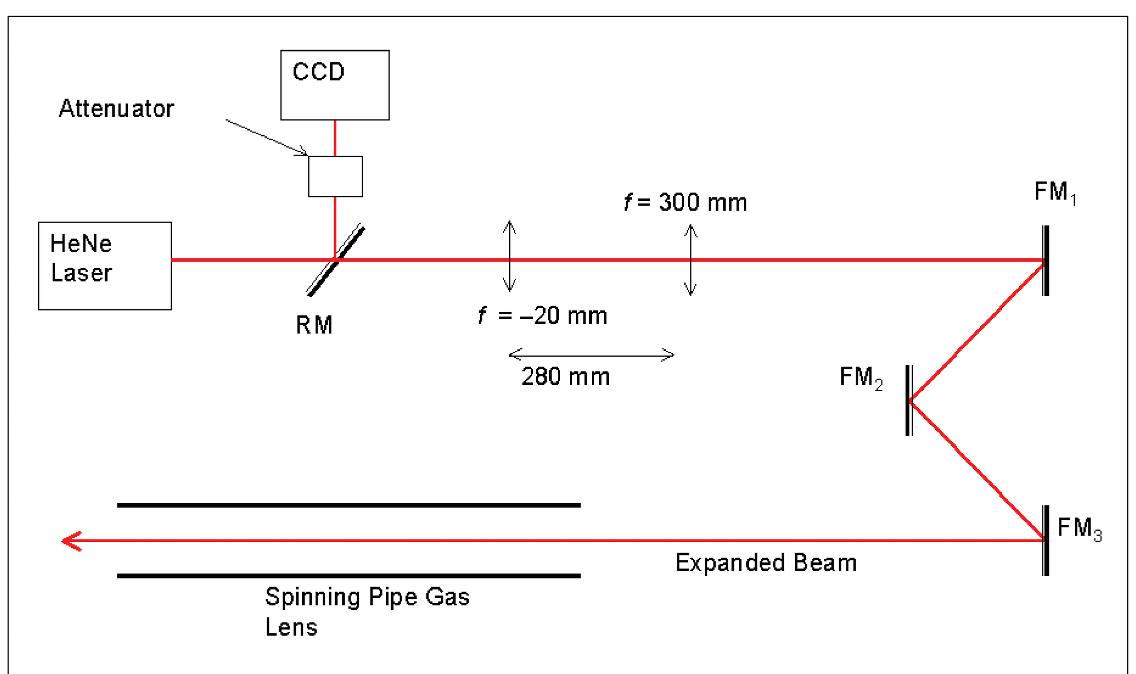

Figure 1: (b) Schematic of the output delivery system

RESULTS

The results can be summarised as follows:

- The heated stationary pipe retains heat inside the pipe.
- The focal spot is of poor quality and "rotates" with the pipe.
- The focal spot is actually a region in space rather than a point.
- The focal length increases with decreasing pipe speed.
- The focal length increases with decreasing temperature.
- The focal length is a constant if all other quantities are kept constant.
- The focal region decreases in length as the lens becomes stronger.
- The possible formula relating focal length, f, pipe temperature, T and pipe speed, ω, was found by regressional analysis to be

$$f(\omega,T) = 8.62\times10^{13}\,\omega^{-1.6}T^{-4.5}$$

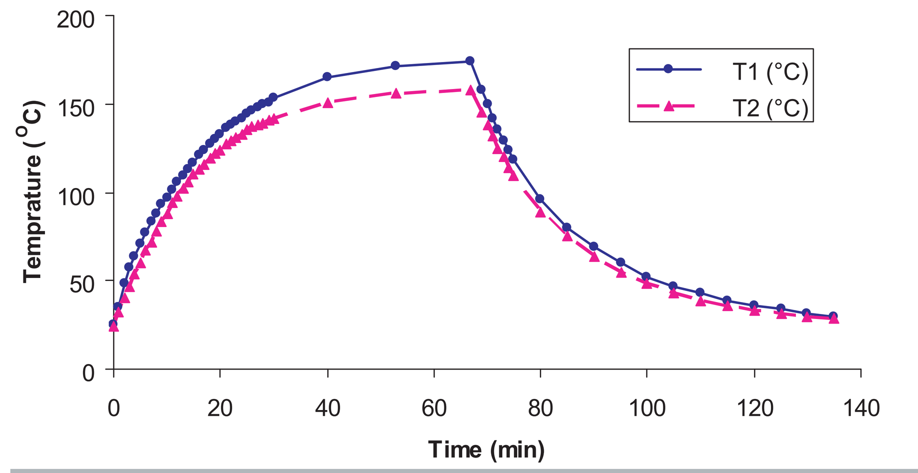

Figure 2: Typical heating and cooling cycle for the gas lens, with the temperature measured at two points along the pipe length. The temperature measured along the length of the pipe shows an almost constant distribution along the heated section, cooling rapidly in the non-heated section

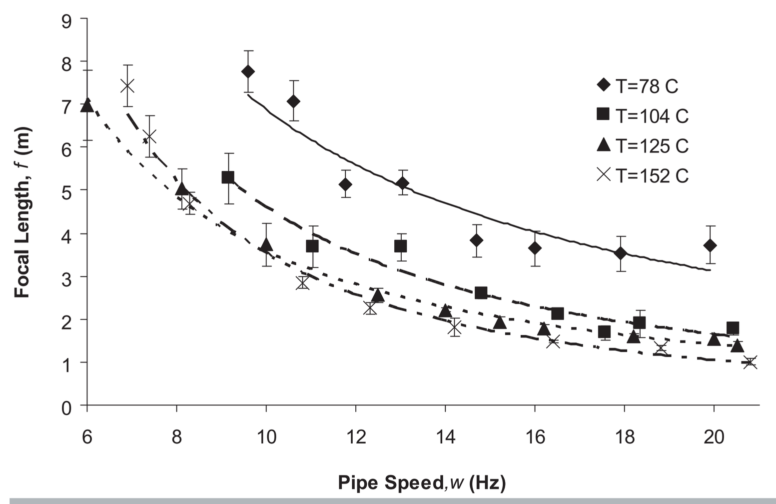

Figure 3: Measured focal lengths of the gas lens as a function of both pipe rotation speed and pipe temperature

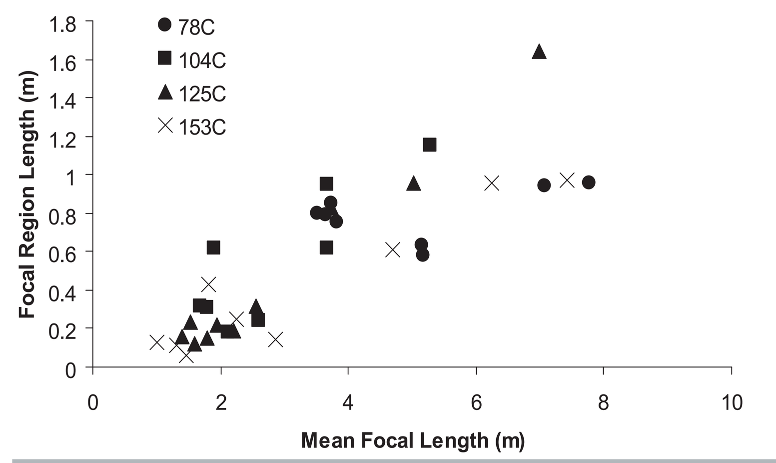

Figure 4: The focal "spot" was found to be more of a region than a spot

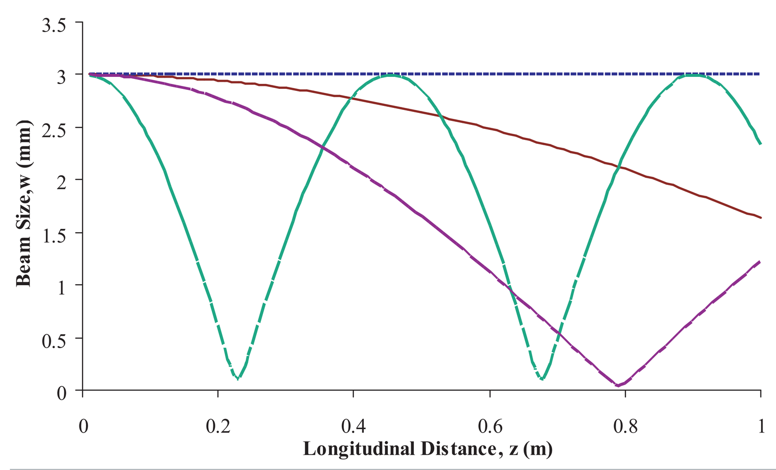

Figure 5: The propagation of the beam inside the pipe is determined by the initial beam parameters, and by the properties of the GRIN system. Here the lens is varied in strength from no lens (γ=0), to a very strong waveguide (γ=5)

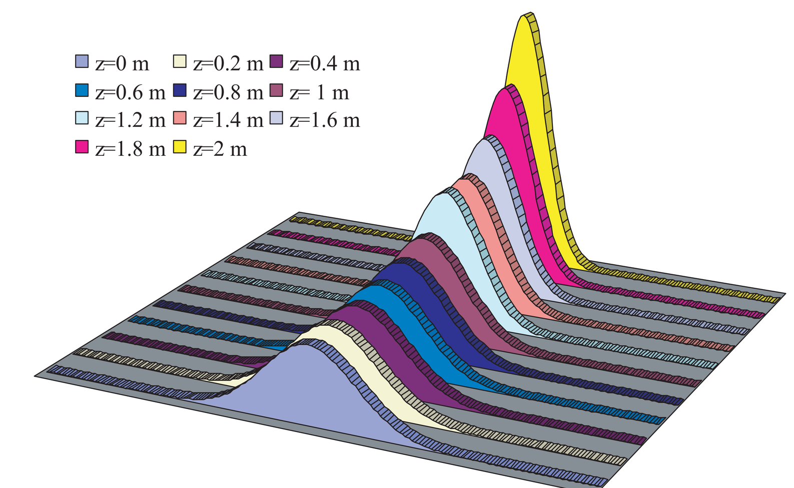

Figure 6: Intensity plots of a Gaussian beam passing through the GRIN system, with γ=0.5. Here the beam starts to focus to a point outside the pipe, similar to the case in the experiment

CONCLUSION AND FUTURE WORK

The properties of a spinning pipe gas lens have been demonstrated experimentally and numerically. This work forms the basis for an extended study of the dynamics of beam propagation through turbulent systems, and in particular, the following aspects will be explored in future work: (I) Using the recent advances in lasers beam propagation theory, the properties of the lens will be characterised in terms of the M^2 parameter and related directly to phase aberrations introduced by the lens. This has not been done before, and would complete the body of work previously done on the subject; and (II) the aberrations introduced to the laser are a function of the distance from the edge of the pipe, as well as the speed of the pipe spinning. This is because of the turbulence near the pipe wall. The speed of the pipe will be used to "control" the turbulence, and the resulting aberrations monitored. This should yield new insights into how the degree of turbulence influences specific Zernike aberration terms. It is also the first stage needed if one is to compensate for the turbulent media by adaptive systems.

REFERENCES

1. A. Forbes "Photothermal Refraction and Focussing" PhD Thesis, University of Natal, 1998.
2. D. Gloge "Deformation of Gas Lenses by Gravity" The Bell System Technical Journals 46 2 (1967) pp 357-365.
3. M.M. Michaelis, P.F. Cunningham, R.S. Cazalet, J.A. Waltham, M. Notcutt "Gas Lens Applications" Laser and Particle Beams 9 2 (1991) pp 641-651
4. M. Notcutt, M.M. Michaelis, P.F. Cunningham, J.A. Waltham "Spinning Pipe Gas Lens" Optics and Laser Technology 20 2 (1988) pp 243-250
5. Anthony E. Siegman "Lasers" University Science Books Mill Valley (1986)
6. P.Kaiser "Measured Beam Deformations in a Guide Made of Tubular gas Lenses" The Bell System Technical Journals (February 1967) pp 179-194
7. P.Kaiser "An Improved Thermal Gas Lens for Optical Beam Waveguides" The Bell System Technical Journals (January 1970) pp 137-153