Neutral Gas Interferometry in Gemini TA1

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1 Introduction

An important step to achieving stable, controlled laser wakefield acceleration is thorough design and characterisation of the gas targetry used. This is the remit of the EPAC gas target development programme, which includes fluid simulation, manufacturing and experimental testing of targets. An interferometry rig has been established in Gemini TA1 for experimental measurement of neutral gas density profiles generated by targets. An overview of the setup and the developments made in the last year are presented here.

2 Setup

The interferometry setup detailed in last year's Annual Report has been upgraded to address to the limitations described in that document. The current layout is shown in figure 1. A Thorlabs, 1 mW HeNe is expanded to approximately 30 mm beam diameter and then split before the chamber. The beam that passes through the jet is imaged back onto itself to preserve spatial resolution on the second pass, before being imaged onto the camera. The reference arm length approximately matches the path length of the main arm since the laser coherence length is finite. It was chosen to keep all optics out of the chamber due to previous experience of the breadboard vibrating when the jet is fired. BS1 in figure 1 is a 3" diameter optic, but due to the footprint of the mount, clips the beam slightly horizontally. This limits the field of view horizontally to approximately 23 mm. When a slightly larger field of view is required, the gas jet can be mounted such that it is facing horizontally. A photo of this system is shown in figure 2.

The gas system in TA1 can operate in low or high pressure regimes depending on whether a gas cell or a gas jet is used. The low pressure system delivers up to 1 bar whereas the high pressure system delivers up to 100 bar. The gas used is Argon as it is diatomic, so gives density profiles representative of Helium, but produces a larger phase shift for a given density, hence increases our density resolution.

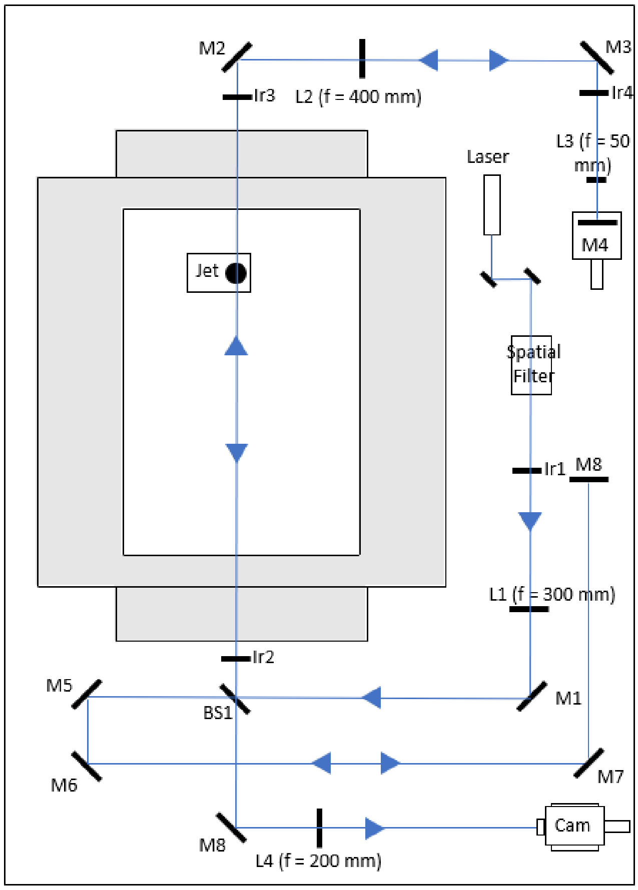

Figure 1: Diagram of two pass Michelson interferometer setup. The shaded area denotes the vacuum chamber. M = Mirror, L = Lens, Ir = Iris, BS = Beamsplitter.

3 Results

The neutral gas interferometry system was exploited to characterise a slot nozzle with 20 mm length. The nozzle design is covered in last year's report. Interferograms were taken with the probe laser travelling through the long side of the nozzle (end on) and through the short side of the nozzle (side on). Filtering of the interferograms is performed using a 1D-FFT based method [1] when the phase shift is $\gtrsim$1 rad and using a 2D continuous wavelet transform based method [2] for smaller phase shifts. The measured width of the phase profile in one direction gives the length of gas the laser propagates through when the nozzle is in the orthogonal

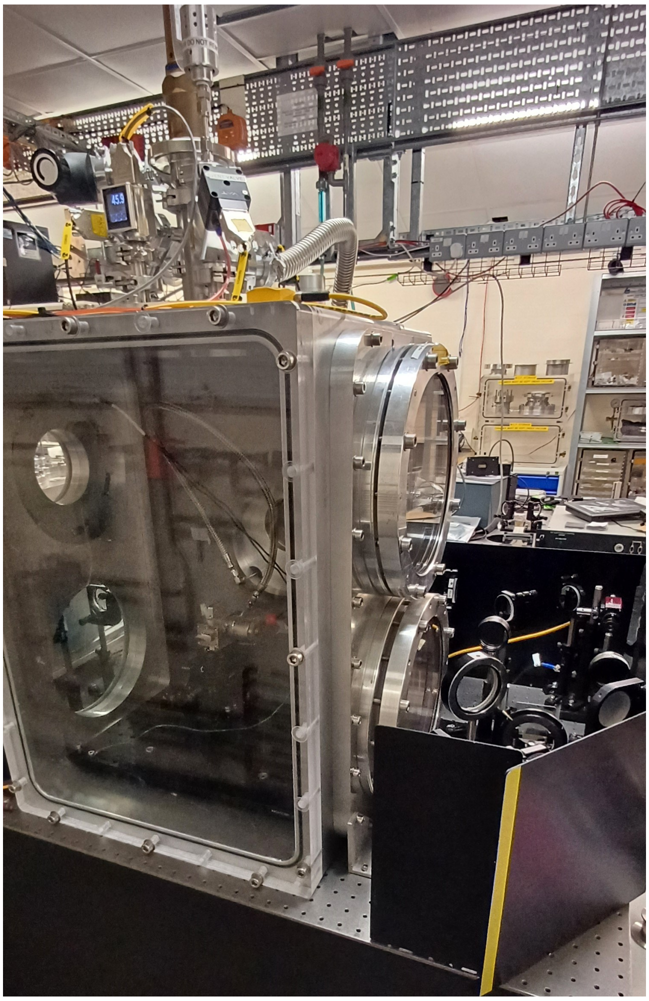

Figure 2: Photo of vacuum chamber and experimental setup in TA1.

geometry, which is required for the calibration from phase to density.

The measured density profile delivered by the nozzle with 20 bar backing pressure in the end on geometry is plotted in figure 3. With the nozzle in this direction, the laser passes through approximately 20 mm of gas and accumulates a few radians of phase shift. In this case, the phase shift is easily extracted from the interferogram and the resultant density profile shows very little sign of noise or defects in the image. The profile here is in good agreement with 3D fluid simulation. In the side on geometry, shown in figure 4, the phase shift is ≈ 1 rad, so the signal to noise ratio is worse. In particular, the measurement of the density ramp on the left edge appears to be impacted by a small image defect. The broad profile of the nozzle though is well captured with this system. The smallest phase shift that can be measured in this system is approximately 100 mrad, which corresponds to $5 \times 10^{17}\,\mathrm{cm}^{-3}$ per mm of argon gas the probe travels through in one pass.

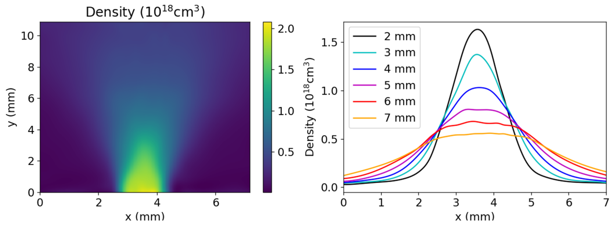

Figure 3: 2D density profile of the nozzle in the end on geometry (left) and line outs at a number of heights above the nozzle (right).

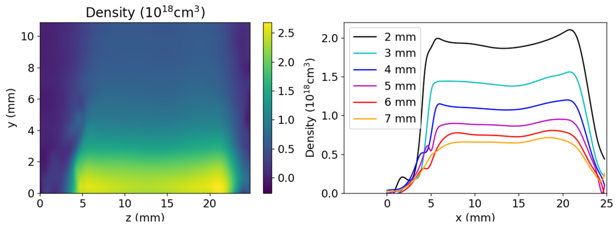

Figure 4: 2D density profile of the nozzle in the side on geometry (left) and line outs at a number of heights above the nozzle (right).

Characterisation of the jet's temporal evolution has also been performed. A Peter-Paul solenoid valve [3] was used for this measurement and the nozzle was placed in the end on geometry with 10 bar backing pressure. The left plot in figure 5 shows the measured gas density versus trigger delay between the valve trigger and the camera trigger for a valve opening time of 20 ms. An approximate steady state is reached when the camera is triggered 12-14 ms after the valve trigger. A number of factors contribute to this delay: the delay between the TTL signal sent by the delay generator and the solenoid valve receiving an electrical signal, the finite opening time of the valve and, once the valve is fully open, the time taken for a steady state to be reached a few mm above the nozzle exit. Given that some gas is measured after 4 ms, that sets an upper bound for the delay generated by the pulser box. To try to deconvolve these factors further, the density response was measured with a fixed trigger delay of 14 ms and a variable valve opening time, as shown in the plot on the right of figure 5. The peak is achieved with 9 ms opening time. The 5 ms difference between opening time and trigger time is a mixture of the pulser box delay and the fill time of the reservoir below the supersonic nozzle, leaving an upper bound of 9 ms for the valve opening time. All of these factors require further study for EPAC, where, at

10 Hz rep rate, a difference of a few ms in opening time corresponds to thousands of pounds worth of gas.

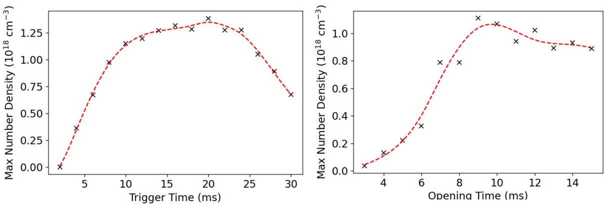

Figure 5: Measured density with fixed, 20 ms valve opening time and variable camera trigger time (left) and with fixed, 14 ms camera trigger time and variable valve opening time (right).

4 Conclusion

A permanent, neutral gas interferometry system has been established in Gemini TA1, capable of measuring phase shifts on the order of 100 mrad. The density profile generated by a 20 mm length slot nozzle has been measured and the time evolution of the density profile has been studied. This system will be vital for EPAC gas targetry characterisation. We can also provide support for visitors from the user community to test their EPAC appropriate gas targets with this setup too.

References

[1] Mitsuo Takeda, Hideki Ina, and Seiji Kobayashi. Fourier-transform method of fringe-pattern analysis for computer-based topography and interferometry. *J. Opt. Soc. Am.* **72,** 1 (1982), pp. 156–160.

[2] Paolo Tomassini et al. Analyzing laser plasma interferograms with a continuous wavelet transform ridgeextraction technique: the method. *Appl. Opt.* **40,** 35 (2001), pp. 6561–6568.

[3] *Peter Paul.* `https://peterpaul.com/valves/2-way-normally-closed/series-20-model-eh22`.