Pinhole alignment system for the Gemini amplifiers

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Introduction

Astra Gemini has now been operational as a user facility since January 2008 [1] and has completed a number of successful experiments. The laser is set up every morning by the laser operators before it is made available to the experimental scientists in the Gemini target area. A key consideration in the continuing system development is to minimise setup time and effort required in order to maximise the availability for the laser users.

Pinhole alignment

Gemini is based around a pair of large aperture Ti:Sapphire amplifiers, used to increase the energy of the split Astra beam from 100 s of mJ up to ~25 J per beam. The alignment of these amplifiers is crucial to their proper function and is checked on a daily basis when setting up the laser.

Vacuum spatial filters (VSFs) are employed in the design of the amplifiers to clean up the beam after every pass though the Ti:S crystal. Spatial filtering removes high spatial frequency intensity components within the beam that could otherwise cause damage to the optics. When an energetic short pulse laser beam such as this is focused to a point, the energy density quickly exceeds the threshold for the breakdown of the medium it is passing though. Were this to happen in air, a plasma would be formed. To avoid this the focal point of the spatial filter is contained within a vacuum vessel. However when the focal region of the beam impinges on a solid target such as the edge of a metal pinhole, a plasma is formed on the metal surface, and is blown off into the surrounding vacuum. The expanding plasma can block the path of the beam in a phenomenon known as pinhole closure [2]. Pinhole closure not only reduces the energy transmission of the VSF, but due to the chirped nature of the pulse, also selectively attenuates the shorter wavelengths which pass though later, leading to spectral clipping at the output.

The alignment system detailed in this report is designed to allow the precise positioning of the beam through the VSF pinholes. It provides the laser operator a quick and straightforward method of verifying the accuracy of the alignment.

Diffracting element and diffraction pattern

Amplifier alignment is checked using a low power CW beam. Direct viewing of the pinholes themselves is awkward due to their position within vacuum vessels.

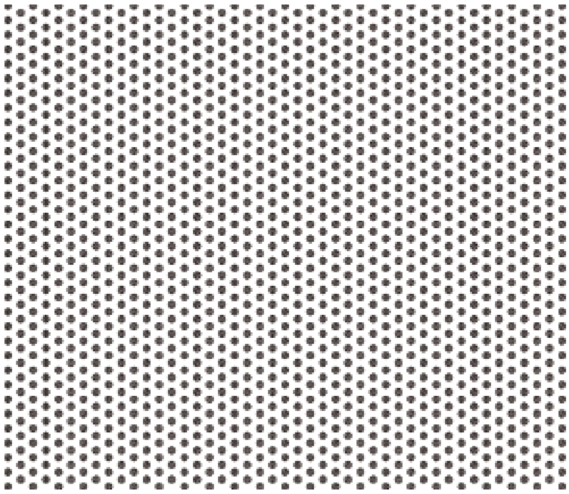

Figure 1. An example of an amplitude mask which creates a hexagonally symmetric diffraction pattern at focus.

Even when this can be achieved, the only way to position the focus is to attempt to minimise scattered light from the pinhole edges, which is not particularly precise, especially for larger pinholes many times the size of the CW laser's focal spot. Much better accuracy can be achieved by using a diffracting element, consisting of a regular array (figure 1), which will create a diffraction pattern at focus which is comparable to the pinhole diameter. The array is implemented as a simple amplitude mask by printing the pattern onto thin transparent acetate.

This diffracting element is placed in the collimated beam before the VSF and the focal plane is re-imaged onto a camera at some point after the output. A diffracting element consisting of a hexagonally symmetric array of spots will lead to a diffraction pattern comprising the central undiffracted spot, surrounded by six diffracted spots, as shown in figure 2.

By choosing the spacing of the diffracting array, d, the diameter of the diffraction pattern can be tailored to match the size of the VSF pinhole.

$$d \sin \theta = \lambda \qquad (1)$$

The grating equation for normal incidence (equation 1) gives the angular separation θ of the diffracted spots. Given the distance to focus, it is then possible to calculate the linear separation in the focal plane.

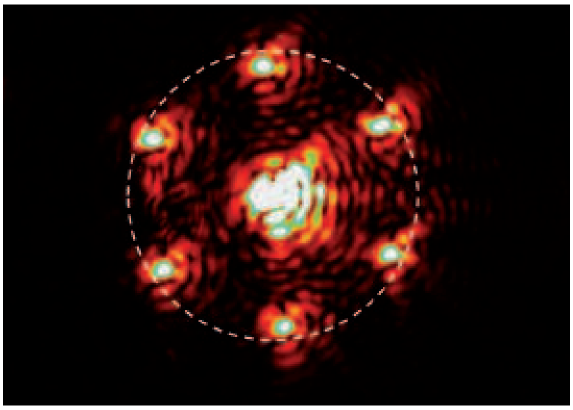

Figure 2. The diffraction spot pattern generated at focus. The dashed line shows the approximate pinhole size.

Optical layout

The concept of the optical layout for the pinhole alignment system is based on removable 'drop-in' mirrors for directing the CW beam to the diagnostic, which can be removed to avoid obstructing the main pulsed beam in normal amplifier operation

A diagnostic channel is formed running across the amplifier, perpendicular to the optical axis of the crystal. Where this intersects with the beam after each pass through the crystal, a kinematically locating magnetic base is positioned which accepts an accordingly mounted two inch diameter mirror. When the mirror is put in place the beam is diverted through a simple plano-convex lens and is brought to a focus, where it is then imaged by a microscope objective onto a CCD camera (Marlin F033B, Allied Vision Technology).

Operation

The pinhole sizes used in the Gemini amplifiers are 1.5 mm diameter for the VSFs after the first and second pass of the crystal, and a larger 2 mm size following the third pass, where the energy is highest. Array spacings were chosen to produce spot patterns slightly smaller than this. Any slight misalignment of the beam is therefore clearly visible as clipping of the diffracted spots on the pinhole edge, as shown in figure 4.

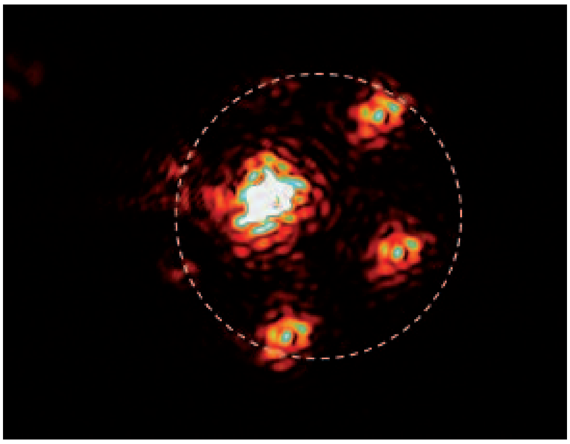

Figure 4. The diffraction spot pattern visible for a misaligned beam, some of the pattern is obscured by the pinhole. The dashed line shows the approximate pinhole size and position.

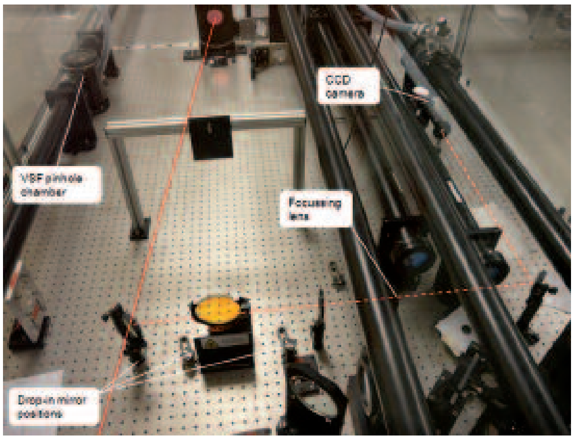

Figure 3. A view of the optical layout looking down from above the amplifier.

Summary and outlook

We have successfully designed and implemented a simple and accurate system for aligning a laser beam through the pinhole of a vacuum spatial filter. The system is based on an aperture mask which generates a diffraction pattern in the pinhole plane, which is then re-imaged onto a camera. Currently the aperture masks consist of a dot pattern printed onto transparency film. The film however can potentially introduce a deviation in beam direction and hence in focal spot position. Therefore it is planned to replace the film with a pattern of holes drilled into an opaque plate.

References

1. C. J. Hooker *et al.*, CLF Annual Report 2007-08.
2. J. S. Pearlman *et al.*, *Applied Optics* **16**, p2328 (1977).