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SHADOWGRAPH ILLUMINATION TECHNIQUES FOR FRAMING CAMERAS

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Many pulse power applications in use at the Pegasus facility at the Los Alamos National Laboratory require specialized imaging techniques. Due to the short event duration times, visible images are recorded by high-speed electronic framing cameras. Framing cameras provide the advantages of high speed movies of back light experiments. These high-speed framing cameras require bright illumination sources to record images with 10 ns integration times. High-power lasers offer sufficient light for back illuminating the target assemblies; however, laser speckle noise lowers the contrast in the image. Laser speckle noise also limits the effective resolution.

This discussion focuses on the use of telescopes to collect images 50 feet away. Both light field and dark field illumination techniques are compared. By adding relay lenses between the assembly target and the telescope, a high-resolution magnified image can be recorded. For dark field illumination, these relay lenses can be used to separate the object field from the illumination laser. The illumination laser can be made to focus onto the opaque secondary of a Schmidt telescope. Thus, the telescope only collects scattered light from the target assembly. This dark field illumination eliminates the laser speckle noise and allows high-resolution images to be recorded. Using the secondary of the telescope to block the illumination laser makes dark field illumination an ideal choice for the framing camera.

Overview

Techniques are being developed to measure particle size distributions of fast moving particles at the Pegasus facility at the Los Alamos National Lab[1, 2]. A shadowgraph back lighting experiment has been fielded in conjunction with holographic and X-ray diagnostics. While the hologram collects a single snap shot of a 3-dimensional volume of particles, the shadowgraph diagnostic is intended to create a short movie of the particle velocities.

Because of the hazardous environment for imaging systems at Pegasus, the expensive framing camera is located 50 feet away. Figure 1 shows typical hardware used to collect optical images of the particle distributions. A long pulse ruby laser passes in and out of a vacuum chamber. In Figure 1 the ruby laser has to share equipment space

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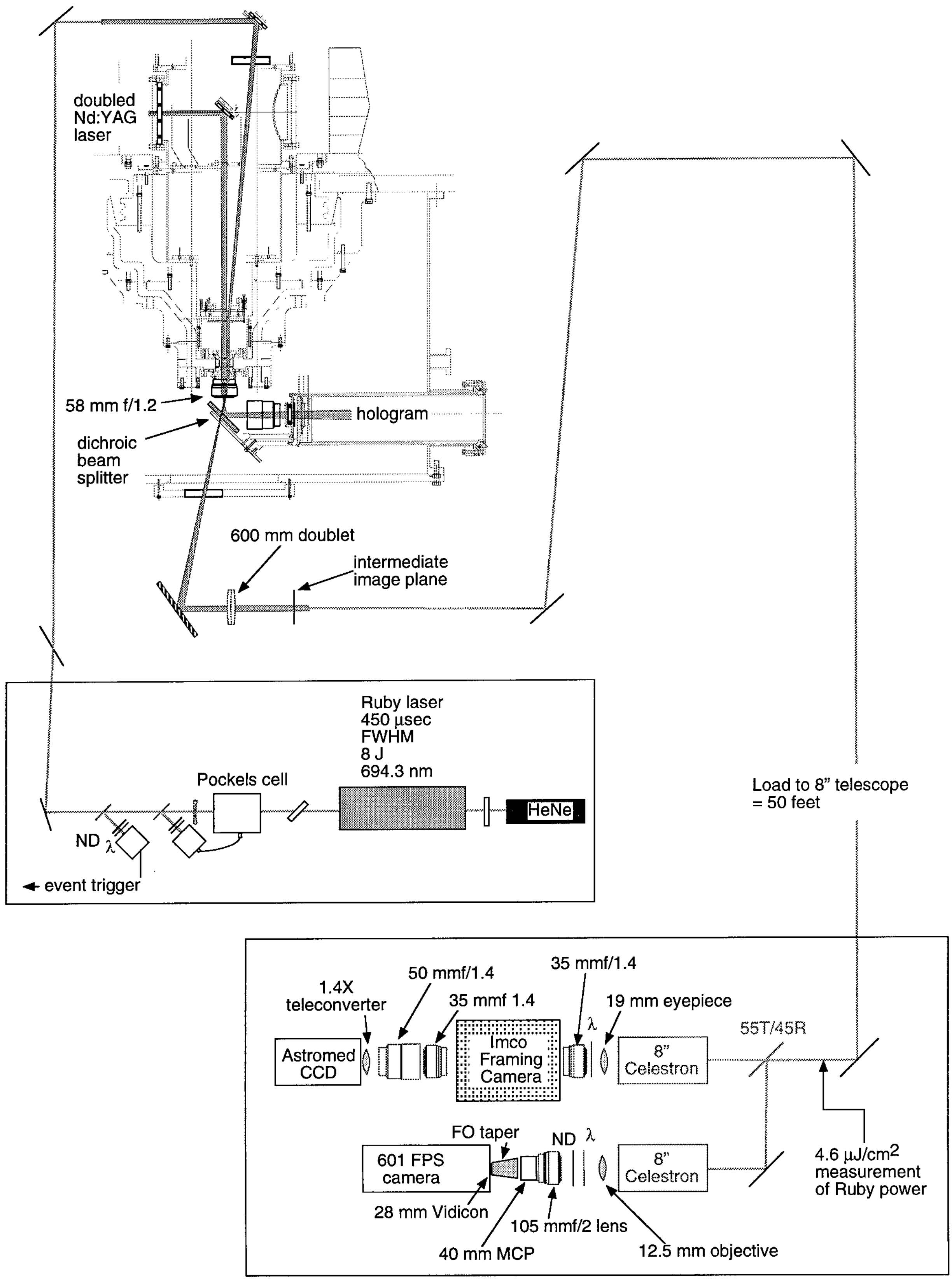

Figure 1. Pegasus hardware layout.

hardware space with holography, the primary diagnostic. An 8-inch diameter telescope located 50 feet away can only resolve 37 μm particle sizes. So, the particles are magnified with a 58 mm and 600 mm lens pair. The telescope focuses on an intermediate image plane.

By comparison, Figure 2a shows a simpler layout where only a telescope collects images from the high-speed particles (ejecta). Here, the interfering 58 mm lens required for the hologram recording is removed. The telescope collects both the illuminating ruby laser beam as well as the scattered light from the particles. This phenomena, called light field illumination, suffers problems with laser speckle which is caused by random phase variations within the laser beam. The laser beam acts as multiple laser beam sources, and the different sources interfere with each other. The amount of speckle depends on the coherence length of the laser.

By contrast, Figure 2b shows the 58 mm and 600 mm doublet lens pair that both relays and magnifies the image. By changing the position of the 600 mm lens, the illuminating ruby laser footprint can be made to vary in size. If the laser beam fills the full telescope aperture, we would have the light field illumination condition as shown in Figure 2a. By focusing the ruby laser onto the secondary mirror of the telescope, the laser beam cannot reach the image plane of the framing camera. This condition, dark field illumination, is shown in Figure 2b.

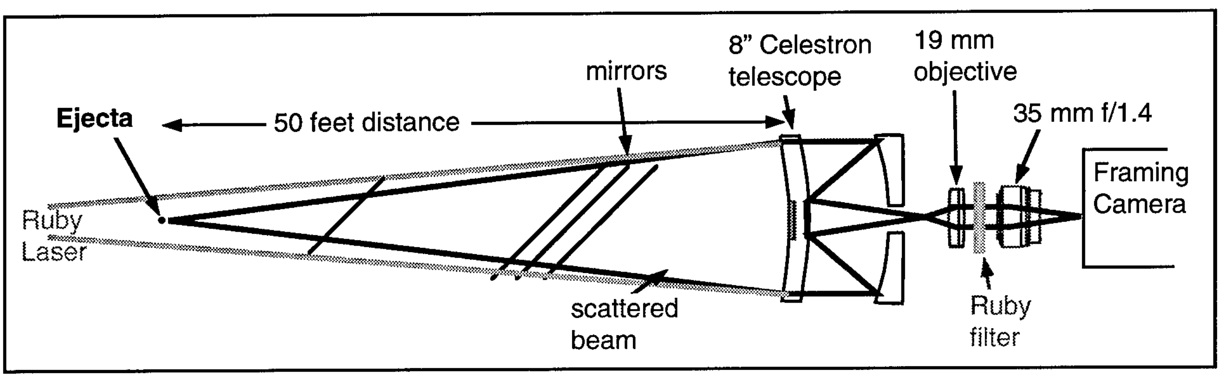

Figure 2a. Light Field Optical Layout.

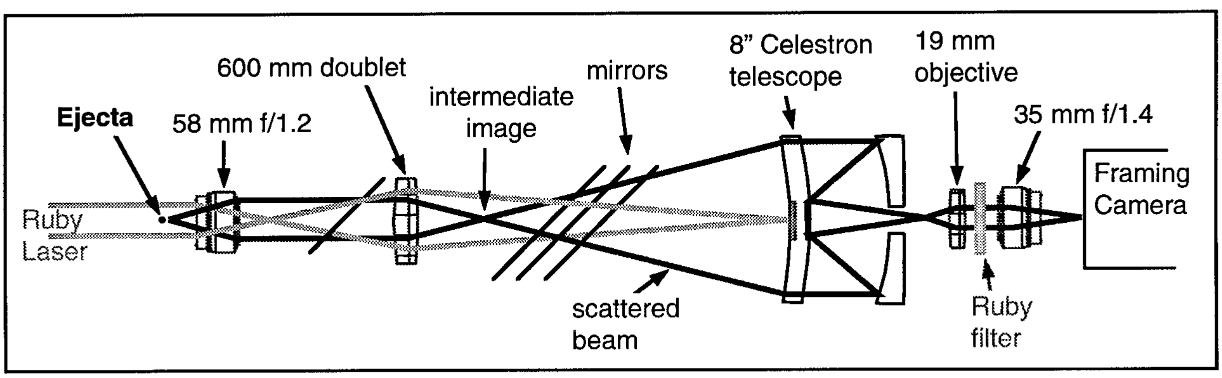

Figure 2b. Dark Field Optical Layout.

In Figure 2b, coherent noise (speckle) in the image is eliminated because the reference beam is entirely blocked at the secondary of the telescope. Additionally, this method effectively blocks the dc component of the Fourier spectrum of the object. This performs edge enhancement on the object data collected.

Experimental Data

A special resolution target was used to evaluate imaging conditions. A HeNe was used as the laser source for these evaluations. For the test results shown in Figures 3a, 3b, 3c and 3d, the optical setup of Figure 2b was used. By moving the position of the 600 mm lens, either a light field or a dark field illumination condition was created. Figure 3a shows a pattern with large structures ranging from 25 μm to 100 μm. Large structures show up reasonably well despite the laser interference patterns in the background.

The dark field condition shown in Figure 3b shows image reversal, a dark background with only edges of the resolution pattern showing up. Because the illuminated light is obscured by the secondary of the telescope, a high-pass filtering of the image occurs, which results in edge enhancement. The high-pass filtered image shown in Figure 3b illustrates the absence of dc (on-axis undiffracted energy), in that the larger bars are dark in the middle and have sharp edges.

Figure 3c shows higher frequency information for the light field condition. The lines and dots vary from 1 μm to 10 μm. Because of the interference of speckle in the image, the limiting resolution is 8 μm.

Figure 3d shows the much higher resolution obtained by using the dark field condition. Limiting resolution is 2.5 μm with much higher signal-to-noise ratios (S/N). The dots appear as bright stars against a very black background. In this higher resolution image, the centers of the dots are filled in. Dots below 25 μm in size are solid with sharp edges.

Dirt on the resolution pattern and the 600 mm lens (which is close to the intermediate image plane) can be a serious problem. Dirt on optical elements near the intermediate image will severely block out part of the image. Any unwanted out of focus ejecta data will also severely block out good data. Proper cleaning techniques are required.

Depth of Focus

The telescope in Figure 2a is 50 feet away, which gives a resolution of 37 μm. At that resolution, the depth of focus is 2.8 mm. Formulas are shown in Figure 4. In the layout shown in Figure 2b, the magnified image has a reduced depth of focus. Magnification is defined by the ratio of the 2 collecting lenses. The resolution is 3.5 μm and the depth of focus is 4 μm. This is extremely short. The first collecting lens is 35 mm away. As shown in Figures 3c and 3d, laser speckle degrades the resolution from 3.5 μm to 8

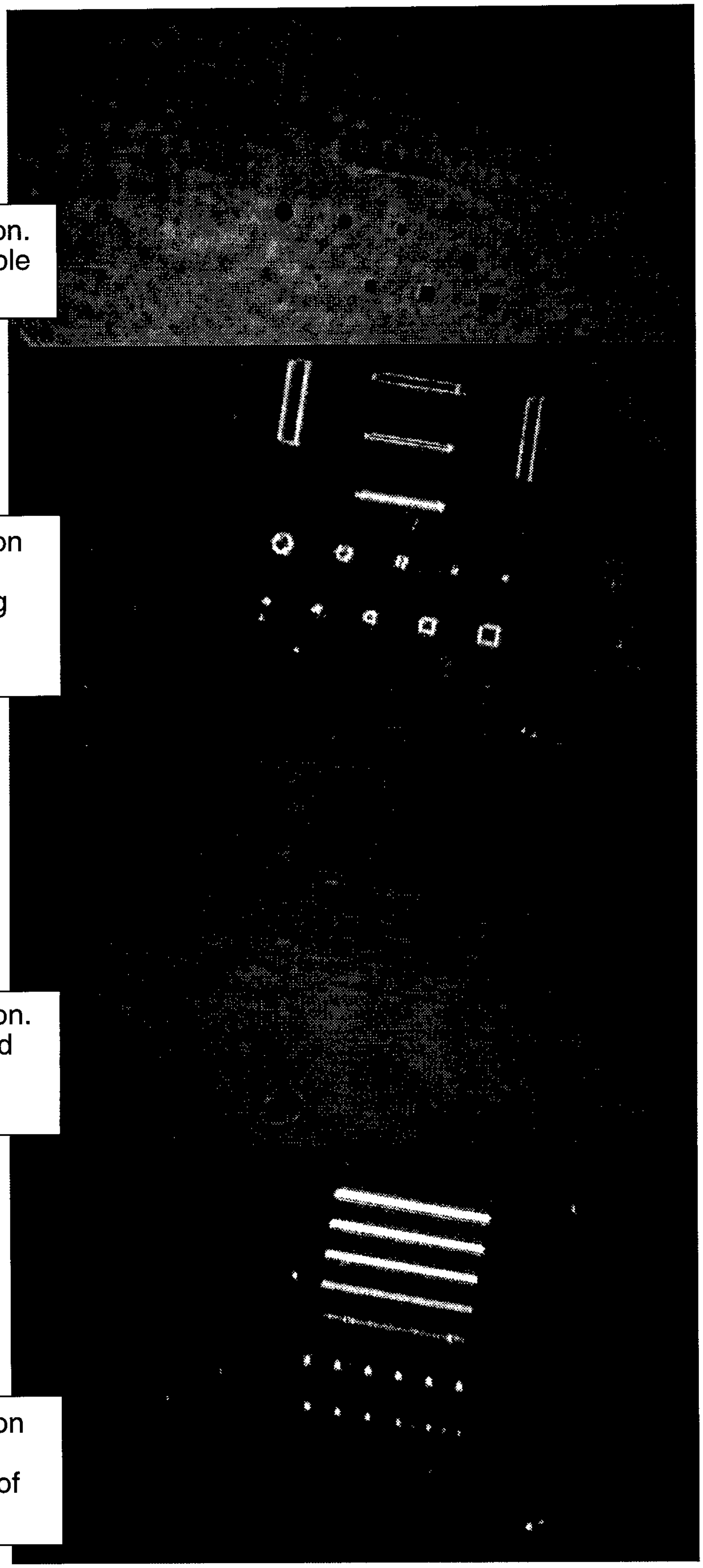

Figure 3a. Light field illumination. Large structures have reasonable S/N ratios.

Figure 3b. Dark field illumination deletes the low frequency content of the image, producing outlines of large structures. <25 μm sizes show correctly.

Figure 3c. Light field illumination. It is very hard to see the second row of dots because of laser speckle. Very low S/N ratio.

Figure 3d. Dark field illumination shows much higher S/N than Figure 3c. You can see a hint of the 2.5 μm dot.

μm, but the dark field condition shows diffracted imaging collection.

Because the depth of focus for the dark field condition is so short, care must be taken to insert a calibrated wire at the image plane to find best focus. Care must be taken so that out of focus material does not obscure the data. This is done with baffles and slits to block unwanted scattering sources.

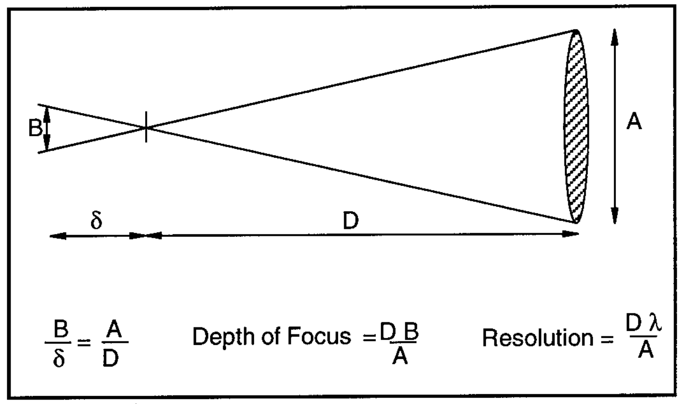

Figure 4. Depth of Focus

At this depth of focus, building vibrations make focusing and alignment challenging, but the event data was collected in 50 ns.

Conclusion

We have tried various methods of using diffusing materials to smooth out the laser speckle with very limited success. A Raman cell to broaden the laser wavelength would decrease the coherent length and reduce speckle. This was too difficult to try inside our experimental vacuum chamber.

An optical imaging system has been developed to relay very small objects onto a telescope to be recorded by a high-speed framing camera. To eliminate the laser speckle from a high-power pulsed ruby laser, the laser beam is imaged onto the obscuration of the telescope. The telescope thus collects only the scattered or diffracted light from the small objects. Superior resolution and signal-to-noise ratio are achieved in the recorded image. Because of the high signal-to-noise ratio of the data, full dynamic range of the image system is achieved by applying a log rescaling to the image.

Framing cameras are light starved and will not record high-speed images without adequate illumination sources. Because high-power laser sources must be used to illuminate the object for a framing camera, a method to reduce laser speckle noise is required to view very small objects. This dark field illumination technique allows the framing camera to collect diffraction limited images.

References

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