Characterization of the OMEGA Sixty-Channel UV Spectrometer

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Abstract

A UV spectrometer has been built for installation on OMEGA to analyze the UV wavelength spectrum of the laser system. Before implementing the spectrometer on OMEGA, the spectral resolution was determined. After the optics of the spectrometer were assembled, aligned, and focused, a neon spectral lamp was used to verify that the spectral dispersion and imaging quality of the system agreed with theoretical values. The experimentally determined resolution of 3.5 pm compares well to the theoretical value of 3.2 pm. The performance was evaluated for installation requirements on OMEGA.

Introduction

At the Laboratory for Laser Energetics, the OMEGA laser system has continued to support the National Inertial Confinement Fusion (ICF) program. In supporting this program, implosion experiments and basic physics experiments are conducted to further research related to high-energy-density phenomena. A major goal of ICF is to develop what will one day become a vast source of power in the future, fusion-based energy production. Currently fusion energy output is only one percent of the input energy, but through the efforts at the LLE, Lawrence Livermore, and other laboratories it is a possible future energy source.

The OMEGA system delivers pulses of laser energy to targets in order to measure the resulting nuclear and fluid dynamics.[1] The system, which is approximately ten meters high and one hundred meters long, is capable of delivering 30kJ of energy on a target of less than one millimeter in diameter in approximately 1 billionth of a second. At the front end of OMEGA, a seed laser pulse from an infrared (IR) laser enters and then propagates through the system where it is amplified, shaped, split into sixty beams, frequency converted into green, frequency converted again into ultraviolet (UV) and then pointed and focused onto the target. These beams are analyzed after conversion into UV by a spectrometer to better understand important processes of the OMEGA system. In measuring these spectra the spectrometer will assist in observing frequency conversion crystal tuning, detecting pinhole clipping, observing B-integral effects, and detecting noise entering the Pulse Generation Room.

Background

Spectrometers use spectral dispersion to produce and observe the spectrum of a light source. Dispersion can occur by two methods: refraction and diffraction. In the case of refraction, light enters a medium and exits according to Snell's Law

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (1)$$

where n_1 and n_2 are the indices of refraction of two adjacent media, θ_1 is the incident angle, and θ_2 is the exiting angle. Because different wavelengths of light travel through different media at different speeds, their refraction angles differ and dispersion occurs.

The other method of dispersion, diffraction, is much more useful for building spectrometers for several reasons. The fundamental grating equation

$$\sin\alpha + \sin\beta = 10^{-6} kn\lambda \qquad (2)$$

dictates how light travels when it hits a grating where α is the incident angle, β is the angle of diffraction, k is the diffraction order integer, n is the groove density (grooves/mm) and λ is the wavelength in nm.[2] According to this equation, it can be shown that diffraction can produce a much larger dispersion as compared to using a refractive medium for dispersion within the same space constraints.

Diffraction gratings are the source of dispersion in spectrometers and allow for resolving spectral lines of angstrom differences. The OMEGA UV Spectrometer was built to analyze the sixty beams produced from the propagation of the initial beam in the OMEGA system. After passing through frequency conversion crystals the sixty beams all have spectral features of interest within Angstroms of each other so a large dispersion is needed to resolve them. It is because of this high resolving power required that diffraction gratings are important as they produce the high dispersion necessary. The spectrometer shown in Figure 1.1 contains three Jobin Yvon 3600 grooves/mm aluminum coated diffraction gratings to meet the required resolution specifications.

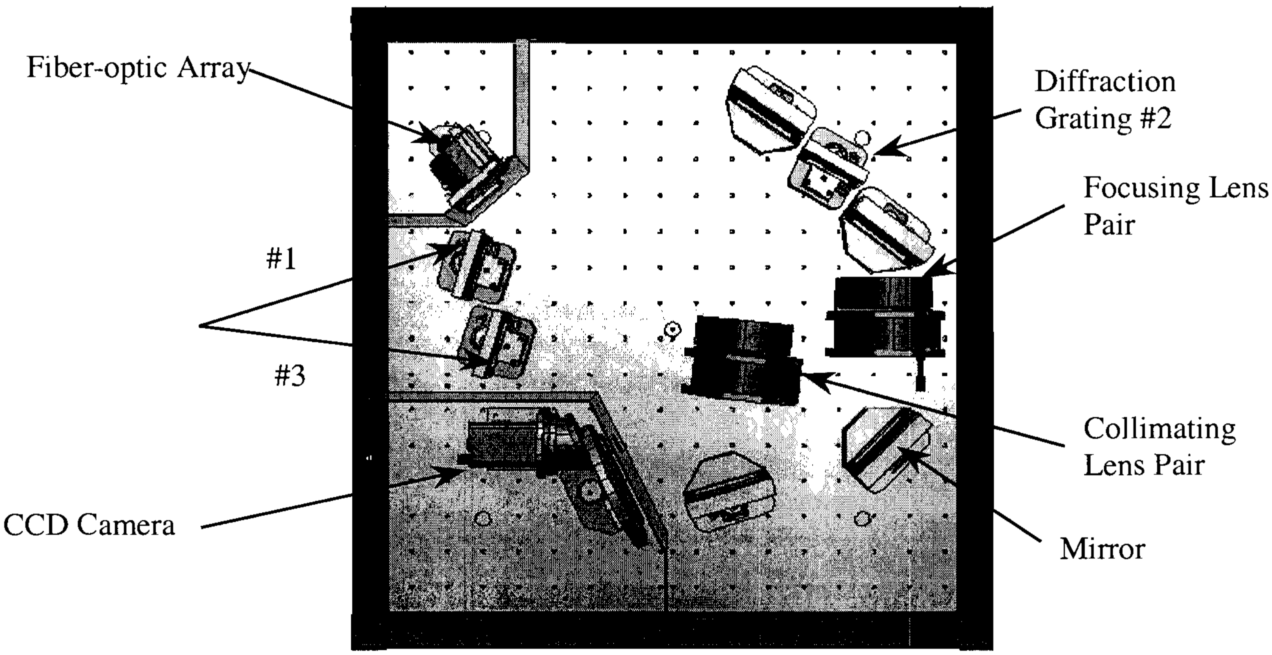

Figure 1.1. An overhead view of the UV spectrometer. Contained in the spectrometer are three Jobin Yvon diffraction gratings, four UV high-reflection coated fused silica mirrors, a collimating lens pair, a focusing lens pair, a fiber-optic cable housing where light enters the system and the CCD camera that records the image of the slit of the fiber-optic cable.

Experiment

The spectrometer is housed on a 4 ft x 4 ft lightweight breadboard. Four aluminum black anodized panels serve as the sides of the spectrometer and a 4 ft x 4 ft Plexiglas cover cut into four removable pieces composes the cover. The spectrometer is composed of three Jobin Yvon 3600 lines/mm holographic reflection gratings, UV anti-reflection coated fused silica lenses and windows, UV high-reflection coated fused silica mirrors, and a Spectral Instruments Series 800 Camera with a 2k x 2k 13.5 μm pixel Marconi CCD chip. Two shrouds were manufactured to house the fiber-optic cable input and the CCD camera respectively.

A one-to-one blueprint of the positions of the mounts was created and laid on the breadboard and then the mounts were installed on the breadboard with positions and angles relative to each other as dictated by the one-to-one tracing. To ensure the optics were properly aligned a 351-nm wavelength, 300-ps pulse width, 0.5-mJ 10-Hz rep rate laser was propagated through the system. At each interface a fluorescent card was used to determine the position of the beam and the orientation of the optics. After fine-tuning and adjustments were made the optics directed the beam path to the next optical interface. This was repeated for all mirrors, lenses, and gratings until the beam arrived at the CCD camera. The reason for this alignment was to ensure that the orientation of all optics was correct and the beam would propagate through the system correctly before the beam was focused.

In order to focus the beam the two lenses, the focusing lens and the collimating lens were adjusted until the width of the image recorded on the CCD camera was minimized. The lamp used for focusing was an Oriel Neon pencil-style spectral calibration lamp with an Oriel 6045 power supply. This lamp also provided multiple spectral lines around 351 nm that allowed for the calculation of the spectral dispersion. This setup also gave an estimation of the width of wavelengths the spectrometer could analyze. The beam path can be seen below in Figure 1.2.

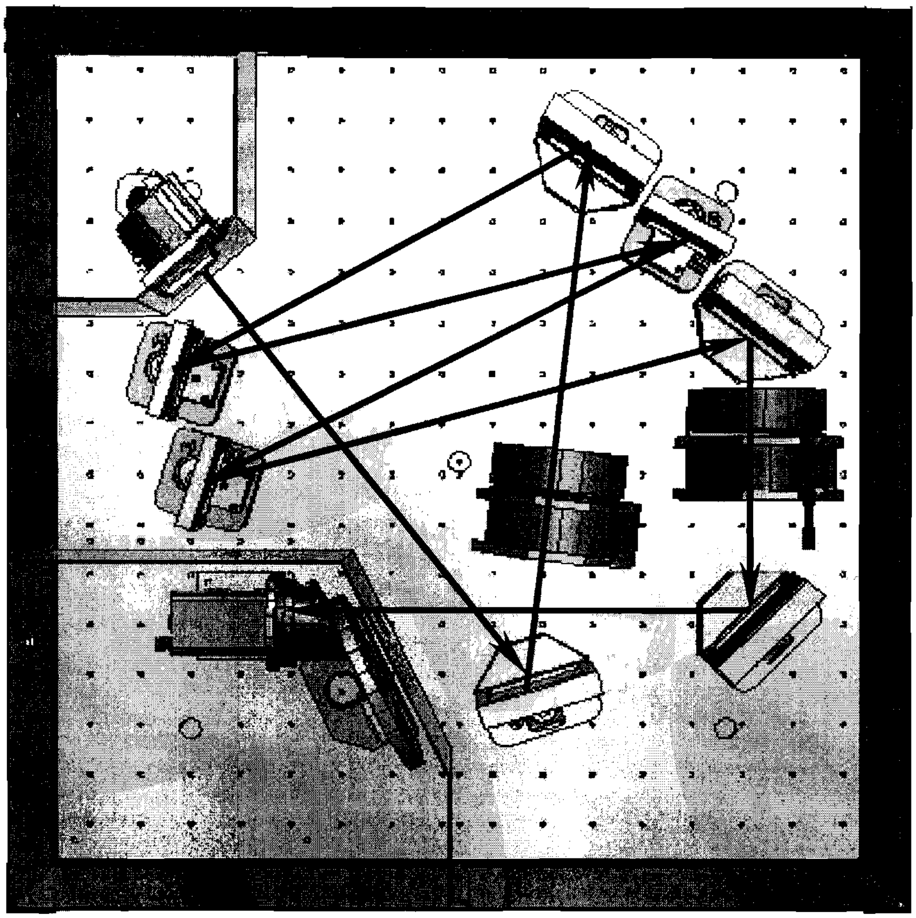

Figure 1.2. The beam propagates from the top left at the fiber optic cable to the bottom left at the CCD camera. The beam path is shown with black arrows.

Results

A neon spectral lamp was used to determine the imaging ability and spectral dispersion of the spectrometer. A Polymicro 300-μm core UV optical fiber with a 40-μm slit was used as the input of the neon source light into the spectrometer. The image of the slit on the CCD camera (figure 1.3) was found to be 40 μm at full width half max (FWHM). This is very close to the predicted image width of 35 μm (due to demagnification of the optical system). A possible explanation for the small discrepancy between the experimental and predicted values is that the optical system was not perfectly focused.

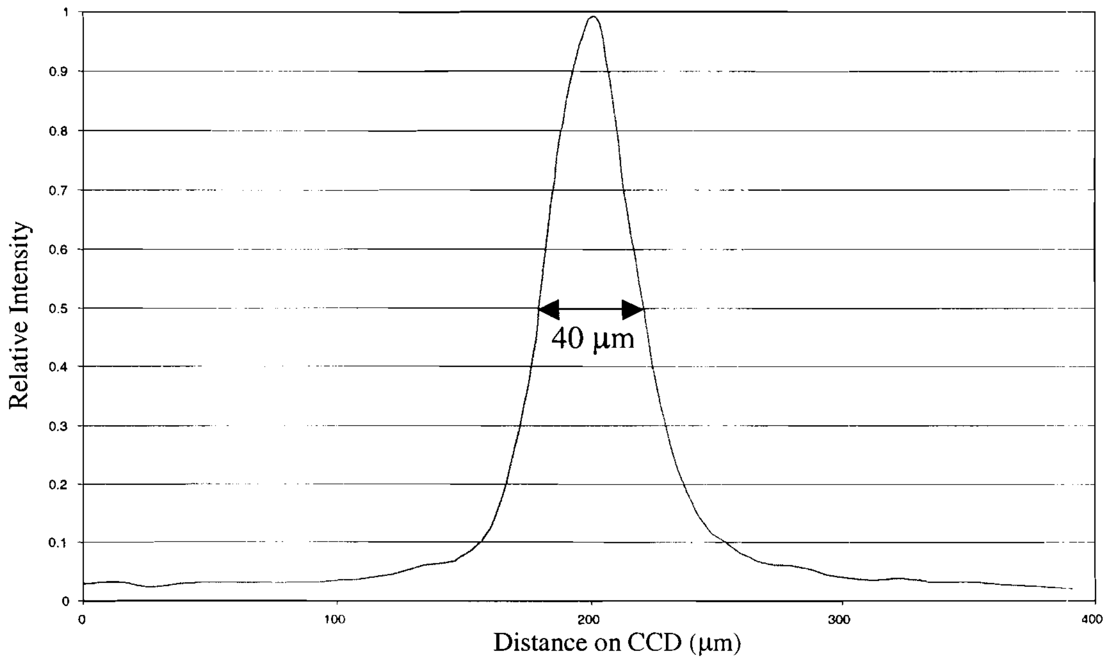

Figure 1.3 Image on the CCD resulting from a single spectrum line input to the spectrometer through a 40-μm slit.

To determine the spectral dispersion, defined as the change in CCD position divided by the change in wavelength, five known Neon I spectral lines were compared to the CCD spectrum data. As seen on the accompanying figures 1.4 and 1.5 the CCD data matches the relative positions of five known Neon I spectral lines. The spectral dispersion was calculated from this data to be 11.6 μm/pm.

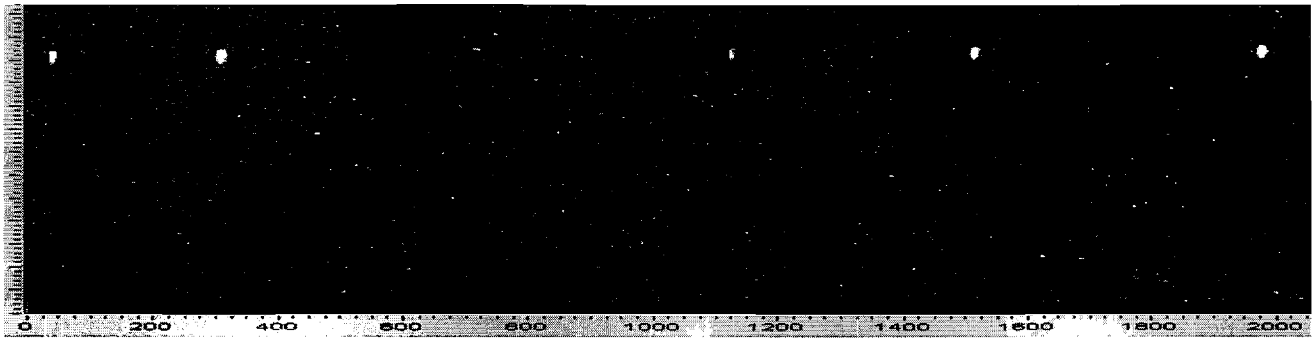

Figure 1.4 CCD Image, 2048 pixels wide (1 pixel = 13.5 μm)

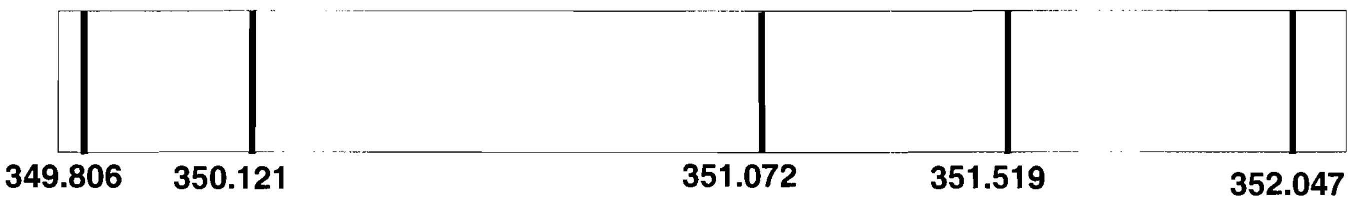

Figure 1.5 Neon I spectral lines from MIT wavelength table (nm)

Using a basic relational definition of resolution[3],

$$R \sim \frac{\text{FWHM Image of Entrance Slit}}{\text{Spectral Dispersion}} \qquad (3)$$

valid when the image size is much larger than the pixel size of the detector, the experimental resolution was calculated to be 3.5 pm.

To compare the experimental results to theory, OSLO, a ray-tracing program, was used to calculate expected values. OSLO predicted an approximately 11 μm/pm spectral dispersion, a 35-μm wide image, and a resolution of 3.2 pm using a 40-μm slit. These results show the new spectrometer has a resolution that is almost two times better than that of the previous spectrometer (6 pm) and that the alignment of the optics in the spectrometer is nearly optimized.

Summary

With the spectrometer nearly optimized, installation on the OMEGA system can soon occur. The UV spectrometer will assist in monitoring frequency conversion crystal tuning, detecting pinhole clipping, detecting excessive B-integral in the amplifiers, and detecting noise entering the Pulse Generation Room. With a resolution approximately two times better than that of the UV spectrometer currently used on OMEGA, and the capability of analyzing all sixty beams of the OMEGA system simultaneously, the UV spectrometer will provide new insight into the workings of the OMEGA system.

References

1. R.L. McCrory et al., *OMEGA System Operations Manual - Volume I -- System Description*, Laboratory for Laser Energetics, 2002.

2. J.M. Lerner and A. Thevenon, "Section 1: Diffraction Gratings Ruled & Holographic," *Spectrometer and Monochromator Discussion – A Tutorial*, Jobin Yvon Web Site. http://www.jobinyvon.com/jy/oos/oos_ch1.htm.

3. J.M. Lerner and A. Thevenon, "Section 2: Monochromators and Spectrographs," *Spectrometer and Monochromator Discussion – A Tutorial,* Jobin Yvon Web Site. http://www.jobinyvon.com/jy/oos/oos_ch2.htm.