Compression of Arago Spot Images for Rapid Position Measurement of Inertial Fusion Energy Targets

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A target position measurement method using a compressed Arago spot image is presented for real time data processing. To decrease the amount of data of the Arago spot image, the image is optically compressed into a one dimensional line image by a cylindrical lens. The experimental results for a 5 mm diameter target demonstrated a measurement accuracy of 0.35 µm when the target was 10 m from a charge coupled device (CCD) camera.

Keywords: target position measurement, image compression, Arago spot, real-time data processing

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In conventional direct drive inertial fusion, a spherical fuel target must be shot by the driver beams with an accuracy better than ±20 µm at the center of the reaction chamber [1]. A fast ignition scheme without a cone is proposed, whereby a high energy electron beam generated by a super intense ignition laser must hit the compressed core plasma [2]. To achieve these conditions, the target position in flight must be monitored with better accuracy. Recently, an accurate target position measurement method was developed using the Arago spot [3, 4]. The Arago spot, also known as the Poisson spot, is a bright spot that appears at the center of a diffraction pattern formed in the shadow of a spherical object, as shown in Fig. 1. Hence, the center of the Arago spot agrees with the center of the projection of a spherical object. Using a divergent laser beam, an accuracy within 0.2 µm was obtained at a distance of 10 m [5].

However, when the target is injected at 400 m/s and the distance from the injection point to the center of the chamber is 16 m, the target arrives at the center of the reaction chamber in 40 ms. For this reason, position measurement in the reaction chamber requires rapid data processing to calculate the target trajectory. In pratice, it is difficult to process raw Arago spot image data in few milliseconds because the amount of data for images obtained by commonly used areal image sensors is large (~MB). If the amount of image data decreases, then rapid data processing is expected.

In this study, we present a target position measurement method using a compressed Arago spot image obtained by a cylindrical lens. Let us assume that the intensity of the Arago spot, which has a characteristic radius c and a peak at $x = a$ and $y = b$, is approximated as

$$I(x, y) = I_0 \exp[-(x - a)^2/c^2 - (y - b)^2/c^2], \quad (1)$$

where I_0 is the light intensity at the peak in the screen.

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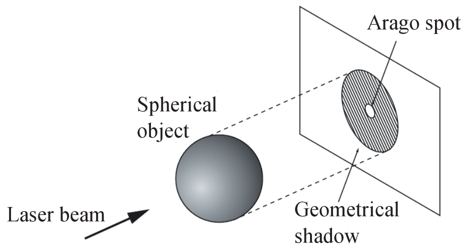

Fig. 1 Diffraction for a spherical object.

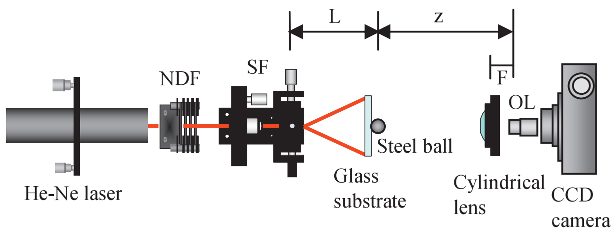

Fig. 2 Experimental setup. NDF; neutral density filter, SF; spatial filter, OL; object lens.

Integration with respect to y yields

$$F(x) = \int I(x, y)\mathrm{d}y = I_0 c \sqrt{\pi} \exp[-(x - a)^2/c^2]. \quad (2)$$

A two dimensional Gaussian distribution can be converted optically into a one dimensional Gaussian distribution, which has a peak at $x = a$ by a cylindrical lens, effectively decreasing the amount of data (~kB) for rapid data processing.

Figure 2 illustrates an experimental setup for a position measurement system using an Arago spot image compressed by a cylindrical lens. We used a He-Ne laser as the light source and 5.0 mm diameter high carbon steel balls as models for spherical fuel targets. The light beam is diverged by a spatial filter (SF) and uniformly illuminates

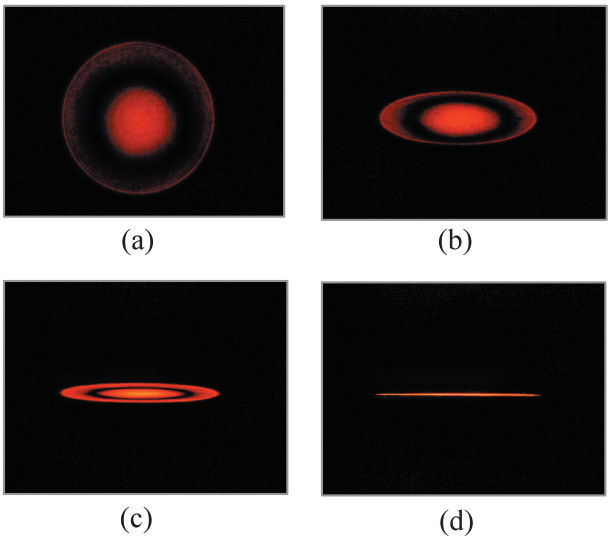

Fig. 3 Compression of the Arago spot: (a) without the cylindrical lens, (b) $F = 10$ mm, (c) $F = 15$ mm, and (d) $F = 20$ mm.

the entire steel ball. The Arago spot formed by the divergent laser beam is compressed into one dimension by a cylindrical lens ($f = 15$ mm). Then, a one dimensional Arago spot image is recorded by a charge coupled device (CCD) camera with a microscopic object lens (OL; 10×, NA = 0.25) to magnify the image. The experiment was performed with $L = 0.25$ m and $z = 10$ m. The steel ball, mounted on a 5 mm thick glass substrate, was moved along the x and y axis by a translation stage.

Figure 3 shows the compression process of the Arago spot image by a cylindrical lens. The recorded image (a) is the Arago spot without the cylindrical lens. The recorded images (b), (c), (d) are the Arago spot with different distances F between cylindrical lens and the object lens.

In the position measurement experiment, the compressed Arago spot was recorded by a CCD camera (Canon IXY DIGITAL 500) with 2592 × 1944 pixels-each pixel measured 3.8×3.8 μm^2. First, the reference line, which has the largest sum of the light intensity, is selected. An example of the light intensity on the reference line is shown in Fig. 4. Then the center of the Arago spot X_C is determined as the center point of the evaluation region $[X_A, X_B]$, where $I > I_{th}$ $(= 0.5 \times I_{max})$.

Figure 5 (a) shows the position measurements as the target was moved along the x-axis in 1 µm steps. The experimental value X_C, the center of the Arago spot, is calculated by the evaluation region on the reference line (2592 × 1 pixels). The theoretical value is calculated from the calibration of the number of pixels of CCD camera and the expansion rate (= 10.25/0.25) of the divergent beam. We obtained the experimental results that the rms measurement error was 0.35 µm on average. Figure 5 (b) is the result when the target was moved along the y-axis in 1 µm increments. We confirmed that, when the target was moved

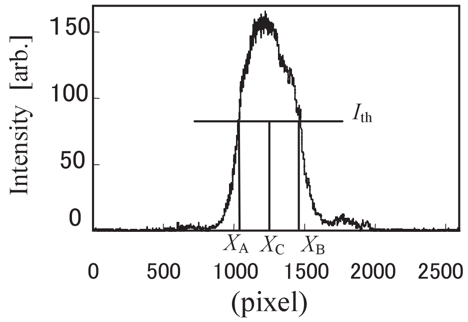

Fig. 4 Intensity distribution of the compressed Arago spot.

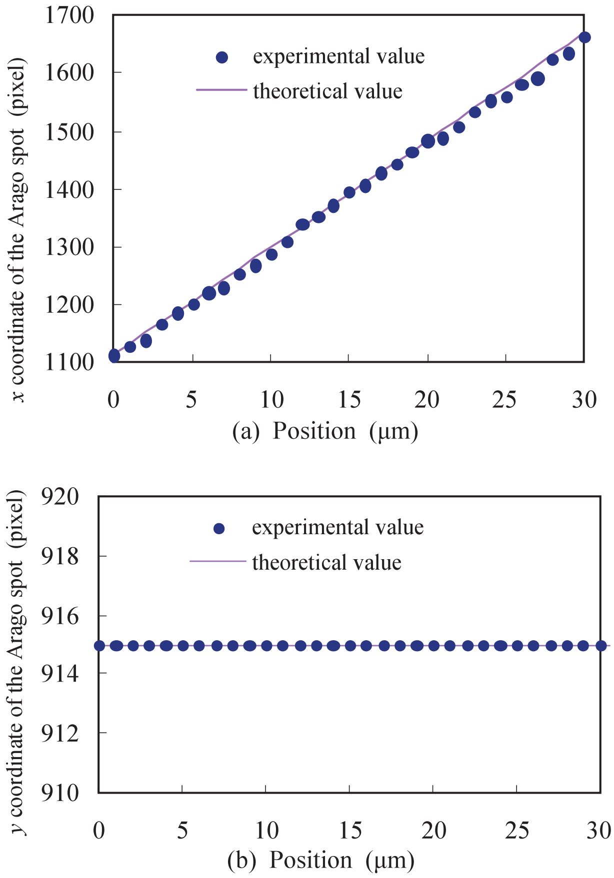

Fig. 5 Position measurement results.

along the y-axis, the selected reference line did not change because the image was compressed in the y direction and became the line at the focal point of the cylindrical lens, as shown in Fig. 3 (d). This result enables us to measure one component of the target position using a cylindrical lens and a linear image sensor.

In summary, a target position measurement method was developed using a compressed Arago spot images.

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