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The Final Focus Test Beam Laser Reference System*

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Abstract

The original design for the SLAC linac included an alignment reference system with 270 diffraction gratings situated along the 3000 meter linac. These gratings have provided SLAC with a global reference line repeatable to within 200 micro meters. For the Final Focus Test Beam, this laser system has been extended and 13 new diffraction gratings have been installed. Improvements in the image detection system, in the calibration of the targets and the availability of new instruments allows us to evaluate the performance of the laser reference system at the 5-10 micro meter level. An explanation of the system and the results of our evaluation are presented.

1. INTRODUCTION

Components of the FFTB laser alignment system are illustrated in figure 1. A 1 mW HeNe laser provides images with peak intensity of approximately 1 lux at the detector. (Note that all FFTB zone plates are less than 150 m from the laser). The divergent lens is chosen such that the intensity of light at the edges of the zone plate is about 75% of the intensity of light at the center of the zone plate.

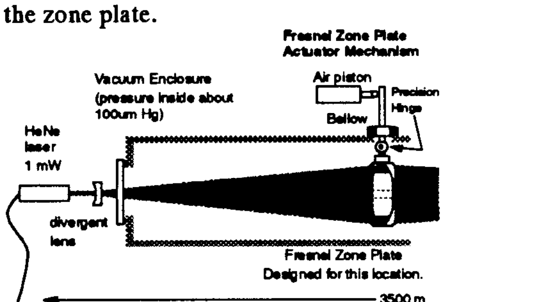

Figure 1a. Components of the FFTB laser alignment system.

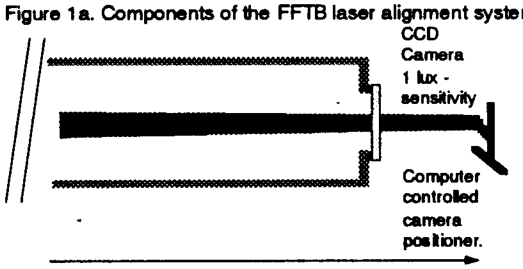

Figure 1b. Components of the FFTB laser alignment system.

A precision hinge which enables the zone plate to return to the same position with each actuation is required; only one zone plate may be lowered into the light at one time.

An inexpensive CCD camera with an array of size 8x6mm is used. FFTB images are much larger than this CCD array. Therefore the camera must be moved many times in order to detect one FFTB image[1]. The accuracy of the camera positioning system is approximately 10 micro meters. However, FFTB images have high sensitivity, figure 2, and need only be detected to within tens or hundreds of micro meters in order to achieve alignment information at the zone plate with precision of a few micro meters.

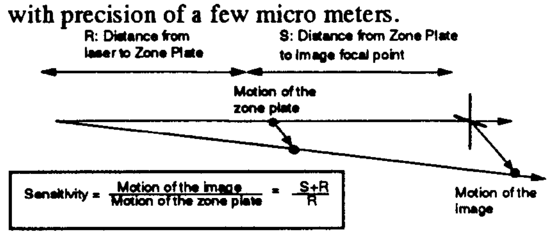

Figure 2. Definition of sensitivity.

2. IMAGE MEASUREMENTS

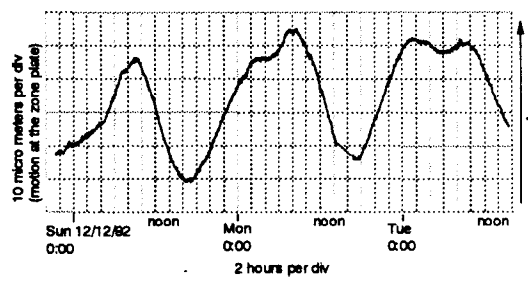

Figure 3a. Measurement of FFTB LSX1 Fresnel zone plate image. VERTICAL LSX1: r = 162.8 m, s = 3284.7 m, N = 20

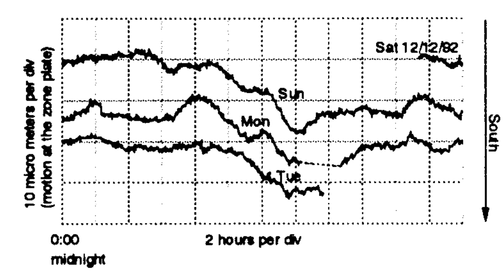

Figure 3b. Measurement of FFTB LSX1 Fresnel zone plate image. (HORIZONTAL)

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Three days of data from the FFTB laser alignment system are show in figure 3. This data was produced by lowering a *single* zone plate and repeatedly measuring the image from this zone plate. Motions indicated by the data are a combination of motions of the zone plate, the camera and the laser. Motions of the camera and the laser may be eliminated when a set of three or more different images are monitored. However that was not done in this case. The data from figure 3 is useful in order to evaluate the standard deviation or quality of the measurements made by the image detection system. The standard deviation of these measurements, computed in terms of the position of the zone plate, is less than 5μm.

3. ACCURACY OF IMAGES

Figure 3 illustrates the *repeatability* of the measurement of zone plate images. However, this data says nothing about the accuracy of these measurements. Notice that the standard deviation of the vertical measurements is less than the standard deviation of the horizontal measurements. The algorithm which is used to detect the center of the image uses (1) the vertical cross section of the image to compute the vertical coordinate of the center of the image and (2) the horizontal cross section of the image to compute the horizontal coordinate of the center of the image.

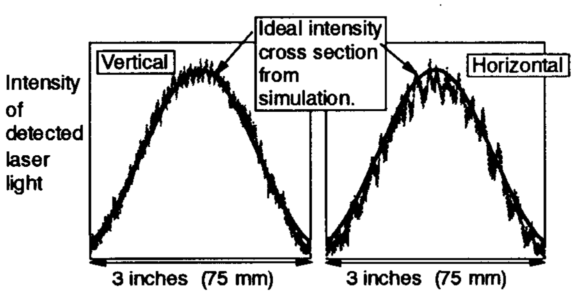


Figure 4. Image intensity cross sections.
(FFTB Fresnel Target LSX7) 12/09/92

Therefore if the standard deviation of the computed vertical coordinate of the image is less than the standard deviation of the computed horizontal coordinate of the image, we would expect that the vertical cross section of the image would be of better quality than the horizontal cross section of the image. Figure 4 illustrates that this is indeed true.

The imperfection in the images shown in figure 4 are caused primarily by stray light, reflected off the interior of the vacuum enclosure. These imperfections are stable; cross sections taken on different days contain the same imperfections.

Looking at figure 4, one might wonder if the computed center of such an image is a good measurement of the center of the "ideal" image. Figure 5 illustrates the image detection algorithm.

By varying the **Reference Level** and remeasuring the center of the image, one may gain a sense of how well we are computing the center of the ideal image.

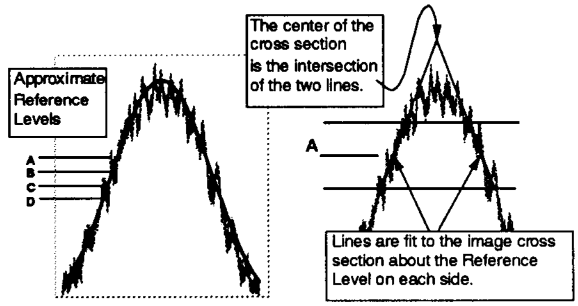


Figure 5. Quick explanation of the image detection algorithm.

The data from figure 6 is taken directly from the database which is attached to the image detection program. This data consists of 12 different measurements of the center of the LSX7 image at 4 different reference levels. X and Y are the horizontal and vertical coordinate of the image in inches as measured in the coordinate system of the image detector. Etime is the time required for the algorithm to converge in seconds. Center Amp determines the effective reference level.

Name	Reference Level	X	Y	Time	MODE	Etime	Cen A
32-7		-0.6011	-0.2413	1992 12/09 14:14	TRANS	317	113.0
32-7	B	-0.6174	-0.2428	1992 12/09 14:21	TRANS	139	113.0
32-7		-0.6154	-0.2414	1992 12/09 14:24	TRANS	150	113.0
32-7		-0.6342	-0.2425	1992 12/09 14:30	TRANS	208	100.0
32-7	C	-0.6358	-0.2432	1992 12/09 14:36	TRANS	273	100.0
32-7		-0.6069	-0.2434	1992 12/09 14:43	TRANS	334	100.0
32-7		-0.6289	-0.2426	1992 12/09 14:48	TRANS	222	85.00
32-7	D	-0.6258	-0.2455	1992 12/09 14:56	TRANS	288	85.00
32-7		-0.6171	-0.2450	1992 12/09 15:00	TRANS	166	85.00
32-7		-0.6187	-0.2283	1992 12/09 15:05	TRANS	268	130.0
32-7	A	-0.6236	-0.2305	1992 12/09 15:09	TRANS	146	130.0
32-7		-0.6192	-0.2380	1992 12/09 15:12	TRANS	151	130.0

Figure 6. Image measurements at different reference levels.

The total range of all the Y (vertical) measurements is 440μm and 840μm for the X (horizontal) measurements. Translating these measurements into distance at the zone plate we have: *Vertical Range: 5.6μm Horizontal Range: 2.9μm.* As far as the image detection algorithm is concerned, these images are quite symmetric. Therefore when we compute the center of the "imperfect" image, we are computing the position of the center of the zone plate to within about 5μm.

6. IMAGE SIMULATIONS

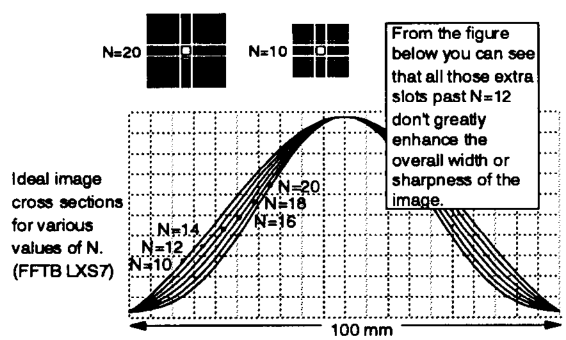
Prior to the construction of the FFTB laser alignment system we investigated the feasibility of a Fresnel zone plate laser alignment system with 5 μm accuracy. Several of the questions on our mind were: (Q1) How precisely must the slots of a zone plate be fabricated? (Q2) How large must a zone plate be? (Q3) Does the angle of the zone plate with respect to the incident light wave matter? (Q4) What happens when light from the laser is not symmetrically distributed across the surface of the zone plate?

In order to answer these questions we conducted one and two dimensional simulations which assumed (1) Light incident on the zone plate has a gaussian intensity profile and has spherical phase, originating at the laser. (2) The zone plate is located at distance R from the laser. (3) The zone plate may move horizontally or vertically with respect to the laser line. (4) The zone plate may pitch or yaw with respect to the laser line. (5) The camera is located distance S from the zone plate.

Available space does not permit a description of the simulation algorithm, therefore we will simply present results.

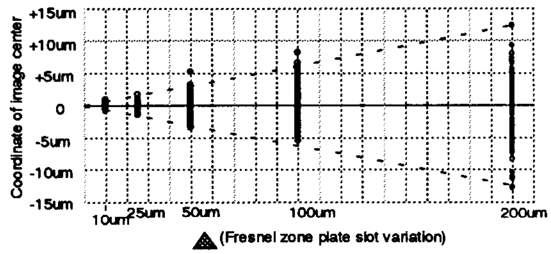
(Q1) How large must a zone plate be.

By "large" I really mean, what is the required number of slots in the zone plate? This is an important issue since as the slots become small, manufacture of the zone plate becomes increasingly difficult and expensive. The number of slots in the zone plate is given by the order of the zone plate, N.

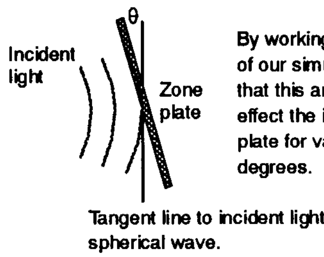


(Q2) How precisely must the slots of a zone plate be fabricated?

Simulations conducted for the FFTB LSX7 (r=22.9 m, s=3424.5 m, N=20) Fresnel zone plate. The simulated zone plate has been given random asymmetric imperfections with standard deviation ▲ and the center of the resultant image has then been computed.

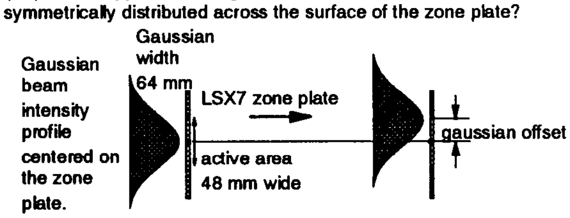


(Q3) Does the angle of the zone plate with respect to the incident light wave matter?



By working through the mathematics of our simulation algorithms we found that this angle θ does not significantly effect the image produced by this zone plate for values of θ less than several degrees.

(Q4) What happens when light from the laser is not symmetrically distributed across the surface of the zone plate?



Gaussian offset	Image offset
5 mm	3.9 um
10 mm	7.0 um
20 mm	13.5 um

CONCLUSION:

Fresnel zone plate alignment systems can provide alignment information with relative accuracy from zone plate to zone plate of 5 μm without expensive image detection hardware and with zone plates fabricated to 5 μm tolerances. FFTB Fresnel zone plate alignment images have been shown to be, (1) Symmetric to within 5 μm (2) Re-measurable to within 5 μm.

References

[1] V.E.Bressler,G.E.Fischer,R.E.Ruland,T.Wang, "High Resolution Fresnel Zone Plate Laser Alignment System", EPAC'92 Conference Proceedings Vol.2 (March 1992), pp. 1613-1615