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TITLE: TECHNIQUE USING AXICONS FOR GENERATING FLAT-TOP LASER-BEAM PROFILES

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Technique using axicons for generating flat-top laser-beam profiles

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Abstract

In certain fusion experiments using CO_2 lasers, like Helios,* it is desired to produce a focal spot several times larger than the nominal focal spot, with a flat beam profile. The typical focal spot in Helios is roughly 70 μm and just defocussing the beam produces beam breakup, with several hot spots with roughly the original diameter, and a gaussian distribution.

A number of schemes were tried to achieve a large spot with desired characteristics. These are described in the article. Axicons were found to produce spots with desired characteristics. Axicons are lenses or mirrors having a cone-shaped surface.

The various schemes are described, as well as an experiment in Helios which confirmed that axicons produced the spots with desirable characteristics. Helios is an 8-beam CO_2 laser which produces 10 kJ at power in excess of 20 TW. It is currently being used for Laser Fusion studies at the Los Alamos National Laboratory.

Introduction

There are several reasons for attempting to generate large spots with a flat-top profile. In the CO_2 ICF program, one of the chief concerns is the generation of hot electrons produced in the laser plasma interaction, particularly at the high intensities of a tight focal spot. One method of reducing T_{hot} then is to uniformly irradiate a target with a reduced average intensity, and the experience at Helios showed that merely defocusing the incident laser beams did not eliminate high intensity hot spots.

Another reason for attempting to generate large spots with a flat top profile was generated by shock wave experiments contemplated on powerful CO_2 lasers.[2] These experiments require uniform planar illuminations over spot sizes much larger than the diffraction limited spot sizes of the focusing optics. In many of the experiments that study the interaction of laser radiation with matter, one would like to have as uniform an irradiance as possible, so that one quantity rather than a range for the intensities can be defined and studied.

Typically, to get a 10 percent variation in the shock velocity, a 30 percent non-uniformity in the laser drive can be tolerated. One of the ground rules for any possible scheme was that it can be implemented on the CO_2 fusion laser without major modifications or difficulties. This meant that modifying the large optics in the system was ruled out, and that the actual alignment procedures already in use in Helios could not be drastically altered. As a consequence, all the methods were tried on a mock-up of the power amplifier-target area of Helios(only the optics were mocked up). The various schemes tried and the results obtained are described. The axicon scheme produced successful results both in the mockup and in the Helios laser system, itself.

Description of the Various Unsuccessful Schemes

Figure 1 shows the optical schematic of one of the beams of the Helios laser power amplifier/target area. In the laboratory, this was the mock-up which was used for these experiments. The gain medium, as well as the saturable absorber was not used. This decision was based on the fact that it would have been too difficult to do the experiments with them, combined with the previous knowledge that they do not appear to affect the optical quality of the beam. The 1-inch-diam gaussian beam from the front end of the system is expanded by a 17x Gregorian afocal telescope, and the central 15 3/4 inches of the expanded beam is chosen by the use of aperture marks. This beam is focused by the off-aperture parabola at the target plane. The typical size of the focused (F/no. = 2.4) spot is 70 μm is diameter. Figure 2 shows a typical focal spot and a typical

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* Helios is an eight-beam CO_2 laser which produces 10 kJ at power in excess of 20 TW. It is currently being used for laser fusion studies at the Los Alamos National Laboratory.[1]

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cross-section of the intensity profile as seen by a vidicon trace. The distribution is gaussian, as is to be expected. This is typical of the spots produced by the Helios laser also. Figure 3 shows the typical appearance of the focal spot at 1 mm defocus. The beam breaks up into hot spots, and each hot spot is again roughly 70 μm.

The first attempt that was made tried to see if the number of spots could be reduced to one, and to see if the pattern of the distribution changed. This was attempted with various aperture masks, a typical one being shown in Fig. 4. The mask was placed in a collimated space between the recollimating mirror and the 45° turning flat. The results are shown in Fig. 5. It was possible to reduce the number of spots to almost one and roughly 2/3 of the energy was in the spot. However, the vidicon trace shows the distribution to be still gaussian in nature.

The next attempt was to use the aperture mark in conjunction with a salt wedge to shift the phase in parts of the beam. This is shown in Fig. 6. This resulted in enlargement of the defocused spot, but as the vidicon trace shows, the flat top distribution was not achieved.

Next, various schemes used by others already were tried, and these did not produce the desired results due to various reasons. It is generally known that for a gaussian circular beam, if an annular part of the beam (the extent depending on the nature of the gaussian distribution) is phase-shifted by $\lambda/2$, at the focal plane, a flat beam profile results. However, for large defocus, that is of the order of 1 mm or so (depth of focus being ±110 μm) this does not appear to work. The next attempt was to sputter the small diverging mirror in the hope of destroying the coherence properties of the laser beam. This was not successful either. The only result was a severe energy loss at focus. Another similar unsuccessful attempt was a mesh mirror which introduced random phase shifts in the beam. Yet another attempt which showed promise was the use of the Rocketdyne deformable mirror.[3] The deformable mirror replaced the recollimating mirror in the power amplifier (Fig. 1). It appeared feasible that the deformable mirror can create a flat top profile in a defocused condition, but unfortunately this particular mirror had only 19 actuators and this proved to be inadequate. A deformable mirror with double the number of actuators probably could have produced a large spot with a flat beam profile.

Use of Axicons

Axicons have the property of producing a long line focus when they image a point source. With finite size beams, the effect is to produce a focal region over a long distance where the beam size hardly changes. We modeled the Helios triple pass amplifier/target chamber area optical system on ACCOS V. By replacing the diverging mirror (Fig. 1) with a 3 μrad axicon, we found that we were able to create a large spot with a flat profile. However, we encountered two practical objections to use of a pure axicon in the system. The first objection has to do with the fact that a pure axicon produces rings at the output salt. This means that the salt would be damaged in the actual Helios laser system because of the tremendous gains that are involved. The second objection has to do with the fact that the laser cannot be aligned using the existing Hartmann scheme.[4] Figure 7 shows the ring structure produced by a pure axicon.

To overcome these two objections, the axicon was modified as shown in Fig. 8. The Zonal axicon which was actually used in the Helios experiments consisted of the central 13 mm of the original diverging mirror, followed by an annular axicon region of 8 mm, again followed by the original spherical mirror contour. The central region acted like a large F/no. system, enlarging the spot size, and the annular axicon region again acting to increase the spot size as well as depth of focus in the image space. Figure 9 shows the 235 μm spot produced by this kind of axicon. The vidicon trace shows that we have indeed achieved the flat top profile we were seeking. Comparison with Fig. 3 shows that we have both enlarged the spot considerably, and made the profile a flat top as opposed to gaussian profile. We digitized the focal spot and confirmed the lack of hot spots in the spot. Figure 10 shows the results of the digitization.

Experiments in Helios

The modified Zonal axicon described above was installed in the Helios laser, replacing the diverging mirror in the triple pass amplifier in beam line 4-A of Helios. Figure 11 summarizes the axicon shots taken in Helios. Figure 12 shows the typical results obtained with x-ray pinhole photographs. At 1 mm defocus, the picture on the left in Fig. 12 shows the non-uniformity in the x-ray pinhole image. The picture on the right shows that the focal spots are indeed uniform. The lowering of the hot electron temperatures, which was noticed also, confirms the fact that the focal spot was large and of uniform intensity. We hope to describe the physics results in a separate paper soon.

Conclusions

The use of the modified axicon indeed does result in a large spot with a flat top beam profile. We also learned that one has to be careful in using axicons in systems where damage could conceivably be a problem.

Acknowledgements

We thank A. Saxman and J. Hanlon for their helpful suggestions during discussion of the various schemes.

References

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4. V. K. Viswanathan and P. D. Bolen, "Infrared Smartt interferometer as an alignment tool for CO_2 laser fusion systems," Los Alamos Conference on Optics 1979, SPIE 190, pp 243-250.

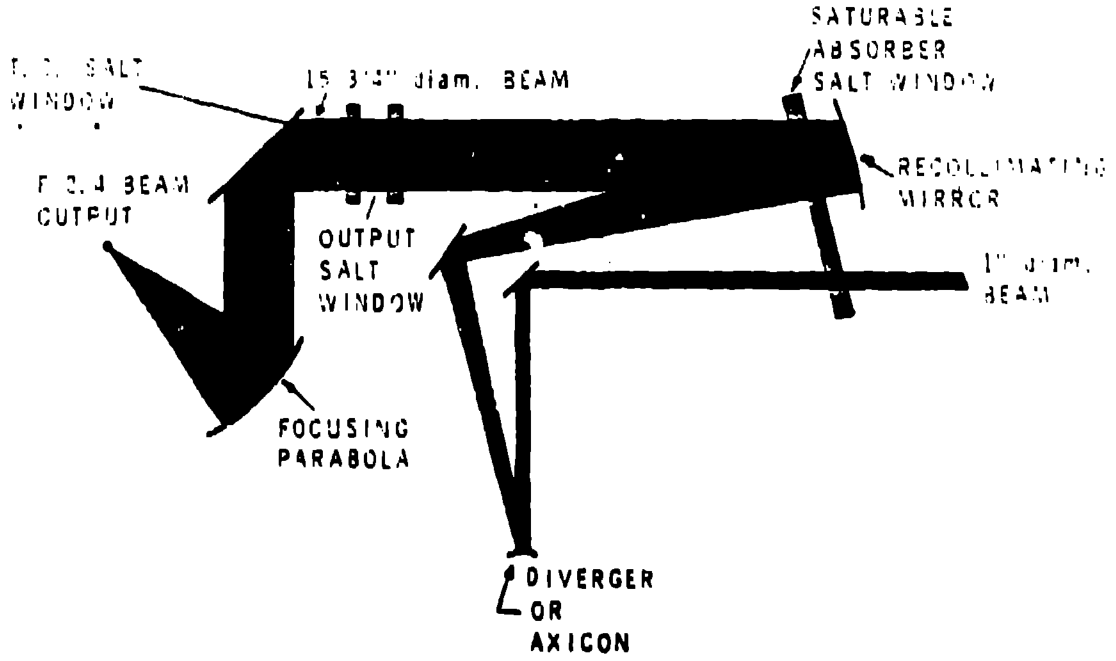

Fig. 1. Helios triple pass optics and target chamber.

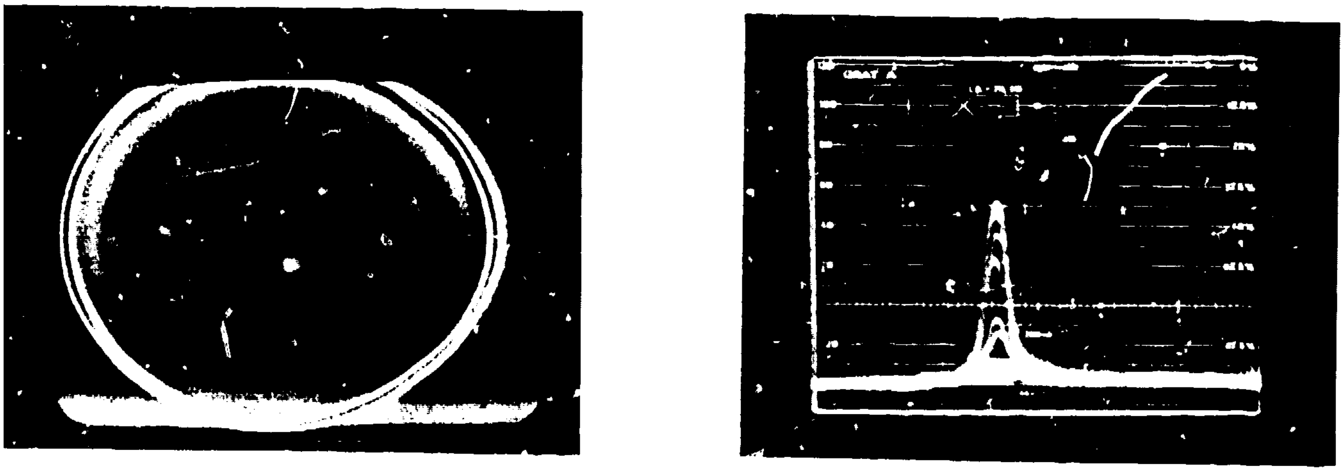

Fig. 2. At best focus (70 µm diam. spot).

ig. 3. Typical appearance at 1mm defocus
each lobe is approx. 70 µm diam.).

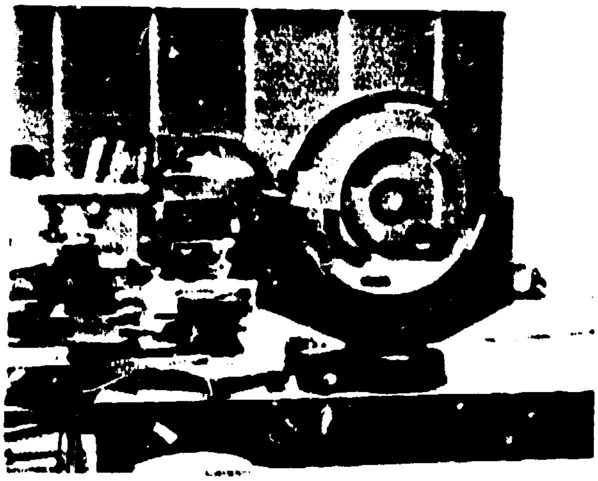

Fig. 4. Typical aperture mask.

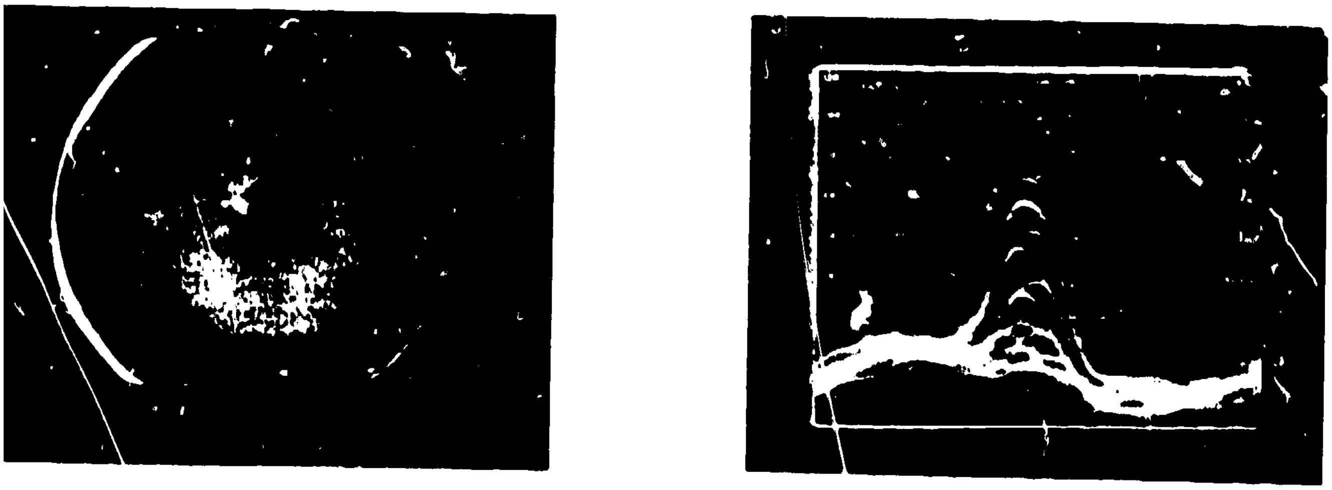

Fig. 5. Aperture mask 66% energy redirection of spots no enlargement.

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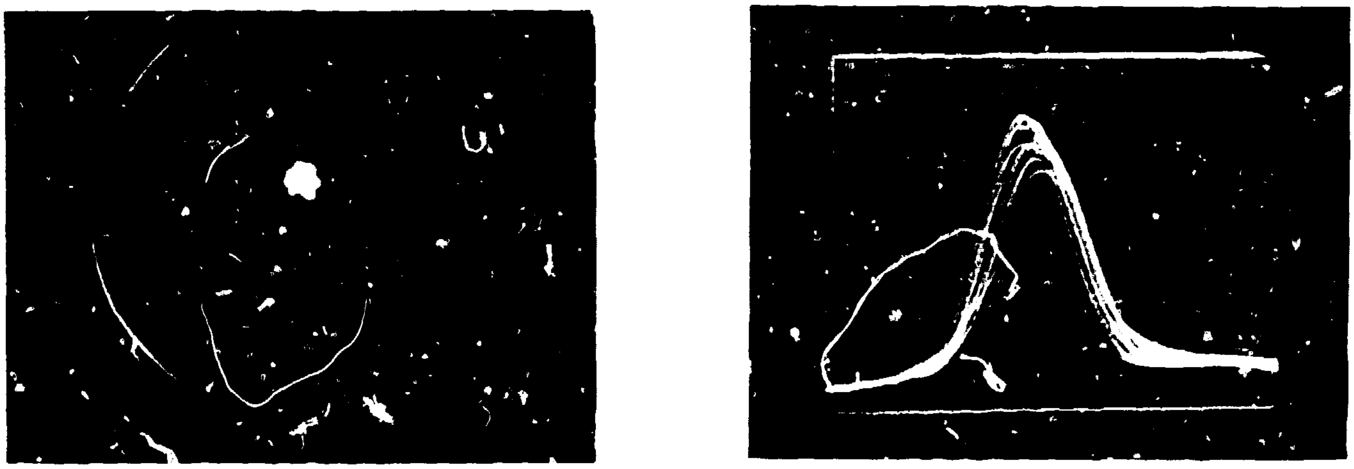


Fig. 6. Aperture mask with salt wedge 75% energy enlargement of spot. Hot spots created.

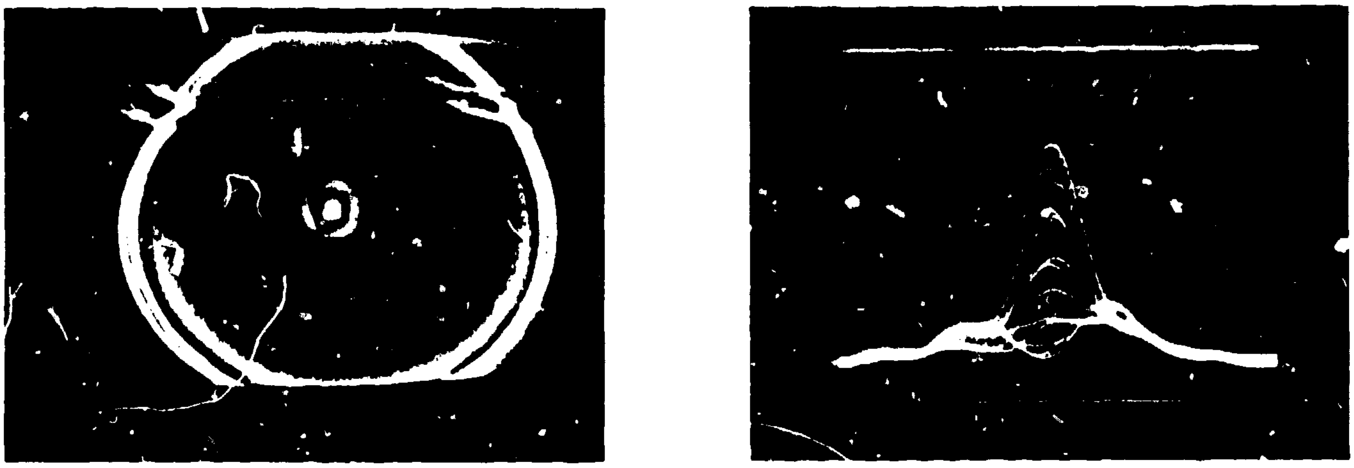
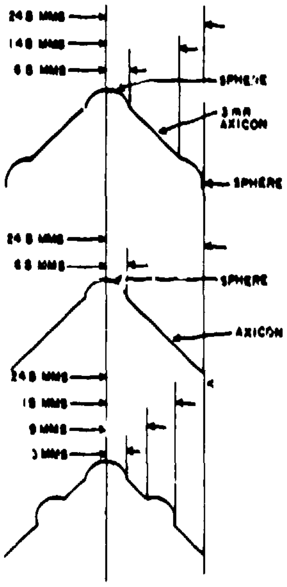


Fig. 7. Ring structure produced by pure axicon.

Descriptions of the various axicons tried in the laboratory.

Twelve axicons were tried in the lab, of the following basic types:



Zonal axicon actually used in the Helios shots did not damage the salt A.R. coatings.

This axicon was used in only one Helios shot. It appeared to damage the A.R. coating on the salt.

This axicon was not tried in any Helios shot.

Fig. 8. Descriptions of the various axicons tried in the laboratory. Twelve axicons were tried in the lab, of the following basic types:

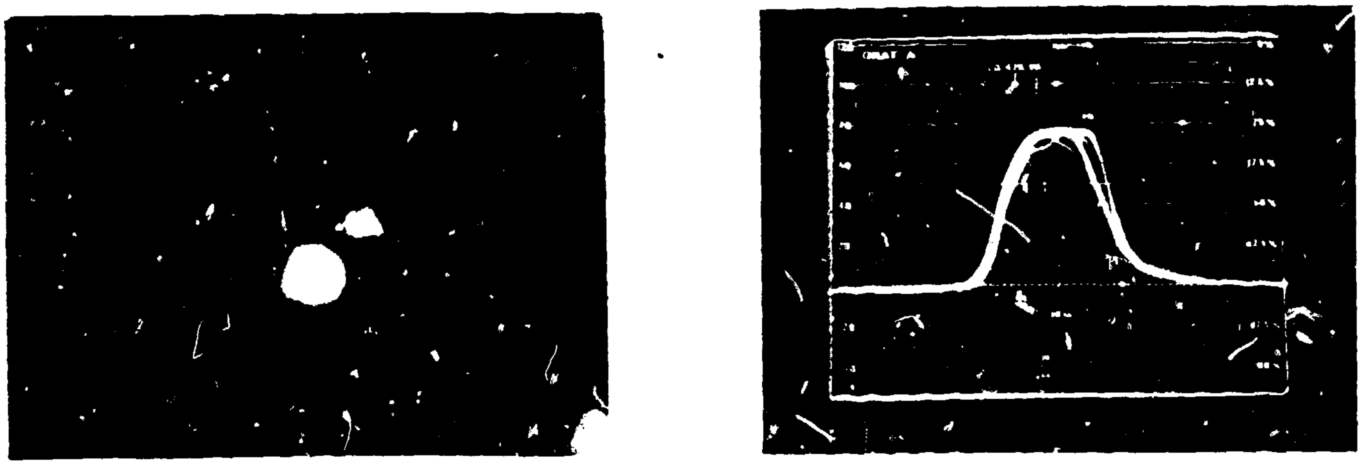


Fig. 9. Modified 3 mrad axicon minimized ring at output salt no rings at focus.

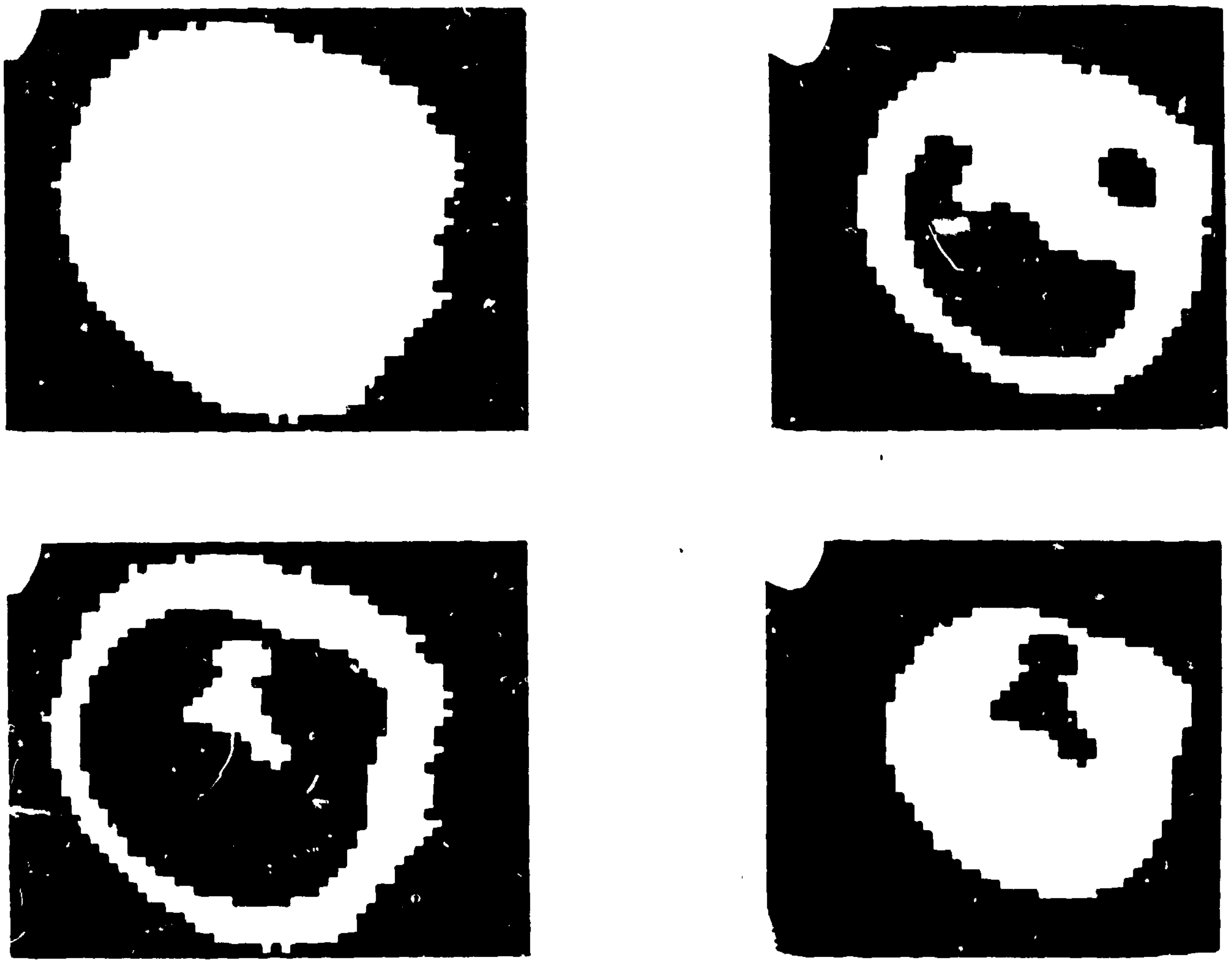


Fig. 10. Results of Digitization.

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SHOT NO.	ENERGY(J)	DEFOCUS(MMS)	COMMENTS
82060402	703	2.5	REFERENCE SHOT WITH DIVERGER. SPOT SIZE:875 microns.
82060707	347	2.35	3mr ZONAL AXICON. SPOT SIZE: 750 microns.
82060408	602	1.5	REFERENCE SHOT WITH DIVERGER. SPOT SIZE: 500 microns.
82060706	347	1.5	3mr ZONAL AXICON. SPOT SIZE: 625 microns.
82060708	352	2.0	3mr ZONAL AXICON. SPOT SIZE: 625 microns.

PLEASE NOTE:

ALL THE SHOTS WERE AT DIVERGER BEST FOCUS, WITH VARYING TARGET SIZES.

Fig. 11. SUMMARY OF THE AXICON EXPERIMENTS IN HELIOS.

Fig. 12. 1 mm defocus with no modifications to beamline.

1 mm defocus with modified 3 mrad axicon in beamline.