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LA-UR -85-2721

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DR-1307-2

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CONF-850345--29

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LA-UR--85-2721

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TITLE PERFORMANCE EVALUATION OF THE ANTARES REFERENCE TELESCOPE SYSTEM

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SUBMITTED TO Southwest Conference on Optics '85
Albuquerque, NM, March 4-8, 1985.

Los Alamos

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FORM NO. 836 R4
ST. NO. 2629 5/81

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Performance evaluation of the Antares Reference Telescope System

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Abstract

The Antares Reference Telescope System is a complicated electro-optical-mechanical system whose main purpose is to enable positioning of targets used in the Antares Laser System to within 10 µm of a selected nominal position. To date, it has been used successfully to position targets ranging in size from 300 µm to 2 mm.

The system consists of two electro-optical systems positioned in a nearly orthogonal manner. This "cross telescope" configuration facilitates accurate positioning in three planes.

The results obtained so far in resolution and positioning of targets using this system are discussed. It is shown that a resolution of 200 lp/mm and a positioning precision of 25 µm can be obtained.

Introduction

The Antares Reference Telescope System (RTS), described in an earlier paper,[1] consists of two nearly orthoganal electro-optical systems. Each electro-optical system is comprised of a telescope whose output is coupled to a high quality television camera. The camera provides a video image for analysis and control requirements at remote locations such as the Central Control Room. Before final installation in the Antares target chamber, these systems were assembled for tests on a large optical bench in the Optics Evaluation Laboratory at Antares. Though not extensive, these tests showed that the systems could "see" 2 µm particles on targets, well with the resolution requirement of 5 µm.

At the final installation checkout on the target chamber, however, it was found necessary to misalign each system by a small amount in one direction to compensate for a deformation in the opposite direction which occurred when the target chamber was evacuated (a bellows connecting the telescope assembly to the target chamber to eliminate this relation was part of the original design, but was apparently too stiff). Therefore at the first opportunity in the busy Antares target shooting schedule, a measurement of the system modulation transfer function (MTF) was undertaken to determine the loss of resolution that might have occurred. The measurement was purposely done under normal operating conditions to determine the resolution of the system as used.

Resolution measurements

A spectroscopic plate copy of a three-bar resolution chart originated by Berlin Brixner at Los Alamos was employed to determine resolution in the target plane in cycles/mm. The position of the reference telescopes in relation to the target chamber and specifically the Target Insertion Mechanism (TIM), required a special holding apparatus to make it possible to measure the MTF of the system under operating conditions. The apparatus developed precisely positions the resolution chart perpendicular to the optical axis of the telescope being evaluated. To fit in the space normally occupied by the target the resolution chart was reduced to a 12.5-mm square. This diminished chart (Figure 1) was mounted on the TIM (Figure 2) and back illuminated by the target rear illumination system.

A block diagram of the measuring and the measured systems is shown in Figure 3. Monitor #1 displays the video reproduction of the chart scene being viewed. The same video signal goes to the television wave analyzer, a Tektronix 1480, where the system response to a selected region of the chart is displayed by selecting t-v scan lines passing through that region. Monitor #2 displays the same chart scene with the selected scan line brightened to indicate the region being analyzed.

The resolution chart is oriented so that the scan lines pass nearly perpendicular to the chart bars. Figure 4 shows a scan line passing through the bottom end of the 72 cycles/mm bars. The 10-degree angle deviation from being perpendicular introduces less than 2% error in the effective bar spacing. The modulation in a typical scan line is shown in Figure 5. From such scan-line modulation displays the signal-to-noise ratios were determined for each discernable set of bar spacings.[2] The MTF(n) at the line-pair number n will then be

$$MTF(n) = \frac{S/N(n)}{S/N(0)} \qquad (1)$$

Actually, zero lines/mm is not available,[3] therefore, a low enough value that the signal-to-noise ratio is constant is selected.[3]

The measurements at the output of the TV camera were expected to be the as-used system resolution, i.e., the product of the camera and telescope MTFs. The measurements were found to include a number of other contributors, some of which are actually a part of the system and some a part of the measurements setup. A small vibration, affecting the alignment of the optical axis of the telescope and camera with respect to the resolution chart, generated a signal modulation which we shall identify as $M_v(n)$. This vibration is due to the Antares vacuum pumps and should be considered part of the system. The contrast of the resolution chart C(n) was found to vary with line #n. A veiling glare V_g severely affected the modulation from the chart. Thus, the MTF measured, M_m, will be

$$\begin{aligned} M_m &= M_s * C(n) * V_g \\ &= M_C * M_E * M_T * M_v * C(n) * V_g \quad , \end{aligned} \qquad (2)$$

where M_s is the system resolution as used, M_C is the television camera MTF referred to the target region, M_E is the MTF of the video distribution system, and M_T the MTF of the telescope.

The determination of each factor is discussed in the following text.

Vibration contribution

The contribution of vibration to signal modulation will be included in but is not separable from the noise. However, if the vibration is assumed to be isotropic, it can be measured* from the broadening of the scan lines at the bar edges (Figure 6). Comparing these edges to those made by the camera alone, when working with an Optoliner,** a vibration induced edge modulation of 0.15-mm rms was determined. The magnification from resolution chart to oscillogram was 54, therefore, at the resolution chart σ=0.15 mm/54 or 2.8x10-3 mm rms. Assuming the vibration induced image motion to be sinusoidal, the effect on the sine-wave response[4] will be a zero order bessel function J_0, i.e.,

$$M_v = J_0\,[2\pi \sqrt{2}\; n\sigma] \qquad (3)$$

Resolution Chart Contrast

Observation of the resolution chart under a microscope showed that at the edges of the bars the developed silver grains had migrated into the open areas. At the higher line numbers these occupied an appreciable part of the clear area, reducing the light transmission and contrast ratio. Scans with a microdensitometer were fitted empirically with the following linear relation to the line number:

$$C(n) = 0.985 - 0.004\, n \qquad (4)$$

Video distribution system

This is a high quality 10-mHz bandwidth system whose $M_E \geq 0.95$ for all spatial frequencies that can be reproduced by the telescope. In the remaining text M_c will be assumed to be one (1).

* This solution was recognized by Ross Graves of S Division at the Los Alamos National Laboratory during a discussion of the problem.

** A television resolution chart device fixed rigidly to the camera.

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Camera MTF

Independent measurements of the camera were made with an Optoliner. These data were improved considerably when the 440A bandpass filter employed with the reference telescope system(1) was inserted into the Optoliner illumination system. These are the contrast transfer functions (CTF) of the system. After conversion[5] to MTF the results for M_c were as shown on the Johnson[6] plot in Figure 7.

Veiling glare (v)

The target chamber at Antares is a nearly spherical 24-ft-diameter chamber. As such it acts as an integrating sphere, although the walls are low in reflectance, so that any light within the chamber causes a nearly isotropic background illumination level at every point within the chamber. Adopting an analysis from Rempolla,[7]

$$\frac{C_R}{C_0} = 1/[1 + \frac{F_b}{F_s}] = V_g, \quad (5)$$

where C_0 is the inherent contrast of the resolution chart, C_R is the return contrast, F_b is the backscatter flux and F_s is the signal flux from the resolution chart. Crude measurements in the target chamber at the resolution chart indicate that F_b = (approx.)$0.1F_S$, whence

$$\frac{C_R}{C_0} = 0.91 = V_g .$$

System MTF

From Equation (2), the MTF of the system

$$M_s(n) = \frac{M_m(n)}{V_g * C(n)} \quad . \quad (6)$$

M_s is also plotted in the Johnson plot of Figure 7. Though less than the initial goal of being able to resolve 5 μm (i.e., 200 cycles/mm) this is the system which has been employed for most of the target positioning work at Antares. It should be noted that this plot includes the mechanical vibration contributions.

Camera plus telescope MTF

Dividing the vibration compoment M_v into relation (6) to get the camera plus telescope MTF, $M_C * M_T$ or M_{s-v}

$$M_{s-v} = M_C * M_T = \frac{M_M(n)}{M_v * C(n) * V_g} \quad . \quad (7)$$

This result is also shown on the Johnson plot of Figure 7. This plot clearly shows an improvement in resolution, indicating that fine observing and positioning of the target should be done with vacuum pumps shut down.

Telescope MTF

It is of interest to determine how much degradation of the telescope resolution was caused by the misalignment required by the target chamber deformation. Combining the plot of the camera MTF, M_c, with relation (7) we get

$$M_T = \frac{M_C * M_T}{M_C} \quad (8)$$

This result is also plotted in Figure 7, though only as far as the measurements. They are extrapolated as shown to the response at 200 cycles/mm. On the same plot is shown the expected telescope resolution. About 50% loss has occurred at 200 cycles/mm.

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Positioning Precision

The procedure employed for positioning a target assures precise positioning in the following manner. First the RTS is aligned to a surrogate target which is inserted by the TIM. The surrogate target is then replaced by an optical detection system and its positioning guided by the aligned RTS. Low power lasers are then used with the optical detection system to guide the alignment of the Antares Laser Optical System. Figure 8 illustrates convergence of half (12) of the beams on the target. Finally the target sphere is inserted by the TIM and the RTS employed to guide its positioning.

Analysis of photos taken at shot times with x-ray pinhole cameras indicates that, typically, positioning of the target is within 25 μm of the beam system center. A typical shot scene is shown in Figure 9.

After the above procedure new targets can be inserted and postioned by the guidance of the RTS without having to go through the alignment procedure with two qualifications. After a lengthy period of operation the bellows stresses introduced by the required misalignment of the RTS (noted in the introduction) may have forced a new position of the RTS. Depending on the positioning precision required it may then be necessary to repeat the RTS alignment procedure. This will also be necessary each time the target chamber goes through an evacuation procedure.

Conclusion

The MTF of the telescope alone, but misaligned has been degraded by 50% from the expected value of 0.3 at 200 lp/mm. The complete system, with vacuum pumps running, would resolve only 100 lp/mm, down 2X from the design goal. Operation without the pumps running would raise the limiting resolution to 200 lp/mm, meeting the design goal of 5 μm. The positioning precision of the RTS is about 25 μm.

Acknowledgements

Discussions of the alignment procedures with Ronald Rench, Geza Keller, and I.V. Johnson, of the operating and alignment crew, have been of great help in understanding the role played by the RTS in positioning precision. Philip Goldstone and Richard Krystal, users of Antares, provided the positioning precision data. Figure 8 was supplied by Walter Bauke.

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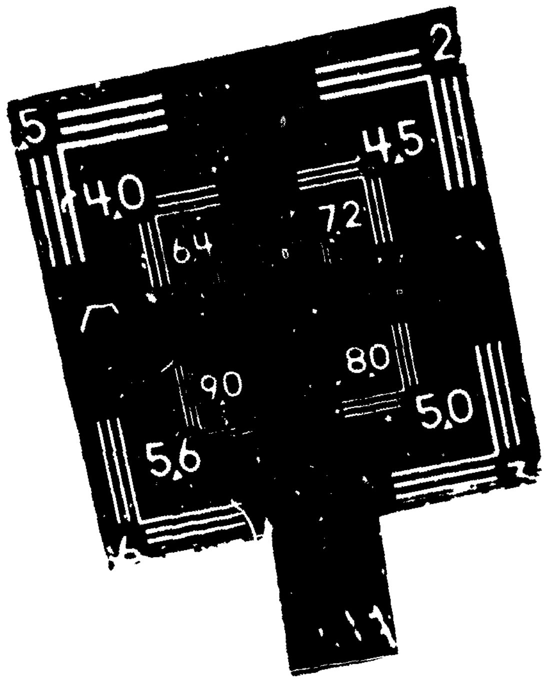


Figure 1

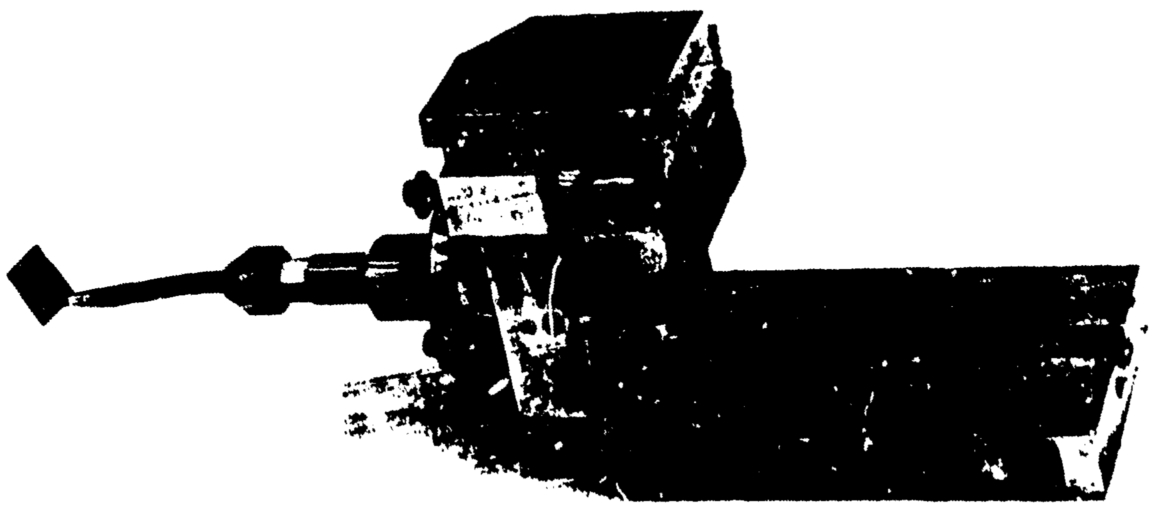


Figure 2

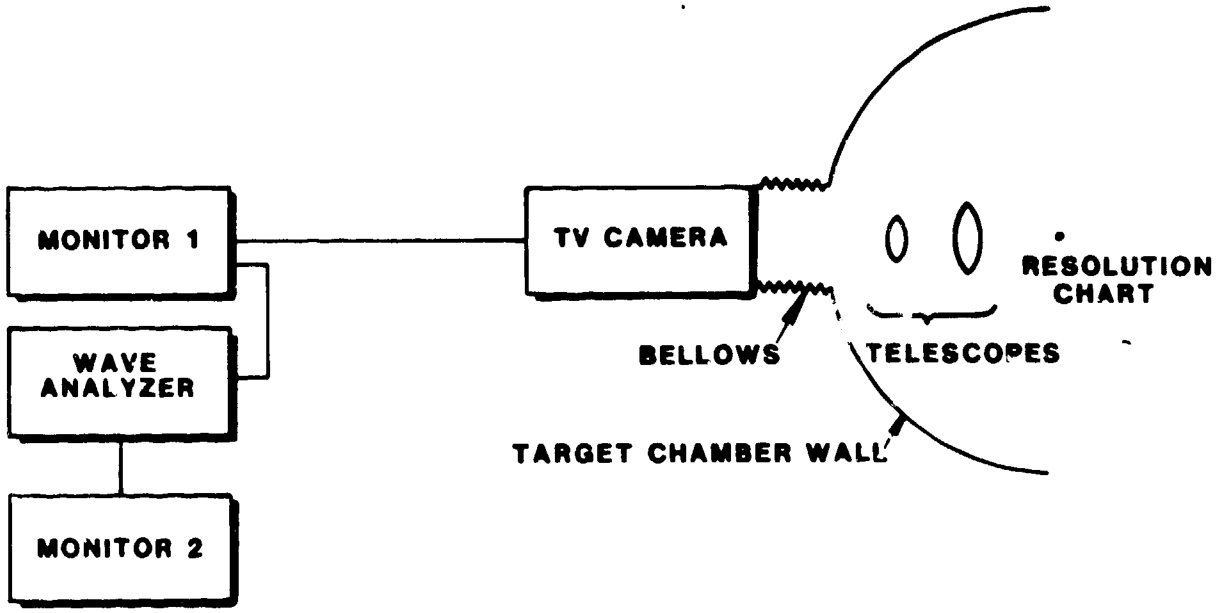


Figure 3

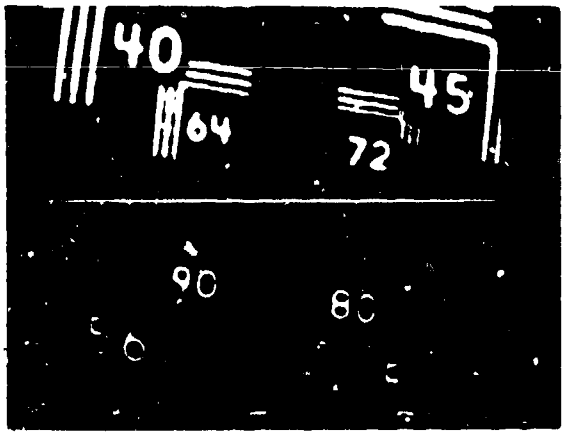


Figure 4

Figure 5

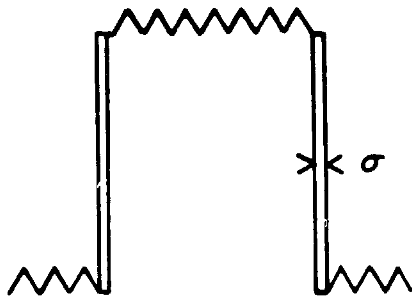


Figure 6. Edge Modulation

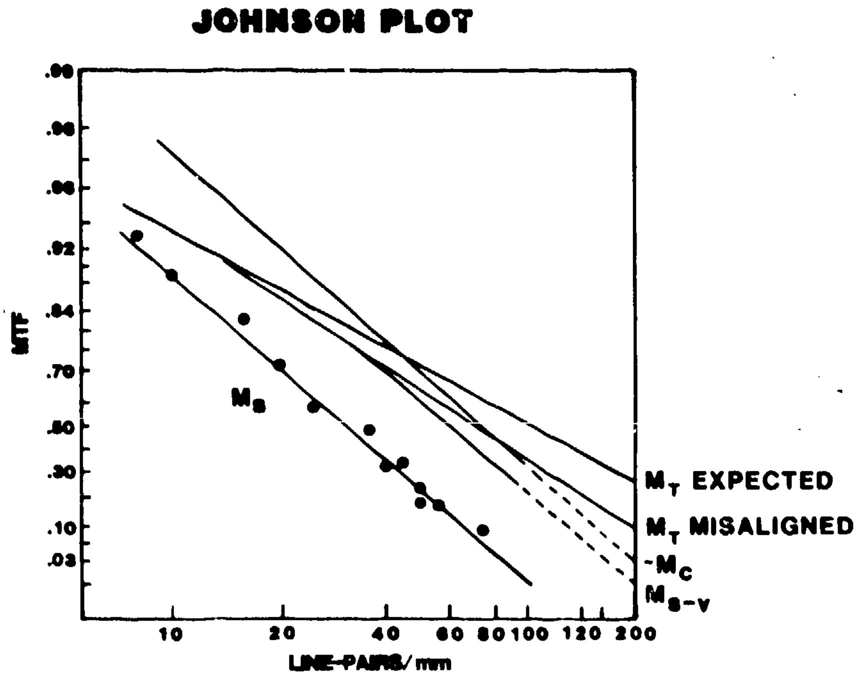
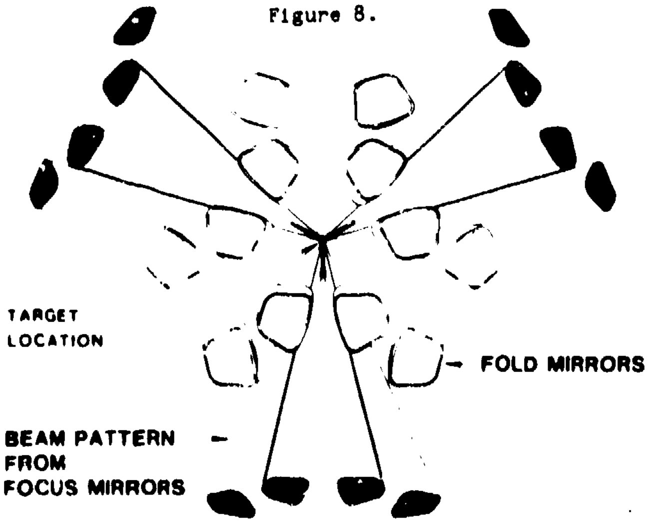


Figure 7.

Figure 8.



TARGET SYSTEM BEAM GEOMETRY

Figure 9. Beam on Target

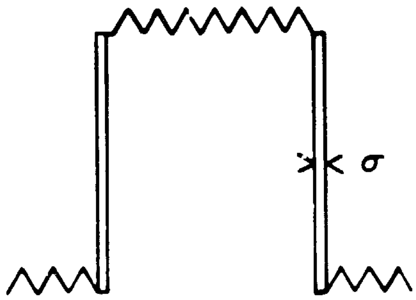


Figure 6. Edge Modulation

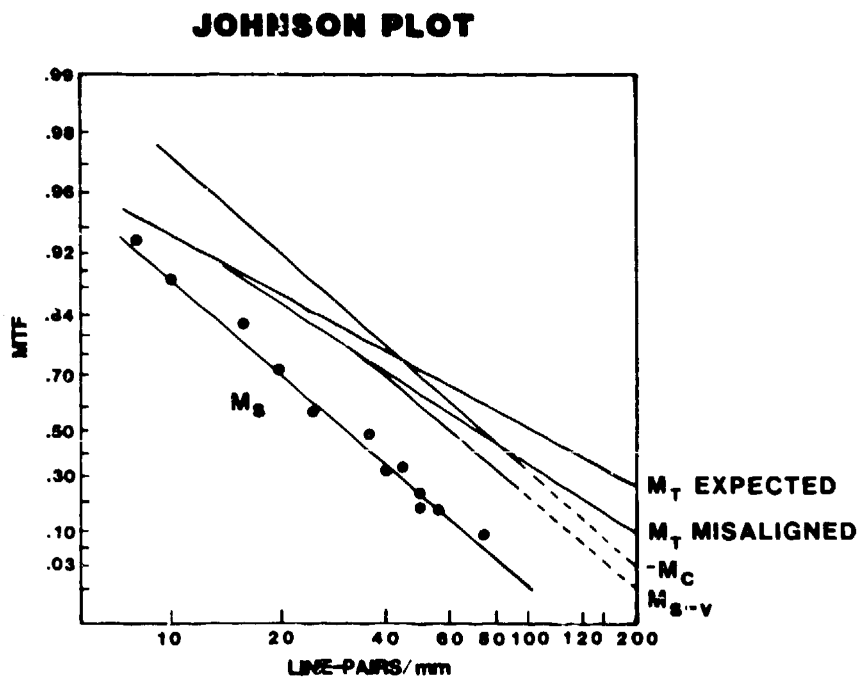


Figure 7.

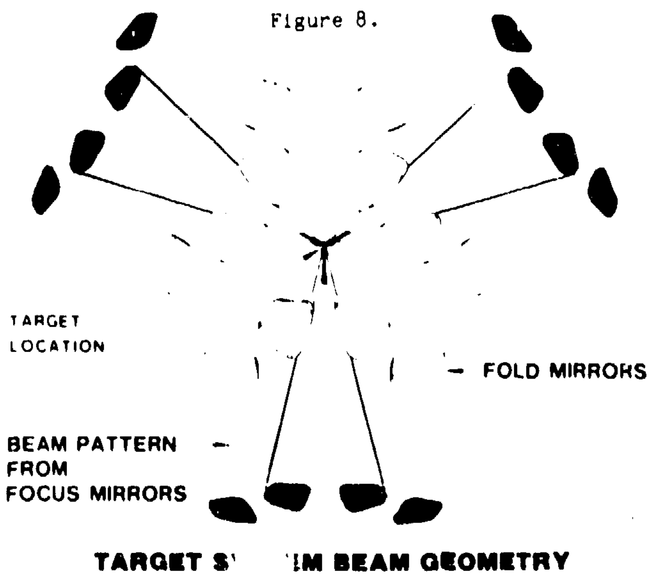


Figure 8.

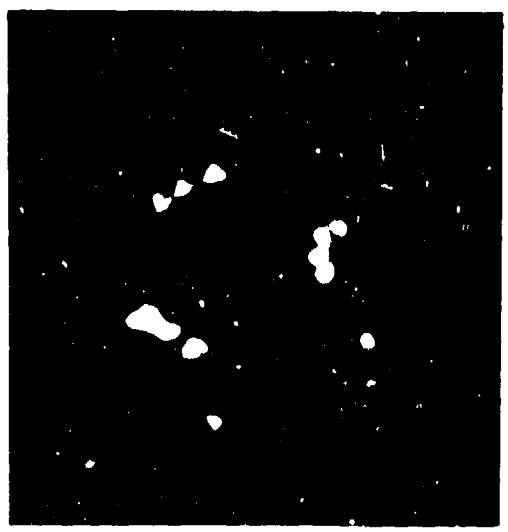


Figure 9. Beam on Target