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Final Report

On NASA Grant NGR 8029 Supplement No. 1

Determination of Particle Size Using Measurement of Scatter

To

National Aeronautics and Space Administration

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Summary

The objective of this grant was to determine if scatter measurements from glass spheres in the size range 5 to 50 microns placed on a mirror could be correlated with size. The spheres were illuminated with a laser whose wavelength was 0.62 microns. A Gonioreflectometer was used to vary the detector between the normal to the mirror and 85° from the normal and in the plane containing the normal to the mirror and the incident laser light. The azimuth of the detector with respect to the source was 180°. The light detector was driven by a step motor. The scatter was dark and bright lines. They appeared as minima and maxima on the output recorder. As the size of the beads increased the number of maxima increased.

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Experimental Apparatus and Procedure

Three major changes were made to the apparatus. As shown in Figure 2a, a scanning system was added in order to obtain a continuous curve of the energy scattered from the specimen. Figure 2b shows the specimen holder used for this grant. This specimen holder has three degrees of freedom. Finally, Figure 2c shows the modified microscope for sizing beads.

Near the end of the first year of this grant we discovered that if we decreased the solid angle sufficiently, we could determine the angular spacing between the bright and dark lines scattered from the specimen which are characteristic when the laser is used. However, getting the precise location by manually moving the detector was difficult. So, steps were taken to motorize the detector. This can be seen in Figure 2a and 2d. A step motor was chosen because it's position error is never greater than 0.25 degrees. With the gearbox used between the step motor and detector this translates into a 3 minute error in the position of the detector due to the step motor error. The main error to consider is the elongation of the cable which is connected to the gearbox and the detector. This "backlash" was minimized by taking all angular measurements after rotating the step motor in the direction that was used to obtain the scatter data.

To relate the inches of movement on the recorder to the angular movement of the detector we started the recorder and detector at the same time and stopped them at the same time.

In the first year of this grant we had difficulty in getting particles whose diameters were less than 50 microns under the laser beam. To solve this problem we designed a holder that has three degrees of freedom. Essentially this allowed us to place particles anywhere on the specimen holder before we made a decision as to what particle we would study. Different particles were brought under the laser by adjusting the specimen holder. By observing the mirror through the microscope we could tell which particle was in contact with the laser beam. Once a particle within the proper diameter was in contact with the laser beam, its size was determined.

Two different lens were used to focus the laser onto the beads. These were of 10 and 20 cm focal length. An area of 0.14 mm^2 was illuminated on the mirror when the 10 cm focal length mirror was used. When the 20 cm focal length mirror was used, the illuminated area was 0.025 mm^2. The reason for using a given focal length for a certain range of bead sizes was to obtain the largest possible signal to noise ratio. In this case noise would be light reflected from the mirror that does not come into contact with the bead.

For the data in Figure 4 to 13 the beads were placed on first surface mirror. In Figure 13 to 22 the beads were placed on a glass neutral density filter. The neutral density filter was used because the scattered light from the surface of the filter was less than that from the mirror.

Another change that was made is the incident angle of the light. With large beads (diameter greater than 60 microns) it is easy to see the location of the beads with the naked eye. But, with smaller beads this becomes difficult. To solve this problem a microscope (Figure 2c) was redesigned so that one could locate the particle that was illuminated by the laser while the particle was on the specimen holder. Because of the closeness of the objective to the specimen it was necessary to increase the angle of the incident light. This angle was changed from 30^o to 54.5^o. For angles smaller than 54.5^o the laser beam hits the objective of the microscope. For angles larger than 54.5^o we can easily see which particle is in contact with the laser beam by looking throught the microscope.

The following procedure for computing angular spacing of the peaks in the data in minutes was used:

1. Record total inches of chart paper movement

from the time the test starts to the time it stops, Δin.

2. Compute the change in the angle of the light detector from the time the test starts to the time it stops, $\Delta\theta$.
3. Compute the number of degrees per inch, $\Delta\theta/\Delta in$.
4. Count the number of peaks from approximately 0.5 inches on the chart paper to approximately 2.0 inches on the chart paper. This gives peaks per inch for some measured distance which is about 1.5 inches. The measured distance starts with a peak and ends with a peak. Within the measured distance the first peak is <u>not</u> counted.
5. Compute $\Delta\theta/\Delta pk. = \frac{\Delta\theta/\Delta in.}{pk./\Delta in.} \times 60$

Discussion

The purpose of this grant was to determine to what extent particles could be sized by observation of the scattered energy. In the first year of this grant most data was taken using a Quartz lamp. Near the end of the first year some exploratory test showed our system was sensitive enough to measure the angular spacing between the scattered dark and bright lines. We gave a preliminary curve of angular spacing versus size for an incident angle of 30°. In this investigation the main effort was modifying the experimental system for the purpose of making the procedure we used for obtaining data less likely to have error. For the data presented the only place for making a blunder is not clearing out the "backlash" on the detector position cable. This is a big improvement from manually setting the angles as was the case in the first year of this grant.

Figure one shows a schematic of the specimen being illuminated by a source at 54.5°. Data were taken for theta (θ) between 0° and 85° and in the plane containing the normal to the mirror and the incident light source.

Figure 3 shows the results of the investigation. This shows that by a very simple computational procedure using the data of Figures 5 through 22 we can get a curve of angular spacing versus size. Using the mirror and the 20 cm focal length lens we were able to correlate the data down to 11.1 microns. The computations for Figure 4 (7.8 microns) is not shown on this graph. The angular spacing for Figure 4 using the first three peaks is 270 minutes which does not agree with the other points on the graph.

The 10 cm focal length lens was used to reduce the area illuminated by the laser. This and the glass neutral density filter were used to increase the signal to noise ratio. With the 20 cm F. L. lens and mirror it was difficult to determine when a 7 micron particle was under the laser. But, with the 10 cm F. L. lens and glass filter there was no problem in this regard. As a matter of fact we were able to take data for 5.6 micron bead as Figure 14 shows.

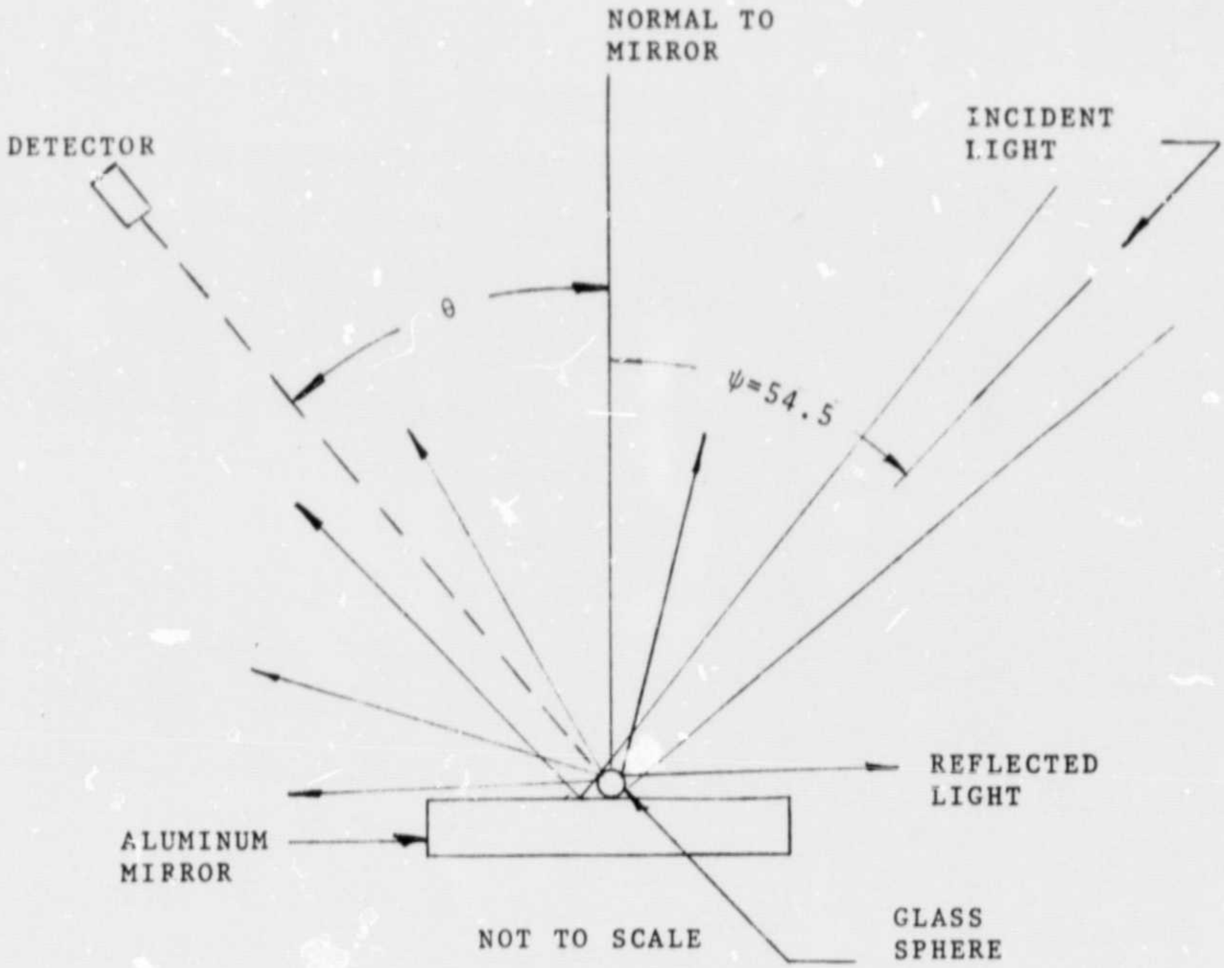
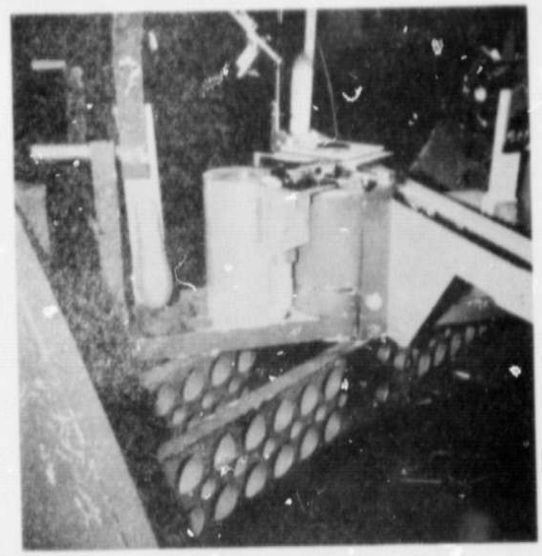
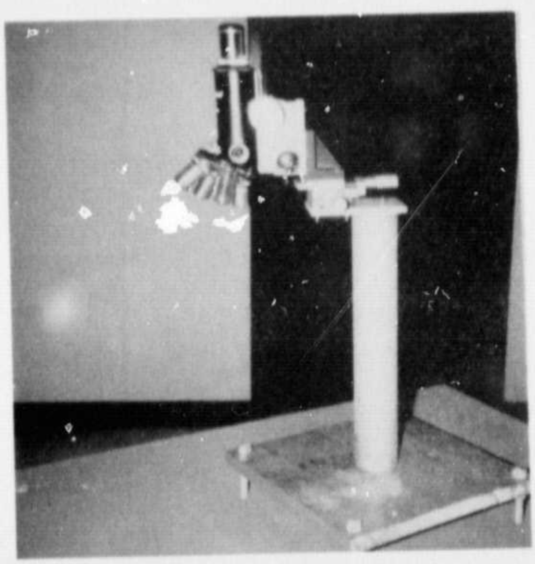


FIGURE 1. Schematic of specimen, light illumination and detector arrangement.

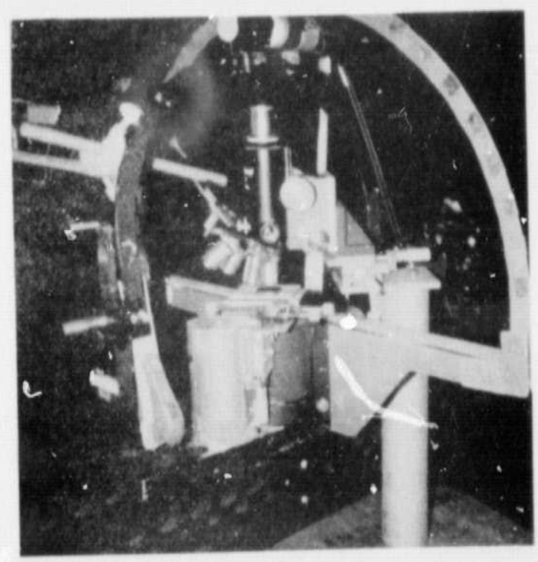
2a. Step Motor Driven Scanning System



2b. Specimen Holder



2c. Modified Microscope



2d. Overall view with Microscope in place for locating and sizing particles

Figure 2. Photographs of Apparatus

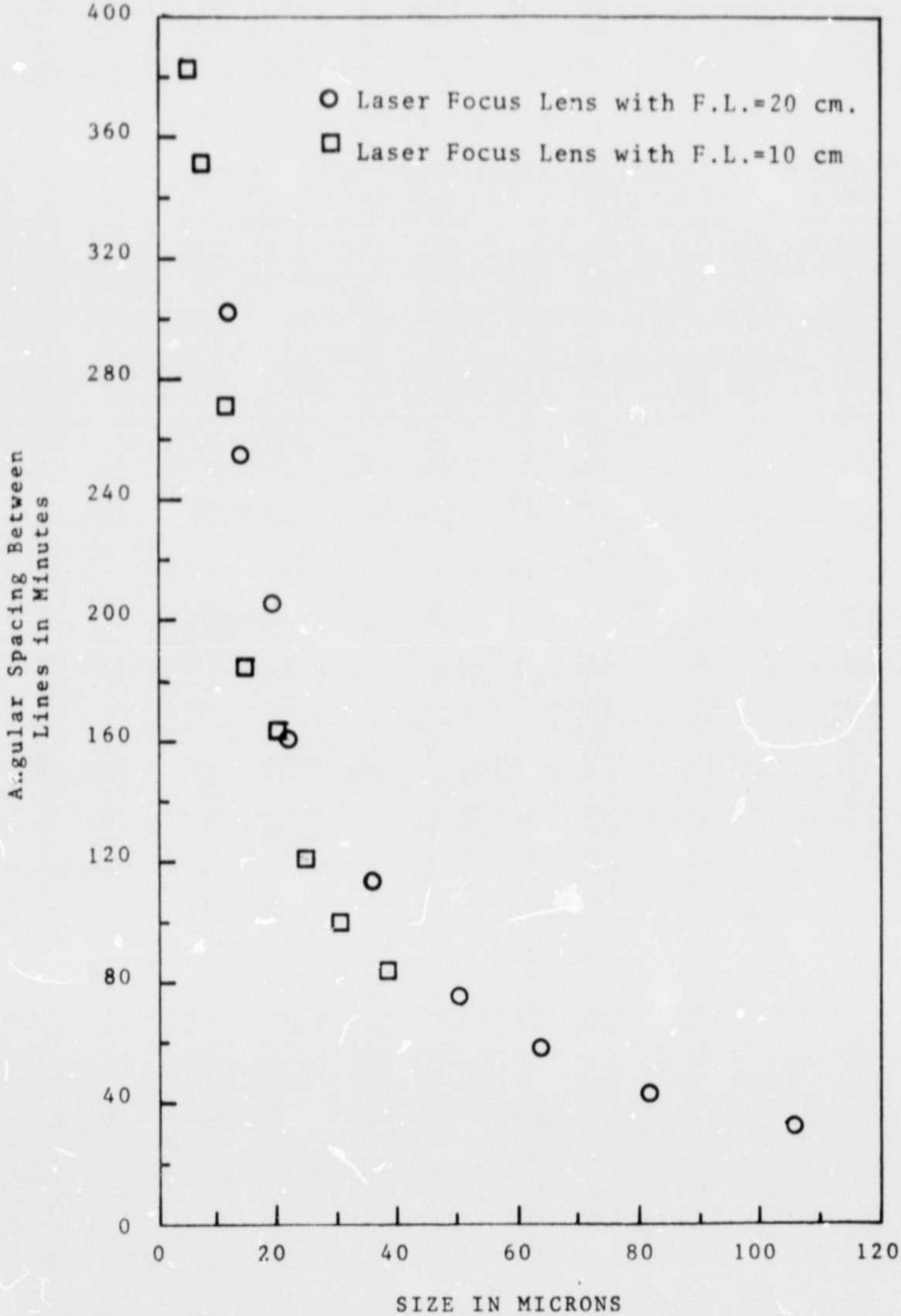


Figure 3. Relation between size of beads and angular spacing of maxima.

TABLE 1

Angular Spacing Between Lines-
Laser focus lens with F.L.=20 cm

Size Microns	Spacing Minute
7.8	220
11.4	301
14.8	254
18.5	205
20.4	161
35.3	114
49.0	72
63.0	55
81.0	40
105.7	31

TABLE 2

Angular Spacing Between
Lines-Laser focus lens with F.L.=10 cm

Size Microns	Spacing Minutes
5.5	381
7.4	350
11.1	274
14.8	182
19.6	162
24.1	120
29.6	100
37.0	82

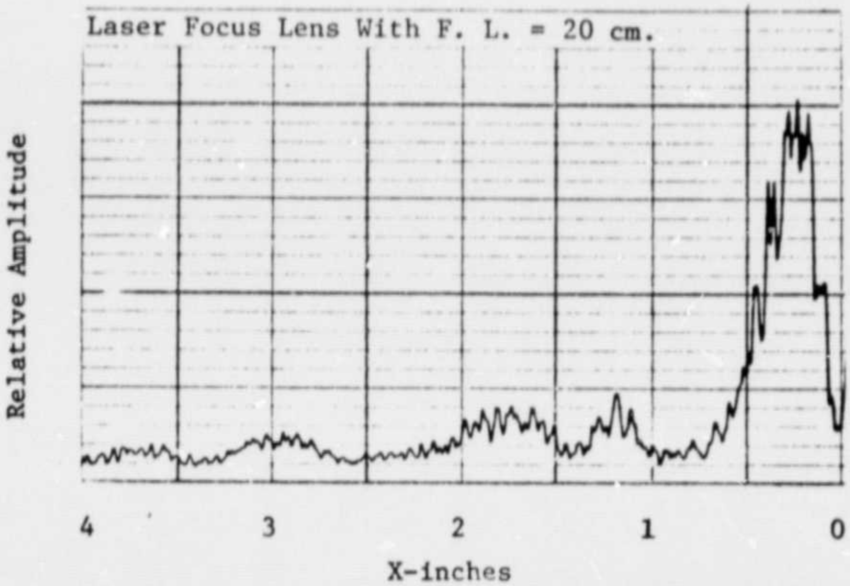


Figure 4. Recorder output for 7.8 micron bead. $\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=24.00^{\circ}$, $\Psi=54.5^{\circ}$

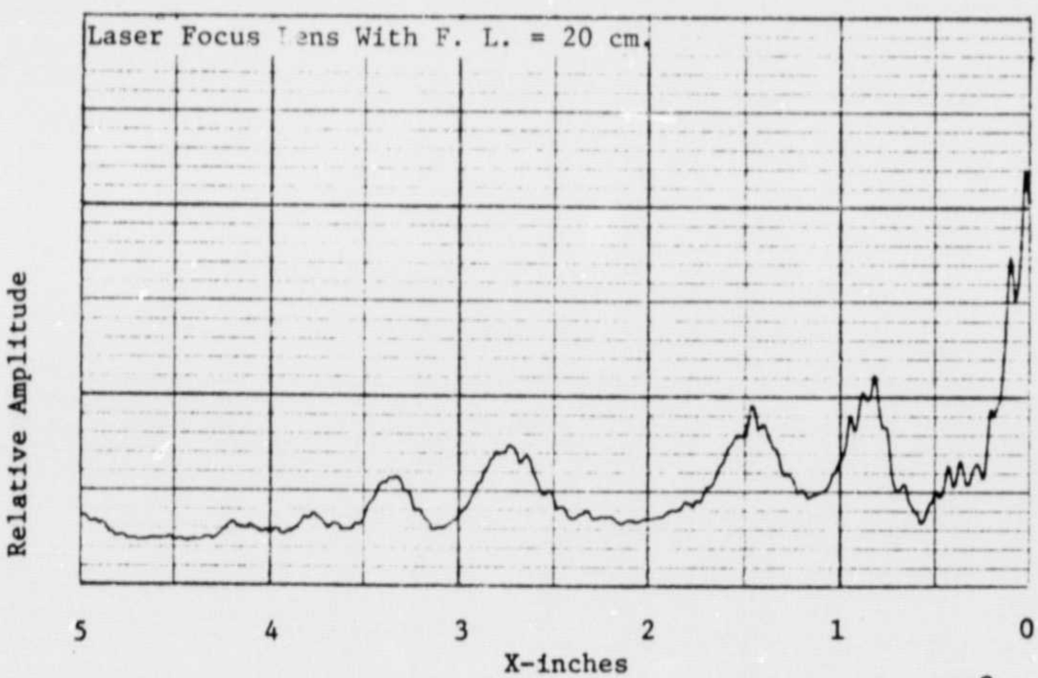


Figure 5. Recorder output for 11.1 micron bead. $\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=24.80^{\circ}$, $\Psi=54.5^{\circ}$

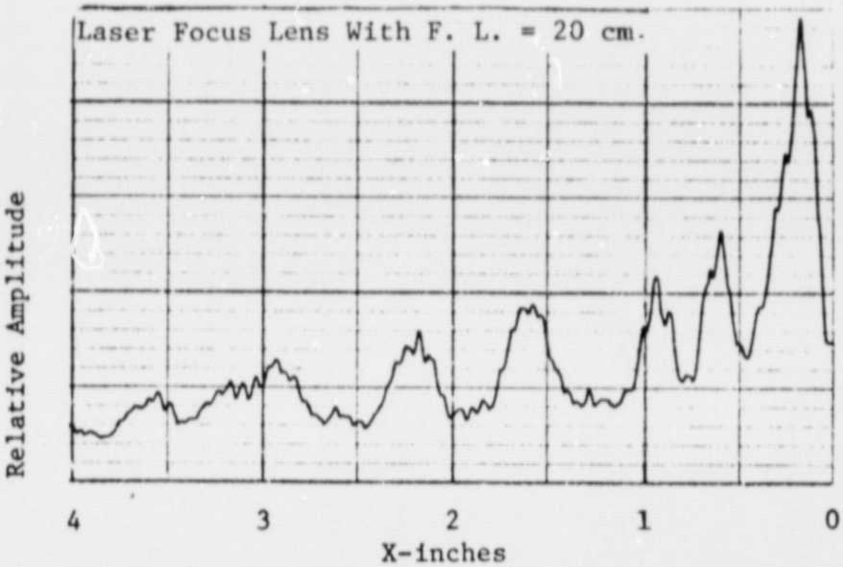


Figure 6. Recorder output for 14.8 micron bead.
$\theta_{x=0}=50^\circ$, $\theta_{x=4}=25.40^\circ$, $\Psi=54.5^\circ$

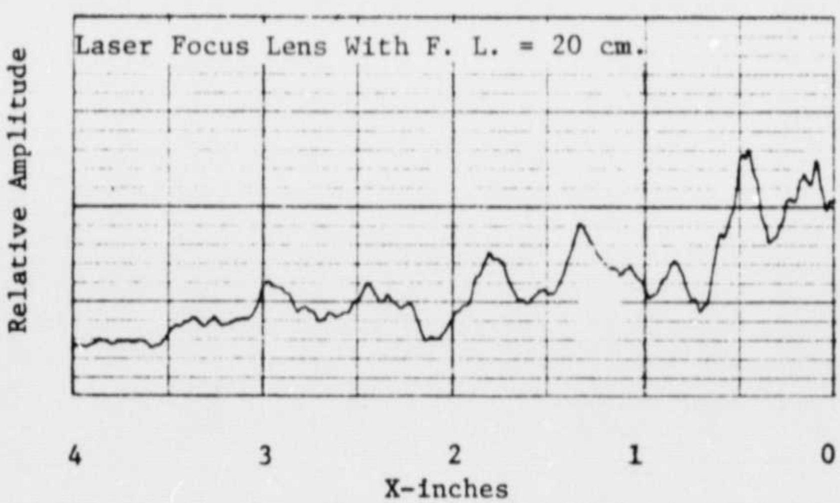


Figure 7. Recorder output for 18.5 micron bead.
$\theta_{x=0}=50^\circ$, $\theta_{x=4}=25.12^\circ$, $\Psi=54.5^\circ$

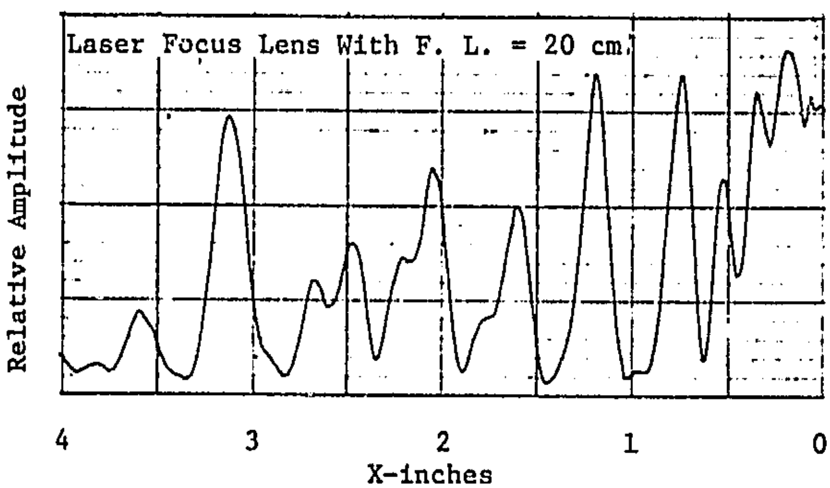


Figure 8. Recorder output for 21.15 micron bead. $\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=25.84^{\circ}$, $\Psi=54.5^{\circ}$

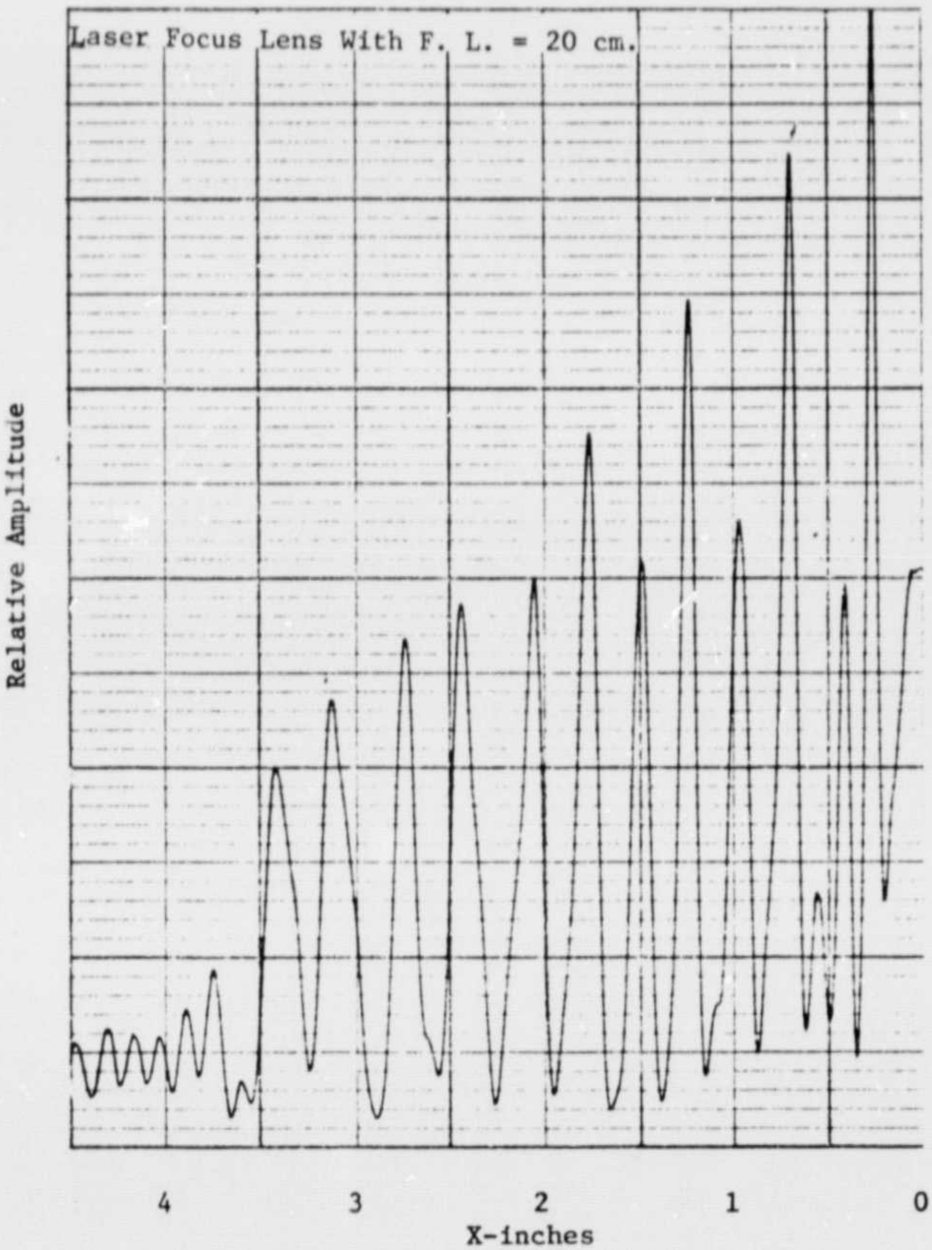


Figure 9. Recorder output for 31.45 micron bead.
$\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=25.20^{\circ}$, $\Psi=54.5^{\circ}$

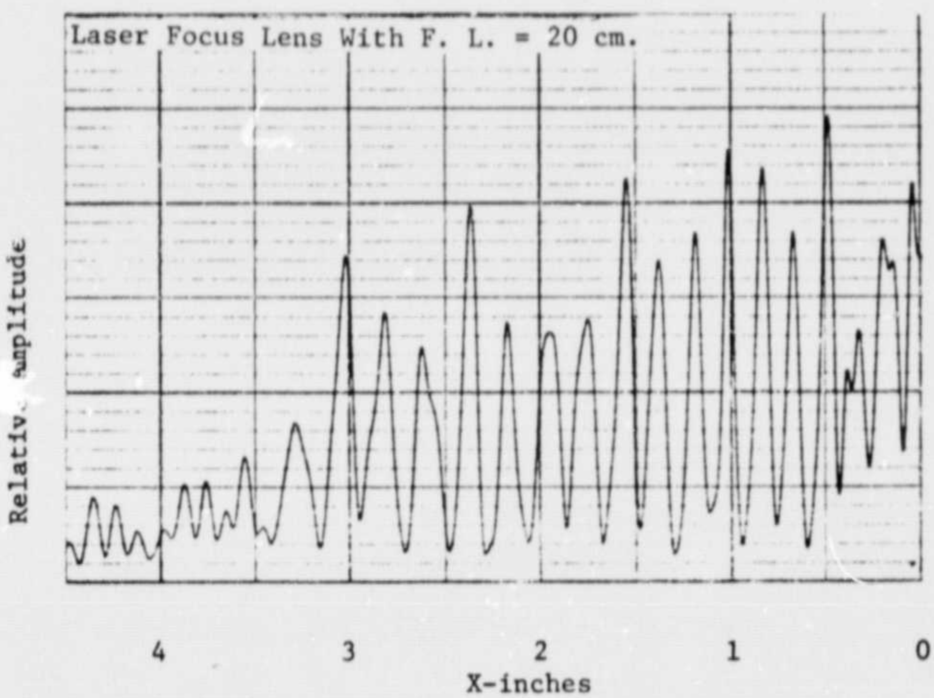


Figure 10. Recorder output for 49.4 micron bead.
$\theta_{x=0}=50^{o}$, $\theta_{x=4}=25.44^{o}$, $\Psi=54.5^{o}$

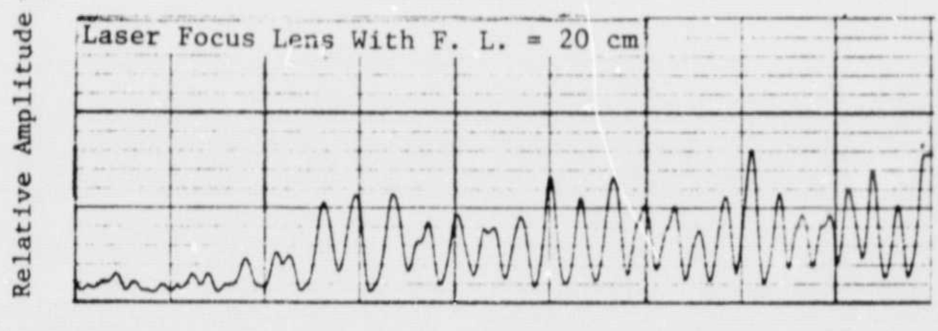


Figure 11. Recorder output for 63.0 micron bead.
$\theta_{x=0}=48^{o}$, $\theta_{x=4}=25.20^{o}$, $\Psi=54.5^{o}$

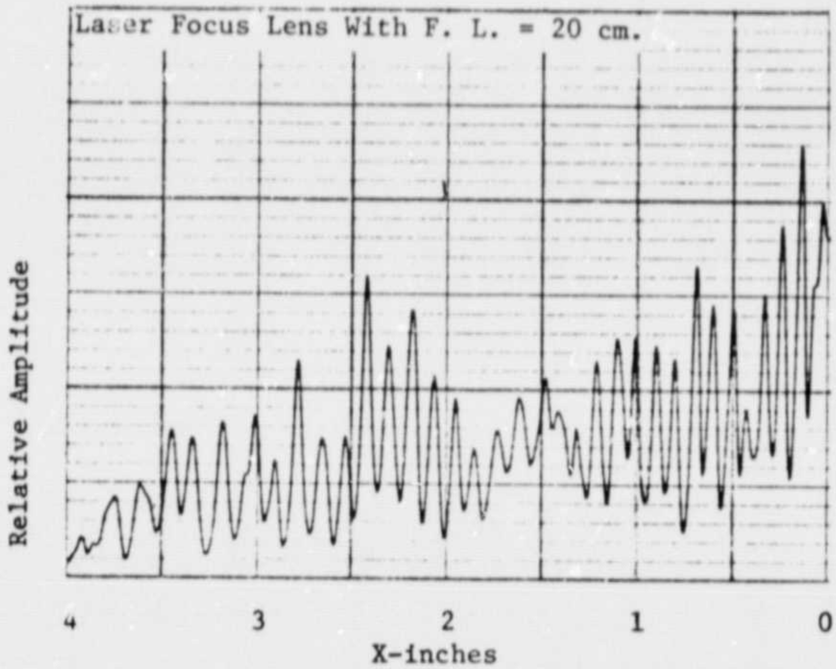


Figure 12. Recorder output for 81.0 micron bead.
$\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=25.48^{\circ}$, $\Psi=54.5^{\circ}$

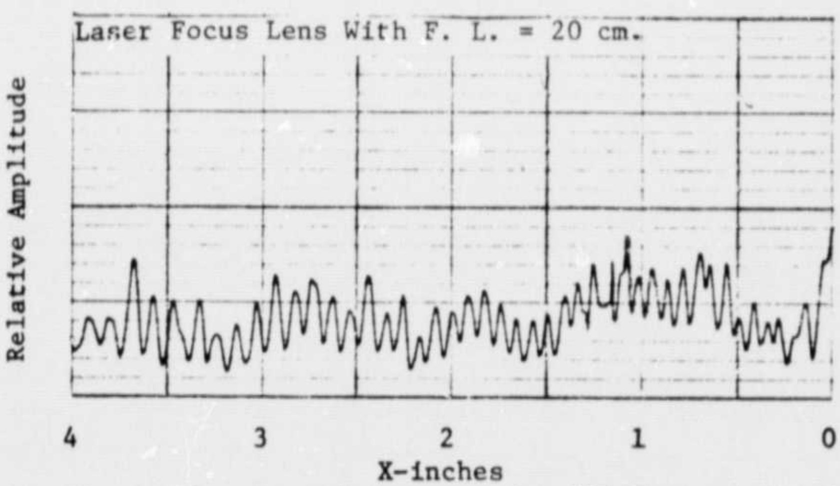


Figure 13. Recorder output for 105.7 micron bead.
$\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=25.20^{\circ}$, $\Psi=54.5^{\circ}$

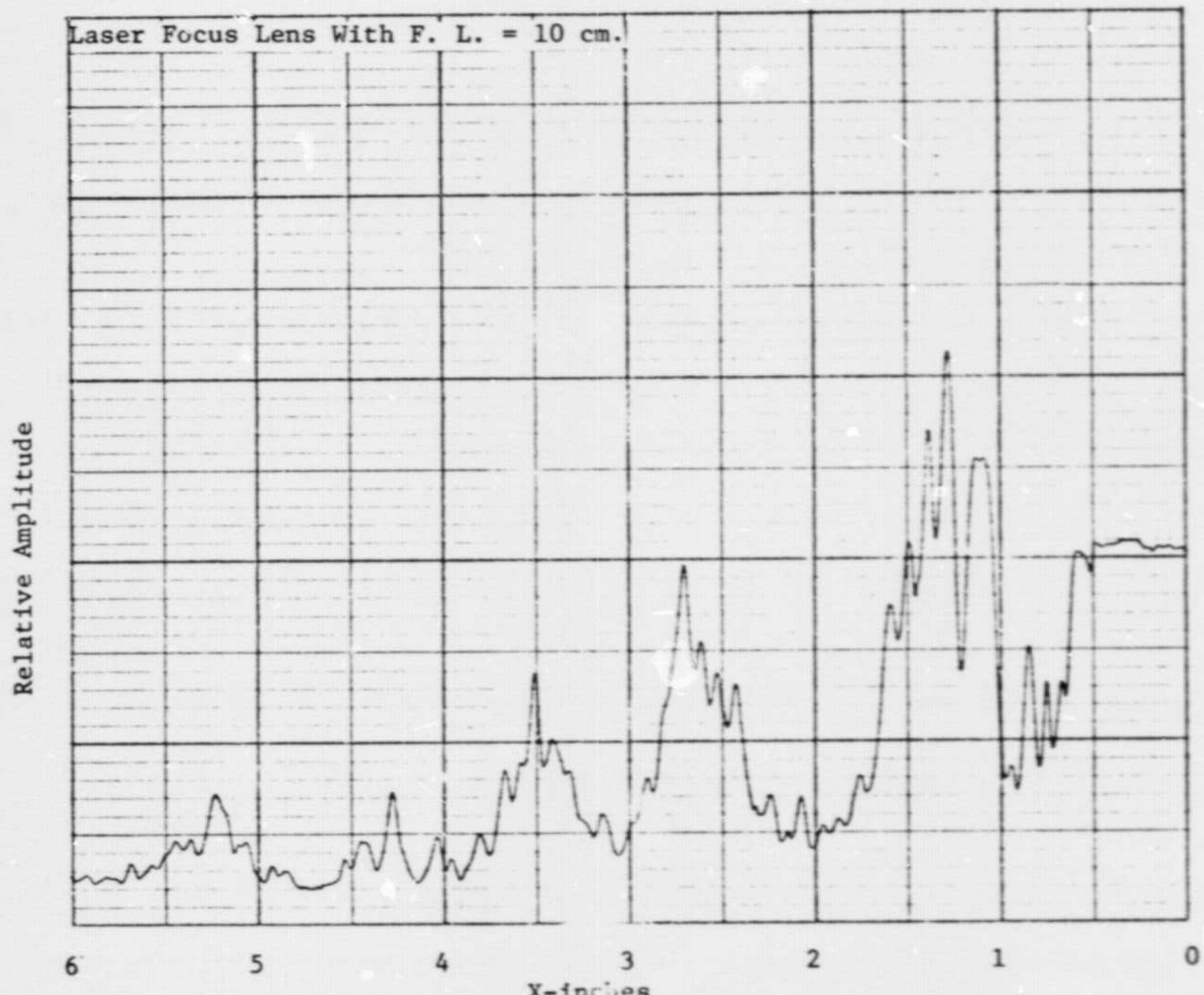


Figure 14. Recorder output for 5.6 micron bead. $\theta_{x=0.5}=50^{\circ}$, $\theta_{x=4}=25.44^{\circ}$, $\Psi=54.5^{\circ}$

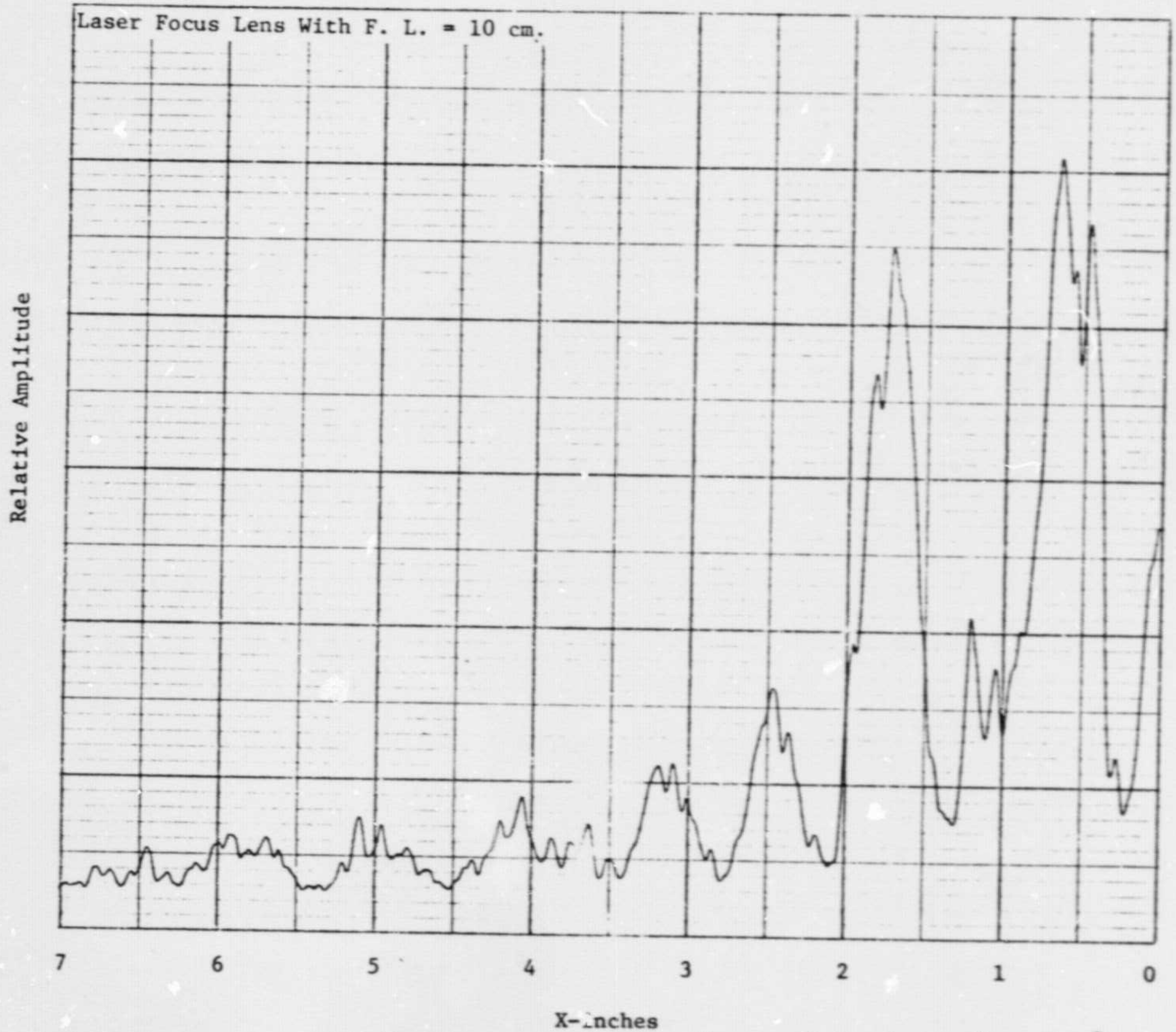


Figure 15. Recorder output for 7.4 micron bead. $\theta_{x=0}=45^{o}$, $\theta_{x=4}=26.12^{o}$, $\Psi=54.$[illegible]

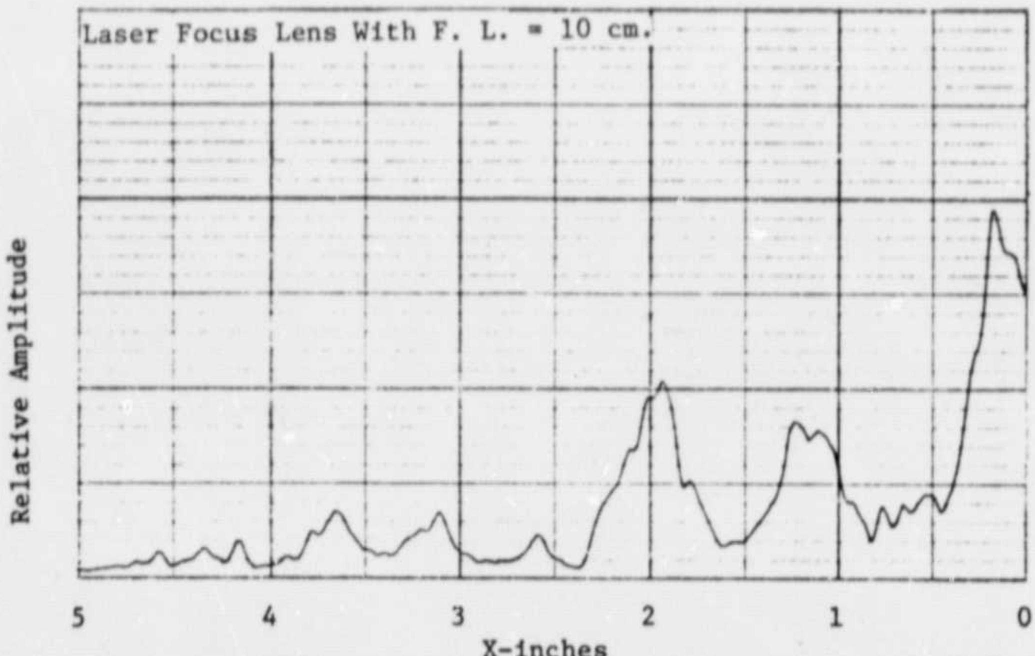


Figure 1 Recorder output for 11.1 micron bead. $\theta_{x=0}=45^{\circ}$, $\theta_{x=4}=25.68^{\circ}$, $\Psi=54.5^{\circ}$

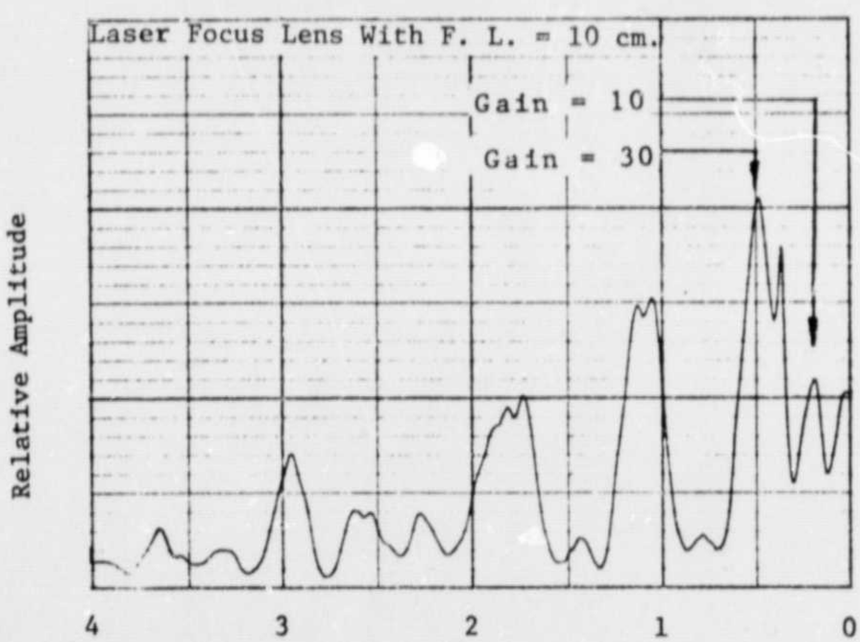


Figure 17. Recorder output for 14.8 micron bead. $\theta_{x=0}=50^{\circ}$, $\theta_{x=4}=26.00^{\circ}$, $\Psi=54.5^{\circ}$

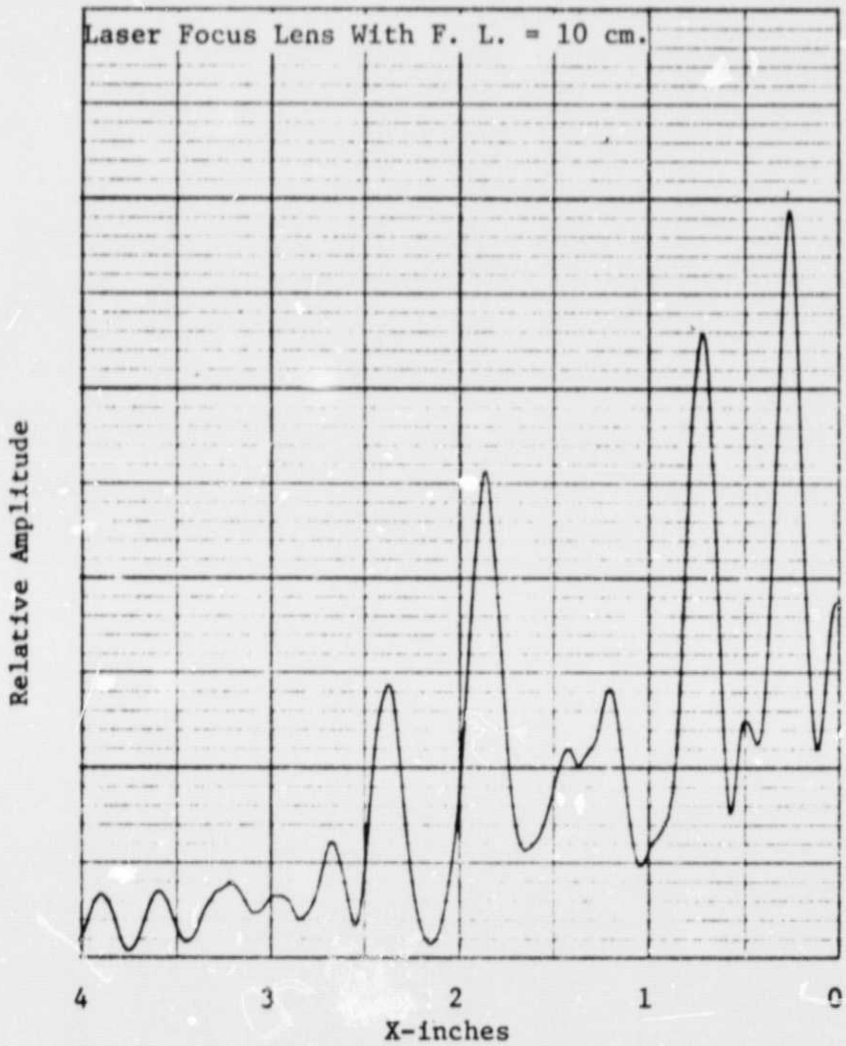


Figure 18. Recorder output for 19.6 micron bead. $\theta_{x=0}=45^{\circ}$, $\theta_{x=4}=25.20^{\circ}$, $\Psi=54.5^{\circ}$

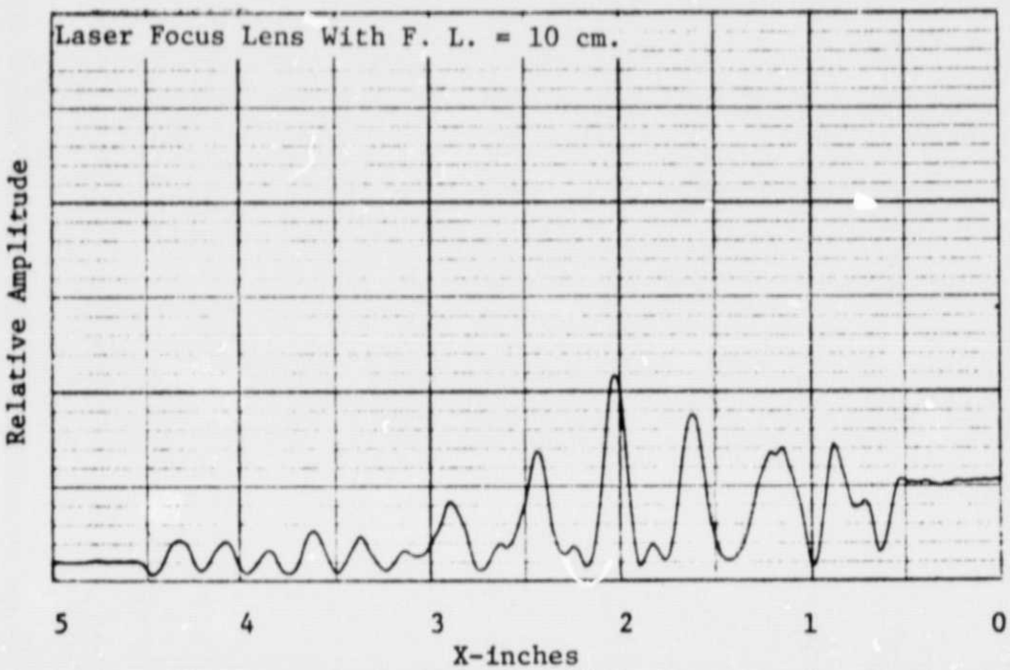


Figure 19. Recorder output for 24.1 micron bead. $\theta_{x=0.5}=45^{\circ}$, $\theta_{x=4}=25.20^{\circ}$, $\Psi=54.5^{\circ}$

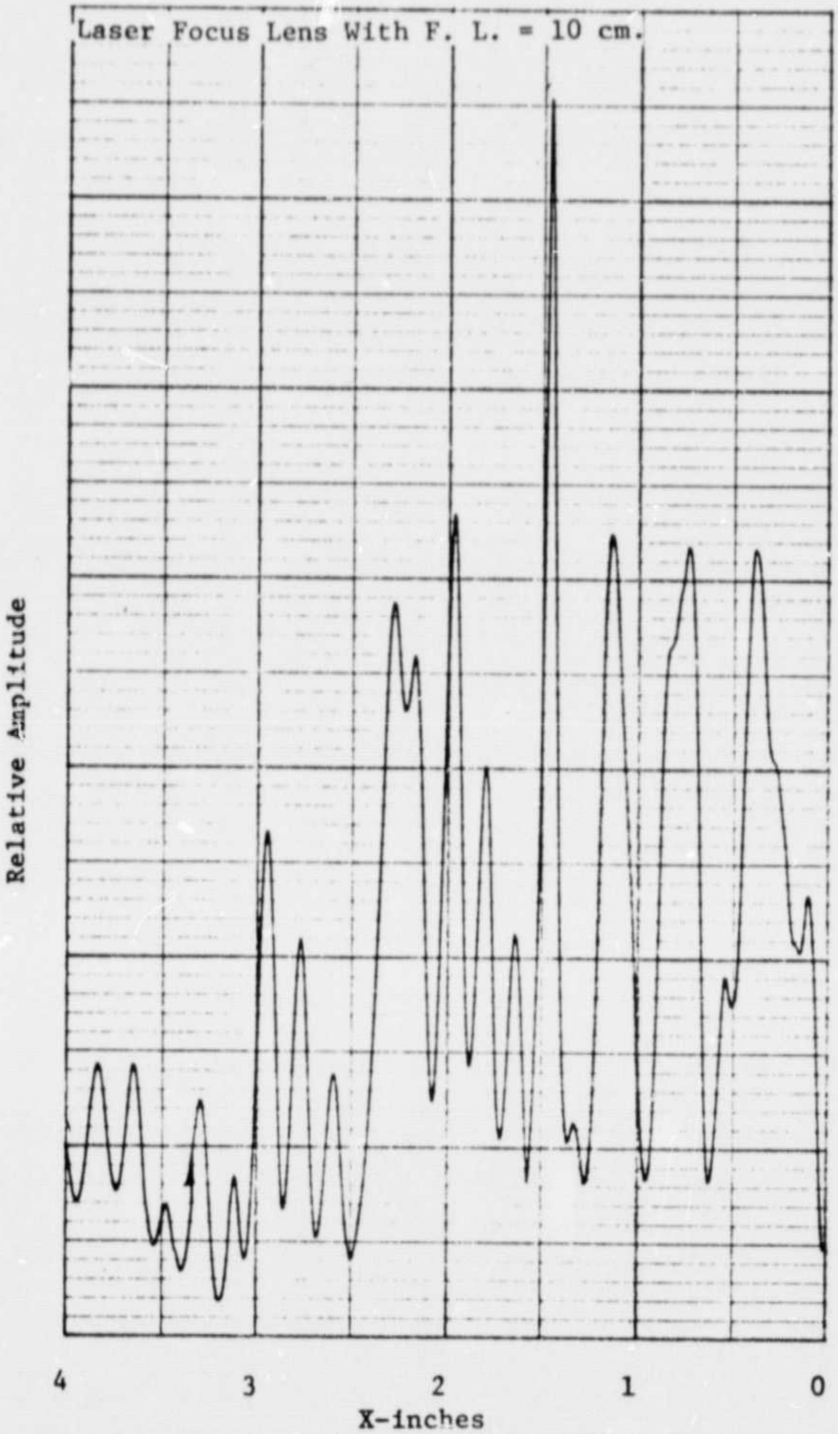


Figure 20. Recorder output for 30 micron bead. $\theta_{x=0}=45^{o}$, $\theta_{x=4}=26.00^{o}$, $\Psi=54.5^{o}$

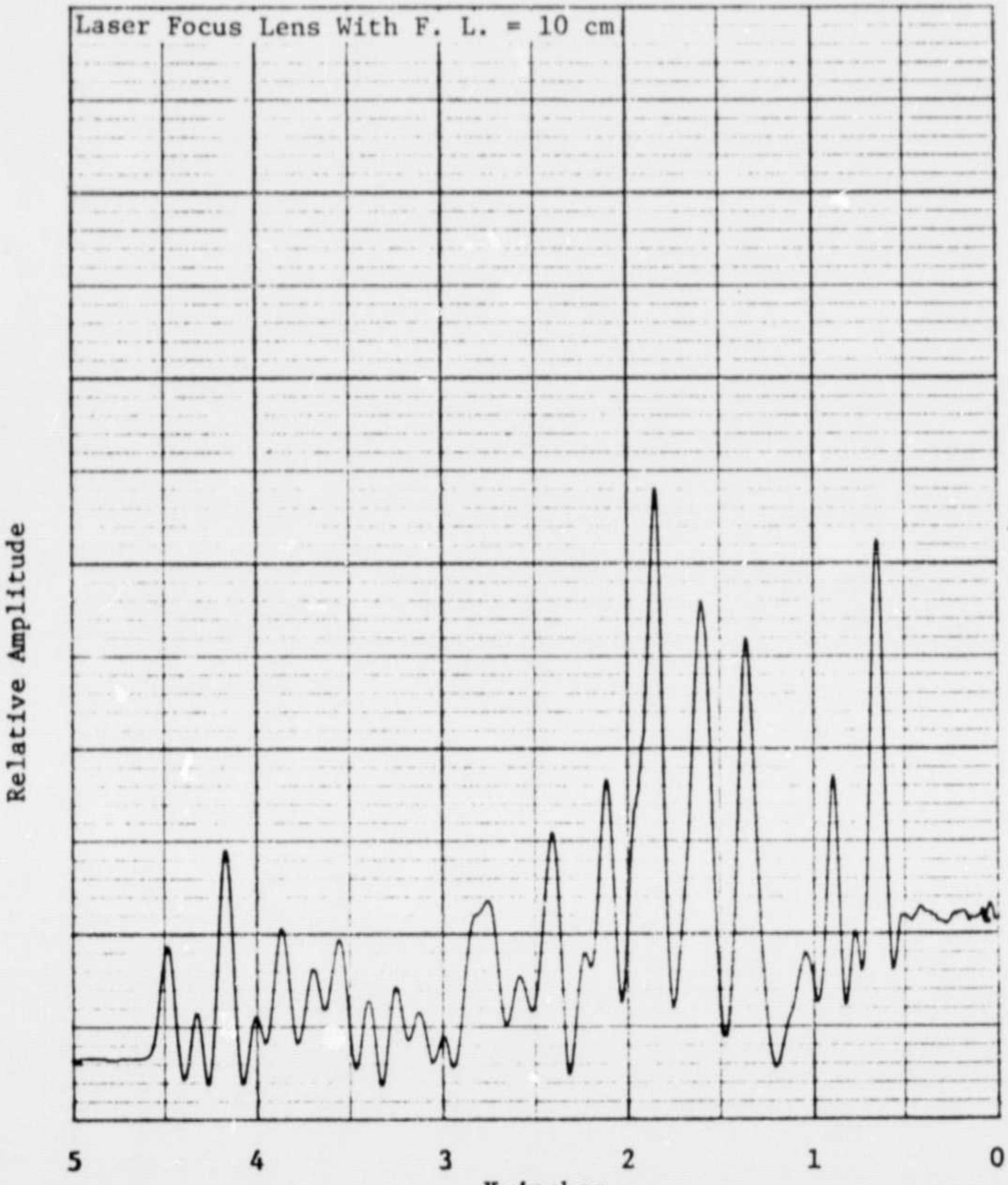


Figure 21. Recorder output for 37 micron bead. $\theta_{x=0.5}=45^{\circ}$, $\theta_{x=4}=25.20^{\circ}$, $\Psi=54.5^{\circ}$

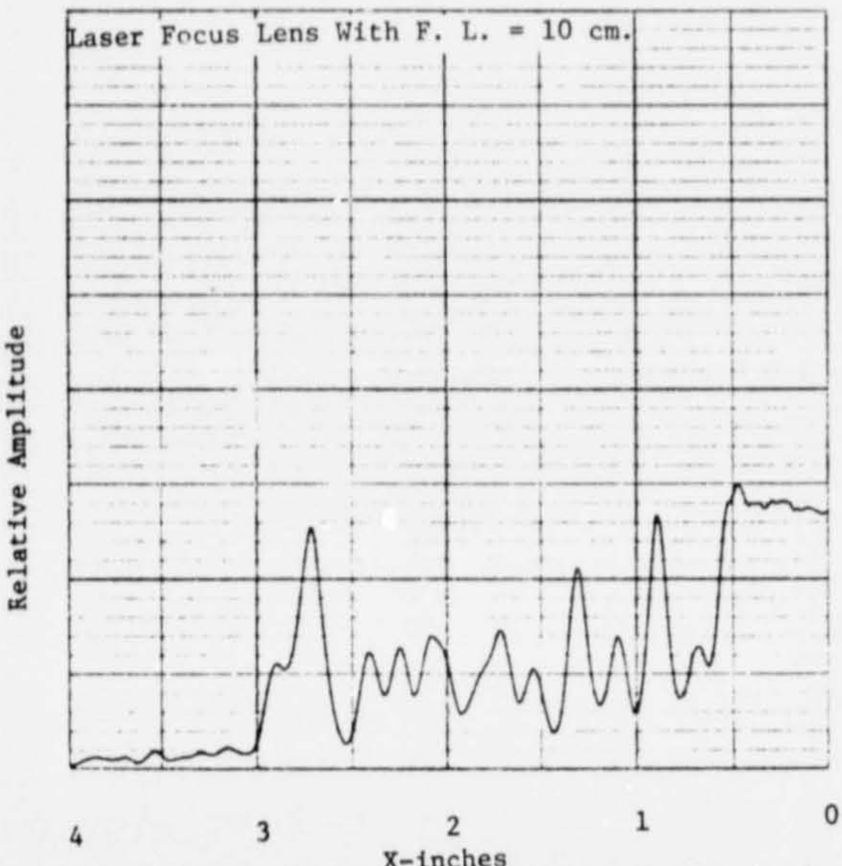


Figure 22. Recorder output for 44.4 micron bead.
$\theta_{x=0.5}=45^{\circ}$, $\theta_{x=4}=25.44^{\circ}$, $\Psi=54.5^{\circ}$