CONF-910810--4

LA-UR-81-1962

MASTER

TITLE: ULTRAPRECISION MACHINING OF OPTICS AT LOS ALAMOS

AUTHOR(S): R. L. Rhorer, A. L. Gauler, E. W. Colston, and J. R. Ruhe

SUBMITTED TO: Society of Photo-optical Instrumentation Engineers
International Symposium
San Diego, California, August 24-28, 1981

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Ultraprecision machining of optics at Los Alamos

R. L. Rhorer, A. L. Gauler, E. W. Colston, and J. R. Ruhe

Mechanical Fabrication Division, Los Alamos National Laboratory
Mail Stop 474, Los Alamos New Mexico 87545

Abstract

Ultraprecision machine tools are used at Los Alamos for single point diamond turning of optics and other precision parts. Measurements of a 50-mm-diam copper flat are used to illustrate the quality of a part which can be machined on the Moore No. 3 lathe. Measurements of a 0.4-m-diam aluminum mirror with a 20-m radius-of-curvature are presented as an example of a part machined on the Moore No. 5 lathe. A varying frequency sine wave grating is used to show a type of special optical grating which can be produced using the Pneumo lathe.

Introduction

In supporting various research projects, the Mechanical Fabrication Division of the Los Alamos National Laboratory has utilized its ultraprecision machine tools to diamond turn some specialized optical components. Some characteristics of the machine tools at Los Alamos are presented in this paper along with measurements of an optical type part turned on each of three different machine tools.

The use of specialized machine tools and high quality diamond tool bits to machine rather than polish metal optics, a method called single point diamond turning, has developed at several different facilities in the past few years. Several SPIE Proceedings[1,2] include papers which present components, machines, and methods for machining optics. At Los Alamos, we consider single point diamond turning to be a special class of ultraprecision machining. In general, we define "ultraprecision" as machining methods more precise than normal precision shop practice. Currently this means working to sub-micrometer levels in contour control with surface finishes on the order of 50-nm peak-to-valley for both optical and non-optical metal parts.

The three numerically controlled machines in our ultraprecision area are a Moore No. 3 and a Moore No. 5 lathe (Moore Special Tool Co., Bridgeport, CT), plus a Pneumo MSG-325 lathe (Pneumo Precision, Inc., Keene, NH). The Moore No. 5 and the Pneumo lathe both utilize the Hewlett-Packard laser interferometer system[3] for a one-microinch resolution feedback. All machines utilize Allen Bradley 7300 series one-microinch resolution computer numerical control units(Allen-Bradley Company, Cleveland, OH).

The Moore No. 3 Lathe

The use of diamond tools with special machines for diamond turning work was begun at Los Alamos in the early 1970's. However, the first complete ultraprecision machine tool at Los Alamos was built on a Moore No. 3 measuring machine base in 1976. We now call this the Moore No. 3 lathe.

To convert the measuring machine into a lathe the vertical column was removed and replaced with a riser block and large air bearing spindle. A photograph of this machine is shown in Figure 1. The air-bearing spindle is the spherical zone type with 150-mm-radius journals. The design for this type originated at Oak Ridge.[4]

The drives for the plain bearing type ways of this machine are permanent magnet motors geared to the lead screws. The position feedback of one-microinch resolution is obtained by resolvers geared to the leadscrews. The axis drives and feedback system were manufactured by Moore Special Tool Company, but were installed and adapted to an Allen-Bradley control unit by Los Alamos. This lathe also uses a Moore ultraprecise rotary table with a one-millionth of a revolution feedback system, making it a machine with three controlled axes.

The closed loop control coupled with the Moore lead screws makes this a very accurate positioning machine; however, the friction of the plain bearing ways makes the small steps necessary for accurate contours difficult to achieve. Therefore, this lathe is used primarily for jobs requiring only single axis cuts-- such as flats, cylinders, and spherical parts with small enough radii of curvature to swing the tool by the rotary table. The lathe produces excellent surface finish on such single axis cuts, as illustrated in Figure 2, which is a surface finish trace of a 50-mm-diam copper flat. Surface finishes of about 30-nm peak-to-valley are routinely produced on this machine.

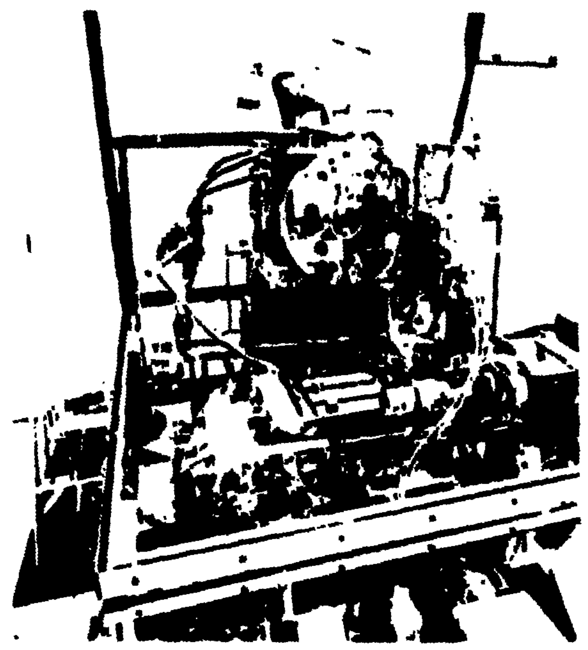

Figure 1. The Moore No. 3 Lathe

For temperature stability we have also added an oil shower system, similar to LLNL design.[5] The oil shower has improved our ability to produce flats with good overall shape or figure accuracy, an example of which is shown in Figure 3. This interferogram of the 50-mm-diam copper flat shows a peak-to-valley flatness of less than one-tenth wave at 632.8 nm. This flatness is routinely produced on special purpose metal mirrors up to about 200 mm sizes.

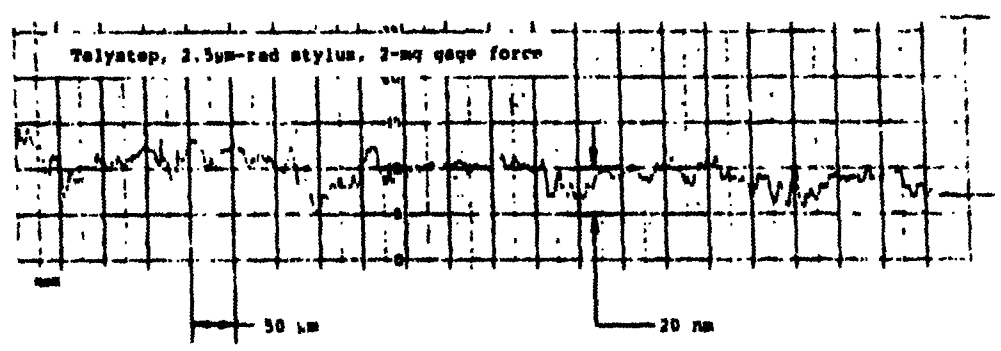

Figure 2. Surface Finish Trace, 50-mm-diam Flat, Moore No. 3

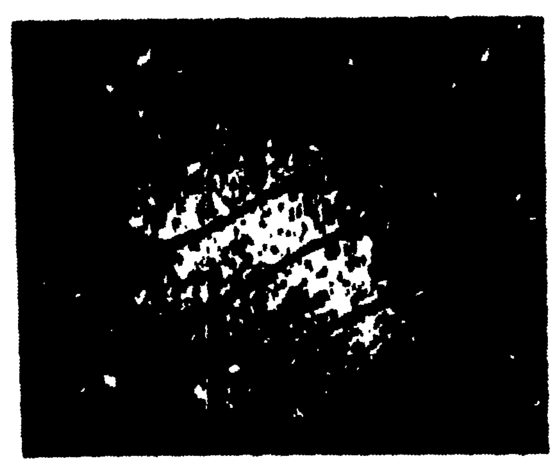

Figure 3. Interferogram, 50-mm-diam Flat, Moore No. 3

The Moore No. 5 Lathe

In March 1980 Moore delivered the No. 5 lathe built to Los Alamos specifications. This lathe has 30-inch travel on both axes and it can swing a 60-inch-diam part. The spindle was supplied by Pneumo Precision and is of the same basic type as that used on the No. 3 lathe.

The control feedback is from a Hewlett-Packard 5501 laser system mounted at centerline height to eliminate som[illegible] the Abbe offset errors. The lathe, before it was installed in its isolation base, is [illegible]own in Figure 4. The roller-way construction of this lathe makes the small steps necessary for contouring possible.

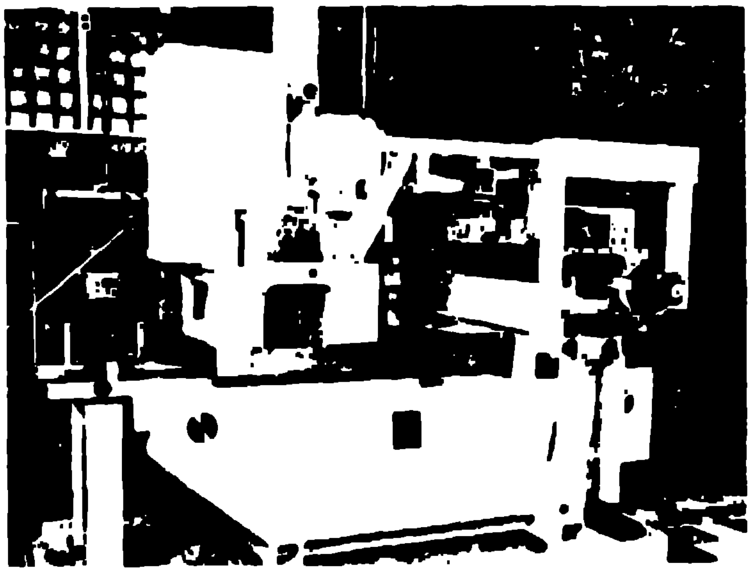

Figure 4. The Moore No. 5 Lathe

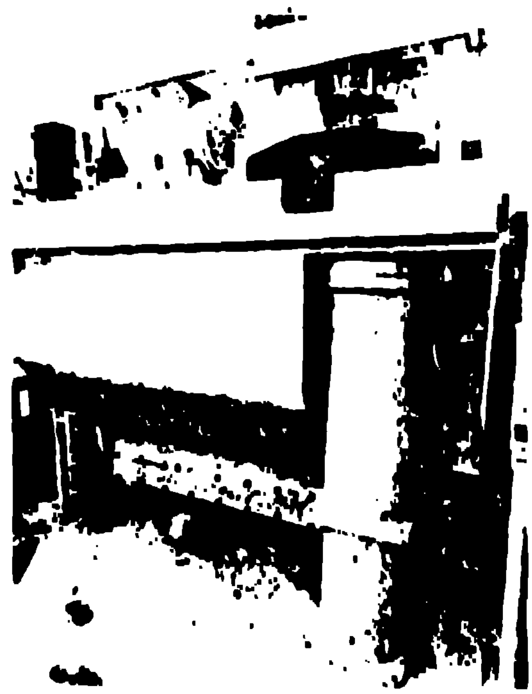

Figure 5. Moore No. 5 Isolation Base

Los Alamos designed and built an isolation base with an integral oil collection pan, which is shown in Figure 5. This isolation base is supported on four pneumatic isolators supplied by Kinetic Systems, Inc. The lathe has a vertical natural frequency of about 125 Hz on this isolation system, and measurements with a high sensitivity servo accelerometer indicate this system does an excellent job of eliminating floor vibration influence on the machine.

The placement of the laser paths for this lathe is shown in Figure 6. The dual z-axis lasers provide a means of correcting for z-axis yaw errors. We have not yet added the software to make a continuous correction for differences between the two z-axis interferometer readings, and we control with either one or the other, not both. However, by reading the z-axis interferometer which is not controlling, a measurement of the yaw effect is available. Measurements indicate the effect of not having both interferometers controlling is very small. For example an angular back lash type error of 0.05 arc seconds is indicated, which can produce an error of approximately 250 nm in position when the direction of approach to a point is reversed.

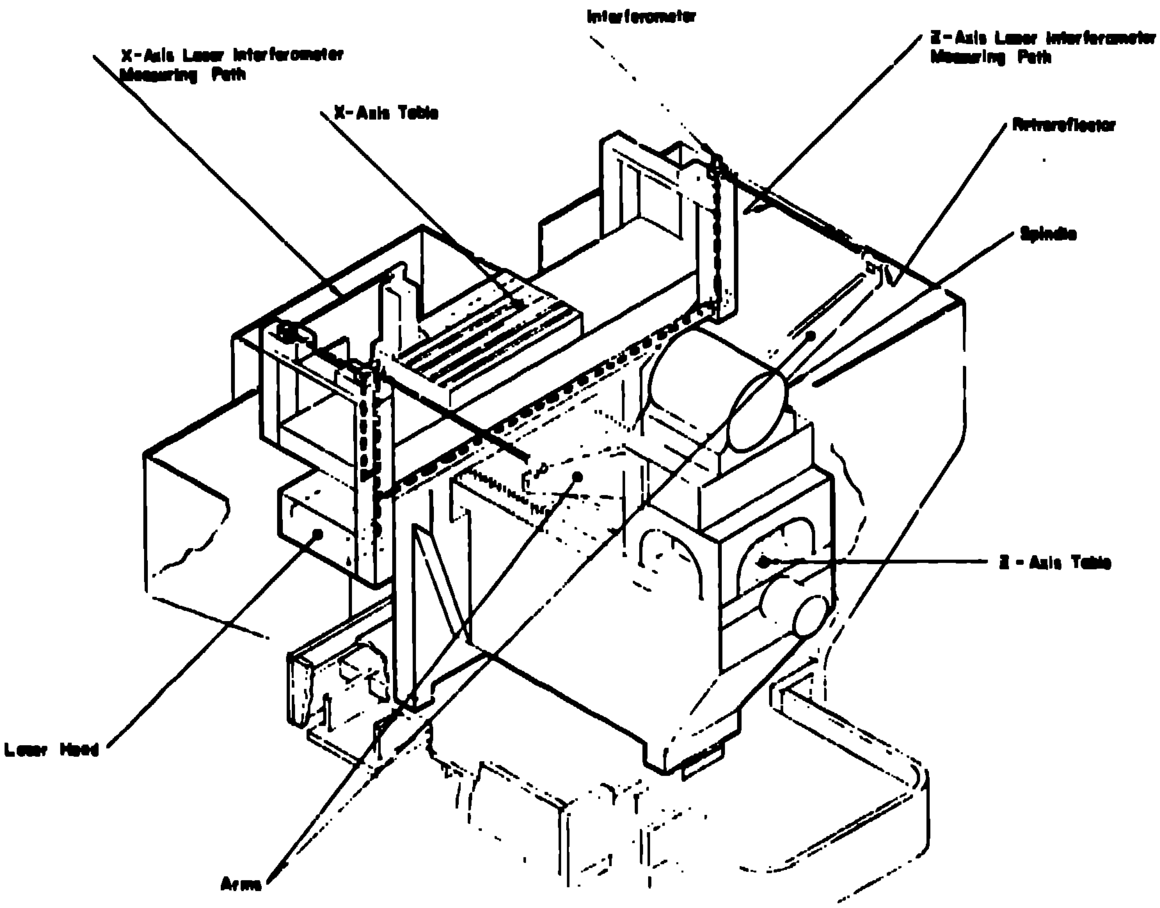

Figure 6. Laser Paths on the Moore No. 5 Lathe

We plan to eventually add either Allen-Bradley software to control with both z-axis lasers or use an external microprocessor to accomplish a correction for yaw angle. Using only one z-axis positioning system does not produce significant errors on parts with small z-axis motion in only one direction, such as large radius-of-curvature mirrors. Such a mirror, a 0.4-m-diam aluminum mirror with a 20 m radius-of-curvature, was machined on the Moore No. 5. An interferogram showing the overall contour of this mirror is presented in Figure 7. Peak-to-valley variation from a true sphere is about one wave at 632.8 nm. Surface finish, illustrated in Figure 8, is about 80 nm peak-to-valley.

The accuracy of similar mirrors in the future can be improved with the better temperature control of a complete oil shower system which we are in the process of adding to the lathe. Also, some improvement might result from a better substrate and fixturing for this type of mirror, which will be investigated if we have a need for making large mirrors.

Working around the laser tubes at centerline height on the Moore No. 5 is inconvenient. To improve the machinists access to the work zone, a work platform was constructed which surrounds the machine. This work platform can be seen in the overall photograph of the machine, Figure 9.

Figure 7. Interferogram, 20-m-rad mirror, Moore No. 5

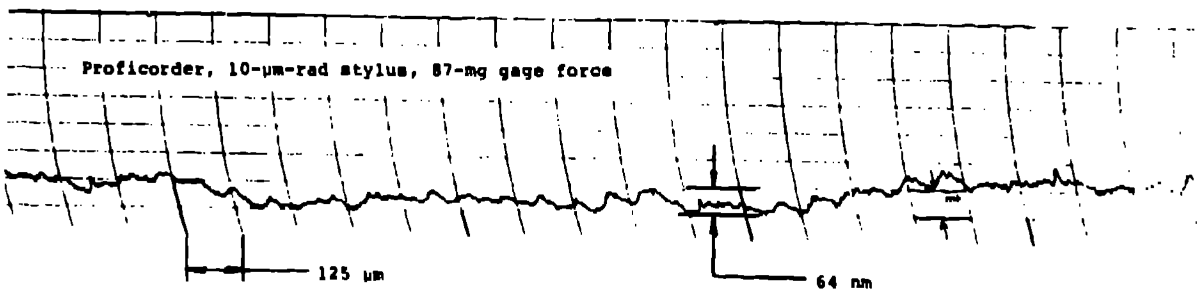

Figure 8. Surface Finish Trace, 20-m-rad mirror, Moore No. 5

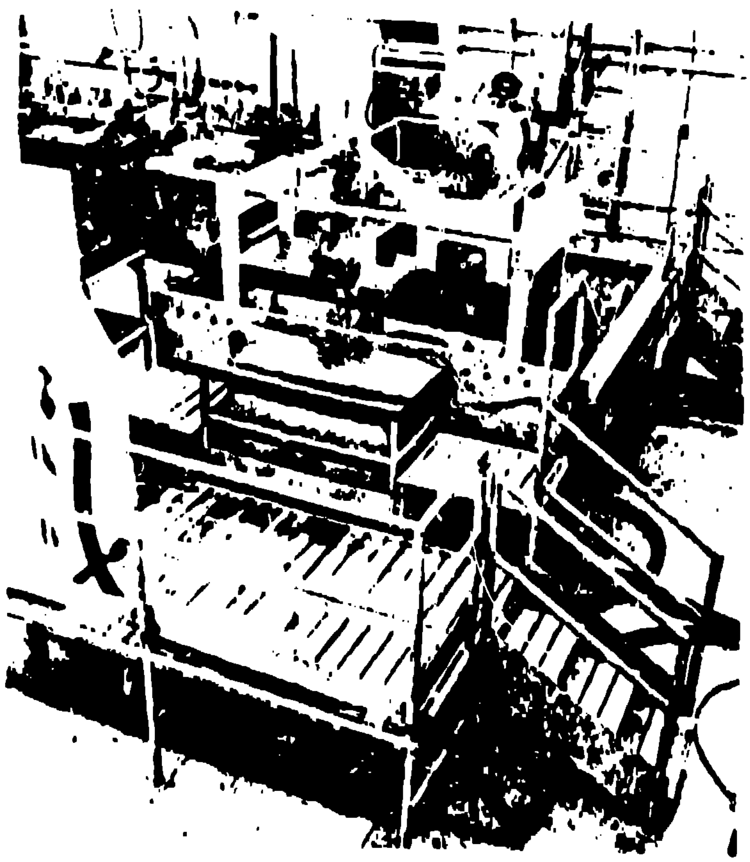

Figure 9. Work Platform, Moore No. 5 Lathe

Pneumo MSG-325 lathe

The newest ultraprecision machine tool at Los Alamos is a Pneumo lathe with air-bearing way construction. The lathe with its one-microinch resolution Allen-Bradley controller is shown in Figure 10. This two-axis lathe was purchased primarily for making small parts requiring very precise contouring. A special grating, sketched in Figure 11, is a type of optics part which can utilize the advantages of this lathe with its computer control and small motion capability. The varying frequency sine wave data (approximately one-micrometer amplitude) was generated on an external computer and transferred to the the lathe controller by punched tape. The surface generated by the Penumo lathe is compared to theoretical points in Figure 12, which is a profile trace of the completed copper part. As can been seen in this figure, peak-to-valley contour accuracy is on the order of one tenth wave at 632.8 nm.

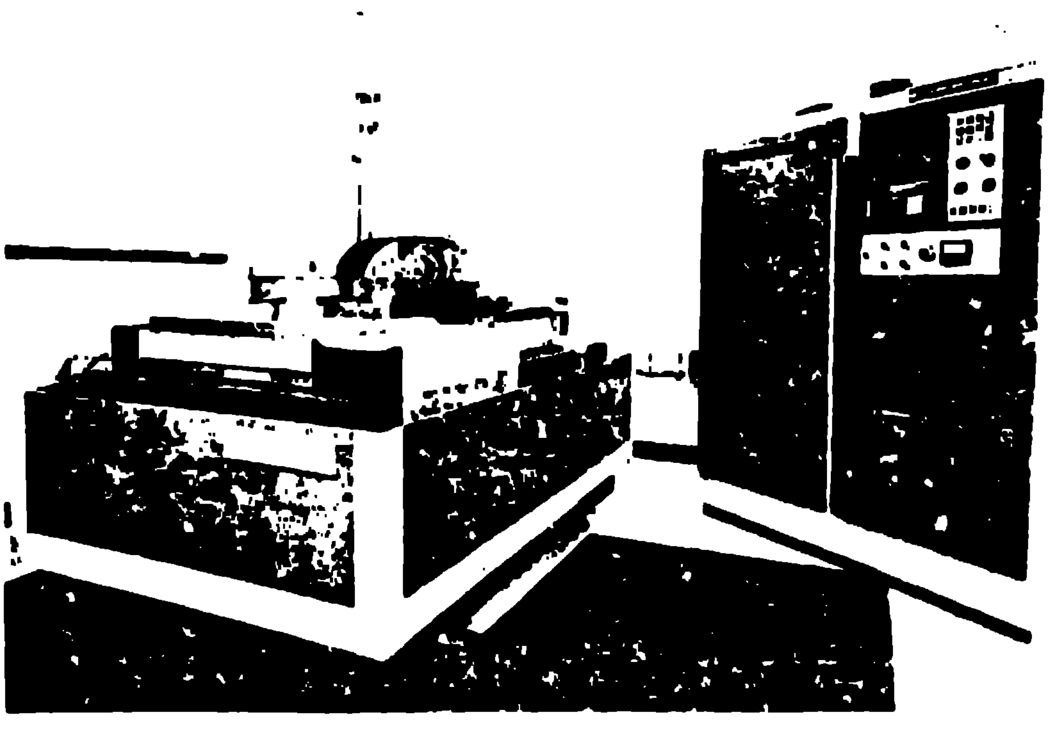

Figure 10. The Pneumo MSG-325 Lathe

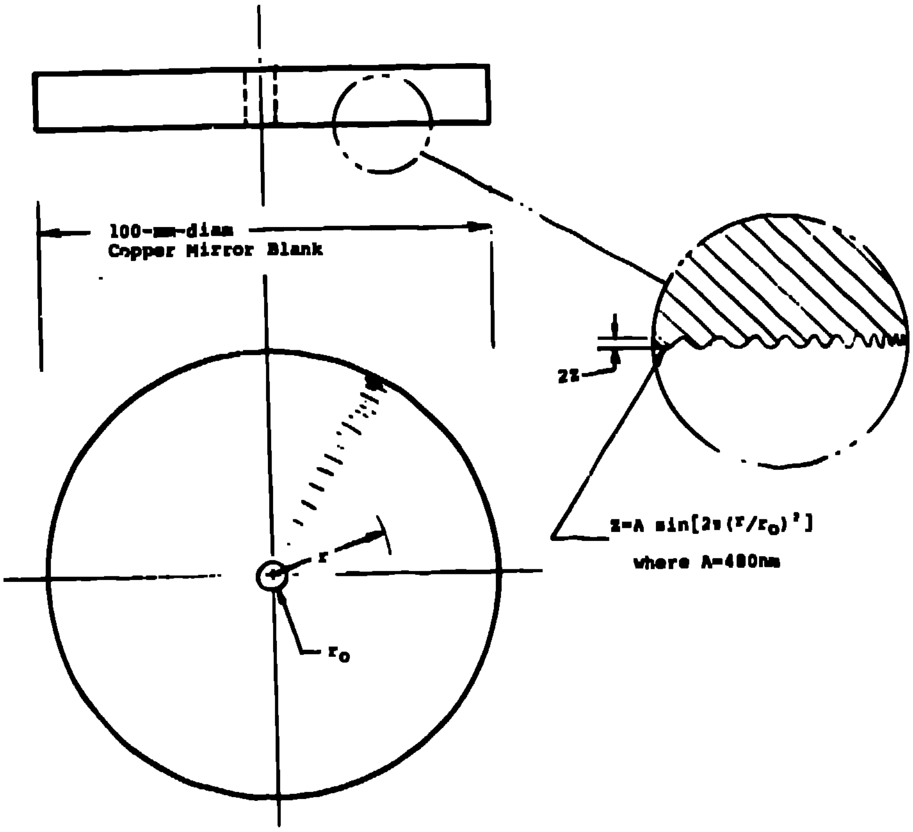

Figure 11. Grating with Sine Wave Surface

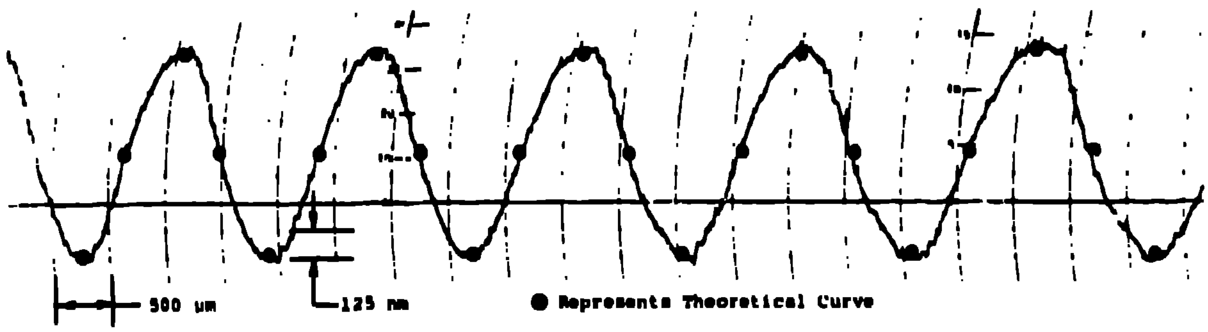

Figure 12. Surface Trace of Sine Wave Grating, Pneumo Lathe

The low friction way construction and one-microinch laser interferometer feedback allow the Pneumo lathe to make small precise motions, and it has the size capability of making metal mirrors up to about 350-mm diameter; however, we use it primarily for very small ultraprecision parts. The lathe was delivered to Los Alamos as a complete working machine in July 1980.

Conclusions

The three ultraprecision machine tools allow the Los Alamos shop to provide Lab researchers with special machined optical components. The Moore No. 3 lathe produces very high quality surface finishes on single axis cut surfaces. The Moore No. 5 allows state-of-the-art contouring and controlled rotary table cuts for components up to approximately 1.5-m diameter. The Pneumo Lathe gives ultraprecise contouring capability to our miniature machining program. All three machines are used for machining development experiments in addition to making both optical and non-optical ultraprecision parts.

Acknowledgements

In addition to the many commerical companies mentioned in the paper, the authors acknowledge efforts by Alfred Zerwas and David Murphy in the first diamond turning work at Los Alamos. Several machinist, including Erich Baumgartner, James Snyder, Fidel Maestas, George Zakar, and Osvaldo Zothner have contributed by operating the lathes and developing special techniques. Metrology technician Tom Novak has contributed with many optical and standard measurements of parts. Senior designer Robert Ansley has supported the project with several special component designs, and Albert Ellis's engineering support was valuable. Many other machinists, to numeroun to name, have supported the program with the fabrication of various components.

The authors also acknowledge the support of many optical scientists, engineers, and technicians at the Lab who design and request many of the optical components we make. Their knowledge, evaluation, and constructive criticism have aided our progress.

References

1. T. T. Saito, Editor, "Advances in Precision Machining of Optics," Proceedings of the Society of Photo-optical Instrumentation Engineers, San Diego, California, August 26-27, 1976, Vol. 92.
2. J. B. DeVelis, Editor, "Precision Machining of Optics", Journal of the Society of Photo-optical Instrumentation Engineers, November/December 1978, Vol. 17/No.6.
3. Hewlett-Packard, "Laser and Optics, 5501 A Laser Transducer," Application Note 197-2, Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California 94304
4. W. H. Rasnick and P. J. Steger, "Gas Bearing and Moethod of Making Same," US Patent No. 3721479, March 1973.
5. J. B. Bryan, R. R. Donaldson, E. R. McClure, and R. R. Clouser, "A Practical Solution to the Thermal Stability Problem in Machine Tools", Society of Manufacturing Engineers report MR72-138.