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TITLE: UPDATE ON PRECISION MACHINING AT LOS ALAMOS

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Update on Precision Machining at Los Alamos

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Abstract

Both metal optics and other high-precision parts are being fabricated at Los Alamos [illegible] state-of-the-art machine tools. This report summarizes this precision machining and diamond turning work.

Introduction

Special precision machine tools have been used in the Mechanical Fabrication Division of the Los Alamos National Laboratory for a number of years to make very precise components to support a large variety of research programs. These components include both metal optics and other hardware requiring submicrometer precision. A report on some of our metal optics fabrication work was presented at the 1981 SPIE Conference, "Contemporary Methods of Optical Fabrication."[1]

During the past two years, we have continued our ultraprecision machining program by both improving our machine tools and using methods originally developed for optics on [illegible] nonoptical precision parts. This paper summarizes the capability of the three ultraprecision machine tools in our shop, discusses some of the machine tool development work we are involved in, and to illustrate the advantages of precision machining methods, presents two parts recently fabricated using these methods.

The need for more precise machining is widespread in most research laboratories. [illegible] some research projects, the basic physics principles are straightforward, but the fabrication of "perfect" parts limits the successful demonstration of these principles. [illegible] experiments, success depends on a multitude of mechanical adjustments that [illegible] for long periods of time. In both cases, the methods of ultraprecision machining [illegible] play a vital role. We can now machine parts to surface finishes and [illegible] tolerances, which were impossible to accomplish a few years ago. Although we still cannot make [illegible] perfect part, we are getting better. With the proper design of components to [illegible] accuracies available, many experimental set-ups can be designed with fewer adjustments, thereby eliminating some of the costs of aligning and realigning experiments. [illegible] precision machining program goals at Los Alamos is to encourage the use of precision [illegible] ing to improve our efficiency and more rapidly fabricate research experiments.

Ultraprecision Machine Tools

The special ultraprecision machine tools we are currently using at Los Alamos [illegible] Moore No. 3, a Moore No. 5, and a Pneumo MSG-325 lathe. The Moore No. [illegible] lathe [illegible] structed at Los Alamos from an existing measuring machine. This [illegible] ing Moore-supplied motors and resolvers, mounting an air-bearing spindle, [illegible] CNC Allen-Bradley control unit.

A special lathe built on a Moore No. 5 base and the Pneumo lathe [illegible] Alamos specifications. These three lathes comprise the main [illegible] cision machining shop, although we have assembled other specialized [illegible] cular jobs using air-bearing spindles and precision slides.

Details of these three machines are summarized in Table 1.

Long Term Stability Tests

The fabrication of precision components depends on many different [illegible] material stability, fixturing, cutting tool accuracy, as well as the [illegible] the precision of the machine tool depends on a number of variables [illegible] in cataloging sources of error in machine tools, for example, [illegible] Tool Task Force.[2] One source of error, obvious to most people wh[illegible] ... is that of temperature changes. A number of methods have [illegible] the stability of machine tools. At Los Alamos we tried a test that [illegible] ting a part with programmed grooves in the cut.

During our development work related to ultraprecision machine tools we have used a variety of different tests, but we have leaned toward the more comprehensive tests, such as cutting and evaluating a part. This type of testing has the advantage of including all possible sources of error, but has some disadvantages in interpreting results. The comprehensive test we use for long-term temperature stability is of this nature. It will tell us if we have a problem, but other tests may have to be done to pinpoint or develop a solution.

This test is shown schematically in Fig. 1. The test involves cutting either a flat (testing for stability in the Z-direction) or a cylinder (checking for stability in the X-direction) over a long period of time in programmed steps. Then measuring the surface finish of the part with a profile instrument. This test is in contrast to mounting an indicator on the machine and recording the output over a period of time. The concerns using the indicator method are that electronic drift in the indicator may be present, changes due to spindle growth may not be included, changes in the tool holder or tool post may be different depending on where the indicator is mounted, and some of the thermal drift may be due to the indicator or its mounting.

Actually cutting to provide a record includes all the variables, but does not provide a continuous record as an analog strip chart and an indicator would provide. A series of tests with different time steps has to be done to avoid missing some higher frequency changes. The test can be done without any special equipment such as noncontact indicators, amplifiers, and strip chart recorders; however, it does require a means of taking a surface finish trace of a completed part.

An example of the surface finish trace from a cut on our Pneumo lathe is shown in Fig. 2, and the plot of the error versus time is shown in Fig. 3. These results are more an indication of the environment where we operate the machine, rather than a judgment of the machine tool.

Machining a Gold Knife-Edge

An accelerator project at Los Alamos required a special slit to collimate a particle beam. Such a slit is fabricated from two sharp knife-edges precisely spaced apart to provide the required opening. The operation of such a slit arrangement is shown schematically in Fig. 4. A series of knife-edges were produced by diamond turning gold-plated copper pieces, as shown in Fig. 5. The knife-edge was produced by the intersection of the two flat diamond-turned surfaces. The surfaces were diamond turned using a fly-cutter in our Moore No. 3 lathe, and holding the parts in a special fixture to allow one surface to be machined and then rotated for the proper angle to cut the second surface. The quality of the knife-edge produced can be seen in Fig. 6, a 400x SEM picture of the intersection of the two machined surfaces. The fabrication of sharp edges in a soft material like gold is very difficult by lapping, but an edge sharpness of about one micrometer can be produced by ultraprecision machining methods.

Sine-Wave Mandrel

Laser fusion research projects involve efforts to compress a very small spherical vessel filled with fuel to high enough pressures to produce fusion energy. A series of experiments in the laser fusion research program at Los Alamos used cylinders to study the effects of surface irregularities. These special cylindrical targets are produced by making a mandrel, plating the required cylinder material on top of the mandrel, and then dissolving the mandrel out and leaving a hollow cylindrical target. To produce a special surface on the inside of this hollow cylinder it is necessary to machine the desired features on the outside surface of the mandrel. An example of such a mandrel is shown in Fig. 7.

A number of these small sine-wave mandrels were successfully machined in aluminum using our Pneumo lathe. Figure 8 is a SEM photo of one of these mandrels. A profile trace of one of these mandrels is shown in Fig. 9. The precise control and computer-based control system of an ultraprecision lathe make the fabrication of these mandrels a straightforward job.

Conclusion

Machines using air bearing spindles and very precise slide motions have many applications, both in metal optics and other components. Full computer control capability allows a great variety of parts to be made. An active program in ultraprecision machining involves measurements and analysis to understand the limitations of the machine tools, such as the long-term stability test described in this report. The machining of a variety of different materials and shapes, as illustrated by the knife-edge part and the sine wave mandrel, add to an important experience base for future application of precision machining

Acknowledgements

The development of ultraprecision machining in MEC Division at Los Alamos has been a team effort since the program started in the mid-1970's. Besides the many machinists, engineers, technicians, and managers who have worked on the machine and supported our efforts, the team includes lab researchers such as John Moses and Allan Hauer who requested that we fabricate the gold knife-edges and sine-wave mandrels described in this report.

References

1. R. L. Rhorer, A. L. Gauler, E. W. Colston, J. R. Ruhe, "Ultraprecision Machining of Optics at Los Alamos," Proc. Soc. Photo-Optical Instrum. Eng., San Diego, California, August 25-26, 1981, Vol. 306, Pg. 122-129.

2. R. J. Hocken, Ed., "Machine Tool Accuracy," Vol. 5, Technology of Machine Tools, Lawrence Livermore National Laboratory, UCRL-52960-5.

Table I Summary of Los Alamos Ultraprecision Machine Tools

Machine Type	Moore No. 3	Moore No. 5	Pneumo MSG-325
Diameter Swing	∿ 0.6 m	1.5 m	∿ 0.35 m
X-Axis Travel	460 mm	760 mm	300 mm
Z-Axis Travel	300 mm	760 mm	200 mm
Spindle Type	Air-Bearing 150 mm radius graphite spherical	Air-Bearing 150 mm radius graphite spherical	Air-Bearing 150 mm radius cartridge
Slide Way Type	Plain Bearing	Roller Bearing	Air-Bearing
Feed Back System	Resolvers on lead screws	H-P Laser interferometer	H-P Laser interferometer
Feed Back Resolution	1 Microinch	1 Microinch	1 Microinch
Controller	3-Axis CNC	3-Axis CNC	2-Axis CNC
Rotary Table	1×10^{-6} counts/rev	1×10^{-6} counts/rev	--

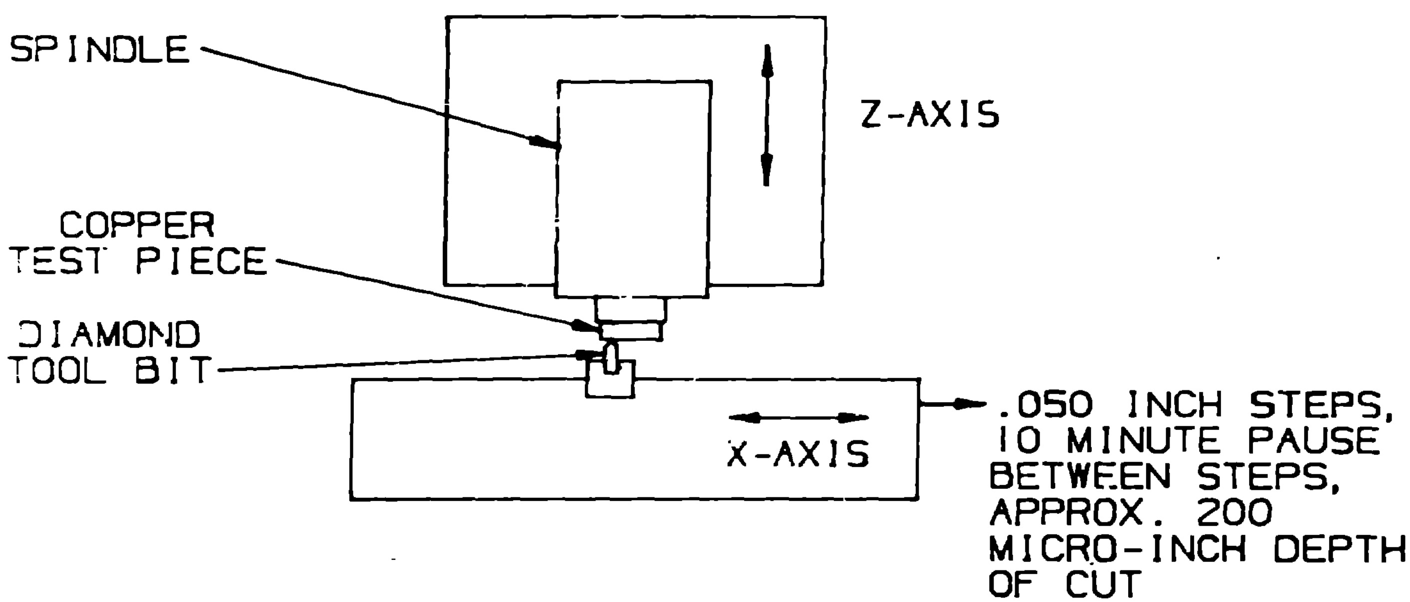

Figure 1. Schematic of long-term stability test

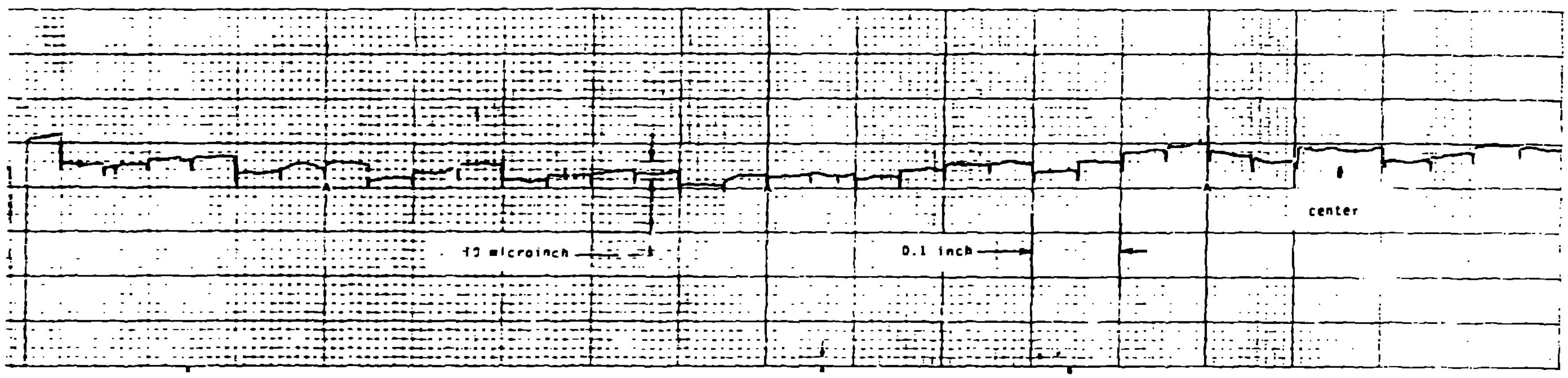

Figure 2. Example of test results, surface finish trace

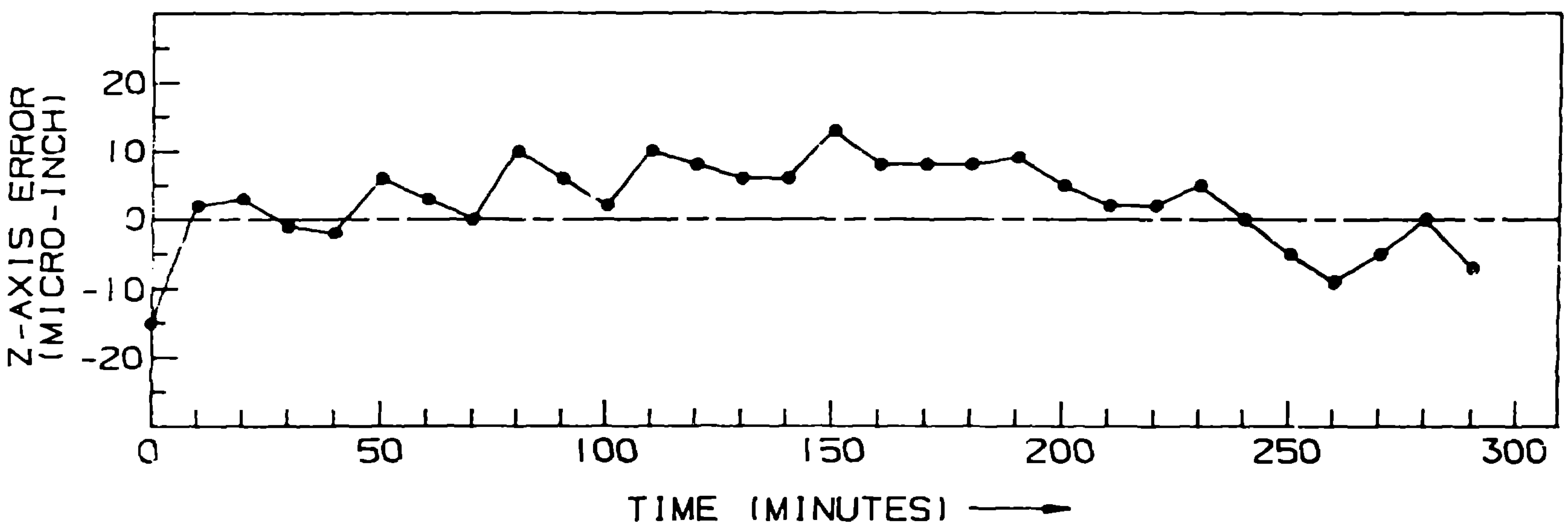

Figure 3. Plot of results, long-term stability test

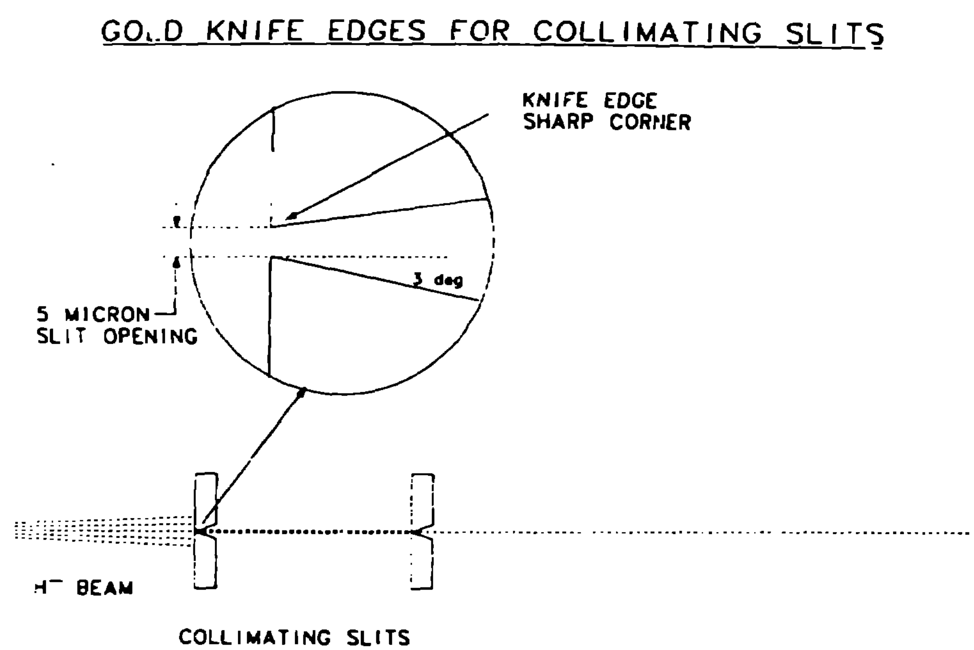

Figure 4. Example of collimating slits