THE RESULTS OF CUTTING TESTS PERFORMED

ON A

SUB-MICRO-INCH RESOLUTION LATHE

David H. Youden

RANK PNEUMO INC
P. O. BOX 543
PRECISION PARK
KEENE, NH 03431

OCTOBER, 1988

INTRODUCTION

During the past two years, Rank Pneumo has invested considerable time, effort, and resources in the production of a "Technology Test Bed" designed to explore the state of the art in diamond turning.

While this machine utilizes many concepts not previously exploited in the field of diamond turning, much of the technology is merely careful execution of previously tested and proven approaches.

GRANITE

The machine is constructed on a 48 by 96 inch granite, 18 inches thick. The size was not dictated by the structures to be mounted on the stone, but merely happened to be dimensions of an old surface plate which was liberated from our Quality Assurance Department. The large area available allowed us to select a layout for the laser interferometry which minimized the number of optics rather than space.

VIBRATION ISOLATION

An active air leveling and vibration isolation system supports the granite. The equipment used is identical to that supplied with every MSG-325 except that, because we did not use the steel frame from the 325, we had to supply external surge tanks. The external tanks are common, 20 pound propane tanks which were purchased from our local bottled gas dealer.

PERIPHERAL EQUIPMENT

The gas tanks are located in an assembly referred to as the "air console". In this case the air console is constructed of plywood. It serves as a mounting for the various air regulators, filters, valves and gauges associated with the operation of the leveling system, the spindle, the tool set station and the spray mist coolant. The vacuum chuck controls are also mounted here.

Air drying and filtration is done with equipment mounted on a separate, free standing air receiver. Vacuum for the chuck is generated by an aspirator, an approach which is much quieter than the usual vane type rotary pump.

The slides used on the test bed require a small hydraulic pump and tank unit to supply 15 cubic inches of oil per minute at 250 psig. This system, which uses a small gear pump driven by a DC servo motor, is located at the right hand end of the granite, on the floor.

SLIDES

The slides used for the cutting tests were of two different designs. The X axis slide, which was described in detail at last year's meeting, is a box way design. The slide top is 15 inches wide and 18 inches long. The slide is driven in translation by an intermediate slide which, in turn, is driven by a ball screw and nut. The intermediate slide drives the X axis through a hydrostatic thrust bearing which serves to isolate the axis from cyclic errors caused by the ball screw.

A different configuration was used for the ways on the Z axis. This slide, which is dimensionally identical to the X axis, was provided with dovetail ways. The reason for the two designs was to compare the cost of manufacture of the two configurations. The results of the experiment indicate that, for us, the box way design was somewhat more cost effective. We are currently manufacturing a new box way slide for the Z axis of our test bed. This new slide will replace the dovetail slide, which has been sold.

CONFIGURATION

Our machine is configured with the spindle mounted on the X axis and the tool holder on the Z axis. The X axis is positioned on fabricated steel risers so that the way covers of the Z axis can pass beneath the X axis. This construction allows the use of rigid, one piece, steel way covers. The way covers do not rub against any part of the machine structure, and so do not interfere with the accuracy of motion of the slides.

POSITION FEEDBACK

X Axis.

Slide position feedback is provided by laser interferometers. Hewlett-Packard equipment was used during the cutting tests discussed here, however Zygo equipment is currently in place on the machine. The X axis beam path during the cutting tests was located at the centerline of the spindle and immediately to the rear of the chuck.

Z Axis.

The Z axis interferometer is, and was located on the axis centerline and immediately below the way cover at the front of the slide. Provisions have been made to incorporate a second interferometer on this axis to measure pitch, however no work has been done with this beyond mounting the optics.

After the cutting tests were stopped, a forth interferometer was added to the system as a refractometer. Test data has been, and will continue to be, collected from this device while we determine the best way to apply the information in the machine controller.

CONTROLLER

All cutting tests were done using a Hewlett-Packard HP-5507 controller containing two 10936A Servo-Axis boards. The tool path was downloaded to the controller over an IEEE-488 buss from an IBM XT which served as the operator interface. The tool path information was generated using the Rank Pneumo Tool Path Generator software. The intermediate interpolation coordinates were generated by the HP Servo-Axis boards. Control over these and the sample clock rate enabled us to adjust the feed rate of the tool. The clock rate for all tests was set at 1 ms. Little effort was made to make this setup user-friendly as the results were deemed more important than the ease of use at this stage.

MACHINE CAPACITY

The capacity of the test bed is to some degree determined by the location of the spindle on the X axis. During our testing the spindle was located at the rear of the slide and cutting was done on the front side of the parts. In this configuration the maximum swing is just under 20 inches. The axial capacity is determined by the location of the toolholder on the Z axis. As set up for our tests the maximum length part was 12 inches.

SPINDLE

A newly designed air bearing workspindle is being constructed for our test bed, but it was unavailable for our initial round of tests. The spindle used for the test cutting was a spindle from a UP-2000 lathe. This spindle has a maximum speed of 2400 rpm and a load capacity in excess of 100 pounds. Almost all cutting was done at 1000 rpm except for the large flat, which was cut at 800 rpm.

TOOLING

Cutting tools for our tests were supplied by Contour Fine Tooling Ltd. The particular tools used were .030 radius, zero degree rake diamonds with a maximum of 20 microinches of waviness over 100 degrees. These tools were held in an Aloris toolholder mounted on a Rank Pneumo micro height adjuster. The feed rate used for our tests was .002 inches per revolution.

WORKPIECES

Cutting tests were done on 6061-T6 aluminum, copper, acrylic, and germanium parts and on electroless nickel plated steel. Workpiece size ranged from 0.5 inch diameter proof of center studs to 18 inch diameter flats. Flats, spheres, and aspheres were cut as well as some stepped parts. In all cases, both machine axes were energized and "alive" i. e. we did not disable the Z axis while we were cutting flat parts.

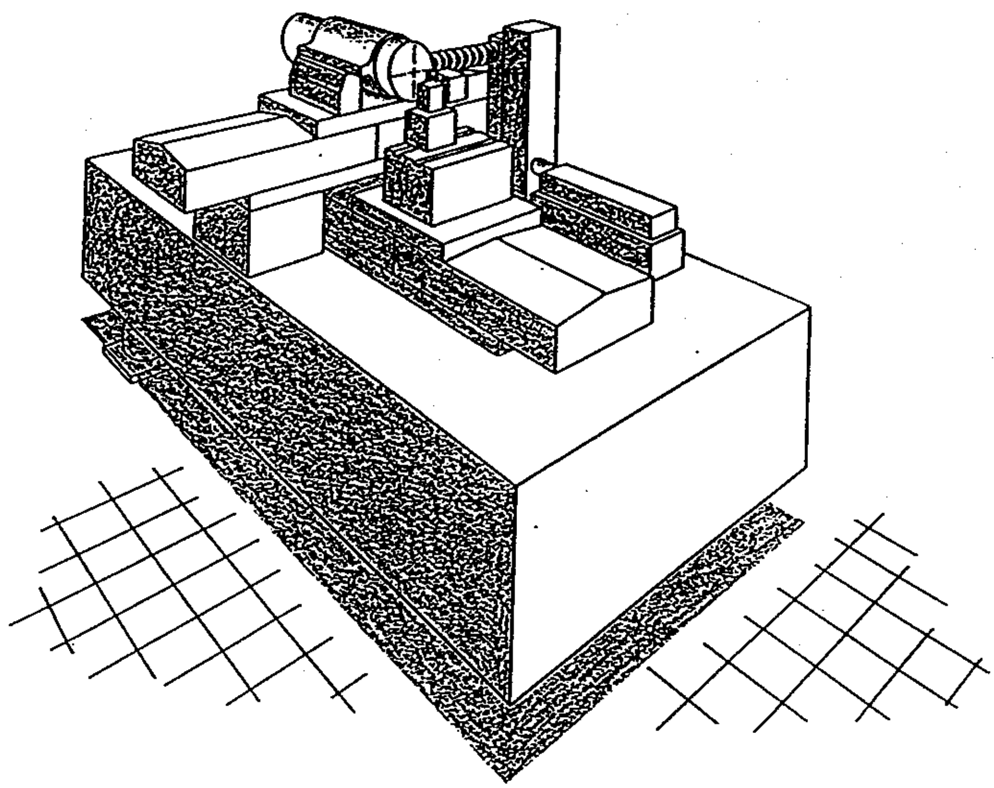


Figure 1

RESULTS

The following illustrations contain, in capsule form, the results of our tests. They include data obtained from Zygo, Wyko, and RTH measuring equipment.

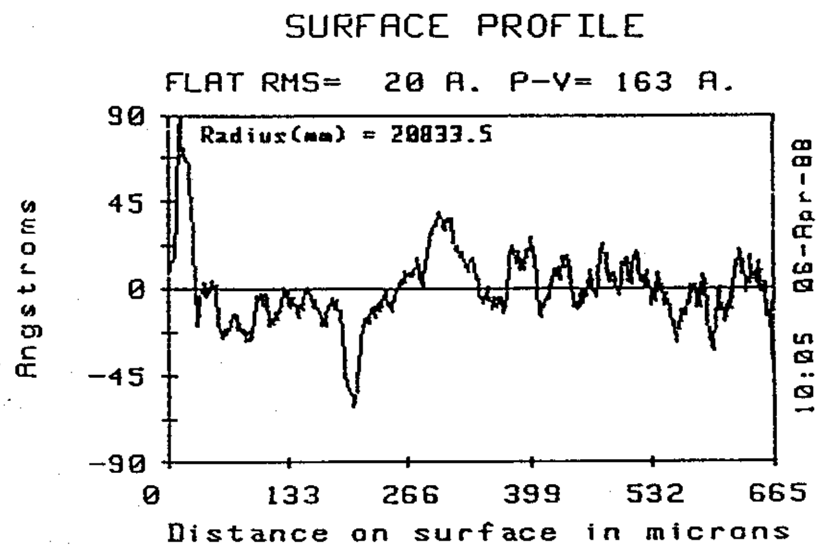
CONCLUSIONS

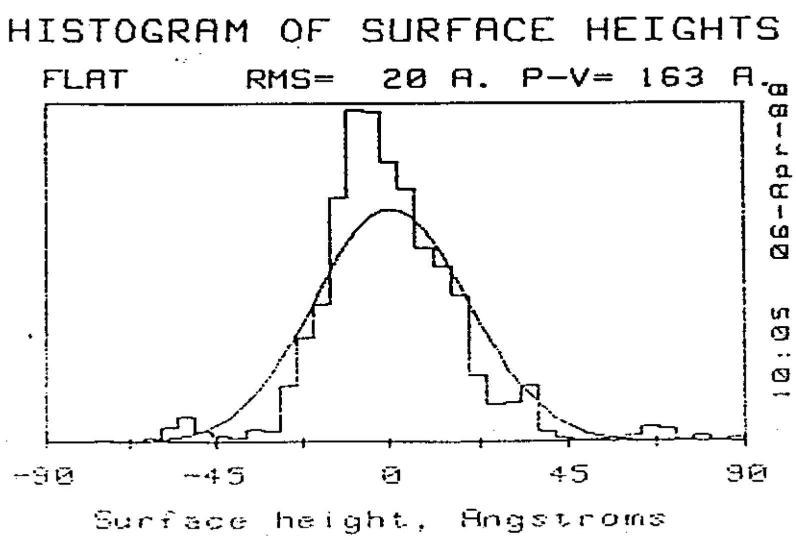
Parts machined on our test bed had surface finishes which ranged from two to four times better than those achievable with other diamond turning equipment. Form accuracy was improved over parts machined on other machines but this is probably related as much to the straightness of the new slides and to the lack of "hash" or noise in the slide traces as it is to the higher resolution of the feedback. All parts shown were cut within a few days of one another shortly after the controller was proven to be operational, and cannot be said to be the result of extensive tuning of the equipment. Attempts were made to cut parts with 0.1 microinch steps in them but these steps could not be found even though we have evidence that the axes do respond to commands at that level. The reason for this becomes clear when we examine the surface with instruments like the RTH Talystep. The topography of even a very good surface includes undulations on the order of one microinch. If our 0.1 microinch steps are there, they are masked by the general surface texture. The implication of this is that machine error compensation can be applied to diamond turning machines at the 0.1 microinch level without affecting surface finish or producing detectable marks on the surface.

FURTHER WORK

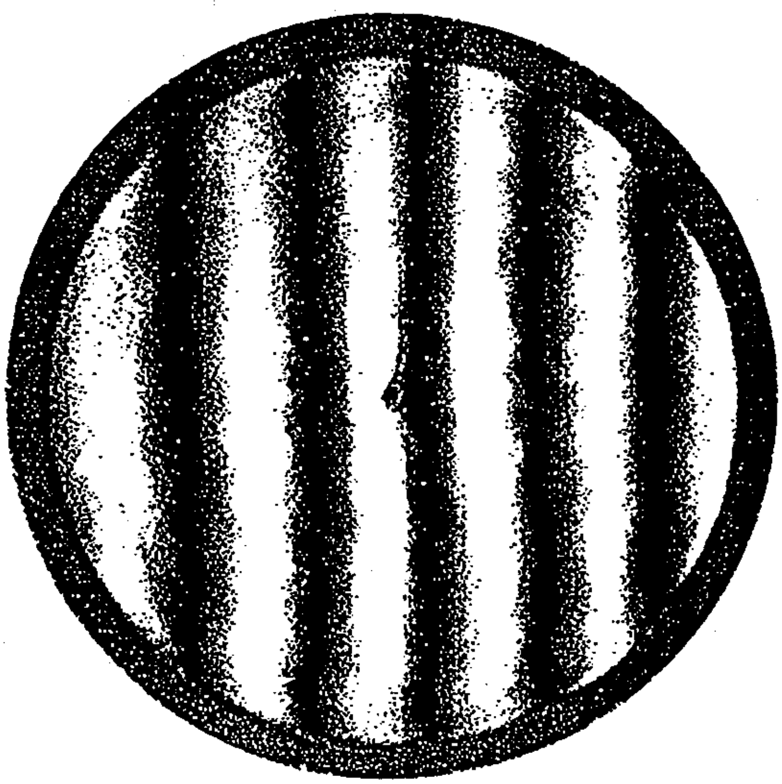
After completing the tests reported here, the test bed was reconfigured with Zygo interferometry and a CUPE Cuproc 16 controller. The timing of this reconfiguration left us with only a few days to perform cutting tests before the scheduled shipment of the machine's Z axis slide. The period of time available proved to be insufficient for us to properly marry the controller, the laser, and the machine tool and perform any meaningful tests. The testing of this configuration will have to await the completion of the new Z axis slide, sometime in the month of November. When cutting tests resume, we will test new tools which have recently become available from Contour Fine Tooling Ltd. These tools have waviness on the order of 5 microinches or less over 75 to 100 degrees.

2 inch diameter aluminum flat

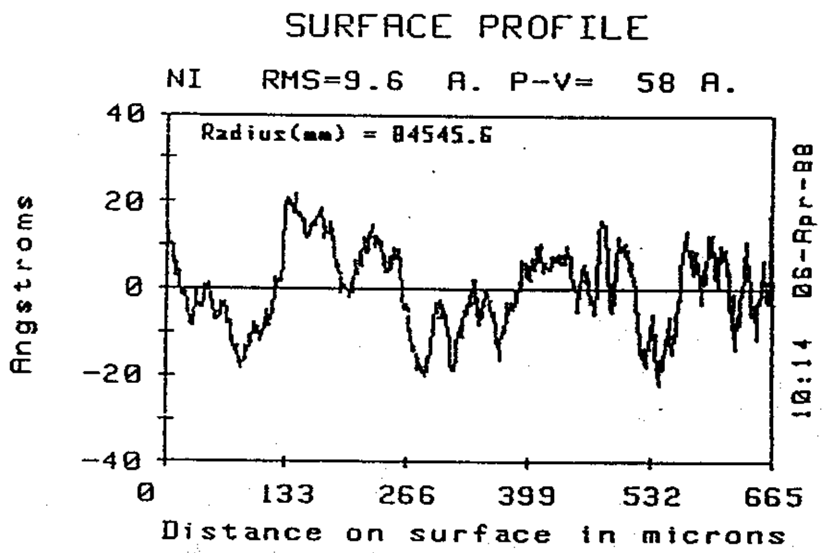


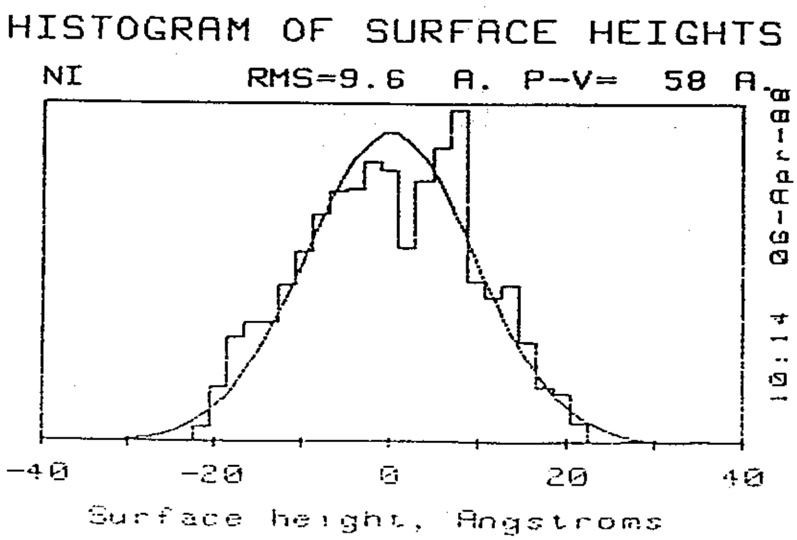


2 inch diameter aluminum flat

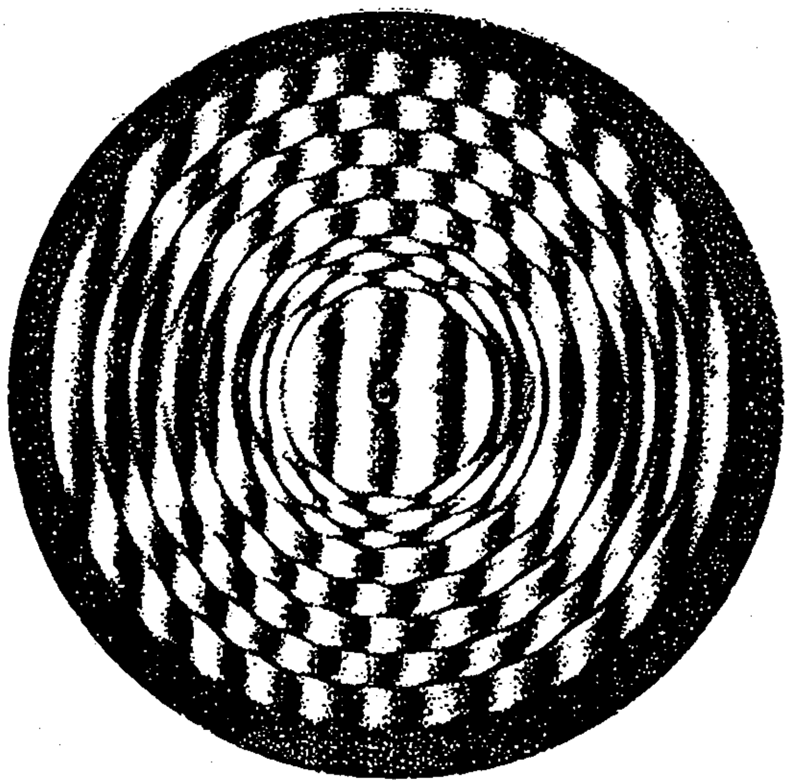


2 inch diameter electroless nickel plated flat



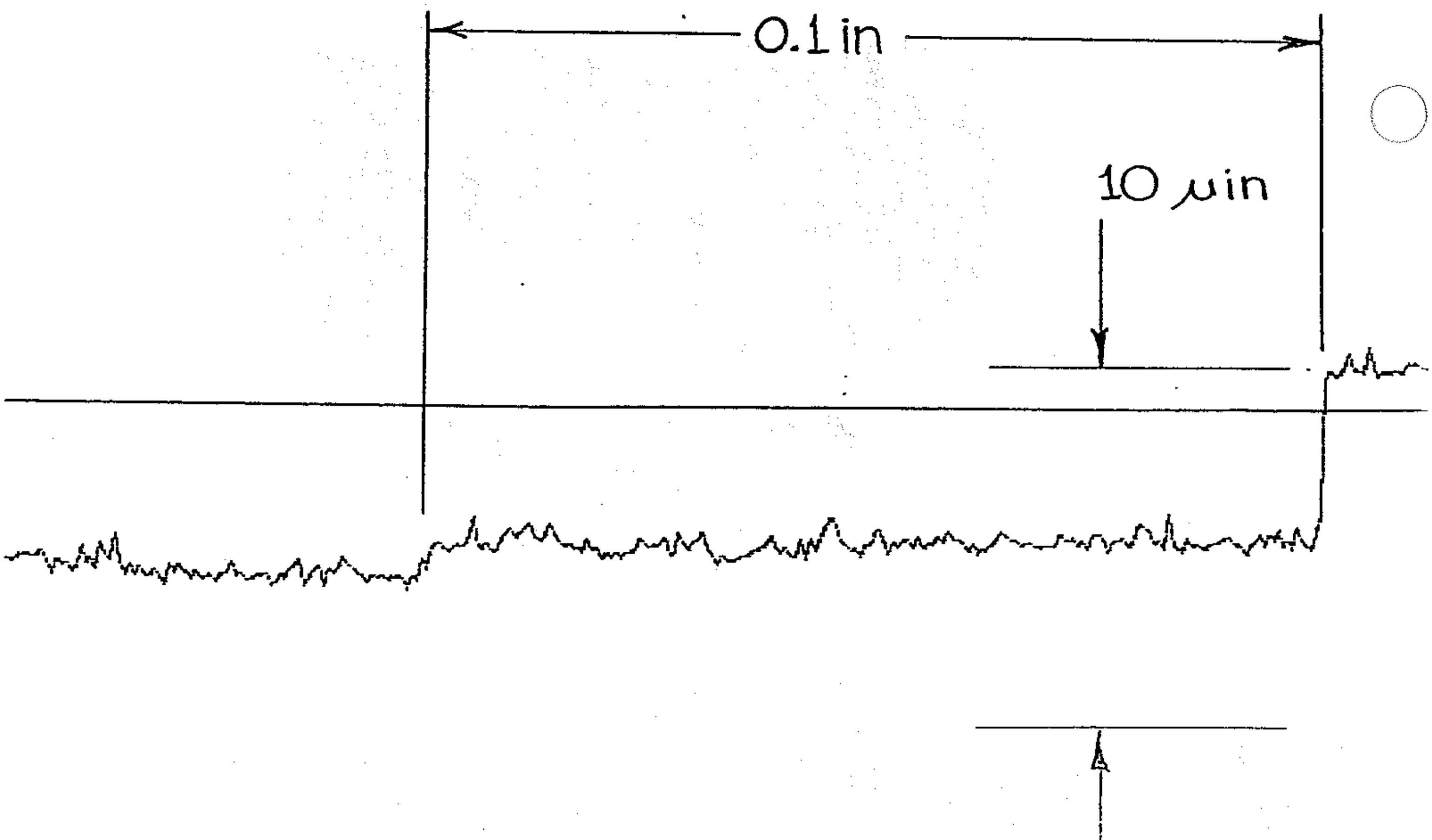


2 inch dia. aluminum part with 6 microinch deep grooves

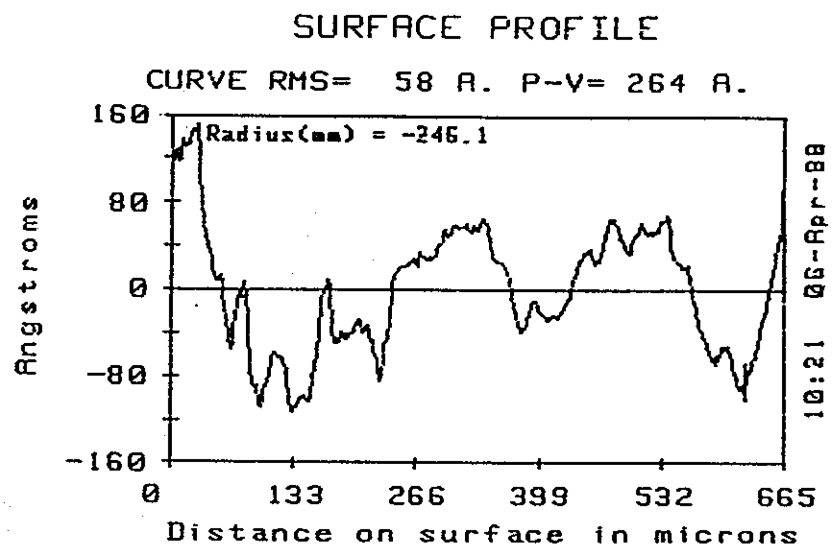


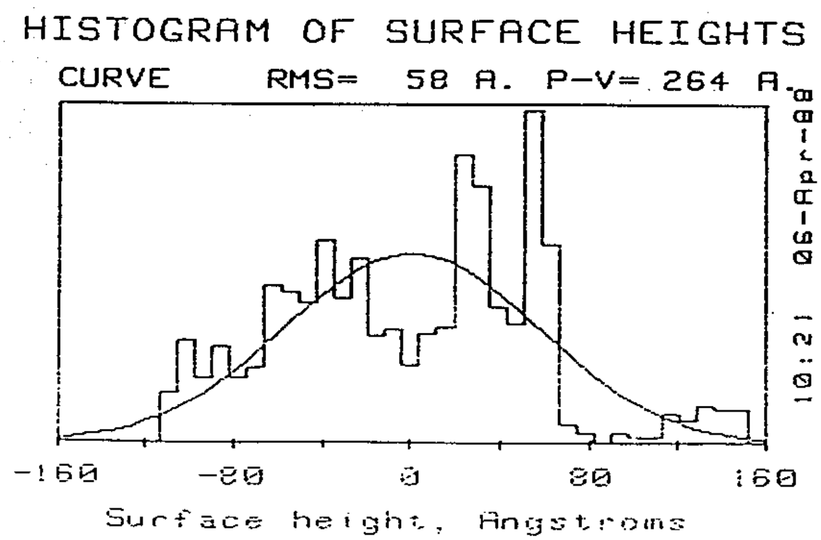
Partial RTH Form Talysurf trace
showing
1 µin and 5 µin steps 0.100 in apart on a flat part

Vertical magnification is 200,000
Horizontal magnification is 50



2 inch diameter, 10 inch radius aluminum sphere





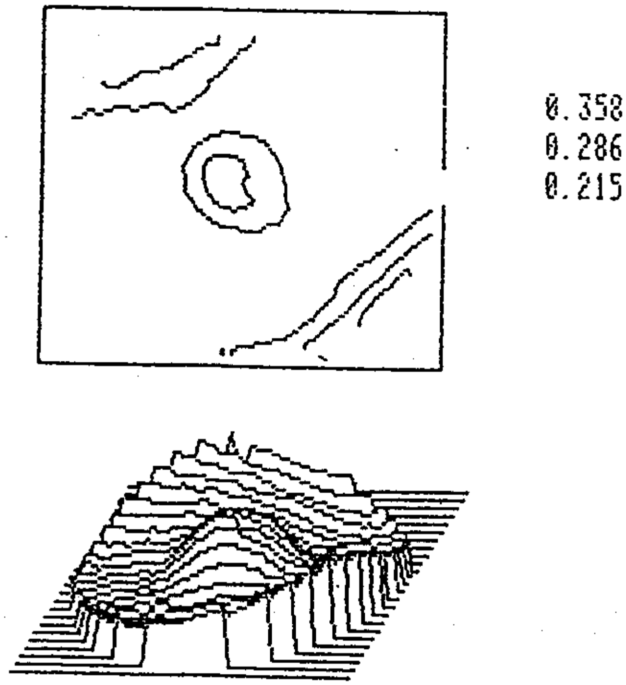
18 inch diameter aluminum flat

26-SEP-1988/10:12:47
Part ID :
Serial # :
Analysis : phase
F/NO : plano   Fast : off
Averages : 4   Trim : 2
Calibrate: ON   AGC : ON
Wave Out : 0.6328   Scale: 0.50
Reference: none
Remove : TLT PWR

PV : 0.430   PTS : 25061
RMS : 0.082

	MAGNITUDE	ANGLE
POWER	1.0191	N/A

*** WAVEFRONT ***



2 inch diameter, 10 inch radius aluminum sphere