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Production techniques for the preparation of sinusoidal profile surface roughness specimens

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Production Techniques for the Preparation of Sinusoidal Profile Surface Roughness Specimens

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Abstract

Using diamond CNC machining equipment, surface roughness specimens have been produced in moderate volume, which have a sinusoidal wave form. Arithmetic average (Ra) values of 0.3, 1.0, and 3.0 micrometers have been produced and delivered under contract to the National Bureau of Standards. The spatial wavelength for all was 100 micrometers. The sinusoidal wave form was diamond machined into the thickness of a .006 inch thick electroless nickel plating on a tool steel substrate. Any combination of Ra and wavelength is possible within the constraints of nickel plate thickness and trough radius. A major consideration was the diamond tool radius, its accuracy, and its effect on the turned profile.

Introduction

There has existed in industry a need for precision surface roughness specimens, which have a sinusoidal wave form. They are used primarily as secondary laboratory standards, although other uses for instrument evaluation have been suggested. The U.S. National Bureau of Standards (NBS) has pursued the development of precise specimens since the mid-1970's, when their computerized system for measuring surface roughness made that need apparent [(1)]. The application of diamond machining technology by the Lawrence Livermore National Laboratory to this need resulted in the first sinusoidal wave form specimens in 1977, but priorities at the Laboratory dictated that a commercial source be found.

In the spring of 1981, Pneumo responded to an industry-wide inquiry from the NBS to produce Standard Reference Material (SRM) roughness specimens with sinusoidal profiles. In the small program that followed, four prototypes were produced and delivered in September, 1981 with a nominal Arithmetic Average (Ra) [(2)] of 0.3 micrometers and a spatial wavelength of 100 micrometers. Peak-to-Valley amplitudes were approximately 1 micrometer. The substrates were 6061-T6 Aluminum Alloy with a thick electroless nickel plate. The sinusoidal forms were cut within the thickness of the plating. The evaluation of the four prototypes with stylus instruments by the NBS indicated Ra values averaging between .33 and .34, which was somewhat higher than the desired nominal value of .30 micrometer. Another shortcoming was the lack of flatness over the test surface, which was greater than one fringe at 632 nm. But as indicated in Figure 1, which was made with a 0.1 um radius stylus, the profile was good and indicated that the diamond tool, machine program, and tooling concept were well executed. In October of 1982, the NBS awarded Pneumo a contract to produce 90 each of three Ra values: 0.3, 1.0, and 3.0 micrometers. All had a 100 micrometer spatial wavelength.

1.0 Production Design

To overcome the shortcomings of the prototype program and to better comply with NBS specifications for roughness specimens, several design changes were made in close coordination with Messrs. Teague and Scire of the NBS.

Substrate - an annealed AISI 01 tool steel was finally chosen as the substrate material after some experiments with a two-part construction of granite and aluminum and a one piece fine grained cast iron block. Machining of granite with even loose tolerancing in small sizes does not produce cosmetically acceptable parts and the cast iron could not be electroless nickel plated with consistently good results. The 01 tool steel is magnetic, which facilitated grinding operations and it possessed good long term stability properties. Its susceptibility to corrosion was not a concern since it was nickel plated all over.

Electroless Nickel Plate - a thick nickel plate of .005-.006 inch (0.13-0.15 mm) was applied all over the pre-ground block with the electroless process. The particular nickel alloy used was one which we have found to diamond machine better than others. Its principal alloying constituents are phosphorus and copper. After plating, the specimen blocks are baked to prove the plate and to enhance hardness. The Knoop hardness, HK, for three test pieces was in excess of 700. This converts to a Rockwell C scale reading of 59.

Configuration - the general size and shape of the specimens is derived from the NBS specifications and is pictures in Figure 2. Outside dimensions are .50 x .96 x 1.31 inches. Three tapped holes are positioned in the center of the mounting pads of the bottom side, which are used to mount the block during machining. It was also felt that they may be useful in certain instrumentation set-ups. A central 6-32 tapped hole is employed to retain the specimen in its instrument box.

Package Design and Part Marking - the NBS logo, Standard Reference Material number, and specimen serial number are laser etched on the right-front side of the blocks. The walnut instrument box which was designed to protect the specimen in transit and storage is shown in Figure 3. The specimen block is attached to a false-floor insert via a captive brass screw. The size of the box was chosen to accommodate an 8½ x 11 calibration certificate, folded twice, and placed below the false floor. The instrument box measures approximately 5 x 4 x 1 3/4 inches (127 x 102 x 44 mm). The NBS logo and Standard Reference Material number are laser etched on the right-front side of the box.

2.0 Single Point Diamond Machining

The MSG-325 2 Axis, Interferometrically controlled machine (Figure 4) was used. Although it was preferable to have straight sinusoidal grooves cut in the specimen it was not possible to produce that geometry in a two-axis machine. A third linear axis would have been required.

Tooling Concept - by positioning the specimen blanks around the periphery of the machine face plate as pictures in Figure 5, the grooving was cut in large radius (6-7 inch) arcs which was deemed acceptable for the intended purpose. Thirty-six blocks were mounted to an adapter plate with three fasteners each. The tapped holes are positioned in the center of the three support pads. The diamond machined adapter plate was then mounted to the diamond-machined vacuum chuck of the machine. This permitted loading of the adapter plate at the bench, which was facilitated with an inclined "lazy susan" as pictured in Figure 6.

Programming - the programming of the repeated sine wave with entrance and exit plateaus at mid-amplitude height was performed off the machine and stored on diskette for subsequent use in the machine processor. The program directed the machine through the sine function in a loop subroutine for the 270 cycles cut across the useable area of the specimens. A surface increment of .00025 inch was used for all cutting. Constants for each SRM type are shown in Table 1.

Table I

	Surface Roughness Arithmetic Average (Ra)	Trough Radius	Maximum Slope Angle
SRM 2071	0.3 um(11.8 u")	.0215" (.546 mm)	1.66°
SRM 2072	1.0 micrometers (39.4 microinches)	.0064" (.163 mm)	5.54°
SRM 2073	3.0 micrometers (118.1 microinches)	.0022 (.056 mm)	16.24°

The three types all have a wavelength of 100 um(.00397")

Diamond Tools - the maximum allowable radius of the diamond tool must be significantly less than the trough radius of the curve in question to permit the tool to generate or "walk around" the radius. Otherwise waviness flaws of the tool would be more evident on the part. The minimum arc of the tool used in the cutting is equal to twice the slope angle at the point of inflection. The maximum tool sweep required was that of the 3.0 Ra specimen, which was 32.5°. The actual included angle of the tool used was 80°. For the 0.3 and 1.0 values, the tool radius was actually .00480 inches; for the 3.0 value, the actual radius was .00040 inches.

In all cases, top rake was zero and front clearance was 5°. Inspection and measurement of the diamond edge quality, waviness, and radius was performed on the Pneumo diamond tool analyzer (Figure 7) which employs a microscope/CCTV system at 1300X magnification.

Job Set Up - after all preparations have been made for the production of the specimens, the machine is set up for the run by first facing the vacuum chuck with a more conventional diamond tool. The job specific diamond tool is then mounted without too much regard to aligning its cutting point to coincide with the machine axes. Height error has only second order effect on waveform accuracy. Machine offset error has no effect at all. Four aluminum set up pieces are then mounted to the adapter plate for machining and checkout of form. When the set-up is proven, the 36 electroless nickel plated specimen blocks are assembled to the adapter, which is then mounted on the machine. Cutting is performed at a spindle speed of 750 rpm, 0.2 inches/min. feedrate, and a 50 microinch depth of cut for the finish pass. A spray mist coolant of mineral spirits (petroleum naphtha) was used for all cutting. The blocks were subsequently vapor degreased and then packaged.

3.0 Machining Results

Form measurements were made employing a Gould Surfanalyzer, which is a contact stylus type of instrument (Figure 8). The diamond stylus has a .0001 inch radius with a 30° included angle. Normal force is 50 milligrams. Strip chart traces for each of the three values are shown in Figure 9. These results indicate an Ra of 0.4 u" below the nominal for SRM 2071, no difference for SRM 2072, and a value of 1.9 u" above the nominal for SRM 2073. More precise data has been taken at the National Bureau of Standards using equipment of higher resolution. That data is currently being statistically analyzed by the Bureau before a calibrated value can be assigned. The test data presented here is only intended to demonstrate control of the waveform parameters. Especially note the difference in horizontal and vertical scales, which belies the gentle slope of the curves. The Nomarski photographs shown in Figure 10 are taken at the intersection of the top surface and the 45° bevel provide much better appreciation of the waveforms. Magnification here is 500X.

Conclusion

There is interest from many sectors of industry to produce forms of different function, wave length, and amplitude. All combinations are feasible, but with the following constraints:

1. Practical maximum thickness for electroless nickel plate is about .010 inch unless cost is of no consequence; then .020 inch may be the limit. The desirability of nickel of course, is based on its hardness. If this is of no concern then aluminum or other non-ferrous material could be machined to any amplitude value within the machine travel limitations.
2. Minimum diamond tool radius is about that used for the NBS 3.0 Ra specimen or .00040". Sharper diamond tools would quickly break down to radii of that order, but without as sharp a cutting edge.
3. The useful arc of the tool radius is practically limited to about 80°-90° (the tool included angle would be 90°-100°). Difficulty with edge waviness over the large angular aperture is one problem; variation of diamond hardness over such a larger change in crystal orientation is another.

References

1. E.Clayton Teague, Frederick E. Scire and Theodore V. Vorburger, Sinusoidal Profile Precision Roughness Specimens, Wear, 83(1982) 61-73.
2. Surface Texture, ANSI Standard, B46.1, 1978.

PNEUMO SPECIMEN A, 0.3 UM RA, 100 UM WAVELENGTH
PROF NO = 1 PTS 1 TO 4000

January, 1982

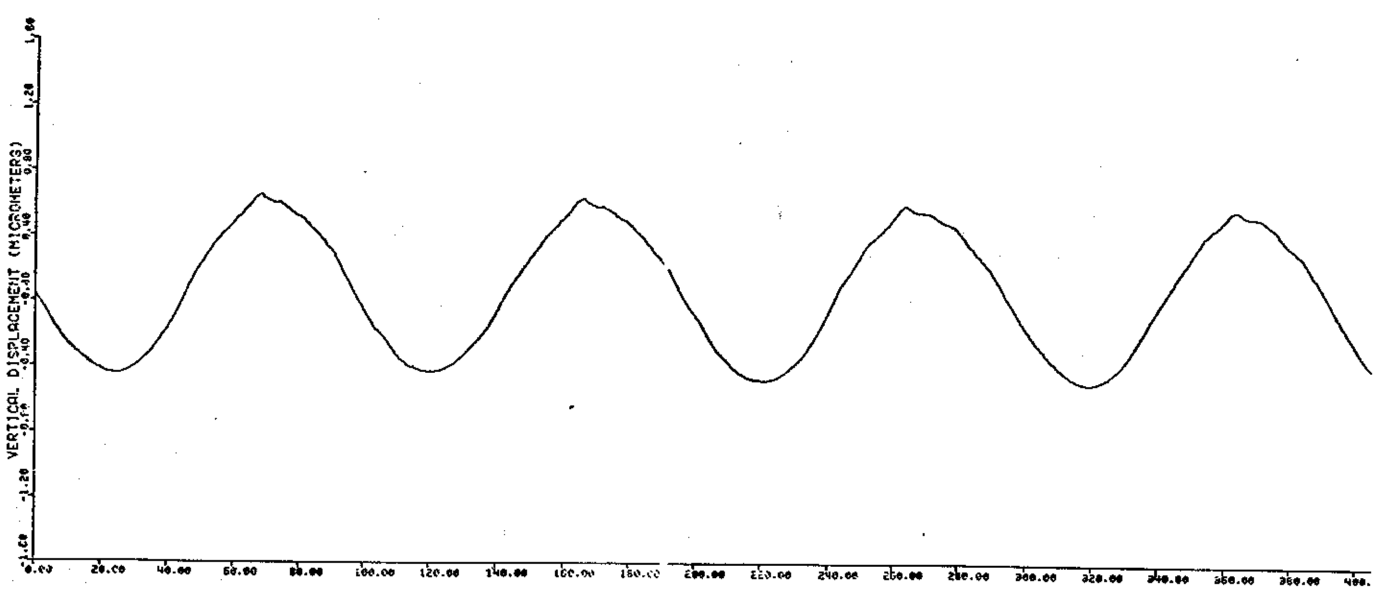


Figure 1. Prototype Waveform

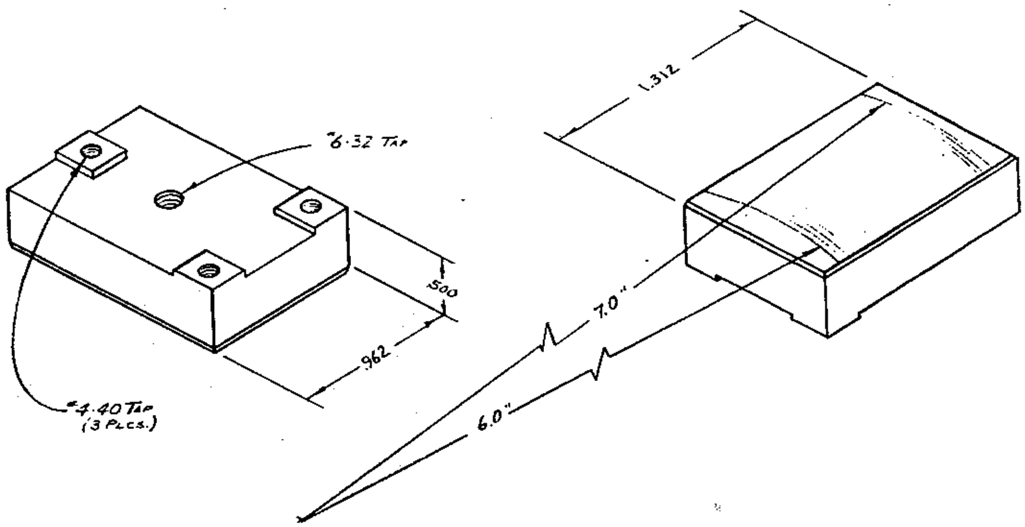


Figure 2. SRM Configuration

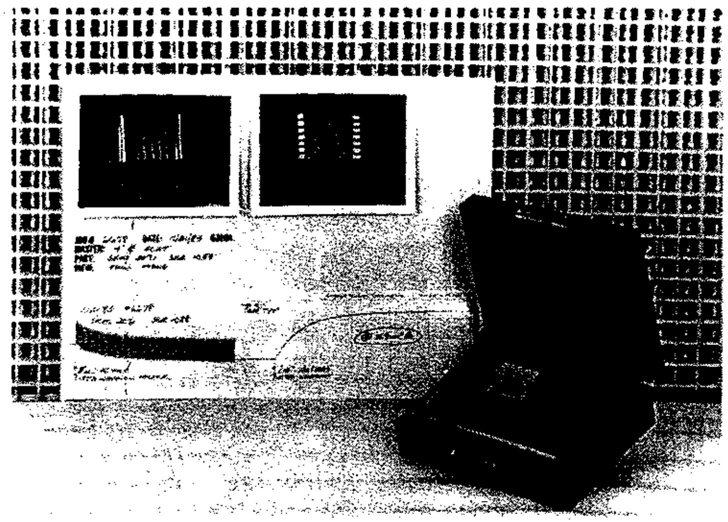


Figure 3. Package Design

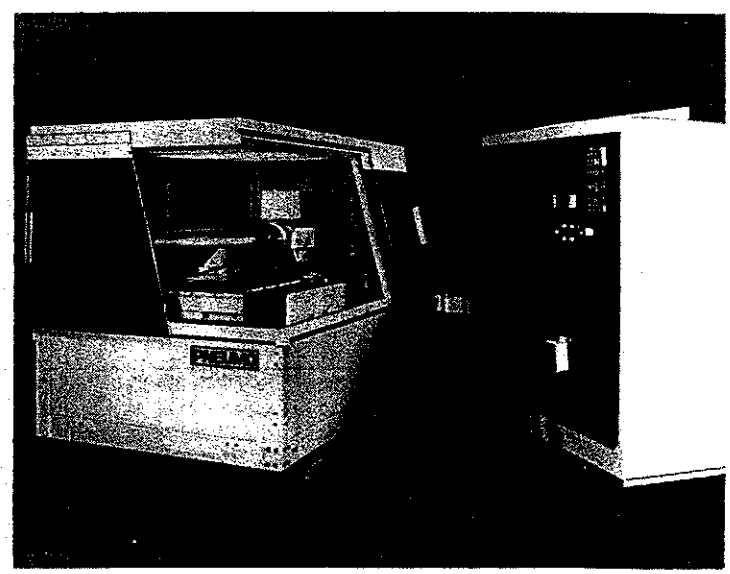


Figure 4. MSG 325

Figure 5. Tooling Concept

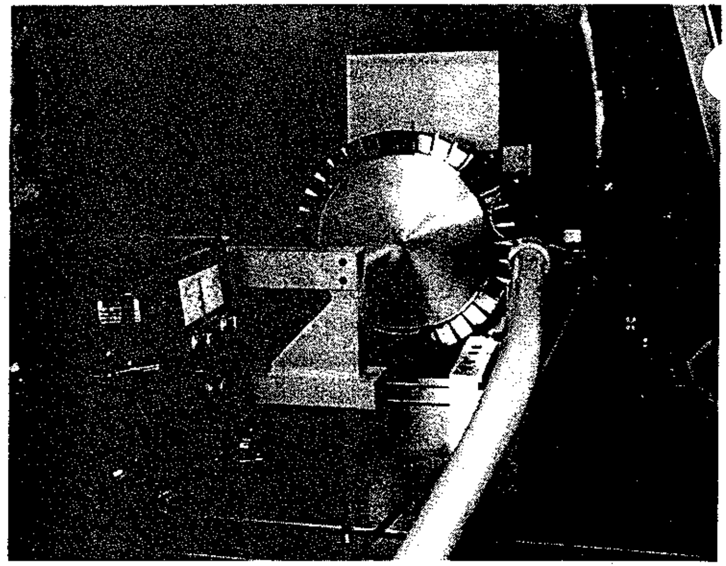
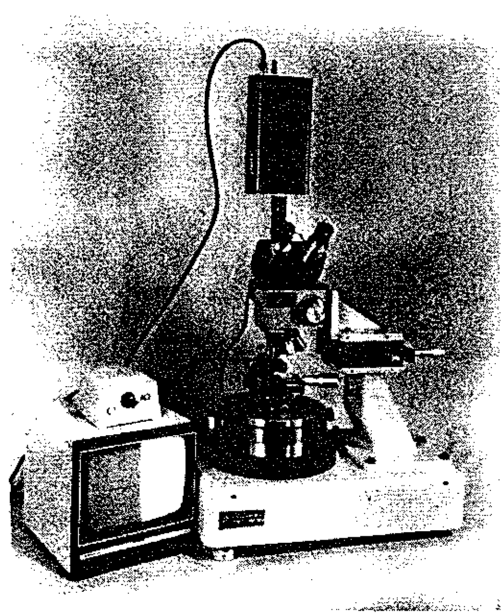


Figure 6. Assembly ''Lazy Susan''

Figure 7. Diamond Tool Analyzer



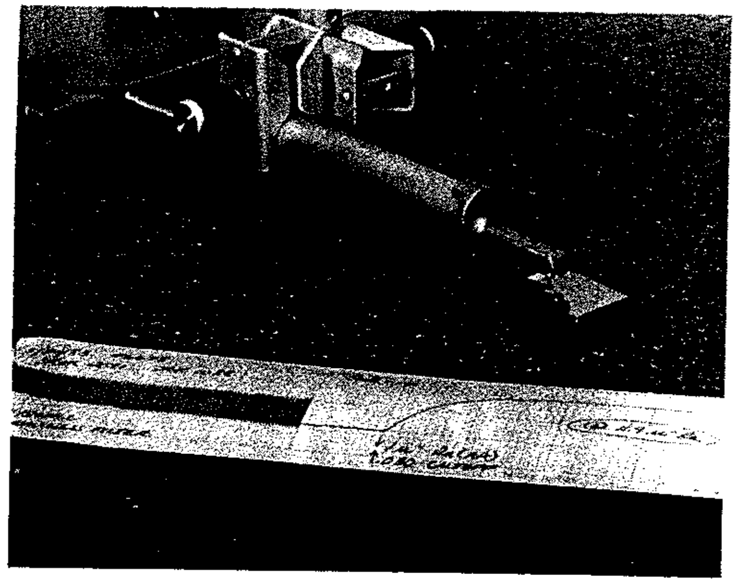


Figure 8. Wave Form Measurement

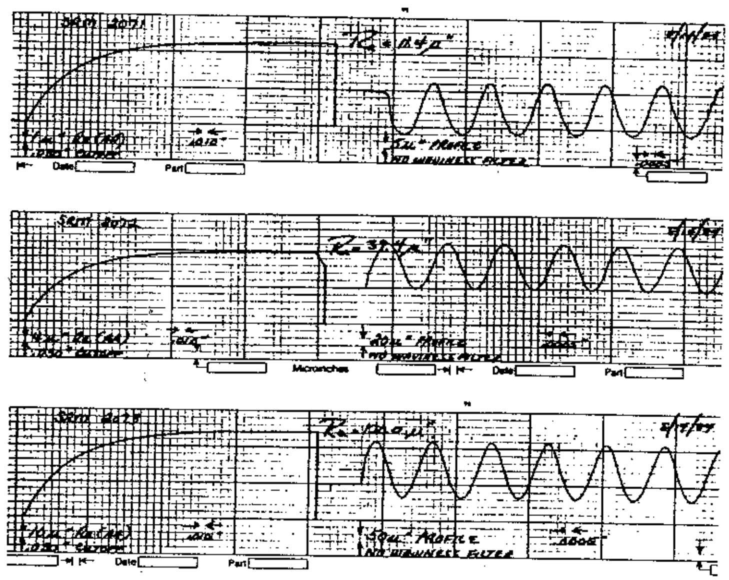
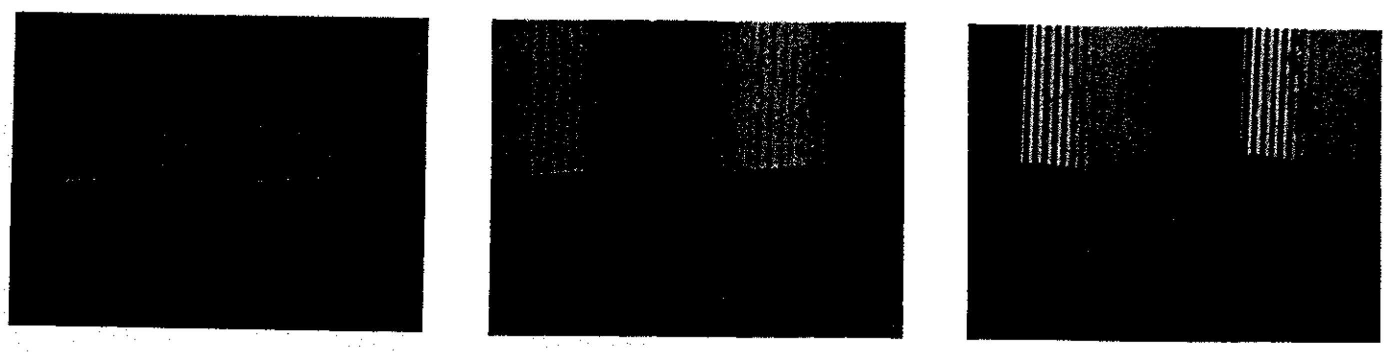


Figure 9. Strip Chart Traces



Ra 0.3   Ra 1.0   Ra 3.0

Figure 10. Nomarski Photographs