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Recent developments in the generation of glass aspherical surfaces

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ABSTRACT

The establishment of Single Point Diamond Machining as a viable production process for metallic, crystalline and plastic optics has resulted in a greater awareness of non-conventional surface geometries from both design and production standpoints.

The development by Rank Pneumo Inc. of an Ultra-Precision Aspheric Grinding machine has been prompted by current and predicted market requirements which call for a precision machining process capable of yielding optically smooth aspherical surfaces to a figure accuracy in the order of one wave or less at 632.8nm on workpieces typically no greater than 150mm in diameter.

1. INTRODUCTION

Current diamond machining system design as refined by continuous user feedback has been utilised in the design of the ASG 2500 (Aspheric Surface Generator); indeed, the majority of the system's critical components have evolved through existing, well proven technology.

Pneumo's approach to investigating the most appropriate process parameters has been influenced by our ultimate goal of developing a machine tool suitable for the economic production of glass aspherical surfaces.

In order to achieve this goal, a brittle-regime grinding process has been adopted to yield high accuracy surface form with surface textures requiring a minimum of post polishing.

Although this process can and has been adapted to accomplish a ductile regime of grinding, the typical cycle times associated with this regime, which are governed by excessively small rates of volumetric removal, do not lend themselves to typical production requirements.

Since glass types available are too numerous for individual evaluation, investigations have been concentrated on five representative glass types, namely BK7, BAF51, SF12, F4 and SF57, which exhibit a range of differing visco-elastic characteristics.

It is our hope that correlation between these characteristics and the resultant ground and polished surfaces, will allow guidelines to be set requiring only a fine tuning of the process if other non-listed glass types are required.

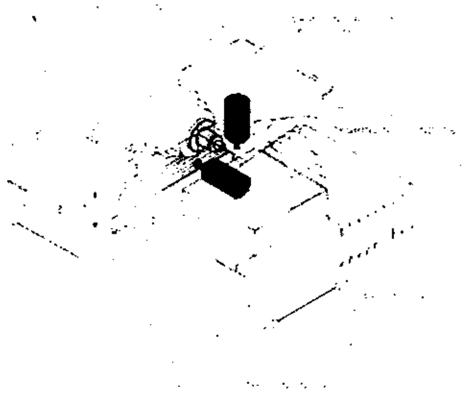


figure 1

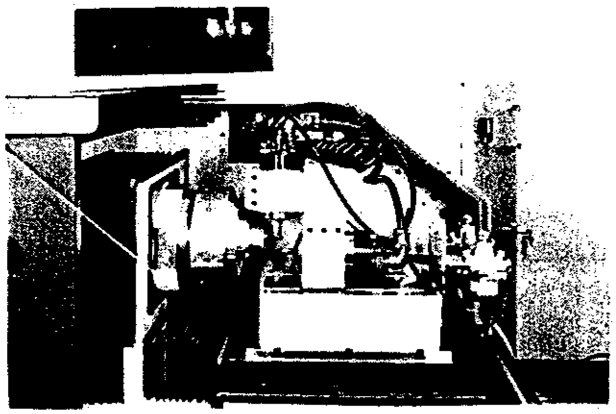


figure 2

Dual Spindle Grinding Attachment

2. DEVELOPMENTS IN GRINDING AT RANK PNEUMO

In recent years demand, predominantly from the Far East, had forced Pneumo to respond with a dual spindle grinding attachment as an accessory for their Ultra-Precision 2000 diamond turning lathe. The capability of this unit was geared toward the requirements of the Consumer Electronics and Photographic Equipments Industries which generally require the high quality and high quantity production of aspheric lens moulds to allow for the moulding or pressing of plastic or glass elements at minimum unit cost. (See figures 1 & 2).

Although the equipment developed for this requirement was limited in the area of workpiece capacity, it did permit Pneumo to gain an understanding of the grinding process and the demands of that process on the machine tool.

3. OVERVIEW OF THE ASG 2500

Unlike the dual spindle grinding attachment illustrated earlier, the ASG 2500 is fitted with a single vertical grinding spindle mounted on a linear X axis slide. A linear Z axis slide is mounted orthoganally in a classical 'T' base design upon which is fitted the workpiece spindle, thus allowing the peripheral cross axis grinding of spherical and aspherical forms (see figure 3).

The machine features a thermally stress relieved cast iron base which is isolated from ground vibration by passive air isolators mounted kinematically on a substantial steel welded outer frame.

The hand lapped bearing ways form an integral part of the base with mating slide carriages running on a film of hydrostatic oil pressurised at a relatively low flow to minimise heat generation.

Oil as a bearing medium exhibits favourable damping characteristics and resultant slide stiffness is considerably higher than that of air.

Both the workpiece and the grinding wheel spindle are of a cylindrical hydrostatic air design utilising rear thrust plates to provide axial stiffness. This design provides a smoothness of motion, and when finely balanced is free from the hammering effect which ultimately propogates cracks beneath the workpiece surface.

An Allen-Bradley 8200 computer numerical control is used to accurately position the two slides simultaneously in the desired contour, using feedback data from a Hewlett Packard laser interferometric transducer.

The machine is supported by various peripheral equipments such as an external grinding cart which provides a continuous temperature controlled and filtered flood coolant from its reservoir. It also houses the grinding spindles drive electronics and coolant unit.

It should be noted that the removal of the grinding wheel will facilitate the fitment of a single point diamond cutting tool to allow the machine to be used for the Ultra-Precision machining of non-ferrous metals, plastics and crystals.

4. ASG 2500 SPECIFICATION

Workpiece spindle

Type........................	Rank Pneumo cartridge type hydrostatic air bearing with rear thrust plate
Speed range.................	100-2400 RPM
Radial/Axial runout.........	0.1 micrometer T.I.R. or less
Axial stiffness.............	14.01×10^7 N/m
Radial stiffness............	8.70×10^7 N/m
Drive.......................	DC Servo motor directly coupled on-axis to spindle giving 0.9 peak horsepower

Grinding Wheel Spindle

Type........................	Whitnon cylindrical hydrostatic air bearing with rear thrust plate
Speed range.................	3000-10000 RPM
Radial runout...............	0.25 micrometer T.I.R. or less
Radial stiffness............	7×10^7 N/m
Drive.......................	Motor cooled by combination of water and air

X and Z Linear slides

Type	Box-way hydrostatic oil
Feed range	0.25 - 762 mm/min
Horizontal straightness	X - 0.5 micrometers or less (full travel) Z - 0.3 micrometers or less (full travel)
Traverse length	X - 254 mm Z - 152 mm
Horizontal stiffness	17.5×10^7N/m
Longitudinal stiffness	3.00×10^7N/m
Drive	DC Servo motor directly coupled to pre-loaded ball screw, which in turn is coupled to slide carriage

Control and Feedback

Type	Allen-Bradley 8200 CNC interfaced to Hewlett-Packard 5518 laser interferometric transducer
Resolution	Resolution of 10 nanometers
Features	Manual laser compensation of temperature, humidity and barometric pressure

Workpiece Capacity

Concave	Max diameter 150mm Max sagittal depth 38mm
Convex	Max diameter 150mm Max sagittal depth 75mm

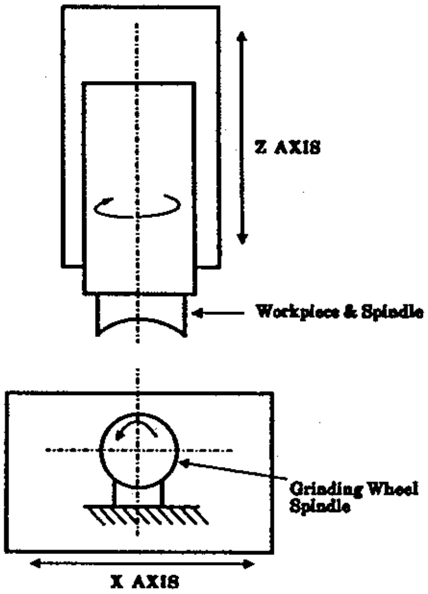


figure 3

ASG 2500 Schematic layout

~~5. THE GRINDING PROCESS~~

Wheel selection and the maintenance of its optimum condition is a critical factor in the achievement of an accurate form and a regular surface texture with minimum subsurface damage. The grinding wheel must remain in a state of free cutting throughout the machining cycle and preferably throughout several machining cycles.

When considering the grinding of concave workpieces, the grinding wheel diameter must be selected carefully as the size of the wheel will dictate the size of mandrel used to connect the wheel to the spindle, and thus there will be a constraint on the sagittal depth.

In addition to this, the grit size and concentrations and its type of bond are of importance, observations made on these three parameters are:

Grit Size: Generally a smaller grit is appropriate for glass types exhibiting a higher knoop hardness. As hardness of glass decreases and therefore cutting forces decrease, the size of the grit can be increased. The use of blocky type diamonds was found to sustain the life of the wheel.

Concentration:	A lower diamond concentration was found to be more appropriate for finish grinding, regardless of the glass type. Minimizing 'loading' of the wheel increases the effectiveness of each individual diamond.
Bond:	The use of resonoid bonding in the wheel matrix provides an elasticity which prevents premature degradation of the wheel structure due to its flexibility. The bond ensures that the whole circumference of the wheel is used. The resonoid bond allows optimum dressing characteristics to be maintained as described below.

An on-machine wheel dressing station utilises the workpiece spindle upon which is mounted a single dressing nib. The spindle is slowly rotated by hand, thus sweeping the diamond along the edge of the grinding wheel (see figure 4). This operation typically takes approximately ten minutes.

Workpiece accuracy is greatly affected by the accurate positioning of the wheel in relation to the spindle centreline. The tool path generated by the X-Z co-ordinates will typically end at X zero; this point must be coincident with the workpiece spindle's axis of rotation if optimum accuracy is to be obtained (see figures 5 & 6).

figure 4 Dressing of grinding wheel

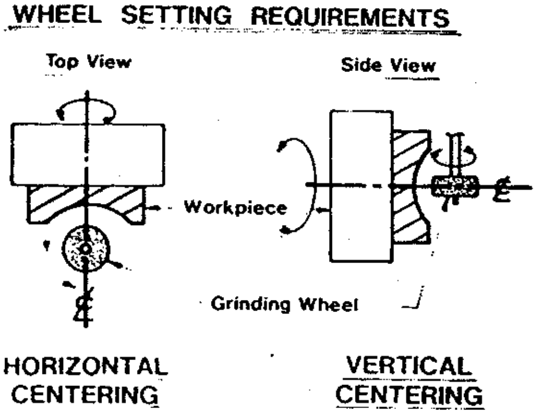


figure 5

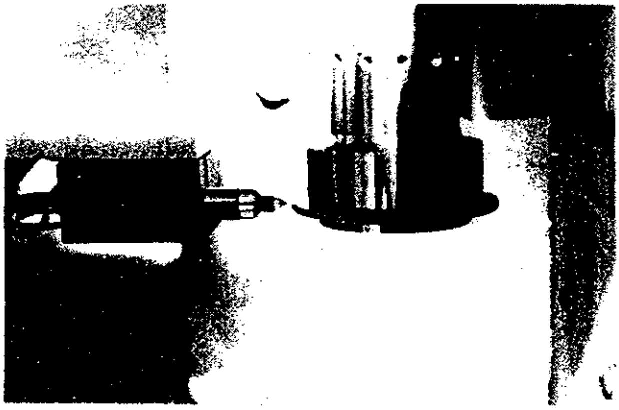


figure 6

The automatic L.V.D.T. tool set station as illustrated in figure 6, calculates the diameter of the grinding wheel and the relative position of its centre to the workpiece spindle's axis.

Specifications for Grinding Experiments:

1. Material BaF51

Wheel:
1800 grit
50% conc.
resonoid bond
75mm diameter
7000 rpm

Part: 700 rpm

Coolant: water soluble oil

Roughing Passes:
number: 10
feed: 25mm/min
doc: 5 micrometers

Finish Passes:
number: 5
feed: 12mm/min
doc: 1 micrometer

2. Material SF57

Wheel:
1500 grit
75% conc.
resonoid bond
75mm diameter
9000 rpm

Part: 700 rpm

Coolant: water soluble oil

Roughing Passes:
number: 10
feed: 25mm/min
doc: 5 micrometers

Finish Passes:
number: 5
feed: 12mm/min
doc: 1 micrometer

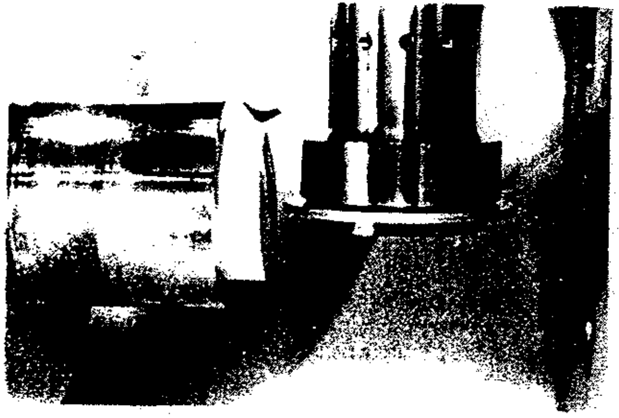


figure 7

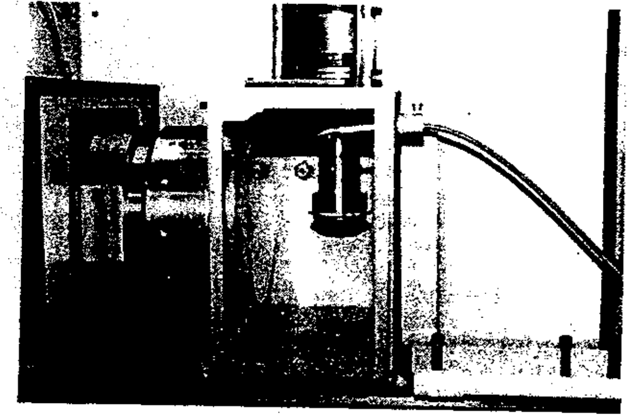


figure 8

The ASG 2500 grinding typical glass workpieces

6. POST POLISHING REQUIREMENTS

As discussed earlier, the surface generated from a brittle-regime grinding process does require slight post polishing to reduce the surface texture and sub-surface damage. The degree of polishing required obviously depends on the state of the ground surface.

A flexible polishing process has been utilised to achieve the goal of minimum polishing times with least disruption to the surface form.

The process in principle consists of a horizontal fixed driven spindle carrying an appropriate polishing tool. The workpiece is mounted on a horizontal free running spindle which swings off-set on a horizontal plane about a vertical axis. The rotating polishing tool is brought into contact with the swinging workpiece, and thus rotates at a lower rotational speed, depending on the pressure between the two. The driven spindle retracts periodically to reduce the generation of heat and to maintain a random polish (see figures 9 & 10).

Specifications for Polishing Experiments:

Polishing Compound: Cerium Oxide
Polishing Medium: Water
Polisher Support: RTH Air Bag Polishing Tool
Polisher Charge: Gugolz 55 Pitch

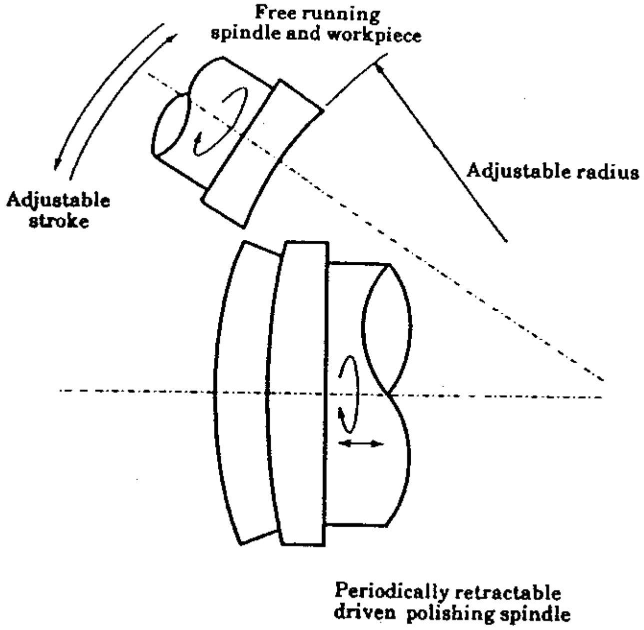


figure 9

Schematic of Flexible Polishing Machine

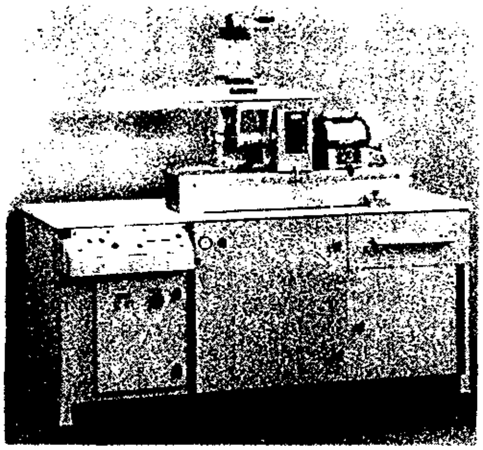


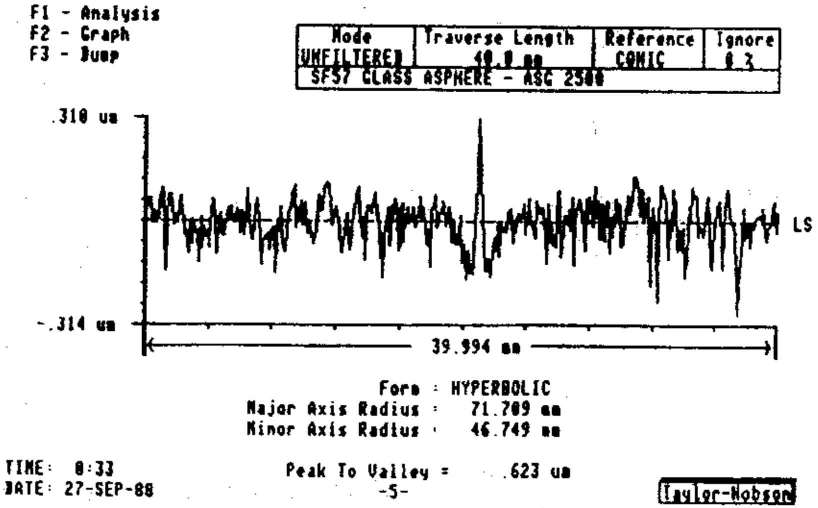
figure 10

Flexible Polishing Machine

7. RESULTS

For ease of measurement the majority of our grinding experiments have been conducted on spherical elements, but it should be noted that due to the X-Z principle of machine operation, identical results are obtainable when grinding aspherical forms. Aspherical forms have been ground, and the results of one such exercise are shown (see figure 11).

Typical surface textures as directly ground, can be found in figure 12. It was found to be possible to polish these surfaces to an acceptable cosmetic quality, and the effects on form accuracy of post polishing as a function of time are illustrated in figure 13.



F1 - Analysis
F2 - Graph
F3 - Dump

Mode	Traverse Length	Reference	Ignore
UNFILTERED	40.0 mm	CONIC	0.3

SF57 GLASS ASPHERE - ASG 2500

Form : HYPERBOLIC
Major Axis Radius : 71.709 mm
Minor Axis Radius : 46.749 mm

TIME: 0:33
DATE: 27-SEP-88

Peak To Valley = .623 um
-5-

Taylor-Hobson

figure 11

F1 - Analysis
F2 - Graph
F3 - Dump
F4 - Expand
F5 - Exclude
F6 - Z_Range

Mode	Cut Off	Filter	Reference	Ignore
ROUGHNESS	0.80 mm	ISO	CONVEX	0 %
SF57 GLASS SAMPLE ASC 2500				

Peak To Valley = .273 um

TIME: 0:30
DATE: 27-SEP-88

-1-

Taylor-Hobson

Mode	Cut Off	Filter	Reference	Ignore
ROUGHNESS	0.80 mm	ISO	CONVEX	0 %
SF57 GLASS SAMPLE ASC 2500				

Lo = 3.932 mm
Rp = .120 um
Rv = .153 um
Rt = .273 um

RADIUS = 109.963 mm
Diameter = 219.926 mm

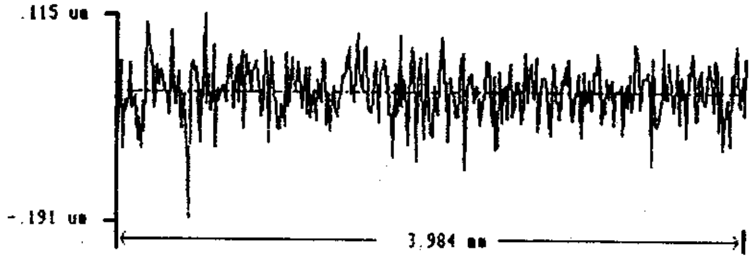
Ra = .030 um
Rq = .039 um
Rsk = -.7
Rku = 4.3
Delq = .26 Deg
Lamq = 54.560 um
S = 22.192 um
Sm = 60.386 um
R3z = .137 um
R3y = .162 um

-2-

Taylor-Hobson

F1 - Analysis
F2 - Graph
F3 - Dump
F4 - Expand
F5 - Exclude
F6 - Z_Range

Mode	Cut Off	Filter	Reference	Ignore
ROUGHNESS	0.80 mm	ISO	CONVEX	0 %
SF12 GLASS SAMPLE ASC 2500				



Peak To Valley = .306 um

TIME: 0:20
DATE: 27-SEP-88

-1-

Taylor-Hobson

Mode	Cut Off	Filter	Reference	Ignore
ROUGHNESS	0.80 mm	ISO	CONVEX	0 %
SF12 GLASS SAMPLE ASC 2500				

Lo = 3.984 mm
Rp = .115 um
Rv = .191 um
Rt = .306 um

RADIUS = 110.540 mm
Diameter = 221.079 mm

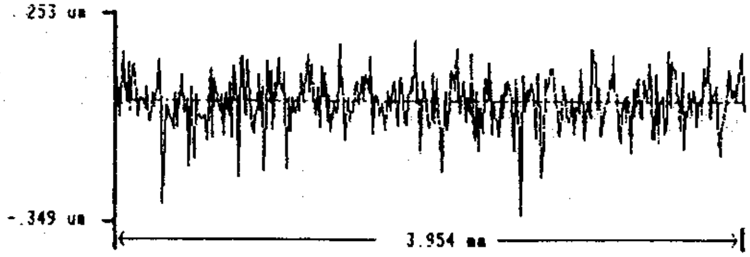
Ra = .033 um
Rq = .042 um
Rsk = -.5
Rku = 3.7
Delq = .53 Deg
Lamq = 20.852 um
S = 15.609 um
Sm = 26.257 um
R3z = .181 um
R3y = .202 um

-2-

Taylor-Hobson

F1 - Analysis
F2 - Graph
F3 - Dump
F4 - Expand
F5 - Exclude
F6 - Z_Range

Mode	Cut Off	Filter	Reference	Ignore
ROUGHNESS	0.80 mm	ISO	CONVEX	0 %
BK7 GLASS SAMPLE ASC 2500				



Peak To Valley = .602 um

TIME: 0:12
DATE: 27-SEP-88

-1-

Taylor-Hobson

Mode	Cut Off	Filter	Reference	Ignore
ROUGHNESS	0.80 mm	ISO	CONVEX	0 %
BK7 GLASS SAMPLE ASC 2500				

Lo = 3.954 mm
Rp = .253 um
Rv = .349 um
Rt = .602 um

RADIUS = 110.369 mm
Diameter = 220.738 mm

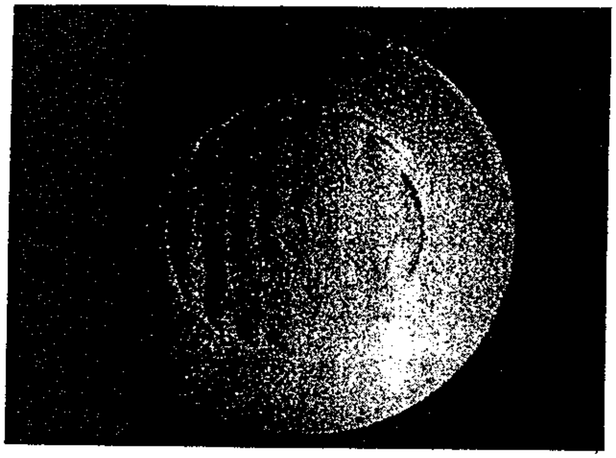
Ra = .061 um
Rq = .079 um
Rsk = -.4
Rku = 4.1
Delq = 1.09 Deg
Lamq = 26.167 um
S = 14.577 um
Sm = 24.364 um
R3z = .351 um
R3y = .378 um

-2-

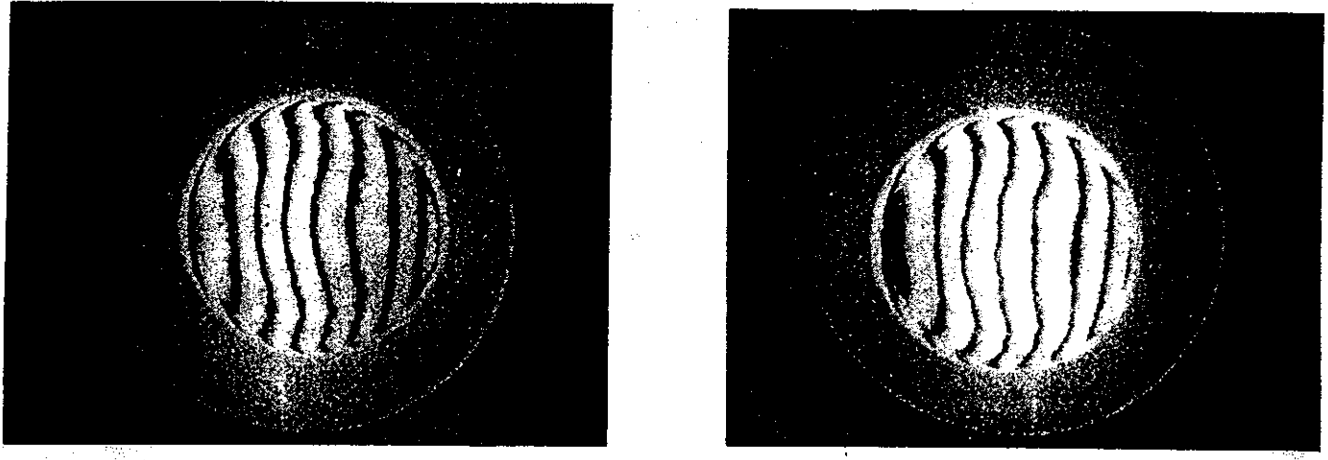
Taylor-Hobson

figure 12

Typical surface textures as ground

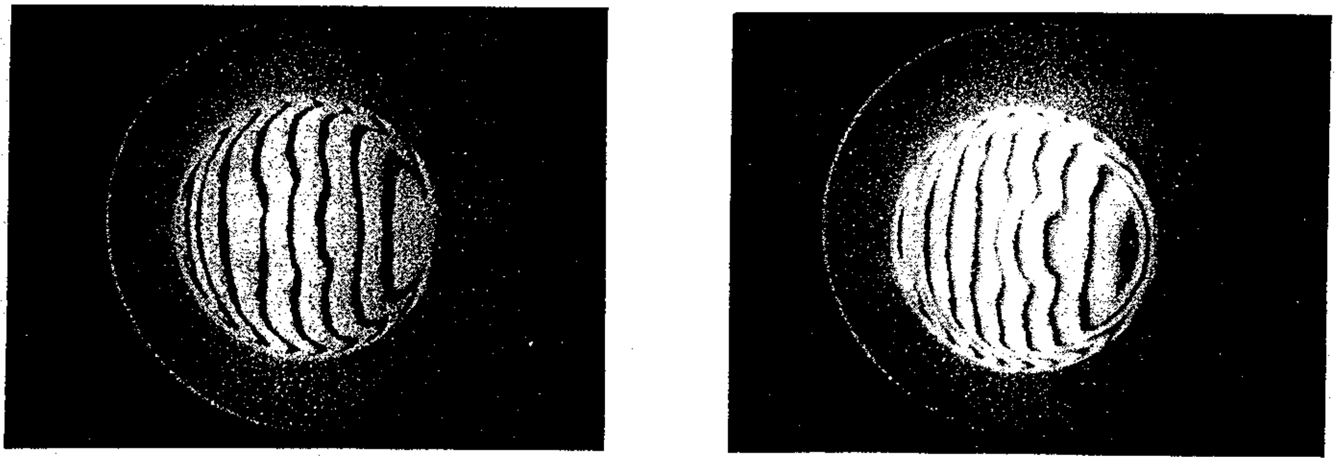


As Ground



After 3 mins polish

After 6 mins polish



After 9 mins polish

After 12 mins polish

figure 13

Effects on form accuracy of post polishing - glass type BAF51

8. CONCLUSIONS

In summary, it has been our goal to develop a viable production process for the generation of glass aspherical surfaces.

The work discussed in this paper, demonstrates that this in fact can be achieved by the foregoing principles of grinding and polishing.

If we consider the combination of these processes being used, it is not unreasonable to assume a total production time of less than 30 mins, from a rough spherically ground blank of 50mm diameter to an optically smooth aspherical surface. This is based on a production run, thus allowing the two processes to be used simultaneously on consecutive workpieces.

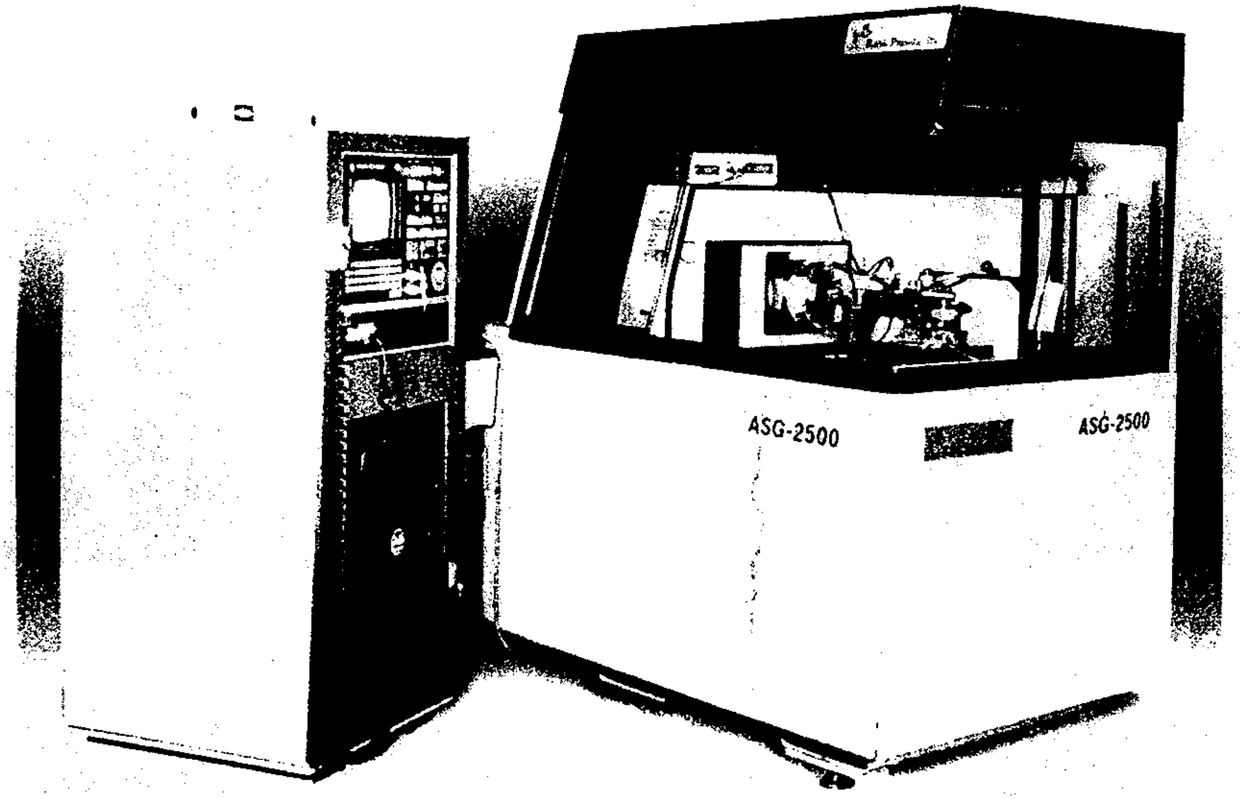


figure 14

The ASG 2500

9. ACKNOWLEDGEMENTS

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10. REFERENCES

1. T G Bifano, T A Dow and R O Scattergood - 'Ductile Regime Grinding of Brittle Materials' - Proceedings of the International Congress for Ultra-Precision Technology. Aachen - May 1988.

2. - 'Diamond Grinding of Optical Surfaces on Aspheric Lens Molds' - SPIE Vol. 656, 17-18th April 1986, Innsbruck, Austria.