ELID DRESSING OF GRINDING WHEELS

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Metal bonded grinding wheels are typically used for their ability to take heavy loads without the hazard of wheel failure, better thermal conductivity, and for better grit retention strengths. Truing and dressing these wheels, however, is difficult.

Research is being conducted in the use of electric discharge or EDM dressing, electrochemical (ECM) dressing, and others, most recently by a method called contact erosion, which is similar to EDM dressing but at lower voltages. Each has its merits, and we have chosen to research electrolytic dressing, nicknamed ELID dressing, which forms oxide products on the surface of a wheel with a steel or iron bond matrix. This oxidation is made to occur at the same rate as the diamonds are worn, eliminating wheel loading and presenting fresh grit at a continuous rate.

The oxide products inhibit the electrical action, halting or slowing the dressing process when the wheel is not being used. The current is restored by the grinding action removing the oxide layer. This mechanism gives some stability to the process and also will cause a wheel with runout to become more true or round with use. In other words, only the high spots that touch the workpiece are dressed.

Our application and my research are in the fine grinding of finish quality surfaces in hard mold materials and aspherical surface grinding of glass lens components using ELID dressed grinding wheels.

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ELID requires a cast iron or steel bonded wheel, a pulsed DC power supply, and coolant that can both conduct electricity and promote the proper chemical reactions at the grinding face. The current is provided a path between the (positive) wheel through the coolant in a gap, to the (negative) electrode. ELID has been demonstrated on surface grinders, OD grinders, and Blanchard style grinders, among others. The only requirement for a particular machine is that there must be access to a portion (1/4 - 1/6) of the grinding wheel grit surface for the electrode.[1] The only sources for wheels, coolant, and power supplies that are currently proven and available are in Japan, where ELID is being used or tested in many companies, mostly for rough grinding operations, but also in making precision flats, forms, and aspherical lenses.

The wheel goes through two phases of dressing using ELID. The first phase is a pre-dressing, which removes the bond matrix for 1/3 to 1/2 of a grit particle size, exposing the grit for use. This phase ends automatically in the creation of an oxide layer which inhibits the electricity flow. The second phase occurs during grinding. As the oxide layer is removed by the grinding action, the electrical current is restored to the portion of the wheel in use, causing further oxide creation in this zone and a fine truing of any remaining runout from the wheel. The process continues to dress the bond in the regions where the grit is used, and wheel loading can be eliminated. Halting the grinding action results in the creation of a new oxide layer and the dressing is inhibited automatically. This ability results in longer wheel life and a larger grinding ratio.

In ELID, the creation of oxide is assisted by the electricity that flows in one direction, on the positive side of the electrode gap. An AC voltage placed across the gap will cause the oxide to form, but with a very thin depth, which is not suitable for both exposing the grits and forming an insulating layer. A constant voltage DC source also creates a thin oxide layer and does not penetrate enough. As the frequency of pulsing the DC voltage is increased, the depth of penetration increases. A pulse rate of 4 microseconds on and 4 microseconds off is typical in ELID dressing. A unit designed for EDM use may prove suitable for ELID dressing, although the current draw will be less than typical EDM currents. Some power supply units have been designed specifically for ELID.

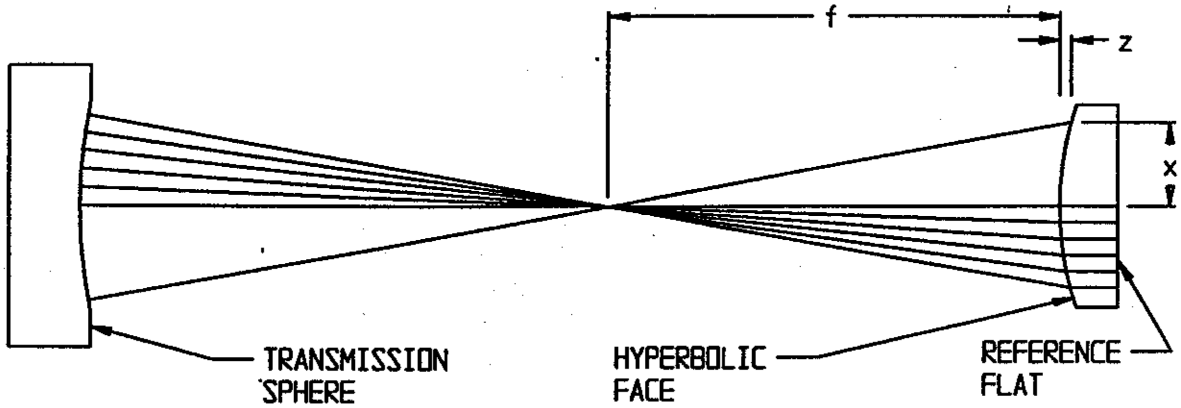
The coolant is a crucial element of the ELID process. It must have the ability to carry electricity, which is not normally a feature of water based coolants. It must also have the right ionic additives such as dissolved chlorine to promote the oxidation of the bond matrix. Some coolants are available for use with distilled water. Others do not work well with distilled water and require the impurities found in tap water. When tap water is used, testing is recommended before usage. Tap water quality can vary by season and test results are valid only for the sample tested.

A grinding attachment is a standard option for our Rank Pneumo diamond turning lathes. This is used in the generation of precision ground aspheres or other rotationally symmetric surfaces in components that are not diamond machinable. This attachment has always used a resin bonded diamond or CBN wheel. When metal bonded wheels were used, chatter could not be eliminated in the surfaces. ELID dressing allows us to grind with metal bonded wheels, achieve the same figure error with better surface finish, while eliminating redressing operations and improving throughput.

The configuration of wheel and electrode is machine dependent, but for these experiments, I made the electrode such that the wheel could be changed without disturbing it. In this manner a roughing wheel could be used for the generation of the proper shape and a finishing wheel used for obtaining the surface finish without requiring complete disassembly to change the wheels. Adapters were designed for the wheel and electrode to insulate both from the machine chassis. I have seen machines working with only the negative (electrode) side insulated, but feel that the corrosion products generated on the wheel could also be encouraged on the machine chassis in such a setup. Insulating the wheel adapter required a rigid insulator, and a machinable ceramic was used. This also required the use of a brass brush ring on the insulated portion of the wheel adapter to carry the current to the wheel. The last requirement is to fill the electrode gap with coolant in order to carry the current flow. This can be difficult at high wheel periphery speeds and a special coolant-manifold was made to flood an enclosed cavity surrounding the gap in order to hold coolant in the gap.

This arrangement was designed to be easily retrofitted to a Rank Pneumo Nanoform 300 or ASG-2500 machine. The hardware mounts into existing bolt holes in the machine and consists of two assemblies. One is the grinding wheel adapter, which contains balancing holes, a brass brush ring, captive mounting screws, and is removable from the spindle without disassembly of the adapter. The other is mounted next to the spindle and contains the coolant manifold, the brushes that carry current to the spindle, and the copper electrode in the shape of the wheel OD. The electrode is adjustable to obtain the proper clearance with the wheel OD and in height to match the wheel height. It is 45 mm long to surround about 1/5 of the 75 mm diameter wheel's circumference. There are two wires which carry the ELID current from the power supply outside the machine enclosure to the stationary assembly.

After early testing with flats and spheres, a hyperboloid of revolution in a glass substrate will be ground. By choosing the conic parameters based on the glass index of refraction, the part can be tested on an interferometer with a spherical wavefront. The hyperbola parameters are chosen so that the wavefront is converted from spherical to planar upon refraction through the glass interface. The wavefront then reflects off a reference flat on the back side and returns on the same path for interferometric analysis of the errors in the asphere. [2]



The hyperbola is defined by requiring the axial optical path length of zn + f be equal to the path of the off axis rays as shown:

$$zn+f = \sqrt{(f+z)^2+x^2}$$

where n is the index of refraction of the glass part. This relationship can be derived to one where the vertex radius of the part is r = f * (n - 1) and the conic constant $k = -n^2$, or

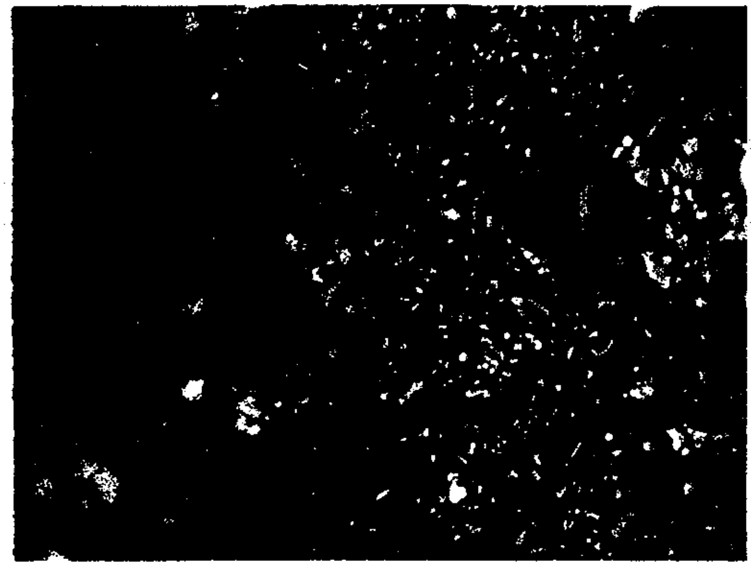
$$z = \frac{r-\sqrt{r^2-(k+1)x^2}}{(k+1)} = \frac{f(n-1)-\sqrt{f^2(n-1)^2-x^2}}{(1-n^2)}$$

By utilizing the hydrostatic slide ways and the air bearing work spindle of a Nanoform 300 machine, ongoing efforts are to use ELID in the generation of optical aspheres which do not require polishing after grinding.

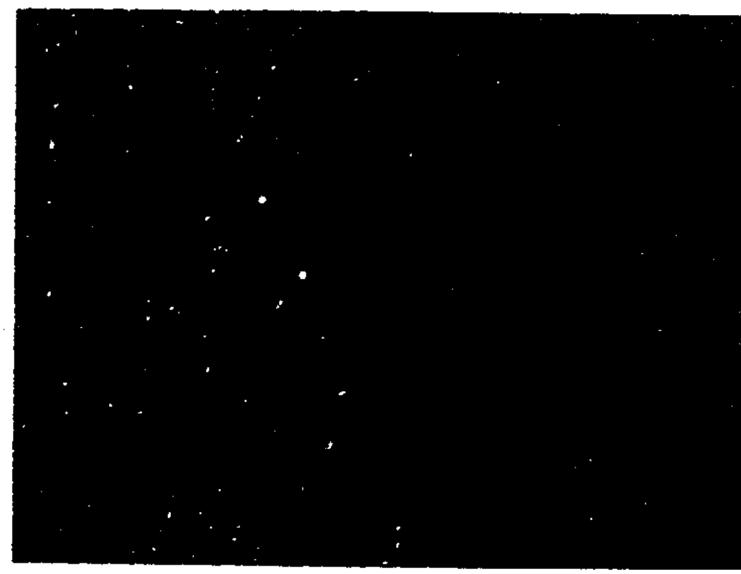
1. H. Ohmori and T. Nakagawa, "Mirror Surface Grinding of Silicon Wafers with Electrolytic In-Process Dressing", Annals of the CIRP, Vol 39/1/1990, pp 329-332.

2. M. Gerchman, "The Grinding of Optical Glasses on an Ultra-Precision Machine Tool", ASPE Conference presentation, Atlanta, GA, 1988.

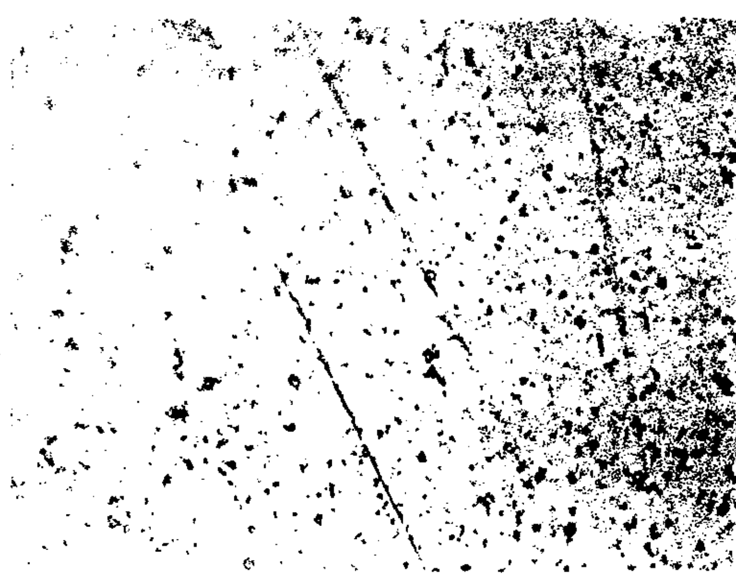
All of the following data is for sample parts made of BK-7 glass. The parts have an OD of 50 mm and 110 mm SR ground using ELID dressing. They all were ground using a Rank Pneumo Nanoform 300 diamond turning machine fitted with the large grinding attachment. The electrode clearance to the wheel was 0.1 mm in all cases.



The top photograph shows the surface of a part as ground using the 400 mesh wheel at 500 X magnification. This shows the surface finish produced by brittle mode grinding. The objective is to finish this fractured surface with ductile mode grinding to achieve both form and finish accuracy previously only obtainable by polishing.

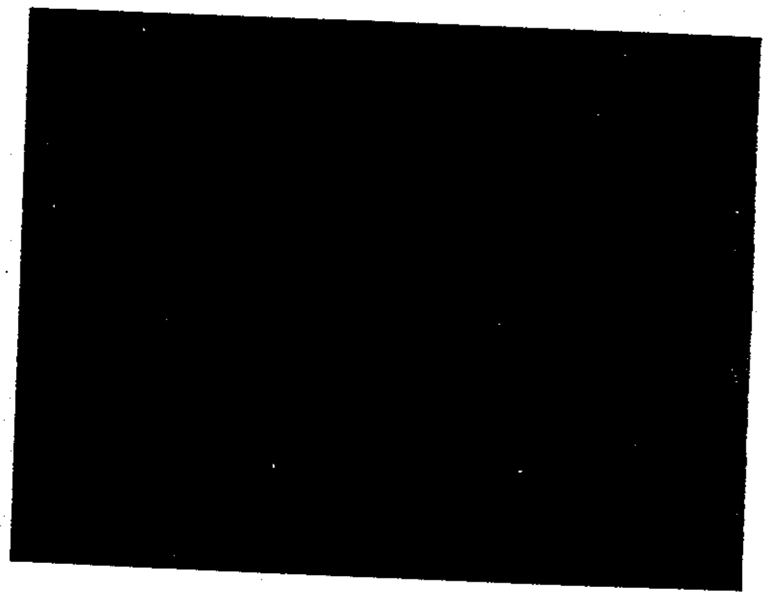


The next photographs show the surface of the part ground with the 3000 mesh wheel. They are both at 500 X and show different areas of the same surface. This part was ground with insufficient ELID current, resulting in surface damage from the bond contacting the surface. Both photographs show pitting and surface scratches but also show areas of little or no visible damage.

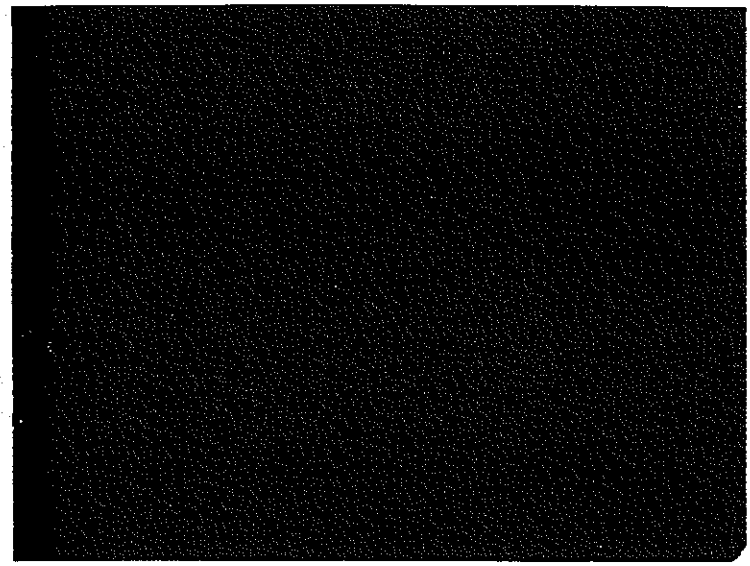


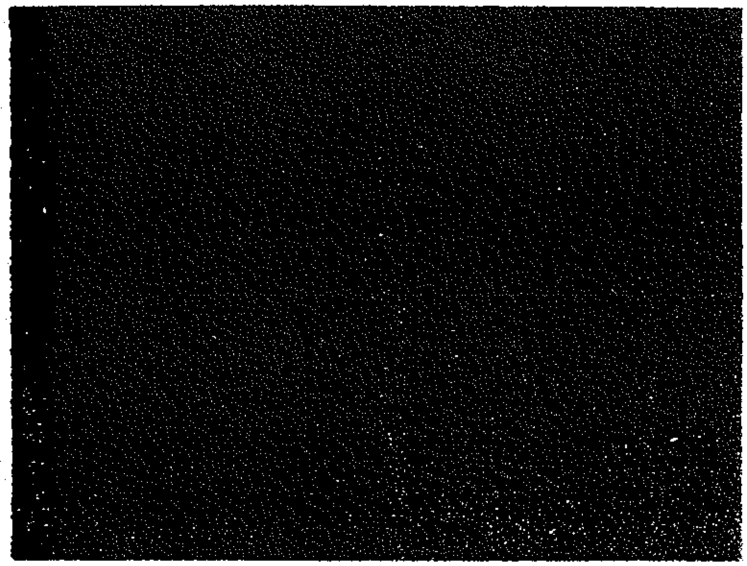
These photographs show the surface of the part ground with the 6000 mesh wheel. They are both at 500 X magnification and show different areas of the same surface. This part was ground with more ELID current than the 3000 mesh part, resulting in less damage.

Both photographs now show slight surface scratches and areas that appear to be porous. Again, areas of little or no visible damage are evident. It still remains to be shown if the process can be tuned to machine a high quality surface without the damage evident in these pictures.



These photographs show the surface of the glass part ground with the 8000 mesh wheel. They are also at 500 X and show different areas of the same surface. This part was ground with more ELID current than the 6000 mesh part, resulting in very little damage. These photographs now do not show surface scratches or areas that appear to be porous. However, there are some pits in the surface, uniformly distributed over the part. In this part, the majority of the surface area contains little or no visible damage. The next step is to modify the variables of feeds, speeds and depths of cut to grind a surface finish that requires no polishing.

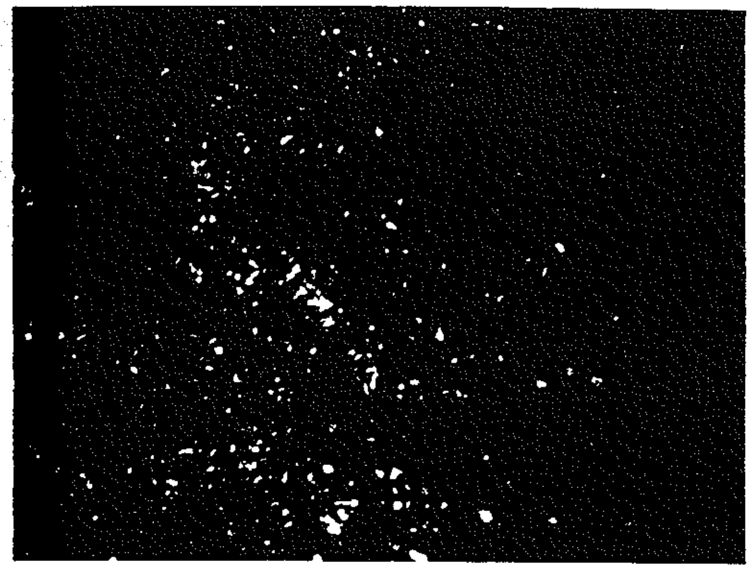




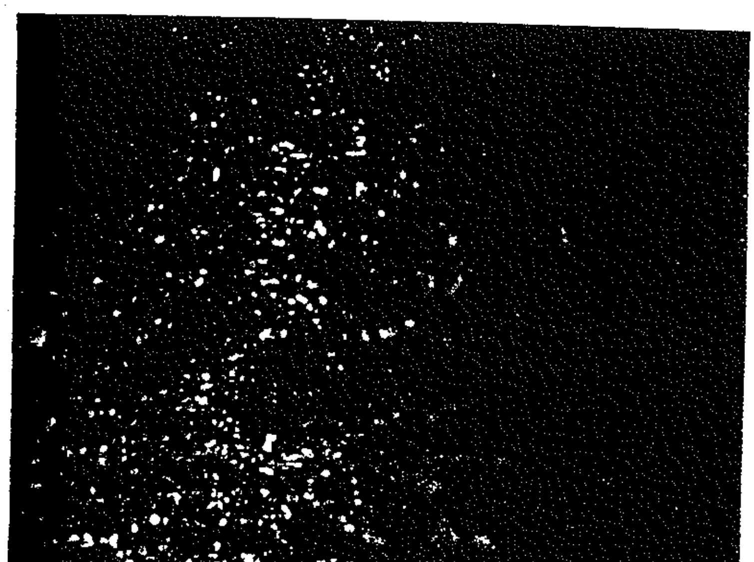
The bottom photo is of a glass part polished by traditional means. There are no pits or porous areas, but there are linear markings from the random polisher. These resemble scratches but are more wide and shallow. It was difficult to focus the photo on these markings.

These photographs show the grit edge of the grinding wheels used. All are metal bonded wheels made by Sintobrator in Japan. All have 1 mm wide grit faces, 3 mm thick bodies and ODs of 75 mm. All are at 500 X magnification.

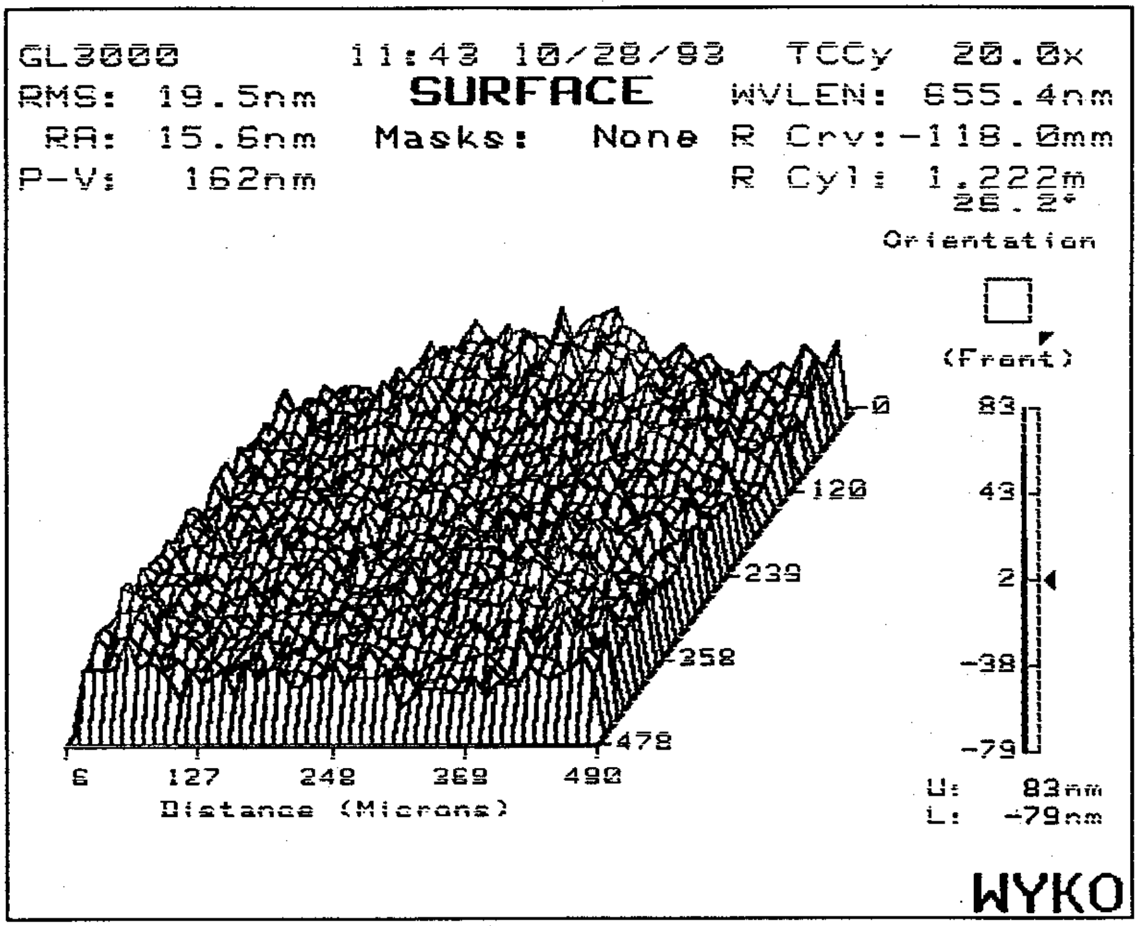
The top photograph shows the roughing wheel I used, a 400 mesh (37 micron) diamond wheel with a cast iron fiber reinforced bond. The diamonds are clearly shown and the bond matrix is also shown, with a somewhat pitted surface. There is no evidence of tool markings or grooves in the bond, and a noticeable clearance exists between the grit edges and the bond surface.



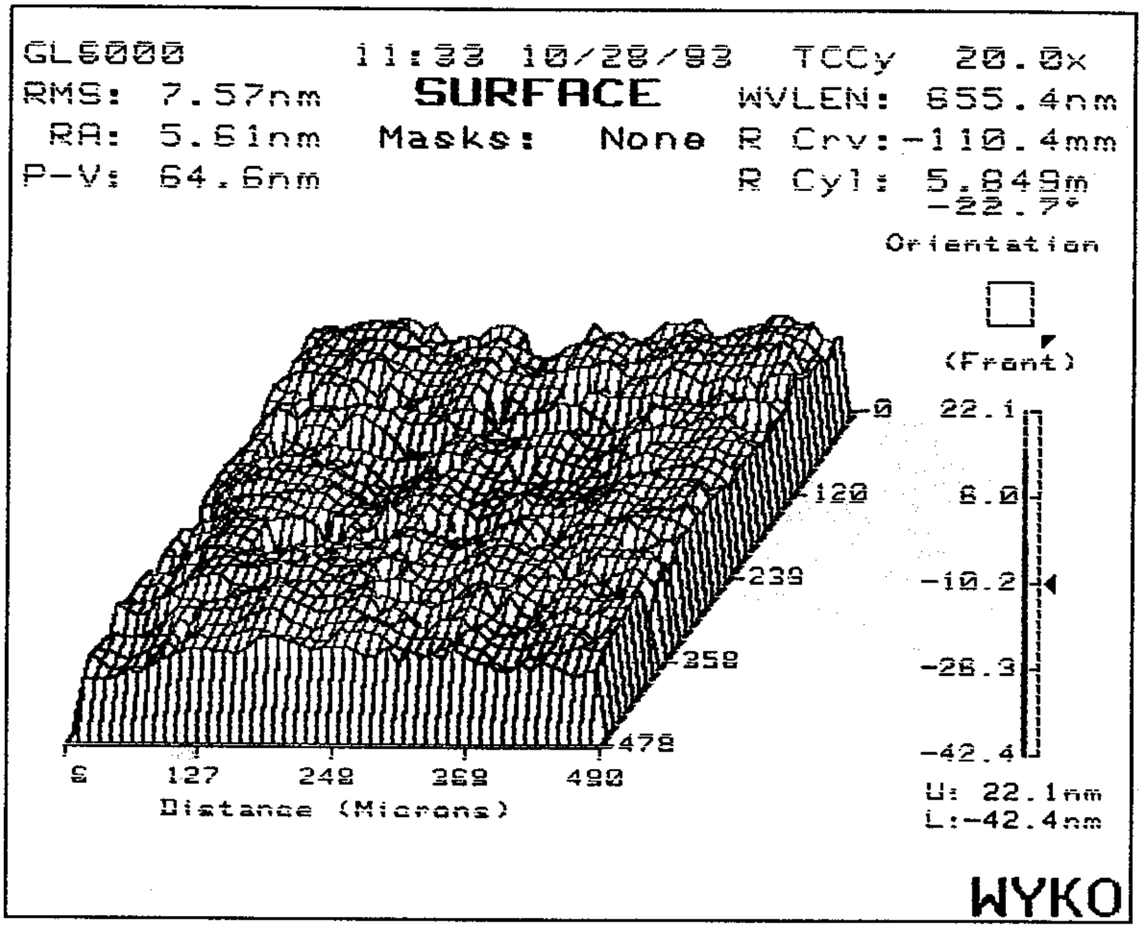
The middle photograph shows a 3000 mesh (4-8 micron) wheel with steel bond. This showed grooves in the bond material, indicating that there was insufficient ELID current.



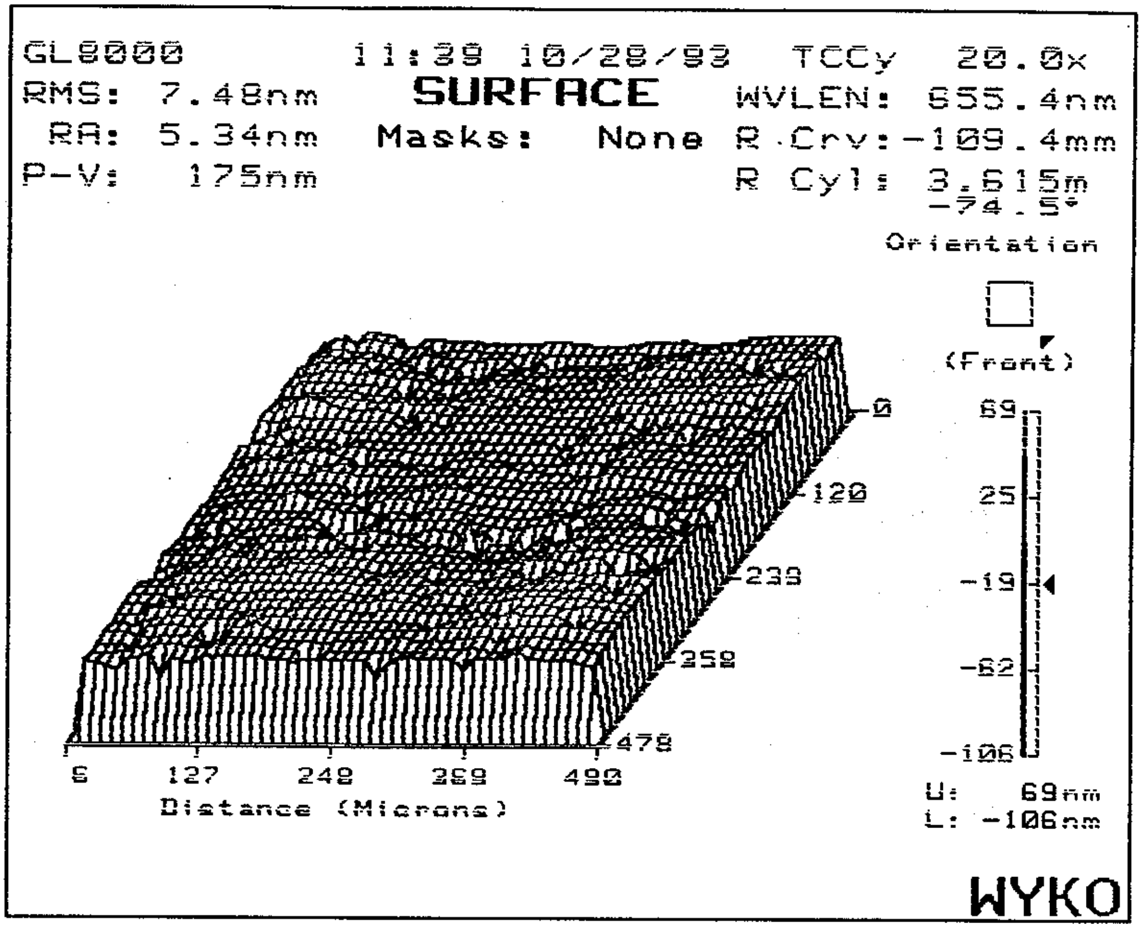
The bottom photograph is of a 6000 mesh (2-6 micron) wheel with steel bond. The diamond grains are much smaller but are readily visible.



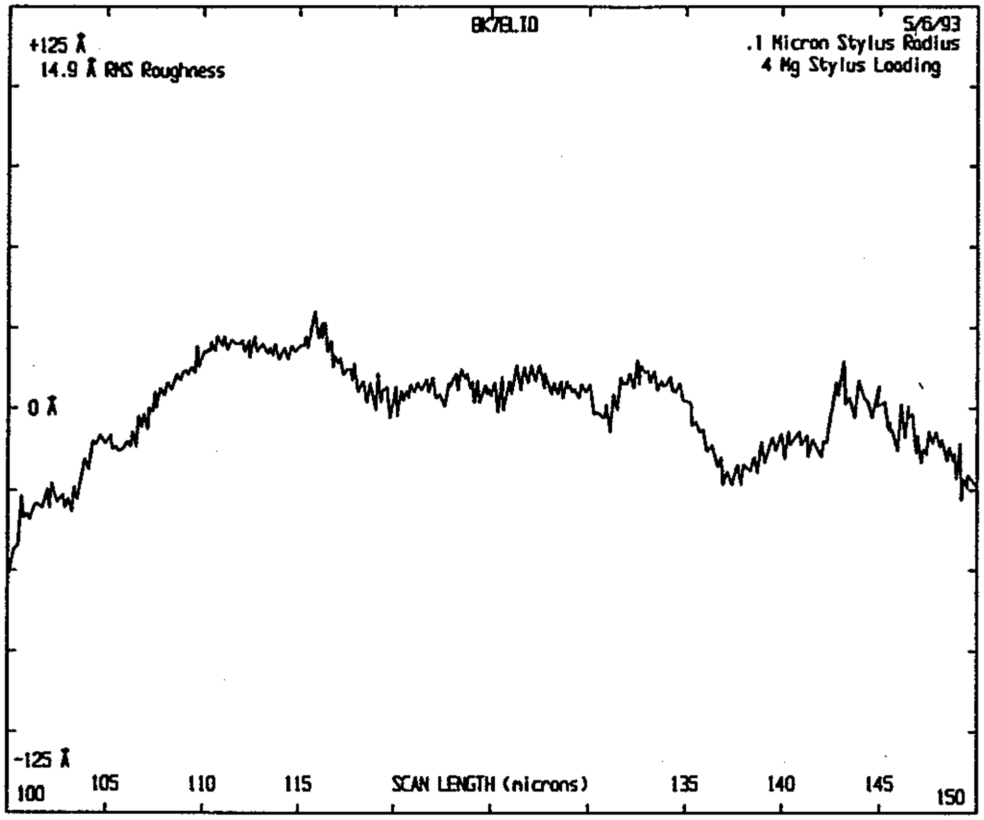
This figure shows surface roughness taken on a WYCO TOPO-3D instrument. The part was ground with a 3000 mesh (4-8 micron diamond) steel bond wheel made by the Sintobrator Company in Japan. The power supply was made by Easco-Sparcatron in Michigan, USA and set at 1 microsecond on time and 9 microseconds off time. Examination of the wheel after this cut revealed that the bond was scratched from hitting the work. This indicates that there was not enough ELID dressing current to keep the bond recessed from the grits. The ELID dressing current during the cut was 0.02 amps. The coolant was Sintobrator ELID No. 35 at 50:1 dilution with tap water.



This figure shows surface roughness taken on a WYCO TOPO-3D instrument. The part was ground with a 6000 mesh (2-6 micron diamond) steel bond wheel made by the Sintobrator Company in Japan. The power supply was made by Easco-Sparcatron in Michigan, USA and set at 2 microseconds on time and 8 microseconds off time. Examination of the wheel after this cut did not show the same scratched bond areas. This indicates that the ELID dressing current was sufficient to keep the bond recessed from the grits. The ELID dressing current during the cut was 0.10 amps.



This figure shows surface roughness taken on a WYCO TOPO-3D instrument. This part was ground with an 8000 mesh (1.8 micron diamond) wheel made by the Fuji Die Company. The power supply was a Sintobrator EDM unit modified to output 60 volts and set at 2 microseconds on time and 5 microseconds off time. The ELID dressing current was 0.2 amps. The coolant was Noritake AFG-M at 50:1 dilution with spring water.



This figure shows 14.9 Angstrom RMS surface roughness taken on a Rank Taylor Hobson Talystep instrument. This is the same part as shown in the previous figure using the 8000 mesh wheel.

I have shown the potential for directly grinding surfaces and obtaining optical quality finishes. This method of wheel dressing is still being developed and I am confident that further testing will show improved results from that shown here. I intend to perform further testing which will include grinding the hyperbolic face shown above and attempting to obtain 1/4 wave or better form accuracy in the parts and 20 angstroms or better surface finishes without post polishing.