DESIGN OF A NEW GENERATION CNC GRINDING MACHINE FOR THE DETERMINISTIC MICRO GRINDING OF GLASS OPTICAL LENSES

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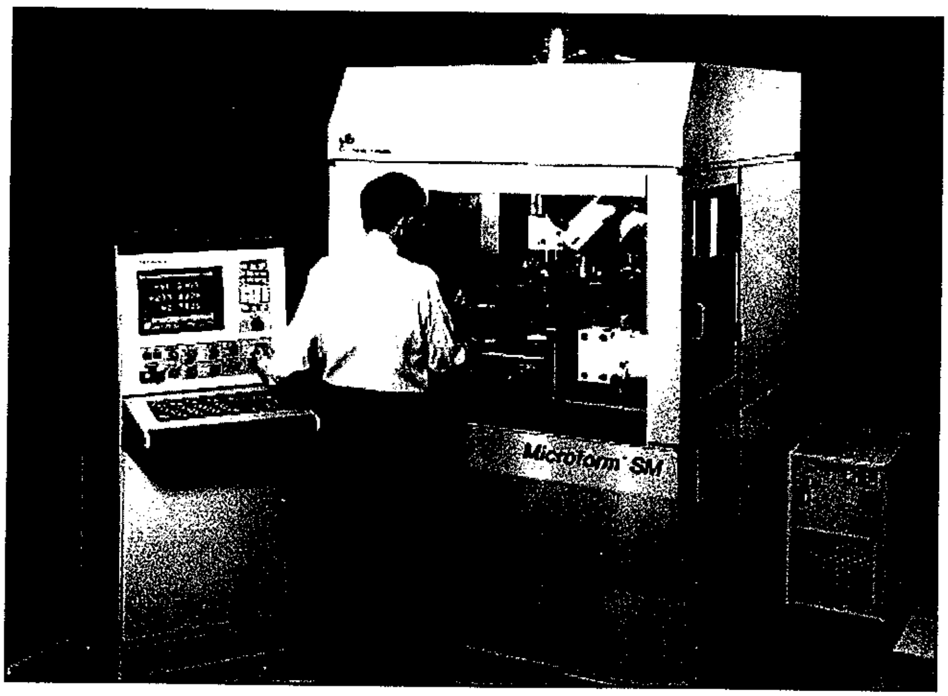
In the early 1990s, the Opticam SM lens grinding machine was designed and built by Rank Pneumo to specifications set forth by the Center for Optics Manufacturing (COM) in Rochester, NY. Rank Pneumo has since undertaken the design of a second generation, production oriented, lens grinding machine, the Microform® SM. This new machine is smaller and less expensive than the original, but grinds glass surfaces to the same specifications as the original machine.

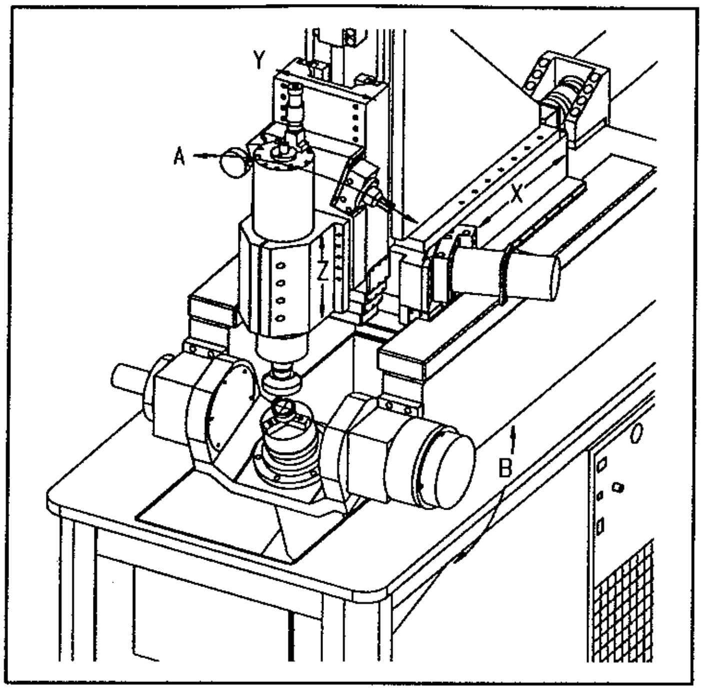


The Microform SM spherical/aspheric CNC deterministic micro grinding machine

The Microform SM machine was newly designed from the ground up and bears no resemblance to the earlier design Opticam SM machine. Its design incorporates constructive inputs from Opticam operators, customers, and technicians at the COM. The work spindle orientation was changed to be vertical, to permit easy access to view or inspect the part. The wheel spindle is then positioned above the work piece for grinding. Three CNC axes (X, Z, and B) are required to move the spindles into the correct orientation for grinding a sphere by chordal generation techniques.

Machine Configuration:

We initially looked at tilting the wheel spindle to make the machine 'look' similar to existing lens generators, and by doing so increase customer acceptance. However, this left the work spindle on the X and Z stacked axes, in a part of the machine heavily splashed by coolant. This was not an acceptable solution. To seal the CNC axes from coolant splash, we had a choice of designing all three axes in a stacked configuration, where the work spindle is mounted directly to the base, and the wheel spindle moves in X, Z, and B; or tilting the work spindle in B (which can be sealed using conventional rubber lip type seals) and stacking the wheel spindle on X and Z, outside the heavy splash zone. We chose the latter design, both for serviceability and to maximize the structural loop stiffness (from wheel to work) of the machine. This presents a different difficulty, that of feeding the wheel into the work. To feed in the direction of the depth of cut requires a coordinated motion of both X and Z along a virtual axis, that rotates with the B angle position.. This is provided by the controller and is invisible to the operator in normal usage of the machine.



Isometric view of the work area showing the X, Z, and B CNC axes, and the Y and A manual adjustment axes.

Reduced Size:

The Microform SM only requires one half of the floor space of an Opticam SM, while retaining the same maximum work piece capacity of 150 mm diameter. It was designed deliberately and intentionally to have a small machine 'footprint'. The base for the older Opticam SM machine weighs an estimated 5000 kg (11,000 lbs) and is supported on five air isolators. The Microform SM base weighs an estimated 645 kg (1420 lbs) and is supported on passive isolators on a steel frame to raise the working height to an appropriate level. It took a concerted effort, especially in the early days of the design, to keep the machine size minimized.

Machine Alignment:

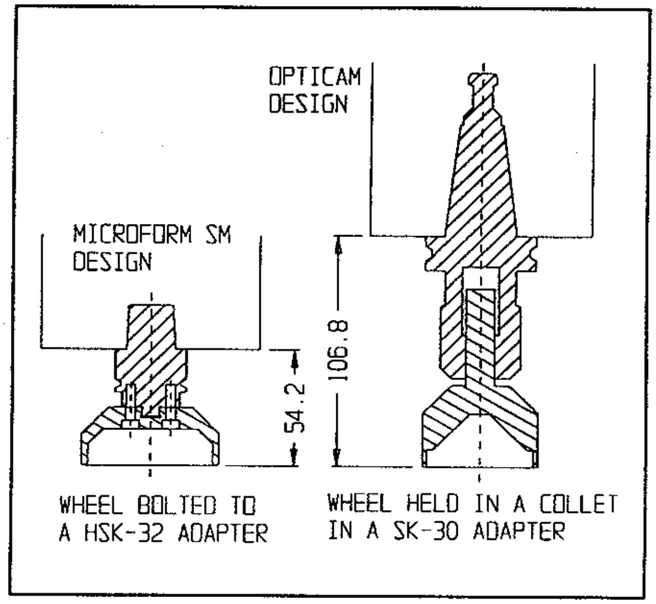
On the Opticam SM, it is difficult to align the two spindles to exactly intersect. This alignment is required to grind a true sphere. We added flexible elements to the new Microform SM machine, to allow the spindles to be moved into intersection without the added cost of a slide way. This motion is driven with a preloaded differential screw that moves the spindle .05 mm (0.002 inch) per revolution of the screw. The flexing elements were designed using Finite Element Analysis to ensure that the motion is provided without over stressing the flexures, while maintaining the desired vertical stiffness of 180 N/micron (1,000,000 lbs/inch).

The previous Opticam machine also suffered from thermal drifting problems during warm up and use. These errors were most detrimental when the drift moved the spindles out of intersecting alignment. The Microform SM has been designed with symmetry about this intersecting alignment plane to minimize the thermal drift in this direction. Temperature changes now expand or contract the machine to both the right and left. The grinding zone, which is in the middle, is left unchanged.

Another source of drift for the Opticam machine is the water cooled high speed wheel spindle. When it is turned off, the spindle chiller still operates, cooling the spindle (which it is supposed to do) but causing the wheel position to drift. However, on the Microform SM we added a coolant bypass valve to reduce the cooling rate, and drift, when the spindle is off.

Work piece and Wheel Fixturing:

The grinding wheels on the Opticam SM are mounted in a collet integral with an SK-30 taper spindle adapter. We changed the design to bolt the wheels directly to a HSK-32 taper spindle adapter. This significantly improved balance quality and increased stiffness, by having fewer joints, and avoiding the neck down to the collet holding diameter in the previous holders.



We also changed the work piece clamping mechanism to a three jaw chuck. This allows part fixtures to be easily made on a lathe. The chuck has a clamping repeatability of 0.0001 inch, to ensure surface alignment accuracy (minimum wedge) in the ground part.

Coolant:

The Opticam SM, due to clearance with the tool changer, requires the coolant nozzles to be positioned about a foot away from the work and wheel. This also requires a large box around the grinding zone to contain the coolant splash. On the Microform SM, the wheel spindle is backed away from the coolant box for tool changing. As a result, the coolant splash box is much smaller and nozzles can be placed without these restrictions. The box is made of stainless steel for corrosion protection. Easy access is provided to the part by sliding back two covers.

A dual canister filter system allows the operator to easily change whichever filter is in use by operating a manual valve. While one filter is being used, the other is closed from the circuit, allowing a contaminated filter element to be changed while the machine is using the other filter.

Controller:

• Grinding programs (software) have been a limitation on previous machinery, forcing the grinding cycle to have one rough, one medium, and one finish pass, for example. Now grinding sequences can easily be rearranged or added as required. Part programs can now accommodate virtually any number of edging, beveling, sagging, concave, and convex surface grinds in one mounting of the lens.

• Coordination of rough, medium, and fine stock removal are simplified. The operator can request the medium grind to start where the roughing grind ended, or to end the medium grind where the fine grind is to start, etc.

• The spherical radius is also adjusted for each grind so an equal depth of cut is taken from the entire surface with each wheel.

• Obviously, grinding wheels wear away during use. Another limiting factor in existing equipment is that stored wheel data consists of a single length and diameter. This requires the wheel to have a sharp cutting edge, so that the wheel grit zone is in the same position for any head angle. Our new Nanopath® CNC Control software keeps track of the wheel wear in a map of the wheel grit area for each wheel. This eliminates wheel dressing to restore a sharp edge. The control software also corrects for any workpiece error resulting from wheel wear. The operator enters the data for a surface ground incorrectly. The controller then updates the wheel grit map to compensate for the error. In this manner, the next part to be ground is correctly surfaced and the wheel grit area map is kept up to date.

Aspherics:
Aspheres are much more difficult to generate and polish than spherical optics. However, the CNC controlled axes on the Microform SM machine also allow an aspheric surface to be ground using a peripheral style grinding wheel with continuous path contouring of the X, Z, and B axes simultaneously. This provides an aspheric surface much closer to the final form than found using the best fit sphere.

A work piece can initially be rapidly rough ground to a best fit sphere by conventional chordal generation techniques, then a peripheral style grinding wheel can be selected by the automatic wheel changer and used for the continuous path contour grinding of the aspheric surface. Additional operations such as edging, beveling, and sagging can still be incorporated on aspheric lenses, which will drastically simplify the alignment of the optical axis during the final assembly of the lens into the system.

Process:
Traditionally, lenses are blocked to fixturing using pitch or wax. These compounds are ideal for conforming to and adhering to the lens surface while remaining flexible, to prevent distortion of the lens. They also require solvents for cleaning. Both the pitch and solvents are coming under increasing scrutiny with regard to workplace health and safety, and could be banned from use in the future due to the hazards involved. Lenses to be ground on the Microform SM can be blocked using a UV curing compound that is easily removed with water. This is environmentally cleaner than bonding with pitch or wax, and cleaning afterward with solvents. Any glass types that can not be exposed to water, or are stained by the UV compound, can be blocked by conventional methods.

Since lenses can be produced in a "semi-polished" state, the loose abrasive lapping or grinding process that traditionally follows the spherical generation is eliminated. This also eliminates the expense associated with the manufacture of cast iron tools that were required for each different radius processed by this interim lapping procedure.

Optional features of the machine:

- An optional coolant system is supplied with a centrifuge for swarf removal from the waste coolant stream. The Opticam SM machine had coolant pump seal failures that we feel were due to the residual levels of contaminants after the coolant had been cleaned using vortex type cyclonic filters. The cyclonic filters only work well down to particle sizes of 10 microns diameter or below. The centrifuge used on the Microform SM continually cleans the coolant each time the coolant passes through it, and a wash nozzle in the machine keeps coolant flowing through the centrifuge at all times.

- A toolchanger is available for the automatic exchange of grinding wheels with an eight station magazine. This allows production parts to be produced with a minimum of operator involvement.

- A mist extractor is used for the removal of grinding coolant mist. Use of the mist extractor extends the life of the machine, as mist is purged before it can condense on surfaces and cause corrosion of components otherwise not exposed to coolant. Mist removal also improves the health and safety conditions in the operator's working environment.

Spherical Grinding Results:

Typical finish ground surfaces are smooth enough to be inspected directly on an interferometer for surface form errors. Rank Pneumo installed the first Microform SM at a customer's facility in March, 1996. In proving the machine capability, a test part lens of BK-7 was ground on all sides. The lens has a 48 mm OD, 100 mm convex and 28 mm concave sides. The part was edged, sagged, and beveled on the SM.

The following accuracies were achieved (after delivery of the machine):

- Surface roughness of 120 Angstroms Rq (RTH Talysurf) and 75 Angstroms Ra (Wyco),
- P-V form error (irregularity) of 0.14 microns (0.5 fringe) (Zygo),
- Radius size error of .003 mm (Electronic spherometer),
- Surface wedge after grinding was measured to be 0.004 mm +/- .001 mm.