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Machine accuracy and dynamics as related to low damage grinding, by Dr. Jeff Roblee

Grinding glassy materials removes stock through the interaction of individual grit particles with the material of the work piece. The interaction can be classified as brittle fracture or ductile regime cutting or a mix of the two. Brittle fracture creates substantial subsurface damage. Ductile regime, or nearly ductile regime, cutting, AKA "low damage grinding", creates little subsurface damage. Rough grinding uses large grit particles and removes material predominately through brittle fracture. As one progresses to smaller grit sizes and reduces the depth of cut per grit, the cutting mechanics generally becomes more ductile and the surface is left with minimal or no subsurface damage. Critical to low damage grinding is having extremely good control of the depth of cut made by individual grit particles.

"Depth of cut" for this discussion is not the macro change in part size per grinding pass due to the in-feed of the wheel into the surface. Depth of cut refers to the instantaneous cross sectional thickness of the material removed as each individual grit particle sweeps through the material. As such, depth of cut is related to not only to the depth of the wheel engagement into the surface but also the feed rate of the wheel along the surface and the RPM of the wheel. An illustration of this meaning of depth of cut is found in creep feed grinding. During creep feed grinding one can take a very deep cut into a surface in a single pass and end up with little residual damage as long as the feed rate along the surface is very slow. With a very slow feed rate the cross sectional thickness of the material removed by each grit particle is kept low and the cutting mechanics approach the ductile regime.

As the feed rate along the surface increases, controlling constancy of the depth of cut and feed rate become even more critical. At higher feed rates, the amount of material removed per revolution of the wheel increases. Low damage grinding with high feed rates depends on the cutting mechanics shifting from brittle fracture as the grit enters the material to near ductile regime cutting as the path of the grit approaches the tangent point. This is only possible if the error motions, deflections and velocity nonuniformities of the grinding platform are kept as low as possible.

Vibration levels and non-repeatable error motions of the machine platform greatly affect the ability to control of the depth of cut per grit during grinding. These error motions increase the lower limit of sub-surface damage that can be produced by grinding on a given platform. Sources of vibration modes and error motion include:

- Static and dynamic compliance and asynchronous error motion of the grinding spindle.
- Cyclical errors associated with ball or roller bearings and lead screws (e.g. sources of non-repeatable motion from one pass to the next and non-uniform slide velocities).
- Reversal errors in slide motion.
- Static and dynamic compliance of any mechanical component that is part of the mechanical loop connecting the work piece to the grinding wheel. -- Static compliance is an important topic because grinding creates widely varying forces occurring over a wide frequency band. These forces acting on compliant components create variations in the instantaneous depth of cut and limit the quality of the surface that can be produced.
- Poor servo system response creates transient motion errors when rapidly following a complex tool path.

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