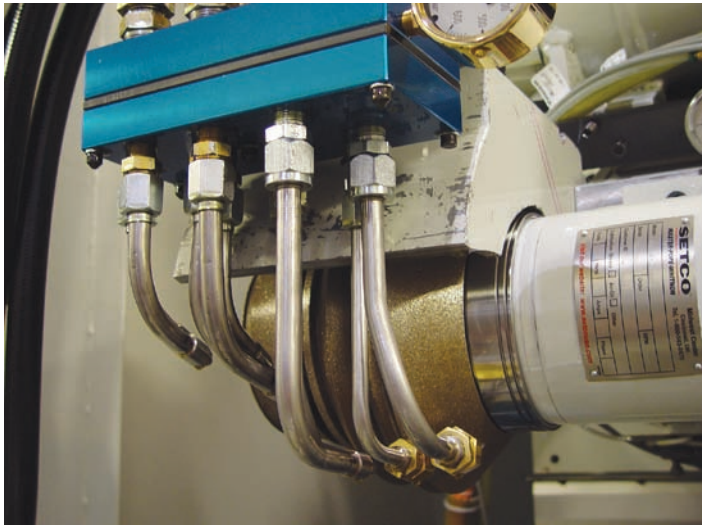


# Compelling Grinding Productivity



KeenFlo coolant nozzles.

There are six areas of grinding process and apparatus that through new technology or practice now are delivering double digit productivity gains. Often, when used in combination, they are delivering multiple productivity gains. In today's global economy, with cheap labor at great distances but complicated by cultural barriers, time zones and long supply lines (high FG inventory) by use of these improvements local manufacturers can either level the cheap labor advantage or beat it.

First, there are computerized advances to process planning to allow for multi-tasking in grinding. Second, there are advances to grinding wheels themselves, from smaller sizes capable of higher speeds, to better material removal rates (MMR) and longer life. Third, there are improvements to fixturing schemes. Fourth, there are advances to coolant application to better transfer heat off the work piece to increase material removal rates and avoid thermal damage to the workpiece material. Fifth, there are advances to application software to deal with normal processing and to assist use of available labor. And lastly, thru long-term use of ISO-9000 principles, machines are becoming exceptionally reliable.

## Multi-Tasking

Using five axis machines, it is now possible to consolidate what previously were several setups in several stand-alone machines into one setup in a single multi-tasking machine. So, instead of several set-ups and machines, one machine can do all the operations to complete a part in one set-up.

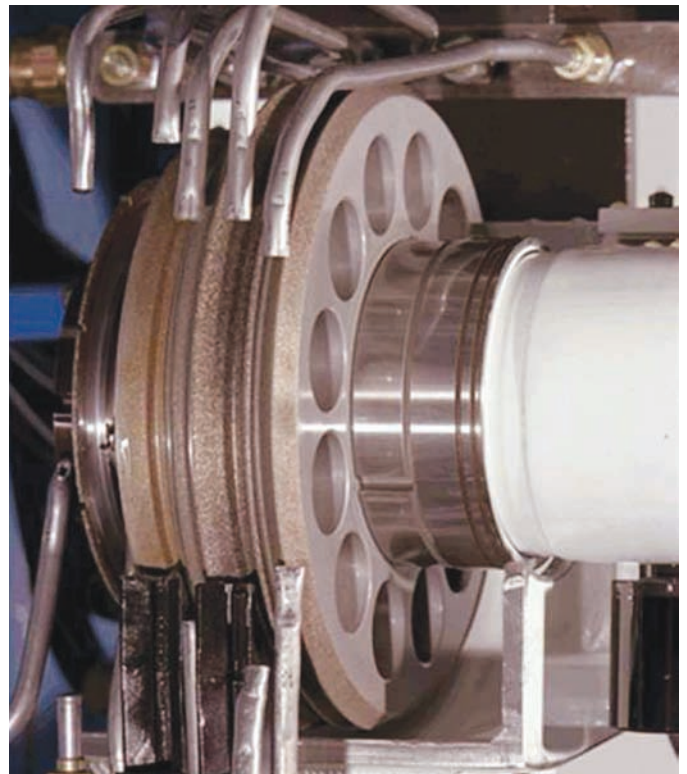
Designing this capability employs CAD/CAM and a virtual process using modeling software like Vericut. First, each part feature to be machined is analyzed. Then the wheel forms required to create them. A sequence of operations is prioritized. Then fixtures are designed and sequenced. Sev-

eral individual part feature wheel forms can be consolidated into fewer wheels and used in wheel packs. This capability requires specially designed fixtures that can withstand side loads, discussed later. The final benefit is a single datum for all features, which makes it easier to produce the interrelated features to tolerances so difficult when using sequential machines due to tolerance stack up issues.

This approach adds up to a truly "0" scrap process, an important goal for quality. By substituting a single part flow process, this method avoids the batch lots required for sequential machine processes that can result in high scrap. Another major benefit is reduced throughput time of the entire production cycle. Instead of days or weeks to sequence batches through multiple machines and multiple setups, the parts are complete as they exit the machine, dramatically lowering in process inventory.

## Wheels

The basic grinding wheel choice is Conventional Abrasive (CA) wheels (in either continuous dress or intermittent dress), or Superabrasive (SA) (in Electroplated CBN (EPCBN) or Vitrified Bond CBN) wheels. EPCBN does not require dressing, and Vitrified CBN requires only infrequent dressing. In the past, the choice was CA wheels that wear out rapidly. Therefore, for utility, CA wheels are large in size that limits the number of features which can be accessed at a time



EPCBN Wheel Pack.

As Seen In



# MANUFACTURING NEWS

and outsizes the machine design driving up machine cost and floor space requirements. The CA wheels wear with each turn, requiring compensation, which is a source of variation and requires a skilled operator.

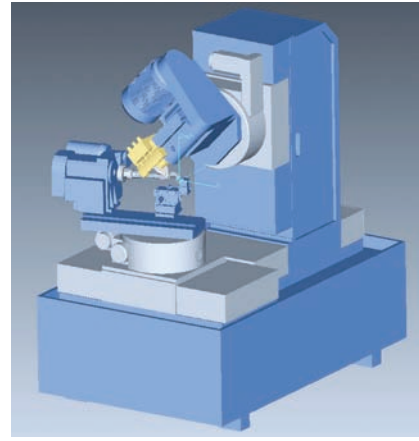
CA wheels require frequent change because of loss of diameter and non-productive time is the result. Also, the CA wheel requires either intermittent or periodic dress to hold form, more nonproductive time. They produce a lot of waste swarth. They take up a lot of floor space.

Product changeovers for CA production lines are measured in hours or more usually in shifts, that is more non-value adding time. CA wheels are normally only partially used before disposal, especially when a small and a large wheel are used at the same time, which drives up abrasive cost. The amount of CA wheel consumed as a percent of the material removed ("G" ratio) is relatively low. Because the CA wheels are glued together materials, they have a speed limit before they explode, that governs speed for material removal. So bigger is better for CA wheel surface speeds, but makes for larger machines, longer changeover times and more difficult handling. Less swarth is created using SA wheels and they require less storage space. Actual SA per part abrasive costs are less than CA.

SA wheels are metal core wheels with a layer of abrasive applied to the Outside Diameter (OD), in either plated, not requiring dressing, or vitrified bonded with infrequent dressing. SA wheels have dramatically higher "G" ratios compared to CA wheels giving them some highly beneficial characteristics.

Because the SA wheels do not appreciably wear part to part, the wheels can be smaller than CA, run at much higher surface speeds and last longer before change out. Because they are smaller, more wheels can be mounted side by side in a wheel pack. SA wheels can run hundreds or thousands of parts before being re-plated (reused). The need for wheel dressing (and a skilled operator) is eliminated. And instead of many machines in sequence, one machine and wheel pack can do the complete part in a "bumble bee on a flower" like action to address all the features to be ground in a single part per cycle.

While the actual MMR rates of SA wheels may be similar to CA, major economic advantages come from the single datum (reduces scrap and throughput time) and faster surface speeds of SA compared to CA wheels, use of more tan-



**Virtual Design.**

gential force, than normal force, applied to the workpiece lowers risk of thermal damage. A SA wheel takes a chip removing heat from surfaces, rather than force heat into the part like a CA wheel.

Unlike CA wheels, Electroplated SA wheels can grind in grooves, CA wheels cannot grind effectively into grooves because of wheel wear, so a milling operation is required instead. So, using SA wheels, a separate operation can be eliminated, i.e. consolidated into the grind process, thereby streamlining the overall process.

Still, today there are many new technology "hybrid" wheels available. New technology CA wheels have higher "G" ratios, in between traditional CA and SA. Often they use ceramic bonding agents. Most importantly, because of the lower wear rates, these wheels can be made smaller than CA wheels and can be intermittently instead of continuously dressed. That means they can be either used in wheel packs, or can be changed in a few minutes, or used with an automatic tool changer (ATC).

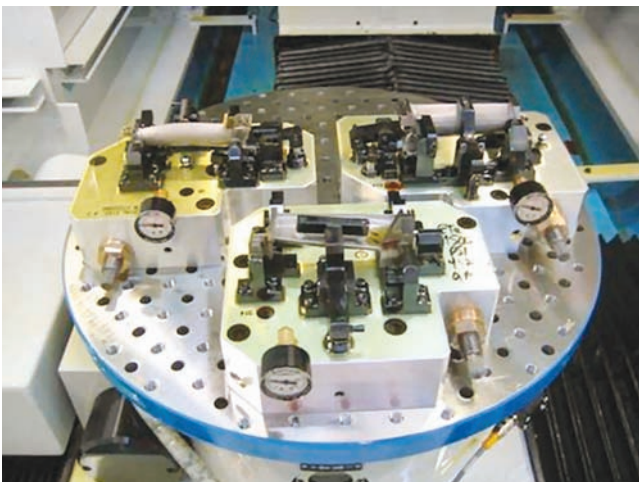
Smaller hybrid wheels allow an ATC to avoid down time to change over of large diameter CA wheels by hand. Instead of a massive continuous dresser, these Hybrid wheels can use a "static" dresser, smaller and less expensive than a roll dresser. The longer grain in the new hybrid CA wheels allows for better coolant effect and higher Materials Removal Rates (MMRs).

### **Fixturing Sequencing and Construction**

The CAD/CAM and virtual design ability mentioned above allows for better fixture utilization, especially using multiple progressive fixtures within a machine. Still, sometimes a part can be chucked once and then finished completely.

Compared to multiple sequential batch processing for parts, this is an advantage for quality and throughput time. Sometimes more complex prismatic parts can be accommodated by multiple fixtures on a table in one machine and then progressively moved through a series of grinding operations on fixtures to complete all features of one part to the same datum. One part per cycle. Often weeks or days of part processing can be reduced to minutes.

Using multiple wheels and multiple surfaces on a wheel in a pack of wheels as mentioned above allows that "bumble bee on a flower" process completing all features in a single chucking, eliminating changing wheels, or changing machines.



**Progressive fixtures.**

## Coolant and Application

For example, complete shrouds can be done one part per cycle, leading edge, trailing edge and slash faces. Fixtures are designed for side wheel loads and taking the force of the heavier material removal rates.

For CA grinding, the conventional wisdom has been much more toward the volume of flood coolant per HP used, than specific direction of the coolant into the grind area, or attention toward the actual heat transfer capability of the coolant. For SA grinding, attention has been more on velocity matching of coolant speed to wheel speed and on controlling the application of the coolant stream to the grind zone. Much work has been done along these lines to specifically design coolant nozzles for better laminar flow and pointing improvements. The result is a coherent stream.

Still, coolants contain a lot of entrapped air, functioning like Swiss cheese between the wheel and work. Now, there is more attention on eliminating aeration from the coolant systems by better plumbing, use of line conditioners, new coolant nozzle designs and better filtration system settling. These work to eliminate the entrapped air that undermines the heat transfer capability of the coolant. Dramatic improvements to MMR are being achieved without thermal damage to the material.

## Application Software

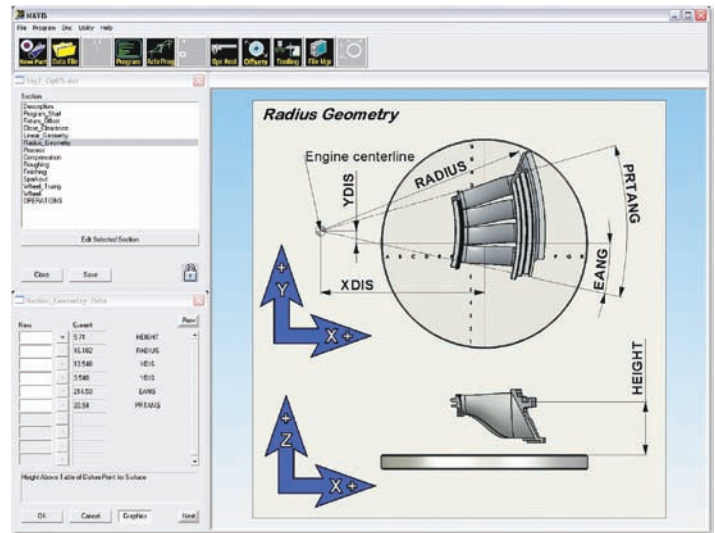
One of the biggest economic benefits has been the evolution of application software to assist the operator to make good parts and reduce down time waiting for highly skilled programmers to make simple process changes to deal with reoccurring process anomalies. Also, with the complexity of many processes, more user-friendly interfaces have been devised to allow use of "available labor" personnel through computer prompting to follow defined procedures. Lastly, manufacturing plans can be stored and updated on the machine for quality control purposes.

The trend is away from hogging parts from solids to use of investment cast or forged raw materials. Investment castings are sort of like exoskeletons with a hard shell or casing left on the metal. When these parts are first machined, internal stresses can be released that cause the parts to "pretzel" in shape. For example, for shrouds with radial grooves or vanes, a rough pass can relieve stress and cause the part to spring out of shape with too deep or shallow a radius, or an incline or decline. CAM programs fail to allow for operator compensation. New software allows operators to compensate for part distortion and the daily reality of residual stress release.

Further, some CA grinding machines use compound tables that require all five axis of motion for each feature. When a part springs out of shape, then it is nearly impossible to accurately use compensating offsets. A better method is to use a "B" and a "C" axis and then position to grind in just 2-3 axis allowing for simplified offsets. With the latter axis configuration, then Machine Application Visual Interface Software (MAVIS) can be used to input offsets to compensate for spring detected by the CMM without stopping production to wait for a programmer.

## Reliability

Lastly, all this technology is for naught, if the machine is



not dependable. When it is down for service, it is not producing. But, long term application of ISO 9000-2000(2008) standards in manufacture, and modular machine designs, are now yielding warranty claims in the .1's of percentages and true machine uptimes of 99+%.

ISO standards require more in depth pre-order customer collaboration to address actual end product and process requirements that can be designed into the machine tool. Base designs can minimize thermal distortions, and chillers maintain grinding thermal excursions to 1 degree. Rotary axis can be designed for zero backlash. Linear axis mapped for accuracy.

Modular machine designs allow customized envelop configurations from standardized components reducing cost, increasing flexibility and lowering downtime. Machine causes for down time can be virtually eliminated.

This confluence of these factors has resulted in significant individual part processing improvements to quality, productivity (faster delivery), lower cost and lower asset utilization that cumulatively create outstanding economic results. For one recent conversion of an aerospace component from a conventional grinding process to a 5-axis, CBN process, a five times productivity was achieved. That amounts to an 80% reduction to cost, prior to the asset reduction to inventory and reduction of floor space and capital required, that also leverage return on investment.

These factors are ushering in extraordinary levels of competitive advantage favorably altering the economics of the entire industry. Individually and collectively they create technical equalizers to offset the cheap labor, long supply lines (inventory), poor response and confusing communications from distant manufacturing locations. These factors together provide compelling economic reason to invest in a down market, to lower cost in the short term and to position for economic dominance in the upturn.

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