A 24-hp Blohm Planomat CF grinder with a 16"×48" work envelope uses a form wheel to go from near-net forging to finished part in minutes, improving precision while maintaining production rates.

JUNE 2007 / VOLUME 59 / NUMBER 6

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Creeping Ahead

Why more shops have replaced milling and broaching with creep-feed grinding.

Creep-feed (CF) grinding has emerged as the primary choice for several grinding applications and is also an effective alternative to milling, based on part quality and consistency and cost per cut.

Traditional surface and profile grinding processes take shallow cuts using rapid traverse speeds. At the end of each pass in these processes, the grinding machine infeeds the part about 0.0003" and repeats the next traverse, so the wheel is constantly exiting and entering the workpiece. Each entry is a small collision, degrading wheel sharpness and form. Also, the wheel is frequently cutting air in reversal mode. Depending on part length, this nonproductive time can equal the time the wheel is in contact with the part.

In contrast, CF grinding takes a relatively deep cut at a slow feed rate, like a bulldozer. The feed ranges from 1 to 60 ipm, depending on the application. CF grinding can be thought of as "micromilling," with the grinding wheel acting as a milling cutter. The wheel removes a large amount of stock even though it is moving slowly across the part. For example, in one CF grinding

CF grinding cuts these serrations on four piston rack nuts simultaneously, removing 60 lbs./hr. of material while achieving tight tolerances.

application, the serrations in a piston rack nut were approximately ½" deep × ⅜" wide (see photo above). Each nut had three teeth. In a high production setup, CF grinding cut the serrations on four nuts simultaneously, removing 60 lbs./hr. of material.

Long Arc of Cut

CF grinding depends on a long arc of cut (a large contact area between wheel and workpiece), so CF wheels typically have an "open" bond to maximize chip clearance and coolant delivery (Figure 1). However, there are many variables when choosing a wheel for CF grinding, and the abrasive itself is a major consideration.

The abrasives for CF wheels range from conventional, such as aluminum oxide, to ceramic grains developed specifically for the process. These ceramic wheels microfracture to expose fresh, sharp edges to the cutting zone. Another alternative is CBN, an extremely hard grain that can maintain its sharp cutting edges for long periods. Therefore, CBN can grind particularly hard materials that other types of abrasives cannot.

Bond selection depends on the workpiece material to be ground and the form to be maintained. The bond must be strong enough to hold the grains so they cut effectively, yet weak enough that dull grains break out to expose a new cutting surface. This critical balance controls part quality and productivity.

A major distinction between CF grinding and other machining operations is the ability to quickly resharpen the cutting tool (wheel) by dressing it to maintain maximum cutting performance, part quality and output. The most common approach to dressing uses a full-form diamond roll with the inverse form of the desired part shape.

An alternative is to apply a standard-form diamond disc, also rotating, to contour a specific shape. This allows operators to dress any form with a standard disc and have the ability to fine-tune a shape. The downside is it takes longer. In both approaches, variables controlling when, how much and at what speed dressing occurs are monitored and controlled.

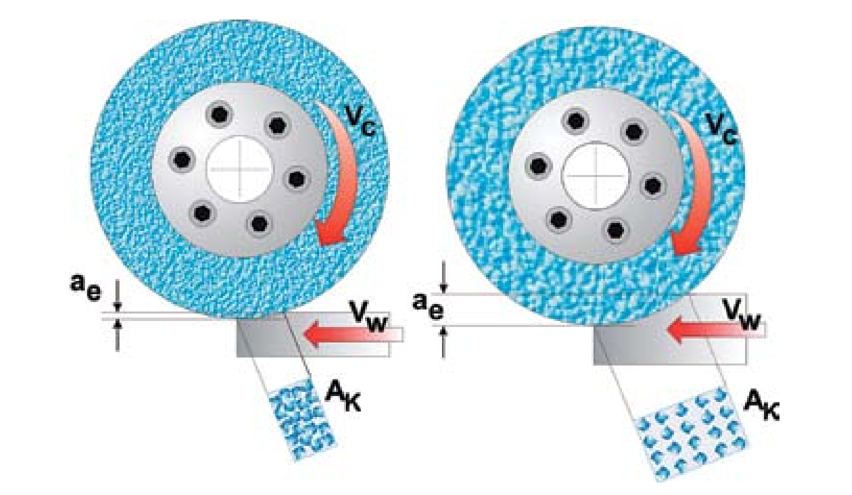


Figure 1: As shown on the right, CF grinding has a long arc of cut and uses an open-bond wheel, while traditional grinding (left) takes a shallow cut and uses a closed wheel.

Coolant is Critical

CF grinding takes a deep cut having a long arc of cut, so heat control is challenging. The process typically relies on large volumes of high-pressure coolant to cool and lubricate the wheel/workpiece interface. Engineered nozzles direct coolant into the cut zone. In a typical example using a 6"-wide conventional abrasive, grinding a 0.300"-deep profile requires approximately 120 gpm at 150 psi. The choice of coolant varies depending on the project, but synthetic coolants are the most common.

Filtration is key when applying a high coolant volume. The filtration choice depends on the workpiece material, coolant type and volume, and swarf type and volume. Coolant must be accurately delivered to the grinding zone, maintained in position and monitored.

Rigid Machine Needed

The CF process relies on a stiff grinding machine to maintain wheel sharpness. Stiffness is also needed to achieve acceptable part quality. Many elements influence machine performance, but guideways are one of the most critical. Guideways are typically "loaded" systems using either linear bearing or hydrostatic designs. The grinding machine base is also important, and castings and composites have been used successfully in base design.

This magnified image of the swarf produced by CF grinding reinforces the concept of micromilling. Note how the individual particles interlock like steel wool, the result of creating long, stringy chips.

The grinding spindle typically has a major influence on overall rigidity. Successful grinding depends on achieving the right balance between performance needs, such as rpm, and overall bearing design.

Coupling a high-performance cutting method with a stiff machine normally produces some resonance—an enemy of the grinding process—so damping mechanisms are critical in CF grinding. To dissipate resonance, system designers typically include hydrostatic guideways, which provide better load distribution via infinite contact points created by the molecules of a thin film of oil.

The CF process requires various system controls beyond the axis motion, positioning feedback and tool management strategies common to CNC grinders. In addition to managing coolant, operators should monitor the main spindle load and use this information for adaptive control of the grinding process. Adaptive control applies the maximum possible torque automatically without damaging the machine or the workpiece. Subsystems, such as workholding, should also be controlled and monitored.

Versatile Process

CF grinding has proven itself in the production of many different parts, from tiny thread rolling dies to precise mold components and corrugating rolls over 10' long and weighing thousands of pounds. A traditional application has been turbine components because the nickel-based Inconel used in the "hot section" of turbines can be ground more efficiently than it can be milled or broached. But there are other materials and part features that also lend themselves to CF grinding.

For example, milling is viewed as an acceptable cutting process for materials with a hardness from 30 to 36 HRC. But while recent developments have allowed more hard milling, the process still has performance and cost limitations, depending on part configuration. These include costly cutters that often experience short tool life and tolerance and surface finish limitations.

Grinding is unusual in that harder materials are often easier to machine than softer ones. Traditional machining operates with much higher forces than grinding, which follows the micromilling principle by minimizing forces. Grinding also has the benefit of applying consistent force. This minimizes problems such as chipping parts when grinding brittle materials.

CF grinding can also eliminate multiple processes. A typical manufacturing operation might call for milling or broaching a part in a soft state, then routing the part through required heat-treat hardening processes. Following heat treatment, a finish grinding process is often required. There are, admittedly, situations in which case hardness or other design requirements dictate this multistep process. But in many other situations, these multiple machining steps can be integrated into a single CF grinding operation. When that's the case, CF grinding saves money by reducing:

- number of operations,
- work in process,
- scrap rates due to tolerance buildup, and
- overall perishable tooling costs.

CF grinding often provides the advantage of being able to start with a through-hardened material and manufacture directly to finished size. A growing trend for higher volume parts is the use of near-net forgings, which fit well into a "creep feed to size" processing plan. Creep feed is also appropriate for grinding P/M components, which need to be more accurate than what current component pressing technology can provide.

High-Volume Output?

Grinding is not typically associated with high-volume production. But with its high metal-removal rate and efficient material handling, CF grinding can be a high-output system. The part shown above is a good example. Note that the part has a slightly curved, or radial, path. This is generated by a combination of wheel profile and multiaxis machine motion. In this case, a CF system delivered a part every 6 seconds while achieving micron-level accuracy at CPK statistical consistency.

Creep-feed grinding can produce the lowest cost per part in many applications, beating broaching by 4:1 in some cases. Still, evaluating the complete costs of any manufacturing process is complex because many elements affect the outcome. Some are obvious, such as tooling costs, labor and productivity. Some are hidden, such as the costs for in-house tool resharpening and tooling inventory.

Automotive rack and pinion steering racks offer a good example. These parts are normally produced in high volumes, often by broaching the tooth form. A steering rack is normally produced from bar stock and roughed on a turning machine.

Depending on the design, there may be a few other operations, such as gundrilling or threading internal holes. After this, centerless grinding finishes the overall diameter. At this point, the teeth are produced—commonly by broaching. After the teeth are cut, some induction hardening, straightening and polishing may be performed.

It's impossible for CF grinding to compete with broaching on individual part cycle time, which would be about 30 seconds floor to floor. However, complete manufacturing cost offers a better comparison.

Depending on teeth size, broaching requires a large machine with a large footprint, and broaches are massive tools that require heavy fixtures. In addition, quality control is a challenge. When an operator installs a new broach in the machine, he must make a number of manual adjustments through shimming or complex hands-on involvement.

Once aligned and in use, the broaching tool is perfect only once because form and sharpness begin to degrade at the first use. As the broach wears, cutting conditions change, affecting quality—and the quality of a steering rack's pitch tolerance and surface finish can suffer.

In CF grinding, operators maintain the wheel form so it cuts the proper form, offering a more consistent process. While the broach can be sharpened after use, this requires labor, equipment and floor space. If sharpening is done externally, logistics, planning, inventory and storage costs for

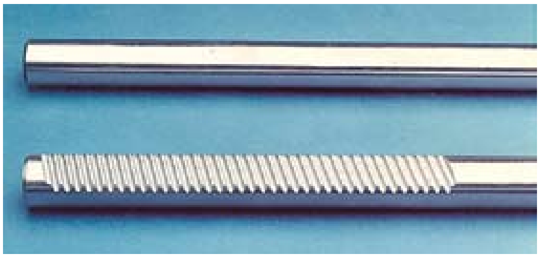
CF grinding produced this part every 6 seconds, with micron-level accuracy at CPK statistical consistency.

multiple tool sets must be considered.

Cost and Quality

A recent example for this application measured the total costs of a broaching system and calculated a cost of 31 cents per steering rack. The same steering rack produced using CF grinding cost less than 8 cents per part.

Even in cases where CF grinding proves to have a cost advantage, superior part quality is often a more important factor. Besides a cost advantage, grinding the previously mentioned steering rack significantly improved overall part quality, both in form tolerance and surface finish. The challenge was to improve pitch spacing between each tooth and, in turn, the cumulative spacing of all teeth. Broaching produced acceptable results in the past, but as steering performance demands increased, so did the requirements for accurate spacing. CF grinding achieved cumulative spacing error of less than 50 microns for all 20 to 30 teeth, which have a 5mm to 7mm pitch. That spacing error was a 100 percent improvement over the previous broaching system. The finer surface finish, measured with a profilometer, also improved part performance.



A 28mm-dia. steering rack before and after creep-feed grinding, which cut the teeth at 25 percent of the total cost of broaching while doubling part accuracy.

Another application of CF grinding involved an aerospace part. The part had to be burr free, making CF grinding a natural choice because it usually doesn't produce burrs. One challenge in producing this part was deciding when to conduct threading. If traditional turning and milling were used, the slots already in the part would be difficult to thread. If the slots were milled after threading, heavy burrs would be placed in the threads, requiring complex and costly removal. It would also be difficult to mill the small chamfer in the thread and slot corners.

Using CF grinding, the slots and corner chamfers could be ground in a single setup. With just one fixturing and handling step, part quality improved by eliminating part distortion and burrs and having more accurate size control. CF grinding also applied less force to the part than milling or turning, so part movement or deformation was not an issue.

The multiple-axis motion of CF grinding provides the ability to machine a variety of surfaces. For example, this function is useful for round parts where a profile needs to be ground parallel to the centerline. These forms can even be ground on the part interior.

CF grinding generated the slots and chamfers from a solid without producing burrs.

Creep-feed grinding delivers three key benefits: quality, consistency and low cost. A CF grinder requires the right abrasive, dressing, tooling and coolant delivery and filtering. Integrating those elements can produce a cost-effective solution that delivers superior part quality. △

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