The Grinding Journal™
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Why measure cutting tools? Toyota's answer

Other perspectives on CNC tool measuring

Productive grinding of superalloys

SUPER service grinding BIG rolls

UNITED GRINDING publication

Fall/Winter 2007

Make A Quality Decision

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CONTENTS

Ed Sinkora
Editor
United Grinding
540.710.2408
edward.sinkora@grinding.com
Janette Dywasuk
Associate Editor

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On the cover: Today's tool measuring technology is a lot more advanced than a tape measure. Turn to pages 6-13 to find out why demand for this technology is taking off.

UNITED GRINDING publication

From Virginia

A Message from Rick Martin
President
United Grinding Virginia

Apparently no credit crunch for machine tools

The mortgage meltdown has dominated headlines for months, with large financial institutions writing off billions of dollars in bad loans. Clearly, significant liquidity has been lost and investors are reluctant to put more in. But surprisingly, several sources report that credit standards, availability, and terms have generally *not been affected for machine tool financing* (other than the usual variation in market interest rates based on T-bills or similar benchmarks).

Why is machine financing different?

There are several fundamental reasons behind the much better situation in capital investment financing:

- The primary machine tool finance companies have not been large participants in the mortgage market and are not hurt by the fallout.
- The manufacturing industry has demonstrated continuous strength and modest growth since 2003. U.S. manufacturing output is estimated to be up 1.8% this year, with a similar increase forecast in 2008. Machine tool sales are up 6.7% through Q3 according to the USMTC report.
- The exchange rate of the "weak" dollar helps exports and strengthens domestic manufacturing, giving lenders confidence.
- Machine tool loans are based on an asset that is *known* to depreciate. Credit is granted based on a company's proven ability to generate revenue, not on the hope that the asset will increase in value (part of the housing dilemma). Lenders structure financing terms like the down payment and monthly payment amounts so that the residual machine value is above the outstanding loan amount at any time.

Two types of machine tool financing

Financing can be structured in many ways, such as an operating lease (aka rental or tax lease), which keeps the transaction off the balance sheet and is reported as an operating expense on the P & L statement. The end user does not take depreciation in this case.

The second general category of financing is called a capital lease or loan. This is recorded as an asset and liability on the balance sheet, and depreciation taken annually on the P & L. Variations such as balloon payments and skip-payments may be available.

Either way, start with the traditional sources. There are several nationwide financing companies that will work with you to address unique needs.

What do lenders look at?

In light of the good news above, it might be helpful to look at some of the criteria lenders use when reviewing an application to finance a machine tool. For an existing company applying for a machine tool investment up to $350k, the evaluation is typically made "application only" – meaning financial statements are not required. The approval is usually handled by software that generates a score and there is little subjective evaluation. Here are some of the key evaluation points:

- At least 3 years in business
- Good personal credit history (a strong indication of how an owner operates his business)
- Home owner, with prior or present history of on time mortgage payments
- "Revolving" credit lines such as credit card, home equity loans, or business lines of credit, ideally $70k or so with less than half currently tapped
- Favorable Dunn & Bradstreet Paydex score demonstrating a history of prompt payments
- History of comparable loans and good payment history, verified by UCC filings or Paynet report
- Traditional bank loans do not always show up in the computerized credit check, so the owner may be asked for such information if the other sources are not sufficient

Contrary to common assumptions, credit reviews typically do *not* consider business plans for generating new revenue with the new equipment. The lender usually wants assurance the company has enough cash flow and profit from present operations to pay the new loan obligations.

United Grinding has several partners and resources in the financing field. We will be happy to assist you in the process of justifying and obtaining financing for new investments. ■

INFO grinding.com
Rick Martin • 540.891.4214
rick.martin@walter-grinders.com

Why measure cutting tools?

Toyota's answer: Product quality and process reliability

Toyota Motor Manufacturing Kentucky (TMMK) churns out 2,200 engines and 4,400 axles per day…from scratch. From start to finish the engine line takes one hour. They build a four cylinder engine every 37 seconds and a V6 every 72 seconds. Keeping that production humming with minimal scrap requires precise cutting tools. *Getting* good tools relies on the ability to *measure* tool quality. And that led Toyota to the Walter Helicheck tool inspection machine.

The transition from trusting to verifying

Mike Johnson, the Assistant Engineering Manager for the Powertrain group explains: "Initially we bought the Helicheck to measure tools coming in from our suppliers as an audit tool. But we took it further to what we call 'Tool Point Management,' in which we want to ensure that every critical tool is correct the first time it hits the line. Plus we wanted traceability of that tool, whether or not there's an issue. Is that tool performing consistently every time, and do we have data to show it? Or is there a problem one out of fifty times, or one out of twenty times? We needed a way to specifically measure critical features on selected tools that have a high impact in the line for tolerance, and to be able to measure those tools quickly and provide the data out to the line."

"We measure our tools to ensure the quality of the product and to increase reliability in the production line, so the first part is good, there is no scrap, and there is no downtime because a tool is incorrect."

– Mike Johnson,
Assistant Manager Engineering, Powertrain

"Before, we were relying pretty much on the people in regrind. Let's say a reamer has to have a 10 micron runout on the lip height. Regrind setup and ran one piece. They'd check it manually with a V-block or an indicator or whatever. If it was OK they'd run the rest of them, put them in a box, and send them out to production. Now, after they've setup the tool, made sure it's correct, and ground them all we bring them all into QC and every tool is measured on the Helicheck. The measurement data is automatically transferred to our database and we have an inspection report for each tool that goes into the box and out to the line. And because every tool has an ID mark engraved on the shank we can trace them all."

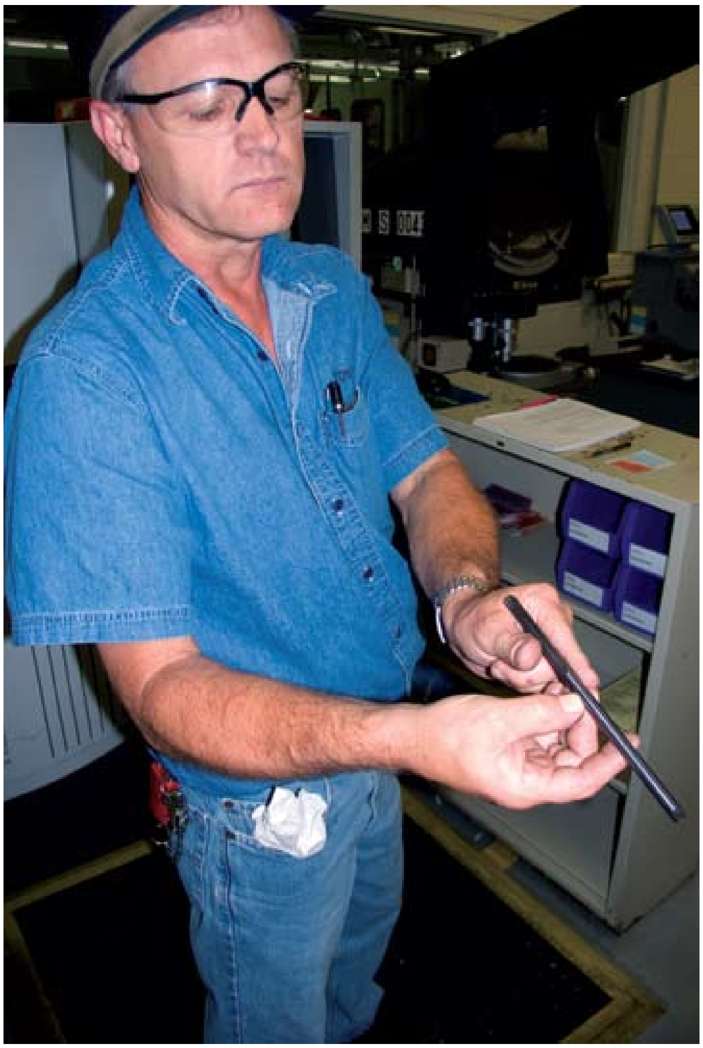
Checking tools a lot better than 50 scrap blocks

Toyota only recently began compiling the measurement data so it's too early to quantify the impact in detail. But Mike can already see it: "We had several size problems with a power steering pump hole in the L4 block. When we instituted this program with the Helicheck we began to measure diameter on reamers to see if they were still holding spec and we found that because of the abrasiveness of that operation in aluminum, some reamers had become undersize through repeated use. Now we catch that before the tool goes out to the line, preventing a problem. Of course we had 'first piece' checks before, but if the first tool produced a part that was within tolerance, but close, it's understandable that they'd run production and before you'd know it you'd have 50 scrap blocks. We've seen those kinds of impacts."

For Mike, QC is serious business and tool measurement is easy to justify in a plant that pumps out 2,200 engines a day: "We can fill this entire engine assembly line with bad parts in an hour. How do you put a dollar amount on that? What's the price tag on shutting a whole engine line down?"

Tolerances down to 10 microns required a measuring machine with better than one micron repeatability

TMMK's regrind shop sharpens 120 tools per man per day, or close to 40,000 tools per month. About 8% are critical tools requiring 100% inspection: All the reamers and some of the drills. Put another way, the critical tools are those with tolerances of 100 microns or less. Most of TMMK's reamers have a tolerance of 10 microns or less. Since the repeatability of the measuring method should be at least ten times better than the part tolerance, they needed a method with better than one micron repeatability.



Team Leader Mike Crouch indicates the etching on the shank that identifies this reamer and ties it to the inspection report

The Helicheck was their only option, as confirmed by Team Leader Mike Crouch, "We've got some reamers that we've tried to measure manually every now and again, like a three flute gun reamer. But we bring it here and the Helicheck measures consistently, much better than we can do by hand, just on account of the length. It's about 230 mm long, so runout is a real concern and we can't measure that manually."

"We've got some reamers that we've tried to measure manually every now and again, like a three flute gun reamer. But we bring it here and the Helicheck measures consistently, much better than we can do by hand, just on account of the length. It's about 230 mm long, so runout is a real concern and we can't measure that manually"
- Mike Crouch, Team Leader

And it's getting even harder

TMMK usually measures lip height, runout of the OD, relief angle, and diameter, and the tools are not always easy to measure: single flute PCD reamers; 6, 8, and odd flute reamers, and so on. And Mike Johnson reports that "the designs are becoming more complex and the tolerances are tighter. We have tools coming in the new engine we have never run before that are very complex and that will cost more than our typical operations but they save money in another place by being able to combine operations and reduce capital equipment."

People tend to see what they expect to see, but the machine remains neutral

There is a natural bias on the part of operators to measure a tool so that it meets the nominal value.

continued on page 13

Other perspectives on CNC tool measuring

Tool manufacturers and cutting tool users have different, but overlapping, views on the need for CNC tool inspection. A tool manufacturer wants to minimize scrap and maintain smooth and efficient tool production. He also wants to make sure his customers don't reject his tools. An end-user (e.g. an automotive manufacturer or an aerospace company) also wants to produce his goods efficiently and at high quality, but for him cutting tools are part of his process, not his end product. (For one user's perspective, see the article on Toyota on page 6.)

Preventing the pain of rejection

Recently, a major Midwest tool manufacturer had a large batch of reamers rejected by one of its biggest accounts (a big car manufacturer in the area). The tool had a very tight tolerance for concentricity and this batch didn't cut the mustard. At that point the auto plant was about to run out of tools due to the unexpected

The Walter Helicheck uses powerful software and high-tech cameras mounted on CNC axes to measure features that can not be inspected using manual equipment, like rake angle, clearance angle on the OD, or clearance at a step.

trouble, placing their production at risk. Needless to say the tool manufacturer was also at risk of losing a big account. The entire problem would have been avoided if the tool manufacturer had measured the tools properly before shipping them.

The Walter Helicheck is repeatable under one micron and (unlike manual operators) isn't swayed by knowing the nominal value. It also prints out a certified inspection report.

Some tool manufacturers include an inspection report along with their tools. This avoids any misunderstanding and builds trust. And it's easy with a Walter Helicheck, because the machine can automatically print certified reports. By the same token, end users should seriously consider either accepting only certified tools or inspecting the tools they purchase.

Predictability is the key to smooth production

A measuring machine can also contribute to Statistical Process Control (SPC), no less for a tool manufacturer than an end user. For example, another unnamed tool manufacturer lost a grinder due to a worn part during a particularly busy time of year. Besides the expense and hassle of an emergency overnight repair, he also risked losing an important order. But after this incident, the tool manufacturer invested in a tool inspection machine and SPC software. They networked both systems so that the slightest problems on any of their tool grinders will be reflected in the tool measurements and shown in the SPC software. Now most problems due to machine wear can be predicted and fixed before a failure. In-process inspection and monitoring also helps eliminate scrap.

A measuring machine can eliminate the "chasing your tail" syndrome, in which you keep changing a design because you're not getting the result you expect but you never confirm that the part meets the spec in the first place because you can't measure it.

"Measuring" can also mean "diagnosing problems"

In another example, a world-wide automotive parts supplier designed a new cutting tool to improve production of a certain part. They then had the tool made by one of their suppliers. But the cutting tool didn't live up to their expectations, so they changed the design. However, this also didn't produce the desired results. With time running out and project costs soaring, it occurred to them that perhaps the tool wasn't being made according to the specs. Neither they nor their supplier had inspection equipment with the capability to check the tools. They were chasing their tail! A measuring machine capable of measuring unique geometries is essential for avoiding such situations.

New geometries and tighter tolerances driving need for better inspection

The demand for higher performance has driven tool design into strange new worlds: micro tools; tolerances in the microns; tools with helixes that vary from front to back, or helixes that differ from flute to flute; tools

A measuring machine is like a life preserver: A small investment that prevents a catastrophe

with variable core diameters; and tools that combine complex geometries for multiple operations. As CNC tool grinding has risen to these challenges, the question remains: How can we measure these new tools? Many of the new features and tolerances simply cannot be measured manually. Keep in mind that the measuring method should be ten times as accurate as the required tolerances for your measurements. So if your tool tolerance is 10 microns the measuring machine must be repeatable within 1 micron. This requires CNC measuring technology like the Walter Helicheck.

Spend a little to save a lot

The quality of a product starts with the control and quality built into the tools used for production. Bad cutting tools put production quality at risk and add huge extra costs. But you can avoid these costs with proper tool measurement.

Or use the analogy of white-water kayaking. Like kayaking, you can expect challenges in business and you'll probably get wet. But you won't drown if you invest in a life preserver. That small investment today can save you later! ■

INFO grinding.com Thomas Hegenbarth • 540.207.5278
thomas.hegenbarth@walter-grinders.com

The Daruma doll in the lobby symbolizes the success of the 2AZ (four cylinder) engine line. The doll arrived with white eyes. Following Japanese tradition, at the start of the engine project the TMMK leadership blackened one eye while wishing for success and the team members signed the doll. When the production line was up and running they blackened the second eye in another ceremony. The Daruma's low center of gravity and self-righting shape also symbolizes the team's belief that although they may stumble, they will persevere and prevail in the end.

So TMMK sometimes uses the Helicheck to verify a manual measurement. Mike says "We use it to check parts from our suppliers that have been measured manually, especially if they say it's borderline. We've had cases in which the manual measurement says the tool is right on the borderline, and the Helicheck proves it's actually 2 microns undersized, yet the supplier denies it."

Helicheck helps troubleshooting

Tooling Specialist Abhijit Kardekar says TMMK also uses the Helicheck for troubleshooting. "For example, we can check a reamer in its holder to see if the holder introduces any runout." He also likes the fact he can check his indexable tools, some of which have features that cannot be checked on a V-block. "You can put it on a Helicheck and check run-out on those tools also…Long drills, standard indexable drills, and endmills too…We can see whether or not the insert was mounted properly and although they don't have the highest runout tolerances, when a part comes out badly we can at least do some troubleshooting and eliminate tool runout as the problem."

Kentucky plant leads the way

Every tool used within Toyota is designed for a specific purpose by the home office. And Toyota also mandates company-wide Quality Assurance programs. But TMMK's tool measuring program goes farther and the rest of the company is beginning to catch on. Mike explains that in Japan "They have a slightly different philosophy on how to use the Helicheck. They're looking only at runout but we didn't think that was good enough."

"We presented our Tool Point Management program to the Global Engine Committee back in May – that's representatives from all the Toyota engine plants – and it was very well received. TPM is being implemented at all Toyota engine plants, but whether they will all implement our particular method remains to be seen. But they see the value of it and we've had their guys from regrind here and they all agree it's great." ■

INFO grinding.com
Ed Sinkora • 540.710.2408
edward.sinkora@grinding.com

Productive grinding of SUPERALLOYS

Grinding an HP vane with a revolutionary new technique that uses the acceleration and speed of linear motors to take many fast, shallow grinding strokes to achieve high material removal with a minimum of heat and stress

Since the early days of metallurgy, alloys have evolved to meet performance requirements. Just as hard steels were developed for swords in ancient times, today tough, heat- and corrosion-resistant alloys are being developed for demanding applications such as nuclear power components, high-performance automotive parts, and jet engine turbine blades, vanes, shrouds and disks able to withstand temperatures over 2,000° F.

Such "superalloys" exhibit excellent mechanical strength and creep resistance at high operating temperatures, with superior resistance to corrosion and oxidation. They generally are based on nickel or cobalt and feature a complex combination of other elements. Superalloys are known under a number of trade names including Inconel®, Hastelloy®, René®, and Haynes®, and also exist as proprietary materials developed by the product manufacturers themselves.

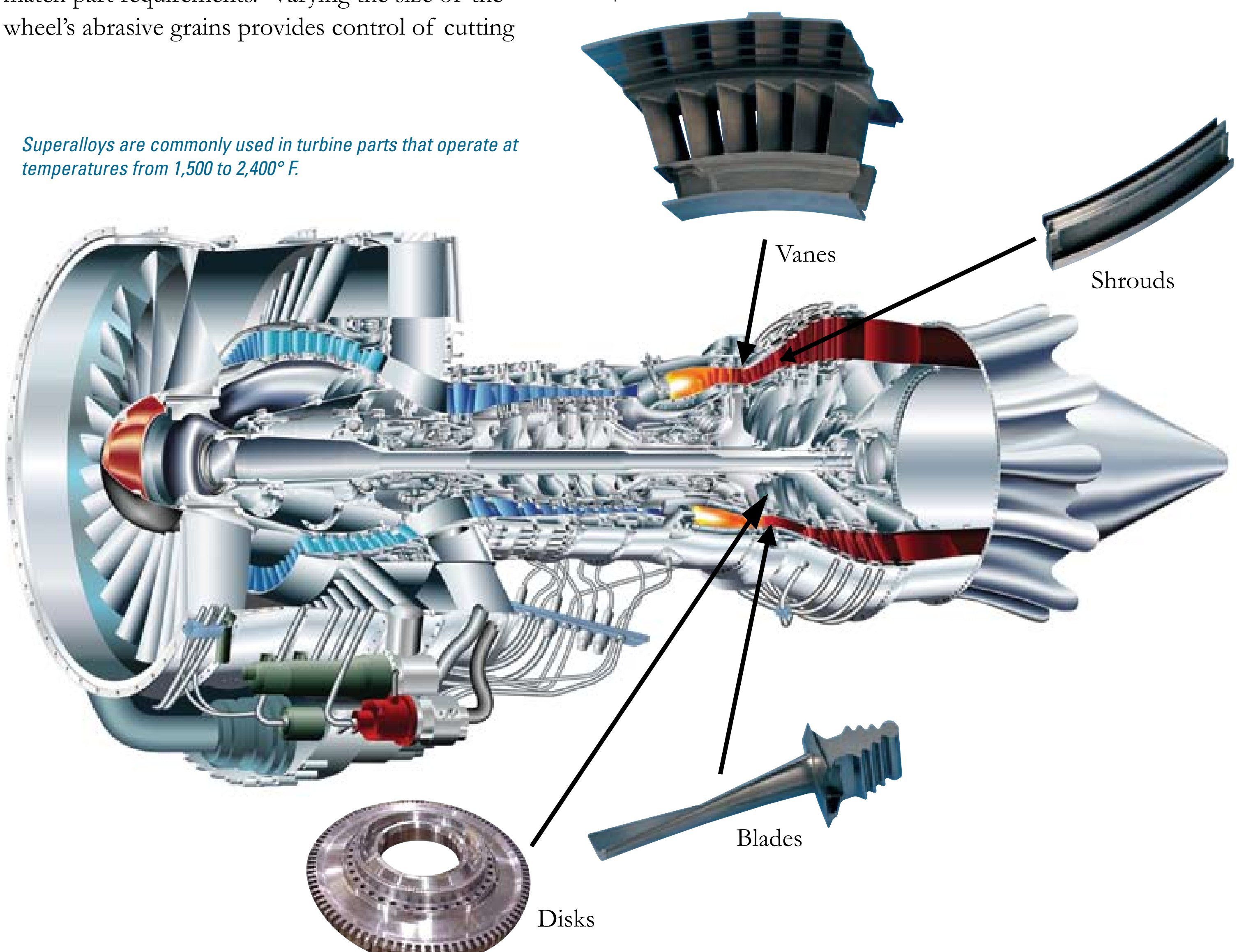
High-performance materials usually present manufacturing challenges, and superalloys are no exception. Superalloys have the tendency to workharden at the surface and generate heat during machining. They are relatively poor conductors of heat, and accumulated high temperatures can interfere with the cutting process and/or deform or damage the part. A relative machinability comparison of selected alloys (considering cutting speed, surface finish, and tool life) places carbon steel 1212 at 100 percent, stainless steel 440 at 45 percent, and Inconel 718 at only 19 percent.

Compounding manufacturing difficulty is the high-tolerance and complex nature of many superalloy components. The shape of the parts often makes them difficult to hold securely for machining. Finally, both the alloys and the parts they comprise usually are very expensive.

Grinding offers advantages for finishing operations

Progress continues in productive rough turning and milling of superalloys, but for finishing operations grinding is generally the process of choice. Although grinding is often thought of as expensive, dirty, and relatively slow, it offers a number of clear benefits when handling superalloys.

Grinding processes can be customized to precisely match part requirements. Varying the size of the wheel's abrasive grains provides control of cutting forces and surface finish. The porosity of the grinding wheel can be manipulated to promote the flow of coolant into the cut and speed evacuation of chips. Diamond dressing enables the formation of highly accurate wheel shapes to produce complex part geometries meeting tolerances of 0.0001" or better. Continual wheel dressing enables process control that is not possible with a cutting tool that becomes duller with each successive cut. Today's grinding machines themselves feature a variety of productivity-boosting systems including process monitoring and automatic loading that further enhance productivity. Metal removal rates achieved with modern grinding techniques can be relatively high, providing an economical way to process superalloy parts compared to EDM and other techniques.



Superalloys are commonly used in turbine parts that operate at temperatures from 1,500 to 2,400° F.

Turbine illustration courtesy Pratt & Whitney

Methods must be matched to the application

To achieve maximum productivity, however, grinding methods and technology must be matched to the specific manufacturing situation at hand. By outlining the primary variables in the grinding process, then analyzing the benefits and limitations of different grinding technologies relative to those variables, we can get a picture of which methods are best for certain applications. Let's consider five key variables in the grinding process:

Investment:

The most conspicuous variable of any grinding operation is the capital investment required. A shop must determine whether it needs a full 5-axis machine with tool changer, or if a simple 3-axis machine will suffice. The coolant system, critical to the grinding process, is another major investment. Even floor space is a cost factor, taking into consideration the size of parts and machining equipment involved.

Strategy:

A second variable is a shop's prevailing manufacturing strategy. Strategic approaches may include a lean production or single piece flow, where a part moves from machine to machine; or an automation approach where tool changing and other technologies permit completing a part on one machine; or a job/prototype shop focus, tailored to provide flexibility to meet constantly changing customer demand.

Environment:

The environmental variable in grinding is increasingly important. Part material and configuration as well as the grinding process itself determine whether oil- or water-based coolant systems will be applied. The choice involves weighing benefits and limitations including disposability, cleanliness, and fire precautions. The amount of material removed and grinding wheel consumption also are environmental considerations.

Design and tolerances:

The design and tolerances of the part being processed make up another crucial variable affecting a shop's overall grinding strategy. Issues include the part's shape (geometry), material and possibly coating, and tolerance and surface finish requirements. Engineers often design complex superalloy parts and then expect a shop to find a way to produce the design. Some delicate components require special attention to avoid distortion from excessive grinding or clamping forces. And of course, part tolerance and surface finish requirements heavily influence the grinding process and abrasives that are chosen.

Workholding:

Finally, in what is in some respects a subset of part design and investment considerations, we must consider the workholding variable of the grinding process. Workholding choices can include methods from hard point tooling to encapsulation of the part being ground. Fixturing costs can sometimes outweigh the cost of the part due to complexity and extra support requirements.

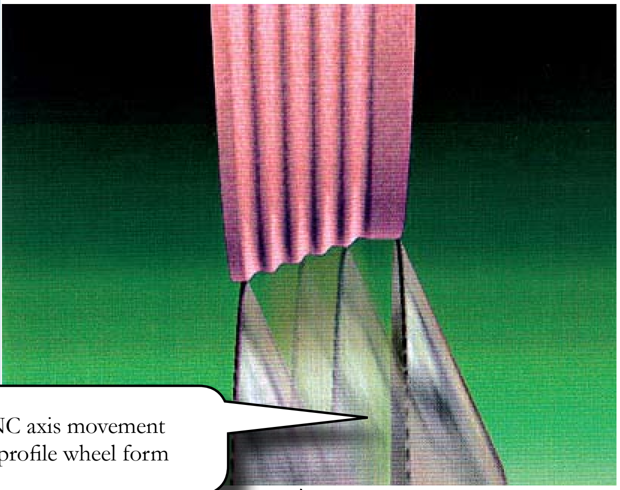
We'll use these variables to evaluate the benefits and limitations of four different combinations of grinding methods and technologies, each based on case studies. We'll also use a "Q-Prime" measurement to compare the metal removal rates of the various grinding techniques. It represents the volume of metal removed per unit of time and provides a basic rule-of-thumb for measuring metal removal rate in grinding. It's typically expressed in cubic millimeters per second (mm^3/sec).

The four grinding methods and technologies we will discuss are:

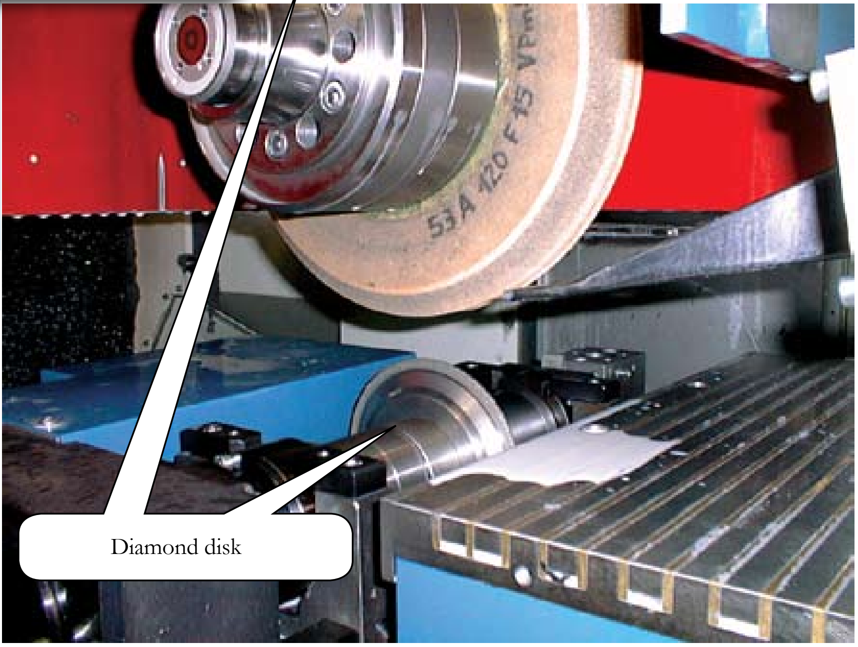
1. Conventional creep feed grinding
2. Creep feed continuous dress (CFCD) techniques
3. Using vitrified CBN (cubic boron nitride) abrasives
4. Using plated CBN wheels

1. Conventional Creep Feed

Part, Feature: Turbine blade, dovetail form
Machine: 3-axis CNC
Wheel: 2"-wide aluminum oxide & ceramic
Wheel speed: 3,500 surface feet per minute (SFM)
Roughing parameters: 0.03" depth of cut (DOC) at 10 inches per minute (IPM)
Finish parameters: 0.002" (DOC) and 20 (IPM)
Coolant: Water base emulsion, 60 GPM, variable PSI
Cycle time: 5 minutes (formed roller dress) 9 minutes (single-point diamond disk dress)
Dressing method: Rotary diamond roller, formed or disk
Workholding: Manual clamping
Q Prime: 3-5 mm^3/sec



This dressing approach uses a standard single point diamond disk to create a variety of shapes on the grinding wheel on demand. Perfect for quick setup on prototypes and small batches.



For creep feed grinding, a 3-axis CNC machine is required to control the in-feed depth, cross speed, and table stroke. The wheel is dressed after every pass via the single point CNC method. A rotary diamond disk (a steel disk with a single layer of diamonds around the exterior) creates the required wheel form via X-Y-Z movement across the wheel guided by the CNC program. Depth of dress is empirically derived pending form tolerance and geometry and typically ranges from .002"to .010"per dress. Another approach is to use a full form roll to dress the form into the wheel.

The workholding in this case is typical of a flexible job shop application, using manual clamping fixtures that are effective as far as flexibility and cost. This application is typical of a job shop where the customers' demands continually change. It's a low volume and low investment situation, because job shops often don't have the capital or time to order long-lead tooling.

The limitations of this process include an inability to grind very complex forms such as radial geometries or some groove and slot forms that would be possible with a five-axis machine. It's also not the most productive way to produce high volume parts due to the amount of dressing and wheel changing that have to occur.

The Single-point CNC dressing method enhances flexibility because it eliminates the need to purchase a custom-formed diamond roller, which for this application might take six to eight weeks to have designed and built. Here, the CNC program shapes the wheel within minutes once the design is entered into the control.

Low cost and flexible

Addressing the five variables outlined earlier, this application features a relatively low investment in capital equipment, namely a basic 3-axis machine. The flexibility of the dressing process complements a job shop/prototype approach, although the need to return the wheel for dressing after each pass negatively affects cycle time, and repeated dressing increases wheel consumption. Coolant consumption is moderate and water-based coolant is environmentally preferred. The individualized nature of the process helps maintain high part quality. Low-volume job-shop production makes manual workholding a practical choice. ●

2. Continuous Dress Creep Feed (CDCF)

Part, Feature: Land-based power generation turbine blade, dovetail form
Machine: 4-axis CNC
Wheel: 6"-wide aluminum oxide, special bonds
Wheel Speed: 4,500 SFM
Roughing parameters: Creep feed 0.06" DOC at 30 PM
Finish parameters: Creep feed 0.002" DOC and 50 IPM
Coolant: Water base emulsion or synthetic, 120 GPM at 100 PSI
Cycle time: 7 minutes per side
Dressing method: Continuous
Workholding: Robust hydraulic clamping with work support
Q Prime: 19 mm^3/sec

Continuous Dress Creep Feed (CDCF) grinding applications typically involve long part runs and dedicated equipment, while providing high-volume stock removal. The heavy cuts involved require robust clamping, work supports, and stiff machines ranging from 50 to well over 100 HP.

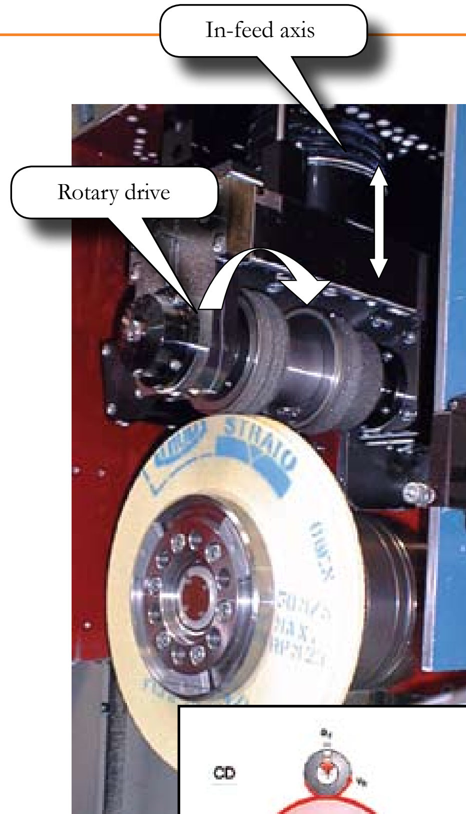
Wheel is always sharp

This application features a 4-axis CNC grinder with an overhead dresser that feeds down and dresses the wheel while grinding proceeds. The result is a constantly sharp grinding wheel that can produce highly accurate forms at very high metal removal rates. The wheel remains open and clean so it keeps the cut cool and works exceptionally well with difficult-to-grind materials such as superalloys. In fact, the creep feed process was originally developed for such hard-to-machine materials. Constant dressing assures a stable process and continual compensation for changing wheel size. The special bonded wheels used here feature a large amount of induced porosity, permitting heavy volumes of coolant to flow into the cut and large volumes of chips to be carried out.

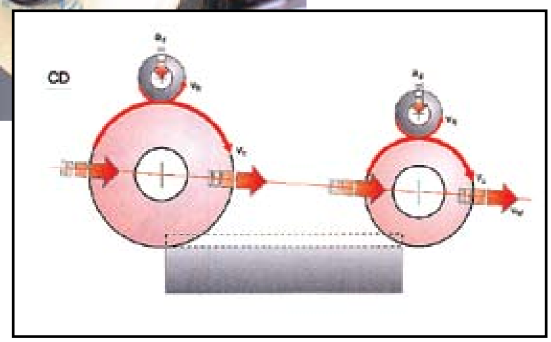
Continuous dressing reduces cycle time because it eliminates time spent moving to a dressing table. Wheel consumption does increase, but newer machines offer the ability to dress intermittently, with dressing rate increased in proportion to the load generated as the wheel dulls.

The high metal removal capability of CDCF grinding makes it an excellent choice for processing large parts, especially land turbine components.

High investment is a limitation of CDCF. Heavy-duty 4-axis machines are expensive. Additionally, the formed diamond roller and overhead dresser limit flexibility in terms of wheel movement around the part compared to other processes. The aggressive nature of the process makes strong work support and clamping critical to assure that the operation is stable and vibration-free.



Invented for grinding superalloys, continuous dressing maintains a sharp wheel with an accurate form throughout the job. It also achieves the highest volumes of stock removal. As illustrated below, the rotary dresser moves on a CNC axis to compensate for the changing diameter of the grinding wheel.



Fastest of the four methods

A key advantage of CDCF is low cycle time; it is the fastest grinding process reviewed in this discussion.

In terms of our analysis of process variables, CDCF grinding involves a significant investment in a heavy duty, multi-axis machine. The abrasive cost per part is high because continuous dressing results in high wheel consumption. Dedicated wheels and dressing equipment limit the flexibility of the process, but enhance its productivity for shops handling long production runs requiring aggressive grinding.

Use of water-based coolant is environmentally acceptable, while large volumes of grinding swarf may pose disposal challenges. From the part design and tolerance aspect, continuous dressing produces high and consistent quality because the wheel is always sharp and open. Depending on the complexity and amount of design work necessary to create workholding for the CDCF operations, workholding considerations are moderate.

CBN: Alternatives for high volumes and complex forms

Cubic boron nitride (CBN), a man-made crystal second only to natural diamond in hardness, is very effective when used as a grinding abrasive for superalloys. In addition to its hardness, CBN is an excellent conductor of heat and can help draw heat generated in grinding away from the part. There are two primary types of CBN tools: Vitrified and Electroplated employ resin, ceramic and vitreous binders, with vitrified materials being those most commonly applied to superalloy aerospace parts.

Vitrified CBN: High volume production

A Vitrified CBN wheel employs resin, ceramic or vitreous binders that holds the CBN grains to the wheel in the form of a dressable layer that is usually .375 to 1.00 inch thick. The core of the wheel is either aluminum or aluminum oxide.

Typically, a vitrified CBN abrasive application involves grinding a large number of precision parts (10,000+) with light requirements for material removal. It requires a rigid machine with three CNC axes (or more, depending on part geometry requirements). Fixturing should be robust as well, to assure process accuracy. Water base coolant should be supplied at pressures from 250 to 1,000 PSI. A wheel cleaner, including low volume coolant injected into the wheel to clean out chips, is also recommended.

Coolant delivery, important in all grinding applications, is critical in achieving maximum productivity and economy with vitrified CBN tools. The position of the flow and its consistency are important. Grinding machine manufacturers provide coolant nozzles engineered to generate laminar flow that eliminates all turbulence in the stream of coolant. Matching coolant velocity to the speed of the wheel also benefits CBN grinding productivity. The required coolant velocity in cubic inches-per-second can be determined by multiplying the wheel speed in inches-per-second times the nozzle area in square inches. Coolant pressures are in the area of 150-300 PSI.

Investment is high in both the grinding machine and the wheels, which routinely are 20 to 50 times the cost of aluminum oxide wheels. The higher initial investment in wheels, however, is often outweighed by the resulting lower cost-per-part in high volume applications. It should be noted that a vitrified CBN wheel generally is dedicated to a specific feature, making it difficult if not impossible to use that wheel for anything else.

3. Vitrified CBN

Part, Feature: Turbine blade, dovetail form
Machine: 3-axis CNC
Wheel: 2"-wide vitrified CBN
Wheel Speed: 9,000 SFM
Roughing parameters: 0.025" DOC at 20 IPM
Finish parameters: Creep feed 0.015" DOC and 10 IPM
Coolant: Water base emulsion, 60 GPM, 250 PSI, via engineered nozzle; wheel cleaner 5 GPM, 1200 PSI
Cycle time: 4 minutes
Dressing method: Rotary diamond roller, formed or disk
Workholding: Robust
Q Prime: 6 mm^3/sec

Dressing is extremely critical and is typically measured in ten-thousandths of an inch. For example, a wheel used in grinding a turbine blade would typically be dressed 0.0002" every three to five parts. Such precision requires high rigidity on the part of both the dresser as well as the machine. Dressing in this case is not a grinding process but rather a crushing action intended to fracture the bonds of the grains in the wheel. A key to dressing CBN wheels is minimizing the dwell time after the dressing pass. A light in-feed of approximately 0.0002" would be followed by immediate retreat of the dresser. A dressing roll speed to wheel speed ratio of .3 -.5 is recommended for vitrified CBN wheels.

High volume with low to medium stock removal Summarizing the application of vitrified CBN tools in regard to variables in the grinding process, initial investment in a rigid CNC machine and dressing system is relatively high. The CBN wheel, dedicated to a specific part feature, also represents a significant investment. However, CBN's long life results in low abrasive cost-per-part. Some users run wheels up to six months or even twelve months between changes, which also minimizes downtime. The dedicated nature of the production process limits flexibility, so vitrified CBN grinding is best for high-volume production runs. Environmentally, water base coolant is easy to manage. Long tool life also enhances process control and achieving product design and tolerance requirements. Rigid workholding is necessary, with its complexity and expense depending largely on the geometry of the part

Proper coolant delivery is especially critical when using CBN wheels. Success depends on nozzles and piping that achieve laminar flow and eliminate turbulence, matching coolant velocity to the wheel speed, providing enough coolant volume, and other factors. For example, in the system pictured here, the nozzle position adjusts automatically as the wheel gets smaller.

and cutting conditions. Because CBN works best with low to medium stock removal rates, cycle time is not ultra fast and the method is not well suited for heavy stock removal situations.

Electroplated CBN: Complex forms

Another method of CBN grinding uses a single layer of CBN grain bonded to a precision steel wheel core. The bonding method is usually nickel-plating. Wheel cores can be re-plated up to ten times, resulting in lower abrasive cost-per-part than experienced with vitrified wheels. Of course, plated CBN wheels can not be dressed resulting in a wheel that dulls with each cut and wheel failure is unpredictable. The accuracy of an electroplated CBN wheel form is at best +/-.0005 and can vary with wheel size and spindle runout. Electroplated wheels perform best in straight oil coolant which reduces the rubbing heat generated when grinding deep groove and slot features. However oil does not conduct heat as well as water-based coolants, necessitating larger filter system with temperature control. Oil also requires precautions against a flash fire during grinding with an active fire extinguisher system.

4. Electroplated CBN

Part, Feature: Turbine blade, medium aero
Machine: 5-axis CNC
Wheel: 1"-wide, two-wheel plated CBN wheel set
Wheel Speed: 12,000 SFM
Roughing parameters: 0.012" DOC at 15 IPM
Finish parameters: 0.002" DOC and 20 IPM
Coolant: Oil base, 60 GPM, high pressure: 150-300 PSI
Dressing: Not required
Cycle time: 8 minutes
Workholding: Robust
Q Prime: 2 mm^3/sec

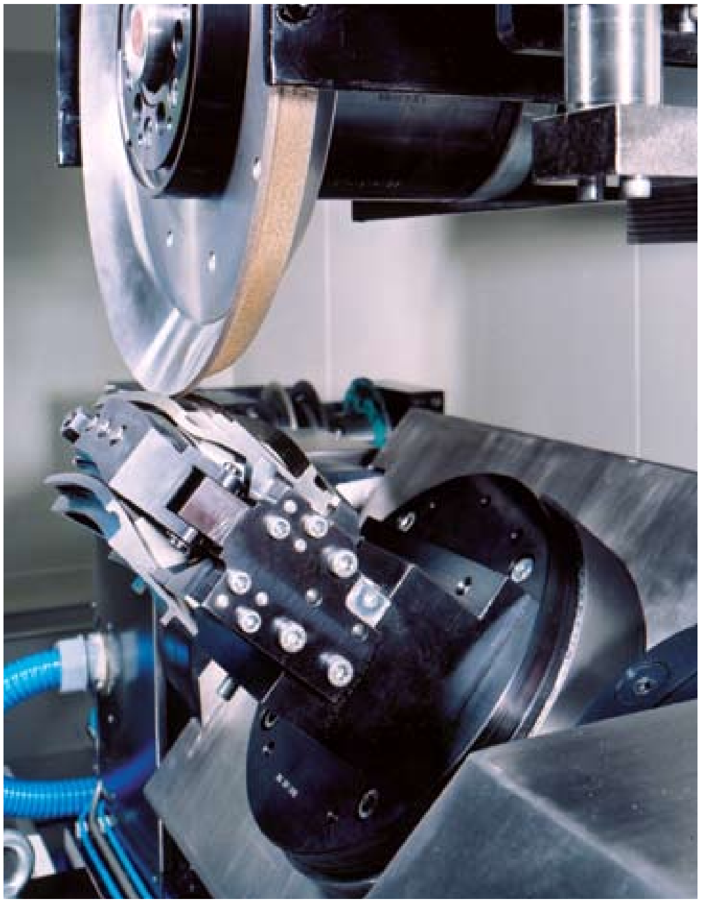
Cuts deep grooves

The main advantage of plated CBN wheels is the ability to generate deep radial grooves and slots with high depth to width ratios, features impossible to make with aluminum oxide or vitrified wheels. Using 5-axis CNC motion control, the wheels can produce shapes previously generated only by EDM. CBN plated wheels can also be stacked in a wheel set to produce multiple forms and enable the grinding of a variety of features at the same time.

After the wheels wear, they can be re-plated up to ten times, but this requires a system to manage the wheel life and return failed wheels to the manufacturer for re-plating.

Complex designs and flexible process

A key consideration in making the decision to use plated wheels is the total amount of material being removed. The wheels have limitations regarding DOC, feed rates, and tool life. If it is necessary to grind a large volume of material – for example, a land base



Plated CBN wheels are best used for grinding deep radial grooves and slots. Using 5-axis CNC, the wheels can produce shapes previously generated only by EDM.

turbine part where perhaps .500" of material must be removed – creep feed or CFCD grinding would probably be a better choice. Plated CBN process offers ability to create complex radial forms and the flexibility to machine multiple features in one set up.

The same machine investment considerations involved in vitrified CBN applications hold true for plated CBN processes. Plated wheels, however, do offer more flexibility, because they can be used on a variety of equipment, including milling machines as well as dedicated grinders. Cost-per-part is also reasonable, because the wheels can be re-plated. When used on a 5-axis machine, plated CBN wheels require no wheel guard, providing the flexibility to grind all the way around a part. From an environmental standpoint, the oil coolant required for the most effective use of plated CBN abrasives poses disposal problems and possible fire hazards. From a part-tolerance point of view, the largest limitation of plated CBN wheels is the difficulty of maintaining quality and controlling the process because tool pressure and heat generation increase as the wheels wear during use. Workholding considerations are similar to vitrified CBN wheels.

Ongoing development combines grinding technologies

Beyond the familiar technologies we've discussed, grinding industry suppliers are continually developing new tools and methods to further improve productivity.

Machine manufacturers offer equipment that can enable a shop to combine a variety of grinding methods. As noted earlier, each grinding process offers one or two capabilities that make it excel in certain applications. Modern grinding machines with tool changing systems, integrated dressing systems and CNC coolant nozzle positioning can now mix abrasives to employ the optimum tool for each part feature. One machine can perform conventional creep feed and CFCD, apply vitrified or plated abrasives, and even carry out other operations like milling. The advantages of each process or abrasive can be applied to specific materials and part geometries.

Multi-tasking: Combining all the best

This multi-faceted grinding approach is excellent for complex parts with features that demand different grinding processes and abrasives. Such machines can even automate part loading and finishing in one clamping. An example of such a machine is the Mägerle MFP-50 9-axis CNC grinding machine with a double axis CNC overhead dresser. It permits continuous dress, creep feed grinding and conventional grinding with ceramic, vitrified CBN and electroplated CBN wheels, all on the same machine. With integrated pallet systems, tool changer, and CNC coolant nozzles, it can run automatically and adjust itself to handle different parts.

This multi-faceted grinding approach is excellent for complex parts with features that demand different grinding processes and abrasives. Such machines can even automate part loading and finishing in one clamping.

Linear motor drives represent another machine-tool technology being developed for grinding. Linear motors have been employed in milling and EDM machines for more than 15 years. The process is very fast, offering advantages similar to those of high-speed milling, where high speed metal removal causes the heat generated by cutting to be carried away in the chip. The light cuts and high speeds benefit wheel consumption by lowering cutting forces and reducing the heat generated. Reduced use of coolant and increased productivity also result. An example of such a machine is the Blohm Prokos 5-axis grinder that employs linear motors for three of the axes. It incorporates a tool changer, CNC coolant nozzle, and an advanced diamond dressing system for multi-axis part grinding.

There's no really easy solution to grinding superalloys. It depends on all the variables in your particular situation. By working closely with the wheel, the dressing, and the machine system there is a solution that will optimize productivity in your particular application.■

INFO grinding.com
Larry Marchand • 937.847.1227
larry.marchand@grinding.com

Tiruna Delivers SUPER Service, Grinding BIG Rolls

With an overall length of nearly sixteen feet, flutes up to ten feet long, and a two foot diameter, a corrugating roll is one heck of a tool. If manufactured and serviced properly, they'll last six to eighteen years and process hundreds of thousands of miles of corrugated board, book covers, fast food cartons and the like. But it takes a very special shop to deliver the necessary service, leading most users to Tiruna America Inc. in Green Bay – a 50/50 partnership between Tiruña S.L. (Pamplona, Spain) and Fosber America Inc (Green Bay).

More complicated than they appear

Corrugating rolls appear to be very similar giants, but there are subtle differences between them that are critical to their performance. Being able to assess and maintain these differences is what sets Tiruna apart.

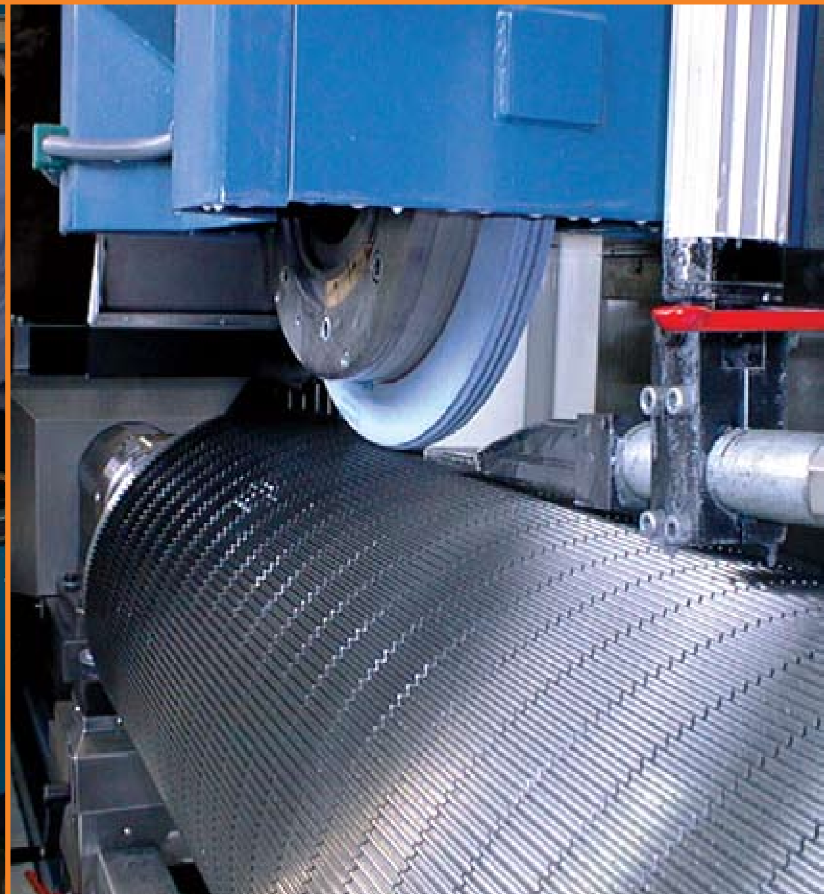
Uniquely groovy

Corrugating rolls operate in pairs, pulling the paper between them and creating folds, or corrugations, by pushing the paper into flutes that run the length of the roll. Depending on the circumference of the roll and the desired output, there may be hundreds of these flutes. Although they appear to be simple grooves, there are many tiny variations in possible flute profiles (Tiruna offers 250) and these variations impact performance. Because rolls are hard (50 Rockwell or more) and their flute forms must be precise, rolls must be ground. Tiruna made their grinding easier and more productive by choosing a Mägerle MGC machine.

When a roll arrives for service, Tiruna takes a casting of the flute with a synthetic resin. Using a program

Easy does it! Doug Botten loads a 12,000 lb. monster – Twenty-four inches in diameter and solid except for a three inch diameter hollow through the center. Like every roll, it presents its own challenges in compensating for sag to achieve the desired linear profile.

written by Roll Grinder Technician Doug Botten, they trace the profile with an automatic state-of-the-art vision system. Once the operator digitizes the profile, he determines the width of each flute "valley" and



Top Left: Although the Mägerle has a probe to measure part position and calculates offsets, craftsman Doug prefers to measure it and make adjustments himself. Top Right: Mägerle MGC with a triple flute C-profile wheel grinding solid core at 31 inches/minute at full depth of cut with a stock removal of 0.15 inches deep.

the distance between tips, which helps him adjust the clearance. It's also important to calculate the many radii in a given flute form, as each flute shape is different and therefore requires a different wheel shape to be ground properly.

It's worth noting that most regrind shops measure flute profiles with an optical comparator, which are highly operator dependent. (The operator tends to "measure" the nominal value.) Tiruna's vision system is operator independent.

Considering coating

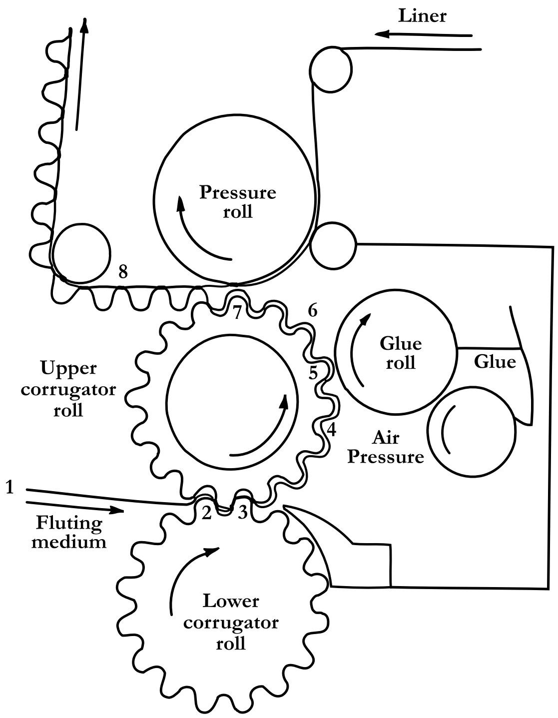
After grinding, Tiruna also recoats the roll with chrome, Hard Chrome, or tungsten carbide in thicknesses of 0.002 to 0.006 inches. The type and depth of coating affects the type of profile and the "depth" of the grind. Some customers rely on Tiruna's experience in adding the right amount of coating based on the roll's flute profile, while others specify a particular type and amount. In either case, Tiruna's experience determines the proper flute profile based on the expected finish coating.

Compensating for sag and other crowning achievements

Because corrugating rolls operate as a set, the flutes must match from one twin to the other and the rolls must mesh along the whole length of the tool (again, perhaps a dozen feet or more). All rolls appear flat, and indeed, some are intended to be. But a flat roll will sag as it's supported at each end. A typical sixteen inch diameter roll will generally have a 10-12 inch diameter hollow through the center, in part to limit the sag by lowering the weight. Yet Tiruna would probably still have to compensate for about 0.002 inches in negative crown to achieve the desired flat profile.

Other rolls are designed to have a slight crown and if the shop who last serviced the roll didn't hold it properly, that crown may not be centered. The user might have determined this by noting that the paper seemed to bind in an area despite equal pressure at each end. If not, Tiruna would have discovered such a problem by measuring the roll before grinding. At any rate, Tiruna would now have to account for this,

and one of the key features of the Mägerle is its ability to easily move the roll to grind the crown in the right place. The roll journals ride on bearings in the Mägerle in exactly the same way they would in a corrugating machine, plus the indexer is height adjustable to correct any skew. The roll is also low and easily accessible in the Mägerle, greatly facilitating setup.



A corrugating machine feeds paper between fluted rolls to create the folds. Optimum flute profiles vary based on speed, material, and other factors. (Operating speeds can reach 1,200 feet per minute.) The end product is used in packaging, displays, and even book covers.

Mägerle power contributes to fast turnaround

With a 100 HP (75 kW) grinding head and wrap-around hydrostatic ways to dampen any vibrations, the Mägerle MGC grinds even the biggest rolls in a day – which is considerably faster than Tiruna's previous approach. For example, Doug might run a triple flute C-profile wheel at 31 inches/minute at full depth of cut (0.15 inches) into solid core.

But he doesn't rush. Once the machine is up and running and Doug has confirmed how many passes he'll make before dressing, "we close the door and leave it running, and that could be as much as sixteen hours, all by itself just running. The longer it runs the better the product at the end. If you push it you might get a little TIR or a little jump at the end. You can't rush grinding." Or as his colleague, Sales Manager Chris Charette puts it: "Doug is…I'll say it nicely...a perfectionist."

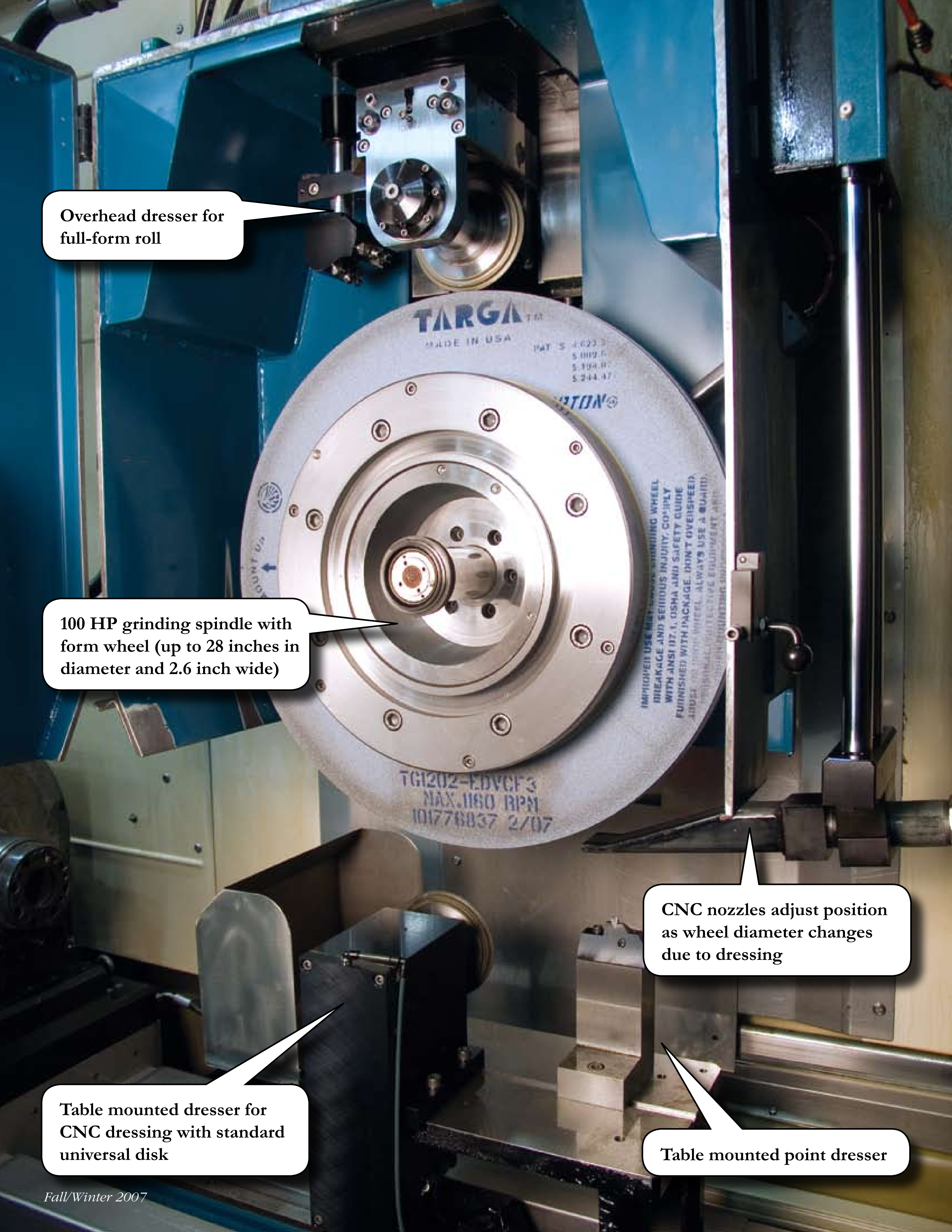
Leaving that door closed also contributes to temperature and process stability. With a part this big a small fluctuation in temperature would have a significant impact on size. Two chillers maintain the coolant temperature to within two degrees of the target.

Maintaining the wheel form

Continuous dressing is a key factor enabling Doug to grind for hours without interruption. The Mägerle boasts an overhead rotary dresser for use with a full-form wheel, a table mounted rotary dresser for CNC dressing with a standard diamond roll, and a table mounted point dresser. Doug reports that he can dress many different forms on many wheels with one standard 1 mm radius roll. But he sometimes uses rolls with a radius as small as a 0.45 mm which admittedly doesn't last as long. If the flute geometry from roll to roll is very different (e.g. "A" style versus "B" style), he'll change wheels rather than dress a completely different form into the wheel. This saves both wheel wear and dressing roll wear.

Whatever method he chooses, Doug finds programming the Mägerle to create and maintain the necessary profile to be straightforward. He also gets very good wheel life, losing only 8-9 mm in wheel diameter in a regrinding operation. Of course roll material and coating affects wheel life. Wheel speeds average about 35 meters/second at 900-1100 RPM.

They look more similar than they really are. Besides variation in size, there are subtle differences in flute profile, material, coating, and the linear profile.


Overhead dresser for full-form roll
TARGA
MADE IN USA
100 HP grinding spindle with form wheel (up to 28 inches in diameter and 2.6 inch wide)
TG1202-EDVCF3
MAX.1160 RPM
101776837 2/07
CNC nozzles adjust position as wheel diameter changes due to dressing
Table mounted dresser for CNC dressing with standard universal disk
Table mounted point dresser

The Mägerle's nozzle system positions automatically and compensates for wheel dressing (Oh, and that traveling column wasn't a bad idea either)

Coolant is important in any grinding operation and Tiruna relied on Mägerle to deliver a complete system. In this case it's a 2,300 gallon vacuum based filtration system with two big chillers and a drier for the swarf. The Mägerle's nozzle system positions automatically and compensates for wheel dressing, so Doug only needs to select "low" or "high" pressure and he gets good flow into the grind zone. (The only time he uses low is for an unusually small roll that flexes under high pressure coolant!) Naturally such a large coolant system takes up a fair amount of floor space. But it's important to note that because the Mägerle's grinding head rides on a traveling column (instead of moving the part on a traveling table), the machine itself needs relatively little floor space given the size of the parts. Plus the machine always moves the same mass, helping the operator optimize performance. In a traveling table design, machine dynamics change every time the mass of the part changes.

Tiruna boasts a unique ability to realistically test rolls both before and after refurbishing

Doing it right the first time

For Doug, "doing his job" means doing it flawlessly, because that "makes everything easier throughout the rest of the process, right down to running the roll." Given the size of the part, the need for a unique wheel shape, and Doug's understandable perfectionism, setting up a first piece typically takes about six hours. The second roll in a set is usually faster to set-up because he's already confirmed that the wheel grinds the proper flute form. (If the second roll is a much different diameter the wheel will likely not cut the same and will need to be dressed. Conversely, if the rolls are about the same diameter the wheel will create the same form.)

After setup, Doug monitors the power level of the machine, the flute depth, and any signs of burning to determine when he needs to dress the wheel again. When he has a stable process it's time to close the doors and let her run till completion.

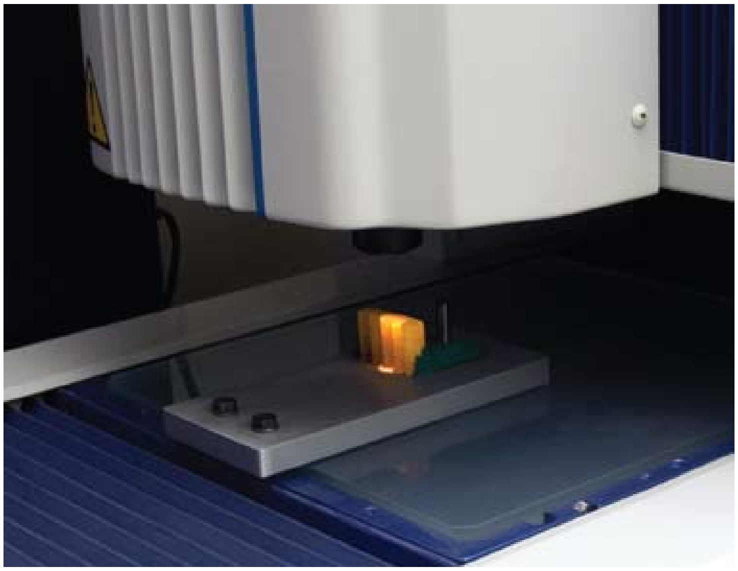
Unique testing capabilities

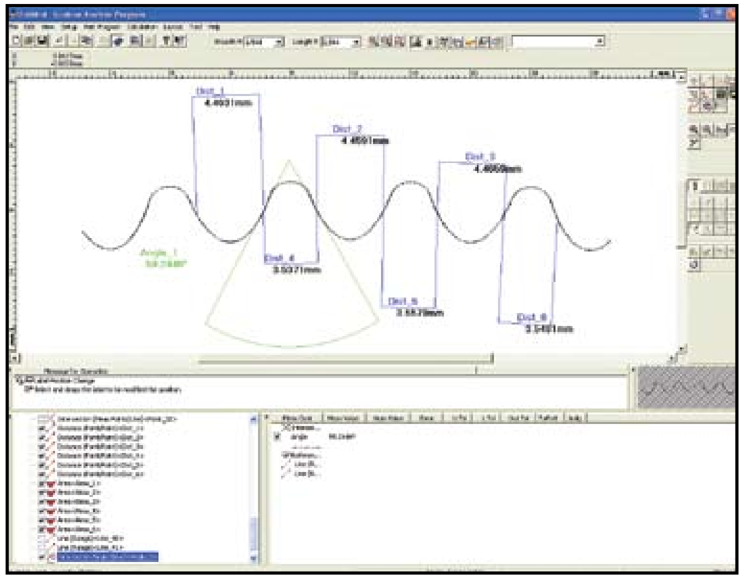
After grinding, Tiruna puts rolls on a test bed to verify performance, duplicating the roll position and hydraulic loading characteristics of the user's setup. Do they get contact across the roll? Do the rolls make marks? This in-house testing capability is unique to Tiruna (there are only two such systems in the world – the other in Spain). The device can even test rolls manufactured by a competitor.

Besides checking their own work, Tiruna can use this test bed to diagnose problems in the field. For example, if a user is experiencing contact problems, Tiruna can eliminate the roll as the source, perhaps pointing to a bearing on the user's corrugating machine.

When do you want it?

Recoating takes ten working days, exclusive of transportation, making the 24 hour grind time seem short. When you add cleaning, inspection, handling, and a few other items not covered here, Tiruna can turn a job around in 8-10 weeks. But they are also willing to store the part while the customer considers their refurbishing recommendations.





A state-of-the-art vision system traces the profile of a casting taken from a corrugating roll's flutes. Doug created a program that uses this profile to calculate the exact flute form, which he can then duplicate in the grinding wheel.

Servicing rolls from all over North America

Every roll is different (even the "twins" in a set have differences). Flute profiles vary. The linear profiles vary and may even be wrong if serviced incorrectly. Different rolls sag differently. Some users send in rolls for rework as soon as the coating is worn, others wait until the flute has been destroyed. Coatings vary.

But Tiruna is so good at diagnosing problems and completely refurbishing tools that people bring them rolls that were manufactured elsewhere. In fact, Tiruna *guarantees* better performance.■

INFO grinding.com Ed Sinkora • 540.710.2408
edward.sinkora@grinding.com

Problem Solver: Harold Tuttle

Customer Support Supervisor, United Grinding Virginia

Flu season? Roads closed due to a foot of snow (a big deal in Virginia)? After 6 PM? It doesn't matter when you visit the customer support center in Fredericksburg, "Iron Man" Harold Tuttle will be calmly helping someone somewhere over the phone. He even takes emergency calls after he leaves for the day!

But he doesn't boast or talk about himself. Maybe that's because he started his career repairing electronic gear for secret government agencies around the world. He joined Walter on the production floor in May 1996, moving into field service six months later. After three years of constant travel (ask him about the time he drove from Guadalajara to Puerto Vallarta via the "direct route") he helped create Virginia's phone support system and soon became a supervisor of that group.

Contrast field service and telephone support

As a field service tech you have to take care of pretty much anything, even if your strength is focused in one area. That's what the phone support team is here for. When a field service guy runs into a problem he can't handle, there's always a specialist in the home office who can assist them in working through the problem. But with nearly 2,000 machines in the field, the majority of calls come directly from customers and not the ten field service techs.

You have to visualize the whole machine and what the customer is doing in order to help him over the phone, don't you?

That's one of the challenges. As products change we have to adapt. It usually takes about a year to visualize a new machine, but the customer is also trying to describe things to you. And many now have a digital camera and internet access, so they can take a picture of their problem and send it to you. That's a big help.

Why review all field service reports?

We track the running time on each machine to predict future service needs. We've been collecting data in SAP for over seven years and we can see trends. Mechanical components wear and we have a pretty good idea how long each item will last. We also track items by vendor and assess the failure rates of each. The goal is to be proactive in solving problems before they affect a customer's production. Plus we write lots of service bulletins that document problems we've seen in the field and their solutions.

Speaking of trends and technology, what else do you foresee for service?

As we cut the number of mechanical components by using linear motors and as machines get smarter the need for electronic and PC expertise continues to increase. But grinding, by its nature, will always be hard on machines. That's why we put such an emphasis on preventive maintenance. We recently visited a customer who has run his machines with very few problems since 1996 because he has an extensive PM program and fine filtration. You can plan PM around quiet times so your machine will be productive when you need it, whereas neglecting it virtually guarantees that it eventually breaks down during peak demand when you really have to get tools out.

What's the funniest thing that's happened to you in grinding?

I once asked a customer to perform a number of steps in troubleshooting an electrical problem. After a while, I realized something just wasn't right because we weren't getting anything. So I asked if the machine was on and he answered "No, you didn't tell me to do that." So being on the phone has taught me the importance of asking the right questions!

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510 Earl Boulevard
Miamisburg, Ohio 45342
Tel: 937.859.1975
Fax: 937.859.1115
E-mail: ugt@grinding.com
Internet: www.grinding.com