BY MIKE PRINCIPATO

# The father of manufacturing, at least in my house

I've received a bunch of e-mails over the last few years from readers wondering how, when and why I became so infatuated with the world of manufacturing, ultimately building a $2.5 million machine shop. I suspect they hope that my "story" might offer them insight into how to inspire similar passion among their co-workers. Or, they've been looking at my goofy picture every month (and despite what the publisher of CTE says, that is not a mullet on my head) and can't figure out how a guy who wears so much hair gel wound up in the grimy world of metalcutting.

Whatever the motivation for their inquiries, I'm dedicating my column this month to the answer to their question … and to the "answer" himself: My father, who passed away a few months ago. In keeping with his lifelong philosophy of dealing with what is rather than whine about what isn't, I'm not going to lapse into a maudlin tribute to the greatest man I've ever known. Instead, I'll simply tell you what I often told him: I hit the parental lottery when I was born, and even at age 45, I still beam with pride when a new acquaintance asks, "Are you Dick Principato's son?"

So let's start there, because I truly believe that when it comes to the critical choices in life about values, education, friendships, faith and career direction, the first and foremost educators are parents. In the space this column allows, let me tell you how my father sowed the seeds of my passion for manufacturing at an early age.

A wise and patient former manufacturing exec, Dad intuitively knew that a son is a work in progress.

In my case, the process at times had to be a little like watching a hot dog being made: Often ugly, but ultimately rewarding. It didn't seem to matter to Dad though, who by quiet and steady example impressed upon me the importance—no, the nobility—of manufacturing.

At 6 years old, while my boyhood buddies were absorbing Phillies batting stats by watching ballgames on television with their dads, I was sneaking up the creaking attic steps after dinner to watch Dad work at his tiny, dimly lit desk. The home office hadn't been invented yet in 1964, and with three young boys crammed into two bedrooms, there wasn't a lot of room for more than a well-used desk and a basic desk chair.

"What are you doing, Daddy?"

"Working on my new company."

"What does your new company do?"

"We make chemicals."'

"What's a chemical?"

You get the picture. It wasn't until many years later that I fully understood the sacrifices that he and my mother made during his rookie years as an entrepreneur. At 34 years old, he worked all day as a purchasing agent for a large chemical company, came home to join us for dinner and went right back to work on his company until the wee hours of the morning. The next year, he was selling his own products by day and making them by night, gaining ground on his dream of owning his own chemical manufacturing company.

It took Dad about 3 years to harness enough of that dream to surprise us by driving home in a brand new Cadillac Sedan DeVille. I'll never forget the look of pride on his face, or the message it sent to me: Big rewards sometimes require big risks.

The car was just a bonus for me, though. It was merely an upgraded transport to the really exciting event: Saturday morning visits to the headquarters of Tower Chemical Co. Dad and Mom (no slouch herself, graduating with honors from Penn State) thought the name sounded "regal … the best … the top." They were marketeers ahead of their time, no?

The company grew and was relocated several times, eventually landing in a large, former block-and-tackle plant on 4 acres of industrial property, filled with just about the coolest stuff this young boy had ever seen.

Giant stainless steel mixing tanks. Powerful pumps. Metering gear. Immersion heaters. Hundreds of steel barrels. Labeling machines. And best of all, a ceiling-mounted hoist, a fantasmagorical device that buzzed, whirred and clicked at the touch of a button while moving chemicals from inventory to mixing tanks. Years later, I would join fellow employee pranksters in giving each other "rides" on that very same hoist. Kind of the industrial equivalent of hay jumping, I suppose.

But those Saturday mornings, free of the workday pressures of running the business, manufacturing school was open and Dad was the teacher, presiding over his latest capital investment and explaining how it would help the business grow. Dad was a patient, articulate teacher with an infectious enthusiasm for the unique challenges and rewards of manufacturing.

He also treated his employees like family long before the concept was extolled by management gurus as a characteristic of great leaders. Dad's employees loved working for him because treating people well came naturally to him; he was as close to an employer without guile as anyone I've ever met.

There is, of course, much, much more to this story, but I've made my point and, hopefully, answered the question upon which this column is based. Why do I love manufacturing and the world of business? Simple. Even at 45 years old, I still want to be just like my dad.

## About the Author

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# Guide the way

Linear guides provide a way to simultaneously transport applied loads of all types—including static (transporting simple weight such as a pallet of material) and dynamic (moving and working, such as a cutting tool turret)—and to guide their linear movement. They are classified into four major groups.

Sliding contact linear guides have a high friction coefficient and, therefore, are considered inferior for precise positioning applications. Rolling element linear guides decrease friction via rolling elements placed between two moving objects, and are for high-accuracy positioning.

Hydrostatic and aerostatic linear guides have pressurized fluid forcibly supplied between two moving objects, one of which is kept floating by the fluid. Depending on the fluid, it is classified as aerostatic or hydrostatic. This type is costly and usually reserved for ultraprecision machines.

Magnetic linear guides keep one of two moving objects afloat by means of magnetic force, either repelling or attracting. This type is also expensive and has limited applications.

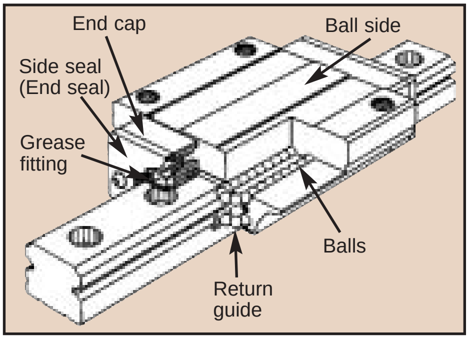
Rolling element linear guides are the most popular and, therefore, the focus of this article. With this type, steel balls (or rollers) move along the ball grooves formed on a rail and a ball slide until they are scooped up by the tip of an end cap. There, they are forced to change their circulating direction by a return guide on the end cap and guided to a circulating hole provided inside of the ball slide. The balls continue to pass through the hole to the other end of the ball slide and, further, go through the circulation circuit to the tip of the end cap on the other side and then return to the ball grooves of the rail and ball slide. Thus, the balls continue their endless circulation.

To eliminate internal clearance between a rail and ball slide (zero backlash) and minimize elastic deformation caused by external force, which enhances rigidity, preload is applied. This is accomplished by squeezing oversize balls into ball tracks to create elastic deformation on balls and ball grooves. It is as if an external load is working prior to applying actual load to a ball slide. Preload can be controlled by minute change of the ball size. Increase in preload enhances rigidity of the linear guides.

To ensure linear guides provide long wear and high accuracy in contaminated environments, special protection and appropriate lubrication are needed. To prevent foreign particles from entering the inside of a ball slide, it has an end seal on both ends and a bottom seal. For higher sealing capability, two end seals are assembled to one end of a ball slide. Protectors, which are attached to the outside of end seals, prevent high-temperature dust particles or hard foreign materials from entering the ball slides. Inner seals are provided to protect ball-contact surfaces from any of those foreign particles that the end seals could not catch.

After the rails are mounted onto the machine base, all bolt holes are plugged by caps so there are no depressions on the top surface of the rail. Such depressions may collect foreign particles and allow them to enter the inside of the ball slide.

Linear guides have various features that allow them to be used in high-speed, high-accuracy applications. The difference between static friction force and dynamic friction force is small, and the variation of friction force due to speed is small. Consequently, there is less stick-slip and precise positioning can be made since linear guides can be fed in minute steps. Low friction force enables high-speed operation with reduced energy consumption and heat generation. Minimal wear means they are capable of maintaining accuracy for a prolonged time.



NSK

**Structure of a linear guide.**

To select appropriate linear guides, some general information is needed:

Application—Type of machine (application), such as machine tool, transporting system or measurement apparatus, for which linear guides are to be used.

Machine structure—Structure of the machine and its relevant aspects of construction such as dimensions around the place where linear guides are mounted to, positions and directions of external forces.

Applied loads—Loads applied to the linear guides, which usually consist of the weight of a table, the weight of transported objects and the forces that are working on a machine tool. The loads are normally applied vertically or laterally against the motion axis.

Speed—Relative speed of the table against the rail. It is expressed, for example, as 100 m/min.

Accuracy—Mounting surface tolerances and running parallelism accuracy of ball slides. The required motion accuracy is expressed in a particular accuracy grade, like P5 or PN.

Required life—This is expressed in a total travel distance, such as 5,000km.

*This information was adapted from a training guide on linear guides from NSK Corp., Ann Arbor, Mich. For more information, call (734) 913-7500 or visit www.us.nsk.com.*

# Reel momentum

**BY BILL KENNEDY, CONTRIBUTING EDITOR**

Crow Corp. provides a number of services, including laser cutting and marking, metal stamping, fabrication and machining. One of its machining jobs is an inertia reel spindle component of a safety belt retractor for Aircraft Belts Inc., a developer of aircraft safety restraints.

The part is made from 1½"-dia., 4130 steel bar stock, hardened to 40 HRC. After the first 0.184" of the reel's 2.913" length is rough-turned to a diameter of 0.927", two 1.01"-dia. flanges, 0.125" and 0.037" wide, are machined with a 0.062" groove between them. The next 2.171" of the part is turned to a 0.892" diameter. For the remaining 0.334" of length, the diameter steps down to 0.446". Both ends of the bar receive 0.01"×0.01" chamfers.

Brian Morgan, lead machinist at Crow, said that one of the greatest challenges in making the part has been developing fixturing to maximize efficiency. For example, the first set of milling operations employs two custom vises that hold a pair of parts horizontally under the spindle of a Haas VF-3 vertical machining center. The reels are moved from vise to vise, enabling both sides to be milled in one setup.

In the first vise, beginning at the 0.037"-wide flange, Crow mills a 1.971"-long, 0.321"-deep flat on one side of the reel. Each end of the flat gets a 0.63" corner radius where it meets the rest of the part. The reel is then rotated 180° around its axis and moved to the second vise, where an identical flat is milled on the part's opposite side. The resulting flat section of the reel is 0.250" thick. Crow mills the flats with a 1"-dia. Iscar Heli2000 HM-90 endmill tooled with two coated-carbide, 0.062"-nose-radius inserts. The cutting speed is 480 sfm, feed rate is 16 ipm and DOC is 0.100". Milling the flats takes 3 minutes.

Then, working on the reel that is clamped in the second vise, Crow machines a 0.200"-wide, 1.971"-long center slot through the flat. The slot has a 0.100" radius on each end. A Garr 3/16"-dia., square-shoulder carbide endmill, run at 360 sfm, 16 ipm and 0.050" DOC, cuts the slot in 4 minutes.

For the next set of operations, another custom-vise setup holds three parts vertically. The first step creates an irregularly shaped, flat-bottom, 0.184"-deep contour in the 0.927" end of the reel. Three Garr carbide, square-shoulder endmills do the cutting: a 3/16"-dia. tool, run at 250 sfm and 10 ipm, a ⅛" at 250 sfm and 5 ipm, and a 1/16" at 120 sfm and 3 ipm. After a No. 11 (0.190"-dia.) Nachi America HSS drill makes one hole at 72 sfm and 4.3 ipm, a No. 43 (0.0890"-dia.) Nachi HSS drill makes two more holes at 72 sfm and 3.9 ipm. Those two holes are tapped with a 4-40 Vega Tool HSS bottoming tap, guided by the Haas machine's rigid tapping cycle. This set of operations consumes 8 minutes.

Keith Jennings, Crow's president and general manager, said the company has worked continually for more than 5 years to optimize the processes used to produce these parts. Experimentation has led to the best combination of tools to produce certain features. For example, Jennings said, when milling the end features "you can't take just a little finish mill and do it, it would take forever. You have to use a rough-cut mill, take most of the material out, then come back with smaller finishing mills to get your final dimensions."

Allen Lee, Crow estimator and raw materials procurement coordinator, added that working with a knowledgeable and responsive tooling supplier can save a lot of process development time. Bass Tool & Supply Inc., a Houston-area tool distributor, provided tool choice and application recommendations. "Next thing you know, we're just zipping along. If we alone were responsible for what they've helped us with, it would have definitely taken us longer," he said.

Crow

**It takes approximately 16 minutes to machine one of these inertia reels.**

For the final operation, Crow clamps each part individually on the VMC's 4th-axis rotary table. The part is oriented horizontally to present the 0.446"-dia. end of the reel at 90° to the machine spindle. Three 0.267"-deep slots are cut in the end with a 2¼"-dia., 0.51"-wide Globus HSS slitting saw run at 300 rpm and 5 ipm. Two of the slots are parallel and 0.053" apart, bracketing the center of the part axis. The third slot cuts through the center axis at a 75° angle to the parallel slots. The rotating table enables Crow to cut all three slots in one clamping. Total cutting time for the reel is about 16 minutes.

Throughout the manufacturing process, Crow holds a tolerance of ±0.005" for the part. The company makes about 2,000 of these reels a year, in lots of about 335 pieces.

*For more information about Crow Corp., Tomball, Texas, call (800) 642-2769 or visit www.crowcorp.com.*

# Calculated metalcutting

**INTERVIEWED BY ALAN RICHTER, EDITOR**

*Edmund Isakov, Ph.D., resides in Boynton Beach, Fla., and is an independent consultant specializing in advanced metalcutting calculations for milling, turning, boring and drilling. For 18 years, he worked at Kennametal Inc., where he served as senior staff engineer. He is also a book author and contributing editor at Industrial Press Inc., a New York-based publisher of manufacturing and engineering books. Isakov's latest book is* Engineering Formulas for Metalcutting. *Isakov spoke about the importance of knowing a workpiece material's hardness, calculating horsepower requirements and limiting harmonic vibration.*

**CUTTING TOOL ENGINEERING:** What's important when determining the cutting parameters?

**Edmund Isakov:** When milling, turning, boring or drilling, determining the cutting parameters depends on type or class of the workpiece and its hardness, which almost always is available. When the cutting edge penetrates into a workpiece at a given DOC and feed rate, a deformed layer from the workpiece transforms into a chip because the cutting edge generates sufficient stress, which overcomes the ultimate tensile strength of the work material. This generates the cutting force, the magnitude of which depends on the cross-sectional area of the chip. Knowing the work material's tensile strength, which depends on the workpiece hardness, and the area of the chip allows the cutting force to be calculated.

**CTE:** How can an end user select a machine tool with the appropriate horsepower?

**Isakov:** Such selection is based on the end user's experience in machining various work materials or just on the old rule of thumb: 1 hp per each cubic inch of material removed in 1 minute. Today, much more accurate methods of calculating horsepower allow end users to select appropriate machine tools. If you know how to calculate the cutting force vs. machining conditions, you can figure out how much horsepower you'll need. Take for example a milling case that was brought to my attention during a trade show. An exhibitor told me his 3-hp, bench-type milling machine kept stalling. I asked him to give me the cutting parameters he selected, and I calculated the needed horsepower. When I showed him the results at the parameters he selected, it was 8 hp. That's why the machine was stalling. So I reduced the cutting parameters in a way that did not exceed the available horsepower. Eventually, I came up with parameters for machining at 2.9 hp. I walked with him to his booth, watched as he reprogrammed the machine and saw how the cutting improved. The workpiece was 4140 alloy steel with a hardness of 48 HRC. The feed rate was 15 ipm, and a 2.5"-dia. milling cutter accepted five inserts. It made a nice, smooth cut with a very pleasant sound, like a sharp cutting tool going into soft material. The chips had a dark blue color. I looked at the gentleman's face and he was surprised.

**CTE:** What causes chatter?

**Isakov:** Chatter is one of the most detrimental phenomena in the machining process because it deteriorates the surface finish of a workpiece, damages tooling and decreases cutting productivity. Insufficient stiffness of the machining system causes chatter. There are two types of stiffness when looking at the machining system: static and dynamic. Static stiffness relates to the machine tool and is measured in pounds per inch, indicating how many pounds of force it takes to deflect the spindle a linear distance of 1". Dynamic stiffness is a measure of the machining system's ability to dampen vibrations from a forced input. If the dynamic stiffness of a system is not sufficient to dampen these vibrations, chatter will occur. Each machining system has a natural vibration, or resonance frequency. If the system is cutting at or near resonance frequency, the force from the inserts entering the workpiece cannot be completely dampened, causing the system to vibrate. As subsequent inserts enter the part, the additional cutting force induces more vibration. Because the vibration is not completely dampened, it continues to build as each insert enters the workpiece. Then, when enough vibration builds, the system becomes dangerously unstable. Consider a battalion of soldiers marching over a bridge in a certain pattern. Everybody, some 200 to 300 people, starts marching with the left foot, then the right foot, then the left foot, and so on. As a result of synchronized frequency, the amplitude of vibration will increase, and the bridge will collapse. The soldiers have to just walk randomly.

Edmund Isakov, Ph.D.

**CTE:** Which is more important, increasing productivity or extending tool life?

**Isakov:** Increasing productivity is more important, because tool life today is not so important compared to the cost of the machining operation. Consider an indexable insert that costs from $6 to $10 and the cost per hour of machining, which is about $100. So if you lose on tool life but gain on productivity, you'll save a lot of money. However, when selecting cutting parameters, running a tool at a higher cutting speed is much better than cutting with an increased DOC and feed rate. The reason is simple: the higher cutting speed won't increase the cutting force, but an increased DOC and feed rate will.

BY DR. JEFFREY BADGER



# A fine surface finish is all in the dressing

**Dear Doc,**

I ID-grind 57 to 62 HRC hardened steel and can't seem to impart the desired 16 $R_a$ surface finish. With a rotary dresser, I rough-dress 0.25mm and rough-grind a depth of 0.6mm. Then, I finish-dress 0.013mm and finish-grind a depth of 0.04mm at slow speeds with a long spark-out. Right now, I'm getting 20 to 24 $R_a$ with a vitrified 100-grit wheel. I've tried using a 120-grit wheel and upping the synthetic concentration from 5 to 7 percent, but it didn't help. Any advice?

**The Doc replies:**

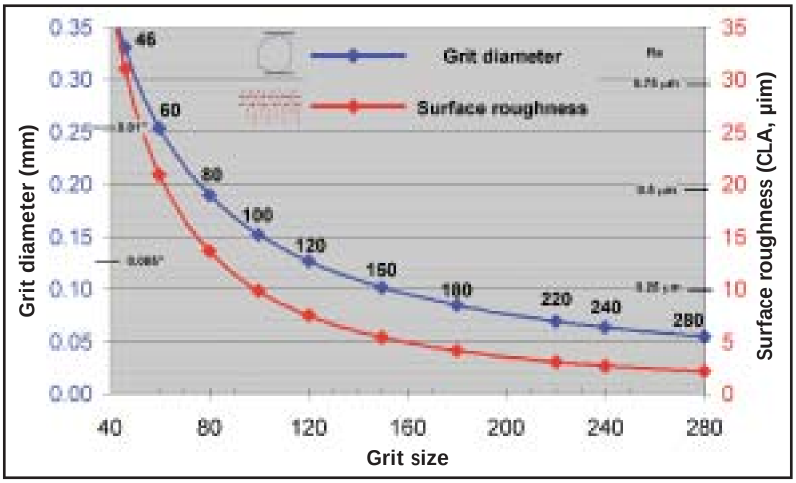
First, altering coolant concentration won't yield much of a change. A university study showed that changes in concentration didn't produce any change in results and, above 5 percent, no difference at all (Howes. *Annals of CIRP*, Vol. 29/1/1990). Based on my practical experience, it's just not worth messing with.

Now, let's look at grit size. Wheel producers publish guidelines for which grit size to use to impart a given surface finish. Of course, surface finish also depends on lots of other parameters, but these guidelines give a general idea of which grit size to start with. The graph, compiled from averages of several wheel producers' guidelines, shows that to achieve a 16 $R_a$ finish, you need about a 70-grit wheel. You're using a 100-grit wheel, so your issue is not grit size.

Next, let's look at your dressing parameters. In most cases, dressing parameters (and grinding speeds and feeds) have a far greater effect on surface finish than grit size. You're rough dressing a whopping 0.25mm off of the wheel. The average diameter of grits in a 100-grit wheel is 0.15mm. So you're dressing almost 2 grit diameters off of the wheel. That's a lot—certainly more than is needed to sharpen the wheel and remove any loading. Most guidelines recommend dressing depths of 0.010mm to 0.050mm. Any depth larger than that doesn't sharpen the wheel any better.

So the question is: Why are you dressing so much? Grinders dress for several reasons: to sharpen the wheel, to clean it up and to retain its form. If you're sharpening to keep up with wheel wear, that's fine. But if so, you should do it after the roughing pass, during which you're removing lots of material and the wheel is wearing the most.

Because rough dressing is producing an open wheel—sharp, with greater spacing between the cutting edges—finish dressing with a measly 0.013mm is probably not changing the topography of the wheel much. Remember, your grit diameter is about 0.15mm, and your rough dressing produces an open wheel. Trying to create a finer topography on your wheel to impart a finer surface finish requires you to close the rough-dressed wheel—and 0.013mm is just a 10th of the grit diameter, which is not enough to replace the rough-dressed wheel topography. So, the small dressing depth that you are using is fine for producing a smoother wheel, but you'll have to take several passes to dress away the open topography remaining from the rough dressing and replace it with a more closed topography that will impart a smooth surface on your workpiece.




J. Badger

Mean grit diameter and appropriate surface finish vs. grit size.

On top of that, since you're certainly getting a fair bit of wheel wear in rough grinding, the small amount you're fine dressing is probably just "chasing" the wheel—i.e., your wheel wear is greater than your dressing depth and you're not fine dressing the wheel at all.

Your grinding DOCs seem reasonable, so I'd recommend keeping those but changing your dressing parameters. Rough-dress a single pass of 0.050mm with little dwell; then rough-grind. Next, take five or so finish-dressing passes—with slow in-feed and longer dwell—of 0.01mm to clear away the rough-dress and impart a fine topography on the wheel. This will give a total fine dress of 0.05mm, or about a third of a grit diameter, enough to clear away the residual rough-dress. Then finish-grind at low speeds. This should give you the surface finish you're looking for. If not, dress with an even smaller depth of 0.005mm at lower speeds and longer dwell.

Intelligently choosing your dressing parameters can help you achieve just about any result you want, be it temperature reduction, burr minimization or finer surface finish. △

### About the Author

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