Grinding Process Solutions

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Introduction

This book will take you from a grinding novice to a process specialist. The material is divided into six sections:

Grinding Process Solutions is as much about process engineering as it is about grinding theory. Being able to apply what you learn is just as important as the knowledge itself. After reading this book, you should be able to walk up to any grinding machine and systematically improve the process.

For grinding training and process engineering support, please visit GrindingProcessSolutions.com

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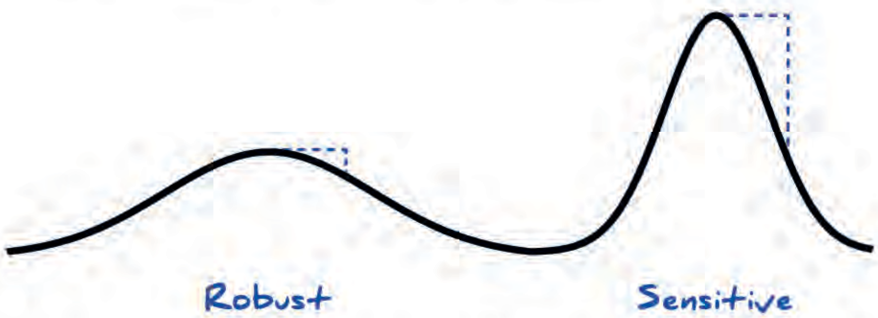
Robust Processes

The inputs of a production grinding process will vary over time and between parts. This is inevitable. In a **robust process**, minor changes to the inputs do not significantly change the outputs.

A robust process is similar to a flat hilltop, where the elevation would not change much even if you took several steps. Conversely, a **sensitive process** is like a steep hilltop. If you were to take a step in any direction, your elevation would change significantly. In practice, a grinding process should not be set up to run at the highest peak, but at the highest peak that is easy to stay on.



Imagine you are trying to grind a circular part to a very tight roundness tolerance. If the wheel goes out of balance, the roundness errors will increase. Two possible solutions are:

1. Install an automatic balancer on the grinding spindle. This prevents you from stepping too far from the peak of the steep hilltop.
2. Replace the current grinding spindle with a stiffer one that does not deflect as much when the wheel goes out of balance. This changes the hilltop from a sharp peak to a plateau. Even if you took a step away from the peak, it would not matter much.

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Pp and Ppk

Pp is the process variation compared to the specification. The formula is:

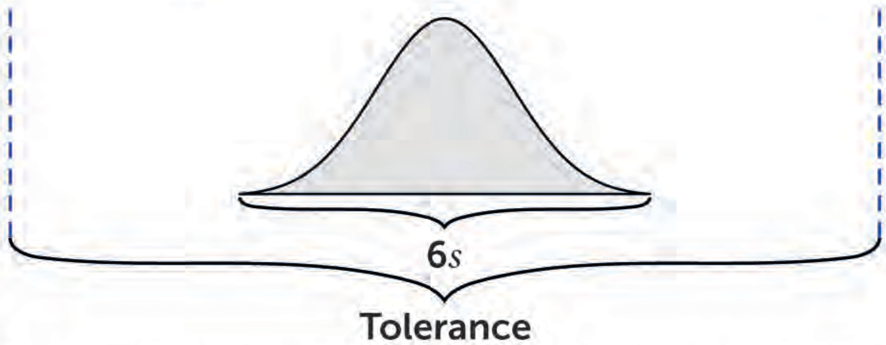
$$Pp = \frac{Tolerance}{6s}$$

Pp

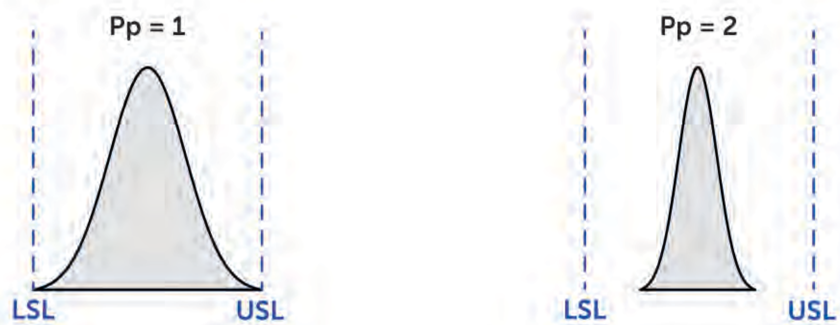
The tolerance is the total specification of the workpiece.

6*s* can be pictured as the width of the distribution of data.

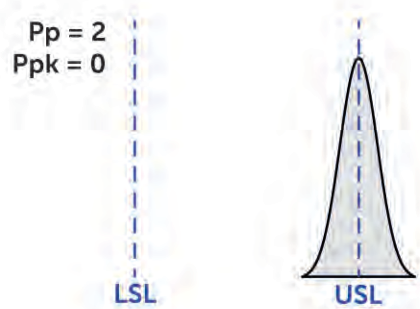
For a normally distributed data set, 6*s* would include 99.7% of all of the data values.



Pp is simply the ratio of the tolerance to the width of the distribution. When the width of the distribution is equal to the tolerance, Pp = 1. If the width of the distribution is half of the tolerance, Pp = 2.



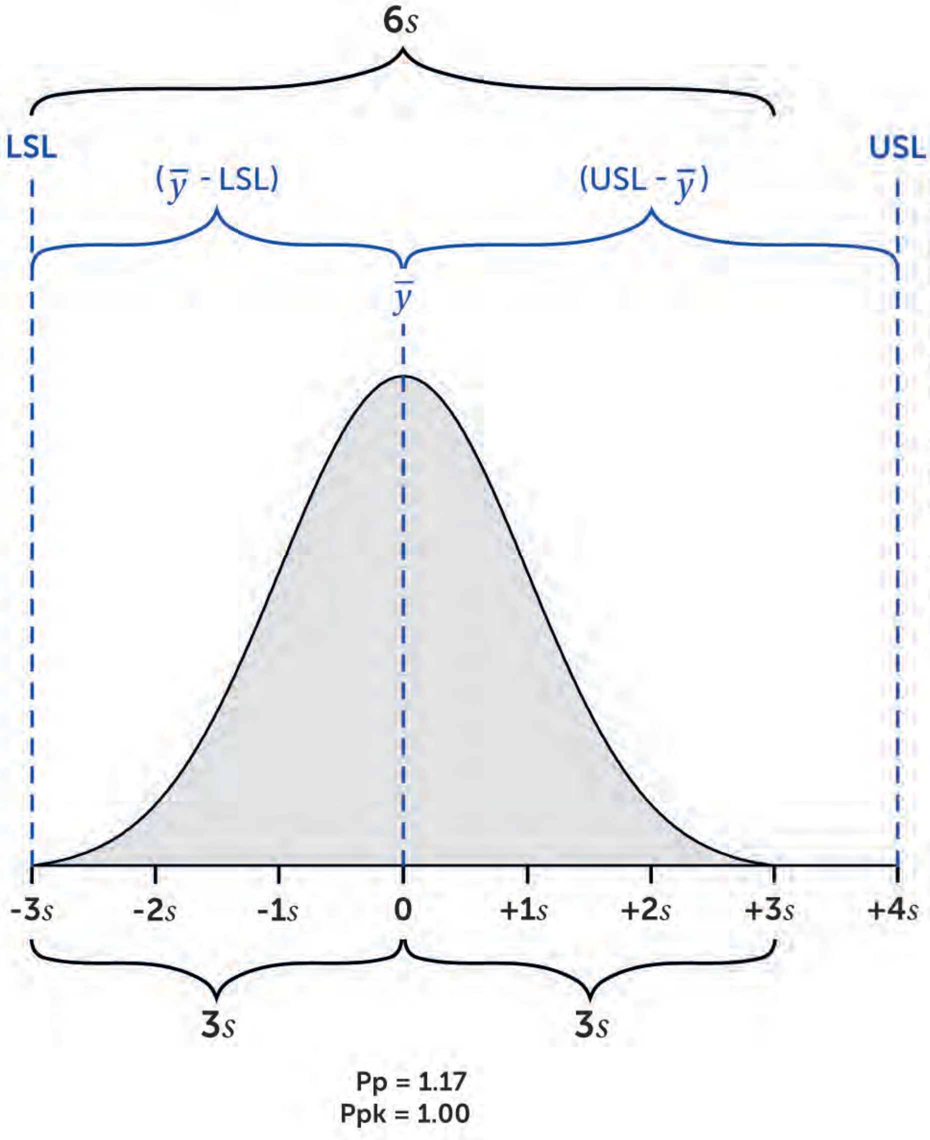
Pp does not take into account how well the data is centered. You could have an acceptable Pp value and still have many parts outside of the specification.



Another number is needed that considers how well the process is centered. **Ppk** does this by determining how far the mean is from the edge of the specification. The formula is:

Ppk = The minimum of either,

$$\frac{(\bar{y} - \text{lower tolerance})}{3s} \quad \text{or} \quad \frac{(\text{upper tolerance} - \bar{y})}{3s}$$



Ppk
To calculate Ppk, first find the difference between the mean ($\bar{y}$), and the upper and lower tolerances (USL & LSL). This will provide two values.

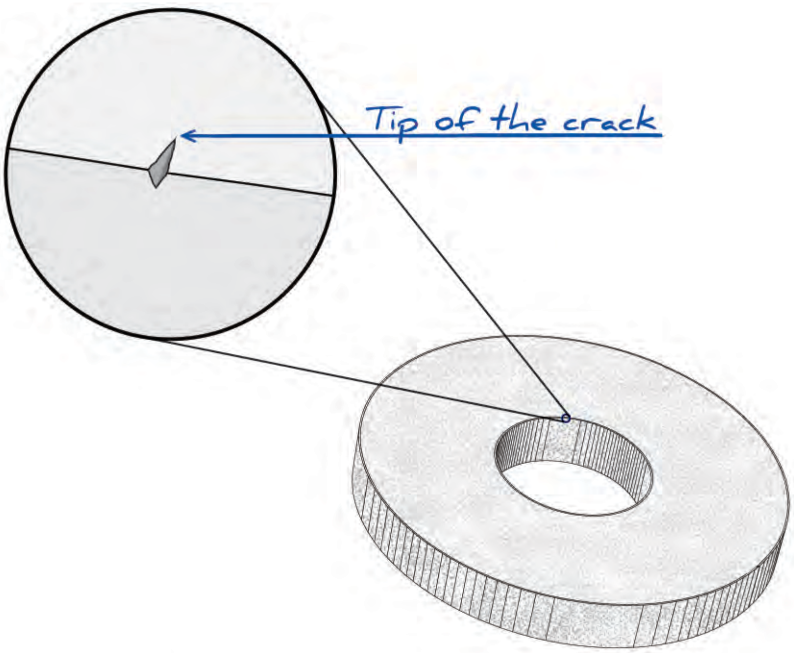
Then divide them by half of the width of the distribution (3*s*).

The lower of the two calculations is the Ppk (the minimum of either).

Fatigue Failure

Fatigue failure occurs when an object fails or breaks apart after being repeatedly loaded and unloaded. Failure may happen under loads that are much lower than you would expect. For example, if you tried to break a metal fork in half by ripping it apart, you would not succeed. However, if you bend it back and forth many times, it becomes easy to pull apart.

The fatigue phenomenon is caused by a crack slowly propagating through the material. All surfaces have tiny cracks in them. If the stress is high enough at the tip of the crack to break even one molecular bond, the crack will grow. If the loading is repeated often enough, this crack will grow until the entire object eventually comes apart.



Sometimes a grinding wheel will blow apart from fatigue failure. The imbalance in the wheel causes the forces to increase and decrease, propagating the crack each time the wheel rotates. To minimize this risk, always keep your grinding wheels below their rated speed.

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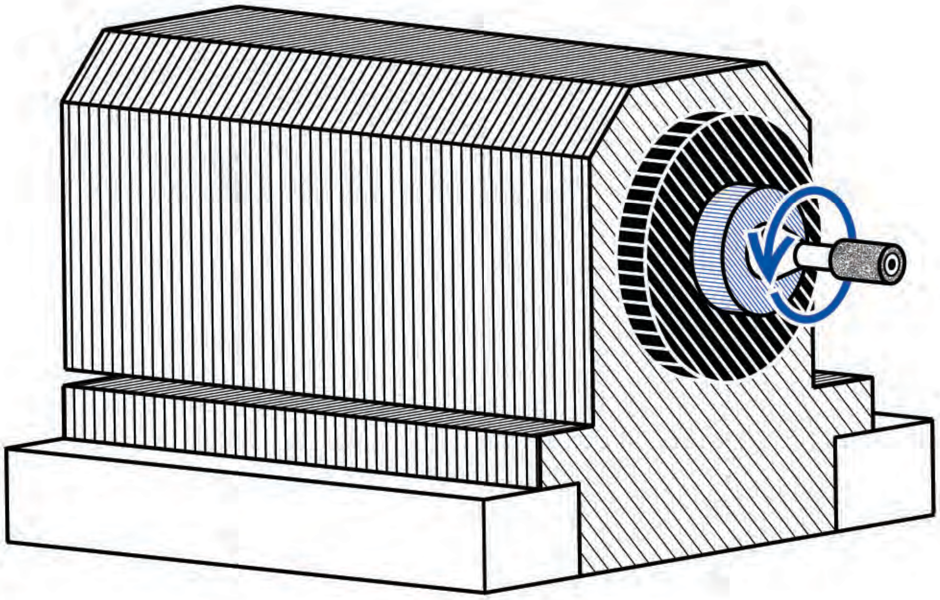
Spindles

Spindles are the devices that provide rotary motion on a grinding machine. Spindles spin the grinding wheel, workpiece, or dressing tool, sometimes up to 150,000 RPMs or more.

Spindles are like slideways that move around in a circle. The basic elements of spindles are the same as slideways: **bearings**, **power unit**, **sensors**, and **controls**.



High speed spindles are usually the least stiff part of the grinding machine, limiting the grinding process capability and productivity. They are also the machine component that wears out or is damaged the most frequently.

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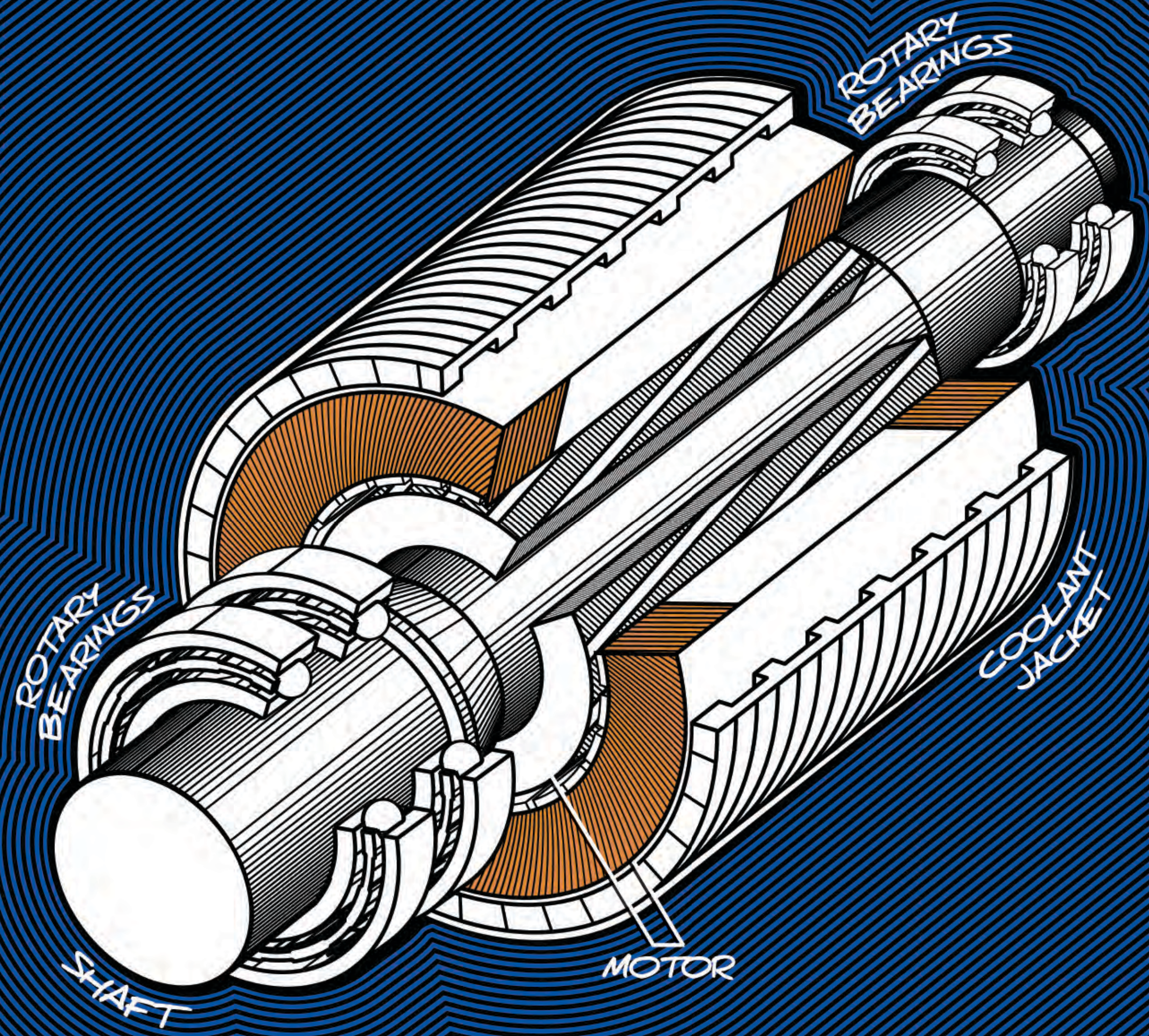
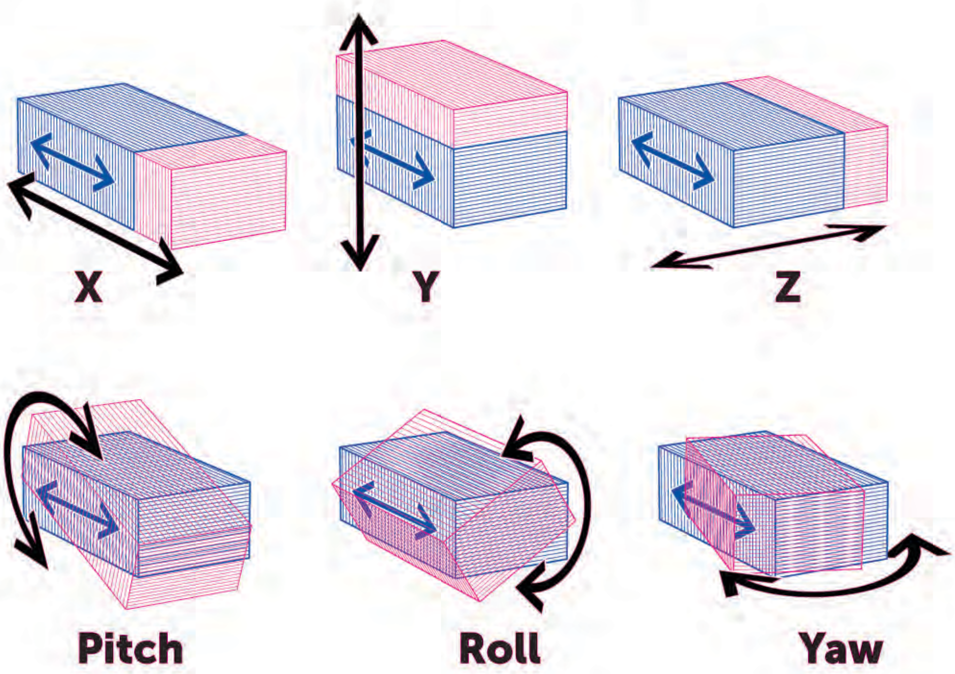

ROTARY BEARINGS
ROTARY BEARINGS
COOLANT JACKET
SHAFT
MOTOR

Analyzing Slideways and Spindles

Error Motion

No slideway or spindle is perfect. When a slideway moves along its track, there will be small errors in the three linear axis, **X**, **Y**, and **Z**, and the three rotational directions, **pitch**, **roll**, and **yaw**.



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Spindles have errors in the axial and radial directions, called **runout**.

There is also a slight tumbling error motion, called **tilt**.

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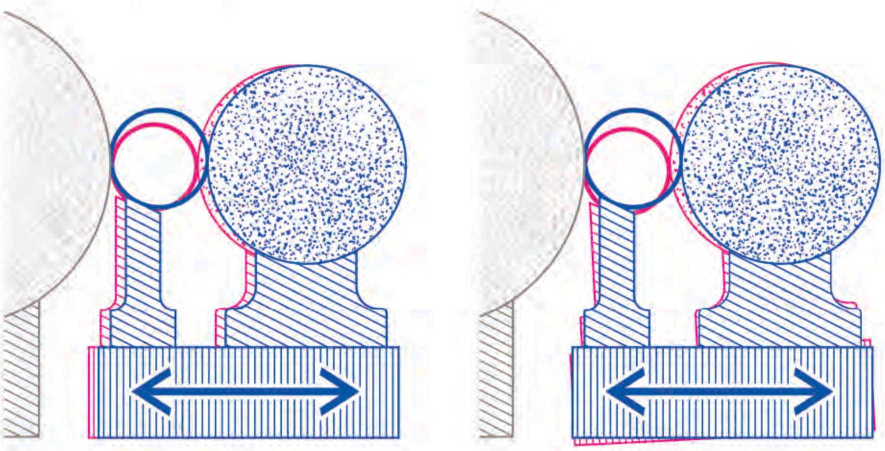
These small movements are known as *error motion*. The error motion will gradually increase over time from normal damage and wear.

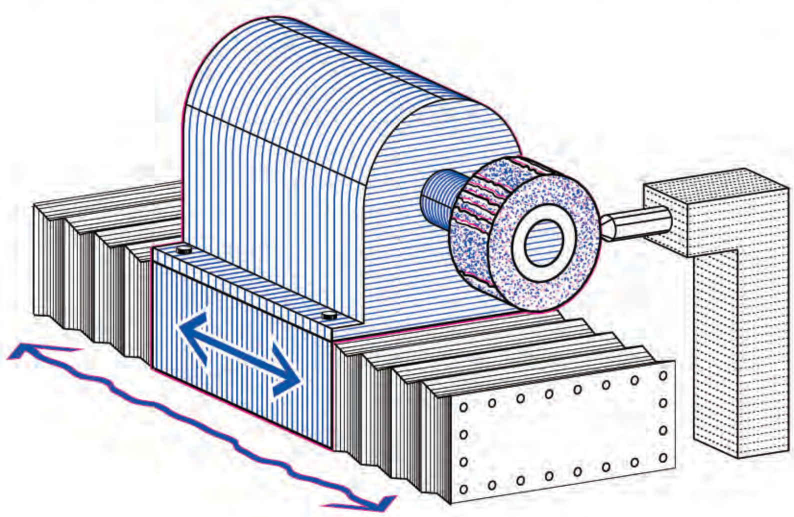
How the error motion affects the grinding process depends on how the grinding machine is configured. Suppose that you are plunge centerless grinding, any **x-direction** or **pitch** errors will affect the size of the workpiece.



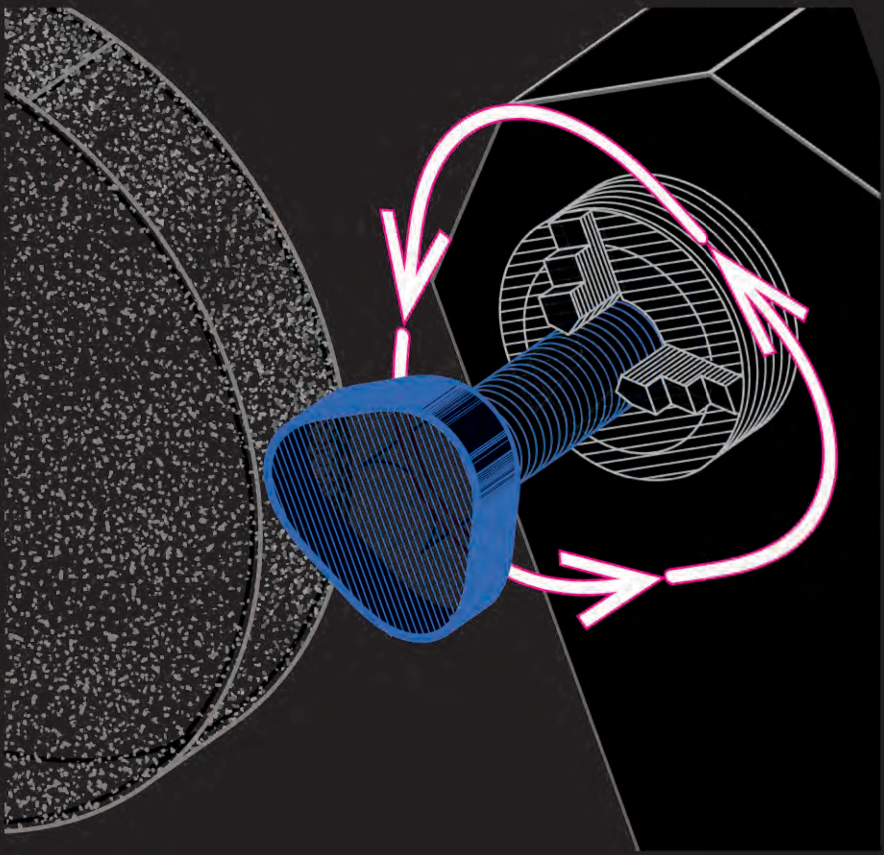
X-Direction

Pitch

If you are traversing a grinding wheel across the face of a diamond tool, any errors in the **z-direction** will create a rough surface on the wheel and impart a rougher surface finish on the workpiece.



The spindle's error motion also affects the workpiece. For example, if you are chucking a part, radial runout of the workhead spindle will translate directly into workpiece roundness errors.



If you suspect that error motion is causing problems in your grinding process, you will need a gauge to measure the displacement.

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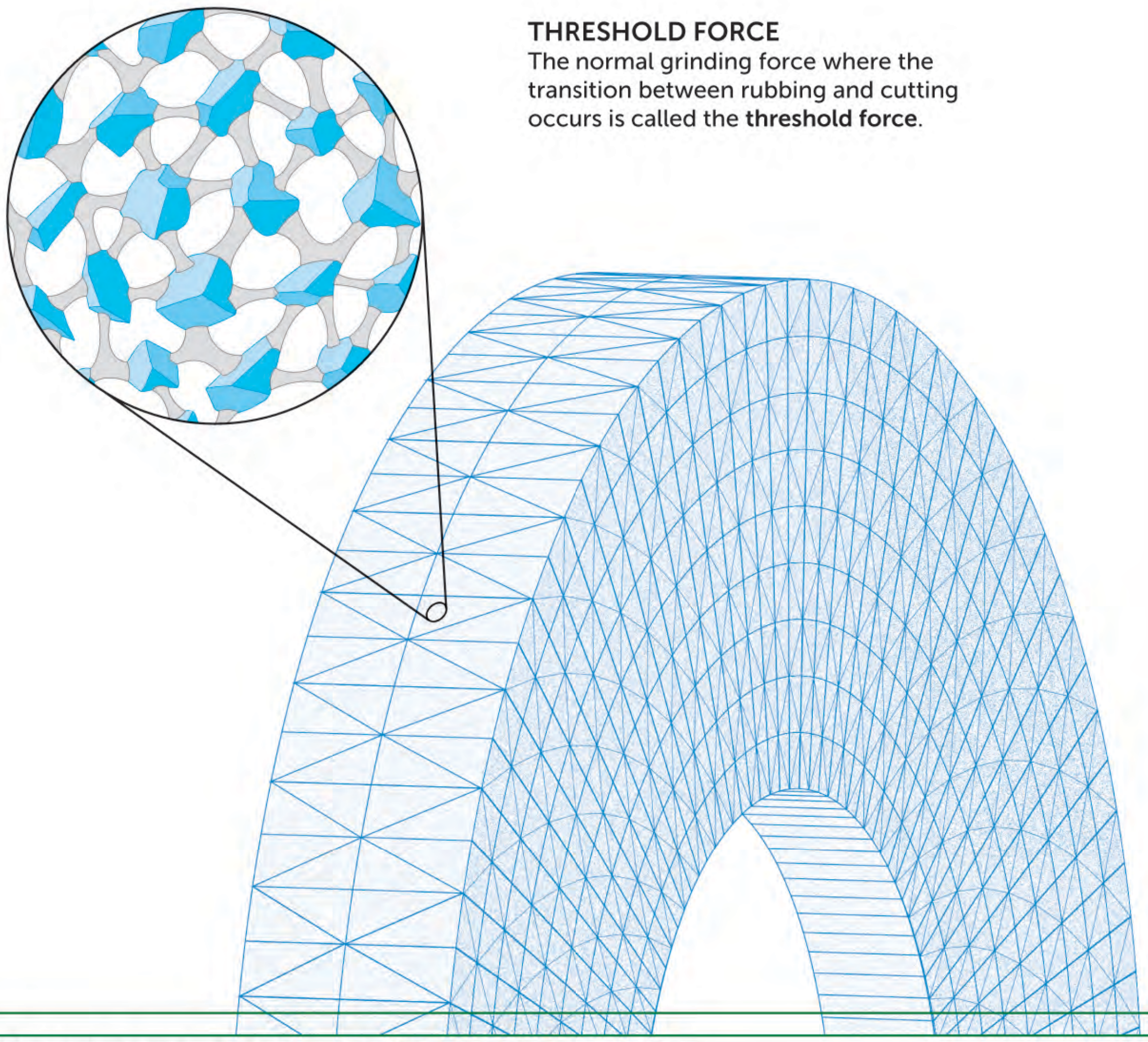
Abrasive Grain Cutting

Grinding wheels are made up of many abrasive grains held together by bonding material. When the spinning grinding wheel contacts the workpiece, the grains on the surface act like several individual cutting tools.

At first, the grains do not carve out chips; they just rub and smear the workpiece material around. Only when the forces are high enough will the grains penetrate the surface of the workpiece and start to carve out chips. Now the grinding wheel is removing material.

THRESHOLD FORCE
The normal grinding force where the transition between rubbing and cutting occurs is called the **threshold force**.



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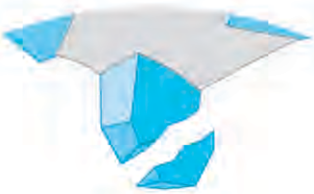
Wear Flat and Self-Sharpening Cycle

During grinding, the tips of the abrasive grains wear down and develop *wear flats*.

As the wear flats get larger, more force is required to create chips. Eventually, the pressure builds on the grain and one of three things happen:

The bonding material holding the abrasive may fail, releasing the grain and exposing the abrasives below.



The abrasive grain may fracture, creating new cutting edges.

The abrasive and bond may withstand these higher pressures, and the wheel remains dull.

When the abrasives fall out or fracture, the wheel sharpens and the wear flat growth begins again. This cycle is happening to all of the active grains on the wheel. You may think that with so many grains, some would be sharp, some would be dull, and the cutting forces would average out. But this is not the case. Most of the individual abrasive grains go through this self-sharpening cycle in unison. As a result, the grinding wheel dulls and self-sharpens as one.

Coolant Flow Rate

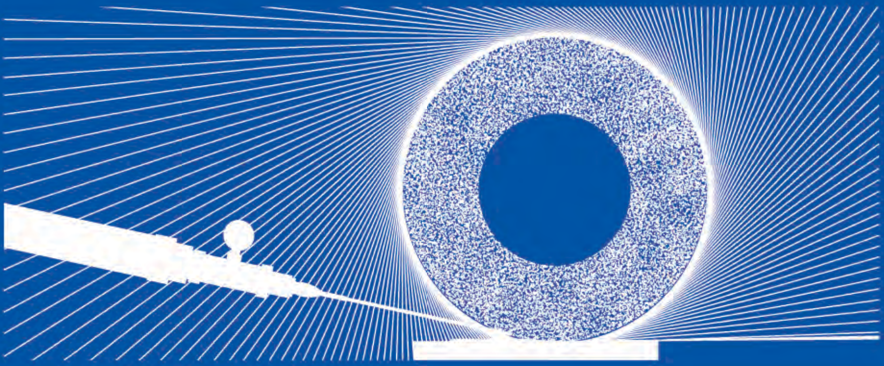
The amount of coolant needed for grinding includes the fluid that gets into the grinding zone, the splashing coolant that cools the wheel and workpiece, and some excess to account for inefficiencies. If too much grinding fluid is used, energy will be wasted pumping and chilling the extra coolant.

You can estimate how much coolant you need from the amount of energy being used to grind. The flow rate should be about ten liters per minute per kilowatt of grinding spindle power (two gallons per minute per horsepower).

If you do not know how much power the spindle is using, you can estimate that heavy grinding will need about 40 liters of coolant per minute for each centimeter of cutting width (25 gallons per minute per inch).

Coolant Velocity and Pressure

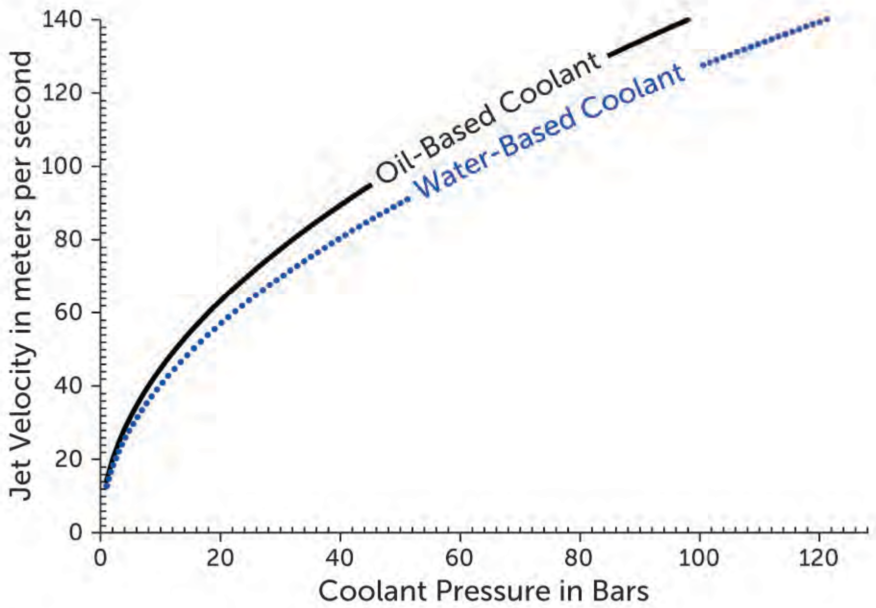
To get the most coolant into the pores of the grinding wheel, the coolant velocity should match the wheel speed. It may not be possible to reach the wheel speed with the equipment you have, but any increase in coolant velocity helps. If you are getting a decent amount of coolant into a porous wheel, there will be a halo of mist and spray coming out of the wheel in all 360 degrees.



The coolant velocity is directly related to the pressure at the nozzle:

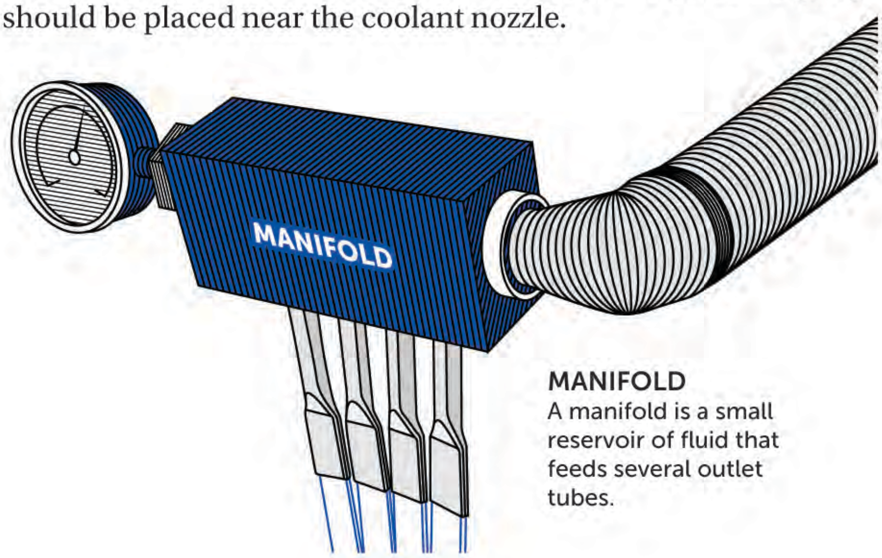
$$\text{Jet Velocity in meters per second} = \sqrt{\text{Coolant Pressure in Bars} \times 200}$$

$$\text{Jet Velocity in surface feet per minute} = \sqrt{\text{Coolant Pressure in PSI} \times 535824}$$



OIL EQUATION
These equations are for water-based coolants. For oil, the velocity is 10% faster.

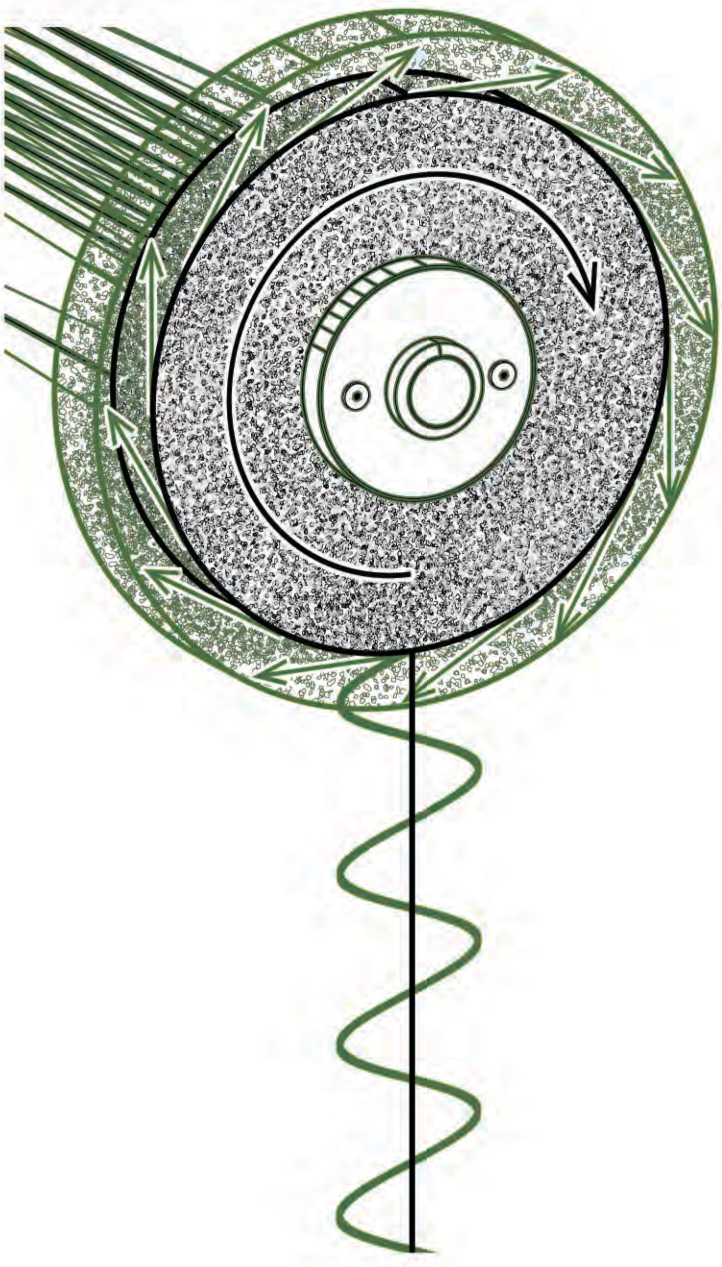
To accurately measure the coolant velocity, the pressure gauge should be placed near the coolant nozzle.



MANIFOLD
A manifold is a small reservoir of fluid that feeds several outlet tubes.

Grinding Spindle Imbalance

The imbalance of the grinding spindle is often the most significant source of vibrations.



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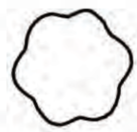
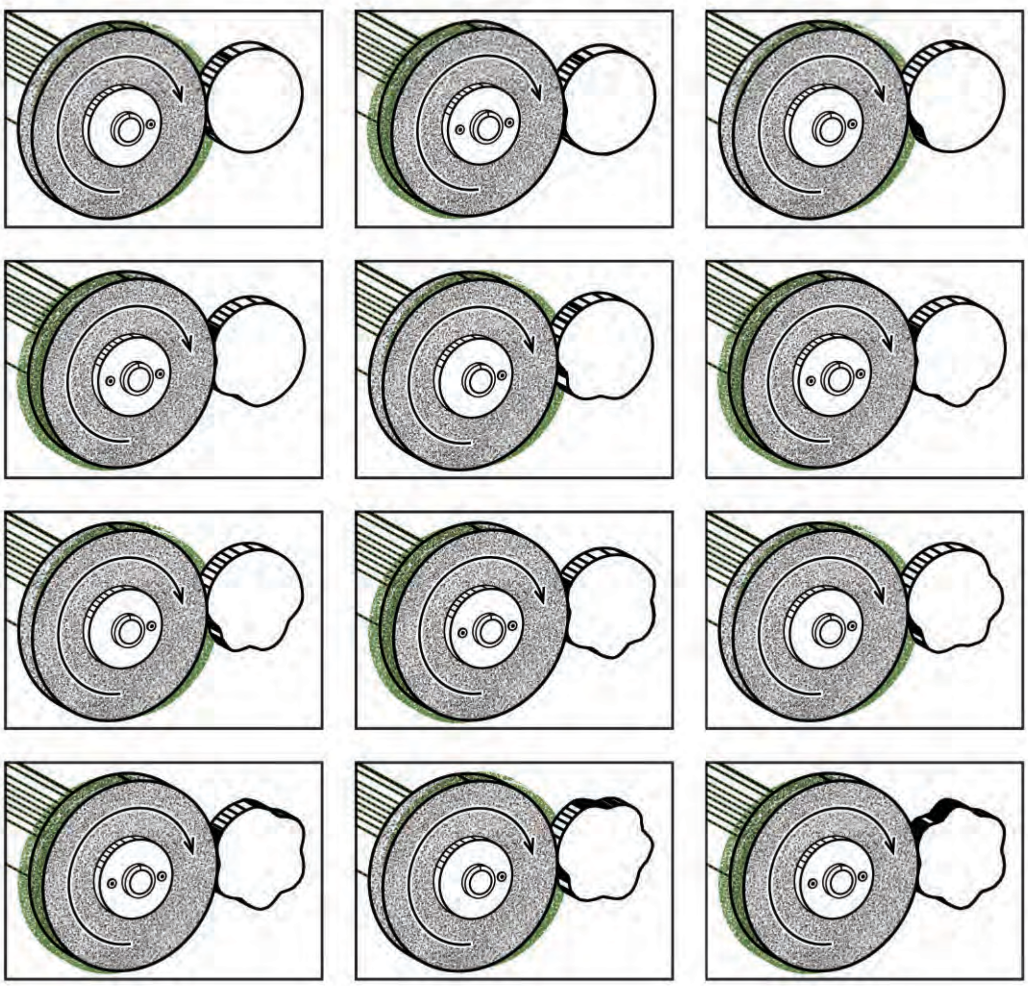
No matter how well the system is trued and balanced, each rotation of the grinding wheel will impart a waveform onto the workpiece. The larger the imbalance force and the weaker the spindle, the greater the roundness error.

The frequency and amplitude of the waveform depends on the ratio of the grinding wheel rotational speed and the workpiece rotational speed. For example, if the grinding wheel rotates six times for every workpiece revolution, then six lobes will grow on the workpiece surface.

$$\frac{\text{Grinding Wheel Rotational Speed}}{\text{Workpiece Rotational Speed}} = 6 =$$





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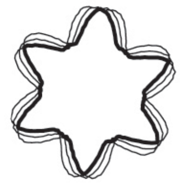
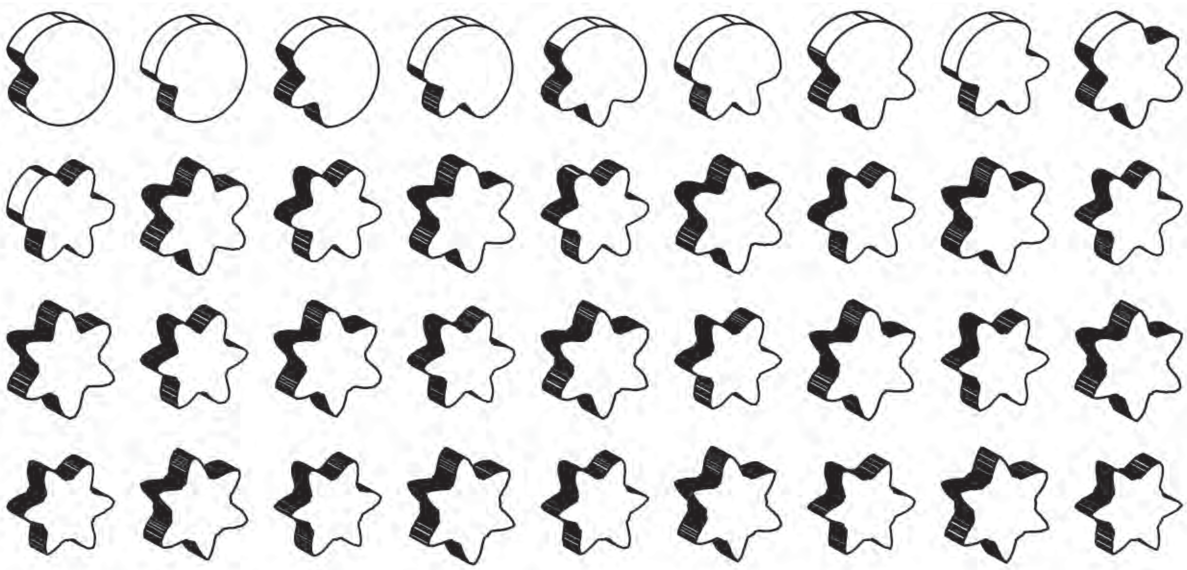
If the ratio of the grinding wheel rotational speed and the workpiece rotational speed is an integer value, the wheel will cut into the same places on the workpiece with every revolution.

$$\frac{\text{Grinding Wheel Rotational Speed}}{\text{Workpiece Rotational Speed}} = 6 =$$

If the grinding speed ratio is a fractional value, the lobes will not line up, interfering with the waveform from the previous workpiece revolution and limiting the roundness error.

$$\frac{\text{Grinding Wheel Rotational Speed}}{\text{Workpiece Rotational Speed}} = 6.1 =$$



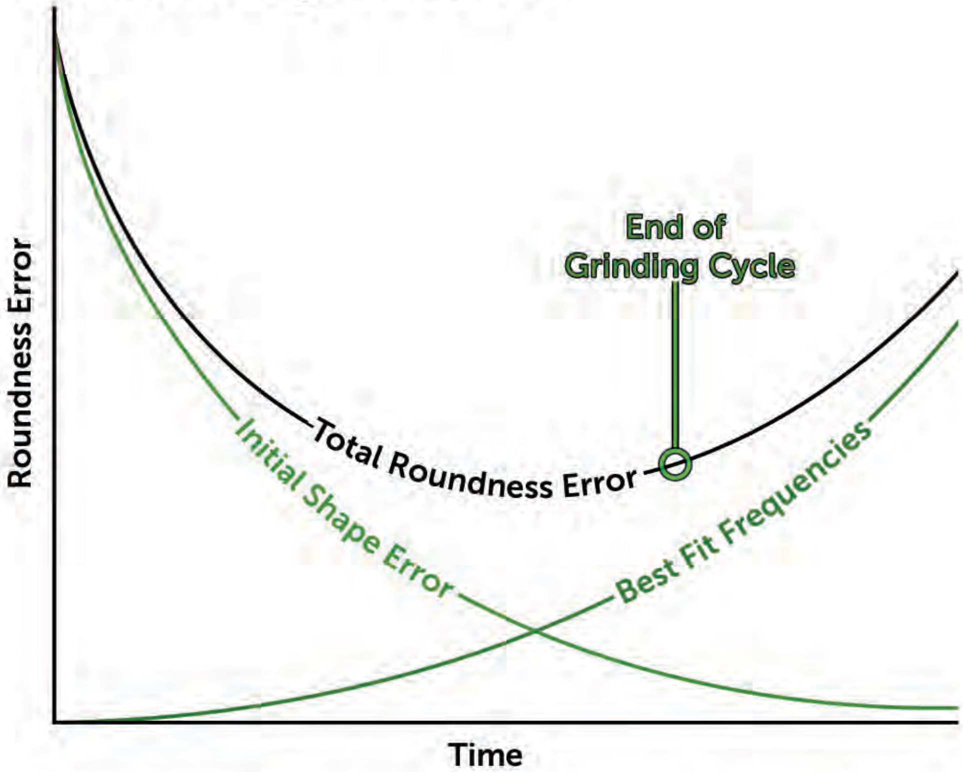


If you try a grinding speed ratio of 6.5, then the low spots will repeatedly line up with the high spots from the previous revolution. The result is a 13 lobed part. No matter what ratio you select, some multiple of the grinding speed ratio will be close enough to an integer value to potentially cause problems.

Two-Step Centerless

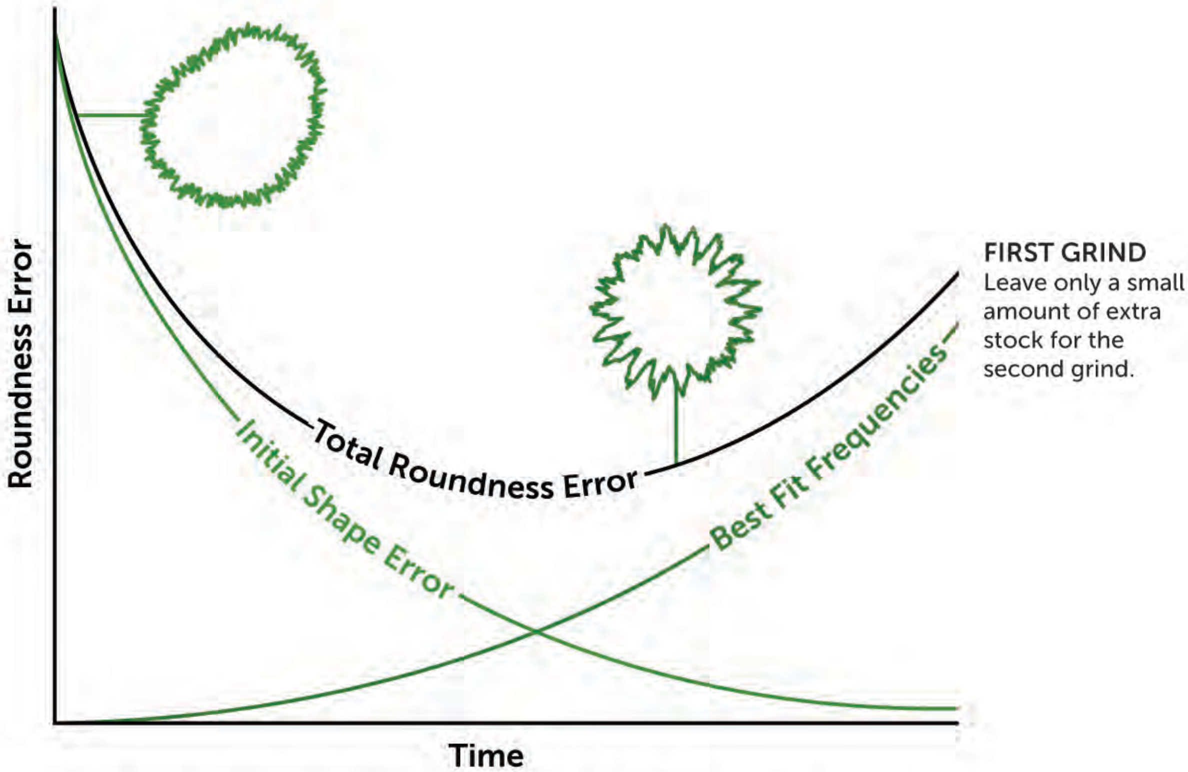
In some cases the required roundness cannot be achieved in a single operation. The initial part may be so out-of-round that by the time the initial shape rounds up, the new lobing pattern is already too large.

Rounding Trends

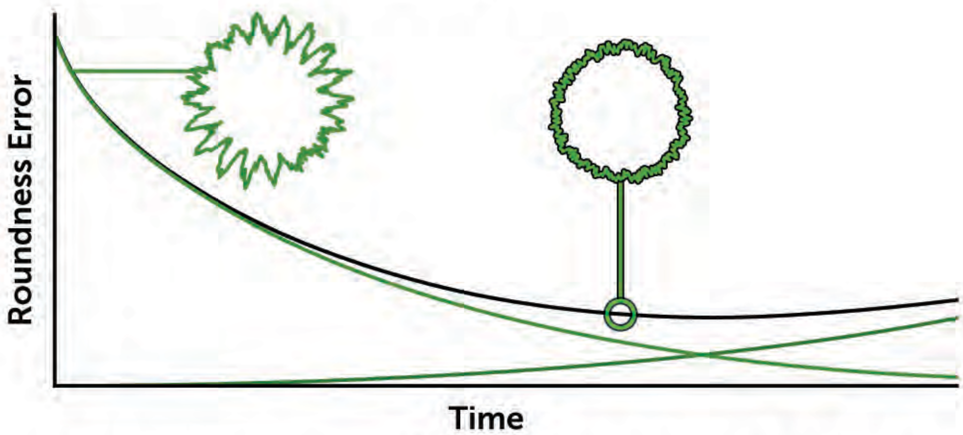


In this situation, further grinding at that same beta angle will not round up your parts. The solutions is a two step grind, with a different beta angle for each grind.

Imagine a plunge setup with incoming parts that have 2 and 3 lobe roundness error. You could set up the first grind with a 7° beta angle which could completely round up those waveforms, but leave you with 18 and 20 lobe roundness error.



Then, you could drop the beta angle to 5° for the second grind and quickly wipe out the 18 and 20 lobes before any low frequency roundness error had a chance to grow.



In a factory environment, this type of two step process works well.

Process Engineering Solutions

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