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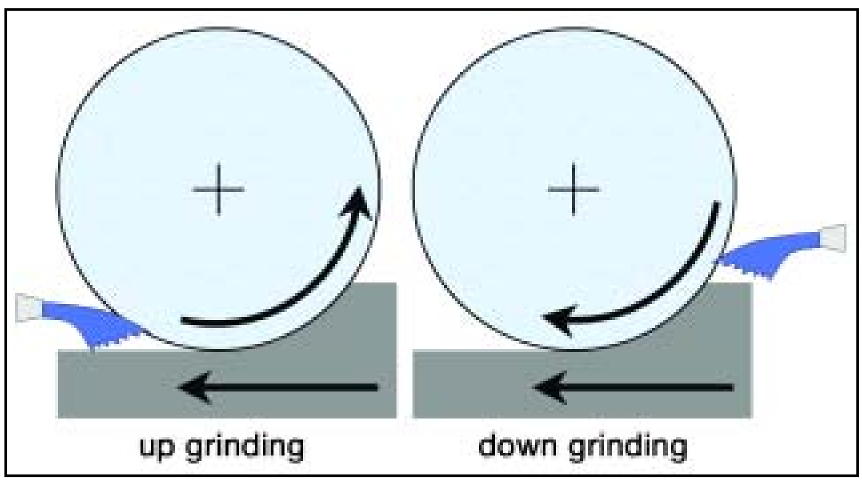
BY DR. JEFFREY BADGER

Choose Your Mode

Deciding whether up or down grinding is right for an application.

A common question production managers and machine operators ask is whether to run their machines in the up-grinding or down-grinding mode. Up grinding, the more common of the two, is when the grits and workpiece move in opposite directions. Down grinding, also called climb grinding because the wheel appears to climb over the workpiece, is when the wheel and workpiece move in the same direction (Figure 1).



Illustrations: J. Badger

Figure 1: The direction of the grinding wheel and workpiece when up grinding and down grinding.

Often, deciding which mode to use is already made for the machine operator. Geometric restrictions in the grinding chamber, particularly with nozzle placement, make switching from one mode to the other impractical. Or, sometimes, the machine is capable of only one mode. But when a machine is capable of both, the operator must make a choice.

Theories and anecdotal evidence abound about up and down grinding, and both modes have ardent supporters. But those looking for a scientific basis on which to make a decision will be disappointed. Not much literature exists on the subject, and that which does contains contradictory theories.

In down grinding, goes one theory, the grits attack at a more aggressive angle. This leads to lower forces and temperatures and promotes greater self-sharpening of the wheel than up grinding. Other evidence suggests the opposite. In up grinding, the grits enter the workpiece at a region that is hotter and softer, resulting in lower forces and temperatures.

Others have theorized that the difference in the relative speeds of the wheel and workpiece in up and down grinding change the aggressiveness of the grind. But calculations show that even at its greatest, any measured difference is less than 1 percent.

To exacerbate the quest for some general guidelines, each study has been conducted under a specific set of grinding conditions, usually in a laboratory. If these conditions are changed, the results may be completely different. And if they are applied in a real production environment, they may not work as expected.

A Controlled Study

The only controlled study on the subject of up vs. down grinding that the author is aware of was done by two university researchers, J.G. Wager and D.Y. Gu. The study, "Influence of Up-Grinding and Down-Grinding on the

Contact Zone," appeared in the Annals of CIRP (International Institution for Production Research), Vol. 40/1/1991.

Wager and Gu conducted a series of tests with a vitrified Al_2O_3 wheel on mild steel. They measured surface temperatures (using a thermocouple), surface roughness, grinding forces and burn area. Shallow cuts (0.00025" to 0.001" deep) were taken and the grinding was done dry.

Their primary findings show:

- Peak temperature was higher during down grinding, but the temperature rose more slowly.
- Down grinding produced higher forces (as much as 80 percent higher).
- The region of highest temperature in the arc of cut was closer to the exit point in up grinding.
- When up grinding, surface roughness was higher in the beginning of the contact zone; when down grinding, surface roughness was higher at the end of the contact zone.
- The oxidation-burn zone was larger and darker in down grinding, probably because of the higher peak temperatures.

Because shallow cuts were made and no coolant was used, the test conditions do not mimic a production environment. And, as will be pointed out later in the article, the researchers' results don't hold true for every application.

In addition, temperature measurements in grinding are notoriously unreliable and unpredictable. The temperature drops rapidly outside the hot spot, the area of the wheel/workpiece interface where the temperature is highest. The sampling rate must be extremely high, and the thermocouple must be in the hot spot. Sometimes the test is set up to grind away the thermocouple in hopes of measuring the highest temperature, right when the wheel contacts the workpiece. But this is enormously difficult to do. The results from such studies are usually noisy signals with huge spikes.

The upshot of all the studies and anecdotal evidence is that there are no definitive answers about up vs. down grinding. There is an exception: cooling the workpiece when the arc of cut is long, as in creep-feed (CF) grinding. In this case, some unambiguous conclusions can be drawn.

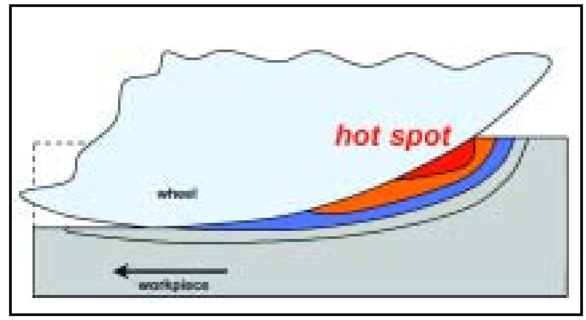


Figure 2: The hot spot in grinding is located near the top of the arc of cut.

Cooling the Hot Spot

For effective cooling, it is necessary to get coolant to the hot spot, which is located toward the top of the arc-of-cut contact area (Figure 2). This is achieved by delivering coolant at a high enough velocity that it penetrates the pores of the wheel and reaches the hot spot.

The amount of heat that the coolant absorbs depends of the length of the arc of cut. This length is calculated by:

$$\text{Length of the arc of cut} = \text{DOC} \times \text{wheel dia.}$$

In grinding operations with a short arc of cut, the coolant absorbs little of the heat generated. In grinding operations with a long arc of cut, such as CF grinding, the coolant absorbs more heat—upwards of 50 percent.

Down grinding offers an advantage over up grinding with respect to cooling the workpiece. In down grinding, the hot spot is relatively close to the top of the arc of cut, meaning the coolant hasn't absorbed much heat when it reaches the hot spot.

In up grinding, however, the coolant is already at an elevated temperature by the time it reaches the hot spot. It may even have begun boiling. (Steam is far less efficient at lowering the temperature compared to a liquid.)

For this reason, CF-grinding operations, with their long arcs of cut, usually run in the down-grinding mode. An exception is the CF grinding of tool flutes. Builders and users of CF flute grinders say up grinding is performed because the forces in down grinding would rip the workpiece out of the collet.

For example, an 8" flute-grinding wheel taking multiple 0.001" cuts would have an arc length of 0.09". Only 1 or 2 percent of the heat would be absorbed by the coolant. Therefore, there wouldn't be much advantage to down grinding.

In contrast, a 16" flute-grinding wheel taking a single ⅛" cut in the CF mode would have an arc length of 1.4". If a good nozzle delivering coolant at a high velocity were used, the coolant might absorb 25 percent of the heat generated. Such an operation would benefit from down grinding.

Run Tests

The cooling aspect for CF grinding indicates down grinding is preferable. But the results of the Wager and Gu study indicate up grinding is the way to go—at least when shallow-cut grinding without coolant.

This type of complex, often contradictory information is why grinding researchers hesitate to go out on a limb and give recommendations. What succeeds under one set of conditions may fail under another. And even within a specific set of conditions, it can be difficult to say with absolute certainly what will happen.

The result is the researcher makes some general comments, which are quickly followed by long, qualified statements and a lot of phrases like "has a tendency to," "under certain conditions" and, worst of all, "that's sometimes true, but it's very complicated and difficult to predict."

The average production manager goes crazy when he hears such qualifiers. He wants a quick answer to his question, not a philosophical discussion on penetration depths and thermocouple response time. He wants something he can use immediately.

So, going out on a limb, here are the author's recommendations: If you're doing CF grinding, use down grinding. If you're not, you'll have to take matters into your own hands and come up with a conclusion based on your specific grinding conditions and by running some tests.

The following is a test you can conduct to help you decide whether up grinding or down grinding is the way to go. Take 40 or so workpieces. Dress the wheel fives times, as usual, to create a clean surface. Grind half of the workpieces in the up-grinding mode while increasing the work speed 10 percent of the original speed after each test. At the end of the test, the work speed should be 3 times the original work speed. Then dress the wheel five times again and repeat the operation in the down-grinding mode. Make sure all other parameters and conditions stay exactly the same. In particular, make sure the coolant nozzle is at the point where the wheel enters the workpiece and is positioned exactly the same way in both tests.

Next, take the workpieces and visually examine them for oxidation burn to determine if they burn more in one mode than the other. Then cook the specimens in acid to test for residual stress. Again, this is to see if stress is worse in one mode than the other.

Finally, check for any breakdown in the profile for each set. This will indicate whether one mode is wearing out the wheel faster than the other.

Based on this, you can determine if up grinding or down grinding is better for you. Depending on the workpiece, the entire task will take about 2 or 3 hours, along with another few hours for stress testing and wheel-wear measurements. It's not rocket science, but it's a robust, one-time test you can perform see which method works best for you.

After this, you may want to use the Smith Wheel Wear Technique to see whether up grinding or down grinding wears your wheels more. (The author discussed this technique in CTE's "The Grinding Doc" column, May 2003.)

With all this information in hand, you can make an informed decision about which option to chose.

About the Author

Dr. Jeffrey Badger is an independent grinding consultant. His Web site is www.jbadger.com. You can e-mail him at badgerjeffrey@hotmail.com.