WHITE PAPER

EFFECT OF DRESSING OVERLAP RATIO ON THE GRINDING PROCESS

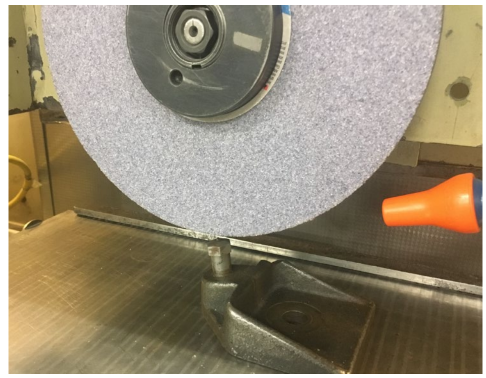
NOVEMBER 1, 2018

A good understanding of overlap ratio dressing parameter and its effects on grinding wheel performance can result in optimal precision grinding operations. Overlap ratio is specifically used when truing and dressing using rotary or stationary dressing tools in a traverse dress mode. Overlap ratio is not used in plunge dressing applications. Precision grinding processes are required to manufacture components with high degrees of accuracy for size, profile, surface texture, etc. Processes must also produce components with damage-free surfaces (burn-free) while optimizing material removal rates.

In order to achieve these requirements, the grinding wheel needs to be trued and dressed. The terms truing and dressing are defined as the following:

- Truing is the process of generating the required profile on the face of the wheel. This profile could be a simple straight face or it could be a complex profile. Truing also includes correcting for wheel runout and/or deviations on the grinding wheel surface.
- Dressing is the process of preparing and maintaining the grinding wheel face sharpness, and openness. This includes removing work material that might be loading on the surface of the wheel, removing excessive bond, dull abrasives, and re-sharpening abrasive.

Figure 1 – Stationary Tool Dressing



Conventional abrasive wheels are trued and dressed in a traverse mode using either stationary or rotary diamond tools. In both cases the diamond tool is moved manually or automatically across the face of the wheel at a predetermined dress depth and dress feedrate. Several passes are often made in order to create the desired wheel shape, or wheel face surface texture. **Figure 1** shows a Single-Point stationary dressing tool in position to dress a grinding wheel.

Truing and dressing is typically carried out initially after mounting the wheel on the machine and then again periodically during the grinding operation for one or more of the following reasons:

- The grinding wheel OD has excessive runout
- The wheel face has chatter marks that need to be removed
- To generate the required profile on the wheel face
- The abrasives are dull and require re-sharpening
- The wheel is loading with work material
- To control the wheel face topography to obtain:
  - A sharper wheel face in order to achieve higher Material Removal Rates
  - A duller wheel face in order to achieve a better quality surface finish

Figure 2 – Single-Point Tools

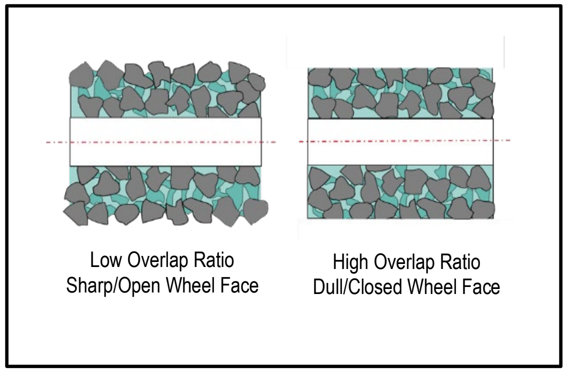
Diamond Dressing Tools

Rotary and stationary dressing tools come in a wide range of designs, shapes, sizes, etc. Stationary tool types include: single-point diamond tools, form tools, multi-point tools, cluster and fliesen tools (**see Figure 2**). Rotary tools include: Infiltrated CNC dressing discs (ICD), which consist of natural diamond and high quality CVD for use on conventional and ceramic grains; brazed profiling rollers (BPR), and IDW metal bond technology for super abrasives (**see Figure 3**). Each of these dressing tools are designed for specific wheel dressing needs.

Figure 3 – Traverse Rotary Tools

Overlap Ratio Definition

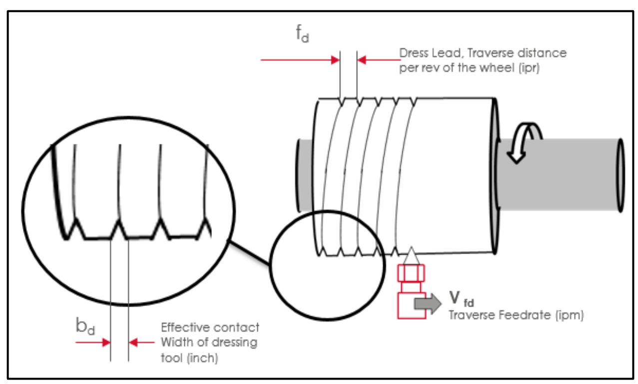
Figure 4 – Sharp and Dull Wheel Face



The overlap ratio is the number of times that any one point on the grinding wheel face will be in contact with the dresser face, as the dresser moves across the wheel. The dressing overlap ratio determines the surface condition of the wheel face. This in turn determines the surface roughness of the workpiece. When the overlap ratio increases, the dresser hits the same grit on the wheel multiple times, creating a fine topography on the wheel surface. This makes the wheel face dull and closed. Hence, the surface finish on the workpiece is finer. Care must be taken to ensure the wheel face is not too closed since it could result in higher grinder power due to the wheel surface being dull, which in turn could cause workpiece thermal damage. When the overlap ratio decreases, the number of times the dresser hits the same grit on a grinding wheel decreases. The traverse rate increases when the overlap ratio is decreased, resulting in a sharp and open grinding wheel face and coarser finish on the work piece**. Figure 4** is a diagram illustrating the effect of adjusting the overlap ratio on the grinding wheel face. The diagram shows that a low overlap results in a sharp and more open wheel face, as opposed to a high overlap that results in a dull and closed faced grinding wheel. The diagram shows two extreme cases in terms of wheel sharpness.

Dressing Lead and Effective Contact Width of Dresser

Figure 5 – Dressing Lead



Typical guidelines for overlap ratio are in the range of 2 to 22, however there are a few processes where the dressing action needs to be very fine with overlap ratio as high as 200 in order to achieve the desired quality and at times is a productivity requirement. In order to calculate the overlap ratio, it is necessary to determine the dress lead (fd) and the effective contact width (bd). Dress lead is the distance the wheel travels in one rotation of the wheel and the effective contact width is the width of the dresser contact with the grinding wheel. **Figure 5** shows the dresser lead and the dresser width. The figure illustrates a dressing action where the dress lead is so large that there appears to be a thread pattern on the wheel face. In this case the lead has been intentionally exaggerated in order to clearly illustrate the dress tool path and the spacing of the dress lead. In reality the actual dress lead would be some value that is less than the effective contact width, creating an overlap (Overlap Ratio), thus eliminating the potential for a threaded wheel face.

The Effect of Overlap Ratio on the Dressing and Grinding Process

As previously discussed, a lower overlap ratio will typically create a sharp and open wheel face, and a higher overlap will create a dull and closed wheel face. **Figure 6** is a diagram showing a visual representation of the effects of three different overlap ratios,1, 2 and 8. In order to increase the overlap ratio from 1 to 8, either the dress tool contact width (bd) can be increased or the traverse feedrate (Vfd) can be reduced, which in turn reduces the lead (fd). **Figure 6** represents a situation where the contact width was kept the same and the dress feed/lead was decreased. It can be clearly seen that by increasing the overlap from 1 to 2 and then to, 8 lessened the wheel face roughness from coarse texture to fine texture. Changing the wheel face topography will have a direct effect on the grinding results in a number of different ways. **Table 1** shows the typical effects expected on the grinding process when comparing a wheel dressed at a low overlap versus a high overlap ratio.
Figure 7 is a graphical illustration of the effect of overlap ratio on the relative roughness of the wheel face, that is, sharpness and openness of the grinding face. It shows that at low overlap ratio the wheel face will be coarser and at higher overlap the wheel face will be finer.

Figure 6 – Overlap Ratio – Low vs. High

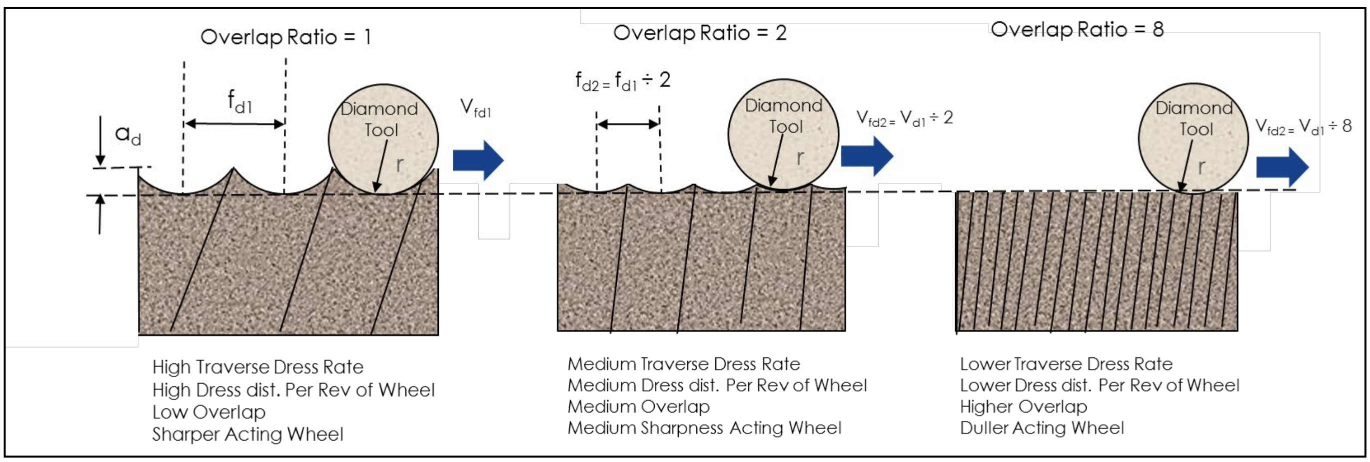
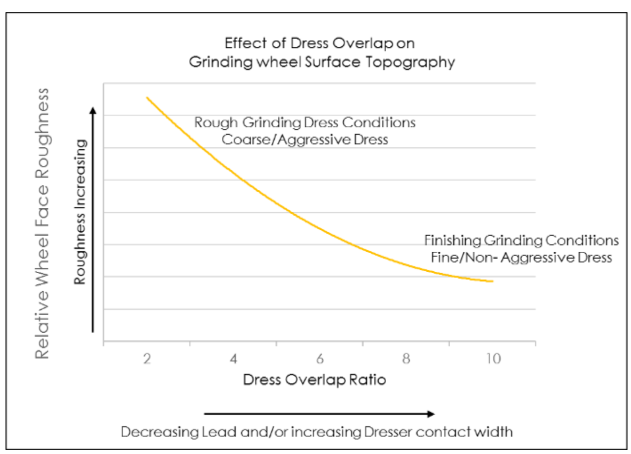


Table 1 – Anticipated Effect of Overlap Ratio on the Dressing and Grinding Processes

	Low Overlap Ratio	High Overlap Ratio
Dressing Traverse Rate	High	Low
Dressing Feed per rev of the wheel	High	Low
Type of Dressing Action	Coarse	Fine
Wheel Face Condition After Dress	Sharp & Open	Dull & Closed
Grinding Power	Low	High
Grinding Force	Low	High
Potential Material Removal Rates	High	Low
Workpiece Geometery	Lesser Quality	Good Quality
Workpiece Surface Finish	Lesser Quality	Good Quality
Dressing Forces	Higher	Lower
Dresser Tool Life	Lower	Higher

Figure 7 – Overlap Ratio vs. Wheel Face Roughness



Calculating Overlap Ratio and Dress Traverse Feedrate

In order to calculate the overlap ratio, the dress lead and dress contact width must first be determined.

Step 1: Calculating Dress Lead
The dress lead is the distance the dress tool travels per revolution of the wheel. It can be calculated using the **Eq. 1**.

Eq 1. Dress Lead = fd = Vfd ÷ Ns

fd = Dress Lead (inch/rev or mm/rev)
Vfd = Dress Traverse Rate (ipm or mm/min)
Ns = Wheel Speed (rpm)

Step 2: Calculating Dresser Effective Contact Width – Radius Tip Tools Only
When using a dressing tool that has a straight face, the dress tool contact width is simply the width of the dress tool. However, when there is a radius on the dressing tool tip, it is necessary to calculate the effective contact width using **Eq. 2**.

Eq 2. Effective Contact Width = $b_d = 2(a_d(2r - a_d))^{0.5}$

b_d = Effective Contact Width (inch or mm)
r = Dresser Tip Radius (inch or mm)
a_d = Dress Radial Depth (inch or mm)

Step 3: Calculating Dressing Overlap Ratio
Having now determined the lead and the effective contact width, the overlap ratio can be calculated using the following equation (**Eq. 3**).

Eq 3. Dressing Overlap Ratio = Ud = bd ÷ fd

Ud = Overlap Ratio (revs)
bd = Effective Contact Width (inch or mm)
fd = Dress Lead (inch/rev or mm/rev)

Calculating Dress Traverse Rate from Overlap Ratio
Very often it is necessary to determine the dress traverse rate from the overlap ratio value. An overlap ratio value would be selected from **Table 2**. Using the previously calculated effective dresser contact width and the wheel speed (rpm), the overlap can be determined using **Eq. 4**.

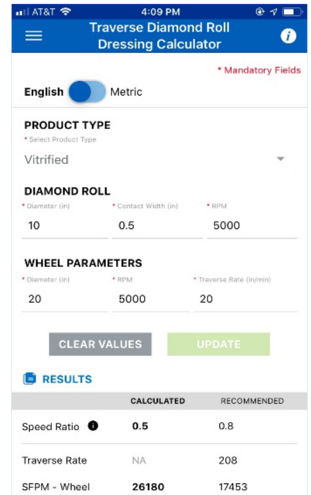
Eq 4. Dress Traverse Feedrate = Vfd = (bd ÷ Ud) x Ns

Vfd = Dress Traverse Rate (ipm or mm/min)
bd = Effective Contact Width (inch or mm)
Ud = Overlap Ratio (Revs)
Ns = Wheel Speed (rpm)

Table 2 – Overlap Ratio Guidelines

	Dress Overlap Ratio (U_d)
Rough Grind	2 - 4
Medium Grind	5 - 9
Finish Grind	10 - 22
Special Applications	up to 200

Figure 8 – Online Grinding Wheel Dressing Calculator



As an alternative to using the equations above, a dynamic calculator hosted on the Norton Abrasives website (**Figure 8**; https://www.nortonabrasives.com/en-us/igrind) can be used to calculate dressing parameters, in addition to getting recommendations for overlap ratios for different wheel technologies.

Case Studies

Case Study 1 – Improving the Number of Parts per Dress Using Overlap Ratio

In a recent process improvement activity, the goal was to improve wheel life by increasing the parts per dress while maintaining the current cycle time. It was critical to maintain the surface finish and the overall quality of the workpiece. Initially, to maintain the required maximum surface finish of 0.80 µm Ra, it was necessary to dress after every 20 parts. The concept of overlap ratio was used to improve the parts per dress in this process. One of the following three factors could be changed to achieve the goal

1. Rotary dresser disk traverse rate
2. Rotary dresser disk width
3. Wheel speed

Considering that the surface finish was the main issue that was hindering the improvement in parts per dress, traverse rate was optimized. The dressing cycle consisted of two traverse dressing passes. Each pass was optimized individually to produce a good quality part with a surface finish of less than 0.80 µm Ra. Parameters in **Table 3 – Case Study 1** were used for this test.

Table 3 - Case Study 1

	Original Dress Process	New Dress Process	
Wheel Dress Speed (N_s)	1990	1990	rpm
Wheel Dress Speed (V_s)	12,598	12,598	ft/min
Dress Depth Pass 1 (a_{d1})	0.0016	0.0020	in
Dress Depth Pass 2 (a_{d2})	0.0012	0.0004	in
Dress Traverse Rate (V_{dr1})	9.4	11.8	in/min
Dress Traverse Rate (V_{dr2})	7.1	3.5	in/min
Dress Roll Diameter	3	3	inch
Roll Width	0.31	0.31	inch
Dress Lead (f_{d1})	0.0047	0.0059	in/rev
Dress Lead (f_{d2})	0.0036	0.0018	in/rev
Overlap ratio (U_{d1})	64	52	
Overlap ratio (U_{d2})	86	172	
Parts per Dress	20	45	

- Dress Pass 1- The traverse rate was increased in order to remove all impurities from the surface of the wheel and the micro-fractured dull grains as well as the bond, which resulted in exposing sharp abrasive grain and coarser wheel surface. Increasing traverse rate in the first pass also helped maintain the dress cycle time.

- Dress Pass 2- The traverse rate was slowed down to achieve a smooth finish on the wheel due to less micro-fracturing of abrasive and bond. This enabled the wheel to produce parts at a much finer surface finish.

The reason dressing was necessary was that as the grinding wheel continued grinding, the surface finish imparted on the workpieces gradually got rougher. In order to not exceed the surface finish limit of 0.80 µm Ra, the wheel was dressed every 20 workpieces. This study showed that the decreased dressing traverse rate in the second pass enabled to lower the starting surface finish right after dress. As a result, it was possible to dress 45 parts instead of 20, before the surface finish became rougher than desired.

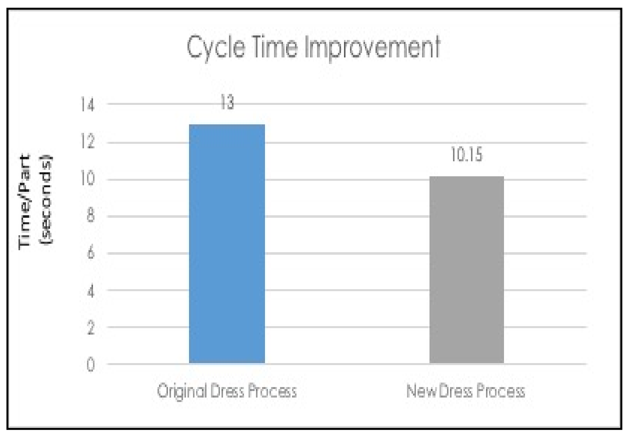
Case Study 2 – Decreasing Dress Cycle Time Using Overlap Ratio

In another test, the goal was to decrease the dressing cycle time. See **Table 4 – Case Study 2** for parameters used. In order to achieve the goal of decreasing the dressing cycle time, the traverse rate had to be increased. As expected, increasing the traverse rate did not produce the required surface finish on the workpiece.
Knowing that the current overlap ratio produced good quality parts, the width of the diamond dresser was increased. As the overlap ratio is equal to the diamond dresser width divided by the dress lead, the overlap ratio increases as the diamond dress width increases. In this case, taking into consideration the clearance in the machine, the diamond roll width was doubled. To maintain the current overlap ratio of 11, the traverse rate was increased from 5.9 inches/minute to 11.8 inches/minute. This resulted in a total (grind+dress) cycle time reduction from 13 seconds to 10.15 seconds (**Figure 9**), an approximated 24% improvement in cycle time.

Table 4 – Case Study 2

	Original Dress Process	New Dress Process	
Wheel Dress Speed (N_s)	1326	1326	rpm
Wheel Dress Speed (V_s)	8,332	8,332	ft/min
Dress Depth Pass 1 (a_d)	0.0007	0.0007	in
Dress Traverse Rate (V_{dr})	5.9	11.8	in/min
Dress Roll Diameter	3.54	3.54	inch
Roll Width	0.20	0.40	inch
Dress Lead (f_d)	0.0044	0.0089	in/rev
Overlap ratio (U_d)	45	45	
Total Dress Time	182	125	Seconds
Total Cycletime per Part (Grind + Dress)	13	10.15	Seconds

Figure 9 – Case Study 2



Conclusion

As demonstrated in the case studies, overlap ratio has a significant impact in grinding processes involving traverse dressing. Overlap ratio should be taken into consideration while optimizing any process involving traverse dressing, as it takes into account the critical parameters of wheel speed, diamond dresser width, and the traverse dressing rate. Overlap ratio improves the surface quality of the workpiece and it can also be used to reduce the total cycle time of the process.

Sources of information for this article:

- Handbook of Machining with Grinding Wheels - Marinescu, Hitchiner, Uhlmann, Rowe, Inasaki.
- Principles of Modern Grinding Technology - W. Brian Rowe

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John Hagan has been a Senior Application Engineer for Norton I Saint-Gobain Abrasives for 8 years where he is tasked with designing and completing grinding projects focused on new process development and the optimization of existing processes. In addition to this, John is heavily involved training related to grinding technology for both internal personnel and customers. With a total of more than 25 years of experience with Norton I Saint-Gobain, John's past experiences include 12 years as a Manufacturing/Process Engineer in additional to several years as a R&D Engineer.