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A Logical, Mathematical Approach to Optimizing Centerless Grinding

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abstract

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A LOGICAL, MATHEMATICAL APPROACH TO OPTIMIZING CENTERLESS GRINDING

(From Set-Up To Trouble-Shooting)

by

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A logical approach to centerless grinding, used with ordinary mathematics can determine 1) the present performance level of the grinding wheel under existing conditions, 2) the level of productivity that could be reached if conditions were changed, and 3) the conditions to specify in order to reach that level.

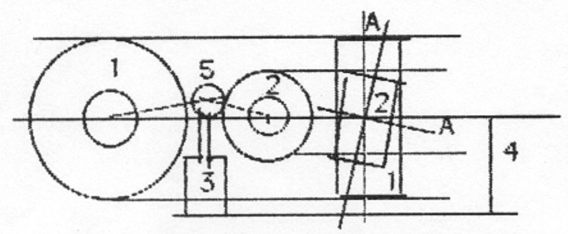
The same approach can be used to set up new applications as well. Formulas used include **Width of Cut**, which can control grinding wheel action, life and productivity, and **Ratio/Proportion**, which calculates the precise adjustments needed to regain lost production due to redressing of the regulating wheel, as well as to coordinate traverse rates when two or more machines are used in tandem.

Compensations for the changes that occur as the regulating wheel becomes smaller in diameter are given. Certain often overlooked machine conditions that cause problems are also discussed.

In order to take greater advantage of the potential capabilities of the centerless grinder it is necessary to understand the basic, but important, principles that are involved in its setup and operation.

First, keep in mind that one pass of the workpiece through the centerless machine is the equivalent of an entire cycle of roughing, semi-finishing and sparking-out passes as performed on a cylindrical grinding machine, except that the centerless machine does it in less time.

COMPONENTS OF A CENTERLESS GRINDING SETUP



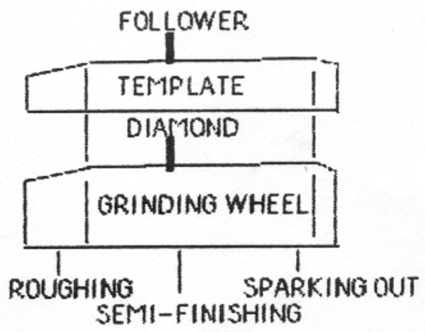
1= GRINDING WHEEL 2=REGULATING WHEEL
(1 & 2 REVOLVE CLOCKWISE)
3=WORK REST BLADE IN FIXTURE
4=HEIGHT FROM BASE TO CENTERLINE
5=WORK PIECE A=ANGLE OF INCLINATION
(5 REVOLVES COUNTER CLOCKWISE)

A drawing will illustrate the three elements of the centerless setup, the grinding wheel, the regulating wheel and the workrest blade. The grinding wheel does the actual grinding but only because the regulating wheel makes it possible by controlling the movement of the work piece and applying pressure against the grinding wheel. The workrest blade supports the work piece vertically, maintaining its position relative to the centerlines of the two wheels so that concentricity will be achieved.

Usually, most of the stock is removed by the front section of one third to one half of the grinding wheel face. Semi-finishing is done by the next third, approximately, while sparking out is done by the final third of the wheel face. All pressure must be relieved before the exit of the workpiece in order to obtain the best possible surface finish without traverse lines.

In the ideal setup, the grinding wheel is prepared for this by dressing a contour from a profile template that provides a lead-in taper on the front end and a short relief on the exit end. The grinding wheel face will normally wear into approximately this shape while grinding. Dressing simply gives the wheel a better start, making it more effective with the first pass.

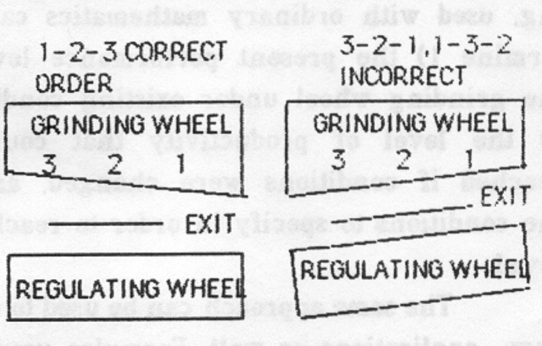
TEMPLATE FOR DRESSING PROFILE



The Diamond Shows What's wrong

When it is used, the diamond dresser is one of the operator's best friends, because it helps him to identify the cause of many of the problems he can experience. For instance, at the time of redressing (the grinding wheel), the operator can observe what part of the wheel the diamond touches first, next, and then last. This will serve to analyze the alignment of the machine and reveal where the grinding is actually being done. The greatest amount of wheel wear will be found where the greatest amount of grinding has been done, naturally. The least wear will be found where little or no grinding has been done. From this, the grinding wheel itself will show what is

ORDER OF CLEANUP WHEN REDRESSING



right and what is wrong in the machine setup or alignment.

Normally, the diamond should first touch the back, then the middle, and finally the front of the wheel face. If it contacts the wheel in any other order, it usually means something should be adjusted in the setup. For instance, if the diamond contacts in the front and the back before the middle it means that the grinding is being done in the middle of the wheel face, instead of at the front.

The cause of the problem is in the alignment of the machine elements (open in the front), the shape of the regulating wheel is wrong (large in the middle), or the work height setting is incorrect (too low), or a combination of these. As a result, the wheel has to be dressed too frequently. The "breaking-in" period of the wheel face can be shortened, or even eliminated, and the interval between dressings can be shortened.in this manner. This situation occurs mostly in the grinding of short length pieces and small diameter flexible rods.

The Regulating Wheel Controls The Workpiece

The regulating wheel is (usually) made of rubber so that its coefficients of friction and compression can regulate, or control, the movements of the workpiece. which are rotational with traverse in thrufeed applications, and rotational with infeed pressure in plunge applications. It acts as a brake so that the workpiece will not rotate at the same speed as the grinding wheel. On its pass through the machine the workpiece will follow the shape of the regulating wheel and will reproduce that shape to some degree. This will be covered in the next two sections.

The Shape of the Regulating Wheel Is Important

Basic to success in the setup is the correct shape of the regulating wheel *at the line of contact* with the workpiece. Four settings create this shape: the angle of inclination of the regulating wheel, the swivel angle of the regulating wheel dresser slide, the setover of the diamond in the dresser slide and the height of the work piece center, either above or below, the wheel centerline.

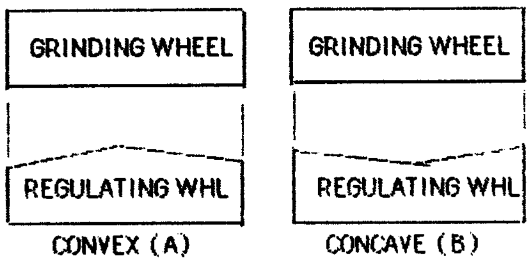
The angle of inclination, which tilts the wheel (high at the entrance end, low at the exit end), causes the workpiece to traverse, and determines the width of cut per revolution of the workpiece. (The width of cut is a very important factor in improving production rates. This is fully discussed further on.) The swivel angle and the diamond setover produce a cylinder whose outside diameter is smaller at the midpoint between the two ends on the regulating wheel face, while the proper height of the workpiece to the wheel centerline brings it all together.

If the height setting is not correct, the shape of the regulating wheel, no matter how carefully it was generated, will not present a straight line of contact with the workpiece. It is in this feature that many operators can become careless.

The Dresser Slide Controls The Regulating Wheel Shape

The dresser slide, located above the regulating wheel, pivots at, or near, the midpoint of the regulating wheel diameter so that the diamond will, in one full pass, cross over at this point. This is where the diamond should touch a new regulating wheel first. When the dressing operation is completed, with the diamond having dressed the full width, the regulating wheel should be smaller at the midpoint than at the two ends.

PROBLEMS WITH REGULATING WHEEL SHAPE



(A) DRESSER SWIVEL ANGLE TOO SMALL
(B) DRESSER SWIVEL ANGLE TOO GREAT

Attention should be paid to the setting of the dresser slide. If its angle is less than required, the regulating wheel will be larger in the middle than it should be. This is where the initial grinding will be done. If its angle is greater than required, the regulating wheel will be smaller in the middle than it should be. This shape can allow pressure on the workpiece to be lost in this area and short workpieces can become "spinners".

An easy way to check the wheel face is to place three or more short work pieces spaced out between the wheels, then with the wheels turned on, gradually bring the regulating wheel in until at least one of the parts revolves and starts to traverse. If the middle piece is the first to move, the regulating wheel face is larger at that point. If either of the two end pieces move first, the regulating wheel face is larger at that point. It is possible to adjust the tilt angle, without dressing, so that it will accommodate the dressing angle.

Operator handbooks have reference tables for the correct settings, which depend upon the ratio of work size to regulating wheel size. Generally, the dresser slide angle is never greater than the angle of inclination. The smaller the workpiece, the lower the contact will be with the wheels, and the closer the angle of the dresser should be to the angle of inclination. For larger workpieces, such as 4" in diameter, the angle of the dresser would be 15 to 20 minutes less than the angle of inclination.

In thrufeed grinding the workpiece will follow the shape of the regulating wheel at the line of contact. Therefore, if the regulating wheel is convex, or barrel shaped on this line, the workpieces will also become barrel shaped (smaller on the ends), depending upon its length if workpieces are short, or on diameter if bars or rods are long. Another result is that the grinding wheel face will become concave as grinding continues, wearing more in the middle section where the actual grinding is being done. Either shape is the reason that "breaking in" becomes necessary before size and finish become stabilized and why redressing becomes more frequent. The quality of production will vary until the grinding wheel wears in or the shape is corrected.

If the regulating wheel is concave at the line of contact, a short workpiece will become smaller in the middle, and the grinding wheel face will become convex as grinding continues, wearing more at the entrance and exit where pressures were applied, than at the middle where less grinding was done.

In infeed, or plunge grinding, the reverse of the above situations is true. The workpiece takes the opposite shape of the regulating wheel. If the regulating wheel is concave, the workpiece will become convex, and vice versa. This may explain problems that are sometimes blamed on the profile cam.

Even when grinding large diameter bars that do not flex appreciably, the shape of the regulating wheel is critical because, if the entire width of the regulating wheel face is not in contact the degree of control is reduced, the bars can slip in rotation, possibly stall, especially with heavy cuts, and probably chatter even with light cuts if the grinding wheel face is glazed. The efficiency of the operation is lowered when the available horsepower cannot be utilized.

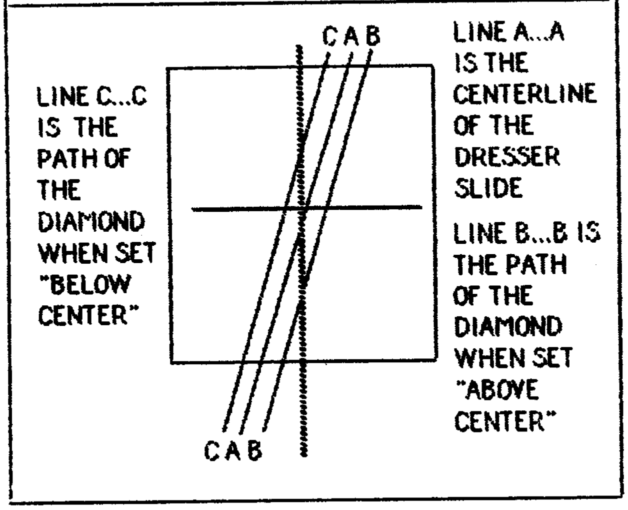
Those are some of the conditions that can be detected when the grinding wheel is redressed that was referred to earlier when it was stated that the diamond is the grinder's best friend.

Operators often neglect to rotate the single point diamond used in dressing the regulating wheel. When the diamond has been worn to a large flat, it can generate a flat on the regulating wheel at the middle where contact crosses from one edge of the diamond to the other while dressing. The wider the flat on the diamond, the longer the flat will be on the wheel face. This can cause problems on infeed profile work.

The Diamond Setover Does Some Interesting Things

It can be seen that, without any setover of the diamond, the regulating wheel will be dressed symmetrically, that is, both the front and exit ends will be the same diameter (assuming the pivot point is in the middle of the regulating wheel). The surface speed will be the same at both ends, but slower in the middle due to its smaller diameter. If the diamond is setover "above center" by some amount, the diamond path is closer to the front and away from the rear of the regulating wheel. The diamond will then dress more off the front of the wheel before the exit end is touched. This results in the front end being smaller and slower in surface speed than the exit end. If the diamond had been setover "below center" instead, the diamond would have dressed more off the exit end before touching the front end, resulting in the exit end being smaller and slower in surface speed than the front end.

OFFSET OF THE REGULATING WHEEL DRESSER



A faster surface speed at the exit end tends to separate short parts as they leave the middle of the grinding area. A faster surface speed at the front end tends to keep the parts together. This is helpful when grinding large diameter thin parts such as valve seat inserts and bearing rings, so that they support each other on their way through the machine.

When diamond or cubic boron nitride grinding wheels are used, they, of course, are not dressed with profile cams as are wheels made of standard abrasives. Therefore, the shape of the regulating wheel becomes even more critical in controlling the grinding area and any unusual wear patterns. Where possible, profile dressing cams are used on the regulating wheel slide. When they are not available, other techniques of dressing have to be used. More on this later.

The Height Of The Workpiece Brings It All Together

The workpiece is supported on a workrest blade held in a fixture located on a bottom slide, which can be moved to the desired position and locked. In most production applications the blade has a top angle of 30 degrees (for diameters 1" and under) to 20 degrees (for larger diameter work) and most often is made of tungsten carbide. Other materials can be used, of course. In this type of application, the workpiece is set above the centerline of the grinding wheel (and the regulating wheel) one half its diameter with a maximum of 1/2". This is to facilitate the rounding up of the workpiece. If the workpiece were set with its center on the same centerline as the wheels, it could become out-of-round, with three or more lobes.

When concentricity is a problem, check the height setting, raising it if necessary. (Caution: Setting the work excessively high can cause chatter.)

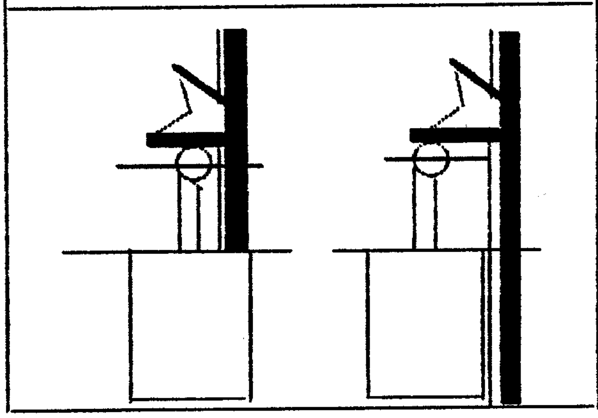
The dimension from the finished base (that the work rest fixture is mounted on) to the centerline of the wheels is 8 7/16" on the *2 machines, and 9 7/8" on the *3 machines. The centerline of the workpiece, (1" or less,) should be set at one half its diameter above that dimension.

(The *2 machine is one that uses a 20" grinding wheel and a 12" regulating wheel. The *3 machine is one that uses a 24" grinding wheel and a 14" regulating wheel.)

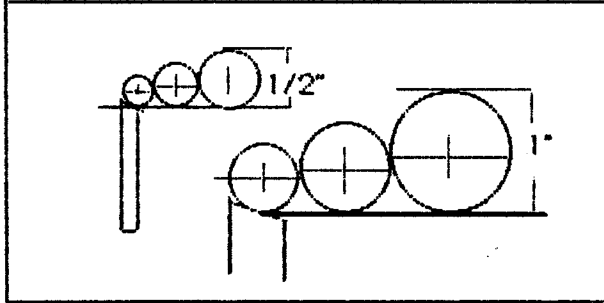
The overall dimension to the top of the workpiece would include the other half of the diameter, of course. The practical maximum setting of the center above the centerline should be .625" for any larger diameter workpiece.

(It should be noted that with the top of the work rest blade set to the centerline, any workpiece (wider than the blade) up to 1" diameter will automatically be one half its diameter above the center line. With this in

CHECKING CENTER HEIGHTS



EASY HEIGHT SETTING FOR DIAMETERS TO 1"



WITHIN THE RANGE SUITABLE FOR THE BLADE WIDTH, CENTERS OF DIAMETERS TO 1" WOULD ALL BE AT THE CORRECT HEIGHT.

mind, fewer changes in the height of the blade itself become necessary.)

One method of setting the workpiece center, perhaps more convenient than measuring from the base, is to establish another reference point on the workrest fixture. This reference base is determined by measuring its height from the base and subtracting this dimension from the standard base-to-centerline dimension. A regular square head and scale can then be used to set the workpiece.

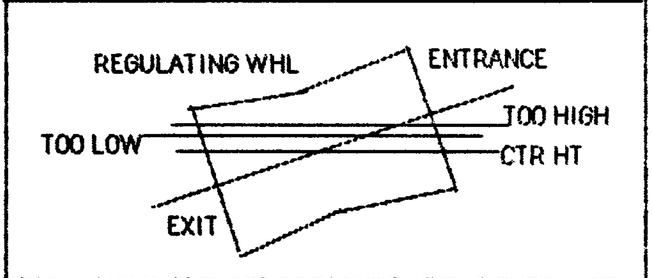
Because each fixture can vary, each reference base should be determined from actual measurement.

The Height Setting Confirms The Regulating Wheel Shape

The setup is good when the workpiece starts to grind in the roughing area and continues to move until the back end stops about 1/2" from the exit end of the wheels. The fact that it stops while still between the wheels is evidence that it has sparked out properly.

Here is an extremely important point. If the workpiece is not set at the correct height, everything else in the setup is "wrong", relatively speaking. The relationship is such that there is only one line that gives the full contact with the work that we need, with pressures distributed across the grinding wheel face satisfactorily. This is an often overlooked but very important cause of many problems, including tapers and poor surface finish.

EFFECT OF HEIGHT UPON GRINDING PRESSURE



"TOO HIGH" INCREASES PRESSURE AT THE ENTRANCE
"TOO LOW" INCREASES PRESSURE AT THE EXIT

It is possible to make improvements of 25% or more on the surface finish of workpieces simply by correcting the workpiece height setting, to allow the wheel to spark out fully.

If the workpiece is set too high there will be excessive pressure at the front and insufficient pressure elsewhere on the wheel face. If the workpiece is set too low, there will be insufficient pressure at the front and excessive pressure at the exit. Traverse lines and poor finish will result from the low position.

Within its own function, the height setting can be compared to the diamond setover, in that moving the work higher, (as "above center" with the diamond), moves the work upward into the front end of the regulating wheel, increasing grinding pressure there. Moving the workpieces lower, (as "below center" with the diamond) moves the work lower into the exit end of the regulating wheel, increasing pressures there. (While this is otherwise a problem in the ordinary setup, it can be used to advantage when a diamond or cubic boron nitride wheel shows excessive wear in one area of the grinding face. By changing the work height slightly, the grinding area can be shifted.) On those machines that do not have a taper correction device, adjusting the height of the workpiece in this manner is the best way to eliminate tapers in infeed applications, as opposed to offsetting the grinding wheel profile template.

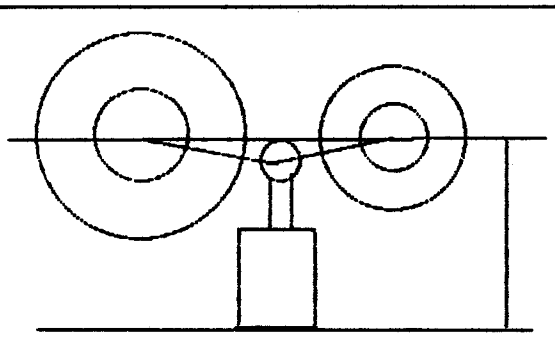
It takes only a few seconds to correct the height, assuming it is somewhere close. Often, the workpiece can be rolled up or rolled down on the top angle of the workrest blade by adjusting the work guides (or the regulating wheel, whichever is more convenient) in or out, and moving the bottom slide and regulating wheel slide into proper position for size. A change of 1/32" can make a significant improvement. In this way, while the height of the workpiece is corrected, the height of the workrest blade is undisturbed.

Contrary to the usual practice of grinding above the centerline there are certain types of work pieces, either very small diameter and light weight or flexible, such as thin wire or guitar strings, that are normally ground below center This prevents their being washed away by the coolant. A hold-down rail is often used as well. The diamond is setover "below center" to generate the correct regulating wheel shape.

The Steel Industry Has Its Own Practices

In the steel industry, when grinding bars on #3 centerless grinders, it is common practice to take heavy roughing cuts, and as the wheel face wears to a taper, use the taper adjustment feature to move the regulating wheel in at the entrance to make the two wheel faces almost parallel again for the finish pass. In this way more of the wheel face is used for the light finish pass and the finish is improved greatly. The grinding wheel is seldom dressed with a diamond.

SETUP FOR GRINDING BELOW CENTER



In this example, there are two hex-head adjusting bolts, one on each side of the regulating wheel slide. One is loosened, the other is tightened to move the slide as needed. The operator uses the flats and points on the hex-head to keep track of the adjustments so that any position is easily relocated. In some situations a dab of paint on one of the flats is used as a marker so that each operator can recognize home position and any movements away from it made during the other shift, for instance.

Bars are usually ground below center while rotating on flat workrests made of a soft material such as brass or bronze. In this position there are greater downward pressures exerted on the bar, eliminating the tendency to chatter as a result of the whipping action of the free ends of the bar.

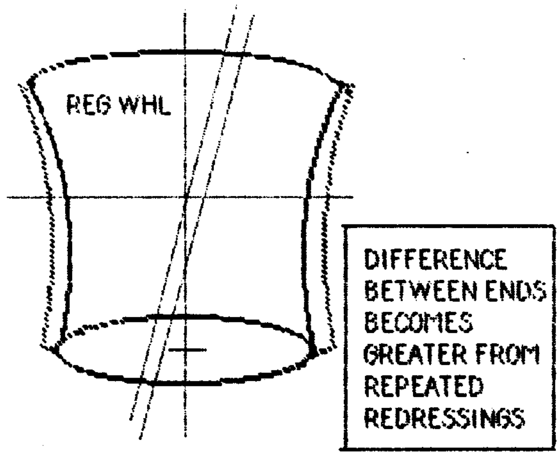
As the workrest wears to the radius of work drops lower. This is usually not a problem, (as it improves roundness) until chatter occurs, or until a change of work size, when a new workrest is mounted in the machine. However, special care should be taken to make sure the bar is resting firmly on the workrest, and not being held up by the outboard feeding equipment. This would result in chatter and "low ends".

While less attention may be paid to the finer details of the setup in the steel industry than in the bearing industry, for example, the shape of the regulating wheel is actually just as important to the steel industry. In the grinding of small diameters, especially on the #2 machines, a barrel shaped regulating wheel will apply excessive pressure on the middle section of the grinding wheel, causing it to wear into a concave shape. Bars with any flexibility will follow the convex-concave path between the wheels and will twist, bend and vibrate. During the wearing-in period, results will be variable and it will be difficult to get good finishes consistently.

The Regulating Wheel Changes—And Keeps Changing

There is one more very important characteristic of the regulating wheel that should

HOW THE REGULATING WHEEL SHAPE CHANGES



be considered. The operator knows that when a new regulating wheel is mounted, the front of the regulating wheel has to be moved **outward** so that the face of the wheel will be properly positioned to the grinding wheel face. Then, after a certain number of dressings, he has to make periodic adjustments to move the front end of the wheel **in** toward the grinding wheel, all the way down to stub size. When a full size regulating wheel is again mounted, he has to move the slide **outward** again and the procedure starts over. So it can never be taken for granted that the faces of the two wheels are parallel.

This is due to an interesting phenomenon that takes place as soon as the regulating wheel is redressed. Even though the settings are left unchanged, the regulating wheel shape starts to change. As pointed out earlier, the front of the wheel is smaller than the exit end (when grinding is above center). This difference becomes greater with each redressing. One quarter of an inch off the diameter becomes significant, in that there is an increase of approximately .001" to .002" in the gap between the two wheels at the front. This is noticeable when the stock removal per pass is low as this slight increase will permit the work pieces to pass the front section of the grinding zone and will increase the amount of grinding that has to be done in the center of the wheel face. Dressing becomes more frequent and the difference increases each time. It becomes especially important after a change in the regulating wheel diameter of one inch. In the case of diamond or cubic boron nitride wheels, the grinding area starts to shift towards the middle of the wheel face.

Compensation for this increase in the difference between the front and exit diameters is no problem when the machine has a taper correction capability on the regulating wheel slide. But it is important to know that this is happening and that the correction is simple. If the operator is unaware of the reason for the change or tries to get around making adjustments by changing something else he usually trades off a simple problem for a more complicated one.

Correcting Without A Taper Correction Device

On machines without a taper correction device, a different method of compensation is necessary. The amount of offset of the diamond on the regulating wheel dresser can be reduced periodically.

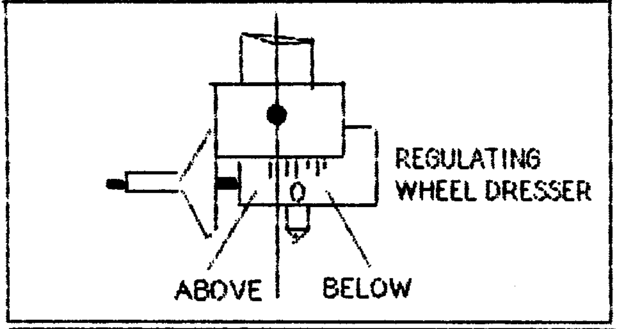
Unfortunately, the actual amount of correction is not consistent for every combination of work size and regulating wheel diameter, and offset of the diamond dresser. (The combinations of small work diameters with smaller diamond offsets result in smaller differences between the wheel ends at the beginning and a smaller change as the wheel becomes smaller in diameter. The combination of large work diameters with greater diamond offsets result in greater differences between the ends at the start and the greater the change as the wheel becomes smaller.)

Each combination of work size, regulating wheel diameter and diamond offset has its own amount of correction, which is constant for all angles in that unit, as well as for all thicknesses of the regulating wheel.

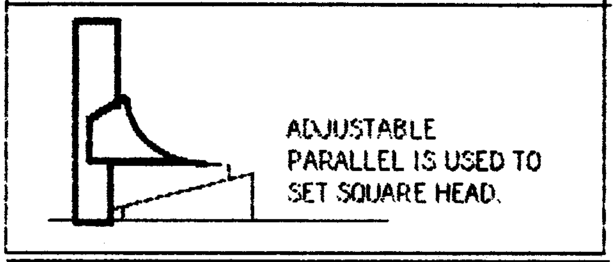
The tilt angle creates the original differences between the ends (the greater the angle, the greater the difference), but not the constant changing of the differences.It is the amount of diamond offset that causes the problem and it is the place to make the correction.

Even with precise numbers available, making the actual correction is usually a trial and error process in that the diamond offset fixture is not calibrated for accurate adjustments. It is possible, however, to use a depth

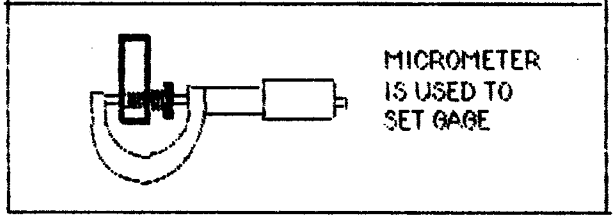
USING DEPTH MIKE FOR PRECISE ADJUSTMENTS



USING SQUARE HEAD TO ADJUST OFFSET



USING SETTING GAGE TO ADJUST OFFSET



micrometer, square head or setting gage to control small adjustments, by measuring the distance from the end of diamond holder to the clamping block, establishing a "zero" position for "no offset", and calculating the new position accordingly. It takes a significant movement of the diamond block to correct for the small changes that do occur.

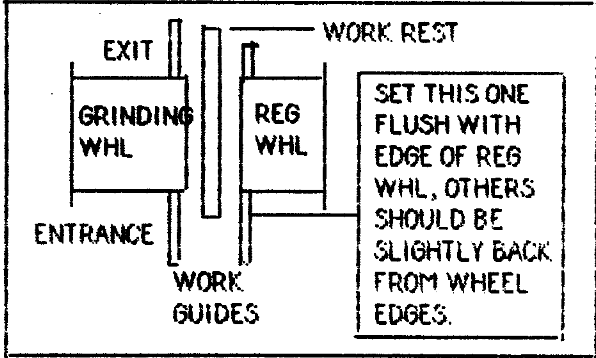
At the end of this paper are tables that show average corrections for a range of work sizes.

Setting Work Guides and Dressing

Before starting the machine, the work guides should be checked. Most important is the front guide on the regulating wheel side. It should be set flush with the regulating wheel face so that the work piece can enter the grinding area smoothly, without hitting the corner of the wheel. The other guides should be set slightly behind the wheel faces so that work pieces will not contact them. They should be square with the travel of the work piece to avoid any lateral pressure on the work piece.

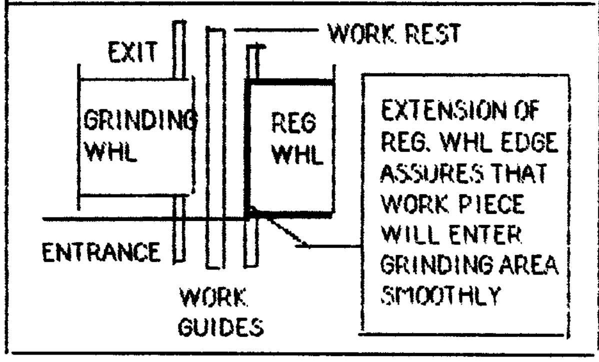
The regulating wheel should be dressed at 300 rpm (or more, if available), traversing the diamond at 1 to 2" per minute, no more than .001" infeed per pass.

PROPER SETTING OF WORK GUIDES



WORK GUIDES MUST BE PARALLEL TO REG WHEEL FACE IN ORDER TO GUIDE WORK PIECES ACCURATELY

USING A WIDER REGULATING WHEEL AS A WORK GUIDE



Centerless Grinding Is Logical

From the foregoing, it can be demonstrated that centerless grinding is a very logical operation, based upon an understanding of the functions of the principal parts of the machine and their proper relationship. Both problems and production depend upon whether or not the relationship is correct. It is a function of cause and effect, in that nothing happens in the operation, either good or bad, without a cause or reason. When there is a problem, look at the relationship of the principal parts. If the original settings on the machine have been recorded somewhere, these can be compared with the current settings and the discrepancies will indicate the corrections to be made.

Centerless Grinding Is Mathematical

A look at a few pertinent formulas will show what actually happens in centerless grinding.

Point number 1). The rate of traverse of the workpiece through the machine is a function of the surface speed of the regulating wheel (in inches) and its angle of inclination:

Formula number 1). TRAVERSE RATE

(SFPM x 12) x sine of angle = Traverse
Sine of 1 degree = .01745.
(100 x 12) x .01745 = 20.94", or 21" per minute at 100 SFPM and 1 degree.

As the angle is increased, so is the sine increased. With 21" for each degree change we can construct a table of traverse speeds, at various angles, for 100 SFPM.

(In this concept, small errors are unimportant. The maximum error at 8 degrees and 100 SFPM is approximately one inch, in 168".)

DEGREES		TRAVERSE
1	=	21"
2	=	42
3	=	63
4	=	84
5	=	105
6	=	126
7	=	147
8	=	168

As the SFPM is changed, so is the traverse rate changed, in multiples of 100 SFPM. That is, 200 SFPM would multiply the above traverse rates by 2. In the same way, 50 SFPM would multiply the above traverse rates by 0.50.

Examples:

50 SFPM at 3 degrees = 0.5 x 63, or 31.5"
150 SFPM at 3 degrees = 1.5 x 63, or 94.5".
200 SFPM at 3 degrees = 2.0 x 63, or 126".

It is important to note that the *diameter* of the workpiece has no influence here because the work will revolve at the same SFPM as the regulating wheel. The only important factors here are SFPM and ANGLE of the *regulating wheel*.

At any surface speed, the revolutions of the part per minute will depend upon its diameter, a point that we will use next.

Point number 2). THE WIDTH OF CUT (W/C), or the distance the workpiece will advance each time it revolves is simply the traverse rate in inches per minute divided by the number of revolutions of the workpiece per minute.

Formula number 2). WIDTH OF CUT

Traverse / Work RPM = W/C
21"/382 = .055" W/C per revolution of work.
(382 rpm =1"dia @100 SFPM.)

As the angle is increased, or decreased, so is the width of cut increased or decreased for any given diameter workpiece. Therefore we can construct another table showing widths of cut for 1" diameter @ 100 SFPM

DEGREES	WIDTH OF CUT
1	.055"
2	.110
3	.165
4	.220
5	.275
6	.330
7	.385
8	.440

As the workpiece diameter is changed, so is the width of cut changed, in multiples of the 1" diameter. That is, a 2" diameter workpiece would have a width of cut of .110" at 1 degree (.055 x 2). Also, a 0.500" diameter workpiece would have a width of cut of .0275" (.055 x 0.5).

It is important to note that *surface speed* of the workpiece has no influence here because the speed of the regulating wheel at any given angle controls *both* the rate of TRAVERSE and the surface speed (and therefore the

RPM) of the workpiece. The RPM of the workpiece (at 100 SFPM) is the key to the W/C.

SFPM	RPM	W/C
(1" DIA. @ 1 Degree)		
50	191	.055"
100	382	.055
150	573	.055
200	764	.055

It is also very important to note that the width of cut is a **fixed** function. That is, for any given ***work diameter*** and regulating wheel ***angle*** setting there is ***only one possible width of cut.*** Changing the regulating wheel surface speed will not change the width of cut. The only way it can be changed is by changing the regulating wheel ***angle setting*** itself.

The TRAVERSE and the WIDTH OF CUT can now be combined in a table as they relate to the angle.

TRAVERSE	ANGLE	W /C
(100 sfpm for 1" Dia)		
(VARIABLE)		(FIXED)
21"	1	055"
42	2	.110
63	3	.165
84	4	.220
105	5	.275
126	6	.330
147	7	.385
168	8	.440
(Work dia. is no factor here)		(SFPM is no factor here)

With the regulating wheel speed kept constant, a change of the angle changes **both** the WIDTH OF CUT and the TRAVERSE RATE.

With the angle kept constant, a change of SFPM changes the TRAVERSE RATE but **not** the WIDTH OF CUT.

While the width of cut remains fixed for any given diameter and angle regardless of surface speed, the rate of traverse can be varied by changing the sfpm to produce any desired thrufeed rate and volumetric stock removal rate per minute.

A practice followed in many shops is to use the same angle, usually 3 degrees, for all workpiece diameters, large or small. A major problem encountered is that larger work diameters will result in wider widths of cut and fewer revolutions per inch of wheel face.

The following table, based on 3 degrees, shows the conditions that result from maintaining one angle for all jobs:

WORK DIA.	W/C	PER INCH	6"WHEEL
0.500".	0825"	12 Rev.	72 Rev
1.000	.165	6	36
1.500	.247	4	24
2.000	.330	3	18
2.500	.412	2.5	15
3.000	.495	2	12
4.000	.660	1.5	9

Obviously, as the work diameter increases, the wheel has to remove much more stock per revolution, in fewer revolutions per inch of wheel face. An otherwise satisfactory wheel will increase its wear or breakdown, making it difficult to hold finish, form and size. This is generally considered to be "softer acting."

On smaller diameters, especially under 0.500", the width of cut is narrow (using 3 degrees), and the amount of work done by the wheel per revolution of the workpiece is much less. An otherwise satisfactory wheel will decrease its rate of wear, the wheel face will become glazed, creating back pressures, heat and size variations. This is generally considered to be "harder acting."

Much of the inconsistency in grinding wheel performance can be traced back to the unrecognized wide variation of conditions under which the wheel has had to do its work.

Using the width of cut, we can calculate the number of revolutions of the workpiece per inch of grinding wheel face in order to select the best regulating wheel angle setting and optimize the grinding wheel performance.

By changing the angle when workpiece

diameters vary greatly, we can maintain both the width of cut and the revolutions per inch of wheel face constant and allow the grinding wheel to do approximately the same amount of work in every case, regardless of the work-piece diameter. Certainly on large volume runs and problem materials, the time taken to set the machine properly with this principle in mind will be justified.

Changing the angle will permit one grinding wheel to become more universal in its application. Otherwise, a wheel selected for small diameters is usually too hard for large diameter work. A wheel selected for large diameters is usually too soft for small diameter work. As a "general purpose" wheel for the general run of average size jobs, a wheel grading between two special wheels should be tested, or at least, considered.

Experience has proven that an excellent width of cut for workpieces normally found in precision production grinding is .220", which gives approximately 4.5 revolutions per inch of wheel face, allowing satisfactory stock removal and tolerances with an acceptable rate of wheel wear.

WORK DIA.	ANGLE
0.500"	6 to 8 Deg.
1.000	4
1.500	2.7
2.000	2
2.500	1.6
3.000	1.3
4.000	1

The width of cut in all cases would be .220". Revolutions per inch would be 4.5. Diameters less than 0.500" could be run between 6 and 8 degrees, a matter of choice.

Rules of Thumb:

Use large W/C to distribute the work and increase breakdown across the wheel face.

Use narrow W/C to reduce wheel wear.

Use high angles for small diameter parts.

Use low angles for large diameter parts.

Use lower than average angles to obtain better surface finishes and closer tolerances when wheel wear is a problem.

Never use a W/C that is greater than the width of the work piece.

A quick method of calculating the angle, and thereforethe width of cut, for any diameter is to divide the number 4 by the workpiece diameter

For instance,:

4/1 = 4 degrees,
4/2 = 2 degrees,
4/3 = 1.3 degrees,
4/4 = 1 degree

Working in metric, divide the number 100 by the diameter in millimeters.

These all reflect the values stated above

In steel mill bar grinding, greater rates of stock removal are required, the necessary horsepower is available and a greater rate of wheel wear is acceptable, therefore greater angles are used. It is common to find 5 to 7 degrees used on #3 centerless machines on some diameters up to 5". On #2 centerless machines the maximum possible angles are used on smaller diameter work. (For best results in this case, the tilt angle should never exceed the maximum angle obtainable on the dresser slide.)

This discussion of the width of cut has been in reference to thrufeed, or traverse grinding. In infeed, or plunge grinding, the regulating wheel should never be tilted more than 1/4 degree. This is sufficient to hold the workpiece against the end stop without creating excessive pressure that could cause slippage, vibration, chatter and problems with holding shoulders. Referring to the width of cut discussion, the pressure against the stop per revolution of the workpiece at 1/4 degree is created by the forward motion of the part equal to one fourth of the width of cut for one degree for the diameter being ground. If there are problems related to end pressure at 1/4 degree, *reduce* the angle. Higher angles would create even greater pressures against the stop.

Manipulating The Centerless Grinding Wheel

Point number 3). It is important to know exactly how manipulations of feeds and speeds will influence the wheel's performance and productivity. (At this time, it is best not to approach centerless grinding with cylindrical grinding in mind, because the response to changes in feeds and speeds is not the same in both types of grinding.)

Remember that the regulating wheel controls both the rate of traverse and the surface speed of the workpiece, with the width of cut remaining fixed. Therefore, in thrufeed, or traverse grinding, any increase in rpm of the regulating wheel (which increases the traverse rate) **does** increase the amount of work the wheel has to do in a unit of time. Both the rate of stock removal in cubic inches per minute and the amount of wheel wear are increased. The wheel could be made to act even "softer" by creating excessive breakdown. A decrease in rpm of the regulating wheel does the reverse, giving the wheel less work to do in a unit of time and making the wheel act "harder" through reduced breakdown.

However, in infeed, or plunge centerless grinding, an increase in rpm of the regulating wheel **does not** increase the stock removal rate in cubic inches per minute unless the infeed rate per minute is also increased. With no change in the infeed rate per minute, the effect is to reduce the depth of cut per revolution of the workpiece, reducing stock removal, and reducing wheel wear. The wheel will act "harder" and can glaze if there is insufficient breakdown to keep the wheelface free-cutting. A decrease in rpm at the same rate of infeed per minute, increases the depth of cut per revolution of the workpiece,with more stock removal as well as wheel wear. The wheel will act "softer."

For greater productivity, the rate of infeed per minute could be increased at the same (or higher) rpm of the regulating wheel, if the wheel grading will permit an increase in the depth of cut per revolution of the workpiece.

Formula number 3). DEPTH OF CUT

INFEED PER MIN./.WORK RPM =INFEED PER REV.

It should be kept in mind that the infeed rate per *minute* controls **productivity**, while the infeed rate per *revolution* controls the grinding wheel's **action**, either improving or limiting the wheel's ability to perform.

Formula number 4).

CUBIC INCHES PER MIN.

MD x 3.1416 x I x T = CUBIC IN. / MIN.

Where:

MD = Mean Diameter, or D+d / 2
D = Starting Diameter of workpiece
d = Diameter after the pass
I = Depth of infeed on the radius
T = Traverse in inches per minute

Example:

(.766" + .750") /2 x 3.1416 x .007 x 126
= 1.05 cu.in/min.

Slower Surface Speeds Reduce Production Rates

As the regulating wheel diameter becomes smaller through repeated dressing, the surface speed becomes slower. This of course, reduces the traverse speed and, therefore, production. A 10 percent loss of surface speed means a 10 percent loss in production. From full diameter to stub size the total change is 17 percent.for the #2 machine and 25 percent for the #3. Unless this is monitored and compensated for, progressively significant losses will be experienced on each job run on the machine. With machines having variable speed changes, an occasional increase in rpm will maintain the surface speed and production However, on those machines with gear levers or gear changes,it becomes more involved. Usually, with each step upward the increments are approximately 33 %, while each step downward is approximately 25%,both of which are often too abrupt for the immediate purpose.In this case, the recommendation is to change the tilt angle for in-between traverse rates.

Another situation in which the regulating wheel speed has to be adjusted is when two or more machines are used in tandem. The traverse rates should be coordinated so that the flow of parts will be consistent and uninterrupted. (Consistent unit pressures in the grinding area produce consistent quality of size and surface finish.) Seldom are the regulating wheel diameters the same so that the same gearing will produce the necessary coordination. It is again necessary to use the angle of inclination, or tilt angle, to bring the traverse rates together.

A few simple formulas, based on ratio and proportion, will take out the guesswork and give the operator confidence that the adjustment he is making will be correct.

Example: The regulating wheel diameter has changed from 12" to 11", with a loss of 8 percent in surface speed When the original tilt angle of 3 degrees, is increased to 3 degrees, 16 minutes, the traverse rate is restored as follows:

FINDING THE NEW ANGLE.

Formula: (D1 * A1)/D2 = A2

where,
D1 = Full diameter
A1 =Original angle
D2 = Present diameter
A2 = New angle setting

Examples:
When the diameter is 11":
(12 * 3)/11 =3.27 deg., or 3 deg. 16 min.
(To convert 3.27 deg. = .27 * 60 = 16 min)

When the diameter is 10":
(11 * 3.27)/10= 3.60 deg., or 3 deg. 36 min.

When the diameter is 9":
(10 * 3.60)/9= 4 deg.

When a full diameter regulating wheel is then mounted, the tilt angle must be reduced accordingly in order to restore the original traverse rate

WHEN A NEW WHEEL IS MOUNTED.

Formula: (D2*A2)/D1 = A1

Example:
(9 * 4)/12 = 3 deg.

TO MAINTAIN TRAVERSE RATE WHEN THE SFPM IS CHANGED EITHER UP OR DOWN

Formula:
Increased: (SFPM1 * A1)/SFPM2 = A2,
or, (RPM1 * A1)/RPM2 = A2
Decreased: (SFPM2 * A2)/SFPM1 = A1
or, (RPM2 * A2)/RPM1 = A1

Where:
SFPM1 (or RPM1)= Before change.
SFPM2 (or RPM2)= After change

Examples:
(SFPM) (122 * 4)/163 = 3 deg.
(RPM) (39 * 4)/52 = 3 deg

(SFPM) (163 * 3)/122 =4 deg.
(RPM) (52 * 3)/4 = 39

Various measurements can be used such as from the wheelface to the flange, the circumferences of the larger and smaller wheel sizes, or the traverse rates (pieces per minute) with the tilt angle. Almost any comparison of common terms will fit into the formula.In any case, combine the item you want to control with the item you can change. The accuracy of the results will depend upon the accuracy of the measurements.

SUMMARY

The following approach will help you get optimum results from your centerless grinding applications:

1) Calculate cubic inch per minute stock removal rates to compare with horsepower potential. (A starting rule of thumb is one cubic inch per minute per ten horsepower with regular coolant, seven horsepower with oil.) This is mainly for stock removal with fairly open size and finish tolerances. As size and finish requirements become more demanding, the stock removal capabilities are, of course, reduced.

2) Use an ammeter, or power meter, to determine the wheel's ability to remove stock on the range of material types that will be ground. It will show when the wheel is breaking down by the drop of power. It will show when the wheelface is glazing by the increase

of power. A steady draw of power indicates an apparently balanced operation in which the grinding wheel is performing to its ability under the conditions of that particular machine setup. Keep records for comparison of stock removal rates on each major type of material ground, as well as the most effective machine setups for important or repetitive jobs. This can be valuable when troubleshooting.

3) Select an infeed rate per pass (or passes) according to the job requirements (stock removal, finish and size tolerances) and your judgment of the wheel's capabilities compared to other jobs already done. This is where the ammeter is especially useful. Workpieces after the last roughing passes should be as consistent in size as possible in order to maintain stock removal rates and pressures for the wheel on the finish pass. Oversize pieces increase wear on the finish wheel and force frequent redressing, for which the finish wheel, rather than the roughing wheel, is blamed. Uneven pressures from variations in size create variations in the finished product.

4) Select the regulating wheel tilt angle that is suitable for the work diameter according to the width of cut and number of revolutions per inch of wheel face. The angle can be changed slightly to maintain traverse rates when speed changes are too abrupt.

5) Select the traverse rate that will produce satisfactory results, considering the depth of cut per pass, total stock removal, size and finish tolerances, along with the power draw. The infeed per pass,the speed of the regulating wheel, and/or the tilt angle, can be changed, up or down, until the power draw is steady.

6) Monitor the actual production at the exit end of the machine, either in inches or pieces per minute, so that the output is maintained on target as the regulating wheel becomes smaller.

7) Pay particular attention to the accuracy of the setup, principally to the shape of the regulating wheel (resulting from the relationship of the tilt angle and the dresser slide angle), and the line of contact with the workpiece, (which depends upon the diamond setover *and* the height of the workpiece in relation to the wheel centerline).This is what should be checked if the part geometry is not satisfactory.

8) If changes are made in the setup that are greatly different from the usual procedures, the wheel specification presently on the machine may become less than satisfactory because it had been engineered to work under the former conditions. Therefore, another opportunity for further improvement in productivity may be gained by upgrading the wheel specification to a more suitable choice for the new conditions. On large volume jobs, or ongoing runs, this is especially advantageous.

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March, 1989

OFFSET-14 X WIDTHS

	A	B	C	D	E	F	G	H	I	J	K	L
1	(INPUT	------	----	-----	-----	INPUT)		RADIAL	TOTAL		(EQUAL ENDS)	
2		REGULATING WHEEL					TRU	DIFF.	ADJUST	ADJUST	TANGENT	CAM
3	WORK			ANGLE	HT	DIAM.	ANGLE	FRT-BK	IN	PER	CAM	SET
4	DIA.	DIA.	WIDTH	0. "	C.L.	OFFSET	0. "	before adj	OFFSET	INCH	TAPER	MIN
5	-----	-----	-----	-----	-----	-----	-----	------	------	------	------	-----
6	1.000	14	6	4.00	.500	.481	3.51	.028			.00464	15
7	1.000	9	6	4.00	.500	.315	3.47	.042	.167	.033	.00464	15
8												
9	1.000	14	8	4.00	.500	.481	3.51	.037			.00464	15
10	1.000	9	8	4.00	.500	.314	3.47	.056	.167	.033	.00463	15
11												
12	1.000	14	12	4.00	.500	.481	3.51	.056			.00464	15
13	1.000	9	12	4.00	.500	.315	3.47	.085	.167	.033	.00464	15
14												
15	1.000	14	20	4.00	.500	.481	3.51	.094			.00464	15
16	1.000	9	20	4.00	.500	.315	3.47	.142	.167	.033	.00464	15

This chart shows four different widths of the regulating wheel: 6, 8, 12 and 20" The radial difference front to back before adjustment are related to the widths, the wider the wheel the greater the difference, front to back,, as would be expected However, the total adjustment in the diamond offset to correct the difference is the same for all widths This is because the diamond offset is the same in all cases.

These four pages are based on formulas in Cincinnati Milacron Company's fine booklet, "CENTERLESS GRINDING, Theory, Principles, Applications."--Copyright 1975.

OFFSET-1/2"-1",12-9

	A	B	C	D	E	F	G	H	I	J	K
1	INPUT	------	----	------	-----	INPUT)		RADIAL		(EQUAL ENDS)	
2		REGULATING WHEEL					TRU	DIFF.	ADJUST	TANGENT	CAM
3	WORK			ANGLE	HT	DIAM.	ANGLE	FRT-BK	IN	CAM	SET
4	DIA.	DIA.	WIDTH	0. "	C.L.	OFFSET	0. "	before adj	OFFSET	TAPER	MIN
5	------	------	------	------	------	------	------	------	------	------	----
6	0.500	12.00	6	6.00	.250	.244	5.52	.025		.00400	14
7	0.500	11.75	6	6.00	.250	.240	5.52	.026	.004	.00400	14
8	0.500	11.50	6	6.00	.250	.235	5.52	.026	.005	.00400	14
9	0.500	11.25	6	6.00	.250	.230	5.52	.027	.005	.00400	14
10	0.500	11.00	6	6.00	.250	.225	5.52	.028	.005	.00400	14
11	0.500	10.75	6	6.00	.250	.220	5.51	.028	.005	.00400	14
12	0.500	10.50	6	6.00	.250	.215	5.51	.029	.005	.00400	14
13	0.500	10.25	6	6.00	.250	.210	5.51	.030	.005	.00400	14
14	0.500	10.00	6	6.00	.250	.205	5.51	.030	.005	.00400	14
15	0.500	9.75	6	6.00	.250	.200	5.51	.031	.005	.00400	14
16	0.500	9.50	6	6.00	.250	.195	5.50	.032	.005	.00400	14
17	0.500	9.25	6	6.00	.250	.190	5.50	.033	.005	.00400	14
18	0.500	9.00	6	6.00	.250	.185	5.50	.033	.005	.00400	14
19								TOTAL	.059		
20	1.000	12.00	6	4.00	.500	.479	3.50	.032		.00537	18
21	1.000	11.75	6	4.00	.500	.470	3.50	.033	.009	.00537	18
22	1.000	11.50	6	4.00	.500	.460	3.50	.034	.010	.00537	18
23	1.000	11.25	6	4.00	.500	.451	3.50	.034	.009	.00537	18
24	1.000	11.00	6	4.00	.500	.441	3.49	.035	.010	.00537	18
25	1.000	10.75	6	4.00	.500	.432	3.49	.036	.009	.00538	18
26	1.000	10.50	6	4.00	.500	.422	3.49	.037	.010	.00537	18
27	1.000	10.25	6	4.00	.500	.412	3.49	.038	.010	.00537	18
28	1.000	10.00	6	4.00	.500	.403	3.48	.038	.009	.00537	18
29	1.000	9.75	6	4.00	.500	.393	3.48	.039	.010	.00537	18
30	1.000	9.50	6	4.00	.500	.383	3.48	.040	.010	.00536	18
31	1.000	9.25	6	4.00	.500	.374	3.48	.041	.009	.00537	18
32	1.000	9.00	6	4.00	.500	.364	3.47	.042	.010	.00537	18
33								TOTAL	.115		

This table shows that the correction for the radial difference front to back, whatever it is for the work diameter and offset, can be apportioned uniformly for each quarter of an inch, or other fraction, throughout the life of the regulating wheel. Therefore, regular small adjustments in the diamond offset would be beneficial, with a minimum of effort and time lost at any one time of redressing.

	A	B	C	D	E	F	6	H	I	J	K	L
1	(INPUT------	------	----	------	------	INPUT)		RADIAL	TOTAL	(EQUAL ENDS)		
2	REGULATING WHEEL						TRU	DIFF.	ADJUST	ADJUST	TANGENT	CAM
3	WORK			ANGLE	HT	DIAM.	ANGLE	FRT-BK	IN	PER	CAM	SET
4	DIA.	DIA.	WIDTH	0. "	C.L.	OFFSET	0. "	before adj	OFFSET	INCH	TAPER	MIN
5	------	------	------	------	------	------	------	------	------	------	------	------
6	0.125	12	6	6.00	.063	.062	5.58	.007			.00110	3
7	0.125	9	6	6.00	.063	.047	5.57	.009	.016	.003	.00110	3
8	0.125	12	6	7.00	.063	.062	6.57	.008			.00130	4
9	0.125	9	6	7.00	.063	.047	6.57	.010	.015	.003	.00130	4
10	0.125	12	6	8.00	.063	.062	7.57	.009			.00140	4
11	0.125	9	6	8.00	.063	.047	7.56	.012	.015	.003	.00150	5
12												
13	0.250	12	6	6.00	.125	.124	5.56	.013			.00215	7
14	0.250	9	6	6.00	.125	.094	5.55	.017	.031	.010	.00215	7
15	0.250	12	6	7.00	.125	.124	6.55	.015			.00251	8
16	0.250	9	6	7.00	.125	.093	6.54	.020	.031	.010	.00250	8
17	0.250	12	6	8.00	.125	.124	7.55	.017			.00287	9
18	0.250	9	6	8.00	.125	.093	7.53	.023	.031	.010	.00286	9
19												
20	0.375	12	6	6.00	.188	.184	5.54	.019			.00318	10
21	0.375	9	6	6.00	.188	.139	5.52	.025	.045	.015	.00318	10
22	0.375	12	6	7.00	.188	.184	6.53	.022			.00372	12
23	0.375	9	6	7.00	.188	.139	6.51	.030	.045	.015	.00372	12
24	0.375	12	6	8.00	.188	.184	7.52	.026			.00425	14
25	0.375	9	6	8.00	.188	.139	7.50	.034	.045	.015	.00425	14
26												
27	0.500	12	6	6.00	.250	.244	5.52	.025			.00420	14
28	0.500	9	6	6.00	.250	.184	5.50	.033	.060	.020	.00420	14
29	0.500	12	6	7.00	.250	.245	6.51	.030			.00490	16
30	0.500	9	6	7.00	.250	.185	6.48	.039	.060	.020	.00490	16
31	0.500	12	6	8.00	.250	.245	7.50	.034			.00560	18
32	0.500	9	6	8.00	.250	.185	7.47	.045	.060	.020	.00560	18
33												
34	0.625	12	6	5.00	.313	.304	4.52	.026			.00432	14
35	0.625	9	6	5.00	.313	.230	4.50	.034	.074	.025	.00432	14
36	0.625	12	6	6.00	.313	.305	5.51	.031			.00520	17
37	0.625	9	6	6.00	.313	.231	5.48	.041	.074	.025	.00521	17
38	0.625	12	6	7.00	.313	.304	6.49	.037			.00607	20
39	0.625	9	6	7.00	.313	.230	6.46	.048	.074	.025	.00607	20
40												
41	0.750	12	6	4.00	.375	.362	3.52	.025			.00410	14
42	0.750	9	6	4.00	.375	.274	3.50	.032	.088	.029	.00410	14
43	0.750	12	6	5.00	.375	.364	4.51	.031			.00510	17
44	0.750	9	6	5.00	.375	.276	4.48	.041	.088	.029	.00520	17
45	0.750	12	6	6.00	.375	.364	5.49	.037			.00620	21
46	0.750	9	6	6.00	.375	.275	5.45	.049	.089	.029	.00620	21

	A	B	C	D	E	F	G	H	I	J	K	L
1	(INPUT-----	-----	----	-----	-----	INPUT)		RADIAL	TOTAL	(EQUAL ENDS)		
2		REGULATING WHEEL					TRU	DIFF.	ADJUST	ADJUST	TANGENT	CAM
3	WORK			ANGLE	HT	DIAM.	ANGLE	FRT-BK	IN	PER	CAM	SET
4	DIA.	DIA.	WIDTH	0. "	C.L.	OFFSET	0. "	before adj.	OFFSET	INCH	TAPER	MIN
5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
6	0.875	12	6	4.00	.438	.421	3.51	.029			0.0047	16
7	0.875	9	6	4.00	.438	.320	3.49	.037	.101	.034	0.0048	16
8	0.875	12	6	5.00	.438	.422	4.49	.036			0.0059	20
9	0.875	9	6	5.00	.438	.319	4.46	.047	.103	.034	0.0059	20
10	0.875	12	6	6.00	.438	.422	5.47	.043			0.0071	24
11	0.875	9	6	6.00	.438	.320	5.43	.056	.102	.034	0.0071	24
12												
13	1.000	12	6	3.00	.500	.478	2.52	.024			.00400	13
14	1.000	9	6	3.00	.500	.362	2.50	.032	.116	.039	.00400	13
15	1.000	12	6	4.00	.500	.479	3.50	.032			.00540	18
16	1.000	9	6	4.00	.500	.363	3.47	.042	.116	.039	.00540	18
17	1.000	12	6	5.00	.500	.480	4.48	.041			.00670	23
18	1.000	9	6	5.00	.500	.364	4.44	.053	.116	.039	.00670	23
19												
20	2.000	12	6	1.00	.500	.459	0.55	.007			.00120	4
21	2.000	9	6	1.00	.500	.350	0.54	.010	.109	.036	.00120	4
22	2.000	12	6	2.00	.500	.463	1.51	.015			.00250	8
23	2.000	9	6	2.00	.500	.356	1.48	.019	.107	.036	.00250	8
24	2.000	12	6	3.00	.500	.461	2.46	.022			.00370	12
25	2.000	9	6	3.00	.500	.353	2.42	.029	.108	.036	.00370	12
26												
27	3.000	12	6	1.00	.500	.442	0.53	.007			.00110	3
28	3.000	9	6	1.00	.500	.344	0.51	.009	.098	.033	.00120	3
29	3.000	12	6	2.00	.500	.446	1.47	.014			.00230	7
30	3.000	9	6	2.00	.500	.344	1.43	.017	.102	.034	.00230	7
31	3.000	12	6	3.00	.500	.447	2.41	.021			.00350	12
32	3.000	9	6	3.00	.500	.346	2.35	.026	.101	.034	.00350	11
33												
34	4.000	12	6	1.00	.500	.425	0.51	.006			.00107	3
35	4.000	9	6	1.00	.500	.330	0.49	.008	.095	.032	.00106	3
36	4.000	12	6	2.00	.500	.429	1.43	.013			.00216	7
37	4.000	9	6	2.00	.500	.334	1.39	.016	.095	.032	.00216	7
38	4.000	12	6	3.00	.500	.432	2.35	.020			.00326	11
39	4.000	9	6	3.00	.500	.336	2.29	.024	.095	.032	.00326	11

This page and the preceeding page show combinations of work piece sizes, offsets of the diamond dressers, recommendations for suitable tilt angles, and truing angle, with the total amount of correction in each case. Intermediate diameters can be interpolated.