HOW TO GET THE BEST RESULTS FROM YOUR SURFACE GRINDING OPERATIONS

by **Charles Pollock,** Technical Editor
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After four years of research on vertical spindle surface grinding with segments at Norton Company, several significant results have been found. These results are of particular importance to the shop doing this type of work. Presented in the form of charts, this material shows the manufacturing engineer and shop foreman how to get the best possible results from his vertical spindle rotary grinders.

Setting the Downfeed Rate

The one area, which has been a continual bugaboo with all machining operations, is determining the feeds and speeds which produce minimum total cost for the machining operation. Much has been written on this subject. However, it all boils down to the need to run a few tests and calculate costs, to find where this minimum is.

Fortunately, in vertical spindle surface grinding, we have found that changes in workpiece area, segment hardness, etc., have only a small effect on the minimum cost downfeed rate of the machine. Also, because the cost curve is generally quite flat in the area of minimum cost, these small variations do not greatly effect the actual cost of the operation. Hence we have been able to draw curves such as shown in Figure 1.

These curves show the approximate downfeed rate at which costs will be minimum, for both mild steel and cast iron. To use them you must first decide what your labor cost, in dollars per hour, is for this particular machine. Here, you should use your company's standard cost figures for machine operating calculations. Once you know these costs, look up the appropriate value on the horizontal axis of Figure 1. Then go straight up until you come to the curve of the material that you are grinding and read the approximate downfeed rate on the vertical axis. If you then run your machine at this downfeed rate, you will be operating very close to the point of minimum cost.

As with all rules of thumb, the chart in Figure 1 is limited. However, it will be valid for almost all common situations and its use is certain to improve your operations.

Loading the Machine

The most significant result of our research program is shown in Figure 2. We found that the rate of stock removal, on a surface grinder, is dependent on the volumetric feed rate of the machine. Volumetric feed rate is the rate of which material would be removed if the grinding wheel did not wear. It is determined by multiplying the downfeed rate of the grinding machine times the area of the workpiece being ground. In other words, it is the amount of material that we are asking of the grinding machine to remove.

Consequently, to increase the out-

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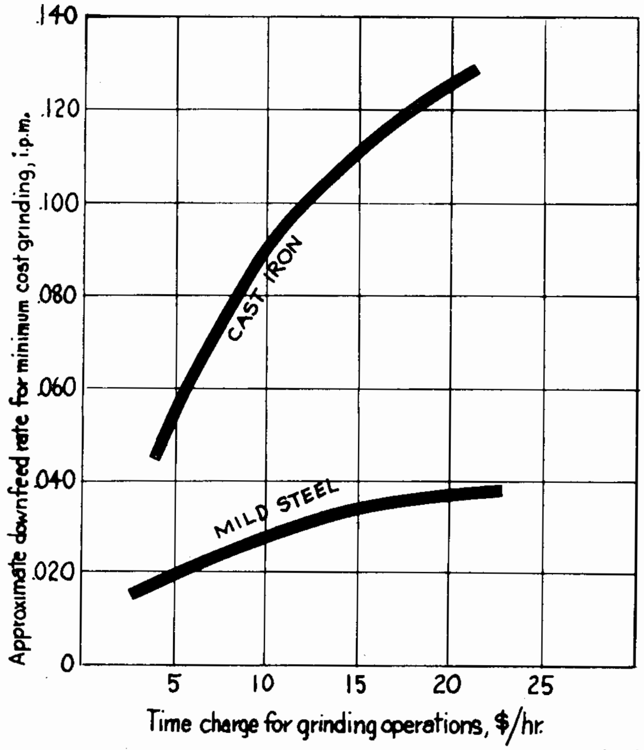

FIGURE 1: The approximate optimum economic downfeed rate, for a vertical spindle surface grinder, versus machine labor rate, in dollars per hours, for cast iron and 1020 hot rolled steel.

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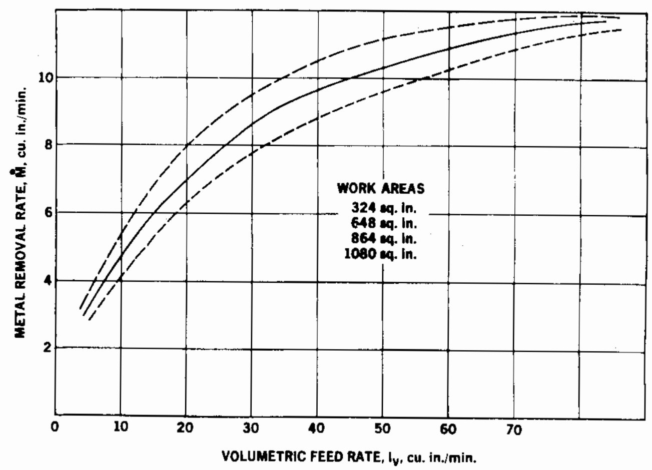

FIGURE 2: Metal removal rate versus volumetric feed rate for A1S1 1020 hot-rolled steel and 32A36-G12VBEP Norton-shape segmental grinding wheels. This curve was developed from data from more than 150 test runs. The dashed lines represent the band in which approximately 95 percent of the data falls.

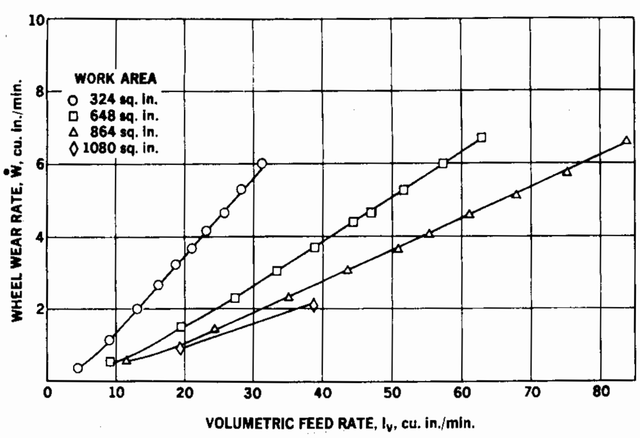

FIGURE 3: Wheel wear rate versus volumetric feed rate for A1S1 1020 hot-rolled steel and 32A36-G12VBEP Norton-shape segmental grinding wheels. Data points represent averages of one to five individual test runs under identical conditions.

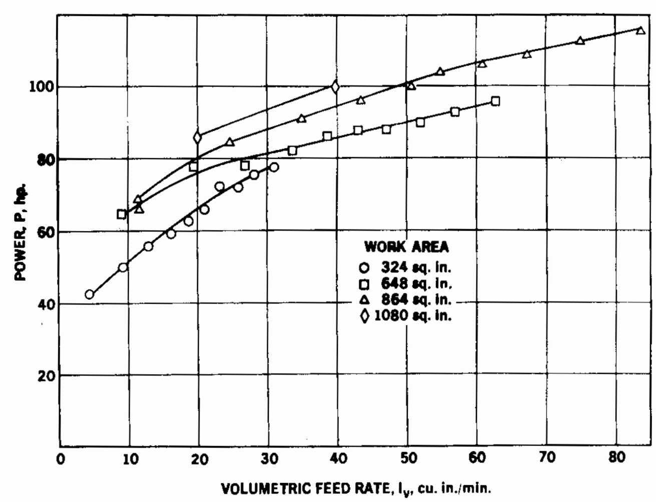

FIGURE 4: Power versus volumetric feed rate for A1S1 1020 hot-rolled steel and 32A36-G12VBEP Norton-shape segmental grinding wheels. Data points represent averages of one to five individual test runs under identical conditions.

put of a vertical spindle surface grinder it is merely necessary to increase the volumetric feed rate. This can be done by either increasing the down feed rate or by increasing the number of parts on the work table, or by increasing both of these together.

The question now arises as to whether it is better, from a cost point-of-view, to increase the downfeed rate or increase the number of pieces ground. Figure 3 gives us the answer. Here we plot the grinding wheel wear rate against volumetric feed rate. The result is a family of straight lines with different slopes. The smaller the work pieces area, i.e. the fewer the number of parts on the work table, the steeper the line. And, conversely, the larger the work piece area the lower the slope.

To answer the question of whether to increase down feed rate or work area let us look at a sinple example. You will notice in Figure 2 that an increase in volumetric feed rate from 15 cubic inches per minute to 30 cubic inches per minute gives an increase in output from 6 cubic inches of material removed per minute to 8-½ cubic inches of material removed per minute.

In Figure 3 let us assume that we are operating the machine at a volumetric feed rate of 15 with a 324 square inch work piece area. Then the wheel wear rate will be approximately 2-1/4 cubic inches per minute. If we now double the downfeed rate, so that volumetric feed rate is 30, the wheel wear rate increases to approximately 5-½ cubic inches per minute; a rather substantial increase. However, if we increase the volumetric feed rate to 30 by doubling the number of pieces on the work table (648 square inches) we see that the wheel wear rate increases to only 2-½ cubic inches per minute; a very small increase.

Thus we have answered our question. It is obvious that if we can obtain the same increase in output by doubling either the downfeed rate or the number of pieces on the work table we will be better off doubling the work because this results in only a slight increase in wheel wear rate.

Also, by increasing the downfeed rate we have also moved away from the lowest cost feed rate selected from Figure 1. However, by increasing the work area we are still operating at the lowest cost downfeed rate. Hence, by doing this, we continue to operate at minimum cost and at the same time we have greatly increased our output without significantly changing the rate of wheel wear. The net effect of doing this is to reduce costs, in our previous example, from 5c per cubic inch of material removed to 3-2/3c per cubic inch of material removed. If we had obtained the same increase in productivity by doubling the downfeed rate costs would have gone up to 8-2/3c.

It appears that we have achieved something for nothing. However, this is not quite the case. Figure 4 shows a chart of power versus volumetric feed rate, and the price we pay is slightly increased power usage. From this figure we see that, grinding at a volumetric feed rate of 15 cu. in. per min., with the 324 sq. in. area, we are consuming approximately 60 hp. By doubling the downfeed rate the power will increase to 77 hp. However, if we double the work area, the machine will draw 83 hp at a volumetric feed rate of 30 cubic inches per minute. However, an extra 6 hp seems to be a low price to pay for a 51% increase in productivity and a 60% decrease in wheel wear per part ground.

What does this mean to you, the user? From this information we can conclude two basic rules of thumb for operating your vertical spindle grinder.

First, using the chart in Figure 1, select the down feed rate which will give you minimum cost grinding.

Second, place as many parts on the work table of the grinding machine as you possibly can. However, keep one restriction in mind. Do not put parts in the center of the work table. During grinding, this small portion in the center of the work table does not have an opportunity to get out from the grinding wheel and, consequently, it does not have an opportunity to get cooled by the grinding fluid. As a result, these parts often become over-heated and they will either burn or expand due to the heat, and the expanded material will be ground away. Consequently, after the parts cool, the heated parts will be undersized.

There is one additional limitation on the use of this information. You will notice that we have said nothing about tool steel grinding. Usually when you are grinding tool steels, the primary limitation on productivity is the tendency of tool steels to burn and warp. Consequently, we are not always free to put the maximum number of pieces on the work table, or to operate the machine at the downfeed rate which is most economical, or to use the full power of a large surface grinder. However, the above rules of thumb can still be used until the heat sensitivity limit of the workpieces is reached.

THE SECOND (Concluding) INSTALLMENT OF THIS ARTICLE WILL APPEAR IN THE NOVEMBER ISSUE OF ABRASIVE METHODS—ED

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CONCLUDING INSTALLMENT OF TWO-PART ARTICLE

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(See October issue for first part of this technical article—Ed.)

Segment Grade Selection

Let's now discuss the selection of the proper segment wheel grade for best grinding results.

In Figure 5 we have plotted the metal removal rate against the volumetric feed rate for four different grades of segments. (Each of these curves represents a curve like the one developed in Figure 2). As we study this chart we see that, for a given volumentric feed rate, as we increase the hardness of the segment from an E grade through an H grade the metal removal rate, or the output of the grinder, increases. However, with each succeeding increase in grinding wheel hardness we notice that the increase in metal removal is less. Consequently, we get less from increased hardness when we are already using a hard segment grade that we get from increasing hardness if we are using a soft grade.

In Figure 6 we see a family of straight lines of wheel wear rate against volumetric feed rate, for the same four segment grades. You will note that the line for the G grade segment is identical to the 648 square inch line of Figure 3. As we would expect, softer grades wear faster, as illustrated in Figure 6 by the fact that the E grade curve is the highest and the H grade is the lowest. However, it is interesting to note that there is relatively little change in the grinding wheel wear rate as we change the grade of the segment.

Consequently, from Figure 5 and 6, we might conclude that we would be best off to use only the H grade segment. This is because the increase in metal removal rate, over an E grade segment, is relatively large and the wheel wear rate decreases slightly. However, we do not always want to use the hardest possible grade of segment.

As a segment is increased in hardness it, of course, wears at a slower rate. This means that the individual pieces of abrasive in the grinding wheel structure are held in place longer and, consequently, become somewhat duller before they are released from the wheel matrix. Thus, even though metal is being removed faster, grinding with a hard grade wheel means that we are also grinding with a wheel which is not as sharp as a soft grade wheel. When we are using a dull piece of abrasive we know it is going to take more power to push this piece of abrasive through the metal we are grinding (it is much the same as trying to cut metal with a dull cutting tool). Thus, when we are grinding with a soft, sharp, E grade segment we would expect that a large portion of the power used by the grinding machine would be used in the useful work of metal removal.

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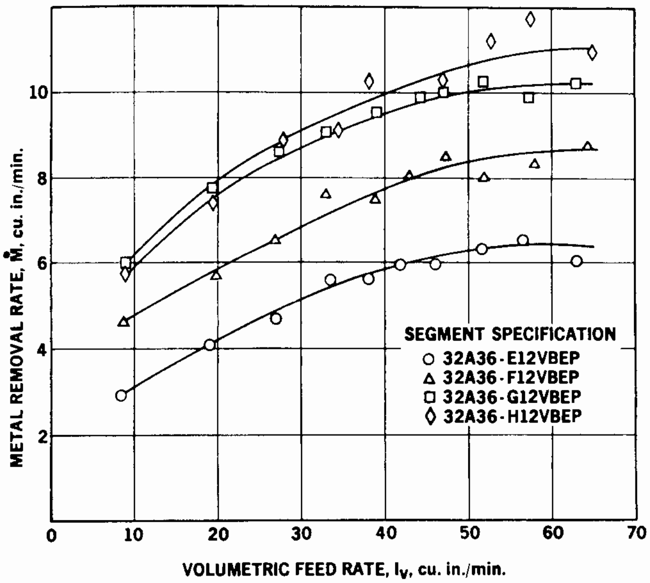


FIGURE 5: Metal removal rate versus volumetric feed rate for AISI 1020 hot-rolled steel with a total grinding area of 648 sq. in. Data points represent averages of one to five individual test runs under identical conditions.

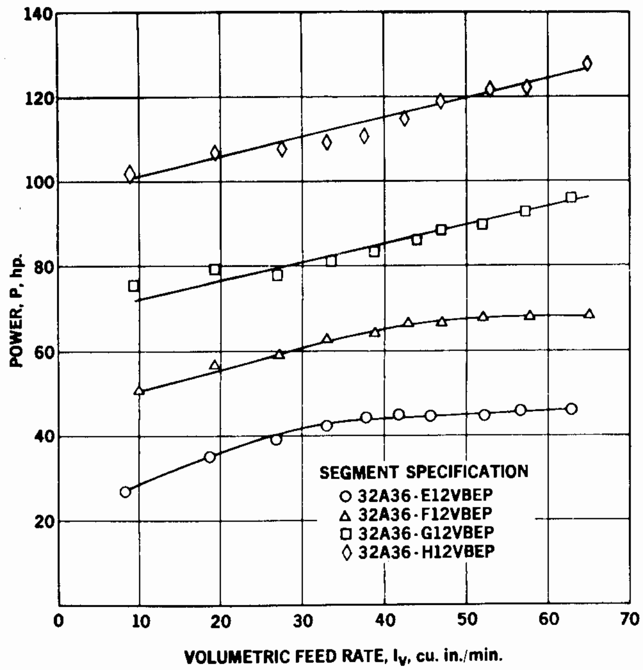
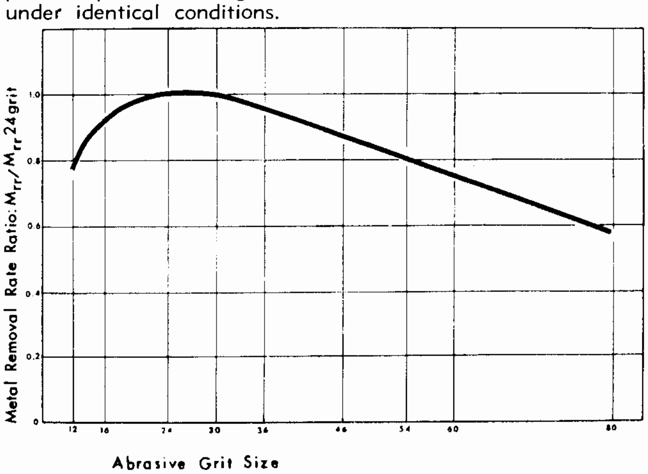


FIGURE 7: Power versus volumetric feed rate for AISI 1020 hot-rolled steel with a total grinding area of 648 sq. in. Data points represent averages of one to five individual test runs under identical conditions.



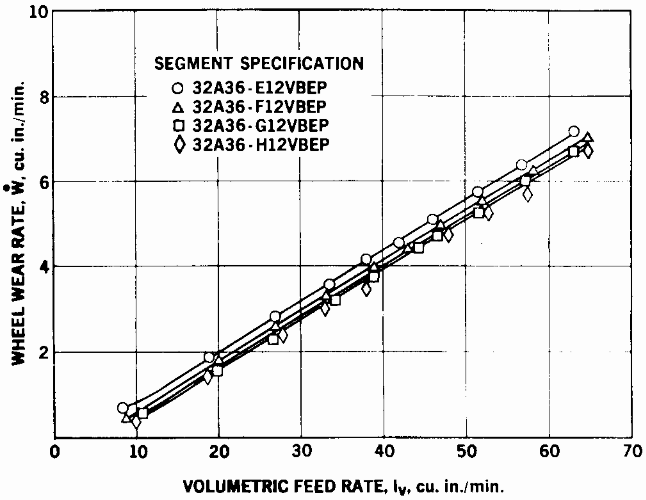


FIGURE 6: Wheel wear rate versus volumetric feed rate for AISI 1020 hot-rolled steel with a total grinding area of 648 sq. in. Data points represent averages of one to five individual test runs under identical conditions.

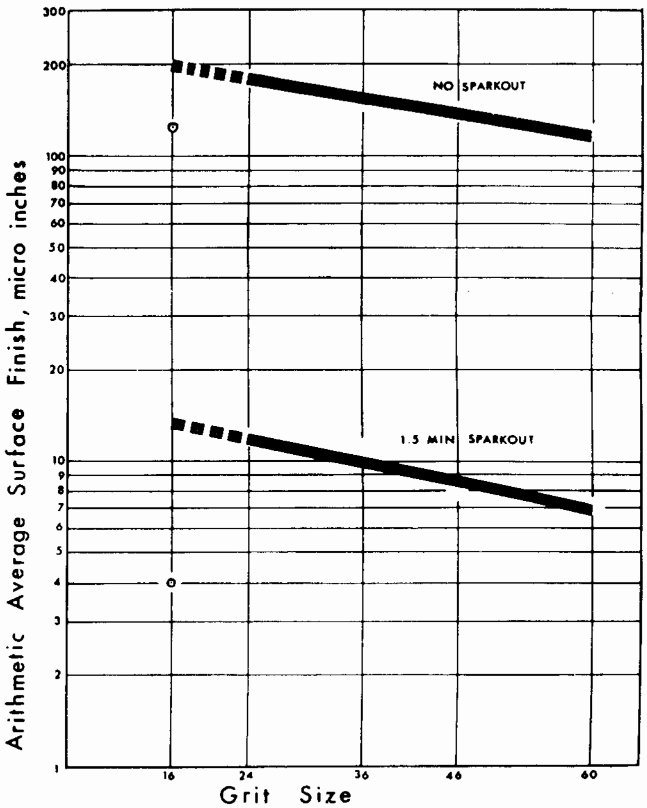


FIGURE 8: Arithmetic Average Surface Finish versus the abrasive grit size which produced the finish on 1020 hot-rolled steel.

FIGURE 9: Metal removal rate ratio versus abrasive grit size for surface grinding 1020 hot-rolled steel. This ratio compares the metal removal rate of various grit sizes to the measured metal removal rate for 24 grit abrasive.

Conversely, when we are grinding with an H grade segment, which is duller, we would expect a greater portion of the power to be consumed in pushing the dull grains through the metal surface.

Thus, we would expect relatively large increases in horsepower when going from a G to an H grade segment while achieving the smaller increases in metal removal rate shown in Figure 5.

Figure 7 confirms our expectation. In this chart we see that increasing segment hardness form E through H grades results in approximately equal increases in the horsepower necessary to remove the material. These equal increases in power, coupled with the reduced increases in metal removal rate, shown in Figure 5, confirm our thinking about the dull grains in hard wheels.

Consequently, if we are performing a grinding operation with a relatively soft grade segment, increasing the grade of the segment to the hardest available, may very well overload the grinding machine or, because dull abrasive generates heat, create burning in the work piece. Thus, in selecting the best segment grade for a particular job we are limited by the power availability of the grinding machine or by the power level at which burning of the work piece occurs.

Therefore, as a *third rule of thumb*, we recommend that, after selecting the downfeed rate and filling the work table, select the hardest grade of abrasive segment which will not overload the machine or cause the work piece to burn or wrap.

Meeting Surface Finish Requirements

Figure 8 shows how the surface finish of a steel workpiece is closely tied to the abrasive grit size. This chart represents the average surface finish which was measured under two sets of grinding conditions. First, after a test run the wheel was immediately retracted at the end of the downfeed, in other words, no spark-out. A second measurement was made after a one-and-one-half minute spark-out period. That is, the automatic feed on the grinding machine was shut off and the wheel and work were allowed to remain in contact for 1-1/2 minutes. These finishes are representative of "best" grinding practice, and were obtained under specific conditions. However, a similar relationship between finish and abrasive grit size will apply in all applications.

Note the similarity of the slopes of the two lines. This confirms the relative dependence of finish upon grit size, providing the segment is not loaded or glazed. We expect that any spark-out period, or similar finishing technique, would show a similar grit size effect.

This chart also indicates that a proper spark-out period is more important in obtaining a good surface finish than merely the selection of a fine grit abrasive. We have found that, unless surface finishes of less than 15 to 20 microinches AA is desired, a 24-grit segment, with proper spark-out, will generally do the job.

Since spark-out is more important in determining surface finish than grit size, our decision regarding the proper grit size for grinding operations should be based primarily on the productivity of different sizes of abrasive. Figure 9 shows this relationship. This figure shows the average effect of abrasive grit size over a wide range of work setups. The data clearly shows that either 24 or 30 grit size will have the best performance for general purpose grinding.

Note, also, the loss of productivity between the peak of the curve (24 and 30 grit) and the low at 80 grit segments. For example, suppose that you are now using 80 grit segments and a 50 microinch finish is satisfactory for your parts. Your output could be increased by as much as 75% by changing to either 24 or 30 grit segments of the same grinding grade.

The metal removal rate ratio shown in this figure is a means of comparing the performance of various grit sizes. It is average ratio of the mental removal rate obtained for a particular grit size divided by the metal removal rate, at an equal power level, for 24 grit size segments.

This ratio, then, says: To find the average metal removal rate, at a specific power level, for an abrasive grit size, multiply the metal removal rate of a 24 grit size segment by the metal removal rate ratio. *Examples*: Suppose that the test results show that a 100 hp and a feed rate of .030 IPM, a 32A23-H12VBEP segment has removed 10 cubic inches of metal per minute. To find the metal removal rate of an 80 grit segment, at 100 hp, and the same feed rate, multiply 10 cubic inches per minute by the metal removal rate ratio from Figure 5, for the 80 grit size. Thus; metal removal rate for 80 grit equals 10 x .57 = 5.7 cubic inches per minute of metal removed by the 80 grit segment.

Summary

From the data presented we can develop four rules of thumb for obtaining the best possible results when abrasive machining steel or cast iron on vertical spindle rotary surface grinders. These are:

1. Select the downfeed rate which will give the minimum cost for your grinding operation. This downfeed rate is based on the hourly charge for the machine and the material being ground.
2. Place as many parts as possible on the grinding machine work table. *Warning*: Do not place parts over the center section of the table (approximately 12 to 18 inches in diameter) this is apt to cause excessive heating of the parts in the center of the table and resulting in poor grinding results.
3. Select the hardest possible grade of segment which will not overload the machine or cause the workpieces to burn or wrap. This, of course, will be somewhat dependent upon the size of the workpieces that you are grinding. For instance, if you are grinding small rims on castings, because of the small total work area, you will be able to use a very hard grade of segment. On the other hand, if you are grinding relatively large flat steel plates, where flatness is desired, you are apt to run into heat limitations and a soft segment grade will be required.
4. Select either 24 or 30 grit segments, unless your surface finish requirements are so tight that a finer grit segment is required. Remember, that excellent surface finishes can be obtained by properly sparking-out the workpiece.

If you follow these four rules of thumb, we are certain that you will notice a substantial increase in the output of your vertical spindle grinders. This increase will also be coupled with considerably reduced cost because you will not only be operating at the minimum cost down feed rate but all of the other conditions will be set so that you are obtaining the lowest possible total cost.