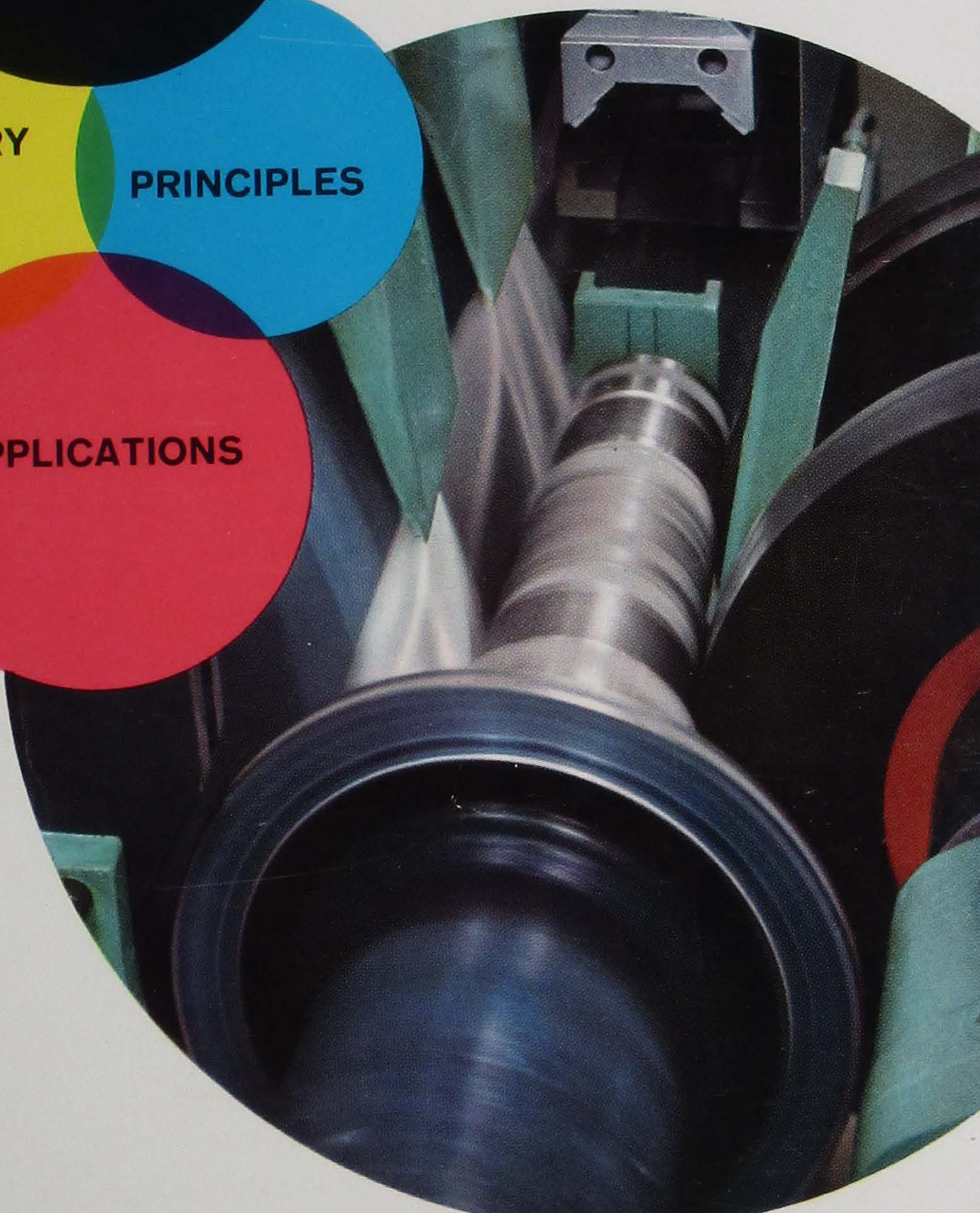
CENTERLESS GRINDING

THEORY

PRINCIPLES

APPLICATIONS



GRINDING MACHINE DIVISION / THE CINCINNATI MILLING MACHINE CO.

CENTERLESS GRINDING . . . THEORY . . . PRINCIPLES . . . APPLICATIONS

The cylindrical grinder was first made as a crude grinding lathe in the early 1860's. Present types, which are the results of some 100 years of development by many men, follow closely the fundamental principles of the early machines. However, the outstanding achievement in the process of precision cylindrical grinding was the introduction of the centerless machine, which took place some 40 years ago. This type of machine has proved itself in both high production and job shops. Its versatility is evidenced by the various types of material it can grind, such as cork, glass, porcelain, wood, rubber, plastics, and the new high alloy steels as well as the more common types of ferrous and non-ferrous metals. Parts as small as .003 of an inch in diameter all the way up to large freight car axles can be ground to dimensions of remarkable accuracy by the centerless method. The centerless grinder incorporates several principles which are entirely different from centertype grinding. This booklet is intended to present and explain the theories, the principles, and show actual applications of centerless grinding and also to supply a working knowledge of the centerless method of grinding to those interested in the subject. The formulae and graphs shown in this booklet are intended to assist the person who is grinding parts to ultra-close tolerances and/or the person who is interested in obtaining maximum production with a centerless grinder.

ILLUSTRATION REFERENCE NUMBERS

For your convenience in quickly finding illustrations referred to in this booklet, we have given all illustrations the same number as the page on which they appear. For example, Figures 12A and 12B are both on page 12.

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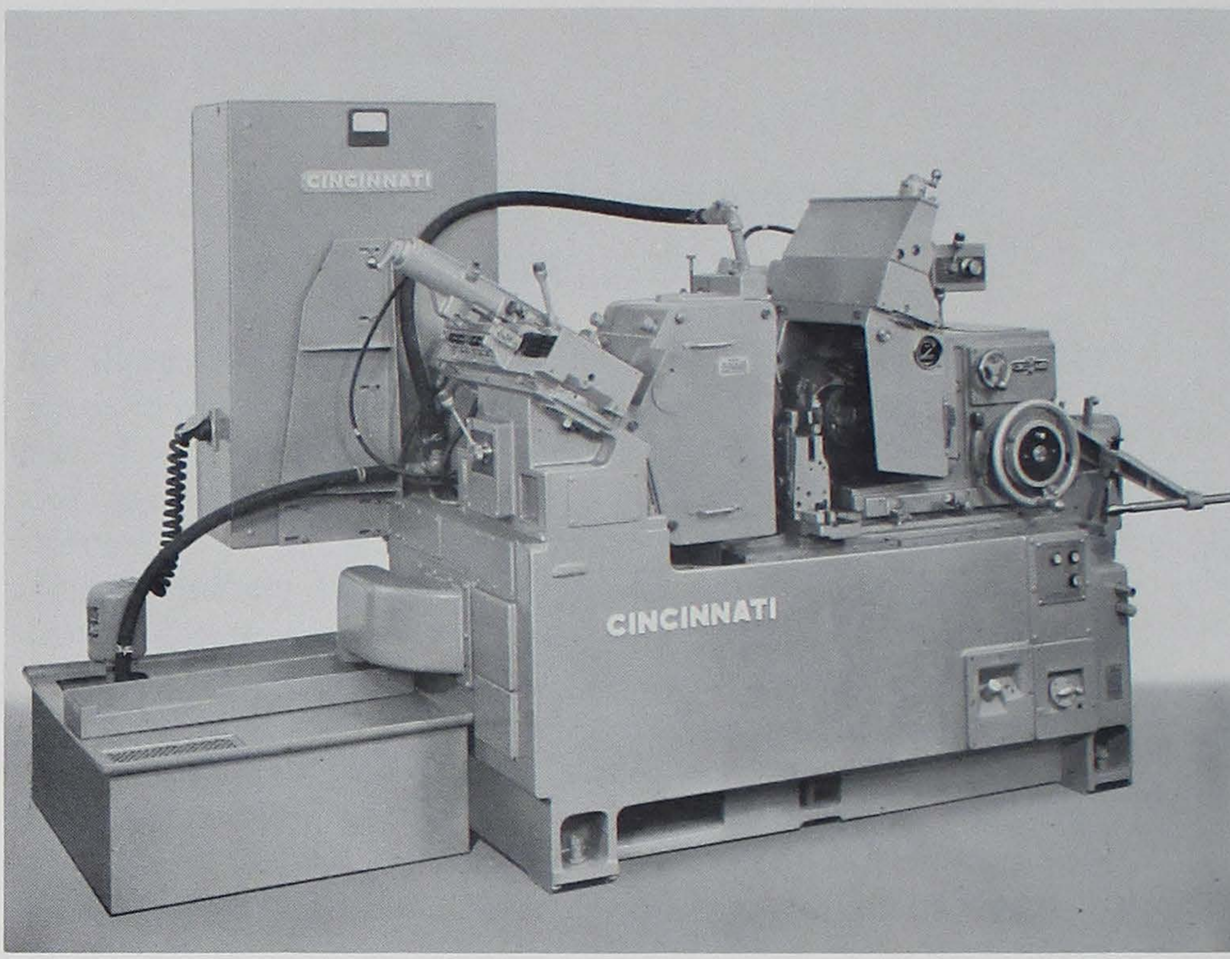
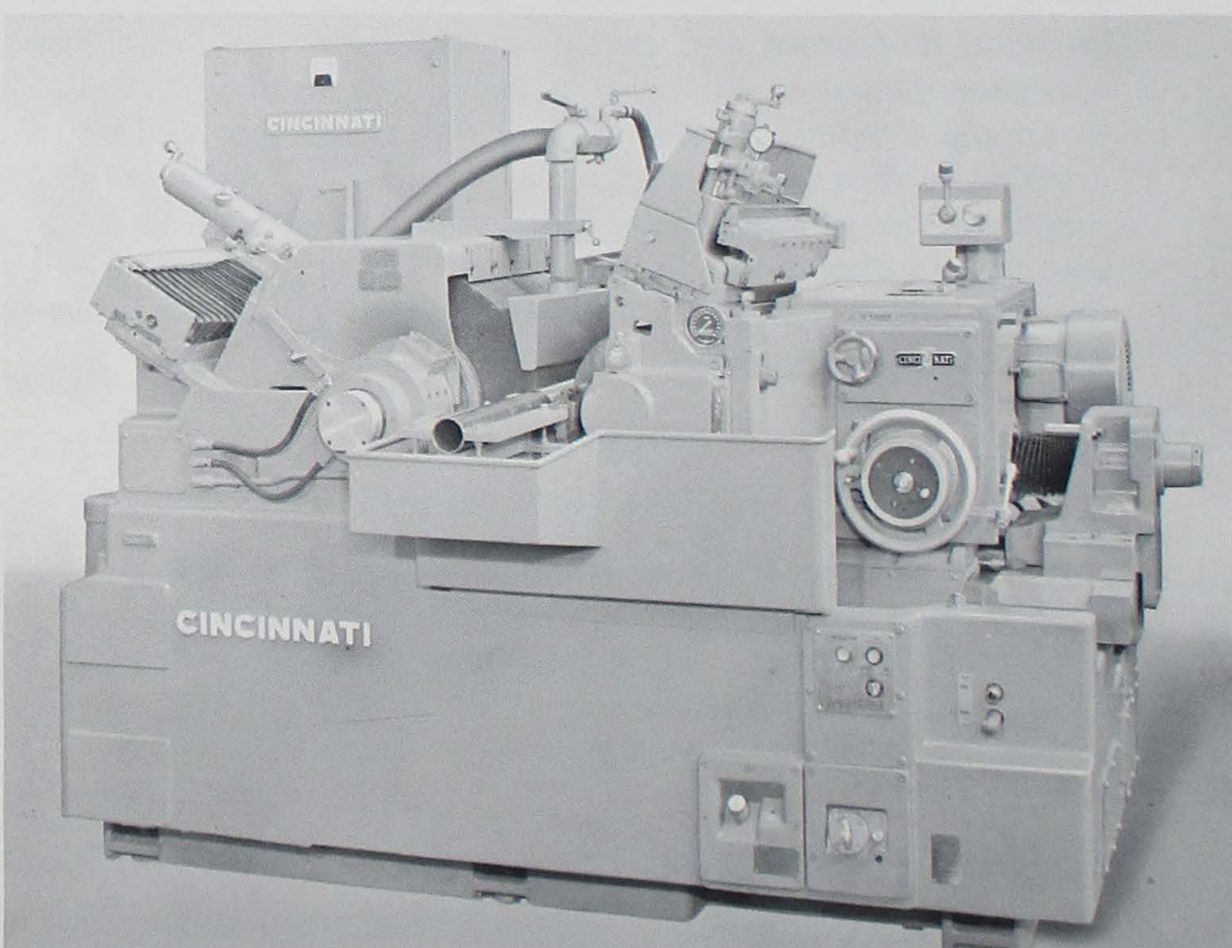


CINCINNATI® FILMATIC® 220-8 Centerless Grinding Machine



CINCINNATI® FILMATIC® 340-20 TwinGrip Centerless Grinding Machine

CONTENTS

CHAPTER I

BASIC PRINCIPLES

The primary elements of a centerless grinding machine are the grinding wheel, regulating wheel, and the work rest (Figure 4A). The thrufeed work rest incorporates suitable guides for leading the work to the wheels and receiving it therefrom, as well as proper means for supporting the work during the grinding cut. The above named elements may be arranged and combined in a number of different ways, but the fundamental principle involved is the same in all cases.

One can readily understand how work is ground round on a centertype grinder. The work is supported between centers and rotated by power while traversing to and fro across the face of the grinding wheel. This action causes the generation of a cylindrical surface. The diameter of the cylinder is governed by the distance from the face of the grinding wheel to a line connecting the center-points.

On the centerless grinder there are no centers, and apparently no method of controlling the roundness of the work exists. The cutting pressure developed by the grinding action forces the work down against the work rest blade and also against the regulating wheel. This wheel is usually made of a rubber bonded abrasive. It serves as both a frictional driving and braking element, rotating the work at a constant and uniform surface speed approximately equal to that of the wheel.

It is evident that the ground diameter of the part is determined by the distance between the two active surfaces of the wheels, but a constant diameter does not necessarily mean a perfect cylinder. In order to clearly present the subject

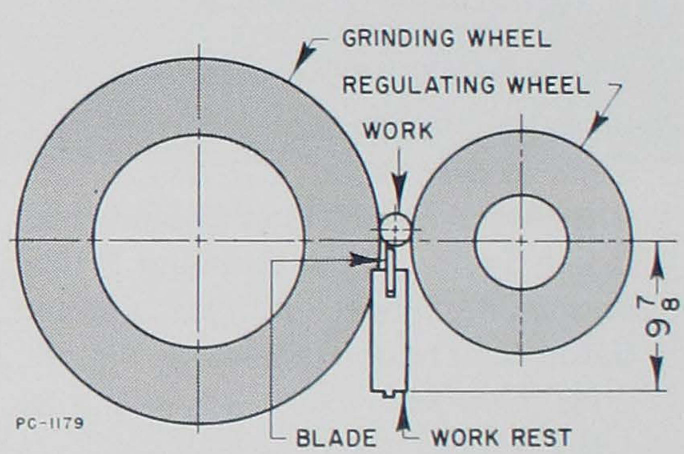


Figure 4A
Primary elements of the centerless grinder

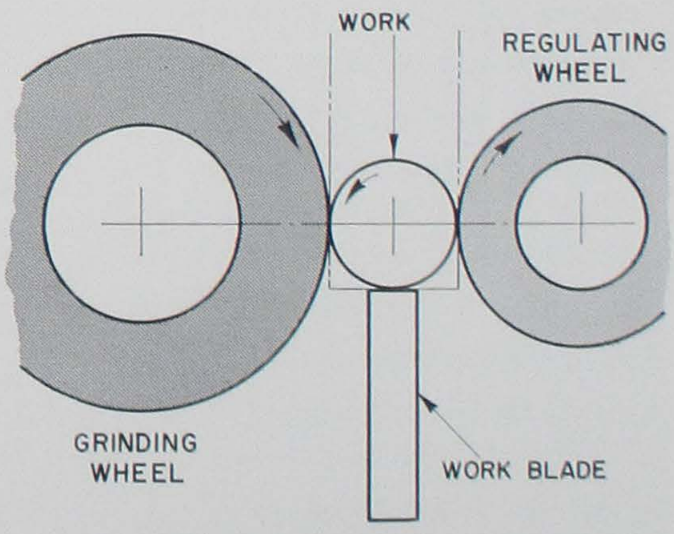


Figure 4B
Flat top blade, with work on center

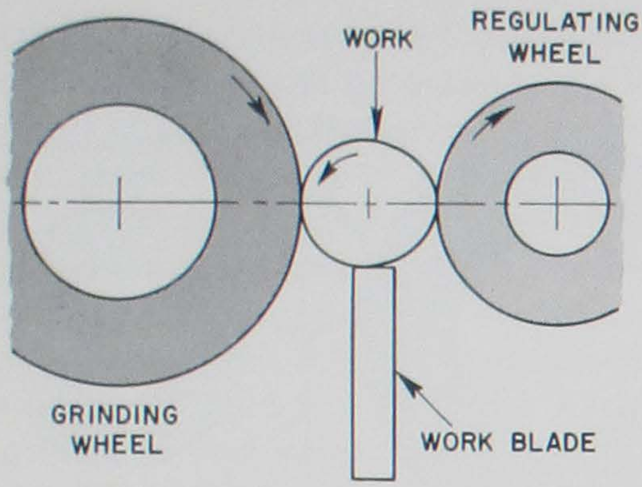


Figure 5A

Effect of out-of-round work on flat top blade, and with work on center

of controlling the roundness of the work on the centerless, we must examine the influencing factors.

The simplest case is considered first. The center of the work is in line with the centers of the grinding and regulating wheels. (Figure 4B). The surfaces of the wheels, together with the flat top work supporting blade, form three sides of a square.

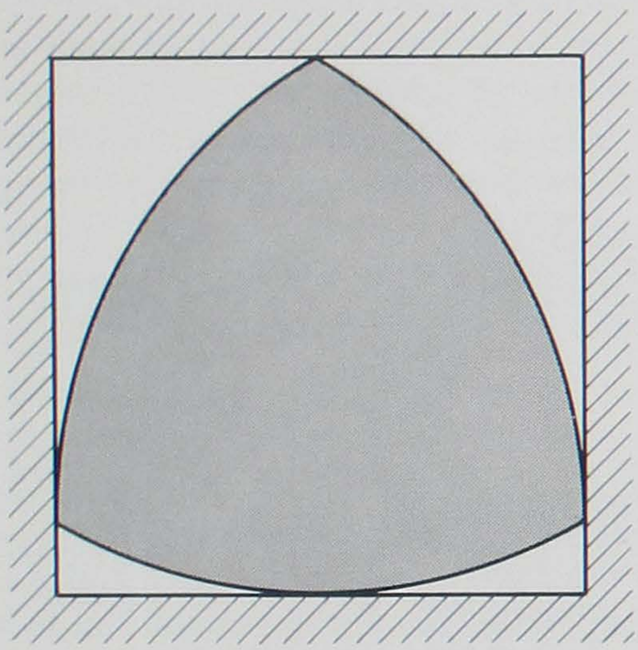


Figure 5B

Exaggerated shape generated by above setup

Any high spot on the periphery of the work coming into contact with the regulating wheel will produce a diametrically opposite low spot (Figure 5A). Grinding with this setup results in work of constant diameter but not cylindrical. An extreme case of the shape generated by this method is shown in Figure 5B, and is known as the three-arc triangle, having a constant diameter but not round.

Now, if the center of the work is elevated above the centers of the wheels by raising the supporting blade, a low spot coming in contact with the regulating wheel will cause a high spot to be generated at the contact with the grinding wheel, *but not diametrically opposite.* As the piece being ground is rotated, the high and low spots will not come opposite each other, as was shown before, and a gradual rounding effect is thus obtained.

To attain maximum corrective rounding action, use has been made of a blade with angular top as shown in Figure 6A. This produces distinct corrective phenomena which is diagrammatically illustrated in Figure 6B. Two lines, A-A and B-B, are drawn tangent at the points of contact of the work with the wheels, and another line, C-C, shows the plane of the angular top of the blade. If a low spot on the work comes in contact with either the blade or the regulating wheel, as in the case of the part shown in dotted lines, the approximate center of the work will be lowered. With centers of both wheels being fixed, the smallest diameter can be generated on their center line. The lowering of the center of the work toward the center line of the wheels causes the reduction in the diameter of the ground piece. Conversely, any increase in height of the center of the work above the center line of the wheels causes generation of a correspondingly larger diameter. Thus the grinding wheel, instead of leaving a high spot on the periphery of the work equal to the depth of the concave spot at the contact with the regulating wheel, generates a proportionally smaller high spot at its contact with the work. Therefore, by a process of diminishing errors, roundness is achieved and approaches a cylindrical shape in infinity. In actual practice the cylindrical form is obtained in a short time.

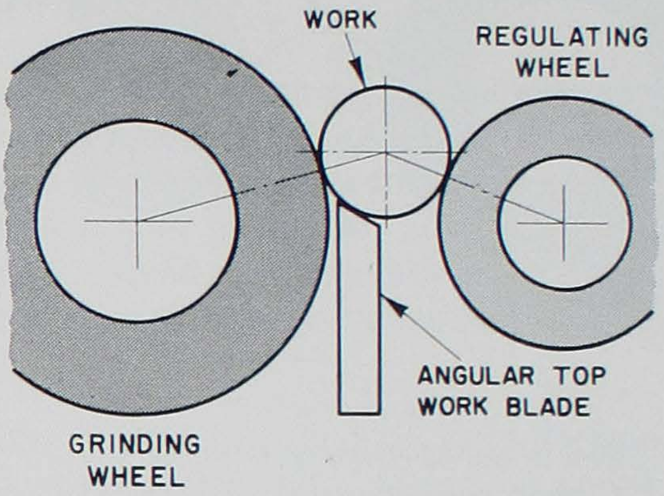


Figure 6A
Maximum corrective rounding action obtained with this basic setup

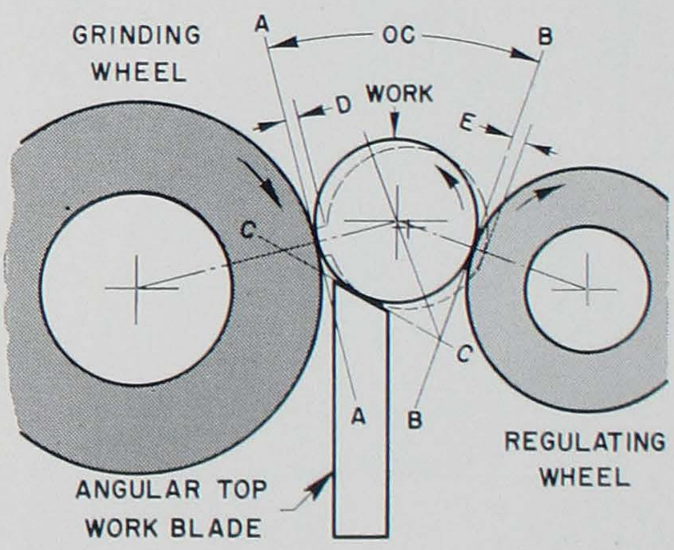


Figure 6B
Diagrammatic sketch of corrective action

This corrective action is very complex and depends upon many variables, such as the angle of the top of the blade, included angle (OC) between the two tangent lines, etc. Experience proves conclusively that if a light cut is taken on a part very much out of round, for example, .010 ″ or .012 ″, only the high spots will be ground, and from the very first spark the machine starts to generate the largest true cylinder which is possible to form out of the irregular outline of the rough part. The higher above center the work is placed, the quicker the rounding action, the limit being when the work is periodically lifted from the blade due to the greatly increased vertical components of the forces involved. It is possible to go higher with soft wheels than it is with hard ones, because the decreased contact pressures reduce the tendency to lift the work from the blade. Consequently, when grinding a part which is particularly hard to round up, work can be placed extra high by using an extra soft wheel.

All other factors being equal, work rotating at a relatively high speed reaches its true cylindrical form faster than work rotating slowly. An upper limit will be reached when the work chatters because of too rapid rotation. Work speed may be increased or decreased as desired by changing the speed of the regulating wheel.

Contrary to the usual centerless practice, when grinding long work, such as steel bars, the center line of the work is sometimes placed *below* the center line of the wheels. By grinding in this position, the whipping or chattering which might result from slight kinks or bends of the bar is greatly reduced, and the work is held firmly down on the blade by the wheels. However, if straight bars are desired, they must be straightened before being sent to the machine, as bent or misshaped bars can not be corrected successfully in the centerless grinder.

All centerless machines employ so-called negative work speed, or in other words, the rotation of the work and that of the grinding wheel are in different directions. The grinding wheel revolves at a standard speed of approximately 6,000 feet per minute. The operating speeds of the regulating wheel may be varied at will, and for a new wheel range from 34 to 942 feet per minute on the 200 Series machine and 40 to 1100 feet per minute on the 300 Series machine.

Summary: For quick rounding action:

(1) The work center should be placed as high as possible.

(2) The work should rotate rapidly.

(3) The rate of traverse (if thrufeed) across the grinding wheel face should be relatively slow.

CHAPTER II

METHODS AND ADVANTAGES OF CENTERLESS GRINDING

There are four primary classes of centerless grinding, namely:

a—Thrufeed

b—Infeed

c—Endfeed

d—Combination Infeed and Thrufeed

a—Thrufeed. Thrufeed grinding is accomplished, as the name implies, by passing the work between the grinding and regulating wheels. Grinding takes place as the work passes from one side of the wheels to the other. Obviously, since all points on the work pass all contact points between the wheels, only straight cylindrical surfaces without interfering shoulders can be ground by this method (Figure 8A).

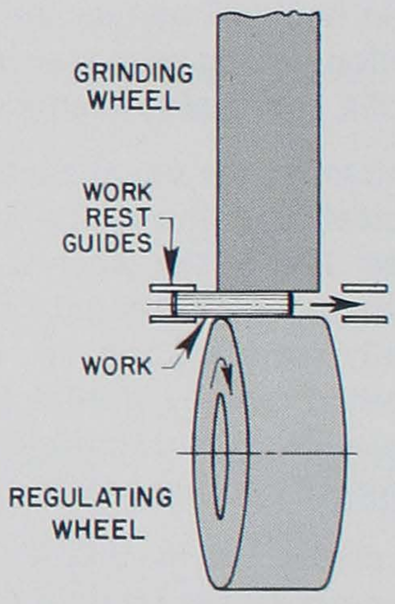


Figure 8A
Thrufeed centerless grinding (top view)

The axial movement of the work past the grinding wheel is imparted by the regulating wheel. The latter can be swiveled about a horizontal axis from 2 degrees below to about 8 degrees above a line relative to the axis of the grinding wheel spindle. Moreover, the speed and diameter of the regulating wheel also influence the feeding rate of the work, closely approximated by the following formula:

$$F = \pi \, dN \sin \alpha.$$

Where $F =$ feed of the work, in inches per minutes. (See pages 57 to 59 for tables.)

$d =$ diameter of the regulating wheel, in inches.

$N =$ speed of the regulating wheel, in revolutions per minute.

$\alpha =$ angle of inclination of the regulating wheel.

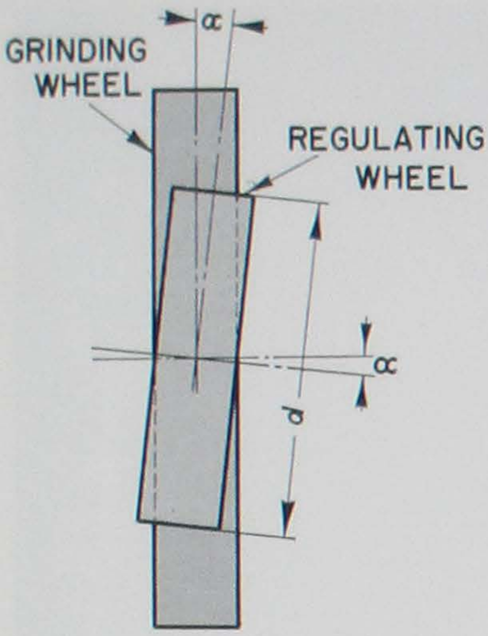


Figure 9A
Sketch showing derivation of feed rate formula

Figure 9A shows diagrammatically these conditions when viewing the wheels at right angles to the axis of the grinding wheel spindle. The theoretical feed (F in the formula) is based upon the assumption that there is no slippage of the work in its contact with the regulating wheel. In actual practice there may be a slight slippage, but it rarely exceeds two per cent. It is often necessary to pass work between the wheels more than once. The number of passes is determined by the amount of stock to be removed, roundness and straightness of the work, physical characteristics of the material, and the accuracy required.

In thrufeed grinding, there is a fixed relation between the grinding wheel, regulating wheel, and the work blade.

The regulating wheel is adjusted so that the distance between the active surfaces of the wheels, together with the height of the work blade, determines the diameter of the ground piece. To compensate for grinding wheel wear, the regulating wheel unit clamped to the lower slide by means of the upper slide clamps (Figure 16A) may be readjusted slightly to restore the original relation between the elements which determine the work size.

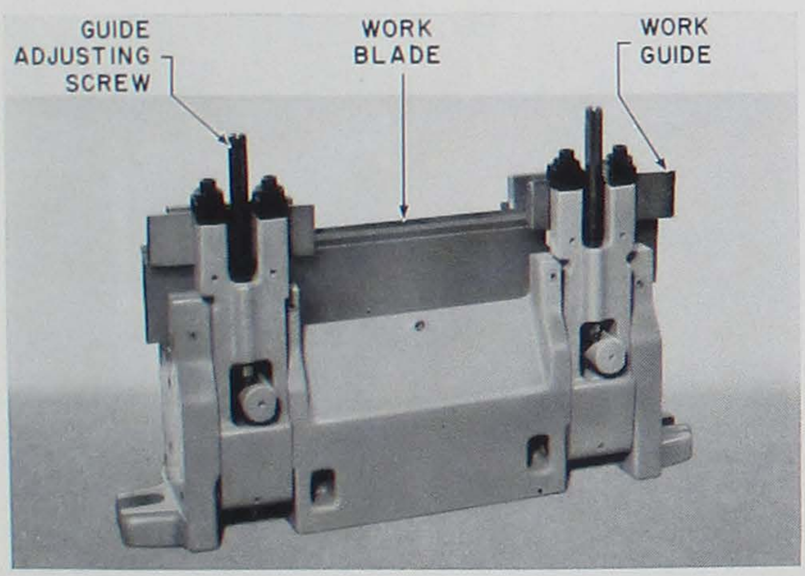


Figure 9B
Thrufeed work rest

A work rest or fixture (Figure 9B) which supports the blade also incorporates adjustable guides, both at the front and rear of the wheels. As the name implies, these guides direct the work in a straight line to and from the wheels. By means of screws, each guide may be adjusted to the correct relation between the work diameter and the active wheel surfaces.

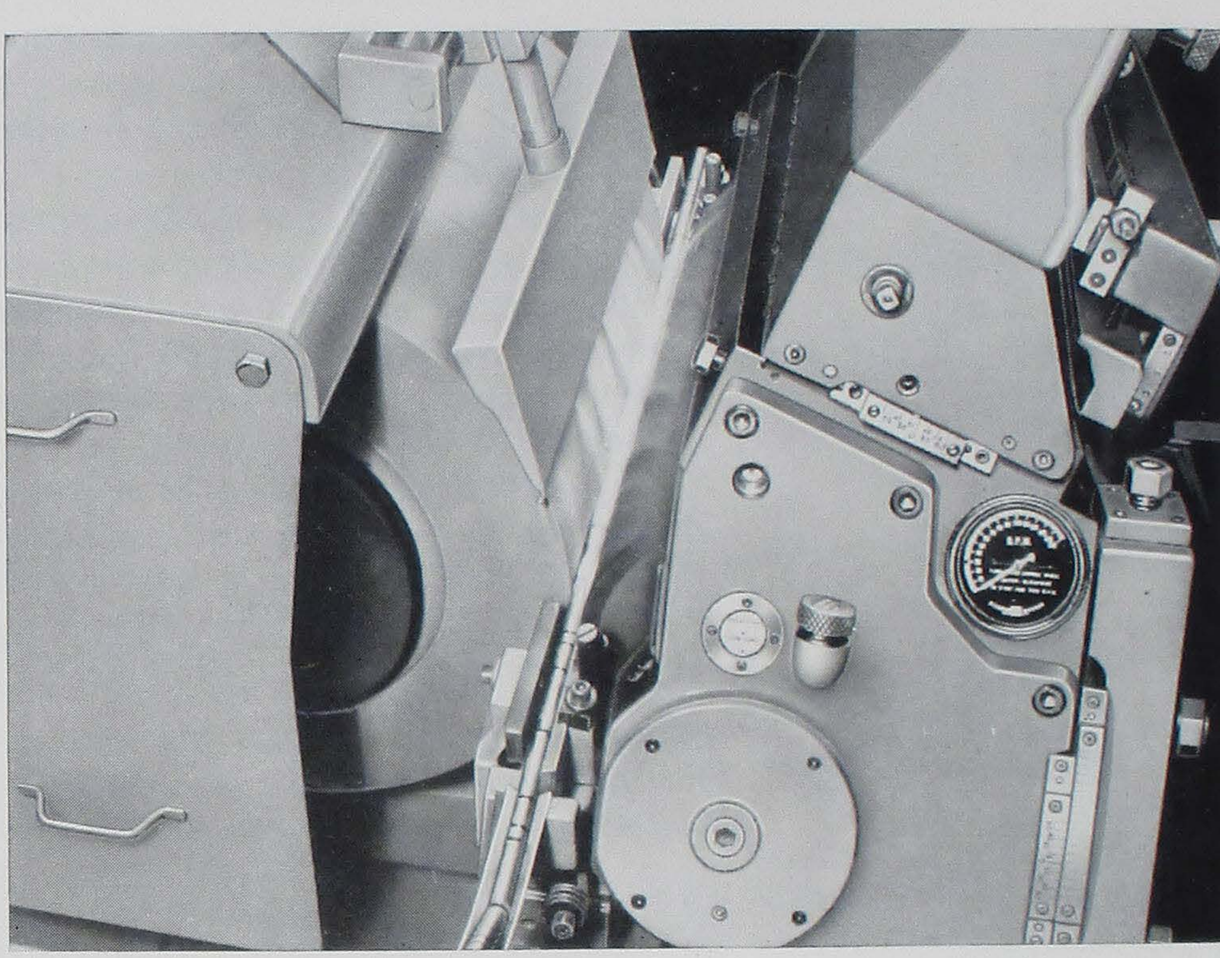


Figure 10A

Thrufeed grinding water pump shafts on a wide wheel No. 3 Centerless. Parts are hardened steel, stock removal .003", taper is within .0001", size within .0005" and feed rate 18' per minute.

Figure 10B

This No. 2 Centerless Grinder is infeed grinding the carbon relief, retainer groove and end chamfer simultaneously on an automotive engine valve. The machine is equipped with a electro-hydraulic infeed attachment, crush truing attachment and automatic sizing compensator. Total stock removal is .120" and size tolerance is ± .002".

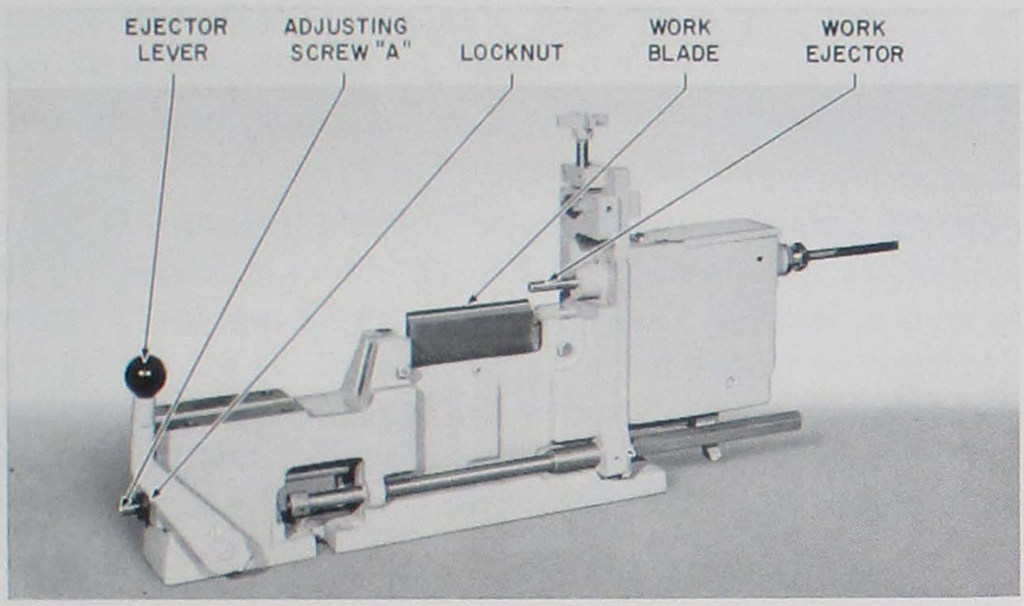


Figure 11A—Infeed work rest with hand ejector

b—Infeed. In general, the infeed method corresponds to plunge cut or form grinding on the centertype grinder. It is usually employed when grinding work which has a shoulder, head, or some portion larger than the ground diameter. This method is also used for the simultaneous grinding of several diameters of the work as well as for finishing pieces with irregular profile. The length of the section or sections to be ground in any one operation is not limited by the width of the grinding wheel, e.g., work lengths longer than the width of the wheels can be ground by the thrufeed-infeed method. (See page 13).

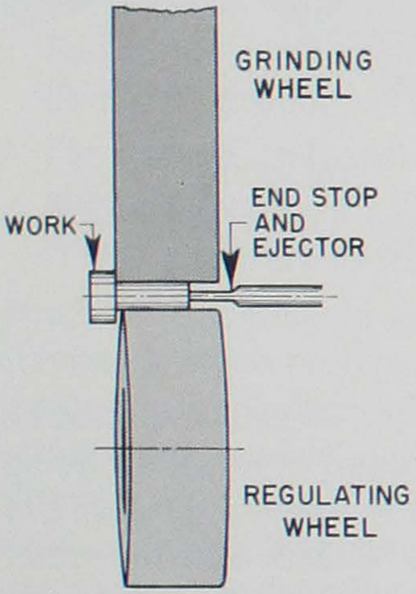


Figure 11B

Infeed centerless grinding (top view)

As there is no relative axial movement of the work, the regulating wheel is set with its axis approximately parallel to that of the grinding wheel. Only a slight angle is maintained to keep the work tight against an end stop.

With the infeed method, there is usually (but not always) a fixed relation between the work support blade and the regulating wheel. The units which incorporate these two elements are supported by two slides, which are clamped together (See Figure 16A—"upper slide clamps") and carry the work to and from the grinding wheel. This movement is performed by turning the infeed lever 90 degrees (Figure 17A). As the lever is brought down, the work and the regulating wheel are advanced to the grinding wheel, the desired size being secured when the lever has made its full swing. Upon reversing the movement of the infeed lever, the gap between the wheels is increased, and either a manually or automatically operated ejector kicks the work out from between the wheels, and another piece is placed in position by the operator.

In some cases, it may be advisable to support the work on two blades, cradle fashion, as illustrated in Figure 12A. This is especially desirable where the work is large and heavy. Here, the work rest (on the lower slide) has a fixed relation to the grinding wheel, and, by advancing the upper slide, the regulating wheel performs the function of lifting the work from the "near" blade, in addition to rotating it against the grinding wheel, as illustrated in Figure 12B. Setups of this type require special infeed work rests.

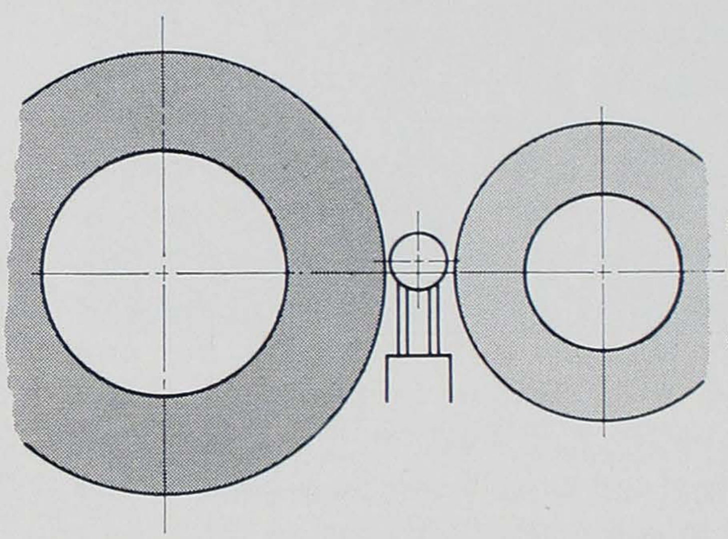


Figure 12A
Infeed work, in loading position, supported by two blades

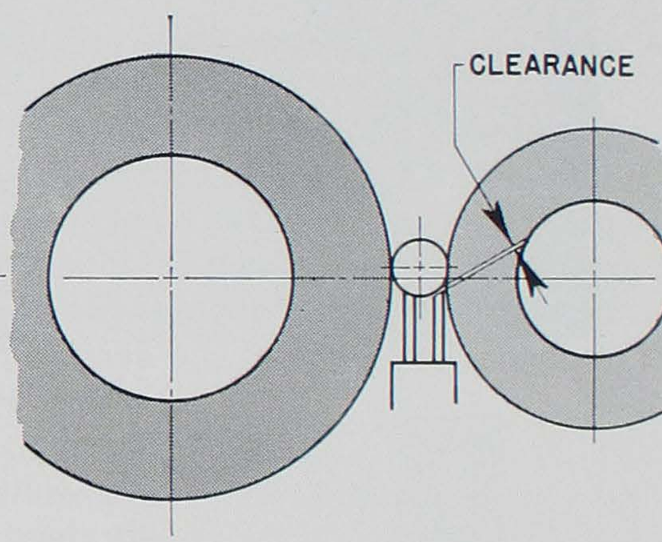


Figure 12B
Grinding position of the infeed work illustrated in Figure 12A

If the part to be ground is longer than the width of the wheels and must be ground only a short distance from the end, a variation of infeed grinding may be employed, called the outboard roller support method. One end of the work is supported by the blade between the wheels and the other end rests on rollers which are usually outside of the machine, but form part of the fixture which is called the infeed roller work rest. (Illustrated on page 54).

The same cycle of operations as described for infeed grinding is used, the only exception being that it is seldom possible to use the ejector, because of the size of work, which is usually larger than that of the standard infeed class.

c—Endfeed. The endfeed method is used only on taper work. The grinding wheel, regulating wheel, and blade are set in a fixed relation to each other, and the work is fed in from the front, manually or mechanically to a fixed end stop. Either the grinding or the regulating wheel, or both, are dressed to the proper taper.

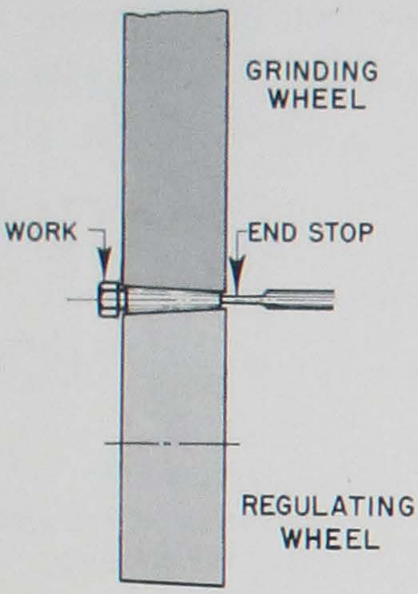


Figure 13A
Endfeed centerless grinding (top view)

d—Combination Infeed and Thrufeed. The infeed and thrufeed methods of centerless grinding may often be combined to good advantage. There are three principal applications:

1. For parts which are more conveniently ground in one pass, but have too large an amount of stock for the conventional thrufeed method.
2. For grinding the smaller diameter of two-diameter parts, where the portion to be ground exceeds the width of the grinding wheel. (Figure 14A)
3. For warped parts, where the warpage or bow does not exceed the total stock removal, and the length of the part is less than the width of the wheels.

The first classification includes shells of various diameters which require a grinding operation on the bourrelet diameter. (Figure 13B). These diameters are relatively narrow, and have a stock allowance of about .020″. The lower slide is fixed and the infeed motion is obtained through the upper slide, with the remainder of the setup arranged for thrufeed work. After placing the shell on the workrest blades, the infeed lever is moved down to the positive stop, as in conventional infeed grinding. Meanwhile, the work passes axially between the wheels as in thrufeed grinding. Obviously, the infeed motion must reach the positive stop before the work has reached the exit side of the wheels.

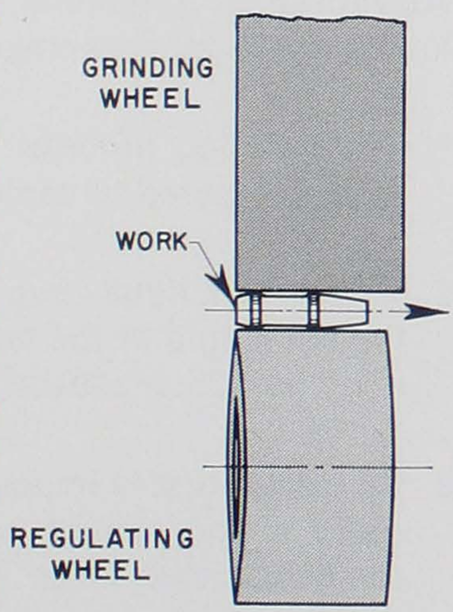


Figure 13B
Combination infeed and thrufeed grinding, Case 1

Parts within the second classification (having two diameters, with the length of the smaller diameter greater than the width of the grinding wheel) may be ground with the type of setup illustrated in Figure 14A. Here, the parts are placed on the work rest, as in conventional infeed grinding, but with the end stop at the *front* of the machine. After the infeed movement is completed and the portion of the work between the wheels has been ground to size (slides arranged as in classification 1), the stop is swiveled out of the way and the work traverses through the wheels to the *front* of the machine. The rear-to-front direction of traverse is induced by setting and truing the regulating wheel at a negative angle. This type of setup should be used only when the work is comparatively short and light, and when a special work rest is available to support the work as it feeds forward.

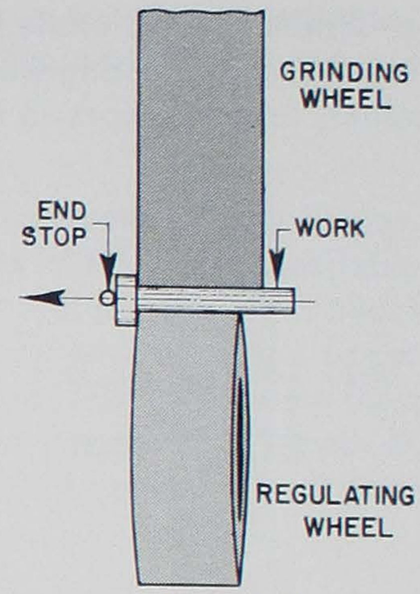


Figure 14A
Combination infeed and thrufeed grinding, Case 2

The third group of parts is mentioned here because they may constitute an important item in shops where a straightening machine is not available. If possible, however, work should always be straight before it is sent to the centerless grinder.

Advantages. In general, all centerless grinding machines offer the following principal advantages:

1. The grinding process is practically continuous, because the loading time, compared to centertype grinding, is exceedingly small.

2. The work is rigidly supported directly under the grinding cut as well as the full length of the cut. No deflection takes place during the grinding operation, thus allowing, if necessary, a heavier cut to be taken.

3. No axial thrust is imposed on the work while grinding. This absence of end pressure makes possible the grinding of long brittle pieces and easily distorted parts.

4. As a true floating condition exists during the grinding process and the error of centering is eliminated, less grinding stock is required, with correspondingly increased wheel life.

5. The possibility of error in setting up the job and in readjusting to compensate for wheel wear is reduced by half, because stock removal is measured on the diameter and not on the radius.
6. Error due to wheel wear is likewise reduced.
7. There are but few wearing surfaces in the machine, and the lubrication of the spindles is automatic; therefore, the upkeep is very low.
8. Large quantities of smaller size work can be automatically ground by use of a magazine, gravity chute, or hopper feeding attachments, provided the shape of the piece will permit the use of such devices.
9. Very accurate size control in production.

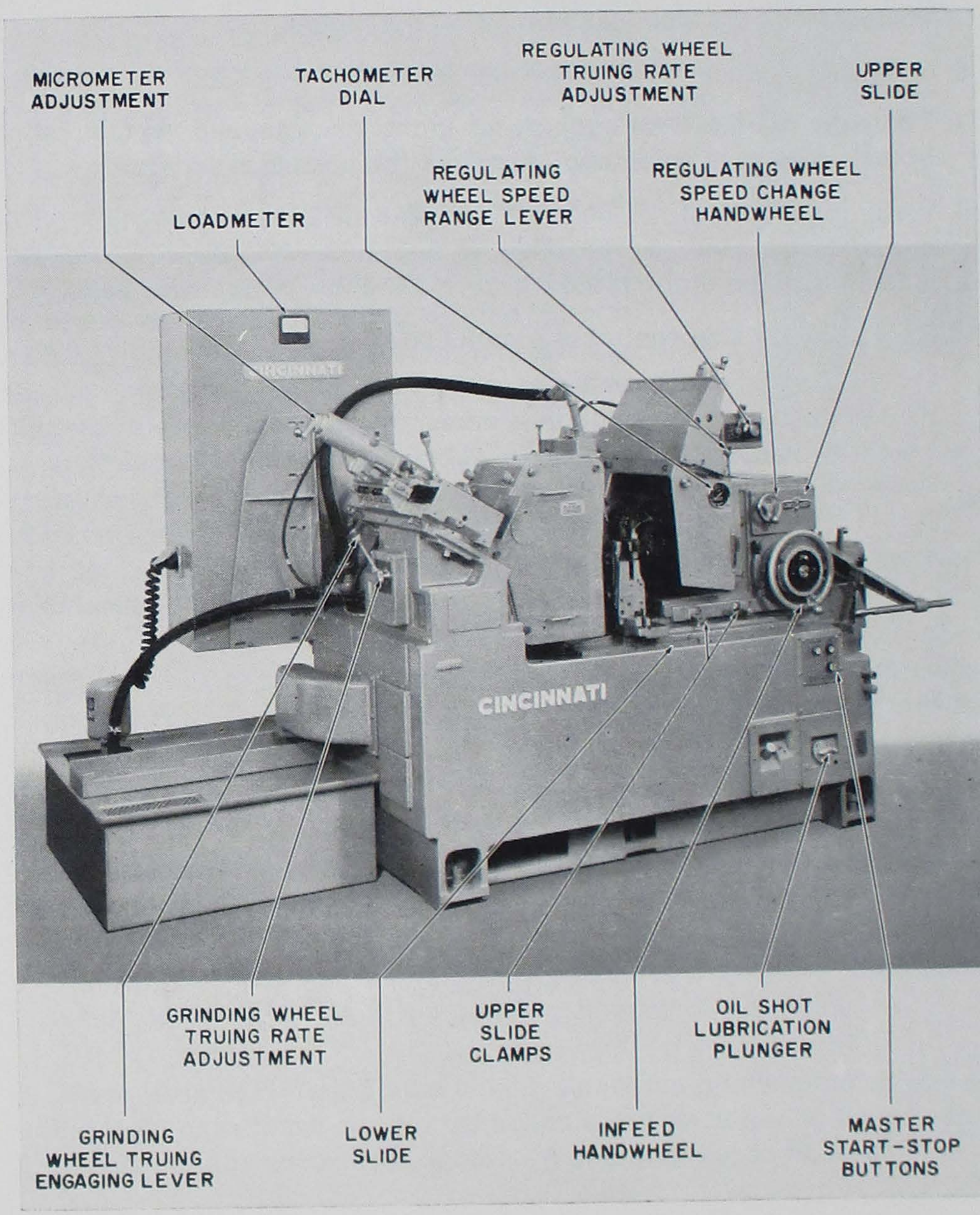


Figure 16A—Front view, 220-8 Centerless Grinder, showing operating controls and construction details

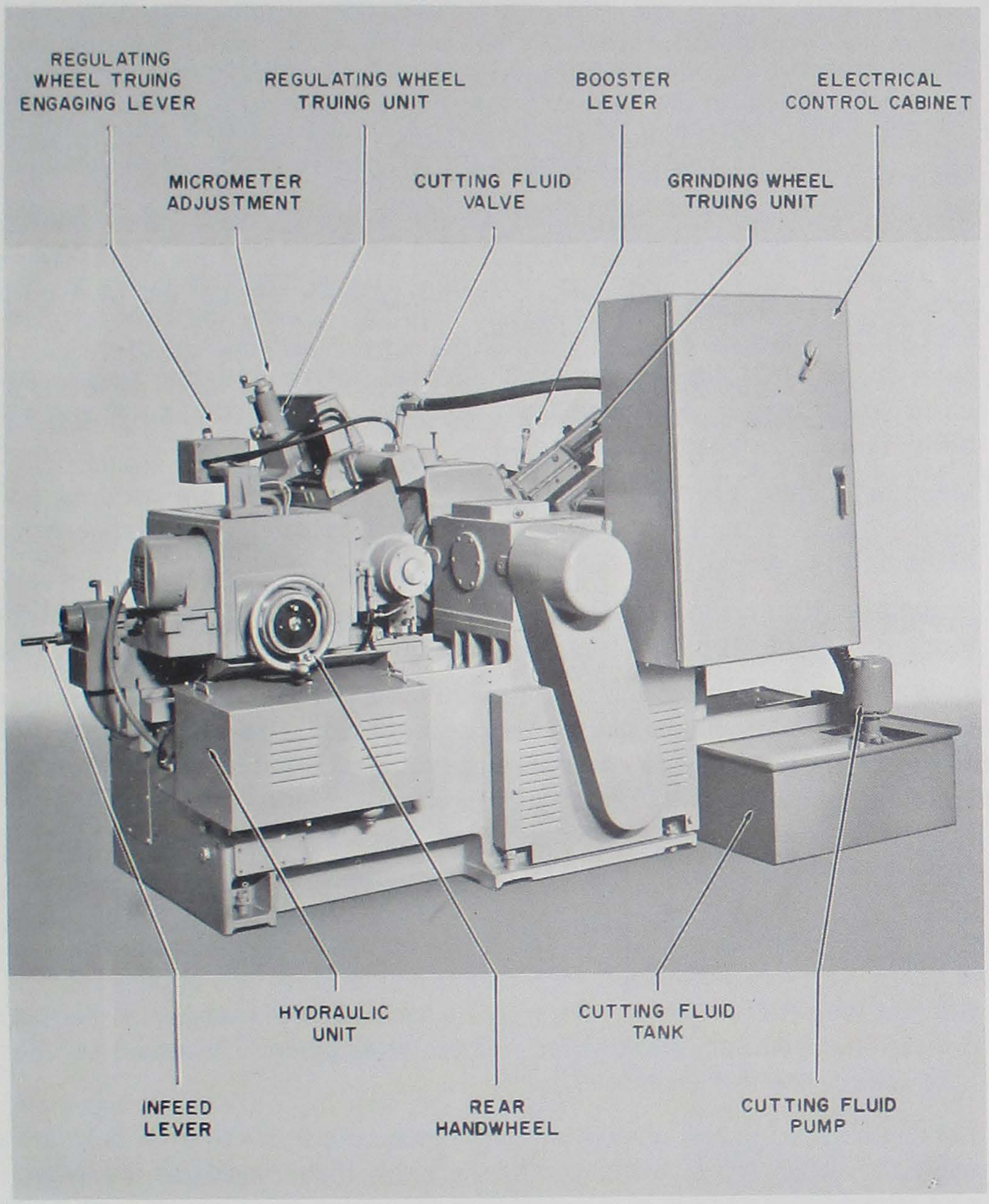


Figure 17A—Rear view, 220-8 Centerless Grinder, showing operating controls and construction details

CHAPTER III

WORK BLADES

Blade Material. Blade material is an important consideration in obtaining a good finish on the work and the greatest number of pieces for each grinding of the blade. The material is usually cast iron or very hard alloys such as high speed steel, sintered carbide, etc.

Sintered carbide, and blades of similar materials have good wearing qualities and should be used for case hardened and oil hardened steels, and for non-metallic materials. Sintered carbide blades will give good results when grinding *stainless steel.*

High-speed steel blades are well adapted for non-ferrous metals; for parts which vary in hardness from one end to the other, such as twist drills; and for very small diameters.

Meehanite, hard bronze and ordinary cast iron blades are used for soft steel work to eliminate the scoring or "picking up" action between the blade and the work.

In general, it is always advisable to start with a hard material, and if the tendency to "pick-up" prevails, to gradually compromise on the hardness by using a different material.

Blade Angle. Having selected the material, the blade angle is chosen next. For the majority of centerless grinding operations the 30° angular top work support blade is used.

When using wide wheels, say 6" or 8" face, and a long blade with too great an angle, chatter is apt to occur. The horizontal component of the work pressure which the blade must resist increases as the blade angle increases.

Since a long narrow blade offers only a small lateral resistance, periodic deflections, commonly known as chatter, take place. The usual solution is to reduce the top angle.

For example, work of a given diameter may be ground with 4" wide wheels on a 30° angle blade with no difficulty, but, if the width of the wheels and length of the blade is increased to 8" and chatter occurs, the angle is usually reduced to 20° or 25° in order to decrease the side pressure on the blade.

For the same reasons, when grinding large diameter work the angle of the blade should be less than when using the same length blade for grinding smaller diameter work. In other words, the larger the diameter of the piece to be ground, the smaller should be the angle of the blade.

Blade Thickness and Length. Obviously, the length of the blade is determined by the width of the wheels. The thickness of the blade should be slightly less than the diameter of the work, the maximum thickness of the standard blade being 5/8" for the 200 Series Centerless Grinder and 3/4" for the 300 Series Centerless Grinder.

Setting the Blade. After the work rest has been positioned, blade is adjusted in the blade slot to the proper height by means of shims.

Generally speaking, work is ground with its center above the center line of the wheels. The type of grinding wheel, work diameter, diameter of wheels, and physical characteristics of the work before grinding all influence this setting. For small work up to about 1" diameter, a good rule is to adjust the blade vertically until the center of the work is above the wheel centers by a distance equal to about 1/2 the work diameter. For larger work the proportion is less, the above-center adjustment rarely exceeding 1/2".

The height of work center relative to the center line of the wheels may be obtained by subtracting 9 7/8" (for 200 or 300 Series machines) from the distance between the center of the work and the finished surface of the lower slide, as shown in Figure 19A.

Grinding too high above the center line of the wheels may produce chatter marks on the work. This undesirable effect is caused by the tendency of the wheels to squeeze the work upward and out of contact with the blade. Technically speaking, the resulting vertical component of the pressure created by the grinding action is increased in proportion to the increase in height above centers. Because of this condition, the work for a moment loses its contact with the wheels and the blade, and is thrown up in the air. It falls back into the grinding position and the process is again repeated. This action is very rapid, causing chatter marks on the work. The remedy is to decrease the work height above the center line of the wheels, thereby decreasing the vertical components of the forces and permitting the work to maintain a firm contact with the wheels and blade.

However, if the height above center is decreased too much, the work will be out-of-round with three high spots. Another remedy is to use a softer grade wheel. The softer the wheel, the less cutting contact pressure required. The vertical component is correspondingly reduced and chatter eliminated.

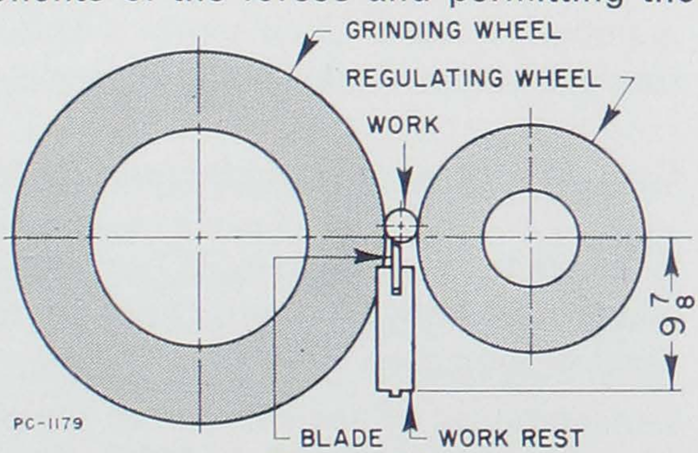


Figure 19A
Height of wheel centers above bottom of work rest on 200 or 300 Series Centerless Machines

The higher above the center line of the wheels the work is placed, the faster is the rounding action. Long work with slight bends or kinks, such as steel bars, is ground below the center line of the wheels. This position of the work is contrary to the usual practice on Centerless Grinding Machines, but is necessary in order to minimize the whipping or chattering which might result when the kinks or bends have not been entirely removed in the straightening operation. By grinding in this position, the wheels hold the bar firmly down on the blade.

Clamping the Blade. After having determined the proper height, the work support blade is clamped firmly in position. The blade slot of the work rest must be perfectly clean, so that the blade will not be distorted or warped under the pressure of the clamping screws. Likewise, the screws located inside the work rest should always be set first to avoid springing the blade.

Regrinding Work Support Blades. Blades made of sintered carbide, high speed steel, and similar materials must be ground very carefully. These blades have remarkable wearing qualities, and therefore are very resistant to grinding wheels. The wheel quickly becomes dull during regrinding. Dull wheels check the blade, but with the proper precautions a blade can be reground to its original accuracy. The procedure given below must be followed if good results are desired:

1. Take light cuts; .0005 " for high speed steel, .0002 " for harder material.

2. If using a conventional abrasive wheel, dress it often.

3. (a) Flood with a cutting fluid if ground on a surface grinder.
   (b) Grind dry on a conventional cutter grinder.

Use a diamond wheel for regrinding sintered carbide blades.

Consult your wheel manufacturer for the proper wheel.

If the blade is narrow, say ¼ " or less, light cuts can be taken dry without danger of overheating and checking, but be careful to avoid cutting fluid or oil dropping on the blade.

CHAPTER IV

WHEELS

The selection of a grinding wheel for a specific grinding operation is dependent on many factors. By evaluating the principal ones that affect wheel performance, it is possible to reduce the number of choices in selecting the best wheel for the job. To help in this task, the main factors are discussed below.

Work Material. In selecting a grinding wheel, first consider the work material. Parts which are made of high tensile strength metals and which are relatively hard, should be ground with aluminum oxide wheels. Examples: machine steels, alloy steels, and tool steels.

For soft materials and for those which are hard and brittle, silicon carbide wheels should be used. The crystals of this abrasive break down more rapidly than aluminum oxide, assuring free cutting and rapid metal removal. Examples: cast iron, brass and bronze, aluminum, stainless steel, carbon, glass and sintered carbides.

Diameter and Length of Work. These two factors largely determine the hardness of the wheel selected. Small diameter work has a short arc of contact with the wheel, causing it to break down more rapidly than larger work of the same material ground with the same wheel. When grinding two-diameter infeed work, a compromise must be reached between too hard a wheel for the largest work diameter and too soft a wheel for the smallest diameter.

The length of work affects the selection of wheels for both infeed and thrufeed grinding. For infeed grinding the general rule is; the wider the wheel used (longer work), the softer the wheel grade. The unit pressure per grain on a wide wheel is lower than on a narrow wheel because the total available force is distributed over a larger area. Thus, by using a softer grade, enough wheel break down is achieved to keep the wheel cutting freely.

In thrufeed grinding, the grinding wheel can act either hard or soft depending on the length and diameter of the work. A wheel acting too hard can be corrected, to some extent, by increasing the angle of the regulating wheel. This increases the feed rate and causes the wheel to break down faster and act softer. When a wheel acts too soft, the thrufeed rate should be reduced in order to lower wheel break down. This can be accomplished by reducing the regulating wheel angle, RPM, or both. However, in both instances, the grinding action can be altered only up to a point. Beyond this point, it becomes more economical to change the grade of the wheel to match the requirements of the job more closely.

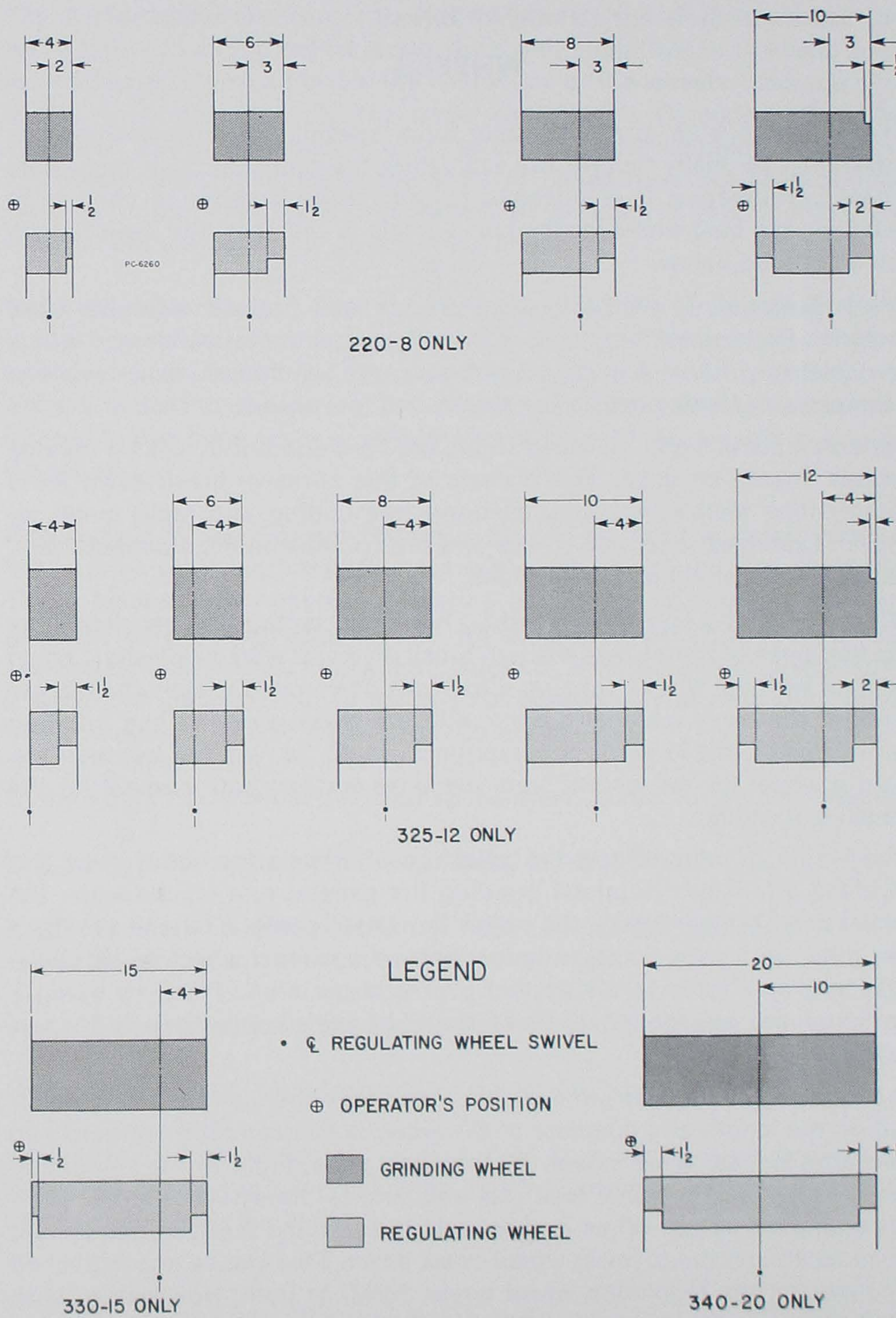


Figure 22A
Relationship between grinding and regulating wheels of various widths for 220-8, 325-12, 330-15 and 340-20 Centerless Grinders

Stock Removal. Parts which are ground from the rough or have a heavy stock allowance require coarse grained wheels. The action here is similar to any other metal cutting process, wherein deep cuts require heavy cutting tools and plenty of chip clearance.

Type of Setup. As a general rule, thrufeed work may be ground with wheels which are softer than those used for infeed work. This is because wheels may not wear evenly, directly affecting the accuracy of straightness or contour of infeed work. Then, too, it is often necessary to infeed grind next to a shoulder, an additional reason for using harder and finer wheels which will not break down too rapidly at the corners.

Accuracy and Surface Finish. Close accuracy and high quality surface finish can usually be obtained with hard, fine grained wheels. However, this is dependent upon removing a small amount of stock. On the other hand, a high grade finish can often be obtained on infeed work with a relatively coarse grained wheel, when the machine is equipped with an automatic spindle reciprocating attachment.

In conclusion, it should be remembered that it is always better to use a wheel which is one grade too soft rather than too hard. The softer wheel removes stock more rapidly, it has considerably less tendency to chatter, score, or burn the work; requires less truing or dressing; and, finally, often has a longer productive life (measured in number of parts produced). The condition of the machine and the skill of the operator also affect the economical production of centerless ground parts, but these factors are properly a function of supervision.

CHAPTER V

TRUING THE WHEELS

Both the grinding and regulating wheels have individual truing devices. As in conventional centertype practice, the grinding wheel may require truing or dressing for a number of reasons, such as (1) wheel balancing, (2) rough grinding, (3) finish grinding, (4) accuracy requirements (especially infeed jobs), (5) to eliminate glazing and burning the work (usually caused by wrong wheel being used) and (6) removing the "loaded" surface of the wheel to improve the finish on soft work such as aluminum and brass. On the other hand, the regulating wheel requires truing in only three cases, (1) when setting up the machine, (2) when the operative surface of the regulating wheel has been marred from rough stock or through carelessness and (3) after regulating wheel spindle bearing adjustment.

Note—When a new regulating wheel is used with blotting paper gaskets, it is advisable to observe this precaution: the second day of operation, retighten the flange nuts and retrue the wheel. This will eliminate inaccuracy caused by compression of the wet paper gasket.

Grinding Wheel Truing Equipment. The standard grinding wheel truing attachment (Figure 24A) supplied with the machine is intended for truing the wheel to a straight cylinder for grinding straight cylindrical parts or for truing a taper or profile contours on the wheel. The profile slide, controlled with a cam, regulates the distance of the diamond from the axis of the spindle as the truing tool moves across the face of the wheel. Cams may readily be interchanged as desired.

Since the truing diamond is within the wheel guard, and normally hidden from view, a peep hole has been incorporated in the guard near the attachment, permitting the operator to see the truing tool. Experienced operators know when the diamond touches the wheel by the "s-s-s-t-t-t" sound, but it is advisable to intently watch the diamond when adjusting it toward the wheel.

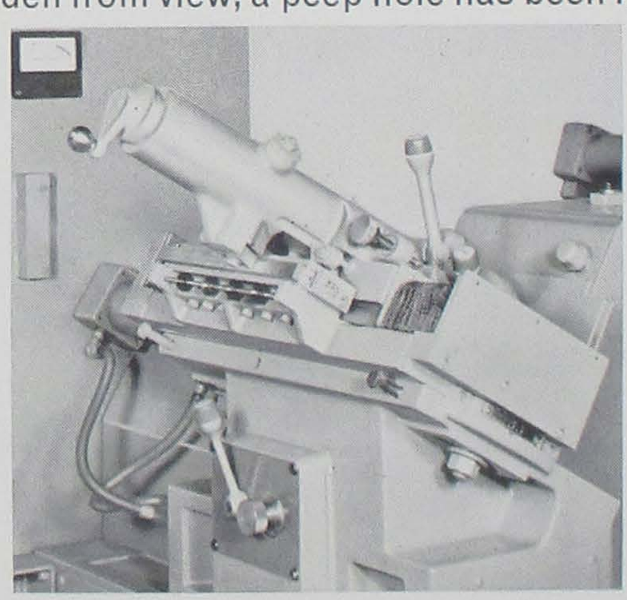


Figure 24A
Grinding wheel truing attachment

Because of their expense, proper usage of the truing diamond is an important consideration in economical grinding. Any industrial diamond company can supply literature on this subject.

The rate of travel of the truing tool across the wheel is governed by the type of truing tool and the grade of finish desired on the work. The following table will guide you in selecting the correct truing speed.

RECOMMENDED TRUING RATES (INCHES PER MINUTE)

	DIAMOND		METALLIC DRESSER	
	Rough Grinding	Finish Grinding	Rough Grinding	Finish Grinding
Grinding Wheel	10 to 20	4 to 7	40 to 60	10 to 20
Regulating Wheel........	1 to 2	1 to 2	not used	not used

General Instructions for Truing. When a diamond or metallic rotary dresser is used, the grinding wheel should be trued with an ample supply of cutting fluid over the tool. Frequent inspection of the diamond is recommended. It is more economical to reset a worn diamond than to continue to use it, because of the possibility of damaging it beyond further use.

When truing with an abrasive rotary tool, cutting fluid should not be used, because of the tendency of the abrasive to load the tool. However, after each truing operation, the grinding wheel should be thoroughly washed with cutting fluid before starting to grind again.

At no time should a cut of more than .001 ″ be taken across the face of the wheel.

CRUSH TRUING OF THE GRINDING WHEEL

The crush truing technique will accurately produce irregular shapes in the grinding wheel. This enables the grinding wheel to reproduce the exact profile in the part quickly and easily. Crush truing's greatest application is in the production of unique shapes which are difficult, or in some cases impossible, to grind with diamond trued wheels.

The reverse form is imparted to the grinding wheel by a hardened steel roll, which has the desired profile on its surface. The grinding wheel and the crush roll are brought into contact and then rotated together under pressure (at a speed of 200 to 300 surface feet per minute) until the complete form of the roll is transferred to the grinding wheel.

High stock removal rates are common when grinding with crush trued wheels. The ability to remove metal rapidly is largely due to the free cutting or "natural" grain structure of crush trued wheels. Because the wheel is more free cutting, wheel wear is less than with diamond trued wheels, less heat is generated while grinding, and less power is required for removing a given amount of stock.

Crush truing is best employed when there is a need to grind in production extremely accurate radii, shoulders, slots from the solid and profile shapes or slender shaft diameters.

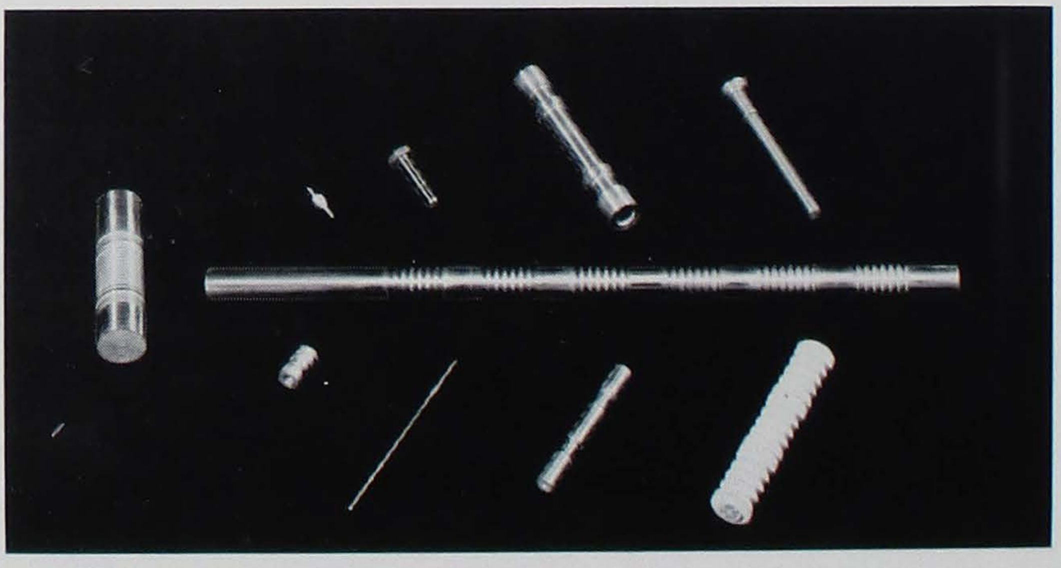


Figure 27A
Typical examples of parts ground with crush trued grinding wheels

The advantages of crush truing over the other various methods of profile truing with diamonds are: (1) a considerable increase in the number of parts per dressing of the wheel, (2) less actual wheel wear per part and (3) faster grinding rates.

As is true with other methods of precision grinding, dimensional accuracy depends on such factors as work material, amount and rate of stock removal, part geometry and repeatability of the machine elements.

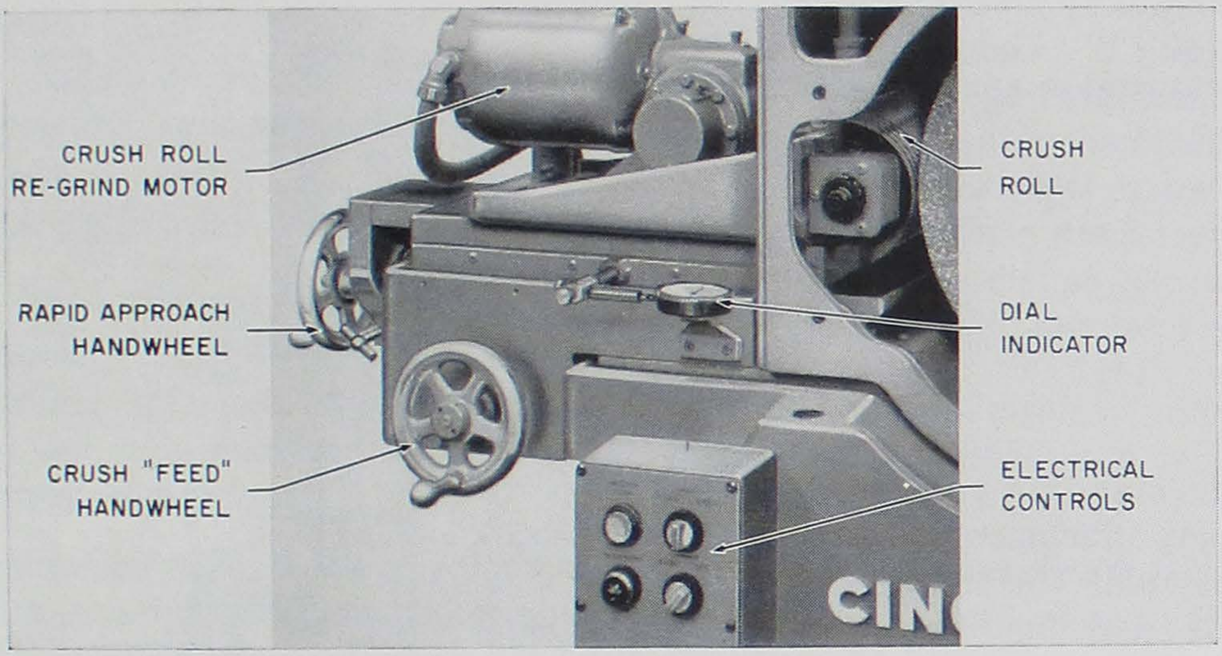


Figure 27A
107-4 Centerless Grinder arranged with a crush truing attachment

TRUING THE REGULATING WHEEL

Regulating Wheel Truing Unit. A brief description of the regulating wheel truing unit, (Figure 28A), will help to a better understanding of the correct method of truing. The diamond, from one to two carats in size, is mounted in a 7/16 " diamond nib 1 " long. This nib is fastened in the diamond holder, and is secured to an adjustable sleeve by means of a clamping screw. The sleeve, which can be moved vertically through its housing, is clamped in position by means of lock screw "B". The micrometer dial provides accurate adjustment of the diamond toward the regulating wheel. Each graduation on the dial equals .001 " and the total movement possible is 1¾ ".

The standard regulating truing attachment is power operated. The truing tool and associated parts are moved across the face of the wheel by a hydraulic piston and cylinder, which is operated by a set of controls similar to those used to operate the grinding wheel truing. These controls are mounted on top of the upper slide unit. The use of a hydraulic piston and cylinder assures a smooth constant speed to the truing attachment.

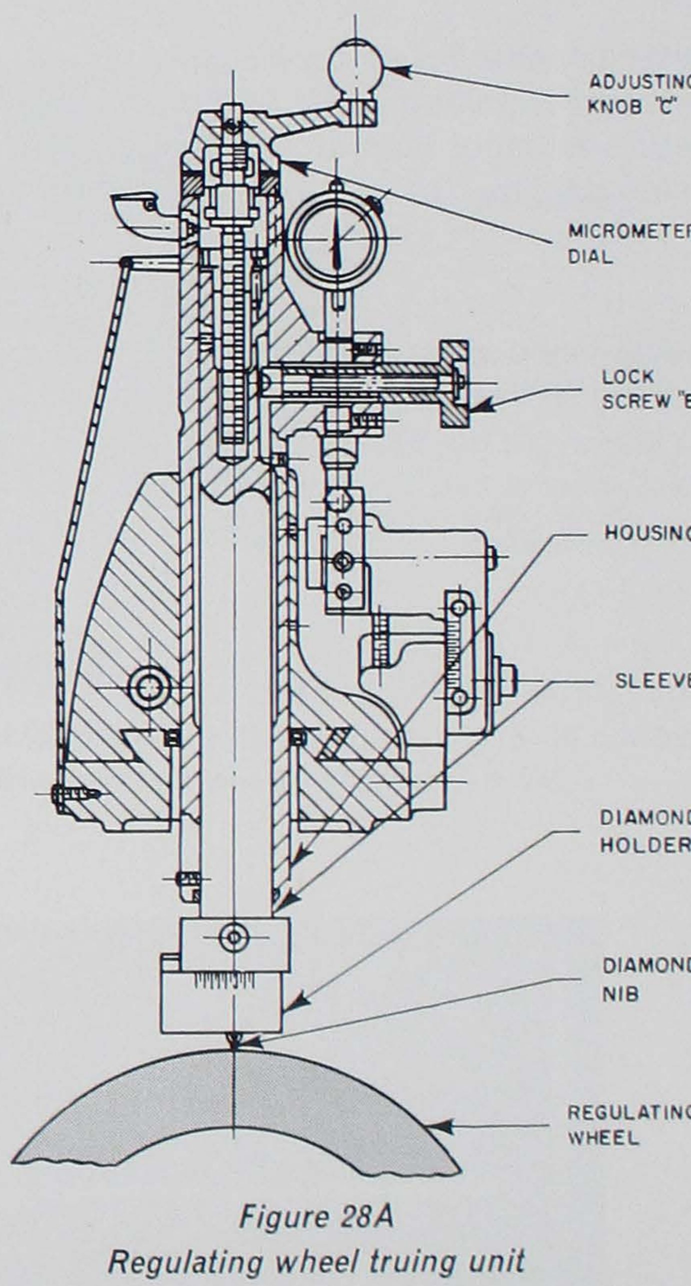


Figure 28A
Regulating wheel truing unit

Profile Truing Units. The standard regulating wheel truing attachment trues the wheel only for straight cylindrical work. If other shapes are to be ground, the profile regulating wheel truing unit, shown in Figure 28A must be used.

Thrufeed Setup Instructions for the Regulating Wheel Truing Unit. Generally speaking, the function of the standard regulating wheel truing unit is to make the diamond follow the same line of contact with the wheel as that followed by the work. In other words, the regulating wheel must be trued so that the work, while passing between the wheels, makes a straight line contact with the wheel face. To obtain this condition, four factors must be taken into consideration.

1. *Angle of inclination of the regulating wheel.*

2. *Location of the center of the work with respect to the center of the grinding and regulating wheels.*

3. *Angle to which the regulating wheel truing slide is swiveled.*

4. *Amount the diamond holder is "set-over".*

The first factor is fixed by the nature of the work. For most thrufeed grinding setups, a positive inclination of 3° can be recommended as a satisfactory starting point.

The second factor is fixed by the diameter of the work. Generally speaking, work is ground with its center above the center line of the wheels. The type of grinding wheel, work diameter, diameter of wheels, and physical characteristics of the work before grinding all influence this setting. For small work up to about 1" diameter, a good rule is to adjust the blade vertically until the center of the work is above the wheel centers by a distance equal to about ½ the work diameter. For larger work the proportion is less, the above-center adjustment rarely exceeding ½".

To find the third and fourth factors above, it is necessary to determine the ratio between the diameter of the regulating wheel and the diameter of the workpiece to be ground. This relationship is expressed by the following ratio:

$$\frac{D}{d}$$

D = Diameter of the REGULATING WHEEL.

d = Diameter of the WORKPIECE.

After establishing this ratio, use the "Truing Setting Chart", (Figure 30A), to find both the "Truing Angle" and the correct "Diamond Holder Setting".

TABLE OF TRUING ANGLES AND HEIGHTS ABOVE CENTER FOR REGULATING WHEEL TRUING

		TRUING ANGLE SETTING									
WORK FEED ANGLE*	7°	6°10′	6°10′	6°20′	6°25′	6°30′	6°35′	6°45′	6°50′	6°55′	6°55′
	6°	5°15′	5°15′	5°25′	5°30′	5°35′	5°40′	5°45′	5°55′	5°55′	5°55′
	5°	4°20′	4°25′	4°30′	4°35′	4°40′	4°40′	4°50′	4°55′	5°	5°
	4°	3°30′	3°30′	3°35′	3°40′	3°45′	3°45′	3°50′	3°55′	4°	4°
	3°	2°35′	2°40′	2°40′	2°45′	2°50′	2°50′	2°55′	2°55′	3°	3°
	2°	1°45′	1°45′	1°50′	1°50′	1°50′	1°55′	1°55′	2°	2°	2°
	1°	50′	50′	55′	55′	55′	55′	55′	1°	1°	1°
RATIO $\frac{D}{d}$		**3**	**3.5**	**4**	**5**	**6**	**7**	**12**	**18**	**24**	**48**
WORK HEIGHT ABOVE CENTER†	1/8″	7/64″	7/64″	7/64″	7/64″	7/64″	1/8″	1/8″	1/8″	1/8″	1/8″
	1/4″	7/32″	7/32″	7/32″	15/64″	15/64″	15/64″	15/64″	1/4″	1/4″	1/4″
	3/8″	21/64″	21/64″	11/32″	11/32″	11/32″	23/64″	23/64″	23/64″	3/8″	3/8″
	1/2″	7/16″	7/16″	29/64″	29/64″	15/32″	15/32″	31/64″	31/64″	1/2″	1/2″
	5/8″	35/64″	35/64″	9/16″	37/64″	37/64″	19/32″	19/32″	39/64″	5/8″	5/8″
	3/4″	21/32″	21/32″	43/64″	11/16″	45/64″	45/64″	23/32″	47/64″	47/64″	47/64″
	7/8″	3/4″	49/64″	25/32″	51/64″	13/16″	53/64″	27/32″	55/64″	55/64″	55/64″
	1″	55/64″	7/8″	29/32″	59/64″	15/16″	15/16″	61/64″	63/64″	63/64″	63/64″
		DIAMOND HOLDER SETTING									

Figure 30A
Regulating wheel truing setting chart

*The "Work Feed Angle" table was calculated from the following formula:

$$\text{Tan } \alpha = \frac{\text{Tan } \theta}{\left(1 + \frac{r}{R}\right)^{1/2}}$$

Where: Tan α = Tangent of truing angle
Tan θ = Tangent of regulating wheel housing angle
r = Radius of part
R = Radius of wheel

†The "Work Height above Center" table was calculated from the following formula:

$$d = d' \left(\frac{(\text{Sin } \alpha)}{(\text{Sin } \theta)}\right)$$

Where: d = Amount diamond should be offset
d′ = Amount part is above center
Sin α = Sine of the actual regulating wheel truing angle
Sin θ = Sine of the regulating wheel housing angle

Example:
Suppose a thrufeed grinding job is being setup on a 220-8 Centerless Grinder. The workpiece is 2″ in diameter and the diameter of the regulating wheel is 12″. In addition, a work feed angle of 3° is set on the regulating wheel housing.

The following then are known:

1. Angle of inclination of regulating wheel = 3°.
2. Location of the center of the work with respect to the center of the regulating and grinding wheels = ½″ above center.

To find:

3. Angle to which regulating wheel truing slide is swiveled; and,
4. Amount the diamond holder is "set-over"; determine, the ratio between the diameter of the regulating wheel and the workpiece:

$$\frac{D}{d}$$

D = Diameter of regulating wheel = 12″.
d = Diameter of workpiece = 2″.

$$\frac{12}{2} = 6$$

Now, to determine the correct truing angle, extend a horizontal line on the "Truing Setting Chart" from a 3° work feed angle to an intersection with a vertical line extending from the ratio "6". The correct truing angle, therefore, is 2° 50′.

To determine the correct diamond holder setting, (for actual contact point of part on regulating wheel) extend a horizontal line on the chart from a ½″ height above center to an intersection with a vertical line extending from the ratio "6". The correct diamond holder setting, thus, becomes 15/32″ (see Figure 31A).

Note—Use the highest regulating wheel speed available when truing.

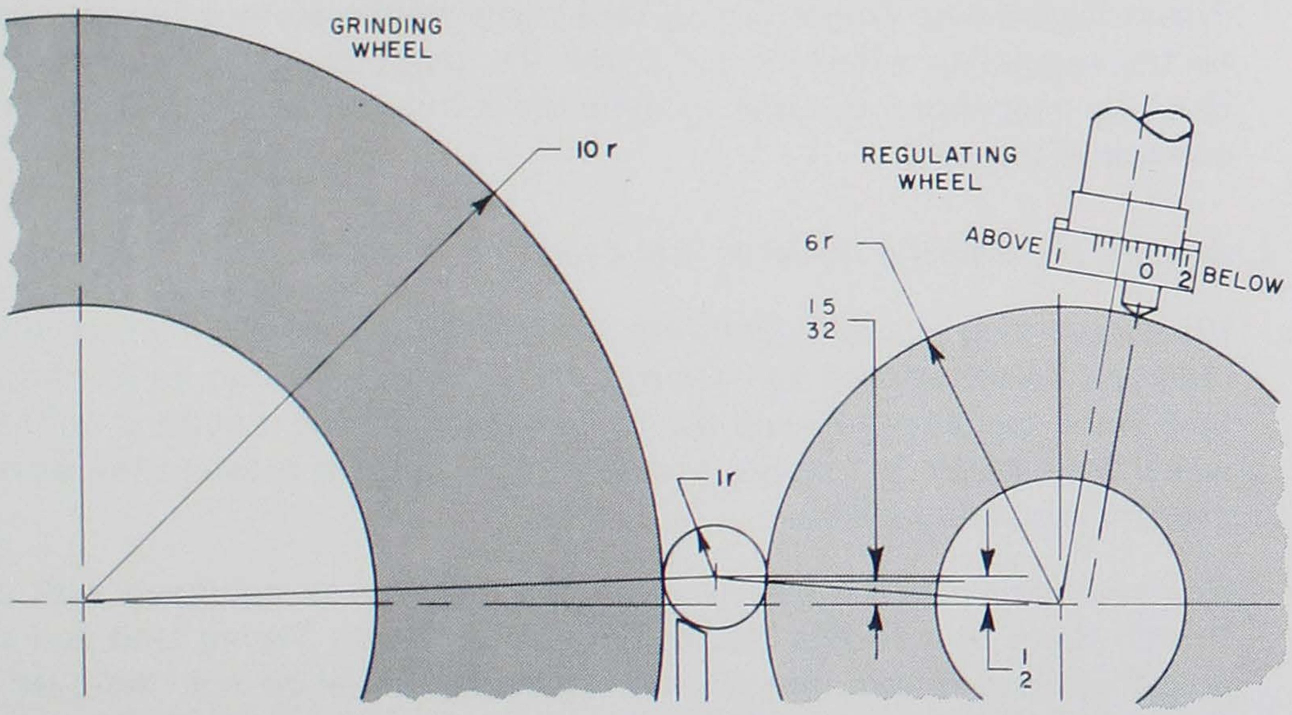


Figure 31A
Setting diamond block to obtain true line contact on regulating wheel

Infeed Setup Instructions for the Regulating Wheel Truing Unit. The standard procedure for truing the regulating wheel for infeed grinding is outlined below:

1. *Angle of inclination of the regulating wheel*

   For most infeed setups, an angle of inclination up to but not exceeding ¼° is recommended. The only purpose of this setting is to keep the workpiece against the end stop during the actual grinding operations. A general rule of thumb is, "the lighter the weight of the workpiece, the smaller the angle of inclination."

2. *Location of the center of the work with respect to the center of the grinding and regulating wheels*

   The procedure for setting the workpiece to the correct height above center is the same for infeed and thrufeed setups.

3. *Angle to which the regulating wheel truing slide is swiveled*

   For general *straight* diameter infeed setups the regulating wheel truing unit should be swiveled the same amount as the "Angle of Inclination" of the regulating wheel. This serves, as in thrufeed setups, to generate a surface on the regulating wheel which will maintain a straight line contact between the work and the wheel face.

   However, when the machine is equipped with a Profile Hand or Profile Power Regulating Wheel Truing Unit and a *profile* surface is required on the regulating wheel *do not* swivel the truing unit. A zero setting must be maintained in order to generate a true profile shape from the surface of the cam.

4. *Amount the diamond holder is "set-over"*

   When grinding *straight* diameter work using the infeed method, the diamond holder should be "set-over" in the same manner as for thrufeed work, see pages 29 and 30. This action develops a surface on the wheel face which will insure a straight line contact between the work and the regulating wheel.

   However, as in item 3 above, when the machine is equipped with a Profile Hand or a Profile Power Regulating Wheel Truing Unit and a *profile* surface is required on the regulating wheel *do not* "set-over" the diamond holder. A zero setting must be maintained in order to generate a true profile shape from the surface of the cam.

Why a "zero" setting is maintained on both the regulating wheel truing attachment and the diamond offset block for profile or step trued wheels. It can be shown by calculation* that if the zero setting of both units is not maintained, the step actually cut into the regulating wheel will not be equal to the step on the master truing cam. The amount of error in the step dressed on the wheel is related to (1) the amount the diamond block is "set-over" and (2) the actual diameter of the wheel.

When the two units are maintained at a zero setting, a perfectly cylindrical wheel is trued instead of the concave wheel needed for a full line contact in thrufeed work. This is why the angle to which the regulating wheel housing is swiveled should be no greater (¼° or less) than is absolutely necessary to hold the workpiece against the end stop during the grinding operation. To increase this angle will only introduce a greater chance for error in the step relation.

The workpiece may be placed at any height above center to obtain maximum roundness, (see page 29, second factor). With the very slight angle of inclination the line of contact of workpiece will be full at any height above center. However, if the angle of inclination is increased beyond ¼° the full line contact will not result and further corrections will have to be made to again obtain a full line contact between the regulating wheel and workpiece.

$$\text{*ERROR} = \sqrt{R^2 - L^2} - \sqrt{r^2 - L^2} - (R-r)$$

Where: R = major radius of regulating wheel

r = minor radius of regulating wheel

L = diamond offset

PRECISION TRUING OF REGULATING WHEELS

The charts shown on the next few pages can best be utilized for precision setups on the centerless grinder.

The amount of concavity dressed in the regulating wheel can be determined from Chart I. This chart can be used only when the diamond holder is not "set-over" and when the centerlines of the regulating wheel and regulating wheel housing pivot point both coincide.* (See page 22).

To illustrate the use of this chart, consider a machine that is setup to infeed grind long slender shafts. The parts when being checked have low ends and high centers. This condition is usually due to the depth of concavity in the regulating wheel and by merely increasing the angle of inclination of the regulating wheel housing, the amount of concavity can be reduced. To find out how much of a concave is dressed in the wheel, follow the example shown below.

Example:

Diameter of regulating wheel = 12″

Width of regulating wheel = 6″

Angle to which truing attachment is swiveled = 3°

To find the difference in diameter between the edges and the center of the regulating wheel, proceed as follows:

Place a straight edge on the chart in such a manner that it passes through 12 on scale (A) and 6 on scale (B). Now mark the intersection point on line (C); the pivot line. Next place the straight edge in such a manner that it intersects the mark just placed on line (C) and 3 on line (D). Now read the answer on line (E). In the case of the example cited above, it would be .004″. That means that the regulating wheel is dressed with a .004″ low center if the above figures are used in the setup.

*Chart was made from the following formula:

$$h = R - (R^2 - l^2 \tan^2 \alpha)^{1/2}$$

Where: α = Truing angle
R = Radius of regulating wheel inches (nominal)
l = Half width of regulating wheel (inches)
h = Difference in radius between edges and center of regulating wheel (inches)

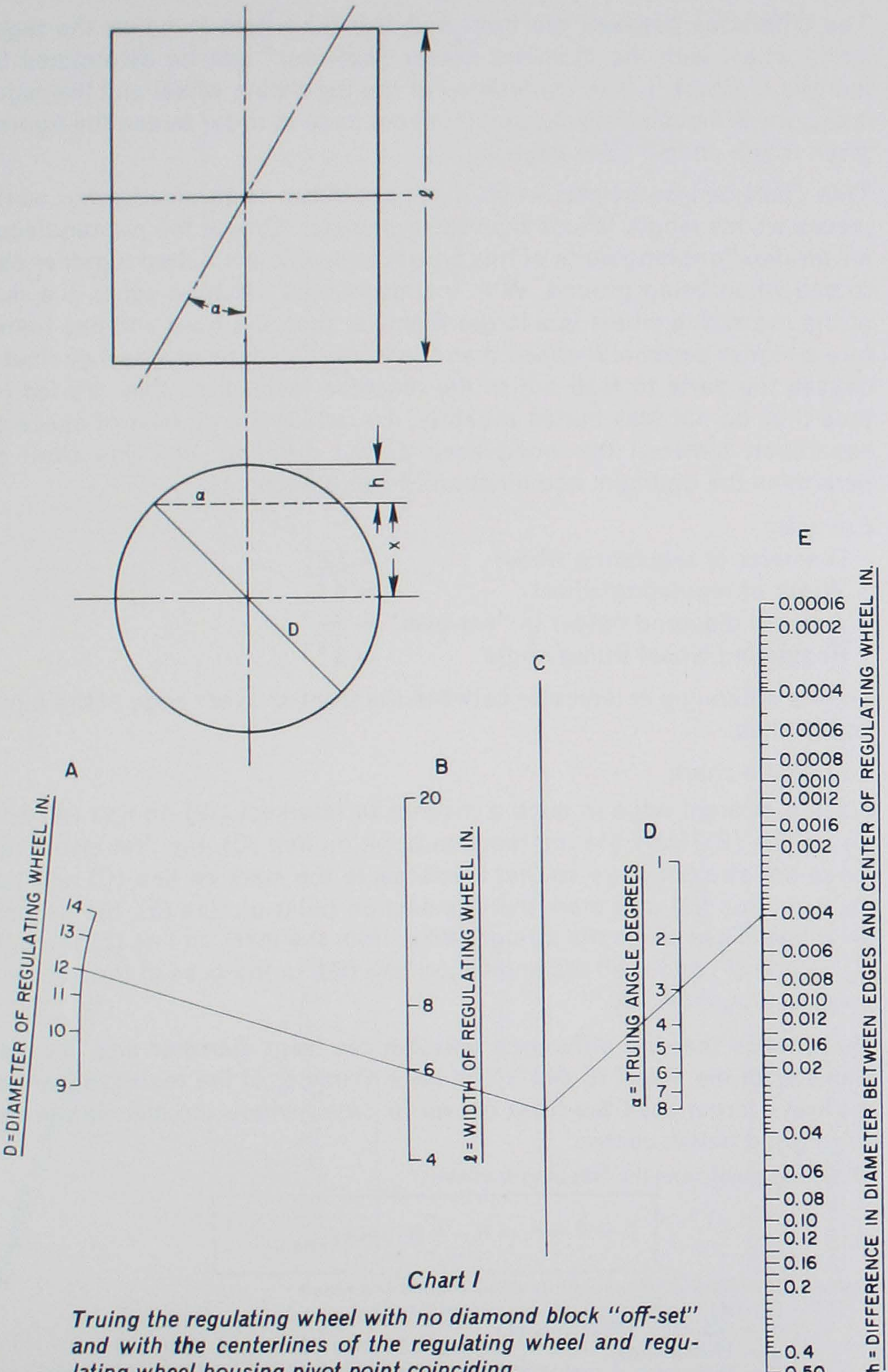


Chart I

Truing the regulating wheel with no diamond block "off-set" and with the centerlines of the regulating wheel and regulating wheel housing pivot point coinciding.

The difference between the front and rear diameters trued on the regulating wheel with the diamond holder "set-over" can be determined by the use of Chart II. The centerlines of the regulating wheel and the regulating wheel housing pivot point must coincide in order to use the figures given in the chart.* (See page 22).

This chart can be helpful when making a setup to thrufeed grind workpieces whose length is less than their diameter. One of the pre-requisites for thrufeed grinding parts of this type is to keep them butted together end to end when being ground. With a conventional machine setup, the rear of the regulating wheel is a larger diameter than the front and has therefore a higher peripheral speed than the front. This type of wheel geometry causes the parts to feed out of the machine faster than they are fed in, thus they do not stay butted together. To reduce the amount of space or separation between the workpieces during grinding, use this chart to determine the optimum combination of setup elements.

Example:

Diameter of regulating wheel	= 12 ″
Width of regulating wheel	= 6 ″
Amount diamond holder is "set-over"	= ⅜ ″
Regulating wheel truing angle	= 3 °

To find difference in diameter between the front and rear edge of the regulating wheel.

To use the chart:

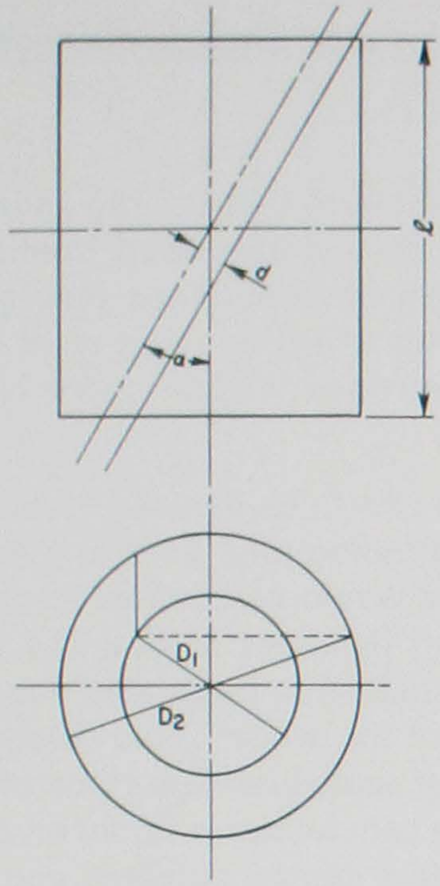
Place a straight edge in such a manner to intersect (12) on line (A) and (6) on line (B). Mark the intersection point on line (C), the first pivot line. Place the straight edge so that it intersects the mark on line (C) and the (⅜ ″) on line (D) and mark the intersection point on line (E), the second pivot line. Then place the straight edge from the mark on line (E) through (3) on line (F) and read the answer on line (G). In the case of the example given, it would be .040 ″.

That means that the difference between the front diameter and the rear diameter of the wheel is .040 ″. The back diameter of the regulating wheel is always larger than the front except in cases where the machine is set up to grind below center.

*Chart was made from the following formula:

$$D = R - R_1 = R - \left(R^2 - 4\,ld\frac{\tan\alpha}{\cos\alpha}\right)^{1/2}$$

Where: R = Radius of regulating wheel inches (nominal)
l = Half width of regulating wheel (inches)
d = Diamond offset (inches)
α = Truing angle
D = Difference in radius between front and back of regulating wheel (inches)



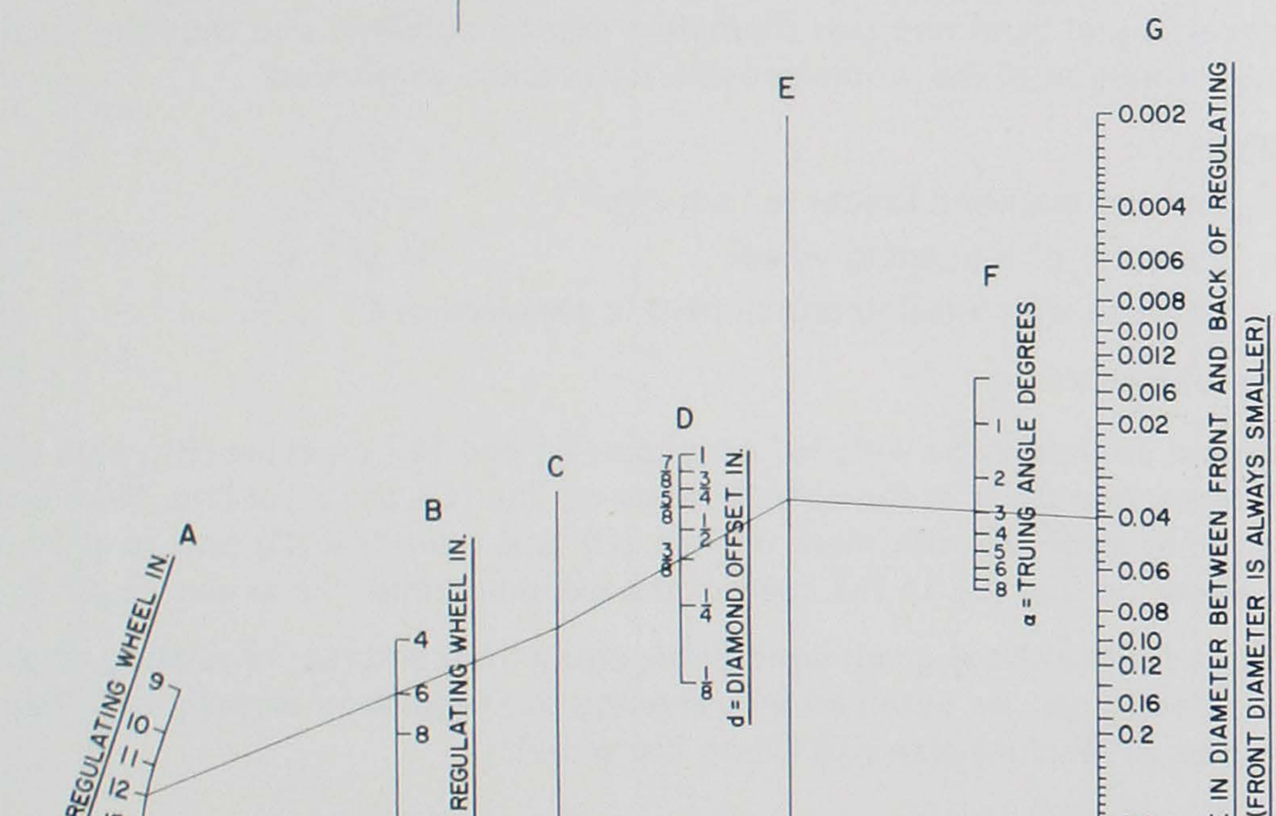


Chart II

Truing the regulating wheel with diamond block "off-set" and with the centerlines of the regulating wheel and regulating wheel housing pivot point coinciding.

Charts III and IV are used mainly for wide wheel applications of centerless grinding.

Chart III can be used to find the amount that the regulating wheel truing cam holder must be swiveled in order to obtain equal front and rear diameters on the regulating wheel when the centerlines (see page 22), of the regulating wheel and the regulating wheel housing pivot point concide.* (Only applicable for machines equipped with a profile regulating wheel truing attachment).

The information derived from this chart can be used to advantage when a wide wheel machine is thrufeed grinding long bars or other similar work. In the normal machine setup there would be unequal front and rear regulating wheel diameters. (See chart II, pages 36 and 37.) Therefore there is a definite tendency for the workpieces to be twisted due to the different peripheral speeds of the edges of the wheel. This twisting usually is a source of chatter as well as other undesirable surface blemishes. However, if the regulating wheel truing cam holder is offset on a compensating taper, equal front and rear diameters can be obtained and thus the twisting condition of the workpiece can be virtually eliminated.

Example:

Amount diamond holder is "set-over"	= ¼ "
Diameter of regulating wheel	= 13 "
Angle to which truing attachment is swiveled	= 4°

To use chart:

Line a straight edge with ¼ " on scale (A) and 13 " on scale (B), mark the intersection point of the straight edge on line (C), the pivot line. Next, line straight edge up with mark on line (C) and 4 on line (D) and read your answer on line (E). In the case of the example cited, the answer is 0° 9′.

Thus for the above given conditions, equal front and rear regulating wheel diameters can be obtained by swiveling the regulating wheel profile cam holder 0° 9′ clockwise and truing the wheel.

*Chart was made from the following formula:

$$\tan \phi = \frac{d}{R} \tan \alpha$$

Where: ϕ = Taper on cam in degrees
d = Diamond offset (inches)
R = Wheel radius (inches)
α = Truing angle

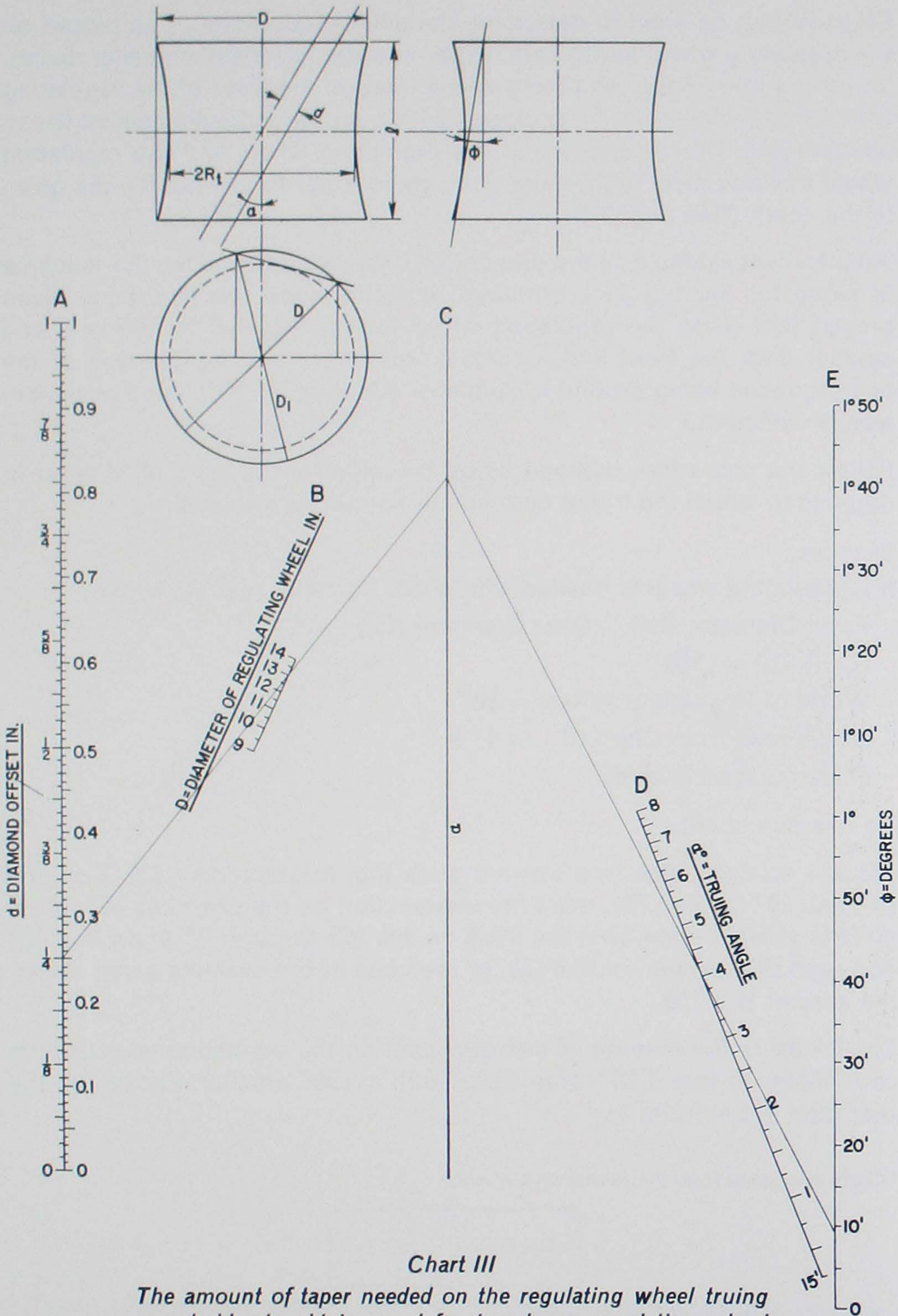


Chart III

The amount of taper needed on the regulating wheel truing cam holder to obtain equal front and rear regulating wheel diameters with the centerlines of the regulating wheel and regulating wheel housing pivot point coinciding.

Chart IV can be used to determine the amount of swivel to be placed on the regulating wheel truing cam holder in order to obtain a smaller diameter on the rear of the regulating wheel than on the front of the regulating wheel.* (Machine must be equipped with a profile regulating wheel truing attachment). The centerlines of the regulating wheel and the regulating wheel housing pivot point must coincide in order to use the figures given in the chart. (See page 22).

An excellent example of the use of this chart would be when the machine is setup for bearing race grinding. In actual shop practice it has been proved that when the regulating wheel is tapered, that is, the rear end smaller than the front end, optimum roundness and squareness of the bearing races being ground is obtained. (Usually ½″ difference in diameters is sufficient.)

Follow the procedure outlined below to calculate the amount of taper in degrees to which the truing cam holder should be swiveled.

Example:

If a regulating wheel is needed with a .500″ smaller rear diameter:

Front Diameter (D_1) — Rear Diameter (D_2)

$(D_1 - D_2) = .500''$

Width of Regulating Wheel = 20″

Angle read from Chart III = 0° 9′

(This must be known)

To use this chart:

Place a straight edge in a manner such that it intersects (.500″) on line (A) and 20″ on line (B), mark the intersection on the pivot line (C). Then place a straight edge from the mark on line (C) through 0° 9′ on line (D) and read the answer on line (E). In the case of the example given above, the answer is 0° 53′.

The 0° 53′ is the amount of swivel placed on the regulating wheel truing cam holder to true a 20″ wide wheel with a .500″ smaller diameter in the rear than in the front.

*Chart was made from the following formula:

$$\tan \psi = \frac{K}{2l} + \tan \phi_1$$

Where: ψ = Taper on cam in degrees
$K = R - R_1$ Difference in radii
l = Half width of regulating wheel (inches)
ϕ_1 = Angle read from Chart III

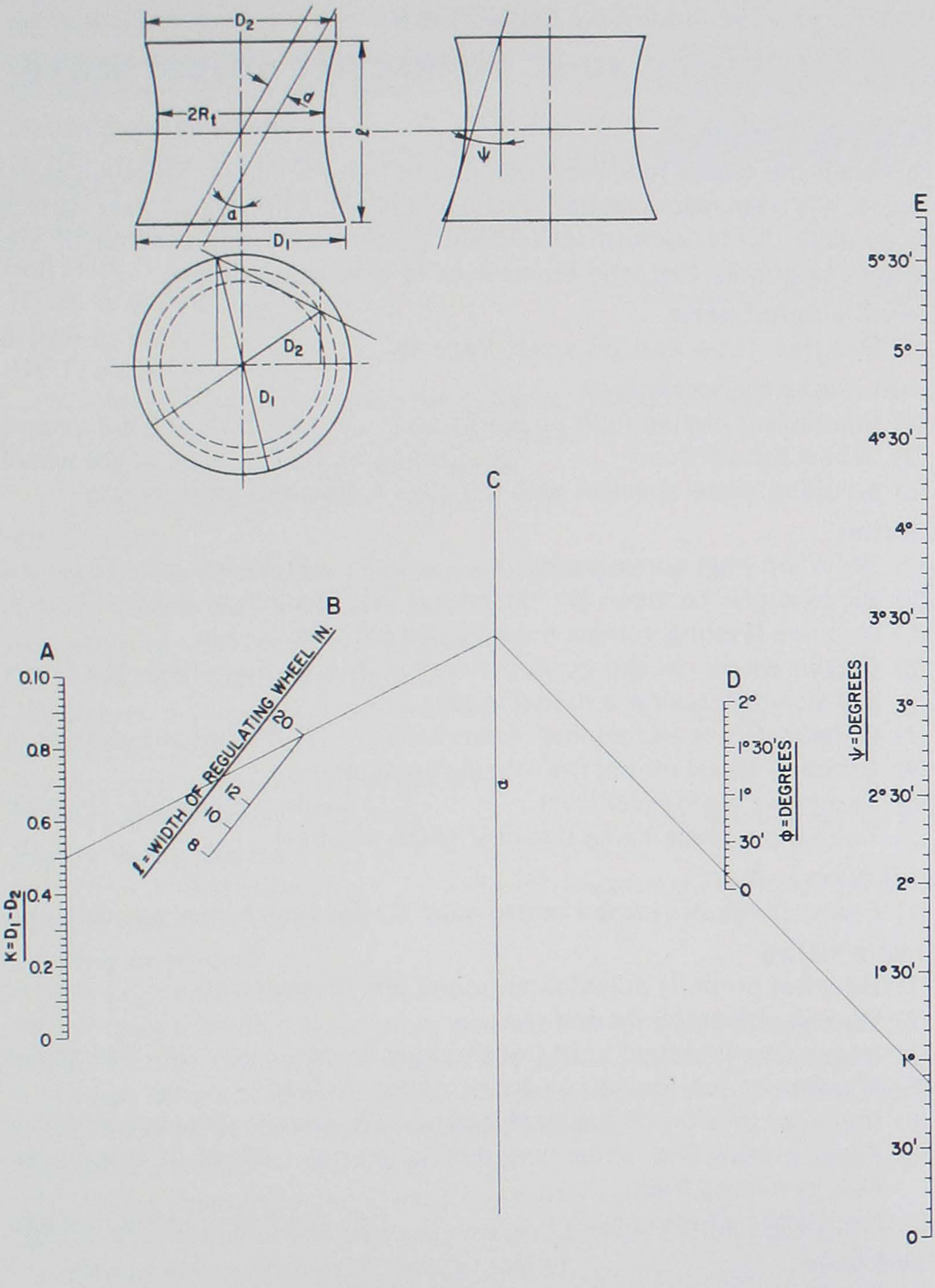


Chart IV

The amount of taper needed on the regulating wheel truing cam holder to obtain a smaller rear diameter on the regulating wheel than front, with the centerlines of the regulating wheel and regulating wheel housing pivot point coinciding.

CHAPTER VI

CENTERLESS GRINDING CORRECTIVE ADJUSTMENTS

Thrufeed and Infeed

To obtain the closer tolerances needed in today's modern grinding techniques, it is necessary that both the machine and setup be as near perfect as possible. This section is devoted to corrective adjustments of the centerless grinder that lend themselves to precision grinding.

Barrel-shaped parts

(1) See Item (Low end on work) Page 43

Burn marks on workpiece

(1) Insufficient cutting fluid on workpiece (2) Dull or flat diamond
(3) Wheel too hard (4) Cutting on trailing edge of the wheel
(5) Grinding wheel dressed with too slow a diamond traverse rate

Chatter

(1) Work too high above center (2) Wheel out of balance
(3) Blade angle too steep (30° standard) (4) Too thin or a warped blade
(5) Machine leveling screws not adjusted for even torque
(6) Glazed wheel caused by dull diamond, too hard a wheel, too fine a grit size or too slow a dressing rate
(7) Outside "Floor Harmonics" (vibration) (8) Motors out of balance
(9) Grinding wheel mount fits loosely on spindle
(10) Too heavy a stock removal (11) Blade not properly clamped
(12) Too long a blade being used for width of wheel

Dull diamond

(1) Diamond nib not turned periodically (2) Excessive infeed of diamond

Erratic sizing

(1) Gibs not properly adjusted on upper and lower slides
(2) Wear in infeed screw and nut
(3) Infeed lever not held tight (for thrufeed work) (4) Soft wheel
(5) Insufficient lubrication on lower slides (infeed)
(6) Improper tension on backlash spring (7) Loose work support blade
(8) Parts overheating under cut due to improper wheel or insufficient flow of cutting fluid
(9) Regulating wheel camming (10) Work improperly roughed

Feed lines

(1) Grinding wheel not relieved on exit side
(2) Work guides improperly set* (3) Cut improper across wheel face
(4) On long bar fixtures—excessive pressure on work by roller hold-down

Finish

(1) Improper wheel grade (2) Dirty or insufficient cutting fluid

**See pages 45-47*

(3) Setup not correct (4) Too fast a diamond dressing traverse
(5) Erratic movement of truing attachments (6) Pick-up on blade
(7) Blade not tight in work rest (8) Blade angle too steep
(9) Unbalanced wheel (10) Loose, cracked or dull diamond
(11) Oil on face of wheel (12) Regulating wheel not tight on its mount
(13) Work too high above center
(14) Regulating wheel S.F.P.M. excessive

Fish tails
(1) Dirty cutting fluid (2) Loose grit in wheel

Grinding wheel
(1) Too hard
  (a) May cause burn marks, heat checks, cracks, or glazing
  (b) Can cause squeal or produce chatter
  (c) Soft materials may "load" wheel
  (d) Sizing trouble, due to no spark out
(2) Too soft
  (a) Sizing trouble, because wheel breaks down rapidly
  (b) Chatter may develop

Height above center of workpiece
(1) If too high chatter can develop
(2) Optimum rounding action will not occur if center height is too low

Intermittent cut
(1) Grinding wheel not correctly trued
(2) Regulating wheel "camming" (3) Warped workpiece

Jumpy truing device
(1) Air in lines (hydraulic) (2) Slides not lubricated properly
(3) Gib adjusted improperly

Loading of wheels
(1) See grinding wheels
(2) Wheels too fine. Larger grain size allows more chip clearance.
(3) Ineffective cutting fluid—due to the lack of lubricity of cutting fluid chips adhere to grit of wheel. Change to coolant with greater lubricity or increase amount of concentration in mix.

Low ends on work*—chamfered
(1) Work guides deflected toward regulating wheel
(2) Face of regulating wheel not straight at work contact point. (Truing device worn or not set to proper angle).

Low center*—High ends
(1) Work guides deflected toward grinding wheel
(2) Same as No. 2 above

Nicks in workpiece
(1) Do not drop parts into tote pans. Provide bumpers to cushion work

**See pages 45-47*

Out of round work *(See page 48)*

(1) Out of balance workpiece (2) Work not high enough above center
(3) Workpiece bowed (4) Regulating wheel not dressed round
(5) Regulating wheel loose on mount (6) Blade angle not steep enough
(7) Not enough stock to round up (8) Regulating wheel speed too slow
(9) Interrupted cut due to keyways, holes, flats, etc.
(10) End stop or ejector may be worn on locating surface (infeed only)
(11) Grinding wheel off grade (12) Flat diamond

Pick-up on blade

(1) Cutting fluid not lubricating work-to-blade contact point. Use cutting fluid with greater lubricity or increase concentration.
(2) Blade material (use cast iron or bronze blade)

Regulating wheel "camming"

(1) Collet screws loose (2) Bearings worn
(3) Regulating wheel spindle eccentric or out of round

Sizing

(1) See erratic sizing

Spiral chatter

(1) Hard spots in wheel (2) Chipped edge of wheel
(3) Loose machine elements

Straightness

(1) Work not straightened sufficiently before grinding
(2) Insufficient grinding stock left on workpiece
(3) Too much stock removal on first pass
(4) Wheel not cutting freely. (Part heats up, relieving internal stresses causing part to bow.)
(5) Insufficient cutting fluid (same thing happens as No. 4 above)

Taper

(1) Work guides not set properly* (2) Dirt under work rest or blade
(3) Loose gibs (4) Failure to keep parts butted end to end on thrufeed
(5) Too much feeding pressure (race-grinding fixture)
(6) Non-uniform spark-out time from one piece to the next (infeed setup)
(7) Wheel not cutting freely (surface temperature expands part behind leading end. This results in tapered part with leading end high.)

Vibration

(1) Check outside sources (2) Leveling screws not snug against floor
(3) Motors not balanced or drive belts too loose
(4) Faulty hydraulic pump transmits pressure vibrations to machine

Warped work (usually long bar or tubing)

(1) Insufficient flow of cutting fluid
(2) Wheel cutting inefficiently. Dressed too fine or too small grit size.
(3) Workpiece not straightened before grinding

**See pages 45-47*

Work Guide Adjustments for Thrufeed Work. For all thrufeed grinding operations, the bearing surface of the front and rear regulating wheel guides (Figure 45A) should be set parallel and in line with the face of the regulating wheel. *Note*—The lone exception being Type "D" Long Bar work in which the guides must be aligned with the grinding wheel. If the guides are set correctly, the workpiece will pass through the wheels in a straight line and one of the causes of poor finish and taper will be avoided. To accurately set the regulating wheel guides parallel with the regulating wheel proceed as follows:

(a) Obtain an aligning bar or other shaft (straight within .0001 ″) having a length at least equivalent to the width of the regulating wheel plus the length of the front and rear regulating wheel guides. The diameter of the bar should approximate the finished diameter of the workpiece.

(b) Set up machine for grinding workpiece. (Set blade for correct height above center—true regulating wheel—set regulating wheel housing to correct feed angle.)

(c) Back off regulating wheel guides behind regulating wheel by rotating adjusting screws "B", (Figure 46A). Place aligning bar on blade and adjust regulating wheel to support aligning bar. Back off aligning bar from grinding wheel and place wooden wedges in position as shown in Figure 45A, to insure firm straight line location of aligning bar between blade and regulating wheel.

(d) Bring front regulating wheel guide forward until it lightly contacts aligning bar. Use a feeler gage and determine if a full straight line contact on the aligning bar is evident. If it is not, adjust the position of the guide as indicated by the feeler gage. This adjustment is obtained by slightly tilting the guide (Figure 45A) in the proper direction. To tilt the guide in either direction, loosen one adjusting screw "C" slightly and tighten the other.

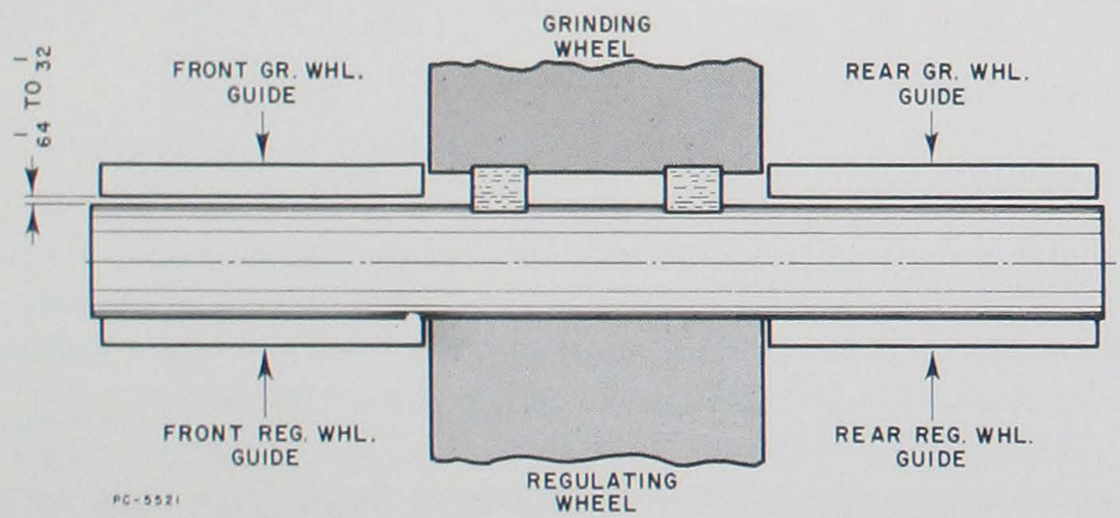


Figure 45A
Regulating wheel and grinding wheel guide arrangement

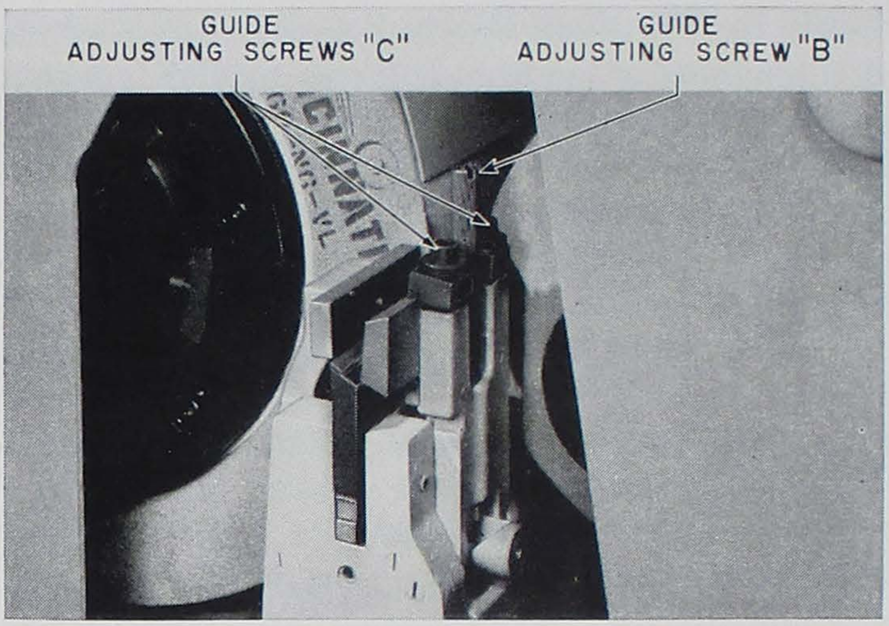


Figure 46A
Regulating wheel guide adjustments

(e) Adjust the rear regulating wheel guide (Figure 45A) following the instructions given in "D", page 45.

After this adjustment has been made and the machine started it may be necessary to move the regulating wheel guides slightly forward to bring them accurately in line with the face of the regulating wheel.

When grinding discs, bearing races, and other narrow width work, the edge of the grinding wheel on the entering side should be trued back about ½ the stock removal to a taper having a length of about ¼" to ½".

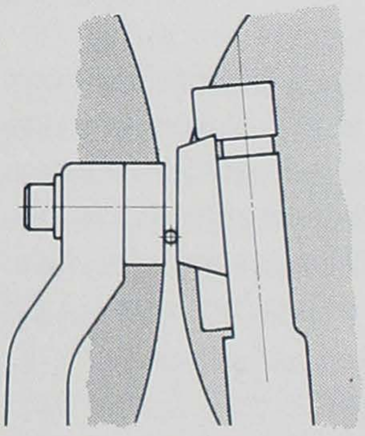


Figure 46B
Guide arrangement for small diameter work

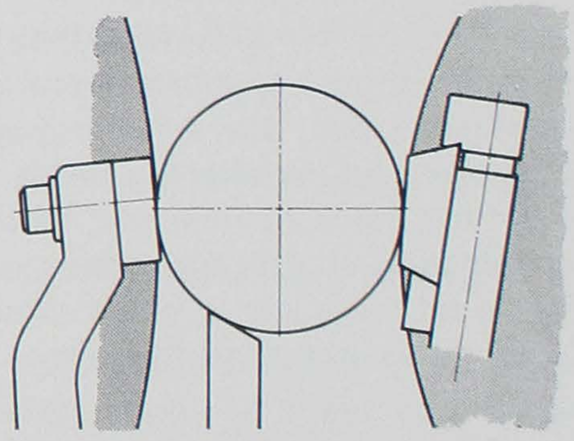


Figure 46C
Guide arrangement for large diameter work

Each guide is mounted and clamped on a separate adjustable bracket of the work rest, (Figures 46B and 46C). Notice that for small diameter work the "thick edge" of the guide lays against the fixed jaw of the clamp. For large diameter work (above 2") the guide is inverted to place the "thin edge" of the guide against the solid jaw.

Adjust the Guides on the Grinding Wheel Side. Work does not bear upon these guides, and therefore, from 1/64" to 1/32" clearance is allowed, depending upon the diameter of work being ground (Figure 45A).

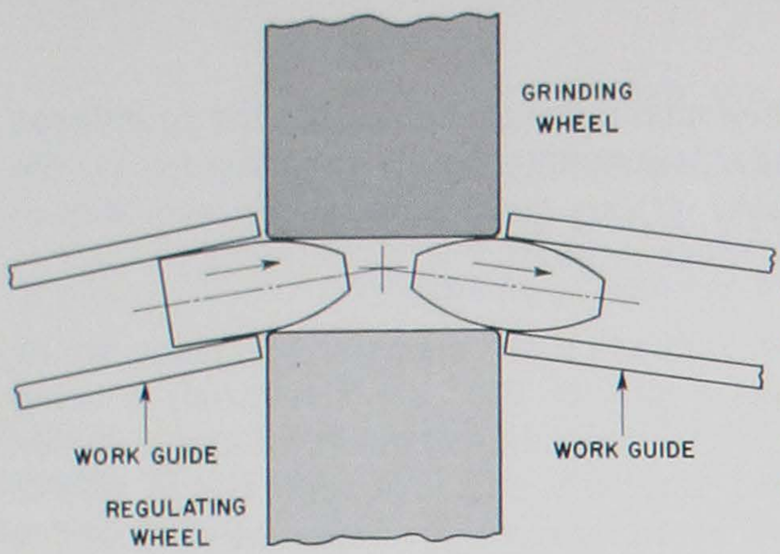


Figure 47A
Effect of deflecting guides toward regulating wheel

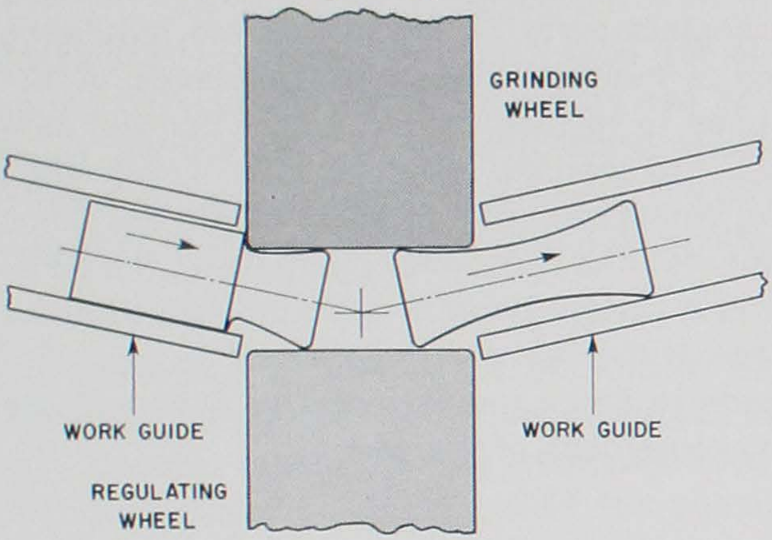


Figure 47B
Effect of deflecting guides toward grinding wheel

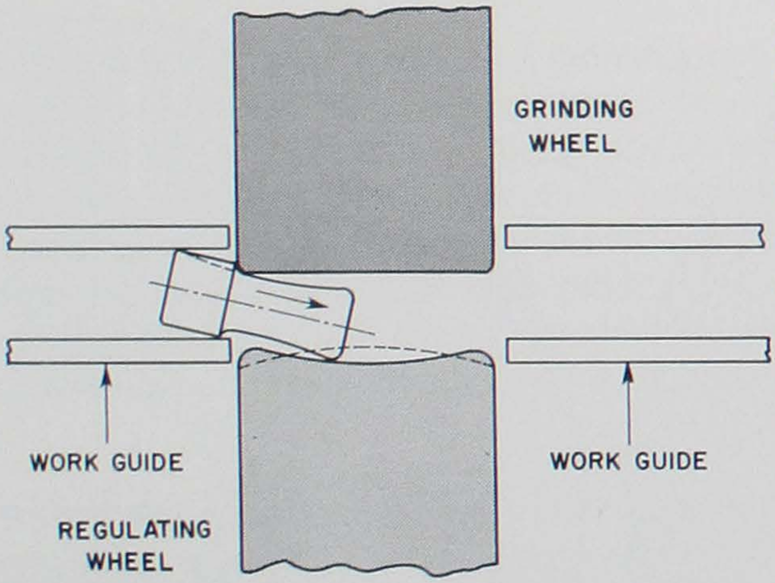


Figure 47C
Effect of convex and concave face regulating wheel

Guide Adjustments when Work is not Ground Straight. Taper on the front end of the work, as it leaves the machine, is caused by the work guides on the entrance side deflected towards the regulating wheel (Figure 47A). Conversely, taper on the rear end of the work is generally caused by the guides on the exit side deflected in the same manner; barrel shaped work is caused by both the front and rear guides being deflected towards the regulating wheel.

Work guides deflected towards the grinding wheel on either one or both sides have a tendency to produce work of hollow shapes (Figure 47B).

A concave face on the regulating wheel will produce work of reduced diameter in the center (Figure 47C). Conversely a convex face on the regulating wheel will result in barrel shape work. (See dotted line, Figure 47C).

If the work must be a true cylindrical shape, avoid the above mis-alignments of guides and blades, and be sure that the wheels are trued correctly. In case of difficulty, check the contact of the work, blade, and regulating wheel with red-lead or prussian blue. A warped blade may cause hollow grinding.

Roundness: Through experimentation it was found that the roundness achieved on a centerless grinder is dependent on 3 main factors: (1) the included angle "a", (Figure 48A) (2) the stock removal per revolution of the workpiece and (3) the total stock removal.

To cite a hypothetical example: suppose a ¾ ″ diameter workpiece, which is out of round .0005 ″ and has a total of .010 ″ stock removal, is being ground, with a contact point on the regulating wheel at 1 ″ above center. A 20 ″ diameter regulating wheel is being used and is set to run at 15 RPM or 78.5′ per minute. With this setup, assume a roundness of .0001 ″ is obtained.

Now, by changing only the diameter of the regulating wheel and keeping everything else constant, the contact point of the part on the regulating wheel will have to be changed to maintain the same roundness. A 12 ″ diameter regulating wheel is used to replace the 20 ″ one. Then the contact point must be lowered to ⅝ ″ (to keep the same angle "a" Figure 48A) and the RPM of the regulating wheel changed to 25 to obtain the same peripheral speed of 78.5′ per minute. The reason for maintaining the same peripheral speed is that there is a certain percent of rounding action for each revolution of the workpiece. If the same surface speed is not maintained, there will be a difference in stock removal per revolution of the workpiece, which will affect the roundness of the part.

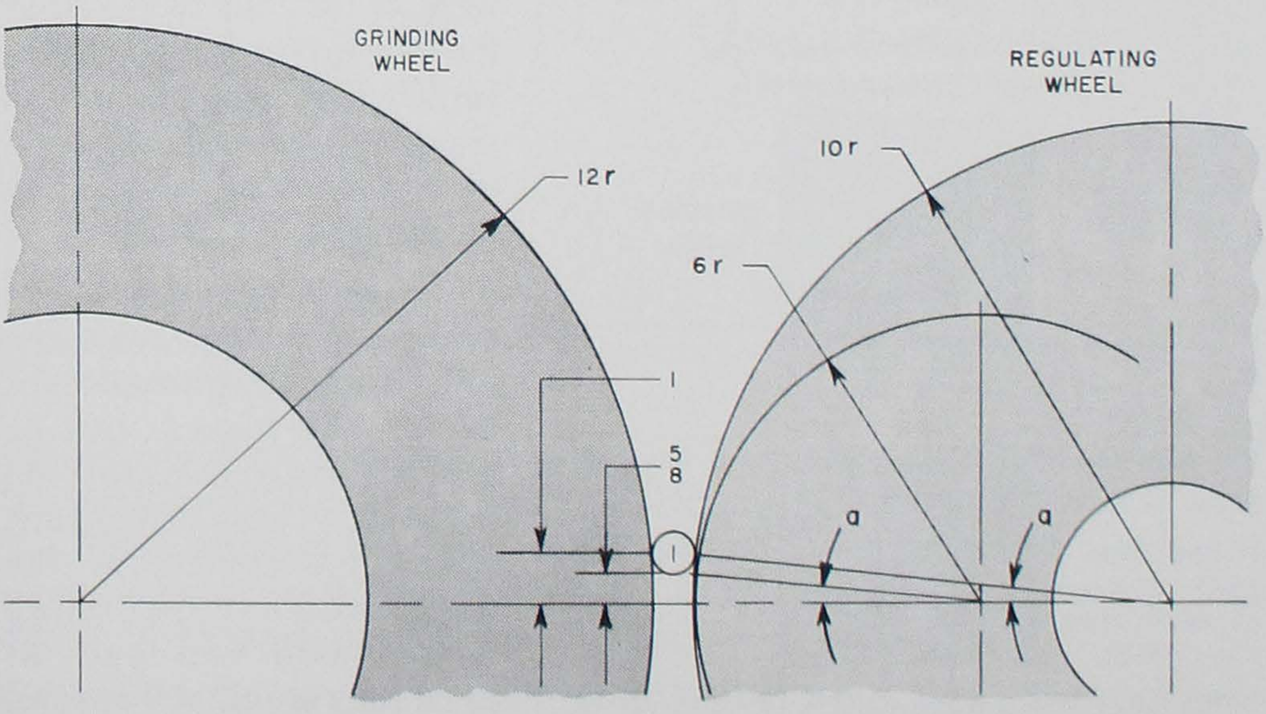


Figure 48A—Angular relationships and diameter of regulating wheel determine rounding effect when centerless grinding

CHAPTER VII

HOW TO ECONOMICALLY GRIND SMALL LOTS ON A CENTERLESS

Reprinted from "American Machinist"

A general but erroneous opinion is that centerless grinding is exclusively adapted to large-lot mass production. Actually the centerless grinder is as well suited to short runs of widely different and frequently changed parts as any machine tool. If it were not, centerless jobbing companies could hardly keep operating.

Occasionally, companies of this type get an order for a million or more identical pieces on which a machine can be kept busy for several weeks. These are few and far between. More often their orders go to the other extreme—a lot consisting of a single piece. The bulk of this type of business is made up of lots from about 25 to 500 pieces.

The centerless grinder can economically handle a wide variety of work. Materials include cast iron, steel of various analyses and hardness, aluminum, copper, brass, bronze, enameled iron, and many types of plastics. Changing materials usually calls for considerable down time, for it is frequently necessary to change wheels and coolant—which involves complete cleaning of the machine and coolant tank.

In the drawing, Figure 50A, is a typical batch of parts to be ground on one machine. Numbers refer to quantity to be produced. Each job, of course, requires its own setup. In most shops which make a wide variety of standard products, it is possible to hold up a small order until enough similar parts have been accumulated to get a fairly long run. This is seldom possible for job shops, for they often must make delivery within a day or so. However, it is sometimes possible to accumulate several less urgent orders for parts made of the same material and run them through together.

Some Ways to Save. The secret of economical centerless grinding of small lots is intelligent production planning. This does not call for elaborate planning boards nor complicated paper work. It is a matter of common sense and knowledge of the time required to change the setup for one part to a setup suited to another.

It takes less time to change the setup for a thrufeed job to that for another thrufeed job than to change from a thrufeed job to an infeed one. Therefore when planning the day's production for a certain machine the work should be all thrufeed or all infeed. In addition to saving time, the regulating wheel and truing diamond will last longer.

Secondly, try to group lots of parts whose diameters are not too different, so that the changes in setup will come in as small steps as possible. It takes longer to make changes for large differences in diameter than for small ones.

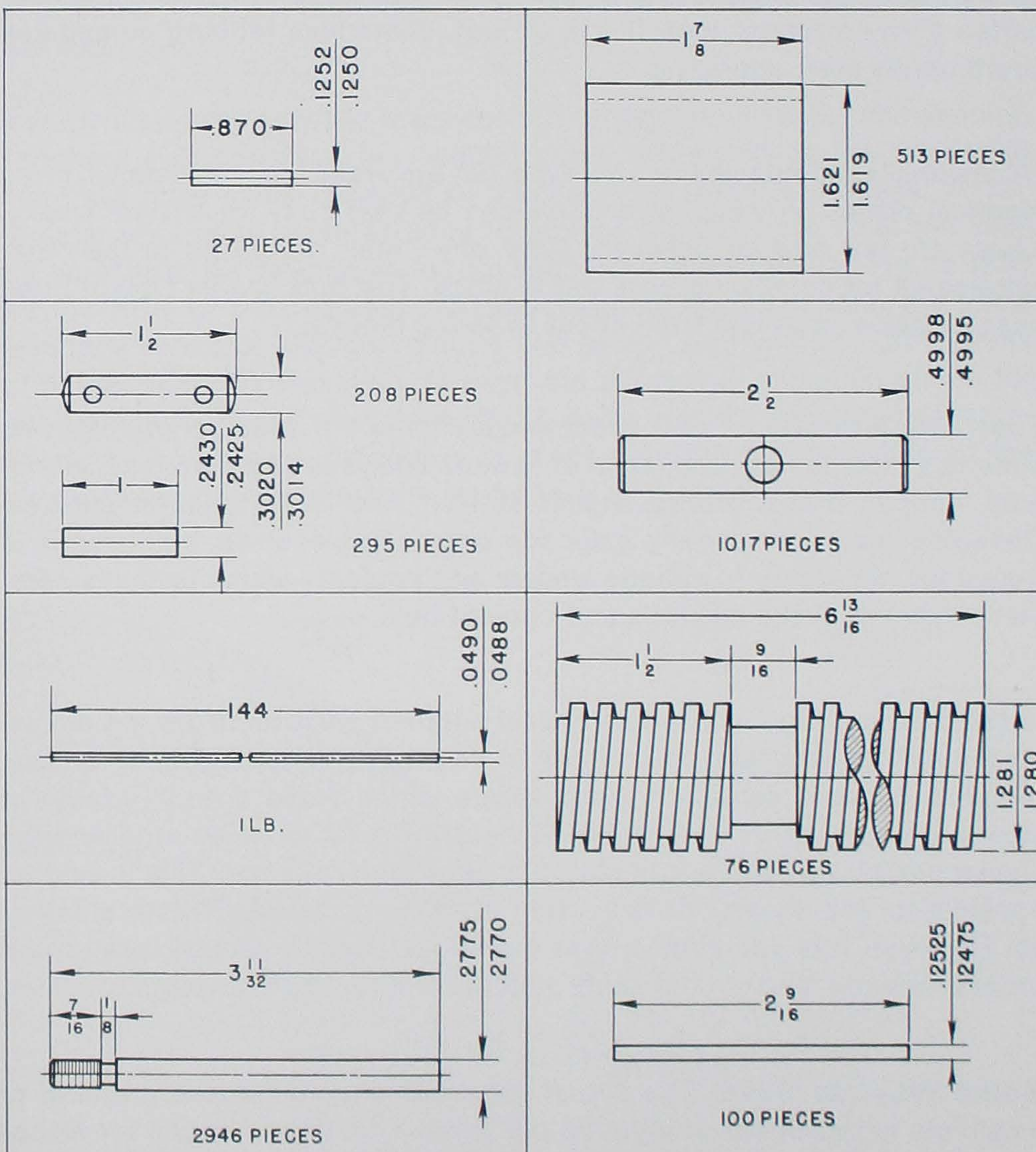


Figure 50A

A group of orders received in one day by a centerless jobbing company

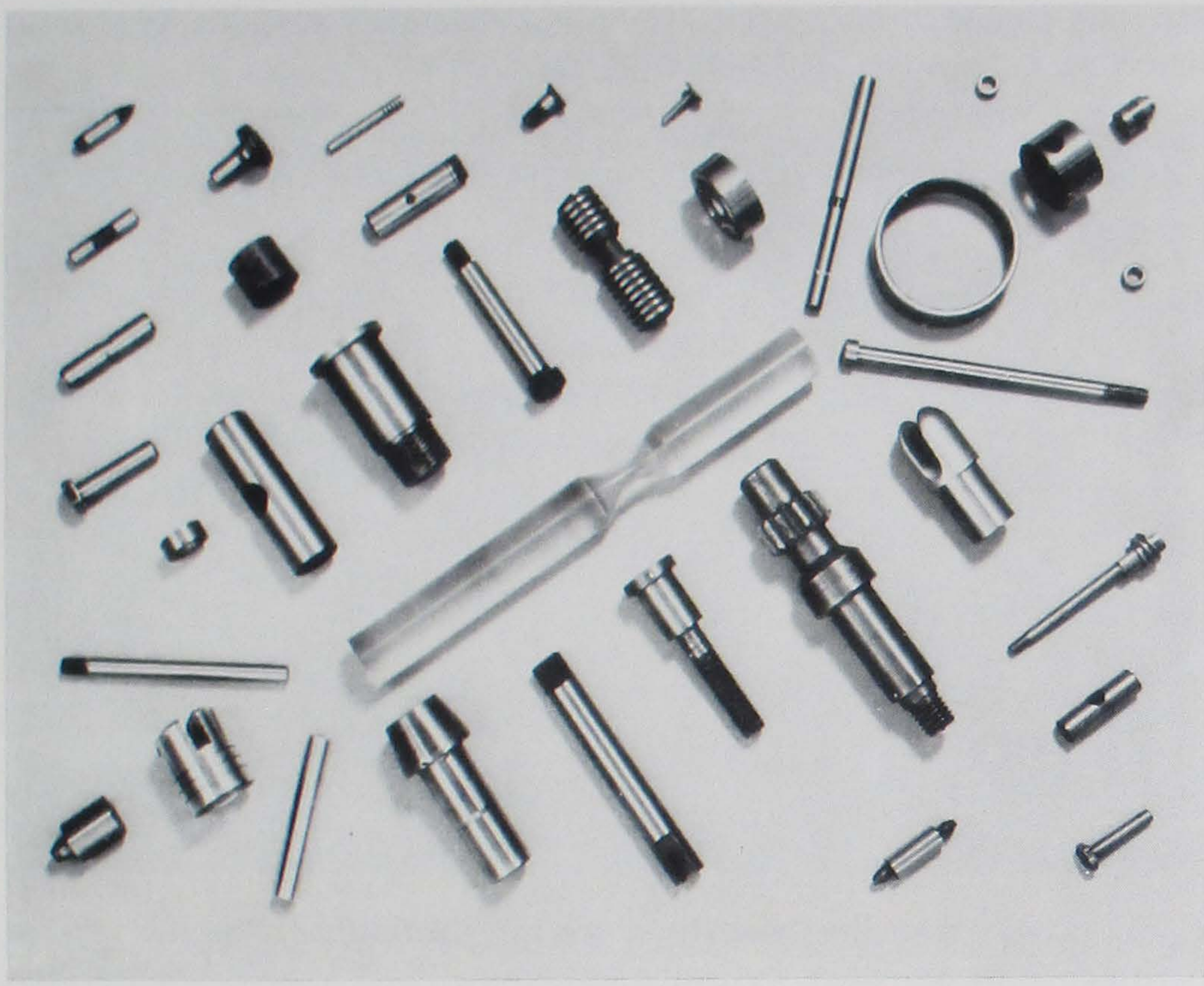


Figure 51A

These widely differing parts were all finished economically by centerless grinding. Quantities ranged from 1,000,000 for the small iron core in the extreme upper left to 1 for the slotted shaft at the bottom. Tolerances were often within two or three tenths. Materials include iron, steel, stainless steel, brass, Bakelite, aluminum, and transparent plastic.

Take the typical jobs illustrated in Figure 50A. They can be scheduled in order of diameters starting with the largest, and ending with the pound of wire. All are thrufeed jobs. If these parts are scheduled in the order in which they are received from the customer, each setup might take from 30 minutes to an hour. But when scheduled so that they are processed in the order of declining diameters, the setup times will shrink to 15 to 25 minutes each. This procedure is elementary, of course; but it is often overlooked or ignored. In it lies the secret of economical centerless grinding of small lots.

How to Compare Costs. For the shop which has both centerless grinders and centertype machines, it is handy to have some formula which will help decide which method will be more economical.

Here is a simple formula which, while not absolutely accurate, is at least indicative. Let

$M.L.$ = Value determining whether the work should be ground on the centerless grinder,

A = Setup time for centerless grinder,

B = Setup time for centertype grinder plus time required for drilling center holes and an allowance for truing center points,

C = Grinding time for centertype grinding each piece,

D = Grinding time for centerless grinding each piece.

Then

$$M.L. = \frac{A - B}{C - D}$$

If *M.L.* is less than the quantity in the lot, theoretically the job can be more economically done by centerless grinding. If *M.L.* is greater than the lot quantity, centertype grinding will be more economical. However, if the difference is slight and if the centerless machine has time available, it may be better to assign the job to the centerless.

Incidental Economies. There are other factors which may make it desirable to do a job by centerless grinding even though the formula indicates that it will be more economical to do it on a centertype machine. Since there is no deflection in the piece caused by wheel pressure, the danger of inaccurate work and poor finish from that cause is eliminated. Then, too, there is no axial pressure, as when work is ground between centers, and this additional cause of possible inaccuracy is also eliminated. These factors tend to reduce losses from spoiled work—resulting in an additional time saving which is not taken into account in the formula.

The point is that long runs need not be available in order to make centerless grinding economical. If the foreman or production man knows his machine and has detailed knowledge of what makes for quick, inexpensive setups, a diversity of parts in surprisingly small lots can be effectively handled on a centerless machine.

CHAPTER VIII
TYPICAL EXAMPLES

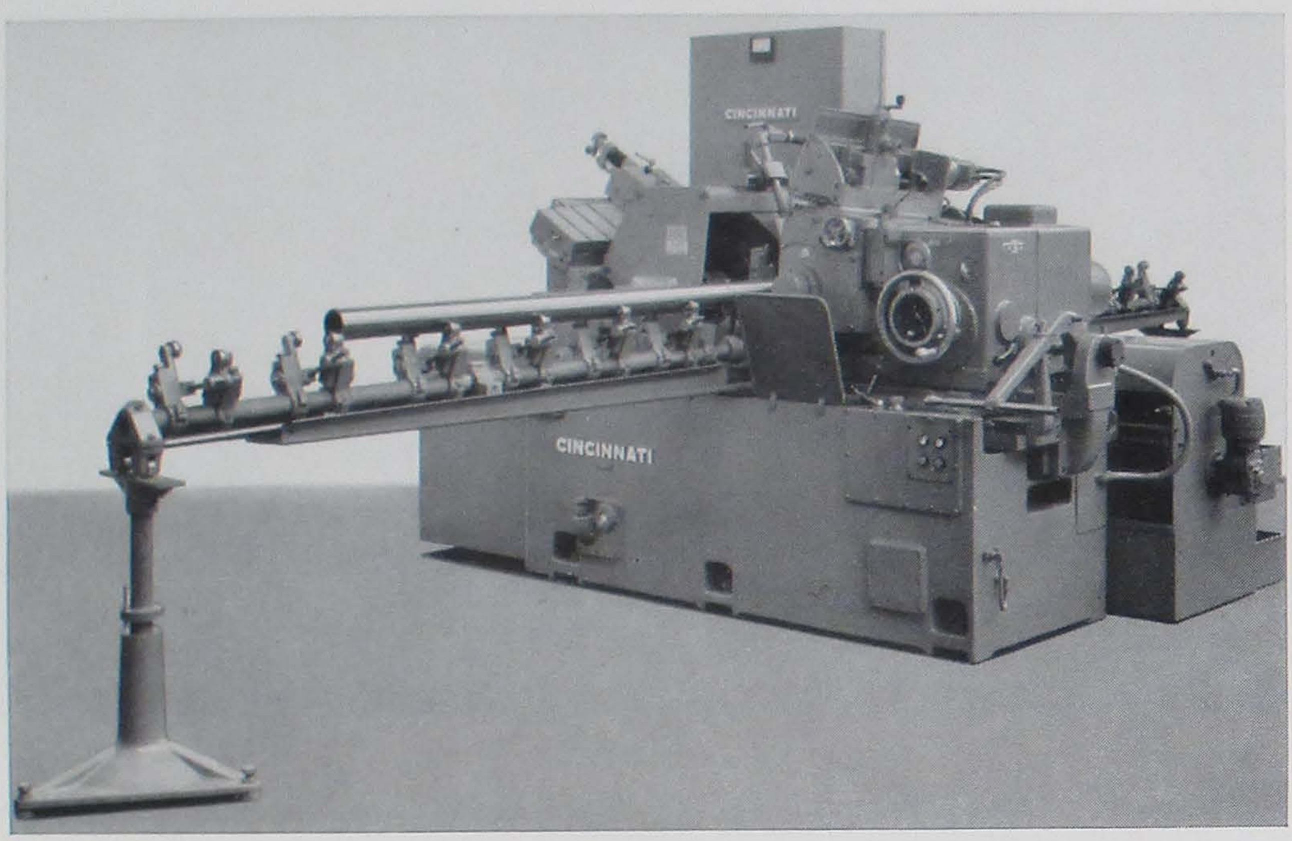


Figure 53A

Grinding 14' steel tubing 2½ " diameter on a No. 3 Centerless. The feed rate for this job is approximately 53 " per minute and stock removal is .003 " - .005 " per pass. The machine is equipped with a long bar fixture and a cutting fluid filter unit.

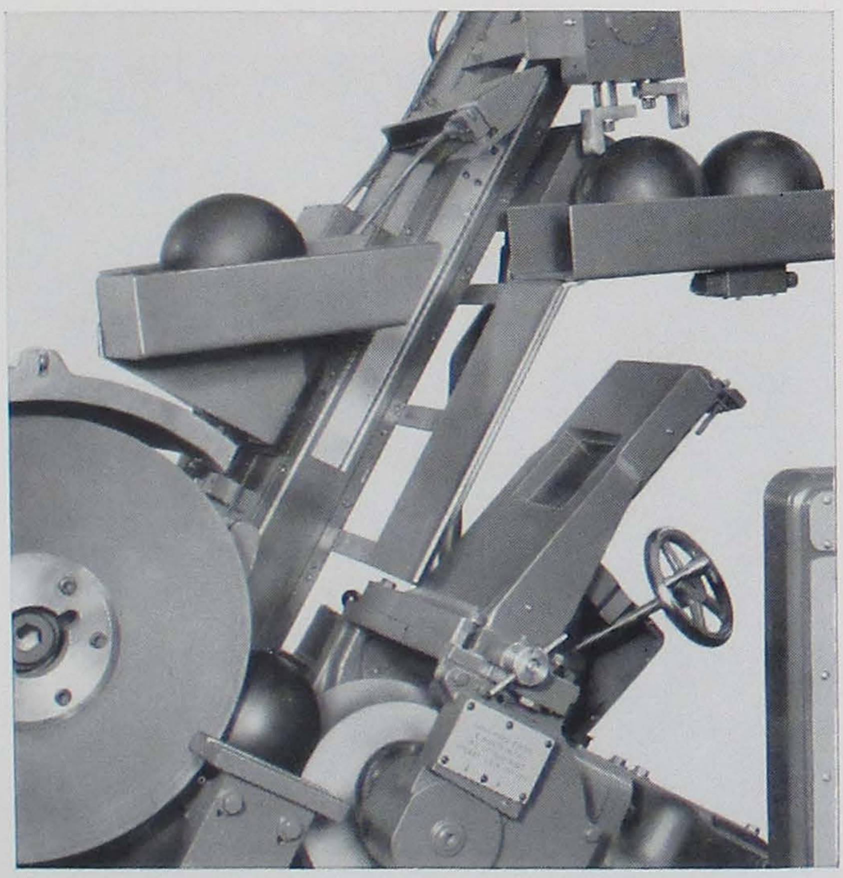


Figure 53B

Grinding bowling balls automatically on a No. 4 Centerless. The material is hard vulcanized rubber, stock removal—.040 ", size is held within .005 ", roundness .002 " and finish 25 R.M.S.

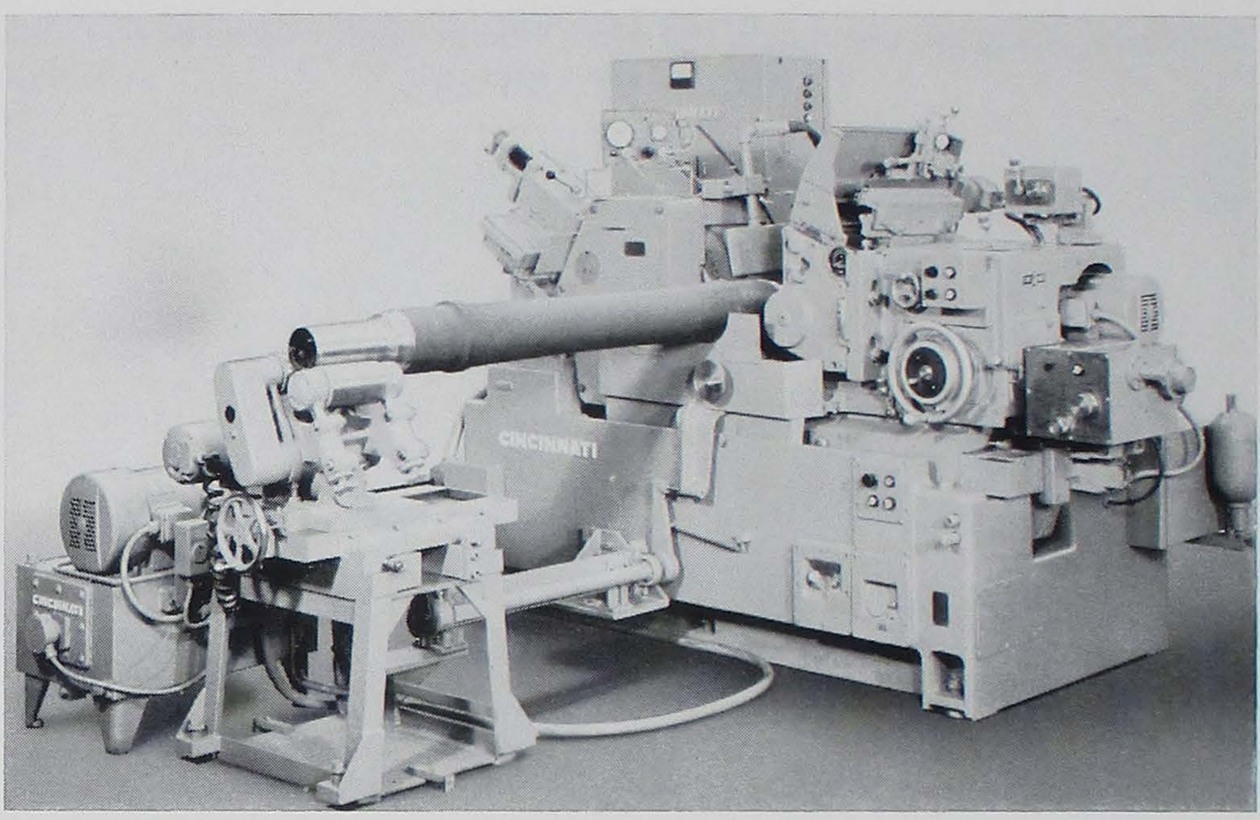


Figure 54A

Two diameters and adjacent radii ground in one operation on this steel freight car axle. The total stock removal is .015" - .025", size tolerance is .001" and roundness is maintained to within .0005". The machine is equipped with an electro-hydraulic infeed mechanism, an automatic gage sizing control unit and a motor driven outboard support.

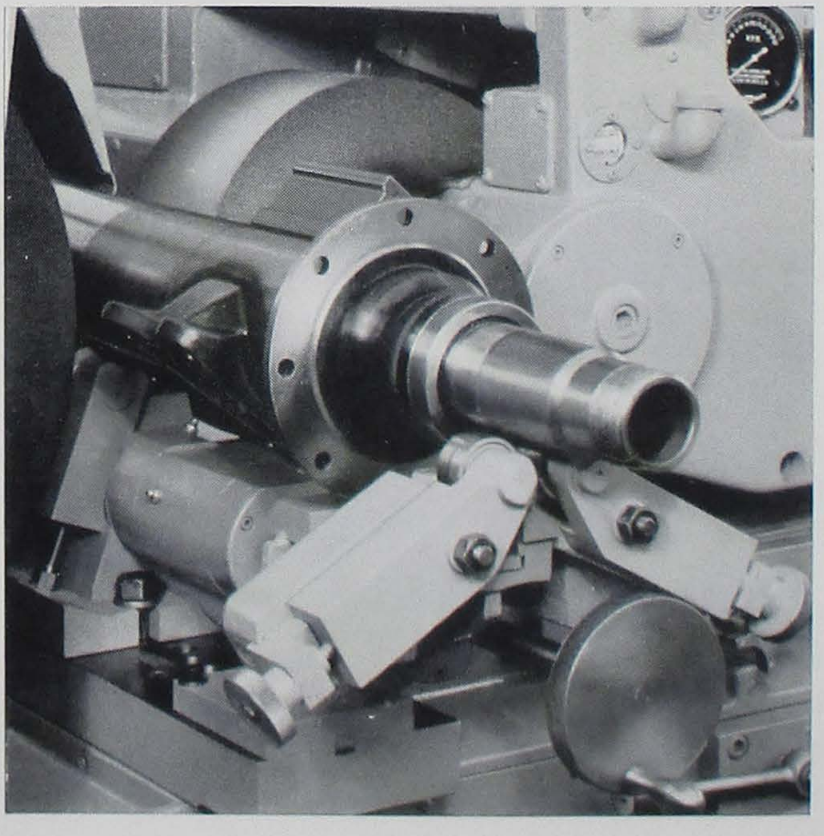


Figure 54B

This steel rear axle tube is being ground on a No. 3 Centerless with the aid of an outboard support. One diameter, a taper and the connecting radius are ground in one operation. The total stock removal is .012" - .016", size is held to within ·.002", roundness .0005" and finish 25 - 30 R.M.S.

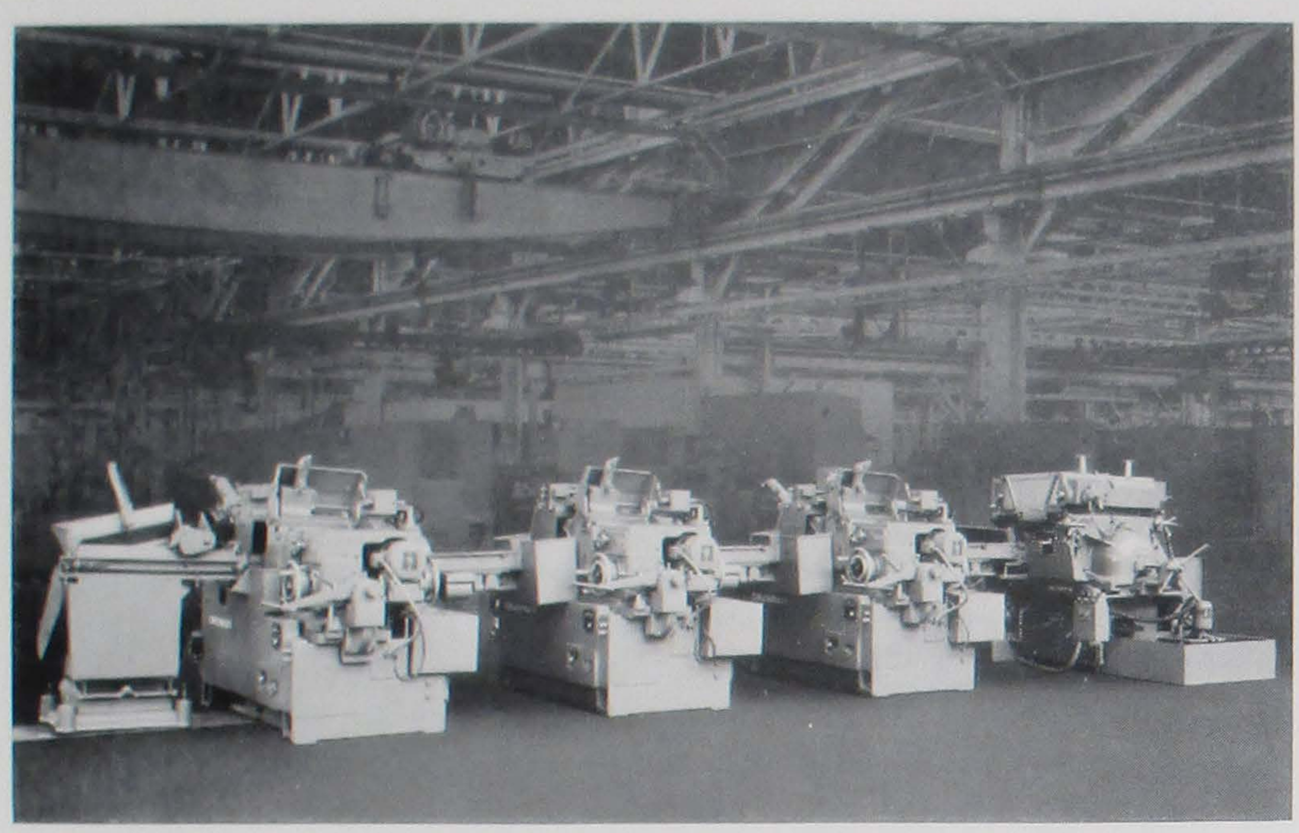
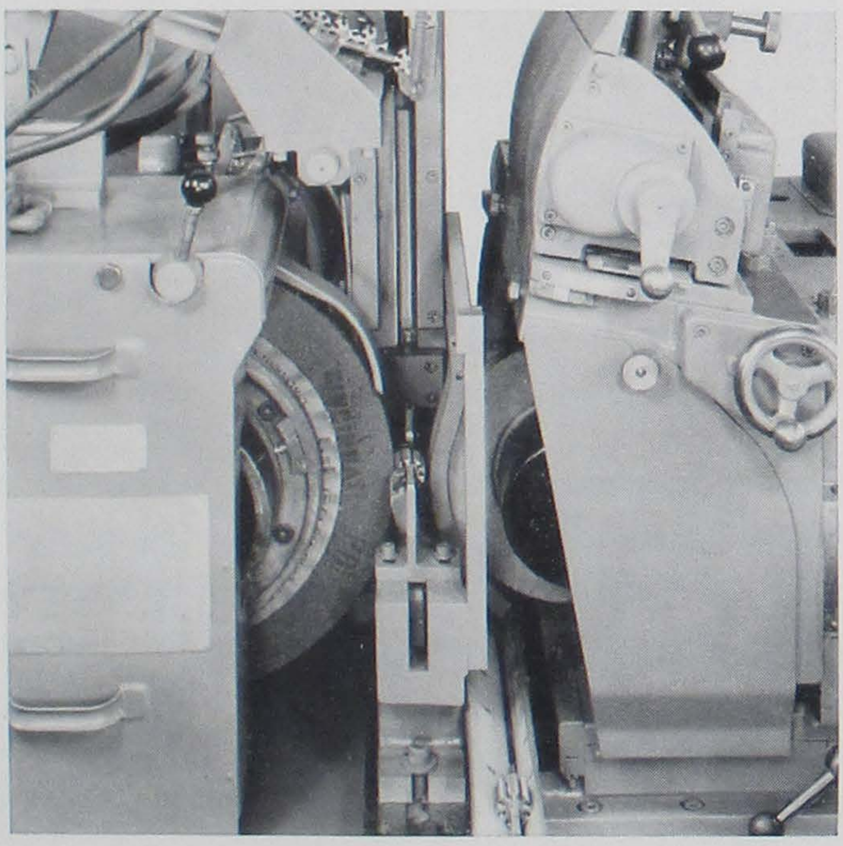


Figure 55A

A thrufeed grinding job with three No. 2 Centerless Grinders and one Centerless Lapper all connected in tandem. The 420-F stainless steel shock absorber piston shafts ground on this line are sized to ±.0001 ", straight within .0001 ", round within .0001 " with a finish of 3 - 5 R.M.S. Total stock removal is .016 " and the feed rate is 6' per minute.

Figure 55B

This No. 2 Centerless is infeed grinding the soft laminated steel center section of this motor rotor. The machine is equipped with an electro-hydraulic infeed mechanism and an overhead loading fixture. Production is 318 parts per 50 minute hour.



CHAPTER IX

TABLES FOR ESTIMATING PRODUCTION OF THRUFEED WORK

Selection of traverse rates for thrufeed work depends upon so many factors that it is not practical to compile exact tables for all the conditions which may be encountered. Perhaps the reason will be more apparent if we tabulate some of these factors; work material (including physical characteristics), stock removal, accuracy standards, blade material, type of grinding wheel, finish desired, diameter of part, weight of part, coolant available, and physical condition of machine. Practically every job must be considered on its own merits. A good practice is to keep complete job records, of the type outlined on page 60, and use it as a guide in setting up duplicate or similar jobs. A few examples are given here to provide a starting point in selecting the correct traverse rate. All of them have been checked by time studies and represent actual shop practice.

PISTON PIN

Size—7/8″ diameter x 3 1/16″ long.

Material—Hardened steel.

Stock Removal—.015″ in four roughing and two finishing cuts.

Finish—High grade commercial.

Wheel—2A—60—K6—VL.

Traverse Rate—12 feet per minute per cut.

Machine—220-8 Centerless.

STEEL ROD

Size—5/8″ diameter x 12″ long.

Material—Soft steel.

Stock Removal—.010″ to .015″, three cuts.

Finish—Commercial.

Wheel—2A—60—K6—VL.

Traverse Rate—7 feet per minute per cut.

Machine—220-8 Centerless.

CHAIN ROLLER PIN

Size—5/32″ diameter x 7/16″ long.

Material—Hardened steel.

Stock Removal—.005″ to .008″, one cut.

Finish—High grade commercial.

Wheel—2A—60—M6—VL.

Traverse Rate—7 feet per minute per cut.

Machine—220-8 Centerless.

PISTON

Size—3 3/16″ diameter x 4″ long.

Material—Cast iron.

Stock Removal—.005″, three cuts.

Finish—Good commercial.

Wheel—CC—46—M6—VP.

Traverse Rate—5 feet per minute per cut.

Machine—325-12 Centerless.

TABLE OF THRUFEED WORK TRAVERSE RATES

Inches Per Minute

The rate at which the work feeds past the grinding wheel on thrufeed jobs depends upon the diameter, speed of rotation, and angle of inclination of the regulating wheel. The following table gives the approximate theoretical work feed rates in inches per minute for all combinations of these three variables.

Reg. Wheel Angle	Reg. Wheel Diam.	Regulating Wheel Speeds, R.P.M.										
		10 r.p.m.	15 r.p.m.	20 r.p.m.	25 r.p.m.	30 r.p.m.	40 r.p.m.	50 r.p.m.	70 r.p.m.	90 r.p.m.	125 r.p.m.	160 r.p.m.
	8.0"	4.4	6.6	8.8	11.0	13.2	17.5	21.9	30.7	39.5	54.8	70.2
	8.5	4.7	7.0	9.3	11.6	14.0	18.6	23.3	32.6	41.9	58.2	74.6
	9.0	4.9	7.4	9.9	12.3	14.8	19.7	24.7	34.5	44.4	61.7	78.9
	9.5	5.2	7.8	10.4	13.0	15.6	20.8	26.0	36.5	46.9	65.1	83.3
	10.0	5.5	8.2	11.0	13.7	16.4	21.9	27.4	38.4	49.3	68.5	87.7
	10.5	5.8	8.6	11.5	14.4	17.3	23.0	28.8	40.3	51.8	72.0	92.1
1°	11.0	6.0	9.0	12.1	15.1	18.1	24.1	30.2	42.2	54.3	75.4	96.5
	11.5	6.3	9.5	12.6	15.8	18.9	25.2	31.5	44.1	56.7	78.8	100.9
	12.0	6.6	9.9	13.2	16.4	19.7	26.3	32.9	46.0	59.2	82.2	105.3
	12.5	6.9	10.3	13.7	17.1	20.5	27.4	34.2	47.9	61.6	85.6	109.7
	13.0	7.1	10.7	14.3	17.8	21.3	28.5	35.6	49.8	64.1	89.0	114.1
	13.5	7.4	11.1	14.8	18.5	22.1	29.6	36.9	51.7	66.5	92.4	118.5
	14.0	7.6	11.5	15.4	19.2	22.9	30.7	38.3	53.6	69.0	95.8	122.9
	8.0"	8.8	13.2	17.5	21.9	26.3	35.1	43.9	61.4	78.9	109.6	140.3
	8.5	9.3	14.0	18.6	23.3	28.0	37.3	46.6	65.2	83.9	116.5	149.1
	9.0	9.9	14.8	19.7	24.7	29.6	39.5	49.3	69.1	88.8	123.3	157.9
	9.5	10.4	15.6	20.8	26.0	31.2	41.7	52.1	72.9	93.7	130.2	166.7
	10.0	11.0	16.4	21.9	27.4	32.9	43.9	54.8	76.7	98.7	137.1	175.4
	10.5	11.5	17.3	23.0	28.8	34.5	46.0	57.6	80.6	103.6	143.9	184.2
2°	11.0	12.1	18.1	24.1	30.2	36.2	48.2	60.3	84.4	108.5	150.8	193.0
	11.5	12.6	18.9	25.2	31.5	37.8	50.4	63.0	88.3	113.5	157.6	201.7
	12.0	13.2	19.7	26.3	32.9	39.5	52.6	65.8	92.1	118.4	164.5	210.5
	12.5	13.7	20.5	27.4	33.2	41.1	54.8	68.5	96.0	123.4	171.3	219.2
	13.0	14.3	21.3	28.5	33.6	42.8	57.0	71.3	99.8	128.3	174.2	228.5
	13.5	14.8	22.1	29.6	33.9	44.4	59.2	74.0	103.7	133.3	177.0	236.7
	14.0	15.4	22.9	30.7	34.3	46.1	61.4	76.8	107.5	138.2	183.9	245.5
	8.0"	13.2	19.7	26.3	32.9	39.5	52.6	65.8	92.1	118.4	164.4	210.5
	8.5	14.0	21.0	28.0	34.9	41.9	55.9	69.9	97.8	125.8	174.7	223.6
	9.0	14.8	22.2	29.6	37.0	44.4	59.2	74.0	103.6	133.2	185.0	236.8
	9.5	15.6	23.4	31.2	39.1	46.9	62.5	78.1	109.3	140.6	195.3	249.9
	10.0	16.4	24.7	32.9	41.1	49.3	65.8	82.2	115.1	148.0	205.5	263.1
	10.5	17.3	25.9	34.5	43.2	51.8	69.1	86.3	120.9	155.4	215.8	276.2
3°	11.0	18.1	27.1	36.2	45.2	54.3	72.3	90.4	126.6	162.8	226.1	289.4
	11.5	18.9	28.4	37.8	47.3	56.7	75.6	94.5	132.4	170.2	236.4	302.6
	12.0	19.7	29.6	39.5	49.3	59.2	78.9	98.7	138.1	177.6	246.6	315.7
	12.5	20.5	30.9	41.1	51.4	61.6	82.2	102.8	143.9	185.0	256.9	328.8
	13.0	21.3	32.1	42.8	53.4	64.1	85.5	106.9	149.6	192.4	267.2	341.9
	13.5	22.1	33.4	44.4	55.5	66.5	88.8	111.0	155.4	199.8	277.5	355.0
	14.0	22.9	34.6	46.1	57.5	69.0	92.1	115.1	161.1	207.2	287.8	368.1

TABLE OF THRUFEED WORK TRAVERSE RATES (Continued)

Reg. Wheel Angle	Reg. Wheel Diam.	Regulating Wheel Speeds, R.P.M.										
		10 r.p.m.	15 r.p.m.	20 r.p.m.	25 r.p.m.	30 r.p.m.	40 r.p.m.	50 r.p.m.	70 r.p.m.	90 r.p.m.	125 r.p.m.	160 r.p.m.
	8.0"	17.5	26.3	35.1	43.8	52.6	70.1	87.7	122.7	157.8	219.2	280.5
	8.5	18.6	27.9	37.3	46.6	55.9	74.5	93.1	130.4	167.7	232.9	298.1
	9.0	19.7	29.6	39.4	49.3	59.2	78.9	98.6	138.1	177.5	246.6	315.6
	9.5	20.8	31.2	41.6	52.1	62.5	83.3	104.1	145.7	187.4	260.3	333.1
	10.0	21.9	32.9	43.8	54.8	65.7	87.7	109.6	153.4	197.2	273.9	350.7
	10.5	23.0	34.5	46.0	57.5	69.0	92.0	115.1	161.1	207.1	287.6	368.2
4°	11.0	24.1	36.2	48.2	60.3	72.3	96.4	120.5	168.8	217.0	301.3	385.7
	11.5	25.2	37.8	50.4	63.0	75.6	100.8	126.0	176.4	226.8	315.0	403.3
	12.0	26.3	39.4	52.6	67.7	78.9	105.2	131.5	184.1	236.7	328.7	420.8
	12.5	27.4	41.0	54.8	68.5	82.2	109.6	136.9	191.7	246.5	342.4	438.4
	13.0	28.5	42.6	57.0	71.3	85.5	114.0	142.4	199.4	256.4	356.1	456.0
	13.5	29.6	44.2	59.2	74.1	88.8	118.4	147.8	207.0	266.2	369.8	473.6
	14.0	30.7	45.8	61.4	76.9	92.1	122.8	153.3	214.7	276.1	383.5	491.2
	8.0"	21.9	32.9	43.8	54.8	65.7	87.6	109.5	153.3	197.2	273.8	350.5
	8.5	23.3	34.9	46.5	58.2	69.8	93.1	116.4	162.9	209.5	290.9	372.4
	9.0	24.6	37.0	49.3	61.6	73.9	98.6	123.2	172.5	221.8	308.0	394.3
	9.5	26.0	39.0	52.0	65.0	78.0	104.1	130.1	182.1	234.1	325.2	416.2
	10.0	27.4	41.1	54.8	68.5	82.1	109.5	136.9	191.7	246.4	342.3	438.1
	10.5	28.8	43.1	57.5	71.9	86.3	115.0	143.8	201.3	258.8	359.4	460.0
5°	11.0	30.1	45.2	60.2	75.3	90.4	120.5	150.6	210.8	271.1	376.5	481.9
	11.5	31.5	47.2	63.0	78.7	94.5	126.0	157.4	220.4	283.4	393.6	503.8
	12.0	32.9	49.3	65.7	82.1	98.6	131.4	164.3	230.0	295.7	410.7	525.7
	12.5	34.3	51.3	68.5	85.5	102.7	136.9	171.2	239.6	308.0	427.8	547.6
	13.0	35.7	53.4	71.2	88.9	106.8	142.4	178.1	249.2	320.3	444.9	569.5
	13.5	37.1	55.4	74.0	92.3	110.9	147.9	185.0	258.8	332.6	462.0	591.4
	14.0	38.5	57.5	76.7	95.7	115.0	153.4	191.9	268.4	344.9	479.1	613.3
	8.0"	26.3	39.4	52.5	65.7	78.8	105.1	131.4	183.9	236.4	328.4	420.3
	8.5	27.9	41.9	55.8	69.8	83.7	111.7	139.6	195.4	251.2	348.9	446.6
	9.0	29.6	44.3	59.1	73.9	88.7	118.2	147.8	206.9	266.0	369.4	472.9
	9.5	31.2	46.8	62.4	78.0	93.6	124.8	156.0	218.4	280.8	390.0	499.2
	10.0	32.8	49.3	65.7	82.1	98.5	131.4	164.2	229.9	295.6	410.5	525.4
	10.5	34.5	51.7	69.0	86.2	103.4	137.9	172.4	241.4	310.3	431.0	551.7
6°	11.0	36.1	54.2	72.2	90.3	108.4	144.5	180.6	252.9	325.1	451.5	578.0
	11.5	37.8	56.6	75.5	94.4	113.3	151.1	188.8	264.4	339.9	472.1	604.2
	12.0	39.4	59.1	78.8	98.5	118.2	157.6	197.0	275.8	354.7	492.6	630.5
	12.5	41.0	61.6	82.1	102.6	123.1	164.3	205.2	287.4	369.5	513.1	656.8
	13.0	42.6	64.1	85.4	106.7	128.0	170.9	213.4	298.9	384.3	533.6	683.1
	13.5	44.2	66.6	88.7	110.8	132.9	177.5	221.6	310.4	399.1	554.1	709.4
	14.0	45.8	69.1	92.0	114.9	137.8	184.1	229.8	321.9	413.9	574.6	735.7
	8.0"	30.6	45.9	61.3	76.6	91.9	122.5	153.1	214.4	275.7	382.9	490.1
	8.5	32.5	48.8	65.1	81.4	97.6	130.2	162.7	227.8	292.9	406.8	520.7
	9.0	34.5	51.7	68.9	86.1	103.4	137.8	172.3	241.2	310.1	430.7	551.3
	9.5	36.4	54.6	72.7	90.9	109.1	145.5	181.9	254.6	327.4	454.7	582.0
	10.0	38.3	57.4	76.6	95.7	114.9	153.1	191.4	268.0	344.6	478.6	612.6
	10.5	40.2	60.3	80.4	100.5	120.6	160.8	201.0	281.4	361.8	502.5	643.2
7°	11.0	42.1	63.2	84.2	105.3	126.3	168.5	210.6	294.8	379.0	526.4	673.8
	11.5	44.0	66.0	88.1	110.1	132.1	176.1	220.1	308.2	396.3	550.4	704.5
	12.0	45.9	68.9	91.9	114.9	137.8	183.8	229.7	321.6	413.5	574.3	735.1
	12.5	47.8	71.8	95.7	119.7	143.5	191.5	239.3	335.0	430.7	598.2	765.7
	13.0	49.7	74.7	99.5	124.5	149.2	199.2	248.9	348.4	447.9	622.1	796.3
	13.5	51.6	77.6	103.3	129.3	154.9	206.9	258.5	361.8	465.1	646.0	826.9
	14.0	53.5	80.5	107.1	134.1	160.6	214.6	268.1	375.2	482.3	669.9	857.5

TABLE OF THRUFEED WORK TRAVERSE RATES (Concluded)

Reg. Wheel Angle	Reg. Wheel Diam.	Regulating Wheel Speeds, R.P.M.										
		10 r.p.m.	15 r.p.m.	20 r.p.m.	25 r.p.m.	30 r.p.m.	40 r.p.m.	50 r.p.m.	70 r.p.m.	90 r. p.m.	125 r.p.m.	160 r.p.m.
	8.0 "	35.0	52.5	70.0	87.4	104.9	139.9	174.9	244.8	314.8	437.2	559.6
	8.5	37.2	55.7	74.3	92.9	111.5	148.7	185.8	260.1	334.5	464.5	594.6
	9.0	39.3	59.0	78.7	98.4	118.0	157.4	196.7	275.4	354.1	491.9	629.6
	9.5	41.5	62.3	83.1	103.8	124.6	166.1	207.7	290.7	373.8	519.2	664.6
	10.0	43.7	65.6	87.4	109.3	131.2	174.9	218.6	306.1	393.5	546.5	699.5
	10.5	45.9	68.9	91.8	114.8	137.7	183.6	229.5	321.4	413.2	573.8	734.5
8°	11.0	48.1	72.1	96.2	120.2	144.3	192.4	240.5	336.7	432.8	601.2	769.5
	11.5	50.3	75.4	100.6	125.7	150.8	201.1	251.4	352.0	452.5	628.5	804.5
	12.0	52.5	78.7	104.9	131.2	157.4	209.9	262.3	367.3	472.2	655.8	839.5
	12.5	54.7	82.0	109.3	136.7	164.0	218.6	273.2	382.6	491.9	683.1	874.5
	13.0	56.9	85.3	113.6	142.2	170.6	227.4	284.1	397.9	511.6	710.4	909.5
	13.5	59.1	88.6	118.0	147.7	177.2	236.1	295.0	413.2	531.3	737.7	944.5
	14.0	61.3	91.9	122.3	153.2	183.8	244.9	305.9	428.5	551.0	765.0	979.5

NOTES ON SETUP DATA

Part Number	Material	Stock Removal	Number of Cuts	Grinding Wheel	Regulating Wheel		Blade		Height Above Center
					Speed	Angle	Material	Angle	

NOTES ON SETUP DATA

Part Number	Material	Stock Removal	Number of Cuts	Grinding Wheel	Regulating Wheel		Blade		Height Above Center
					Speed	Angle	Material	Angle	

MEMORANDUM

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PRODUCTS OF THE GRINDING MACHINE DIVISION

Grinding Machines

Plain

Universal

Angular Wheel Slide

Roll, Traveling Table

Roll, Traveling Wheelhead

Centerless

Centerless Lapping

Micro-Centric

Chucking

Accessories

Special Machines

Automotive Piston Relief

Automotive Valve Seat and Stem

Machines for Aircraft Jet Engine Components

Precision Machines for Guided Missile Components

Heavy Duty Centerless Bar Grinding

Multiple Wheelhead

Automation Systems through Several Machines for Multiple Operations

Numerically Controlled

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