CHAPTER 9

The Index Head and Indexing Operations

Indexing may be defined as the process of causing the work to be moved any desired amount on its axis.

In the construction of modern machines, there are many parts that are round or circular in shape and that have slots, teeth, or spaces cut across their peripheral faces. A common example is the spur gear, or the roller chain sprocket. The basic requirement of such machine parts is that the distance from one slot, tooth, or space to the next is the precise amount required for its functioning. Each tooth of a gear or sprocket is the same size and shape as its neighbor and they are spaced exactly the same distance apart. This exact spacing is accomplished by means of a machine operation called *indexing.* Many methods of indexing are in use in modern machine manufacture. Mass production of machine parts requires the service of quick indexing attachments to speed job operations. In order to make this possible, indexing mechanisms are developed for the machining of single parts. None of them can be used for any other part that is of different shape or that is divided into a different number of parts (see Fig. 9-1).

Index Head. The attachment called the *index head* was originally developed for use on the milling machine. Its use has been extended to cover shaping and planing operations. The index head, or as it is commonly called by machinists, the *dividing head,* is nearly always used in conjunction with a *footstock,* often called a *tailstock.* Together they are known as *index centers.*

Of the several types of index centers, the simplest is called the *plain index head* (Fig. 9-2). The plain, or direct, index head is used for work of average accuracy. The index crank is connected directly to the headstock spindle and the crank and the spindle rotate as a

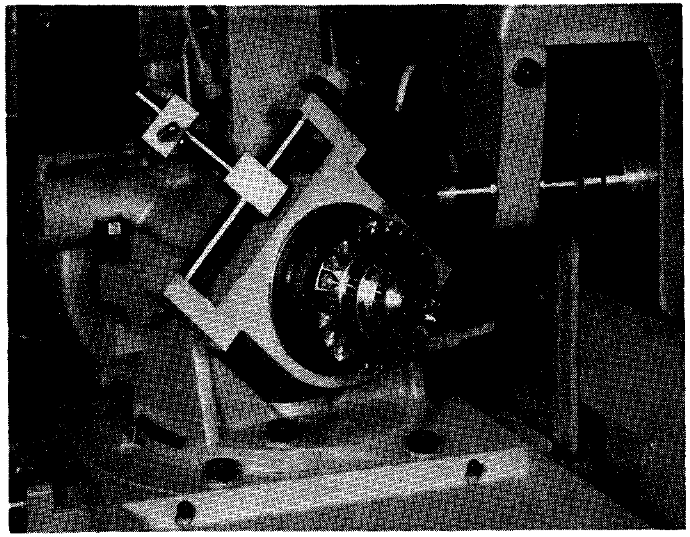


Fig. 9-1. Indexing fixture for the machining of rock-bit drill head used in the drilling of oil wells. (*The Cincinnati Milling Machine Company*)

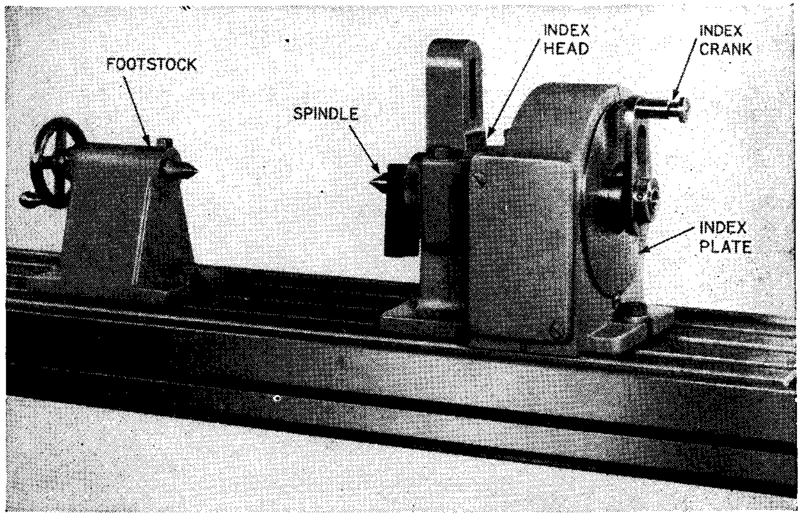


Fig. 9-2. The plain or direct index head, sometimes used when handling a large amount of work which requires indexing on jobs where great accuracy is unnecessary. (*The Cincinnati Milling Machine Company*)

unit. This is known as *direct indexing*, and the number of divisions will be limited to the number of holes in the index plate; the maximum number possible is 50.

Gear-cutting Attachment (Fig. 9-3). The gear-cutting attachment is used for spur-gear cutting and similar work requiring a higher degree of accuracy and numbers above 50. Indexing on this type of index head is accomplished through a worm and a worm gear having a 40 to 1 ratio (to be described in a later section). All numbers

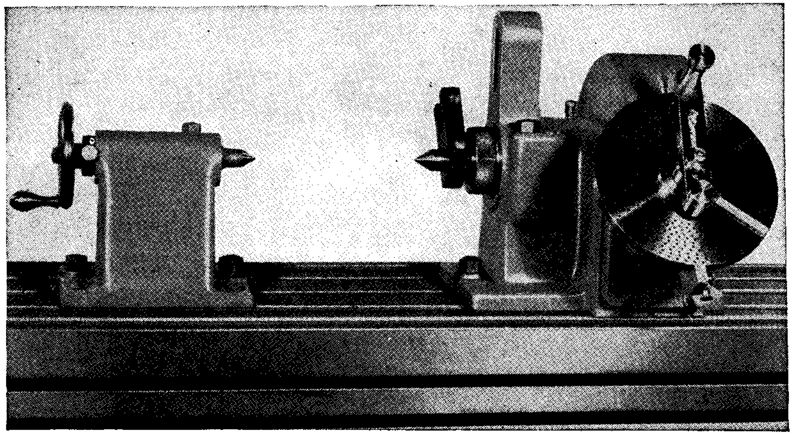


Fig. 9-3. The gear-cutting attachment is used for spur-gear cutting and similar work. (*The Cincinnati Milling Machine Company*)

up to and including 60, and all even numbers and those divisible by 5 from 60 to 120 can be indexed with this attachment.

Spiral Milling Head (Fig. 9-4). This attachment is similar in all particulars to the gear-cutting attachment, except for the addition of the driving bracket by which the headstock is connected, by gearing, to the lead screw of the milling machine. This arrangement makes it possible to cut helical gears, flutes in drills and milling cutters.

Universal Spiral Index Head (Fig. 9-5). This head is the one most likely to be found in the majority of machine shops. As its name implies, this type of index head can be used to execute all forms of indexing. It is not only versatile but accurate. Work can be supported between centers or held in a chuck. It is possible, through

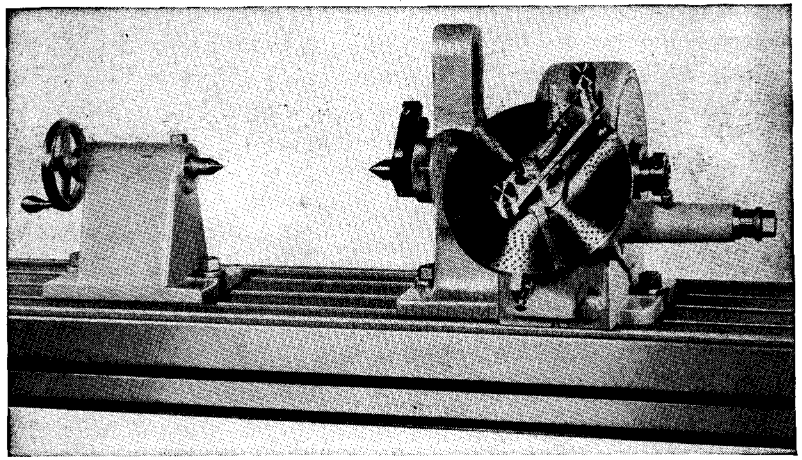


Fig. 9-4. The spiral-milling head. (*The Cincinnati Milling Machine Company*)

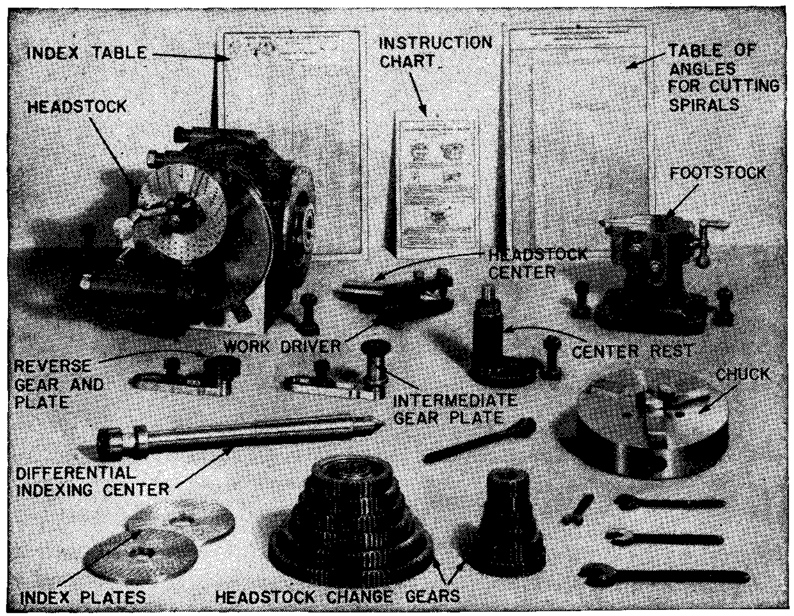


Fig. 9-5. The universal spiral-index centers with full equipment. (*The Brown & Sharpe Manufacturing Company*)

a train of selected gears, to index and rotate work in conjunction with the movement of the table.

The practice of several manufacturers is to arrange the index centers on the milling-machine table with the head at the left (Fig.

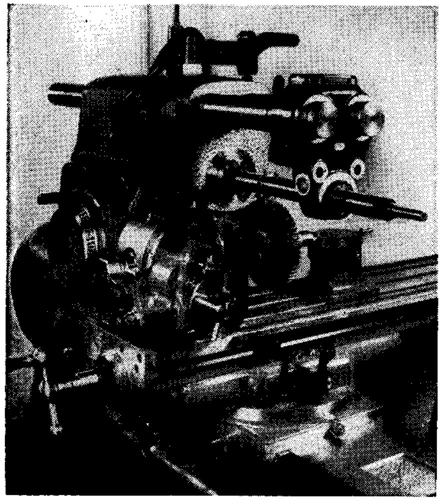


Fig. 9-6. The Brown & Sharpe index centers. The head is on the left end of the table. (*The Brown & Sharpe Manufacturing Company*)

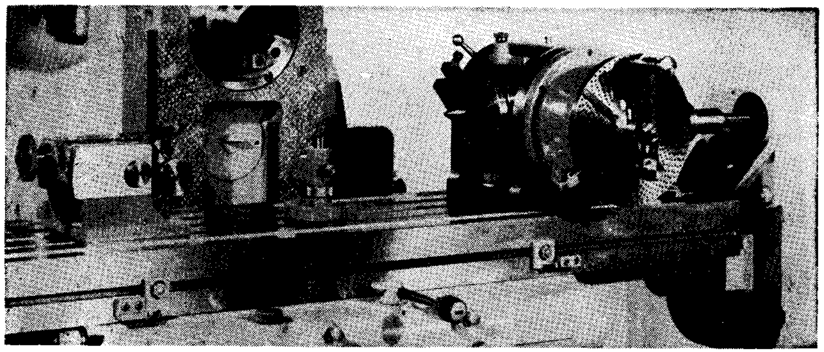


Fig. 9-7. The Cincinnati index centers. The head is on the right end of the table. (*The Cincinnati Milling Machine Company*)

9-6), while other manufacturers design the head to be used at the right end of the table (Fig. 9-7).

Headstock. Although there are differences in the design and construction of index heads, the principle of their operation is basically

the same. The headstock (Figs. 9-8 and 9-9) contains the work spindle and the mechanism for obtaining a rotary movement of the spindle when required.

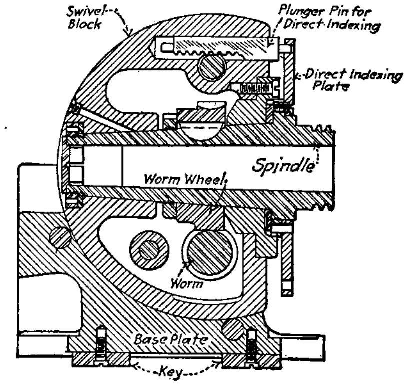


Fig. 9-8. The vertical section of a Brown & Sharpe index head.

The *work spindle* is provided with a taper hole to receive the live center or the taper shank of other tools, special arbors, or work-holding tools. The nose of the spindle is threaded to hold a chuck. The spindle has a large bearing surface accurately fitted and, in addition, a clamping device to give greater accuracy and rigidity under a heavy cut. The spindle is carried in the *swiveling block*, which is arranged between housings cast as an integral part of the base plate. The swiveling block is constructed so that it may be tilted until the spindle is in any desired position,

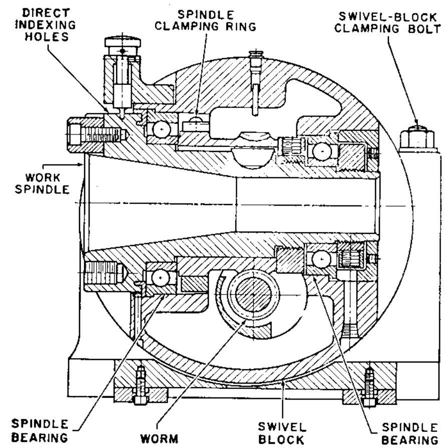


Fig. 9-9. The vertical section of a Cincinnati index head. (*The Cincinnati Milling Machine Company*)

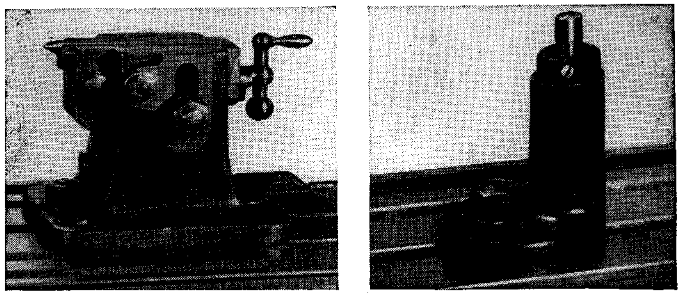
from 5 deg. below the horizontal to 10 deg. beyond the perpendicular, and then be clamped rigidly to the base.

Graduations on the side of the head indicate the angle of elevation to half degrees. The alignment of the head with the table longitudinally is provided by means of two aligning tongues on the underside of the base plate, which fit a T slot in the table.

Descriptions of other parts of the index head are given when the mechanical functions are discussed.

Footstock (Fig. 9-10*a*). The footstock is used for supporting the outer end of pieces being milled. Primarily, it is for work held on centers, but it is also used to support the end of work held in a chuck.

The footstock center may be adjusted longitudinally and, in addition, the block which holds the center and its adjusting screw may be moved vertically. It can also be tilted out of parallel with



a *b*

Fig. 9-10. The footstock, *a*; the adjustable center rest, *b*. (*The Brown & Sharpe Manufacturing Company*)

the base, in order that it can be kept in alignment with the headstock center when the head is tilted for milling tapered work.

The adjustable center rest (Fig. 9-10*b*) is included with the universal spiral-index centers and is used to support long, slender work held between centers. It is adjustable and can be locked in position.

Methods of Indexing. The primary purpose of the mechanism of the index head is the exact division of a circle, or a part of a circle, into a specified number of parts. It is also possible to index for angular distances.

There are several methods of indexing, namely, *direct*, *simple*, *compound*, and *differential*. Of these methods, the direct and the simple are those most commonly in use. Compound indexing, which was extensively used in the past, is now almost obsolete, mainly

because of the chances for error and the inaccuracies resulting from its use. Differential indexing gives accurate results; but it is not in common use because of the longer time required for setup. In certain instances this method offers the only solution for indexing numbers beyond the range of simple indexing.

Direct Indexing. To accomplish direct indexing, it is necessary to remove the plunger pin at the back of the direct-indexing plate

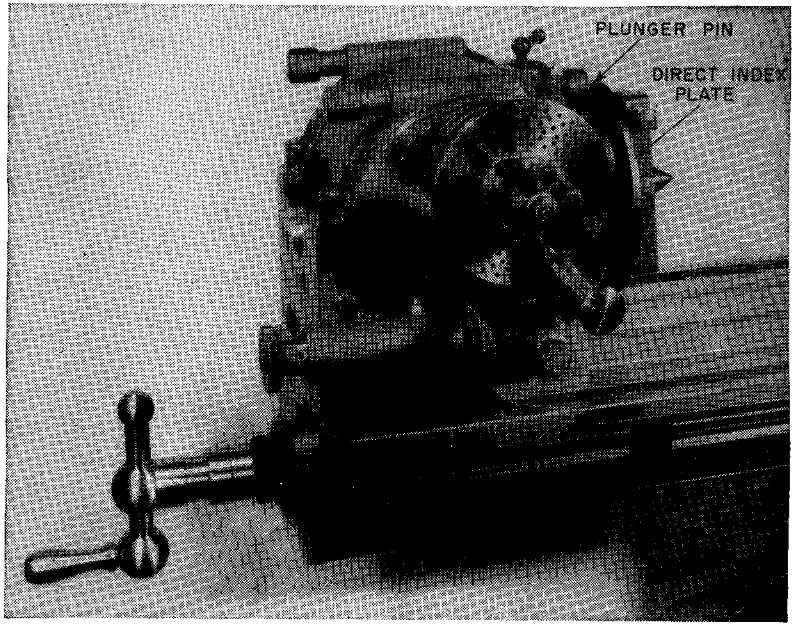


Fig. 9-11. The Brown & Sharpe index head showing the plunger pin and the direct-index plate. (*The Brown & Sharpe Manufacturing Company*)

(Fig. 9-11). The construction of the universal index head permits disengaging the worm from the worm wheel. This is accomplished by turning, through part of a revolution, a knob or handle that operates an eccentric bushing or pin (Figs. 9-12 and 9-13).

Direct indexing (often called *rapid indexing*) is accomplished after the worm is lowered from the worm gear. The spindle can then be turned freely and the distance measured by the number of holes on the direct-index plate passing the plunger pin. The direct-index plate is to be found behind the threaded end of the spindle on a Brown & Sharpe index head. Near its outer edge it has 24 equally spaced holes, into which the plunger pin can be inserted (Fig. 9-11).

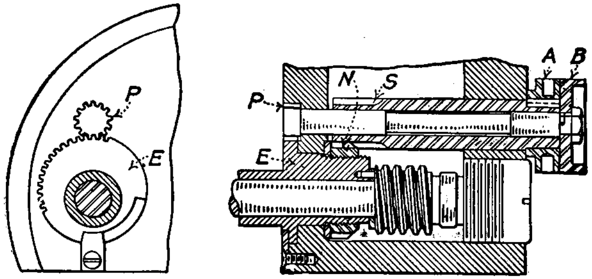


Fig. 9-12. Portion of *horizontal* section of a Brown & Sharpe index head. To lower the worm out of mesh with the worm wheel, *first disengage stop pin from index plate*, then turn knob A about one-quarter revolution in the *reverse* direction to that indicated by an arrow on A. This will loosen nut N, which clamps eccentric bushing E. (*Note:* The sleeve S and the nut N are provided with gear teeth.) After N is loosened, turn both knobs A and B; this will turn the pinion P and revolve the eccentric bushing E, which lowers the worm.

The plunger pin holds the plate in position. When the plate is turned by hand through the required part of a revolution, the index spindle and the work also turn, the same part of a revolution.

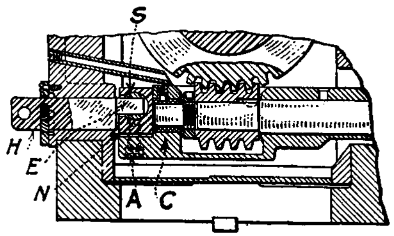


Fig. 9-13. Portion of *vertical* section of a Cincinnati index head. The worm is lowered out of mesh with the worm wheel by moving the handle H one-half turn. This operates eccentric E, which is journaled crosswise in the cylindrical sliding piece S carried in the holder N. The worm carrier C is fastened to N (by two screws A). Consequently, when the slide holder N is raised or lowered, the worm casing and the worm are raised or lowered.

Direct indexing is used to advantage for the milling of squares, hexagons, and fluting taps. Any number of divisions that is a factor of 24 may be quickly indexed, as 2, 3, 4, 6, 8, 12, and 24.

The latest models of Cincinnati dividing heads make use of a 24-hole circle for direct indexing. Previous models were fitted with a plate having three circles of holes, 24, 30, and 36.

The 24-hole circle will divide into 2, 3, 4, 6, 8, 12, 24 equal parts.
The 30-hole circle will divide into 2, 3, 5, 6, 10, 15, 30 equal parts.
The 36-hole circle will divide into 2, 3, 4, 6, 9, 12, 18, 36 equal parts.

To find the correct movement of the direct indexing plate, divide the number of divisions required into the number of holes on the circle being used.

EXAMPLE: Determine the indexing movement required to mill a hexagon through a 24-hole rapid indexing circle or plate.

SOLUTION:

1. Formula to be used is $\frac{24}{N}$.
2. Substitute 6 for N in formula: $24/6$
3. Spaces required for job equals $24/6$ or 4.
4. When cutting a hexagon, put plunger pin in every *fourth* hole on direct-indexing plate using the 24-hole circle. This will give an accurate hexagon.

Simple Indexing. Simple indexing, also called *plain indexing*, is accomplished by means of a mechanism (Fig. 9-14) which consists essentially of a 40-tooth worm wheel fastened to the index-head spindle, a single-threaded worm, a crank for turning the worm shaft and an index plate. Since there are 40 teeth in the worm wheel, one complete turn of the index crank will cause the worm wheel to make $1/40$ of a turn or, in other words, 40 *turns of the index crank revolves the spindle one full turn.*

If it is required to cut 8 equally spaced teeth on a reamer and 40 turns of the index crank makes one full revolution of the work, then $40/8$ or 5 turns of the index crank after each cut will space the circumference of the reamer for exactly 8 teeth. If it is required to equally space for 10 cuts, then $40/10$ or 4 turns of the index crank for each cut will give the desired result.

Note that in the examples given above, the answer in each case was a *whole number*. There are many cases in which a whole number is impossible as an indexing result. For example, let it be required to index for 6 equal spaces; then $^{40}/_{6}$ equals $6\frac{2}{3}$ turns. If 14 equal

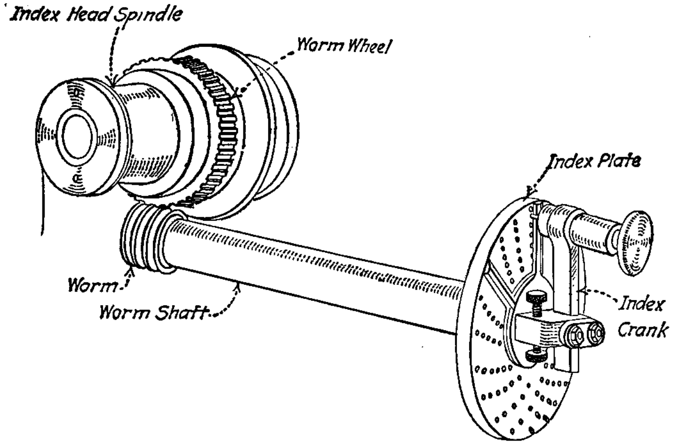


Fig. 9-14. Simple indexing mechanism.

spaces are required, then $^{40}/_{14}$ equals $2\frac{6}{7}$ turns. In these examples, the answer was a mixed number.

RULE FOR CALCULATING THE NUMBER OF TURNS OF THE INDEX CRANK

> To obtain the number of turns (whole or fractional) of the index crank for one division of any desired number of equal divisions on the work, divide the number of turns for one revolution of the spindle (usually 40) by the number of equal divisions desired.

The formula to find the number of turns is

$$T = \frac{40}{N}$$

where T = number of turns or parts of a turn and N = number of divisions required.

EXAMPLE 1: Index for 5 divisions.

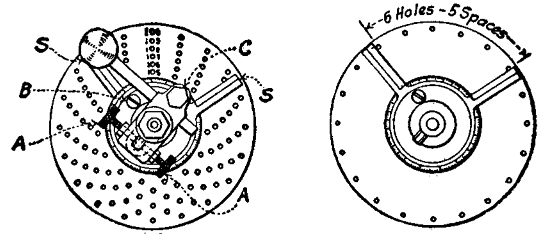
SOLUTION: Using the formula above and substituting 5 for N, we get $^{40}/_{5}$ or 8 turns.

EXAMPLE 2: Index for 7 divisions.

SOLUTION: Using the above formula and substituting 7 for N, we get $^{40}/_{7}$ or $5\frac{5}{7}$ turns.

EXAMPLE 3: Index for 48 divisions.

SOLUTION: Using the above formula and substituting 48 for N, we get $^{40}/_{48}$ or $\frac{5}{6}$ turn.



a b

Fig. 9-15. Index plate and sector.

INDEX PLATE AND SECTOR. The fractional parts of a turn involve the use of an index plate and a sector. Referring to Fig. 9-14, it will be observed that the index pin at the end of the index handle enters a hole in the index plate. If only full turns were used in indexing, one hole only would be necessary; if only turns and half turns were required, two holes in opposite sides of the plate would answer; but a great number of different fractional parts of a turn are required for different spacings, and in order to measure them accurately and easily, the index plates and the sector are provided.

The *index plate* (Fig. 9-15) is a circular plate, arranged in front of the index handle, provided with a series of six or more circles of equally spaced holes.

The Brown & Sharpe Manufacturing Company regularly furnish index plates with circles of holes as follows:

Plate 1	15–16–17–18–19–20
Plate 2	21–23–27–29–31–33
Plate 3	37–39–41–43–47–49

For divisions which cannot be obtained with any of these circles differential indexing is used.

The Cincinnati Milling Machine Company regularly furnishes one plate drilled on both sides which has circles of holes as follows:

First side——24–25–28–30–34–37–38–39–41–42–43
Second side—46–47–49–51–53–54–57–58–59–62–66

This company furnishes as an "attachment," three plates drilled on both sides with holes as follows:

Plate	*A*	30–48–69–91–99–117–129–147–171–177–189
	B	36–67–81–97–111–127–141–157–169–183–199
Plate	*C*	34–46–79–93–109–123–139–153–167–181–197
	D	32–44–77–89–107–121–137–151–163–179–193
Plate	*E*	26–42–73–87–103–119–133–149–161–175–191
	F	28–38–71–83–101–113–131–143–159–173–187

The method of numbering the circles of holes in the index plates has been set by The Brown & Sharpe Manufacturing Company and the Cincinnati Milling Machine Company. Other manufacturers of index heads conform to one standard or the other.

The Kearney & Trecker Corporation conforms to the Brown & Sharpe method, while The LeBlond Machine Company's indexing attachment has almost the same circles as the Cincinnati.

With the index plates regularly furnished it is possible to obtain the spacings ordinarily used for gears, clutches, milling cutters, etc. Two examples will illustrate:

EXAMPLE 1: To mill a hexagon.

SOLUTION: Using the rule: $40/6 = 6\frac{2}{3}$ turns, or six full turns and two-thirds of a turn on any circle divisible by 3: for instance, 12 spaces on the 18 circle or 26 spaces on the 39 circle.

EXAMPLE 2: To cut a gear of 42 teeth.

SOLUTION: $40/42$ or $20/21$ turns, that is, 40 spaces on the 42 circle (Cincinnati) or 20 spaces on the 21 circle (Brown & Sharpe).

Referring to Fig. 9-15, the index crank is adjustable radially (first loosen screw *C*), so that the index pin may be used in any of the circles of holes in the plate. The index pin is held in the hole by a spring contained in the handle and when the pin is pulled against the force of the spring, out of the hole, the crank may be moved.

The *sector* (Fig. 9-15) consists of two radial arms *S*, so constructed that the angle included between them may be changed (first loosening the binding screw *B*). The use of the sector obviates the necessity of counting the holes, at each cut, for the fractional part of a turn, and in addition to saving time makes for accuracy. Select a circle divisible by the denominator of the required fraction of a turn (reduced to lowest terms) and bring the beveled edges of the arms of the sector to include the fractional part of the circle desired. In counting the holes in the plate when adjusting the sector *remember it is really the number of spaces between the holes that gives the desired fractional part of the whole circle.* Consider the hole the pin is in as zero. An example is illustrated in *b*, Fig. 9-15.

When the spindle is not clamped, the index handle should turn easily.

The sector is under spring tension so that it will remain set. It should, however, be easy to move to the next setting. Move the sector *immediately* after indexing, then it will always be in position for the next indexing operation.

The number of spaces on the index circle indicating the fractional part of a turn should be included between the *beveled* edges of the sector arms.

Form the habit of turning the *index handle to the right*, to avoid confusion. Stop between the last two holes and, gently rapping the handle, allow the pin to snap into place. If the handle is turned too far, turn it back far enough to *take up the lost motion* before allowing the pin to snap into place.

Sometimes after the work has been exactly adjusted—to a cut already made, for example—the index pin will come between two holes in the plate, and merely moving the pin to enter either hole will move the work a trifle, perhaps enough to spoil the cut. A means of allowing the pin to enter the nearest hole, *without moving the work at all*, is provided in the Brown & Sharpe machine by adjusting the screws *A* (Fig. 9-15); and in the Cincinnati machine, the index-plate lock is loosened, and the plate moved until one of the holes comes to the pin.

The worm and worm wheel and the spindle are so arranged within the swivel block as to permit of indexing in any position within the angular range, and this feature of the head is used for cutting clutches, end teeth on cutters, and many other jobs.

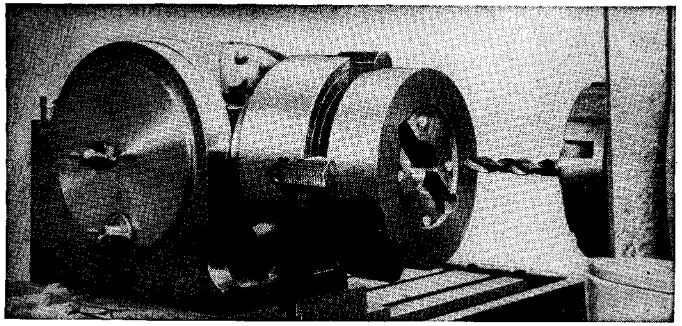


Fig. 9-16. Using the index head to locate holes at specified angles. (*The Cincinnati Milling Machine Company*)

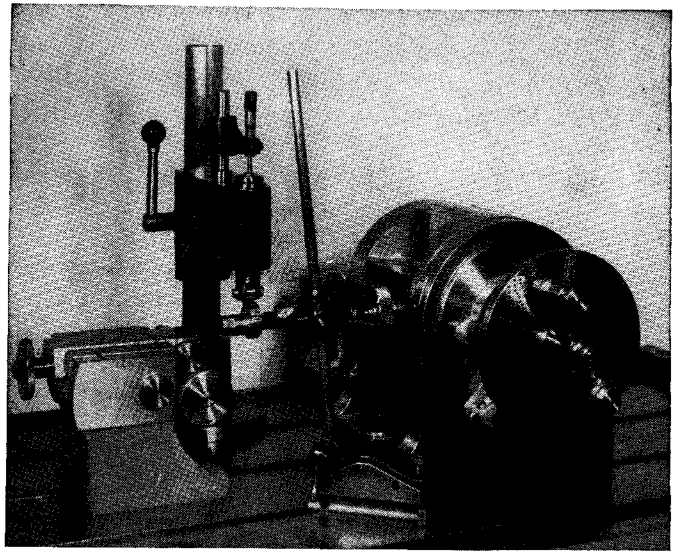


Fig. 9-17. The Index head being used to inspect a camshaft. (*The Cincinnati Milling Machine Company*)

Angular Indexing, or Indexing in Degrees. Simple indexing can be used also for moving the spindle a specified number of degrees. This permits surfaces to be milled, or holes to be drilled, a required number of degrees from each other (Fig. 9-16). It also makes the index head suitable for use on the inspection table (Fig. 9-17).

There are 360 deg. in a circle and, since the index crank must turn 40 times to revolve the spindle one complete revolution, it can be seen that 40 turns of the index crank will turn the spindle exactly 360 deg. One turn of the index crank will revolve the spindle $1/40$ of 360, or 9 deg. Consequently, one-ninth of one turn of the crank will rotate the spindle 1 deg.

In order to determine the number of turns, or a part of a turn, of the crank required to index for an angle given in degrees, it is necessary to divide the number of degrees movement required by 9.

EXAMPLE: Index for 72 degrees.

SOLUTION: Divide 72 by 9 and the answer is 8 turns.

Simple indexing can also be used to index fractional parts of a degree. Using the B&S dividing head, it is possible to index $1/3$, $2/3$, and $1/2$ of a degree if the 27-hole circle is used for the $1/3$ and $2/3$ of a degree. The 18-hole circle is used to index the $1/2$ deg.

To index $1/3$, $2/3$, and $1/2$ deg., it is necessary to use a circle of holes divisible by 9.

EXAMPLE 1: Index for $5\frac{1}{2}$ deg.

SOLUTION: $\frac{5\frac{1}{2}}{9} \times \frac{2}{2} = \frac{11}{18}$

The fraction $11/18$ means that 11 holes on the 18-hole circle must be used.

EXAMPLE 2: Index for $6\frac{2}{3}$ degrees.

SOLUTION: $\frac{6\frac{2}{3}}{9} \times \frac{3}{3} = \frac{20}{27}$

The fraction $20/27$ means that 20 holes on the 27-hole circle must be used.

The 54-hole circle on the standard plate provided by the Cincinnati indexing attachment permits the indexing of $1/3$, $2/3$, $1/2$, and $1/6$ of a degree. For smaller divisions than $1/3$ deg. on a B&S index head, the method of differential indexing must be used. For smaller than $1/6$ deg. on the Cincinnati, one of the extra plates may be used (Fig. 9-18*a*).

Approximate Indexing in Minutes. If it is required to index angles given in minutes and if some tolerance is allowed, the index crank movement and the correct index plate can be determined as follows: If one turn of the index crank revolves the spindle 9 deg., then 9 multiplied by 60 will equal the number of *minutes* obtained with one turn of the index crank ($9 \times 60 = 540$ min.). This number, 540, divided by the number of minutes required will give the circle of holes on the index plate on which the index pin should be moved one hole. This one-hole movement of the crank on this given circle of holes will result in the required number of minutes.

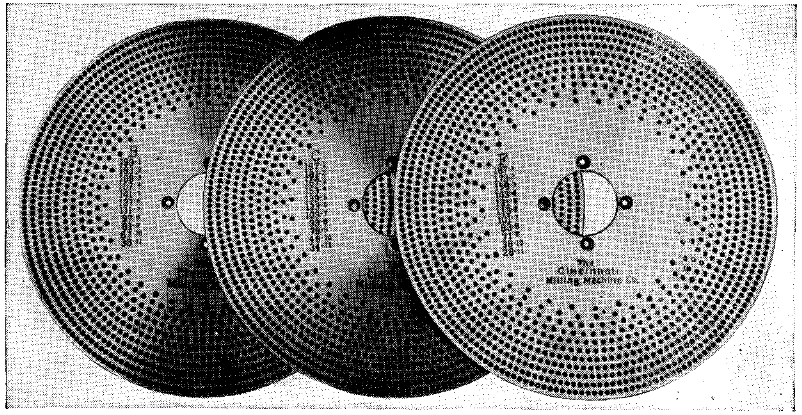


Fig. 9-18*a*. High-number indexing plates, drilled on both sides, giving a wider range of indexing. (*The Cincinnati Milling Machine Company*)

This method can be used only for approximate angles, since the resultant number may be one for which no index plate is available. However, if the number is nearly equal to a circle of holes in an index plate, that circle can be used with a slight error resulting.

EXAMPLE: Index for 24 min.

SOLUTION: $540/24 = 22.5$

There is no 22.5 circle of holes on the index plate, but a 23-hole circle could be used.

Brown & Sharpe have simplified the accurate indexing of angles in degrees and minutes by making available angular indexing plates (Fig. 9-18*b*). An angular indexing plate can be attached to the index

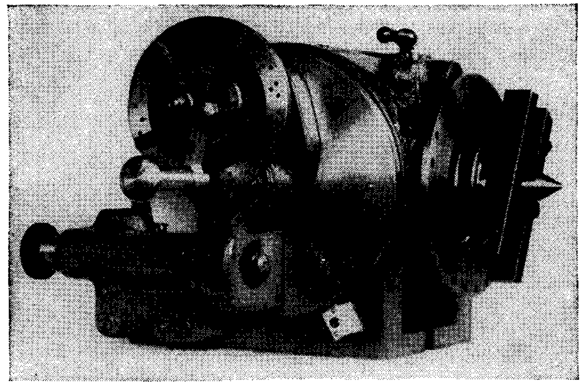


Fig. 9-18*b*. Angular indexing plate mounted on the headstock. (*The Brown & Sharpe Manufacturing Company*)

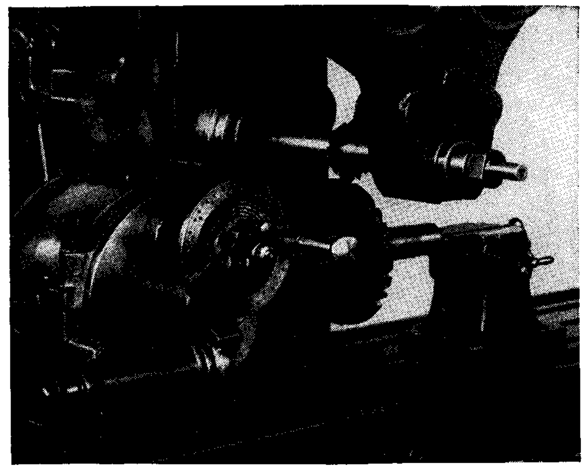


Fig. 9-18*c*. Cutting a special disk, using an angular index plate. (*The Brown & Sharpe Manufacturing Company*)

head in place of the standard index plate. It has two circles of holes. The inner circle has 18 holes, each hole representing ½ deg. The outer circle contains 30 holes, each hole representing 1 min. Both the back pin and the index-crank pin are used with the plate. At times, both pins are withdrawn from the plate, which can then be revolved in either direction (Fig. 9-18*c*).

Differential Indexing. There are many divisions of the circle that are not possible to obtain with simple indexing. It then becomes necessary to use the method known as *differential indexing.*

The term *differential* is used because the needed division is obtained by a combination of two movements: (1) the simple indexing movement of the index crank, and (2) the movement of the index plate itself. These two movements happen at the same time with a *differential* in their movement relationship.

The amount that the plate moves for each turn of the index crank and the direction in which it moves are governed by change gears. This will be explained in detail in a later section.

Differential indexing may be used for divisions that cannot be obtained by simple indexing. With the change gears and the three index plates that are standard equipment with the B&S index head, it is possible to index all numbers not obtainable by simple indexing, from 1 to 382. In addition, many other divisions beyond 382 can be indexed.

The index-head spindle and the index plate are connected by a train of gears so that the index plate will turn either in the same direction as the movement of the crank or in the opposite direction, depending upon the requirements of the job. The stop pin at the back of the index plate must be released from the plate before the gears can be operated.

The speed of the movement must be exact, so that when the crank has been moved the precise amount, the index-plate movement will also be precise. This will result in the exact alignment of the latch pin with a hole in the index plate. The gears to use and their arrangement offer about the same problems as gearing a lathe for cutting threads. It is first necessary to understand how the index plate is caused to move.

In simple indexing, the index plate is held from turning by a stop pin; the index crank is turned and serves to revolve the worm shaft in the sleeve L (Fig. 9-19) and the worm moves the worm wheel and the index-head spindle. Again it must be emphasized that in differential indexing, the stop pin is withdrawn.

Note in Fig. 9-19 that the gear B_3 and the index plate are both fastened to the sleeve L; therefore if the gear B_3 is caused to move, the plate will move. To do this, a train of gears is arranged between the index-head spindle and the auxiliary worm shaft M.

The permanent gears within the index head are diagramed in Fig. 9-19, to show how this motion is transmitted. The explanation follows:

A special arbor is fitted and held securely in the taper hole in the index-head spindle and is hereafter referred to as the "spindle." One end serves as the live center and the other end projects through and holds the spindle gear S.

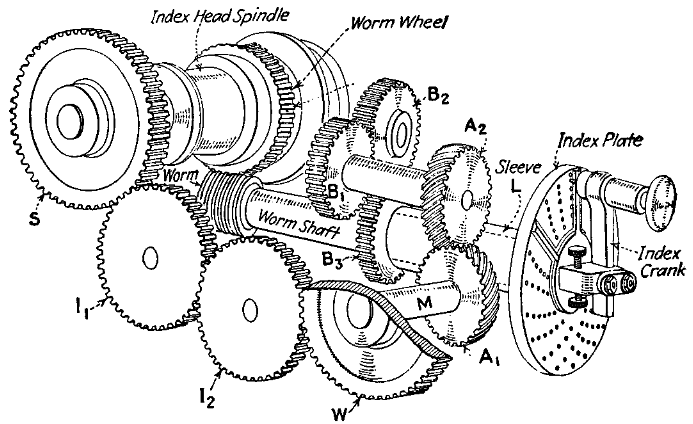


Fig. 9-19. This figure illustrates the gearing for differential indexing with a Brown & Sharpe index head (extended for clearness). In practice, one idler, or two idlers, or a compound of any two of the change gears with or without an idler, may be used between the gears S and W.

Arrange the train of gears: the spindle gear S, the idler gears I_1 and I_2, and the worm gear W (on the auxiliary worm shaft M). Disengage the stop pin that locks the index plate to the head, turn the index crank and note the following: (1) The spindle, and the gear S, are put in motion by the movement of the index crank, through the worm shaft, worm, and worm wheel, in the ratio of 40:1, as in simple indexing. (2) The movement of the spindle gear S is transmitted through I_1 and I_2 to gear W. (3) From W, through shaft M, the motion is given to spiral gear A_1, to other spiral gear A_2, to B_1, which is fastened to the same stud as A_2. The gear B_2 is an idler gear, and motion is transmitted from B_1 through B_2 to B_3, the sleeve L and the *index plate.* (4) The amount the index *plate* will move, relative to the movement of the index *handle*, will depend upon the relative sizes of the driving and driven gears (as S and W, in simple train or compounded). (5) The movement of the index plate may be in the direction of the movement of the index crank, or in the opposite direction, according to whether one or two idlers are used.

Suppose there are equal gears, S and W, on the "spindle" and the "worm," respectively, with two idlers between them, and that the index pin is in a hole in the index plate referred to here as (1). Now pull out the index pin and move the index handle clockwise, then the index plate will move counterclockwise, and 40 turns of the index handle will cause the *index plate* to make one revolution, and the index pin will have caught up with the (1) hole just 41 times. If the handle is stopped each turn, that is, each time the pin comes to the (1) hole, and a cut is made—in a gear blank, for example—a gear of 41 teeth will be cut.

Now if only one idler is used, the movement of the index plate is clockwise, or in the same direction as the movement of the index handle. By making 40 turns of the index handle, the pin catches up with the (1) hole just 39 times, because of the one whole turn of the plate itself. If a cut is made each time the pin reaches the (1) hole, 39 cuts will be made.

Investigate a little further by putting a 48-tooth gear on the spindle, a 24-tooth gear on the worm, and use one intermediate. The ratio of the spindle to the worm is then 2:1, and when the spindle revolves once, the index plate will revolve twice, and the index pin will have caught up with the (1) hole 38 times.

With the above setting (with one idler), a "turn" from (1) hole to (1) hole each indexing will give 38 divisions; with 2 turns, 19 divisions; with ½ turn, 76 divisions; ⅔ turn, 57 divisions, etc. With two idlers, divisions as follows may be made: 1 turn, 42; 2 turns, 21; ½ turn, 84; ⅔ turn, 63 divisions, etc.

With a ratio, spindle to worm, of 3:1, the machinist can make, with one idler, 1 turn, 37 divisions; ½ turn, 74 divisions, etc. With two idlers, 1 turn, 43 divisions, etc.

Take a fractional ratio of spindle to worm, for example, ⅔:1 (that is, 2:3), 32 gear on spindle, 48 gear on worm:

$$40 - \tfrac{2}{3} = 39\tfrac{1}{3}$$

One-third turn ($39\frac{1}{3} \div \frac{1}{3}$) gives 118 divisions.
Two-thirds turn ($39\frac{1}{3} \div \frac{2}{3}$) gives 59 divisions, etc.

Enough has been said to illustrate the principle of differential indexing, how different ratios of gears from spindle to worm give divisions, such as prime numbers, that would otherwise be impracticable if not impossible. Following is an explanation of how the gear ratios are calculated, and, to simplify the calculations, definitions and notations are given.

DEFINITIONS AND NOTATIONS: DIFFERENTIAL INDEXING

Simple Index Number (40). The number of turns of the index handle to turn the spindle one revolution as in simple indexing.

Differential Index Number (D). The number of moves (turns) of the index handle [from (1) hole around to (1) hole] necessary to make one complete revolution of the spindle.

Change-gear Ratio (x). The ratio of the train of gearing between the spindle and the worm (and, *in effect*, between the spindle and the index plate).

NOTE: It will be observed from the examples given that the change-gear ratio is always the ratio of the difference between the simple index number and the differential index number and 1. For instance, in one of the examples given above the difference between 40 and 39⅓ is ⅔, or a *ratio* of spindle to worm of ⅔:1 or 2:3.

(1) 40 = simple index number
(2) D = differential index number
(3) N = number of divisions required
(4) N_1 = some number of divisions, usually quite near the required number, that may be obtained by simple indexing
(5) S = gear on spindle
(6) G_1 = first gear on stud } driving gears
(7) G_2 = second gear on stud
(8) W = gear on worm } driven gears

(9) $D:40 = N:N_1$ that is, $D = \dfrac{40N}{N_1}$

(10) x = ratio = $(40 - D):1$, when 40 is larger than D
(11) x = ratio = $(D - 40):1$, when D is larger than 40

(12) $x = \dfrac{S}{W}$ (for simple gearing)

(13) $x = \dfrac{S \times G_1}{G_2 \times W}$ (for compound gearing)

(14) The ratio should not exceed 6:1 on account of the excessive stress on the gears.

(15) When the differential index number is less than 40, use one idler (or the compound); when greater than 40, use two idlers (or one idler and the compound).

(16) The movement of the index handle will be the fraction of a turn indicated by $\frac{40}{N_1}$.

NOTE: The numbers in parentheses in the following explanation and examples are references to the notations above.

Method of calculations:

a. Select N_1 (4)
b. Substitute for N_1 its value, and solve for D (9)
c. Find the ratio (10) or (11)
d. If the ratio is not practicable (14), select another number for N_1 and try again
e. Having ratio, arrange simple gears (12) or compound gears (13)
f. Set the index pin and sector (16)

EXAMPLE: $N = 59.$ (3)

SOLUTION: $\frac{D}{40} = \frac{N}{N_1} \qquad \frac{D}{40} = \frac{59}{60}$ (9)

$$60D = 40 \times 59$$

$$D = \frac{40 \times 59}{60}$$

$$D = 39\tfrac{1}{3} \qquad (9)$$

$$x = (40 - 39\tfrac{1}{3}):1 = \tfrac{2}{3}:1, \quad \text{or} \quad 2:3 \qquad (10)$$

$$\tfrac{2}{3} = \tfrac{48}{72}; \quad 48 \text{ gear on } S, \quad 72 \text{ gear on } W \qquad (12)$$

Use one idler, I (15)

Movement of index handle $\tfrac{40}{60} = \tfrac{2}{3}$ turn (16)

Alternate Method of Finding Differential Indexing Setup. Figure 9-20 shows a Brown & Sharpe index head geared for 271 divisions. Select an approximate number of divisions (A) that is either greater or smaller than the required number (N). The approximate number selected when divided by a factor of 40 will give a number that can be indexed by plain indexing. Form a fraction with 40 as the numerator and the approximate number (A) as the denominator. Reduce to a fraction having as a denominator a number equal to the holes in an index plate. To illustrate for 271 divisions: $A = 280$

$$\tfrac{40}{280} = \tfrac{1}{7} \times \tfrac{3}{3} = \tfrac{3}{21}$$

which means using 3 holes on the 21-hole circle.

The formula for finding the gearing ratio is as follows: Let R equal the required ratio of gearing; let N equal the required number of divisions; and let A equal the approximate number. Then

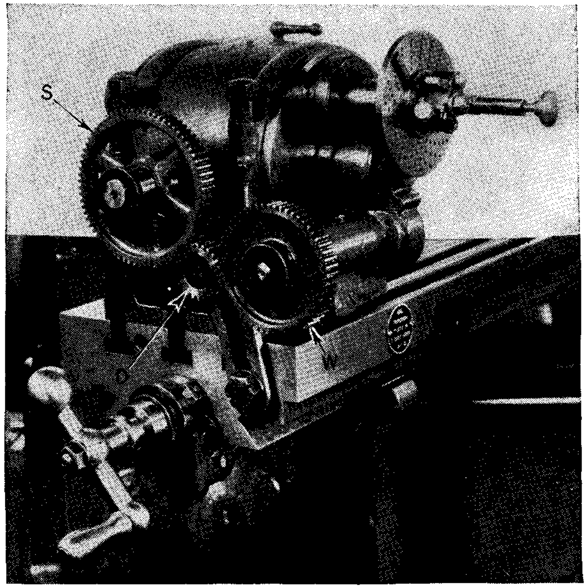


Fig. 9-20. A Brown & Sharpe index head geared for 271 divisions. (*The Brown & Sharpe Manufacturing Company*)

$$R = (A - N) \times \frac{40}{A}$$

EXAMPLE: If the required number (N) is 271 and the approximate number (A) is 280, then

$$R = (280 - 271) \times \tfrac{40}{280} = \tfrac{9}{1} \times \tfrac{40}{280} = \tfrac{9}{7}$$

$9/7$ is the ratio of the *driver* to the *driven* gears. The fraction $9/7$ when raised to obtain numbers equivalent to available gears will be

$$\frac{9}{7} \times \frac{8}{8} = \frac{72 \text{ on spindle}}{56 \text{ on worm}}$$

The purpose of idler or intermediate gears in the gear train used for differential indexing is to (1) rotate the index plate in the same

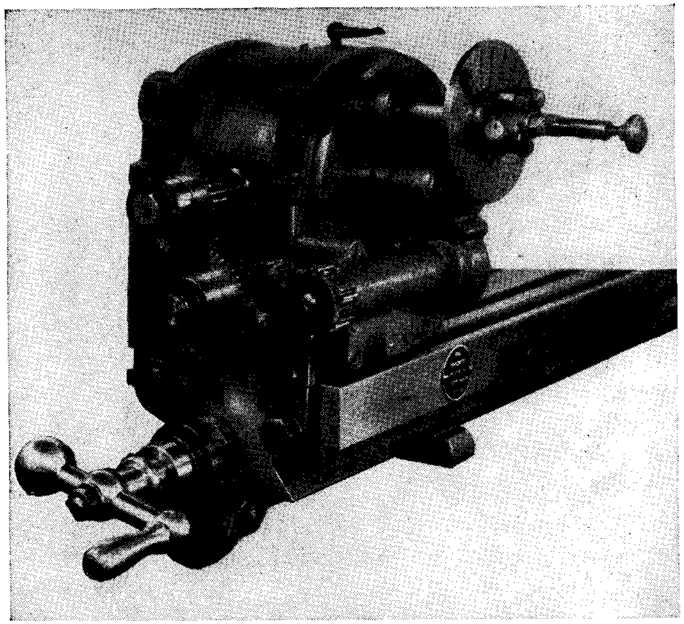


Fig. 9-21. A Brown & Sharpe index head geared for 250 divisions (two idlers). (*The Brown & Sharpe Manufacturing Company*)

direction as the crank, or (2) to rotate the index plate in the opposite direction. The direction depends upon whether it is necessary to either increase (1) or decrease (2) the indexing movement.

When the approximate number (A) is *greater* than the required number (N), the index plate and the crank revolve in the *same* direction. Simple gearing will require one idler; compound gearing, no idler. When A is *less* than N, simple gearing will require two idlers and the compound gearing will require but one idler. The indexing

plate and the crank must rotate in opposite directions in this case (see Fig. 9-21).

Compound gearing will be required when the ratio of gearing does not conform to the available gear sizes or is impracticable to use. Figure 9-22 shows a B&S index head geared for 319 divisions with

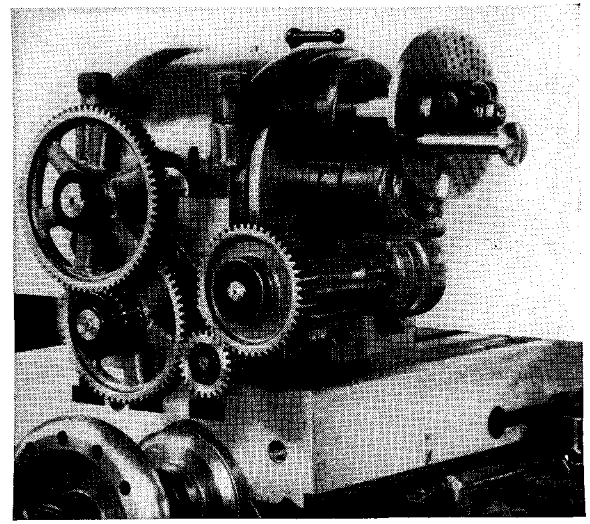


Fig. 9-22. A Brown & Sharpe index head geared for 319 divisions (compound gearing with one idler). (*The Brown & Sharpe Manufacturing Company*)

compound gearing and one idler. Let A equal 290 and N equal 319. Then using the formula

$$R = (N - A) \times 40/A$$

Substituting the values for N and A we get

$$R = (319 - 290) \times 40/290 = 29/1 \times 40/290 = 4/1$$

In terms of gears (compound) we get

$$\frac{4}{1} \times \frac{3}{3} = \frac{12}{3} = \frac{3 \times 4}{1 \times 3}$$

$$\frac{3}{1} \times \frac{24}{24} = \frac{72}{24} \qquad \frac{4}{3} \times \frac{16}{16} = \frac{64}{48}$$

Combining both fractions, we get

$$\frac{72 \times 64 \text{ drivers}}{24 \times 48 \text{ driven}}$$

Since A is *less* than N, compound gearing will require but one idler.

$$\text{Movement of the index crank} = \frac{40}{290} = \frac{4 \text{ holes}}{29 \text{ circle}}$$

Change gears available with the B&S index head have the following teeth: 24 (two gears), 28, 32, 40, 44, 48, 56, 64, 72, 86, 100.

Graduating with the Index Head. Although the index head is regarded mainly as an attachment for dividing the circumference of work into accurate spaces, it can also be used for the accurate division of flat stock. This procedure is known as *graduating* and is used for accurate spacing of the divisions on flat scales and verniers.

The operation requires the use of the universal spiral index head and a single pointed tool, which is held stationary in a fly-cutter arbor or boring bar, mounted directly in the spindle. The scale to be

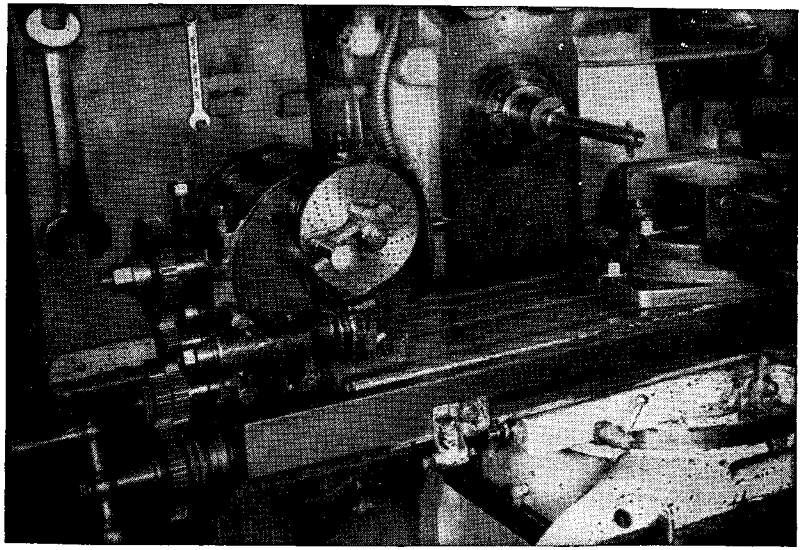


Fig. 9-23*a*. The Brown & Sharpe index head geared for graduating a flat scale or a flat surface. (*James Anderson*)

graduated is clamped to the surface of the table parallel to the slots or mounted in a vise or a fixture. No power is required, the lines are cut by moving the table transversely under the point of the cutting tool. This movement is done by hand (see Figs. 9-23*a* and 9-23*b*).

The dividing-head spindle is geared to the table feed screw with compound gearing. The indexing for the divisions required is obtained by moving the index crank the necessary number of holes on a particular circle of the index plate. The movement of the index crank rotates the spindle, the gear attached to the spindle transmits the movement through the gear train to the table feed screw.

It has already been explained that one turn of the index crank moves the headstock spindle $\frac{1}{40}$ of a revolution. If equal gearing is employed between the spindle and the table feed screw, the feed screw will likewise turn $\frac{1}{40}$ of a revolution.

The lead screw of a milling-machine table has four threads to the inch. The pitch of the thread is 0.250 in. Therefore, one turn of the index crank will move the table $\frac{1}{40}$ of 0.250 in., or 0.00625 in.

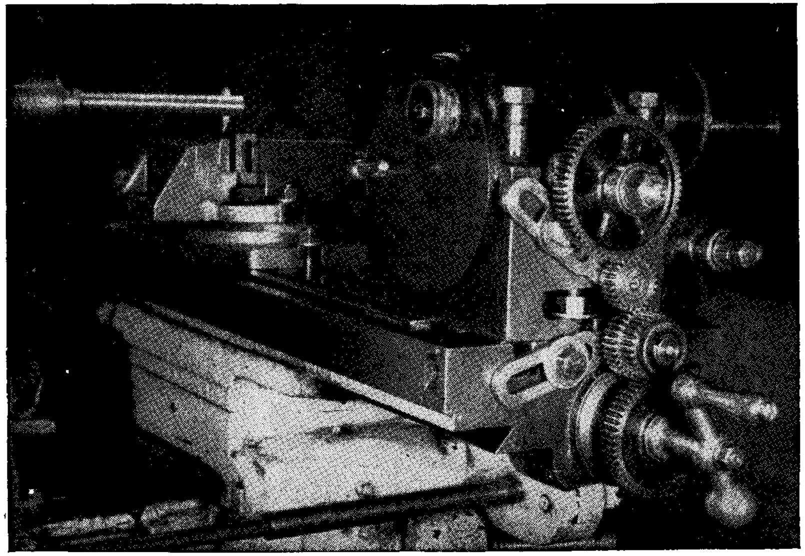


Fig. 9-23*b*. Rear view of the graduating setup, showing the gearing used between headstock spindle and feed screw. (*James Anderson*)

Suppose it is required to graduate a scale with lines 0.03125 in. apart. Quick observation will tell that, if one turn of the index crank moves the table a distance of 0.00625 in., it will take more than one turn to move the table a distance of 0.03125 in. Therefore, $\frac{0.03125}{0.00625} = 5$ turns are needed of the index crank to space a distance of 0.03125 in.

If it is required to index the divisions on a vernier reading to a thousandth of an inch (0.001 in.) and the divisions are 0.024 in. apart, the indexing movement will be $\frac{0.024}{0.00625} = 3.84$ turns. The fractional movement of 0.84 turn can be obtained within close limits by indexing 26 holes in the 31-hole circle. Three complete turns will move the table $0.00625 \times 3 = 0.01875$ in. and $^{26}/_{31}$ of a turn will give a table movement equal to 0.00524+ in. Therefore, 0.01875 plus 0.00524 equals 0.02399, which is 0.00001 in. less than the required amount of 0.024 in.

In order to prevent errors caused by any play or backlash, either in the gearing of the index head or wear between the threads of the table feed screw and nut, the index crank must always be turned in one direction, preferably clockwise—to the right.

The *Practical Treatise on Milling and Milling Machines*, published by the Brown & Sharpe Manufacturing Company, includes several pages of tables compiled by that concern for determining the circle and holes to be used for longitudinal graduating.

Wide-range Divider. The Cincinnati Milling Machine Company has a *wide-range divider* unit that can be applied to a Cincinnati universal dividing head (Fig. 9-24). It can be used for divisions ranging from 2 to 400,000 and for any desired angle in degrees, minutes, and seconds. The three indexing plates shown in Fig. 9-18*a* are utilized to obtain this wide range of divisions. The ratio between the worm shaft and the spindle is 40 to 1. The mechanism operates through a reduction gearing of 100 to 1 ratio within the housing.

The 40:1 ratio between the index crank and the spindle will be found in nearly all the index heads used in modern machine shops. However, there is one exception which merits description.

The Kearney & Trecker Corporation manufacture a dividing head that has a 5:1 ratio between crank and spindle. The model K uni-

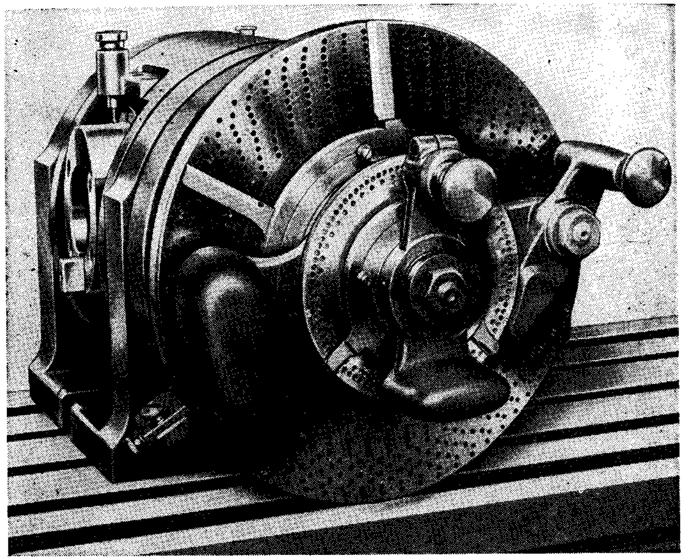


Fig. 9-24. The Cincinnati universal index head with a wide-range divider. (*The Cincinnati Milling Machine Company*)

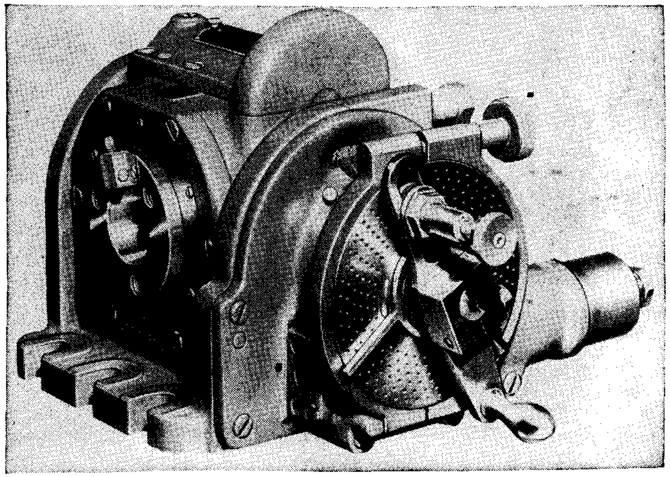


Fig. 9-25*a*. The Kearney and Trecker (Milwaukee) Model K universal spiral dividing head, 5 to 1 ratio. (*The Kearney and Trecker Corporation*)

versal dividing head, Fig. 9-25*a*, has such a ratio. This company claims that more than 90 per cent of all indexing operations lie between 6 and 36 divisions. Using a 40:1 ratio dividing head, more than one full turn of the index crank is required to index any of these divisions. With a 5:1 ratio model K, all numbers within this 6 to 36 division range can be indexed with less than one revolution of the index crank. The movement between the index crank and the spindle is transmitted through a hypoid bevel gear and a pinion (Fig. 9-25*b*).

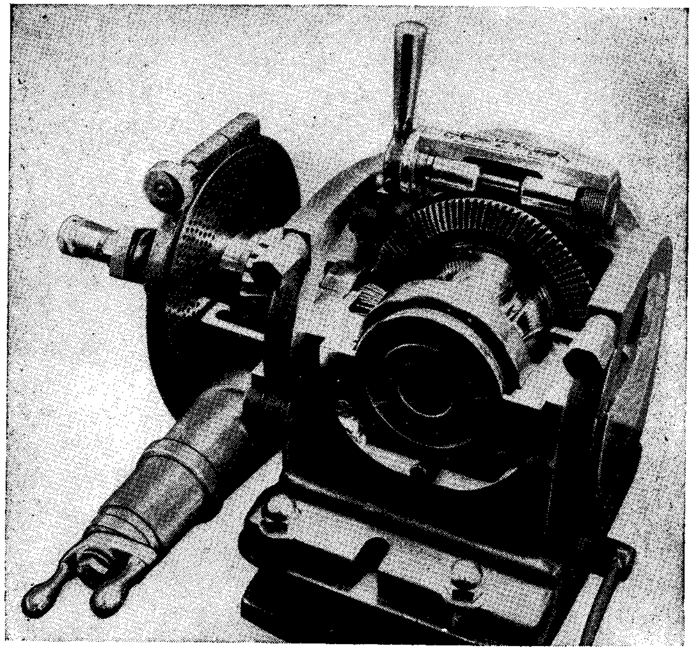


Fig. 9-25*b*. The Kearney and Trecker (Milwaukee) Model K dividing head showing the hypoid bevel gearing, 5 to 1 ratio. (*The Kearney and Trecker Corporation*)

One index plate comes as standard equipment for this index head. It consists of two standard plates bolted and doweled together. The plate can be reversed, making available seven circles of holes on each plate. These plates have the following circles of holes: No. 1—98, 88, 78, 76, 68, 58, 54 and No. 2—100, 96, 92, 84, 72, 66, 60.

A set of two high-number index plates are made available also. With the three plates it is possible to index for all divisions from 2 to 100, plus many other divisions up to 500 (Fig. 9-25*c*).

Because of the ease of obtaining the lower number of divisions, a direct indexing plate is found unnecessary.

The design of this index head provides for mounting gears for differential indexing.

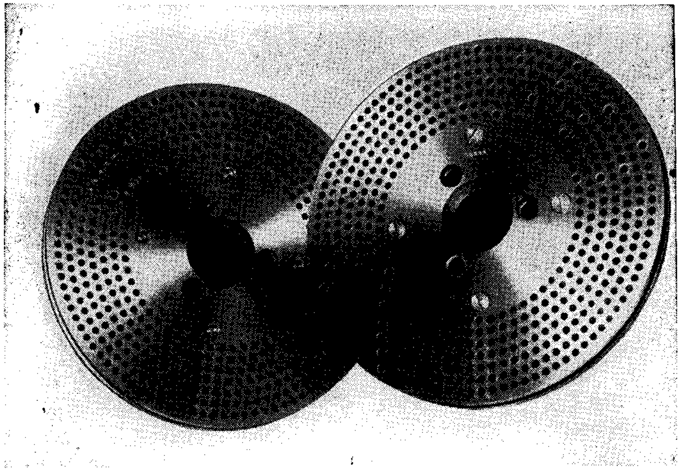


Fig. 9-25*c*. A set of two high-numbered index plates available with the Kearney and Trecker (Milwaukee) 5:1 index head. (*The Kearney and Trecker Corporation*)

The index-crank setting is calculated in the same way as for other dividing heads, except that 5 is used in place of 40. Thus, to index for the cutting of a 36-tooth gear, the following will illustrate the procedure:

$$\frac{5}{N} = \frac{5}{36} \text{ of a turn}$$

$$\frac{5}{36} \times \frac{2}{2} = \frac{10 \text{ holes}}{72 \text{ circle}} \qquad \text{No. 2 plate}$$

QUESTIONS ON THE INDEX HEAD AND INDEXING

1. Define the machine operation called *indexing*.
2. How many turns of the index crank are necessary in order to rotate the spindle one full turn? Use the Brown & Sharpe index head.