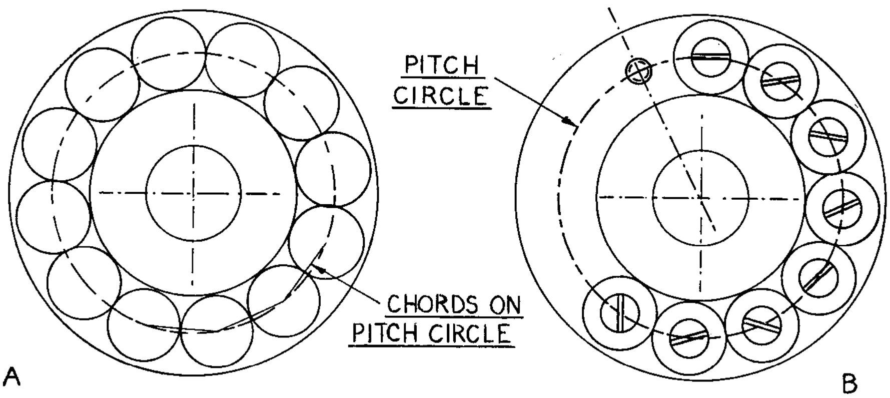
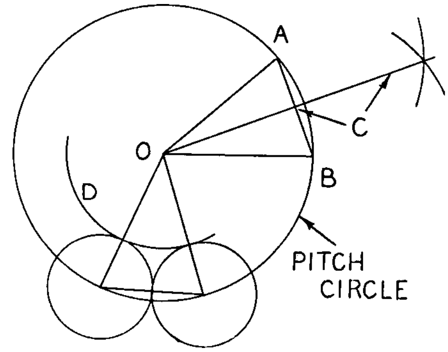


Left, Fig. 1: Master index plate, showing A, geometric layout: B, mechanical assembly

Below, Fig. 2: How chordal lengths are calculated by geometry



MARTIN CLEEVE EXPLAINS THE TECHNIQUE FOR PRODUCING SUB-DIVISIONS OF EXTREME ACCURACY

MASTER INDEX PLATES

WHENEVER you use the chuck jaws to mark off three or four equal spaces on a piece of work, you are performing the operation of indexing, although in a crude form.

In engineering, indexing of some kind or other is an everyday event, and so special apparatus is provided to do it efficiently. The accessory is known as an "index head," and it is used to equi-space gear teeth, shaft splines, circles of holes, and so on.

An index head requires a number of steel discs, usually hardened, and containing, at different convenient radii, a series of precision equi-spaced holes. To take the first example that comes to hand, Brown and Sharpe of Providence, USA list a series of twelve index plates, the first of which is 4-3/4 in. dia and has six circles of holes : 15, 16, 17, 18, 19, and 20; thus, even without an index head proper, with simple adaptation, this particular plate would give directly, not only the divisions equal to the number of holes in its various circles, but sub-divisions of those numbers. Thus, for example, 15 would give you 5 and 3. Note that 17 is a prime number, and therefore to obtain primes, prime circles are always necessary. I should note here, however, that prime circles can be indexed by processes known as either " differential " or " compound " indexing, but neither of these methods can give the accuracy obtainable from a master index plate.

Although it is easy to make copies of index plates supplied by manufacturers, an interesting question arises when we ask how a circle is accurately sub-divided in the first instance. An understanding of this will give the student an insight into a basic principle of precision engineering.

The design of a master division plate, or the accurate sub-division of the circumference of a circle into a number of equal portions depends, for the purpose of making copies, on the principle that a number of identical bushings all touching each other and all touching the periphery of an inner disc, must exactly sub-divide a circle with an accuracy depending only upon the precise machining and squaring of the bushings and the turning of the inner disc to the calculated diameter.

The left-hand drawing, Fig. 1, shows what I mean. You will appreciate that, from a geometric point of view, where machining errors are not recognised, the twelve circles touching each other and the inner circle give twelve precise divisions.

Simple theory

The geometric demonstration of the whole process is simple, and I ask you to refer to Fig. 2. Here we have a circle with a diameter of 1 (one). This can be an inch, a centimeter, a yard or a mile, provided you hold subsequent measurements in the same module.

Let the centre of the circle be ***O***, and ***AB*** a chord the length of which depends upon the angle ***AOB*** which is found by dividing 360 degrees by the number of spaces required. You have, then, to find the length of the chord AB.

Let ***OC*** bisect angle ***AOB*** by the usual geometric principle. As the triangle ***AOB*** is isosceles, ***OC*** will bisect the chord ***AB*** at C, giving a right-angle triangle ***AOC. You*** now have sufficient data to complete your calculation by trigonometry. You know the length of ***OA = 1/2,*** because we chose a diameter of 1. You know the angle ***AOC = 1/2*** angle ***AOB,*** therefore you can calculate the length of half the chord, ***AC,*** by taking the sine of the degrees in angle ***AOC*** and multiplying by the length ***OA.*** Twice your answer will give the length of chord ***AB***.

In practice, the diameter of the bushings equals the chordal length. The fact that you will, during assembly, displace the bushings so that the ends of the chords join the centres of the bushings as I have shown in the lower part of Fig. 2, is of no consequence.

Let us find the length of the chord for twelve spaces on a circle having a diameter of I. Referring to Fig. 2 :

(I) Angle AOB = $\frac{360}{12}$ = 30 deg.

(2) Half of angle *AOB* = 15 deg.

(3) Sine 15 deg. = 0.2588.

(4) Therefore 1/2 chord AB (i.e. AC)
= 0.2588 x hypotenuse OA
= 0.2588 X 1/2

(5) Therefore whole chord *AB*
= 0.2588 X 1/2 X 2
= 0.258X.

From the foregoing you will see that at (2) we divided the degrees by 2; at (4) we multiplied the sine of the angle by the hypotenuse (sine X 1/2); at (5) we again multiplied by 2. But (2) and (5) cancel out and (4) reduces to the equation,

$$\text{Length of chord} = \text{sine } \frac{360}{N} \times 1/2$$

$$\text{sine } \frac{180}{N}$$

where N is the number of spaces required.

Using the simplified formula for obtaining the length of the chord for twelve spaces we have :

$$\text{sine } \frac{180}{12} = 0.2588$$

Assuming that we require these 12 equal spaces on a circle having a diameter of I, you will see from Fig 2, that the diameter of the inner disc, part of which I have shown at D, will be equal to your diameter I less two half-radii of the bushings. Or diameter I less one bushing diameter (I minus 0.2588 = 0.7412).

In those cases where the number of divisions give an exact number of degrees, or an exact number with a reasonable fraction, typical schoolbook sine tables will give a good enough figure, but when an awkward fraction is encountered,

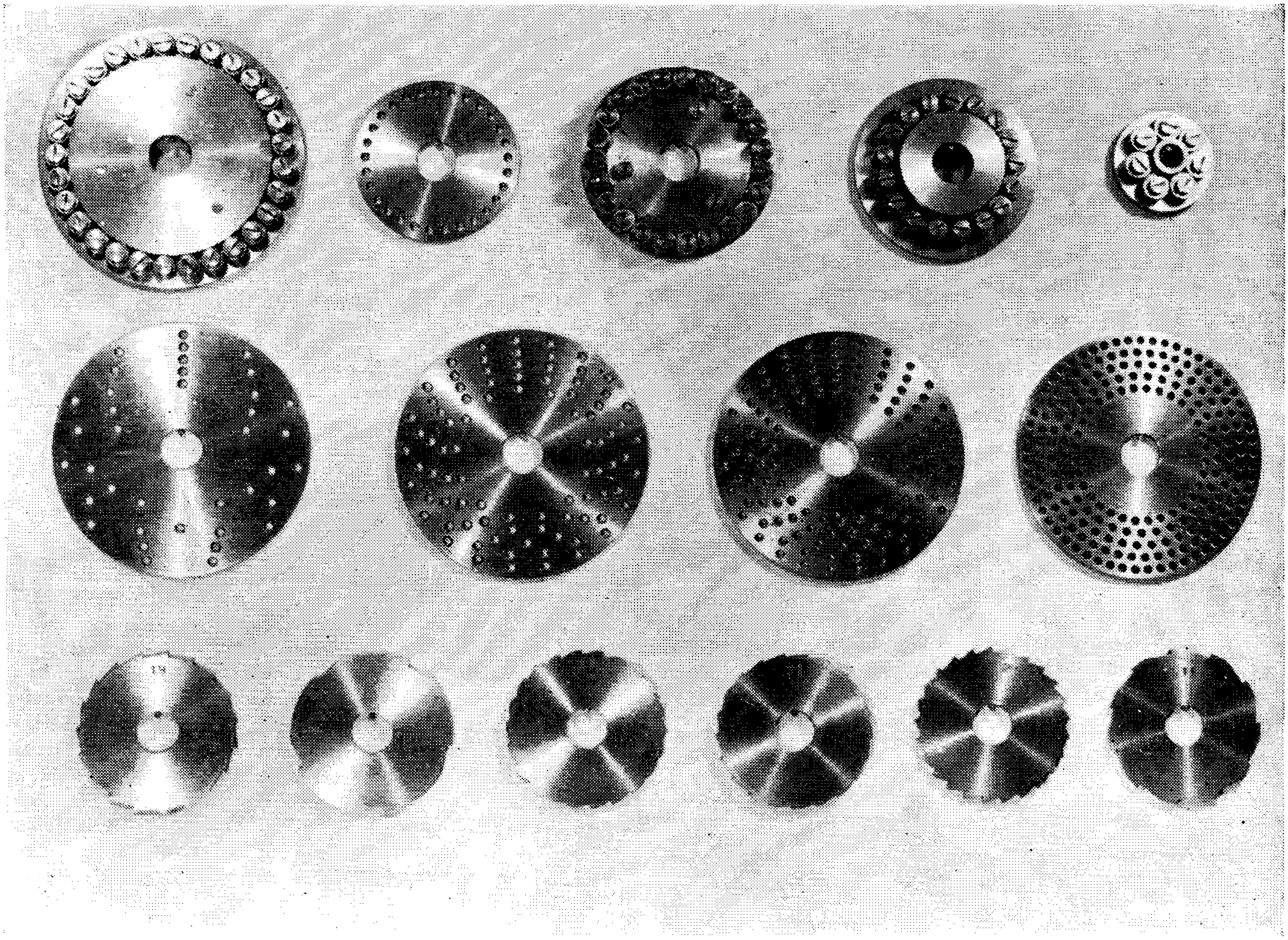


Fig. 3: A variety of index plates made by the author

you need five-figure sine tables set out fully in degrees and minutes: tables such as are compiled for nautical use.

On the other hand, ***Fowler's Mechanics' and Machinists' Pocket Book*** (an annual compilation) lists chordal lengths for spacing a circle with a diameter 1 into divisions of from 3 to 100 inclusive. For spaces above 100, there is so little difference between the chordal and the circumferential lengths that pie divided by the number of divisions gives a sufficiently accurate figure. You may like to note that Fowler's give the chordal length for 100 spaces (on circle with diameter 1) as 0.0314.

Minimising errors

As we are not planning a symmetrical landscape, we would work in inches, or fractions of an inch, but from a practical point of view the chordal lengths for space above about 9 on a circle with a diameter of 1in. give bushings of an inconveniently small diameter for making and handling, and I have found that a bushing diameter in the neighbourhood of 3/8 in. is more satisfactory. Additionally you should note that ultimate accuracy depends on the overall size of the master together with the size of the component to be copied from the master. For example, if a master is only 2 in. dia. and you wish to equi-space a disc at the periphery of a 4 in. circle, a 2/10 thou error in the size of one of the bushings would be magnified to 4/10 at the double radius of the component.

The diameter of the pitch circle around which the centres of a series of larger bushings should be placed is found from a knowledge of the chordal length and your own decision as to what diameter bushings you propose to make. It may be shown as:

$$\text{Pitch circle diameter} = \frac{\text{bushing diameter}}{\text{chordal length for dia. I.}}$$

Practical application

I have made 17, 23 and 29 masters for use in conjunction with my home-produced indexing arrangements. You can see the 29 master at top left, Fig. 3. The same illustration, in the middle row, shows index plates of the more conventional type and the bottom row shows a selection of ratchet-type index plates, which I favour for certain work. Brief notes on how I made the 29 master might serve as an example of the construction and use of an index plate, and so I will outline the reasoning and methods.

From the standard table of chordal lengths for spacing a circle with diameter 1, the length of the chords for 1/29 division = 0.1081 in., therefore a circle of cylinders or bushings of 0.1081 in. dia. at a radius of 1/2 in. for their centres, would all touch, but would be inconveniently small.

Accordingly, let the bushings have a dia. of 0.365 in., i.e 0.010 in. less than 3/8 in. so that they can be made from 3/8 in. dia. bright steel rod.

The number of times 0.1081 is contained in 0.365 will give the new pitch diameter for the larger bushings, thus:

$$\frac{0.365}{0.1081} = 3.376503 \text{ in., say, } 3.3765 \text{ to the nearest } 1/10 \text{ thou.}$$

To find the diameter of the single inner disc, deduct the diameter of one bushing from the pitch diameter, thus:

3.3765 minus 0.365 = 3.0115 in.

To find the overall outside diameter of the backing, or mounting disc, to which the bushings will be fixed, add the diameter of one bushing to the pitch diameter, thus:

3.3765 plus 0.365 = 3.7415 in., say 3-3/4 in.

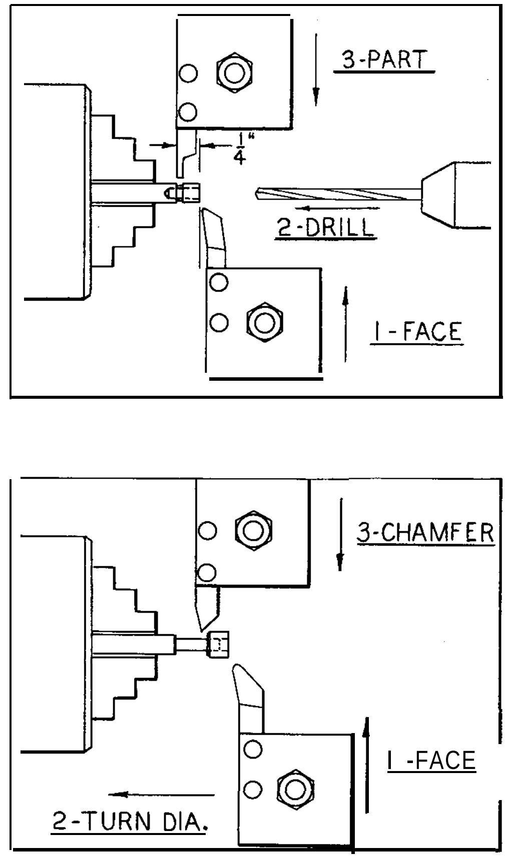
I made the backing plate from a piece of 4 in. X 1/4 in. section bright steel bar, and the inner 3.0115 in. disc from a 1/4 in. thick piece parted from a bar of 3-1/2 in. dia. steel, although, of course, I could have used strip material for both.

I bored the blanks 5/8 in. to close limits, and fixed them together with three screws, and then I mounted the assembly on an accurate mandrel and finish-machined true. For guidance during the assembly of the bushings, I scribed the pitch circle at 3-3/8 in. dia. Great accuracy in scribing the pitch circle is not necessary, as you will see.

I made 29 bushings to a diameter of 0.3650 in. (minus o, plus 0.0002 in.). For good results the bushings require careful preparation. They should be parallel, machined to close limits, and the abutting ends should be absolutely square by the cylindrical surface.

The bushings have reamed 3/16 in. holes and are fixed with No. 4 BA screws. The slackness obviates the need for extreme accuracy in positioning the fixing holes, as you will see in due course.

A convenient lathe set-up for making the bushes is shown in Figs. 4A and 4B. At 4A we have a parting tool at the rear and a facing tool at the front of the cross slide. They are set to give a gap of a few thou over the 1/4 in. length required of the bushings. After an initial facing and centring of the 3/8 in. stock the lathe saddle is locked and the sequences shown in the drawing are followed.



Figs 4A and 4B: Diagram of set-up for making the bushes.

To be continued.

MASTER INDEX PLATES

Continued from July 15

Assembling and testing the bushes

by Martin Cleeve

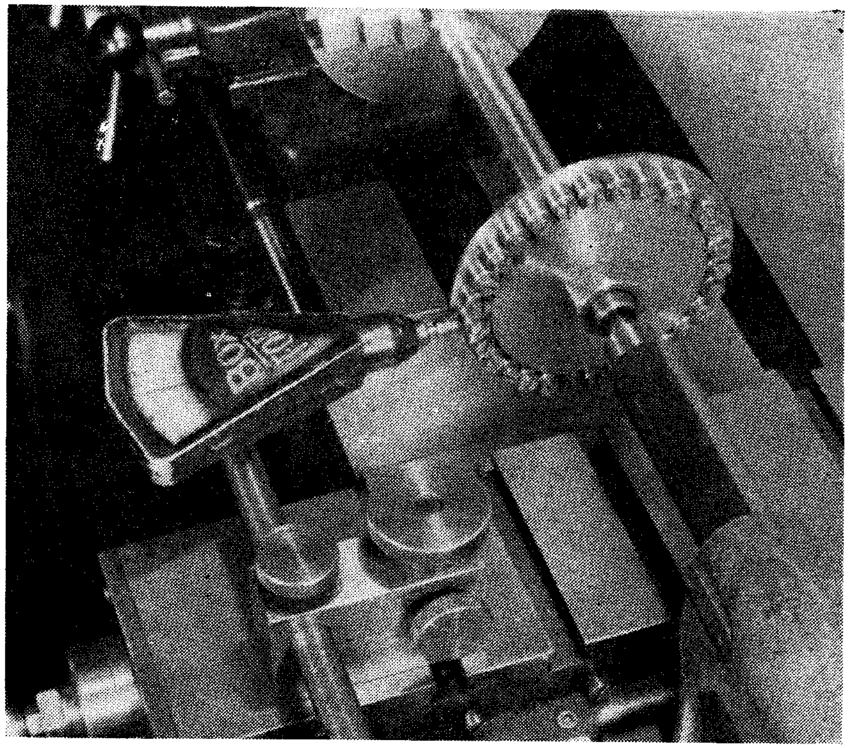


Fig. 5: Checking a master index assembly

You will see that the front tool may be used as a stock-stop to gauge the bushing lengths: if you hold the bar tightly against the side of the tool while you lock the chuck jaws the stock will be biassed forward sufficiently for you to subsequently take a facing cut of sufficient depth to clean up the more rough-parted surface, whereupon drilling and parting may be repeated.

The set-up gives the best results if you can arrange some sort of forward dead-stop for the drill. At the fourth or fifth drilling I found that the drill had wandered and I had to use a centre drill. Had I to make a considerable number of bushings I would use a stub-drill or make a special holder to give an ordinary drill close support at its cutting end. Such drills do not need a centre hole. Use a No. 13 drill.

It is as well to make a few extra bushing blanks, for if you have an accident in finish-sizing you will not have to reset as in Fig. 4A. On completion of the rough set, each was chucked and reamed 3/16 in. to a good internal finish.

Fig. 4B shows the set-up used to finish the bushings. An odd piece of steel was chucked and a short length machined and polished to such a diameter that each bush, in turn, could be forced on, rough-parted side facing outwards, for end facing and machining to the required diameter at the one-work setting. This ensured absolute squareness. Lastly, for identification, the rear tool was made to put on a slight chamfer to what was to be the top of the bushing on assembly. I removed the bushings from the spigot with pliers, but interposed a wrapper of zinc strip cut from a sheet.

Assembly

Fig. **1B** will serve to indicate the method of assembly. First a centre pop is made at any point on the pitch circle. and a No. 4 BA hole drilled and tapped. One bushing is centralised, fixed and checked for close contact with the inner disc. The position of the hole for the next bushing is easily marked by resting against the first bush a piece of bright steel having a thickness of one half the bush diameter, and using the edge as a guide. I used a pencil instead of a scriber. A pencil mark does not raise a burr, and the centre punch more readily falls into the pitch line groove. On fixing the next bushing, great care had to be taken to see that it was in close contact with the first and the inner disc, and that the assembly was free of grit or swarf.

The remaining assembly was mere repetition, but when I reached the last bushing, it would not enter the space. This indicated that either all the bushings were a few tenths too large, or that the assembly was not sufficiently tight. To recheck tightness I loosened about five adjacent bushings and gave increased pressure on retightening, and after doing this in three or four different places I could complete the assembly.

Testing assembly

The process showed that the bushings were in tight contact with each other, but to check that all were properly in contact with the inner disc, I adopted the set-up shown in Fig 5. Here the master was mounted on an accurate mandrel between centres for free revolving, and the dial indicator probe was set to touch one bushing and to read "zero" at maximum radius. On carefully revolving the master, bush by bush, and noting the maximum reading on the indicator for each, I found that none was out of position.

It will be convenient here to remind the student that a master plate for industrial use would be made from hardened and precision-ground components to limits far closer than we can hope to attain with a lathe. Nevertheless, for demonstration purposes, or for use by any amateur who happens to be reading this, our mild steel masters are worth making.

A set-up showing the copying of a master is shown in

Fig. 6. Here it is mounted on a mandrel which is held in a split bearing-block that can be adjusted to allow the mandrel to revolve without bind or shake, and which can also be closed, by the ball-handled lever and screw, to grip the mandrel tightly between indexing movements.

Rotation of the master, bush by bush, is controlled by the spring strip which you can see engaging with the bushings. The master is first rotated in a direction away from the strip, then the upper and nearest bushing is biassed back so that it is in close contact with the end of the strip. The action is assisted by the springiness of the steel and, in fact, the strip is biassed so as to press on the bushing immediately beneath the end. The spring strip method of indexing will always be found to give extremely accurate results because there are no mechanically moving parts like those found in the " plunger" type of detent where accuracy depends upon the fit of the plunger in its guide hole.

Spring steel is not necessary. I find that 1/2 in. by 1/16 in. mild steel strip serves very well. The worst that can happen with the strip method is that it will warm up slightly during indexing, but if precautions are taken by maintaining a uniform room temperature, then precision is assured.

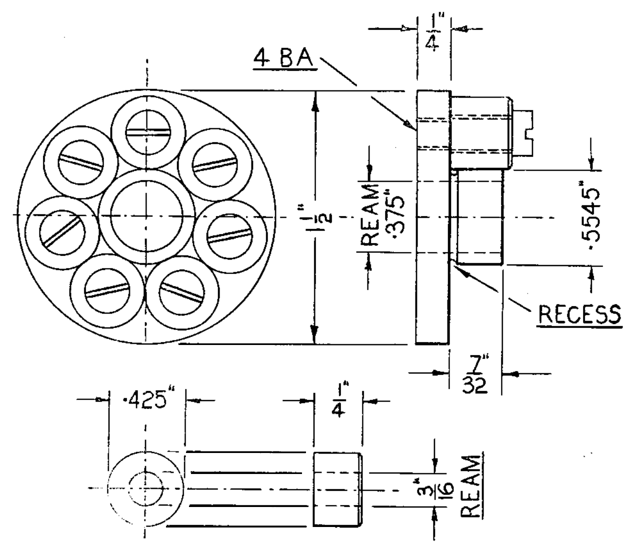
At the chuck end of the mandrel (Fig. 6) you will see a small steel disc in the process of having 29 holes drilled to form an index plate of the more conventional kind. The finished plate is shown second from the left, in the top row, Fig. 3. In this case the holes were drilled with a BS No. 2 centre drill, and no doubt the spacings are sufficiently accurate for all purposes where extremely high precision is not required.

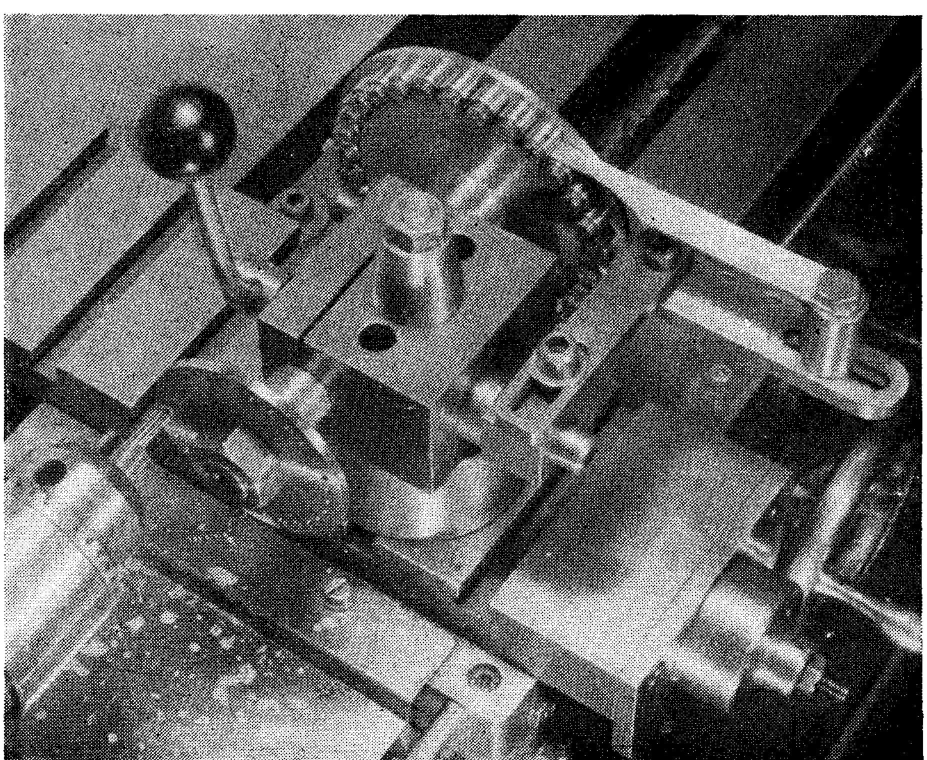
In precision engineering the copy disc would be larger in diameter and greater accuracy would be assured by drilling undersize and boring each hole with a revolving single point boring tool: a method that cannot run off centre.

Some school workshops may be interested in indexing. I appreciate that school time is strictly limited, but so as not to disappoint those who seek something practical, I constructed a little seven-space master that could be made and assembled in a comparatively short time. You can see it at the top right in Fig. 3, and you will find, in Fig. 7, sufficient details to enable you to proceed.

The chordal length for seven spaces on a circle with a diameter of 1 in. = 0.4339 in. I decided upon bushings having a diameter of 0.425 in. They can be made from 7/16 in. dia. bright steel. With these bushings, the diameter of the pitch circle becomes 0.9794 in., and so a pitch circle scribed to 0.010 in. over 31/32 in. dia. will serve, and can be read from the cross-slide index.

The bushings should be left 0.0001 in. or so oversize





Left, Fig. 6: Copying from a master plate. Above, Fig. 7: Details of a master index

rather than undersize, then if they will not assemble, each can be lightly repolished. This is one reason for reaming the bush bores and finishing on a true running spigot: if further treatment is needed, the bushes are easily remounted.

For those interested in the general subject of indexing I can recommend ***Machine Shop Training Course*** by Franklin D. Jones (Vol. 2), published by the Industrial Press (Machinery Publishing Co. Ltd). ❑