IN THE WORKSHOP

by "Duplex"

37—Gear-cutting in the Lathe

ALTHOUGH the involute form of gear tooth has not, perhaps, in every instance the geometric accuracy of the cycloidal gear, it is nevertheless, now used almost entirely in high quality engineering products such as motor-car gears and the geared mechanisms applied to machine tools ; moreover, gears of this type are more easily produced to a high standard of accuracy, and the latitude permissible with regard to accuracy of machining is less exacting for satisfactory working.

In view of these observations, it is proposed to deal only with the cutting of involute gears, and later with the making of cutters of this form ; however, many of the principles involved can also be applied to other tooth forms should the need arise.

In the subject matter that follows, practical description will, as far as possible, displace mathematical references ; but some of the latter are unavoidable, and, for those so minded, manuals such as Messrs. Brown & Sharpe's *Practical Treatise on Gearing* will prove interesting reading.

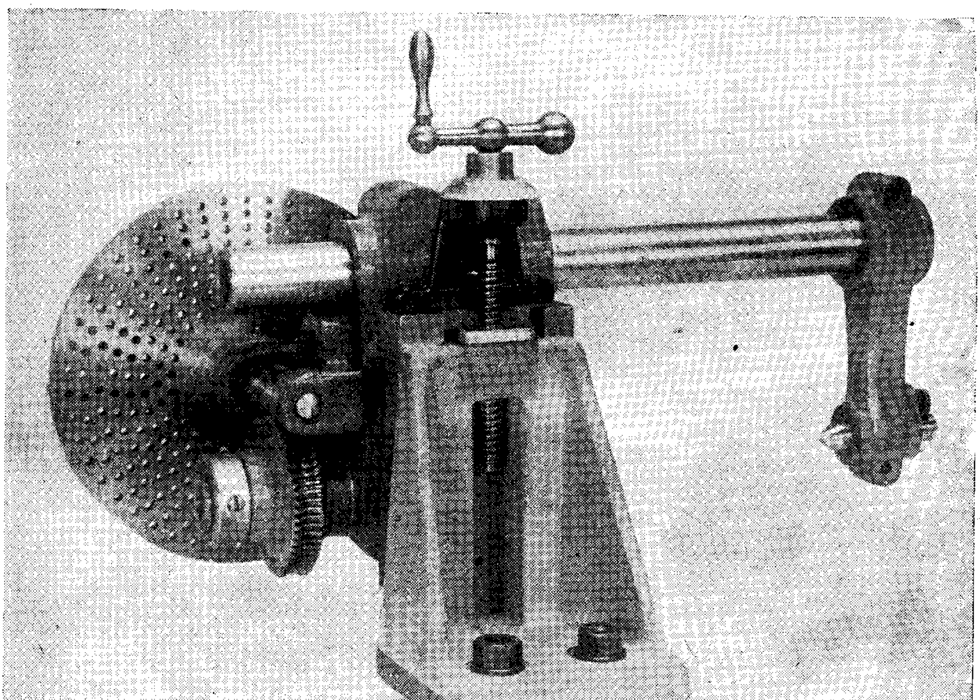

Fig. 1. The Myford attachment, showing details of dividing gear

At the outset, it may be pointed out that, given suitable equipment, there is no great difficulty in cutting straight-tooth gear wheels such as those, for example, that form part of workshop appliances, internal combustion engines, and some types of steam engines. There are, no doubt, many who are deterred from doing this work by the high initial cost of the actual cutters, for if a variety of work is undertaken it is quite possible that a number of these expensive tools will be required.

To overcome this difficulty, a method will be later described in detail for making these cutters which should enable highly satisfactory results to be obtained.

Gear-cutting Appliances

There are two main methods used for gear-cutting in the lathe: either the gear blank is attached to the arbor of a gear indexing device secured to the lathe saddle, and the cutter, mounted on a mandrel between the lathe centres, is driven from the lathe headstock; or this procedure is reversed so that the work is mounted on the lathe mandrel, which is controlled by an indexing device, and the cutter is driven by an attachment fixed to the saddle.

The first method has the outstanding advantages that the full power of the lathe drive can be applied to the cutter, all the lathe mandrel speeds, including the back gear, are available, and in addition the cutter mounting is very rigid.

In the second method a subsidiary drive is required for the gear-cutting attachment, but, here, the automatic saddle traverse can be employed for the actual machining operation.

An advantage gained when using this method is that, in some instances, the gear-cutting operation can be carried out without having to remove the work from the chuck after the gear blank has been turned and bored to size.

Driving the Cutter from the Lathe Mandrel

This method of driving the gear cutter has gained in popularity since the general adoption of a self-contained drive for the lathe, thus replacing the older and usually less efficient form of drive from an overhead countershaft, which entails fitting a device to maintain a constant belt tension when the cutter undergoes a considerable change of position during the machining operation.

With the application of ample power to the rigidly supported cutter, the machining can be more quickly carried out and with less fear of inaccuracy arising, provided that the work, too, is properly mounted.

The gear blank, in this case, is mounted on an arbor carried in the gear-cutting attachment, which is secured to a vertical milling slide bolted to the cross slide of the lathe.

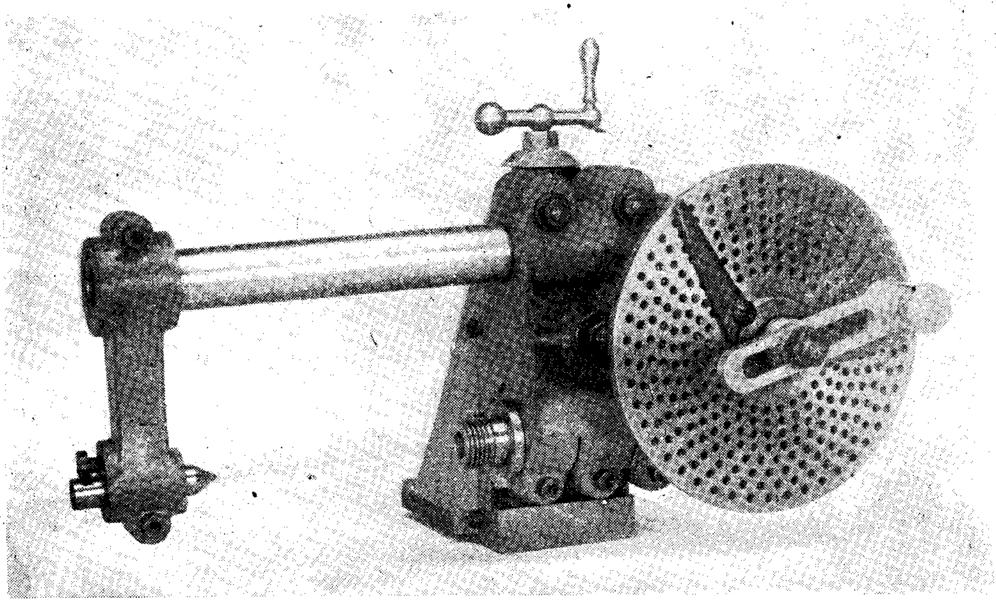

Fig. 2. Opposite side of the Myford gear-cutting attachment

Three views of the Myford gear-cutting attachment are shown in Figs. 1, 2 and 3, and it will be seen that additional support is provided for the arbor carrying the work by means of an adjustable over-arm fitted with a supporting centre.

The spindle nose is, here, made a facsimile of the lathe mandrel to enable chucks and other fittings to be used as required. The rotation of this spindle is controlled by the indexing device which, as will be seen in the illustrations, consists of a worm shaft meshing with a worm wheel secured to the main spindle. The two division plates supplied for attachment to the worm shaft provide for a dividing range of from 1 to 360 deg. and nearly all the numerical divisions from 1 to 100.

Although the fixed form of vertical slide may be used when cutting straight-tooth or spur gears, the swivelling slide can be employed, as shown in Fig. 3, to set the device at an angle suitable for machining bevel gears.

The Southbend gear-cutting attachment, illustrated in Fig. 4, is similar in principle, but the vertical slide forms part of the appliance,

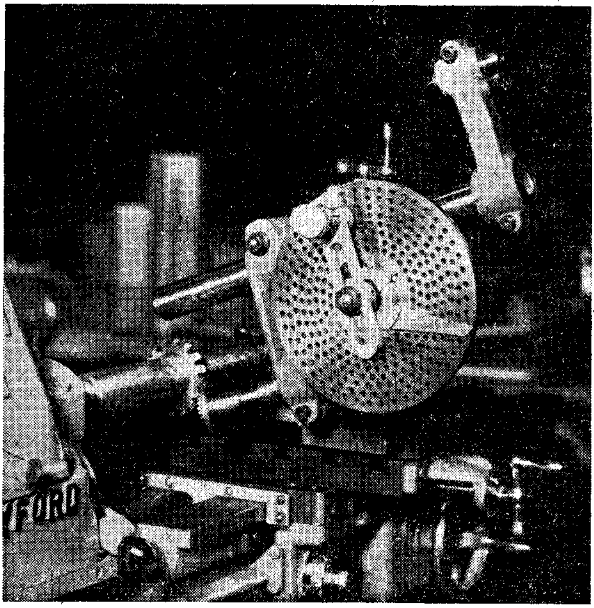

Fig. 3. *The Myford attachment used for cutting a bevel gear*

and its feedscrew is furnished with an adjustable type of index.

As will be seen in Fig. 5, the Atlas gear-cutting attachment is secured to the standard pattern vertical milling slide, but for indexing the work, a change wheel, controlled by an adjustable detent, is mounted on the end of the spindle farther from the work.

Driving the Gear-cutter from a Saddle Milling Attachment

As has already been pointed out, when the milling attachment is used for driving the cutter, an additional drive of some form becomes necessary.

The original Drummond gear-cutting attachment illustrated in Fig. 6 is driven from an overhead countershaft which is provided with a keyway to allow the driving pulley to slide along it and so keep in step with the driven pulley fitted to the attachment ; in addition, a belt-tensioning device, controlled by a weight-arm, is fitted in order to maintain the correct tension in accordance with the movements of the lathe cross-slide and the vertical milling slide.

The vertical slide which forms part of the attachment has an adjustable index collar fitted to its feedscrew, and the spindle carrying the driving pulley is provided with a ball-thrust bearing at either end.

The cutter spindle is driven by means of a pair of spiral gears designed to give a speed reduction of 5 to 1.

The dividing-head is attached to the headstock casting in place of the forward wheel guard, and its worm wheel meshes with the 66-tooth back gear wheel which is keyed to the lathe mandrel.

An Improvised Gear-cutting Attachment

The attachment illustrated in Fig. 7 is bolted to the vertical milling slide, which can in turn be secured either to the lathe bed for milling work mounted on the boring table, or it can be attached to the cross-slide for gear-cutting operations. The gear-cutters are mounted on the spindle of a Potts drilling and milling attachment, and, in order to reduce the speed of the drive, a back gear having a 4 to 1 reduction has been fitted in addition to the bevel wheel drive with its 3 to 1 reduction ratio.

The bevel pinions were obtained from a discarded drilling machine, but the pinions for the back gear were cut with the aid of the actual attachment here described.

As it may be necessary to mount the cutter with considerable overhang beyond the spindle bearing, it is advisable to support the lower projecting end of the spindle in an outboard bearing.

This has been accomplished as shown in Fig. 8, where it will be seen that the bearing bush is carried in a bar attached to the lathe cross-slide ;

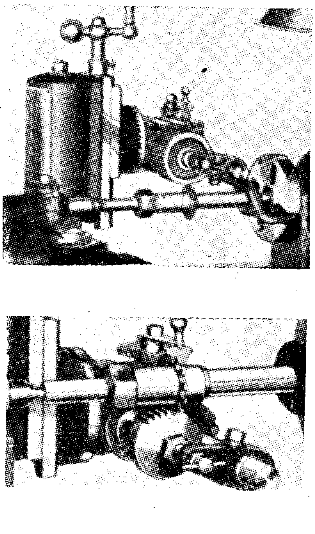

Fig. 4. *The Southbend gear-cutting attachment*

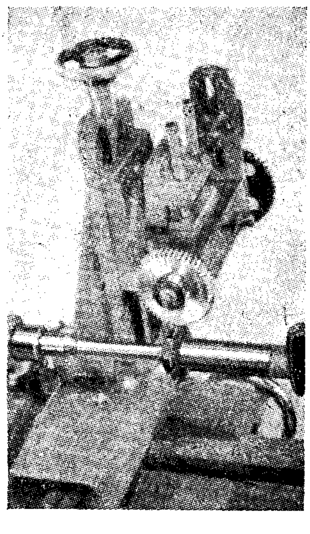

Fig. 5. *The Atlas gear-cutting attachment* in addition, an umbrella-shaped shroud is fitted to the spindle to prevent the ingress of chips into the bearing.

The belt drive to the attachment is taken from a pulley mounted on an overhead shaft, and to adjust the belt tension a pair of jockey pulleys are carried on a sliding bracket. As the belt tension in a drive of this length will vary but little with the small amount of saddle traverse required for ordinary gear-cutting, it is hardly necessary to fit a device for automatically maintaining a constant belt tension.

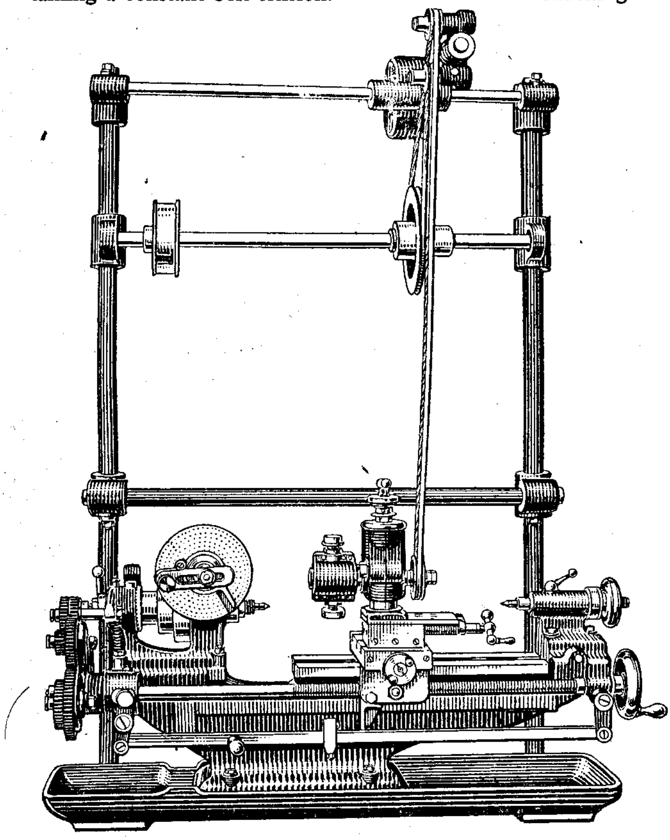

Fig. 6. The Drummond gear-cutting and indexing attachment

When this method of gear-cutting is adopted, the work can be bored and turned to size while secured in the lathe chuck; there is then no necessity to remove the part from the chuck for the gear-cutting operation. This is certainly an advantage, as the concentricity of the bore and the gear teeth is thus assured.

The gear blank can, however, if required, be secured to a mandrel mounted between the lathe centres.

The gear teeth are indexed either by means of a dividing-head controlling the rotation of the lathe mandrel, as illustrated in Fig. 9, or a change wheel secured to the tail of the mandrel can be used for this purpose, in conjunction with a suitable detent.

In the event of a train of change wheels being employed, inaccuracies in dividing will be reduced if the backlash in the gears is taken up by a weight, suspended from a cord attached to the chuck so that a constant rotational pull is exerted. The mass of the weight must, however, be sufficient to overcome any tendency for the gear-cutter to rotate the work under the machining stress imposed.

Where a change wheel is available with the same number of teeth as the wheel to be cut, the indexing is simple and direct, for the wheel is then secured to the mandrel and a rigid detent is used; likewise, intermediate divisions can be obtained by utilising the appropriate tooth spaces.

When these conditions do not apply and a wheel having, say, 24 teeth has to be cut, then $24 = 6 \times 4$, and 6 is multiplied by 5 to represent the standard 30-tooth wheel which is mounted on the mandrel. To reduce the number 30 to 24 it is multiplied by 4/5, and the wheel train is accordingly arranged as shown in Fig. 10.

A 50-tooth and a 40-tooth wheel are keyed together and mounted on the stud; the 50-tooth wheel is then meshed with the 30-tooth mandrel wheel, and the detent is used to index the tooth spaces of the 40-tooth wheel.

To prove the train, the driven wheels are multiplied together and then divided by the driving wheel:—

$$\frac{40 \times 30}{50} = \frac{1200}{50} = 24$$

Arranging the Feed

Where the cutter is driven from the lathe mandrel, the gear-cutting attachment carrying the work is traversed across the line of the cutter teeth by means of the cross-slide feedscrew. If the lathe has an automatic cross feed, the gear-cutting operation is facilitated and the regularity of the feed helps to impart a good finish to the work. Usually the rate of automatic cross feed is less than the corresponding longitudinal feed, so that, for example, in the small Southbend lathe fitted with a gearbox, the minimum rates obtainable are a half and one-and-a-half thousandths of an inch respectively for each turn of the mandrel.

On the other hand, when the work is mounted on the stationary lathe mandrel, the cutter is traversed along the work either by hand feeding, or by means of the power feed obtained from the leadscrew. The simplest way, perhaps, of arranging a drive for the leadscrew, independent of the lathe mandrel, is to disengage the mandrel driving belt, and then to fit a light round belt to transmit a drive from a small pulley on the lathe countershaft to a large pulley carried on the first quadrant stud. The latter pulley is keyed to a small

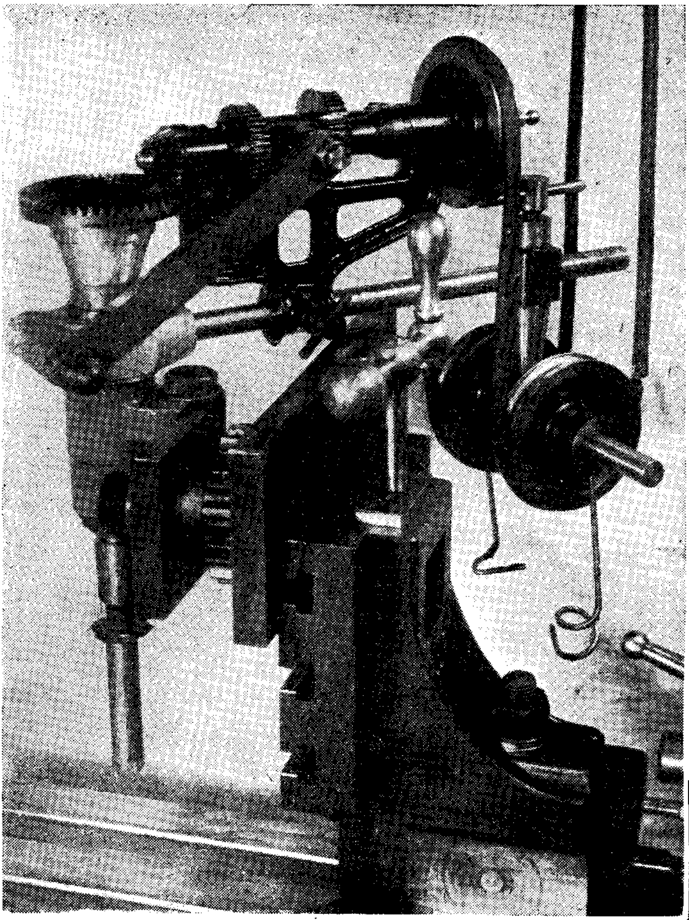

Fig. 7. A back-geared bevel-driven attachment mounted on the vertical slide

change wheel which in turn drives the leadscrew through a train of gears. By an arrangement of this sort, a saddle feed is usually obtainable sufficiently slow for ordinary gear-cutting.

An alternative and convenient method of providing an independent feed for the saddle is illustrated in Fig. 9. Here, the reduction of the countershaft or overhead shaft speed is obtained by means of a worm drive having a reduction ratio of some 80 to 1. As will be seen, this unit is built in the form of a closed gearbox and is attached to an adjustable arm bolted to the lathe quadrant. The worm wheel shaft is designed to carry a change wheel of any size that may be required to actuate the leadscrew in accordance with the rate of feed desired, and for the sake of convenience an idler wheel is interposed, but this does not, of course, affect the overall gear ratio of the drive. As the power transmitted is very small, the mechanism of the worm drive can be of quite light construction.

In passing, it may be noted that the worm consists merely of a portion of ½-in. Whitworth thread finished by lapping, and the worm wheel was machined by using a corresponding tap as a hob; the gears are supported in bushes fitted to the oil-tight gearbox. If the oil in the box is maintained at a level to allow the worm wheel to dip, adequate lubrication will be assured and little wear will take place under the light loading imposed.

Gear-cutters

There are many, no doubt, who will prefer to buy the cutters required for any particular gear-cutting operation; but as these tools are expensive, and as many workers are interested in making their own equipment, a detailed description of the production of these cutters by simple but effective machining methods will be given in a subsequent article.

The most widely known form of circular involute gear-cutter is, perhaps, that manufactured by Messrs. Brown & Sharpe and illustrated in the catalogues of leading tool merchants..

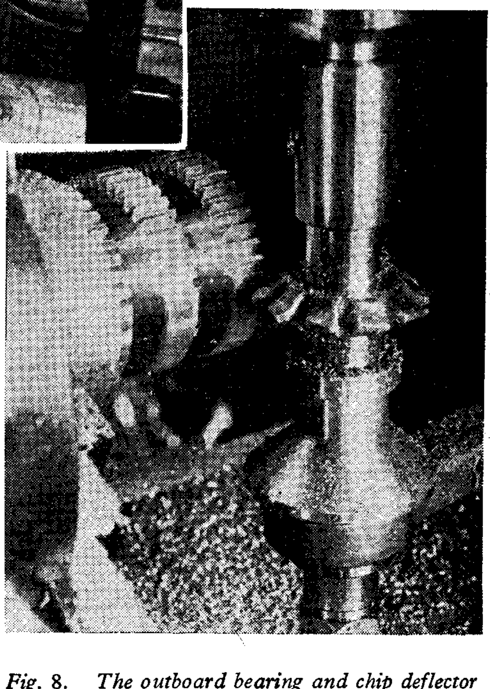

Fig. 8. The outboard bearing and chip deflector fitted to the spindle

These cutters are also made in this country, notably by the B.S.A. Company; besides these, small cutters of Swiss manufacture designed for clockmaking and instrument work are at times procurable.

As the radius of the curvature of an involute tooth varies with the number of teeth on the pinion, cutters of the correct diametral pitch must also correspond with the number of teeth cut on the gear blank. For each diametral pitch, therefore, a series of cutters is manufactured to cover the whole range of wheels from the smallest with 12 teeth to the largest having 135 teeth or more.

The following Table shows that, in accordance with the Brown & Sharpe system, eight cutters are required to cut the full range of wheels of any particular pitch, and it should be noted that all gears cut to the same pitch with these cutters will work together.

No. 1	will cut wheels from	135 teeth	to a rack.
2		55	134 teeth
3		35	54
4		26	34
No. 5	will cut wheels from	21 teeth	to 25 teeth
6		17	20
7		14	16
8		12	13

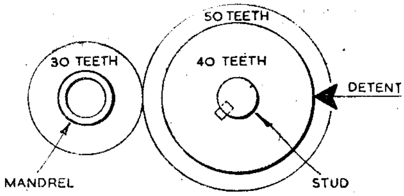

Fig. 10. *A gear train used for indexing a 24-tooth wheel*

It will be seen that the smaller the number of teeth on the wheel the more critical is the form of the cutter, and so the less its range. The provision of a single cutter to machine gears, having different numbers of teeth over a small range, has been planned to produce gears giving a satisfactory performance under ordinary working conditions; but an intermediate series of gear-cutters, designated by half numbers, is also available when greater accuracy is required. To obtain a tooth form of still greater accuracy, a separate cutter for each tooth number should be employed. Accurately cut involute gears have the advantage that the angular velocity of the individual members of a gear train remains constant, even if the depth of meshing is not exactly correct; this fact is of importance where a gear train is employed for indexing operations.

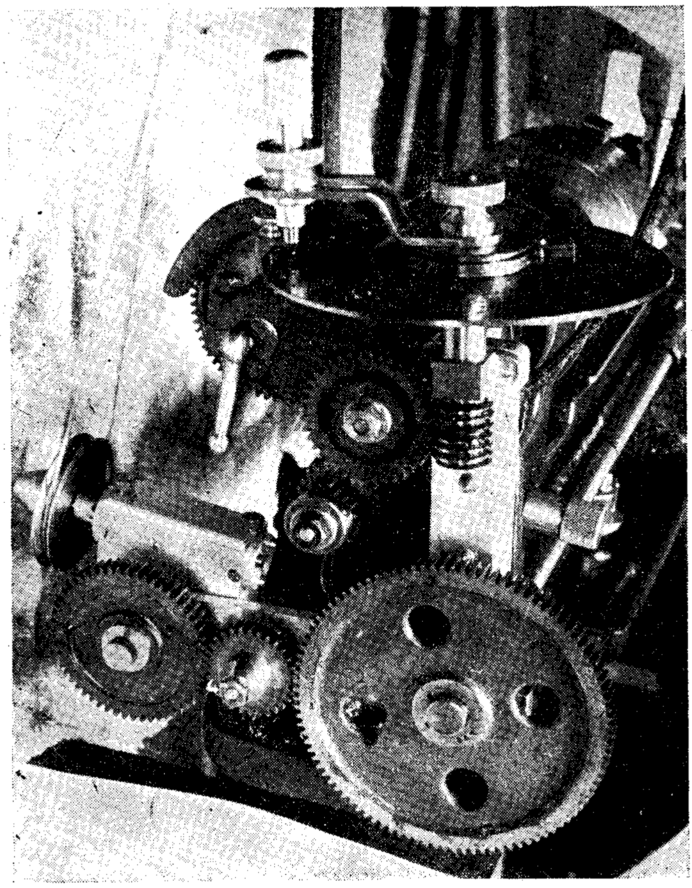

Fig. 9. *The mandrel dividing-head and the worm-drive attachment for driving the leadscrew*

A further factor to be taken into account when selecting an appropriate gear-cutter is the pitch of the gear teeth. This can be reckoned either as circular pitch, denoted by the distance between the centres of two adjacent teeth measured on the pitch circle, or as diametral pitch represented by the number of teeth to each inch of the pitch circle diameter.

Diametral pitch is in general use for the gears fitted to machine tools and other engineering products of this quality; moreover, this system simplifies the calculations required in gear-cutting and in laying out the correct working centres for the assembled gears.

As an example, a

32-tooth gear wheel of 16 diametral pitch will have a pitch circle diameter of $\frac{32}{16}$ in. = 2 in.; further the diameter of the gear blank is obtained by increasing the number of the teeth by 2 and again dividing by the diametral pitch, so that this diameter equals $\frac{32 + 2}{16} = 2\frac{1}{8}$ in.

The working centre distance between any two wheels is determined by adding together the radii of their pitch circles.

Thus, to mesh correctly two wheels of 16 diametral pitch and having 64 and 32 teeth respectively; the diameters of the two pitch circles are $\frac{64}{16} = 4$ in. and $\frac{32}{16} = 2$ in.; the sum, therefore, of the radii, $2 + 1 = 3$ in., represents the distance between the working centres of the two gears.

To obtain the best results with machine-cut gears, and at the same time to promote quiet running and good wearing qualities, especially where high speeds are used, a fine, rather than a coarse pitch, should be employed; the strength of the individual teeth to withstand the load imposed is then ensured by making the wheel face of adequate width. A narrow tooth of coarse pitch will be less able to withstand shocks and will be noisier in operation than a broad tooth of fine pitch.

Materials for Gear Wheels

The gears made in the small workshop will usually be of ample strength to serve the purpose for which they are designed, and attention will be directed more to ensuring quiet running and long working life.

Cast-iron gears, such as lathe change wheels, work well together at low or moderate speeds and under light loading, but better operation at higher speeds and greater tooth strength will be obtained if the smaller wheels are made of steel.

Cast-iron gears have the advantage that with use, and if not overloaded, the teeth assume a glazed, hard-wearing surface requiring but a minimum of lubrication.

Where the teeth are more highly stressed and subjected to shock, as in the gearboxes fitted to lathes, the gears are preferably made of hardened alloy-steel of high tensile strength.

To correct any distortion that may result from the hardening process, these gears have their teeth accurately form-ground as a finishing operation. Case-hardened mild-steel gears have excellent wearing properties, but if they are brought into mesh while running, the edges of the teeth may become chipped.

Soft steel gears should not as a rule be run together, as with this combination wear may be rapid if light loading is exceeded.

To distribute tooth wear more evenly between the wheels, the pinion, or smaller gear, should be hardened; in the small workshop it is advisable to restrict the hardening or case-hardening process to small gears, for it is not usually possible to correct the distortion that is apt to arise in large gears and those of slender form.

Where a bronze gear wheel is used, the smaller wheel or pinion should be made of steel and preferably hardened in order to resist wear. For light drives at moderate speeds a gear wheel machined from duralumin can be employed to run with a bronze or steel pinion.

Gear wheels made of plastic material such as Tufnol are excellent for quiet running and have good wearing properties, but it should be borne in mind that some plastics cause rapid wear of steel cutting tools, and a gear-cutter may in this way be subjected to abnormal wear.

Gears made from plastics or plasticised fabrics must be backed by a brass plate when being cut, or they will become ragged at the point where the cutter emerges from the blank at the end of the cut.

(*To be continued*)

LIMITS—and Limitations!

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drudgery instead of being, as it should be, a pleasure. The conditions under which the model engineer works approach more nearly to those of the old-time craftsman than the modern works operative, and I believe most readers will agree with me that this is how it should be.

The outlook of the model engineer, who regards his work as a recreation and a pleasure, not to mention an outlet for his creative urge, cannot be compared to that of the professional engineer, whose incentive is entirely different, and in many cases must produce accurate work in the minimum time, and cope with other economic factors which are not encountered in the amateur workshop.

With regard to the comparison between fractional and metric systems of measurement, I think there is very little difference or difficulty in working to either, but I believe the alleged advantages of the metric system are largely fallacious. Many competent workmen, when measuring either in metric terms or decimal-inches, will either consciously or unconsciously translate them in progressive fractional divisions of an inch "plus or minus a sixty-fourth," and if one seriously thinks it over, it will often be found that this is a more "natural" method of subdividing small dimensions than the use of any decimal system. However, to those who dislike either system, there are always conversion tables available, and in cases where odd or inconvenient figures emerge, it is usually possible to work to the nearest round figure, and use "comparative" methods of measurement to ensure accurate fitting of essential parts.