IN THE WORKSHOP

by "Duplex"

*38—Gear-cutting in the Lathe

IF a gear wheel is to work satisfactorily, it is, of course, essential that its bore should be formed concentrically in relation to the circle on which the teeth lie. The blank is, therefore, either turned and bored at one setting, or the bore is first machined and the outer diameter is then turned to size with the work mounted on a true-running mandrel supported between the lathe centres; alternatively, a stub mandrel, turned to size while gripped in the chuck, may be used for this purpose.

When a mandrel is used in this way, both the side faces of the work can be finished-turned to reduce the blank to the correct width. Where the diametral pitch system is used, it has already been seen that the number of teeth divided by the diametral pitch gives the diameter of the wheel measured on the pitch-line of the teeth; also, if the overall diameter is required, then two teeth are added and the total is again divided by the diametral pitch. Supposing, therefore, that a pinion of 32 D.P. having 30 teeth, has to be cut; the outside diameter of the blank will then be $\frac{30 + 2}{32}$, which equals 1 in.

When turning the blank to its finished diameter, it is important that an exact measurement should be made with a micrometer, for, as will be seen later, the teeth are cut to the correct depth and thickness by feeding the cutter inwards and using the outer diameter of the blank as a reference surface.

If the finished blank has to be removed from the chuck, it is essential for the gear-cutting operation that it should be remounted on a true-running arbor, supported either between the lathe centres or in the gear-cutting attachment as the case may be.

Cutter Speed

It is advisable to drive the cutter at approximately the correct speed, for if it runs too slowly the machining operation will be unnecessarily prolonged, and if too fast, the teeth are apt to become blunted.

As in ordinary turning, the cutting speed depends both on the material being machined and on the type of steel of which the tool is made. In milling operations, such as gear-cutting, it is the common practice, in the case of steel at any rate, to use a cutting speed of some two-thirds that employed when turning.

The following Table shows the linear feet per minute at the outer diameter of the cutter appropriate for different materials; this refers to a carbon-steel gear-cutter, but these speeds can be safely doubled when a high-speed steel cutter is used.

Material	Peripheral speed of cutter ft. per minute
Carbon-steel ..	25-30
Mild-steel ..	30-40
Cast-iron ..	40-50
Bronze ..	60-80
Brass	90-100
Aluminium ..	200-300

The following are the approximate peripheral speeds for cutters of various diameters.

Revs. per min.	Diameter of Cutter	Speed ft. per min.
100	1 in.	25
100	1¼ ,,	30
100	1½ ,,	37
100	1¾ ,,	44
100	2 ,,	50

To obtain the revolutions per minute the cutter should run, multiply the figure 100 in the first column by the peripheral speed required, and divide the product by the figure shown in the third column; thus, supposing a 1 in. diameter cutter is to be given a peripheral speed of 50 ft. per min. for machining a cast-iron pinion: then $\frac{100 \times 50}{25} = 200$ r.p.m.

This example may also be worked out quite simply by dividing the peripheral speed required by the approximate circumference of the cutter expressed in feet: $50 \div \frac{3}{12} = 50 \times \frac{12}{3} = 200$ r.p.m.

It will not, of course, be possible in many cases to drive the cutter at exactly the calculated speed, but this is immaterial, as the cutting speeds given can be only approximate and vary over a fairly wide range; it is important, however, to run the cutter too slowly rather than at an excessive speed in order to preserve the sharpness of its teeth.

Centring the Cutter

After the cutter and the gear blank have been mounted in the lathe, and the rigidity of the assembly has been enhanced by employing, whenever possible, the tailstock centre and the supporting centre fitted to the overarm of the attachment, the next step is to align the cutter and the gear blank so that the teeth will be machined in a truly radial direction. If this adjustment is not correctly made, the teeth will

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in some degree have the form of ratchet teeth; Fig. 1 illustrates diagrammatically the appearance of the teeth resulting from faulty centring.

Care is taken in the manufacture of commercial gear-cutters to ensure that the teeth are formed equidistant from the two side faces of the cutter; this allows measurements to be taken from these two surfaces when setting the cutter exactly on the cross centre-line of the work.

Fig. 2 illustrates one method of locating the cutter by means of a try-square resting on the lathe cross-slide, and applied in turn to either side of the work. The distances A and B between the sides of the cutter and the edge of the square can then be checked for equality, either with the aid of the inside calipers or by employing a micrometer.

When the cutter is mounted vertically, as in Fig. 3, it can be set with reference to the lathe centre height (A) by setting the lower face of the cutter below this height by an amount equal to half the thickness (B) of the cutter. Needless to say, these measurements must be made with greater accuracy than can be obtained by merely using a rule for the purpose; instead, the thickness of the cutter is measured with the micrometer and the distance (C) is then correctly adjusted with the aid of the inside callipers set from the micrometer.

An alternative method is to turn a piece of rod held in the chuck to a diameter equal to the thickness of the cutter, next, as represented in Fig. 4, the dial test indicator is applied to the rod and a reading is taken; the cutter is then raised until the indicator in contact with its upper surface records a similar reading. Should it not be found possible to apply the contact point of the indicator directly to the cutter in this way, the reverse attachment, designed for application to bored holes, is fitted to the indicator and its ball-ended lever is then brought in turn into contact with the *lower* surface of the rod and the cutter.

Much trouble may be saved if a small adjustable

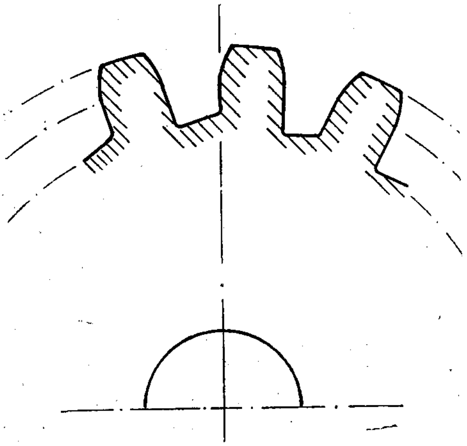


Fig. 1. *Showing teeth cut off-centre*

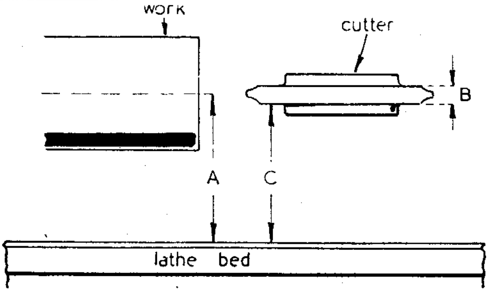


Fig. 3. *Centring cutter from lathe bed*

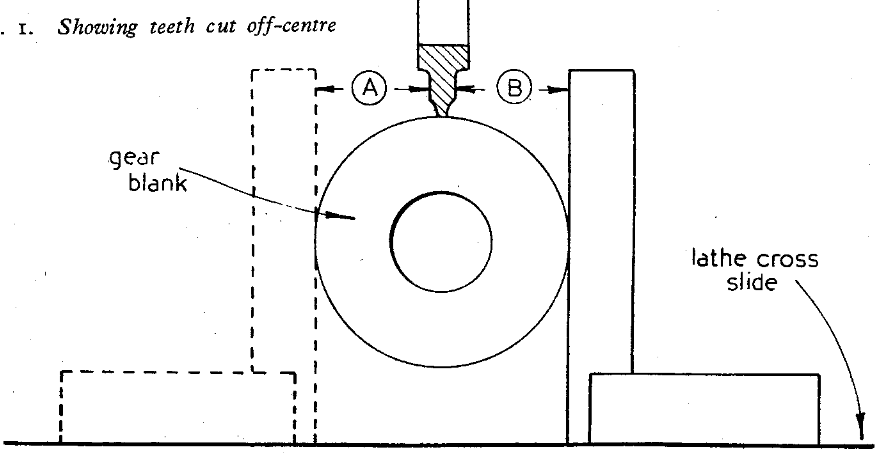


Fig. 2. *Centring cutters with a try-square* gauge of the form shown in Fig. 5 is employed to set the cutter.

This gauge stands on the lathe bed or cross-slide, and the V-notch, after being set to centre height against the tailstock centre, is offered to the cutter, which is then adjusted until both limbs of the V make even contact with the tips of the teeth.

An alternative form of setting gauge is that depicted in Fig. 6, which is designed for fitting to the scriber clamp of the surface gauge; this allows the fine adjustment of the gauge to be used to facilitate the initial setting operation.

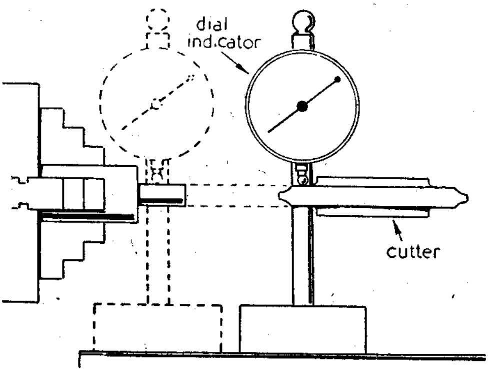


Fig. 4. Centring cutter with test indicator

One disadvantage of this type of device is that it may be found rather difficult to determine the exact setting of cutters of very small pitch; but this will be largely overcome if in this case a V of very shallow form is used.

One method of checking the setting of a vertically-mounted cutter is to bring it into contact with a centre-line scribed on the work by means of a V-tool mounted on its side at centre height; the cutter is then turned by hand until, as shown in Fig. 7, it just cuts the edge of the work; examination with a lens should then reveal any error of setting requiring correction.

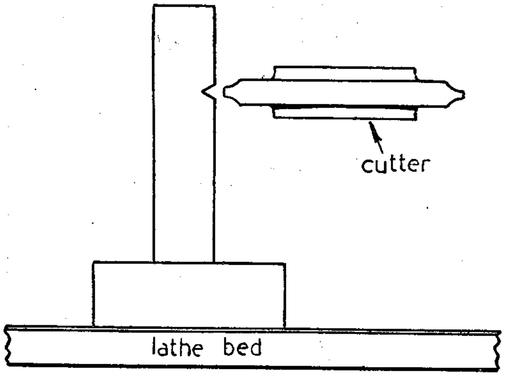


Fig. 5. Using V-gauge for centring cutter

This method can also be applied when the gear blank is mounted in a gear-cutting attachment, but in this case a cross centre-line should be scribed on the blank at the time of the turning operation. This cross line is set vertically by means of a square, and the adjustment of the cutter, mounted between the lathe centres, is checked, as in the previous instance, by an examination of the impression made by the cutter teeth.

Rate of Feed and Depth of Cut

Now that the speed of the cutter has been set and its correct alignment with the work adjusted, it remains to determine the rate of feed and the depth of cut in order to carry out the actual machining of the gear teeth.

The feed recommended by Messrs. Brown and Sharpe for a high-speed steel cutter of 12 D.P., when machining the gear teeth to full depth at a single passage, represents a cut of approximately 2 thousandths of an inch per tooth, or a total of some 30 thousandths for each revolution of the cutter. These figures apply to a commercial type of milling-machine of great rigidity specially designed for this work. This performance should not, however, be expected of a small lathe, and the amount of metal removed in a given time must be correspondingly reduced.

In ordinary turning operations, where the rate of feed is perhaps 200 turns of the mandrel for each inch of traverse, the depth of cut might be, say, 60 thousandths of an inch for roughing and may be 5 thousandths for finishing the work.

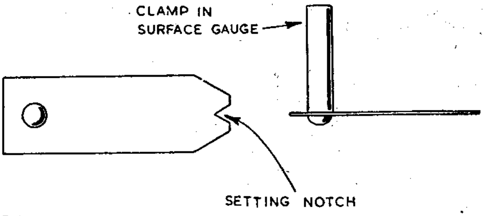


Fig. 6. V-gauge for fitting to surface gauge

In this instance the conditions are favourable for the rapid removal of metal, for the tool is provided with suitable rake and the cut is continuous; the gear-cutter, on the other hand, cuts simultaneously on three faces which have little or no rake, and in addition, the cutting action of the teeth is intermittent.

If, when gear-cutting, the rate of feed mentioned, and representing a cut of 5 thousandths of an inch per revolution of the cutter, is retained, it may be found that the depth of cut has to be reduced to obtain satisfactory machining, but this will depend largely on the rigidity of both the milling attachment and the lathe itself.

This cut of 5 thousandths of an inch per revolution represents half a thousandth per tooth where the cutter has ten teeth; this should ensure that every tooth shares in the cutting operation, and that some do not become blunted by merely rubbing against the work, for it is almost inevitable that the cutter, when mounted, will not run with absolute truth. Should the cutter run markedly out-of-tooth, the brunt of the work will fall on a few teeth only and the gear-cutting operation, besides being slowed in proportion, will be more akin to fly-cutting.

The depth to which the tooth must be cut, termed in gear-cutting parlance the Whole Depth of Tooth, is given in the following Table for the more commonly used diametral pitches.

Diametral Pitch	Whole Depth of Tooth
10	0.2157 in.
12	0.1798 „
14	0.1541 „
16	0.1348 „
18	0.1198 „
20	0.1079 „
22	0.0980 „
24	0.0898 „
26	0.0829 „
28	0.0770 „
30	0.0719 „
32	0.0674 „
34	0.0634 „
36	0.0599 „
38	0.0568 „
40	0.0539 „

Should the tooth depth of other pitches be required, this information will be found in any standard reference book dealing with the subject.

To determine the depth of cut allowable, it is advisable, in the first instance, to take a trial cut using a hand-feed as nearly as possible equal to the power feed to be employed; the feel of the cut, the noise produced, and any resulting vibration or chatter will then serve to indicate to the operator when the maximum allowable depth of cut has been reached.

Needless to say, the lathe slides should be correctly adjusted to eliminate shake, and it is advisable to set the cross-slide gib to give rather stiff working; in addition, in order to maintain rigidity, any slide that is not in actual operation should be firmly locked.

If, after taking these precautions, there is any tendency for chatter to develop, it may be found advisable to reduce the speed at which the cutter is driven.

To ensure that each tooth is cut to the correct depth, the cutter is brought into contact with the gear blank, and the index of the cross-slide or vertical-slide, as the case may be, is set to the zero mark and locked in that position.

From time to time during the machining operation the adjustment of the supporting centres should be checked so that any slackness that may have developed can be taken up.

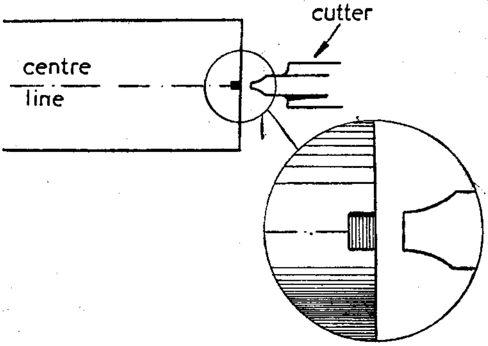
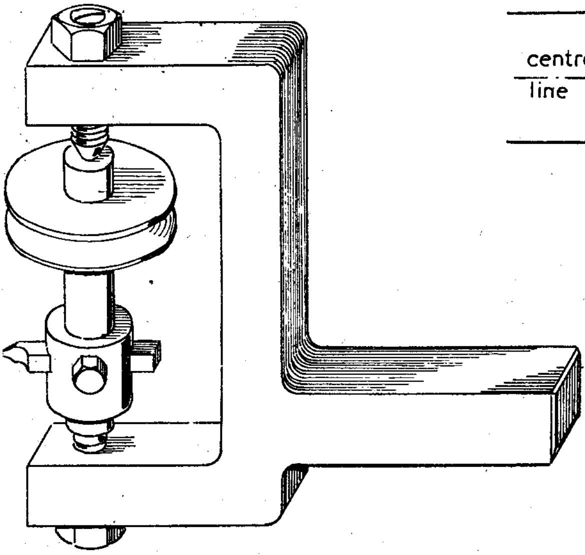


Fig. 7. Checking the setting of the cutter



Left.—Fig. 8. Fly-cutter mounted in cutter frame

The advantage gained by cutting each tooth to the full depth at a single passage of the cutter is chiefly that of time and trouble saved, for the teeth have then to be indexed once only.

On the other hand, when two or more cuts are used and a light finishing cut is taken over each tooth in succession, both the mechanism and the work are subjected to less stress and the accuracy of the teeth will in consequence be enhanced; furthermore, the finishing cut will remove any inaccuracy resulting from distortion due to local heating during the machining operation, and any wear of the tool's cutting edges will be more equally distributed over all the teeth.

Fly-Cutting Gear Wheels

To save the expense of buying the appropriate circular gear-cutters, some workers use fly-cutters for machining toothed wheels. Although this operation might be found intolerably slow for cutting large or coarse-pitch gears in steel or cast-iron, it is quite satisfactory for machining brass or duralumin wheels of moderate or fine pitch, particularly where the tooth face is narrow.

In the case of the latter materials, the cutter can be run at high speed, and the speed can be correspondingly increased as the radius of the cutter is reduced; this will allow a rate of feed to be employed that will be found sufficiently rapid to give satisfactory working.

The cutters can be conveniently made of silver-steel and, after they have been filed to shape by using a gear wheel as a template, the cutting edges must be backed off to form the necessary clearances. If, following the hardening and tempering processes, these tools are carefully honed with an oilstone slip, a very high finish will be imparted to the surface of the teeth cut.

Cutters of this form can be readily mounted and operated in a cutter frame of the type illustrated in Fig. 8. The projecting lug on the frame is secured in the lathe toolpost, and the spindle, which is driven from the overhead, runs on two adjustable, coned bearing-screws.

As shown in Fig. 9, the enlarged portion of the spindle is cross-drilled and then filed to provide a seating for the cutter, which is secured in place by means of a set-screw.

The cutter can be set to the centre height of the work by using packing strips in the toolpost, but it may be found easier to make the final setting by adjusting the pivot-screws to raise or lower the cutter for an exact distance.

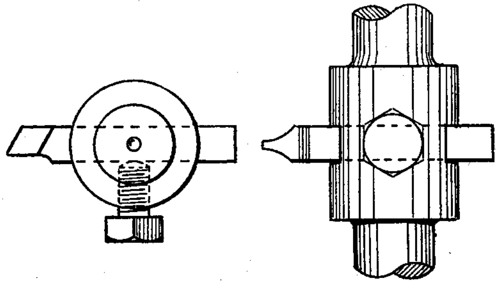


Fig. 9. Fly-cutter secured in spindle of cutter frame

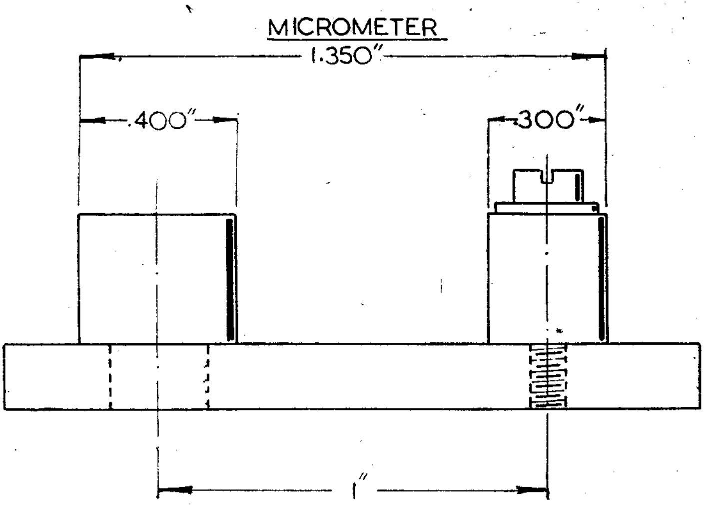


Fig. 10. Setting gear centres with a toolmaker's button

It may be mentioned that single-pointed cutters of this type can be used to plane or shape gear wheels in the lathe.

For this purpose, the cutter is mounted on its side at centre height in the toolpost. The gear blank is held in the chuck or is mounted on an arbor supported between the lathe centres, and the teeth are indexed either by using a mandrel dividing-head or by means of a change wheel secured to the tail of the mandrel. The tool, which is fed inwards by operating the cross-slide, is moved across the face of the blank either by traversing the saddle or, if preferred, the top-slide feedscrew can be removed to allow this slide to be worked to and fro by means of a hand-lever pivoted to the lathe bed or to the cross-slide.

When machining bronze gears in this way, it is advisable to withdraw the tool from the work on the return stroke, otherwise it may be found that the clearance at the cutting edges is soon worn away.

Meshing Gear Wheels

Before leaving this subject, it may be opportune to describe briefly the methods commonly employed in small machine shops for locating gear wheels to mesh and run correctly. In large concerns this work would, of course, be carried out with the aid of suitable jigs.

Gears cut on the diametral pitch system should be meshed so that the pitch circles of the teeth are in contact.

As previously explained, the diameter of the pitch circle is equal to the number of teeth on the wheel divided by the diametral pitch; the distance between the wheel centres is obtained, therefore, by adding together the radii of the pitch circles of the two wheels.

When setting out the position of the two whee shaft bearings, it is advisable to mark-out and machine one bearing and then to locate the second from this; in this way any error arising in the boring of the first bearing will be eliminated at the subsequent setting to locate the second shaft bearing.

Where it is required to locate a pinion to mesh with a wheel whose shaft bearing has already been machined, the following procedure, illustrated in Fig. 10, may be adopted.

Here, the two 32-tooth gears of 32 D.P., taken as an example, have a pitch circle 1 in. in diameter, and their working centres will therefore lie exactly 1 in. apart.

A spigot is turned to fit the bored bearing accurately, and its head is made to an exact diameter of, say, 0.400 in.

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ratio is so large on models that the full T.E. cannot be utilised in the ordinary way. Compare, for example, two engines, one having double the Tractive Effort of the other. Hauling an equal load, in all probability the fuel consumption of each would be practically the same, but the result of the formula including this factor would indicate one as being twice as good as the other. Furthermore, area of piston rod and friction losses are ignored, both of which become increasingly important as the size of the machine diminishes. In a full-size locomotive the ratio of T.E. to Adhesive weight is usually kept about 1 : 3½ or 1 : 4 and a high proportion of the boiler pressure is available in the steam-chest. In small models, on the other hand, with the large cylinders commonly used, the T.E./A.W. ratio is vastly different. Slipping under heavy load is avoided by careful starting and sand, but advantages in economy and speed are obtained by linking up. Even so, it is doubtful if high pressure is maintained in the steam-chest, except at low speeds. Note the wonderful showing of the "Rainhill" locomotive at the South London trials, where it would seem that practically the full "Theoretical T.E." was "gainfully employed."

In the following table the percentage of steam-chest pressure exerted on the piston is shown for different cut-offs :

Cut-off	at	75%	stroke,	mean	effective	pressure	90
"	"	67%	"	"	"	"	80
"	"	50%	"	"	"	"	69
"	"	33%	"	"	"	"	50
"	"	25%	"	"	"	"	40

(Source of information—*Molesworth's Engineering Pocket-book.*)

It will be seen that for one-third of the steam consumption, nearly half of the power is available.

A table showing calculations for three hypothetical engines is reproduced on the previous page.

From the foregoing figures, which it will be seen should give equal results for the three engines, columns as in Table I are tabulated below :

	Gauge	4	5	6	7
A. Based on Theoretical load (line 6)	5 ft.	350	70.7	1,698	14.6
	5 in.	29.2	13	25.9	14.6
	2½ in.	14.6	8.1	8.1	14.6
B. Based on Actual or probable load (line 12) without taking into account any probable increase in fuel consumption	5 ft.	350	70.7	1,698	14.6
	5 in.	43.8	19.4	39	21.9
	2½ in.	26.3	14.6	14.6	26.3

In the Workshop

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A standard toolmaker's button, or one made for the purpose, having a diameter of 0.300 in. is then attached to the work face with its centre at a distance of 1 in. from the spigot centre, that is to say as nearly as this can be measured with a rule.

To locate the button accurately, its position is determined by applying the micrometer over both it and the spigot, as indicated in the drawing ; when the position of the button has been adjusted in this way, the central clamping-screw is tightened to secure the button firmly in place.

The micrometer reading required is equal to the 1 in. centre distance between the gears, plus half the diameters of both the spigot and the button which is $\frac{0.400}{2} + \frac{0.300}{2} = 0.350$ in., thus giving a total distance of 1.350 in.

Finally, when the work has been set-up in the lathe so that the button is located on the lathe centre-line, the bearing for the second gear wheel shaft can be bored with the assurance that it will be correctly positioned. Where the work is bolted to the boring table, it is located by applying the test indicator, while secured to the lathe mandrel, to the button and then turning the mandrel slowly by hand ; but if the work is held in the chuck, the test indicator is then used to set the button to run truly.

Should there be any difficulty in locating the gear centres by the above methods, the following alternative procedure for ensuring the correct meshing of the wheels may be adopted.

One wheel bearing is bored and a pivot is fitted to it to carry the wheel ; next, a second short pivot, akin to a toolmaker's button, is made to fit the second wheel. The latter pivot is lightly secured to the work face by means of its clamping-screw, and its position is adjusted until the wheels appear to mesh correctly and are found to run smoothly together with but little backlash. The second bearing can then be bored, as in the previous example, by using the button as a guide when setting-up the work in the lathe.

(*To be continued.*)