ELEMENTS OF SPHERICAL TURNING

A review of methods and appliances for machining contours involving circular arcs

by Edgar T. Westbury

THE NEED to machine components to spherical contours is often encountered in mechanical engineering, and many devices varying in design and complexity, have been produced for this purpose. Several of these have been described at various times in *Model Engineer*, but in view of the many queries concerning spherical turning which have arisen, there is a call for a general review of the principles employed and the methods applicable to particular kinds of work.

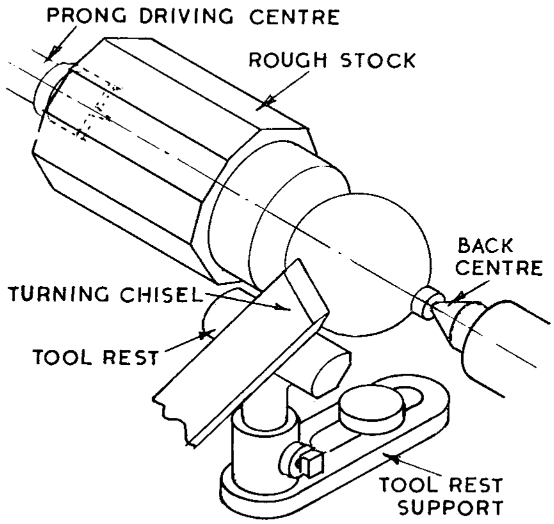
Freehand methods

A great deal obviously depends on the degree of accuracy required in the spherical contour of the work, and when using simple devices, this calls for considerable skill on the part of the operator. More positive accuracy can be obtained by devices with mechanical control of the tool movement, but only provided that these are well designed and properly adjusted. In this respect, the results obtained are not always of a quality commensurate with the elaboration of the apparatus employed. Simple hand-controlled tools will often produce a standard of accuracy sufficient for practical purposes. In wood turning, for instance, the appearance is the main, or possibly the only, thing that matters, and the skilled turner obtains the desired result with no other tools than the roughing-out gouge and the oblique-edged chisel (Fig. 1). These are normally applied at a tangent near the top surface of the work and tilted or swivelled on the hand rest to produce convex contours.

Most spherical contours comprise only a part of a complete sphere, with a supporting stem or stalk. Such parts as balanced handles for machine tools, stanchions, or handrail knobs, and ball-ended rods and links are in this category. The production of a complete ball is not often necessary in mechanical turning practice, because balls of precise accuracy, in a wide variety of sizes and various materials, can generally be obtained ready made. It may, however, be worth while to refer briefly to the production of such items as billiard balls, in which high accuracy has been obtained by the use of hand tools alone. Cup chucks, often made in hardwood, are generally employed to hold the material, which is roughed out as closely to finished shape as possible, and then chucked crosswise, and at other angles, to its original axis, for the correction of spherical errors. These operations, needless to say, call for a special skill of both hand and eye; they may, perhaps, have now been completely superseded by modern production processes, but were certainly employed up to quite recent years.

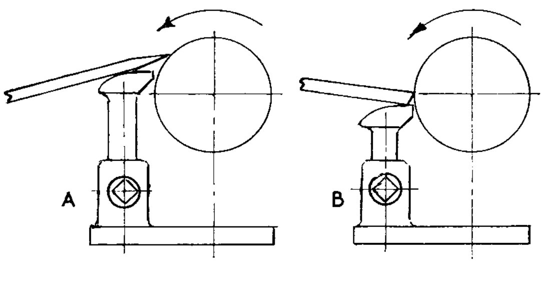
Cutting angles

The tools and techniques employed in turning wood and other relatively soft materials (Fig. 2A) are not so well suited to working on hard metals, in which cutting angles, and to some extent methods of application, are necessarily different. Tools for metal are usually applied with the top



Above: Fig. 1.

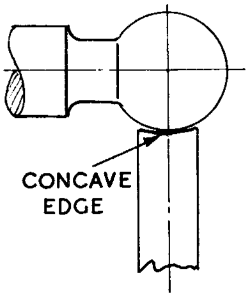
Below: Fig. 2.



cutting edge near level with the horizontal centre-line of the work (Fig. 2B), and the cutting angles are much more obtuse, so that the loading is higher, and generally results in less controllable action. Though hand tools are applicable to metal turning, and may in certain cases be used to advantage, they are rarely seen in modern machine shops, and in consequence few turners acquire the skill necessary to manipulate them properly. I have always believed that it is worth while to obtain some practice in using hand tools, as jobbing work often involves some contours which are more readily produced in this way than in any other. One of my friends, whom I recently persuaded to try out hand tools for turning machine tool handles, was agreeably surprised by the ease with which pleasing contours and high finish can be obtained by their aid.

Special hand tools

Some turners employ a concave-form hand tool as shown in Fig. 3 for turning spherical or other convex contours. This certainly helps in producing the shape, and avoiding the formation of hard lines or ridges, but the radius of the cutting edge should always be greater than that of the spherical curve to be produced. No attempt should be made to use the tools as a *forming* tool in the accepted sense; it still calls for some manipulative skill to produce the right shape.



Left: Fig. 3. Hand turning tool with concave edge.

A type of tool frequently recommended for spherical turning is that which consists of a tube with the end ground at a bevel angle to form a cutting edge. As steel tubing of a nature suitable for hardening and tempering is not easy to obtain, this tool can be made from silver steel rod, drilled concentrically to a size which leaves a wall thickness of about 1/16 in., and long enough to give good hand control, with or without the addition of an extension handle. The end is turned to a suitable bevel angle to provide a cutting edge, and after hardening and tempering, this can be sharpened by means of an oilstone while running in the lathe.

It is interesting to observe the effect of different cutting angles, and their angular position in relation to the work, when using this type of tool. Sometimes the edge is bevelled internally at a fairly acute angle (Fig. 4A), which is usually most convenient for working on soft materials, with the tool on an elevated rest, or inclined upwards so that it is presented more or less tangentially. It thus works as an internally-ground gouge, which is not the easiest of tools to manipulate on harder material, even when the acuteness of the angle is considerably reduced. The tool is liable to become clogged with cuttings or swarf unless openings are provided for its clearance.

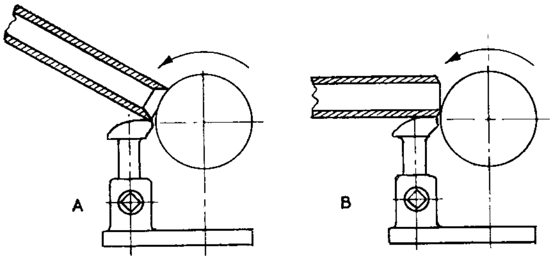


Fig. 4: The use of tubular turning tools on soft and hard materials.

An externally-bevelled edge, at an angle to suit the material to be turned, as in Fig. 4B, is generally easier to manipulate, and may be used on either convex or concave contours. There may be a case for a tool with both internal and external bevel angles in certain conditions, but so far I have never had occasion to try it. Another useful hand tool for spherical turning may be made from flat carbon steel by drilling a hole near the end and countersinking it to a suitable angle. This also should be made long enough for comfortable handling, preferably by providing a pointed tang to which a handle can be fitted. Tools of this type are applied on the top of the work, with an elevated tool rest, but the cutting thrust is in the tangential direction, so that for anything more than a mere scrape, they call for more physical effort than tools in which the load is taken on the tool rest.

Gauging contours

When forming contours by " freehand " methods such as those described, form gauges or templates may be used with advantage to check accuracy. Standard radius gauges will give a wide range of precise circular arcs, applicable to spherical contours, but most of them only extend over 90 deg., with straight tangential sides not applicable to wider arcs. This prevents them being used on work which is supported by a stem on the left or right-hand side, as it nearly always is. I have found it worth while to make radius gauges as required by drilling and reaming holes in thin sheet metal and cutting away the unwanted part; they may be adapted to check the shape of the neck or stem of the sphere, and also to cope with

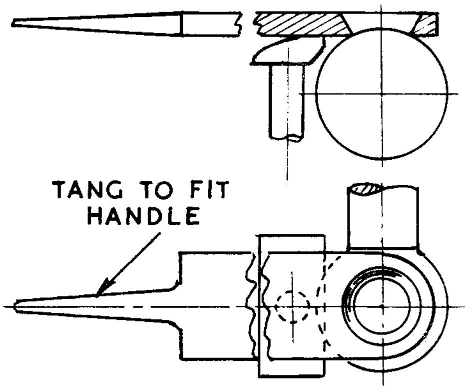


Fig. 5: Flat tool for ball turning.

more complex shapes. When using a template, a sheet of white paper, or other reflector of *diffused* light, should be placed behind the work, so that the slightest deviation in its contour can readily be detected.

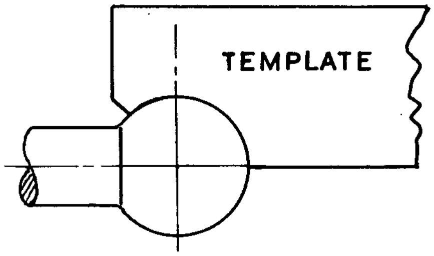


Fig. 6: Use of template to check contour.

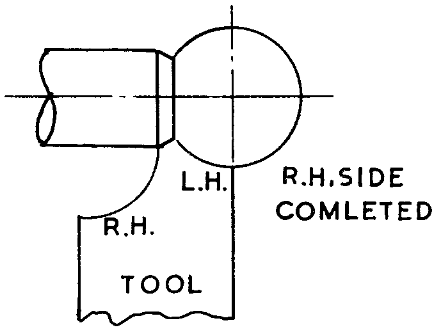
In industrial production, spherical and other contours are often turned by means of form tools mounted in the slide rest in which the cutting edge is of negative shape to that of the article to be turned. The extent to which such tools can be used in jobbing work, however, is rather limited, primarily because accurate forming of the edge, by grinding or otherwise, is a difficult operation, and one tool will only produce one contour. Precision of circular form is only possible at an exact radial setting, and allowance must be made for rake and clearance angles. If the tools are of substantial width, the cutting load is very high, and when used in light lathes, they are liable to chattering or digging in. For certain small components which have to be produced to uniform shape and size in quantities, form tools can be usefully employed, and undoubtedly enable time to be saved compared to other methods, but apart from this they have little application in the small workshop. Small form tools are generally made from flat tool steel, which, after annealing, can be filed to the required shape, and honed to a keen edge before hardening and tempering. When re-sharpening is required, they should be ground on the top face only. For heavier and more continuous use, form tools of circular disc shape can be turned to the required contour and notched to provide the cutting edge. These obviously have a much longer life than flat tools, as the cutting edge can be ground away and re-set many times before they are worn out. Success in their use depends upon selection of suitable tool steel and its heat treatment, also on producing the highest possible finish of the contour face.

Some small ball turning operations can be speedily carried out by the use of tools which form approximately *half* the contour at one setting. A single tool, with approximately a quarter of the contour formed on each side as in Fig. 7, can be used, and as it is not practicable to turn the left-hand side of the ball right to the centre, the right-hand side of the form tool is shaped to allow for leaving a certain diameter for finishing, or to provide a supporting stem if required. The circular arcs of the cutting edge can be machined to shape by end milling cutters of suitable diameter. For accurate work, both the lateral and radial settings for the right and left hand contours must be critically adjusted. Such tools are suitable for producing contours on work up to about ½ in. diameter on small lathes; beyond this, the breadth of the cutting edges becomes too great for smooth and efficient operation.

Generating spherical curves

When it is necessary to machine spherical curves to very close limits of accuracy, such as for use in a smoothly articulating ball-and-socket joint, the only practical method of doing so is by traversing the cutting tool in a circular arc so that it generates the contour, instead of copying a fixed form. It is thus possible to produce spherical contours of any size by radial adjustment of the cutting tool, and maintain precision in all cases. The principle employed is simple, involving some form of pivoted tool carriage, capable of partial rotation, and generally including a slide for radial adjustment of the tool.

Right: Fig. 7. Half contour forming tool.



In the past, lathes have sometimes been equipped with built-in rotating tool slides, though more often, separate attachments have been provided for spherical turning operations. The specialised lathes made for ornamental turning about a century or more ago were notorious for their array of ingenious and complicated attachments, some of which, I am sure, were never fully understood or mastered by many of their operators. While most of these lathes and their galaxy of gadgets are now obsolete, some of the principles of mechanical movement which they employed have been adapted for use on the metal turning lathes used for special instrument or so-called "precision" work. These include spherical turning appliances, which have been made in a variety of forms, either by manufacturers or individual lathe users. It was, I believe, claimed for one well-known "universal" lathe that with its special movements, one could not only turn a sphere, but also cut a thread on it (or even inside it !) though just why anyone should want to do so is not clear to me.

A ball clamp

Some years ago, I was faced with the problem of producing a practical form of ball clamp, which involved the need for turning both external and internal spherical contours. As this was a one-off job, which was not likely to recur often, if at all, I decided to make the simplest possible form of appliance I could think of which would fulfil the requirements for accurate work. This consisted of nothing more than a hand lever, pivotally attached to a bolt fixed on the cross-slide of the lathe, and provided with a tool-post having some latitude of radial and slewing adjustment for the tool bit. Despite its primitive design, this device was found capable of carrying out the required operations satisfactorily and has since been found useful for innumerable other jobs.

Among important factors in the success of this or indeed any other spherical appliance are the rigidity of the pivot, and the elimination of both end and side play. It is clear that unwanted movement must necessarily affect the position of the tool point and thus produce inaccuracy of form. The pivot must be located exactly under the centre of the work axis both laterally and crosswise to produce a true spherical contour in the right place. If the pivot centre is displaced crosswise the work is no longer spherical.

In terms of solid geometry, the result will be either an oblate spheroid or an ellipsoid, according to whether the pivot centre is displaced towards the front or the back of the work centre.

For this reason, the provision of some means of setting the pivot in true centre location is, to say the least, very desirable, though surprisingly enough, this has been omitted in some of the elaborate appliances I have seen. To cope with this requirements, the pivot T-bolt, which is anchored in one of the T-slots in the cross-slide, is made hollow, and a close-fitted gauge pin is provided which serves a dual purpose. When setting up the appliance, a true running live centre is fitted to the lathe headstock, and the pivot located from it with the aid of the gauge pin. Lateral adjustment is of course ignored at this stage, as it will depend on the length and position of the work piece, but the cross-slide is adjusted so that the gauge point coincides with the lathe centre point as closely as possible, using a lens to assist visual observation if necessary.

Setting the tool point

The gauge pin can also be used for setting the radial position of the tool point, by raising it sufficiently to allow the distance between the cylindrical part of the pin and the tool to be measured, by calipers or other means. It is, of course, necessary to allow for the diameter of the pin (which should be a standard or, at any rate, known dimension) by adding *half* this amount for external settings, and subtracting it for internal settings. The need for this allowance can, however, be avoided by cutting away the top end of the gauge pin to exactly half its diameter.

In using this appliance, the lateral position of the pivot must be adjusted to a distance equal to half the diameter of the sphere from the end of the work piece, assuming that a full curve right to the centre is required.

The cross position of the pivot should be noted on the slide index or, better still, located by a limit stop. It is permissible to run the slide out for dealing with oversize work, but it must be set to the predetermined position for finishing, and at no time fed in beyond it. For most purposes, spherical rather than diametral accuracy is the more important, except when matching to internal contours is necessary.

There are obviously many ways in which this simple appliance could be improved, and these will be discussed in subsequent articles. From experience in its use, however, I think that the most practical improvement would be to increase the bearing surface of the pivot, and in particular to eliminate end play at the thrust faces. The diameter of the pivot bush flange might well be increased, together with that of the retaining washer on the top of the lever. A frictional spring washer under the nut has been tried, but while this *resists* the tendency of the lever to move up or down, it does not positively prevent such movement. Some degree of friction does, however, assist in hand control in traversing the tool.

To be continued.

ELEMENTS OF SPHERICAL TURNING

Part II *Continued from May 5*

by Edgar T. Westbury

WHETHER the device employed for producing spherical contours is simple or elaborate, the very first principle to be observed in its operation is the location of the centre around which the generating tool is rotated, by means of a hand lever or other means. This was referred to in the previous issue, but in view of its importance, further explanation of it is given in Fig. 9, which shows the effect of displacing the pivotal point in either direction. If carried to the extent indicated, the error is readily visible to the eye, but for work in which high spherical precision is necessary, even the smallest discrepancy may spoil the finished results. For this reason, some positive means of locating the pivot centre on the cross-slide or bed of the lathe is an advantage, and in some cases may be absolutely essential.

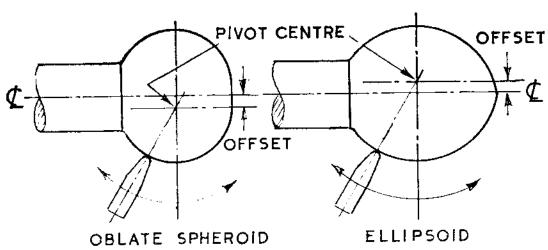


Fig. 9. Effect of inaccurate location of spherical generating tool.

In general work, some method of radial adjustment for the tool point, to deal with varying sizes of work, is equally important; it is also an advantage to provide the smoothest possible feed movement of the rotating tool fixture. But it may be mentioned that in commercial production, spherical curves of fixed dimensions, over a limited angle of arc, are accurately produced by methods and appliances which do not provide either of these facilities. Components such as ball-and-socket joints for motor car steering and suspension systems, in which smooth articulation is absolutely necessary, are often finished to close limits of precision by means of a hollow grinding wheel, running at high speed on an axis at 45 deg. to that of the work, as shown in Fig. 10.

The spherical arc generated in this way is usually limited to about 90 deg., which is sufficient for the particular purpose, provided that the rest of the surface is undercut or relieved, as indicated in the example of work dealt with. In order to maintain the uniformity of the spherical diameter despite the inevitable wear of the grinding wheel, it is dressed, when necessary, on the front *flat* face only. The same generating principle could be applied to the use of a cutting tool such as a hollow milling cutter. Increasing the angle of the tool axis in relation to the work would enable the spherical arc to be extended within certain limits, but it would always leave either a cone or a flat on the front end of the work. It is just as important, however, to observe the first principle, in locating the axis of the grinding or cutting tool so that it exactly intersects that of the work.

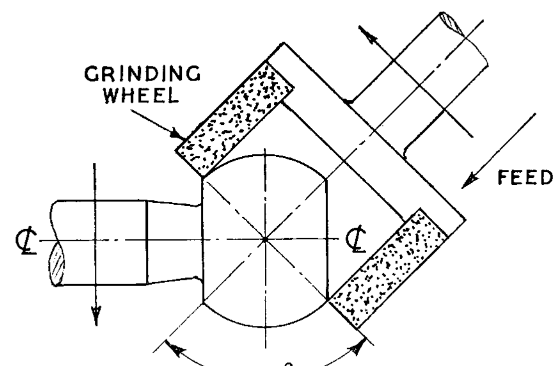


Fig. 10. Method of generating spherical contour with hollow grinding wheel.

It has already been mentioned that many ingenious spherical turning appliances have been produced for use on the lathe, either by manufacturers or lathe users. Fig. 11 shows a typical example of such a device, based on, but not copied exactly from, an exhibit seen many years ago at a ME Exhibition. It is designed to be mounted either on the bed or cross-slide of the lathe by means of two bolts, and it incorporates a geared rotary movement, in conjunction with a radial tool slide. As an example of machine tool component design, it deserves commendation, and the mechanical details are well made and fitted.

The worm gear provides an adequate turntable for the radial slide, with a broad under-surface to form a thrust bearing, with adjustment for end play from below, in the recessed bolster plate. A removable gauge pin, cut away to the centre to facilitate radial measurement, is fitted to the centre of the worm wheel. The radial sliding member is fitted with a gib for adjustment, and is moved by a feed screw with a balanced handle, having an indexed sleeve, though the markings on it are not visible in the photograph. A lantern type of tool post, with rocker adjustment for the tool height, is anchored in a T-slot which enables the latitude of radial movement to be extended. Smooth and steady motion of the rotary traverse is facilitated by the worm gearing, and the worm shaft is fitted with a flexible drive, so that it can be operated from any convenient position, or even coupled to a self-acting drive if required.

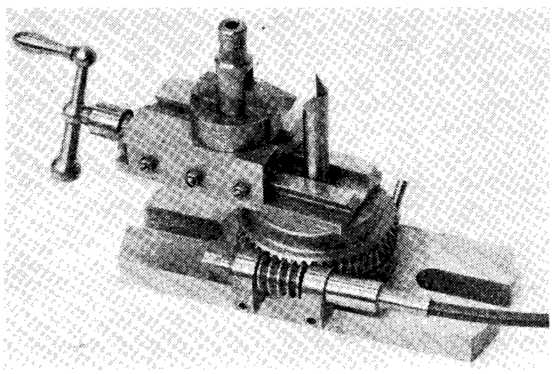


Fig. 11. A worm-geared spherical turning appliance.

The utility of this appliance, however, is restricted in certain respects, wherein its refinements may, in fact, constitute a handicap rather than a practical advantage. In the first place, the vertical height of the bolster, worm gear, and radial slide impose a limit on the size of the work which can be machined on a lathe of small centre height when using the appliance. Though it is likely that most of the spherical turning required will be on parts of small diameter, there are occasions when large work may be encountered, calling for the maximum possible clear swing. The space occupied by the worm gearing, etc., can then ill be spared, and the appliance is at a disadvantage, compared with one having a direct lever feed.

Most spherical turning operations, other than those which are limited to a relatively small arc, involve the need for rotating the tool as far as possible to the left, to carry the curve right down to the neck or stem. When the work is held in a normal chuck, or between centres, the radial slide and its handle may not be capable of swinging far enough round without fouling the chuck or other revolving parts. It is possible to make the handle removable, which helps to some extent, but I have often found that this does not give sufficient clearance. The only thing to be done then is to slew the tool round to the left in the tool post, but though this enables the arc of surface to be increased, it reduces the advantages of fitting a slide which gives direct radial tool adjustment. It will be clear that the movement of the tool slide is no longer truly proportional to the radial adjustment at the actual tool point.

As I have often had to carry out spherical turning, in the course of solving those awkward little machining problems which are passed on to me from time to time, I have devoted a good deal of time to the design of appliances which give maximum facility without serious limitations for work of this nature. The photographs, Figs. 12 and 13, show one of the most useful of these which I have so far been able to produce. In the drawing, Fig. 14, a few minor modifications have been introduced in order to simplify construction with materials most likely to be readily available.

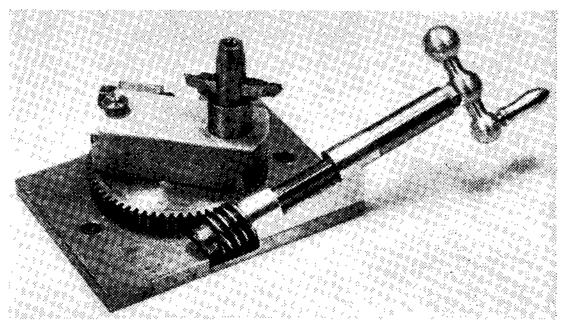
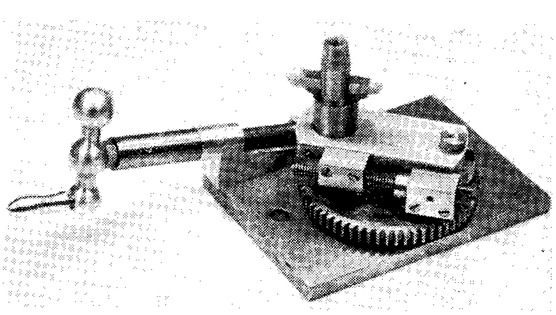
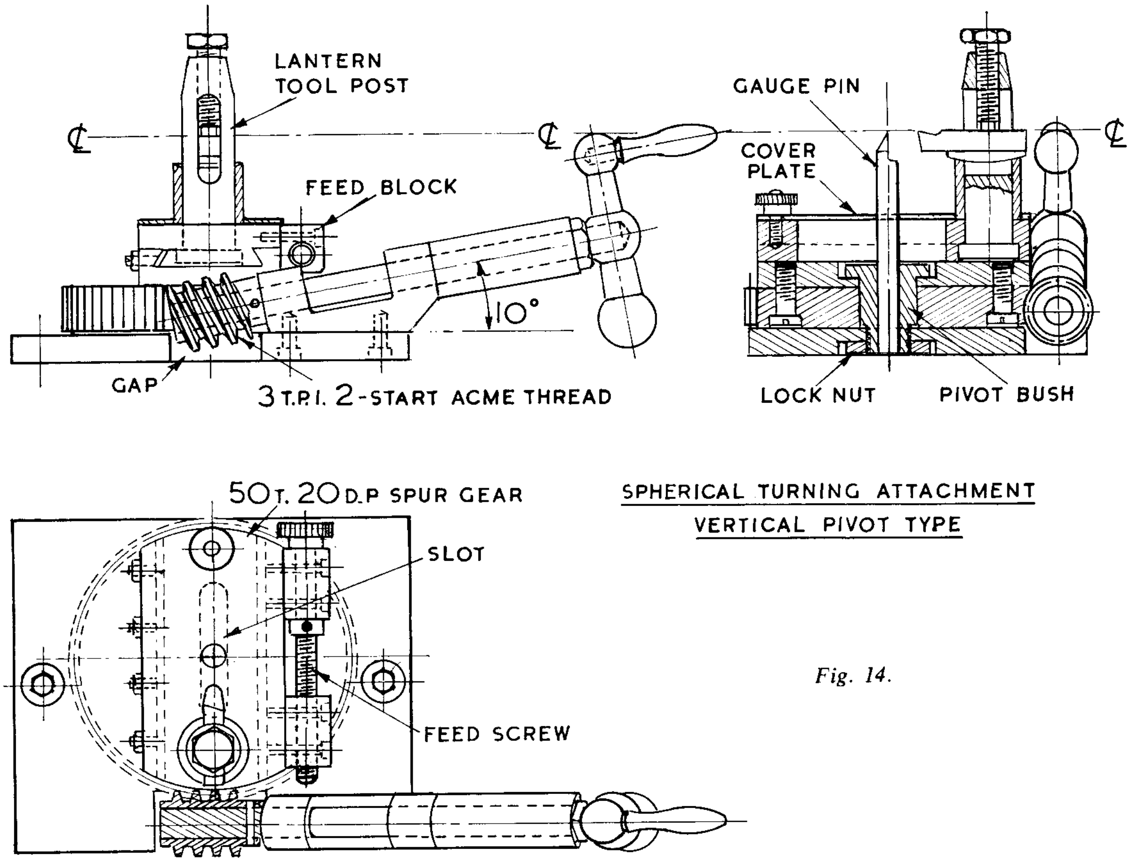


Fig. 12. A spherical turning appliance with oblique wormshaft.

The base of the appliance is a rectangular piece of $\frac{1}{4}$ in. steel plate, scraped flat and true on both sides. For mounting it on the cross-slide of the lathe, two recessed socket head screws are provided, which engage with $\frac{1}{4}$ in. B.S.F. tapped holes in a strip suitably shaped to fit the T-slots of the cross-slide. This method, incidentally, can be

Below: Fig. 13. Another view of the appliance showing method of adjusting the radial slide.





SPHERICAL TURNING ATTACHMENT
VERTICAL PIVOT TYPE

Fig. 14.

recommended for securing all sorts of attachments to T-slotted cross- or vertical-slides. It facilitates quick setting-up and removal, avoids the need for loose clamps and bolts, or projections which may get in the way of operations. Moreover, they reduce the risk of overstraining the T-slots, by providing increased bearing surface over their full length. The strips can easily be made from mild steel bar by milling or shaping; they should slide easily in the T-slots, with clearance on the top surface, so that they lie below the slide level.

A hole is drilled and tapped $\frac{3}{8}$ in. × 26 t.p.i. in the centre of the baseplate, which is recessed on the underside so that a thin locknut can be fitted to secure the pivot bush when it is screwed in to eliminate end play of the rotating parts. As in the appliance illustrated in Fig. 11, worm gearing is used for the rotating movement, but instead of using a proper worm wheel, it makes use of a spur gear with straight axial-cut teeth. The reason for this is to allow the wormshaft to be inclined upwards at a sufficiently steep angle to give ample clearance for the operating handle, over the cross-slide. Whether this shaft is located parallel to the lathe axis, or at any other convenient angle, it allows the gearing to be operated with the minimum interference from other slide movements.

The gear wheel actually used for the original appliance was one which happened to be available, in the traditional model engineers' "treasure chest" (some unkind people refer to it as the "jackdaw's nest"). But in order to cater for those who may not be able to obtain a gear wheel of the same size and pitch, the drawing has been modified to show one which may more readily be available. Change wheels of 20 d.p., and with varying numbers of teeth, are used on several popular lathes, and are obtainable as spares from makers or dealers. The 50-tooth wheel shown is a convenient size, but the exact gear ratio is not important. Both sides of the wheel should be flat and parallel on their essential bearing surfaces; recesses, if they already exist in one or both sides, are permissible, and the teeth on the lower side should be relieved.

Worm details

To mesh with a 20 d.p. gear wheel, a worm of 6 t.p.i. will serve for the purpose in view, though it is not perfectly accurate and in fact, calculations are complicated by the angle at which it is presented to the wheel. Perfectionists who insist on everything being exactly right may find, after working out details to the *n*th decimal point, that the exact pitch cannot be produced by any means at their disposal. In the solution of many engineering problems, approximate accuracy is permissible, and gives quite satisfactory practical results, with certain reservations where the utmost efficiency is absolutely necessary. I mention this because theoretical errors in such matters are often a happy hunting ground for valiant Knights of the Slide Rule; I am not deriding their worthy and often necessary efforts in working out difficult problems in workshop mathematics, but simple methods will often produce the desired results.

The term 6 t.p.i. defines the distances between the crests of adjacent teeth, or in other words the "apparent pitch." This is also the true pitch for single-start worms, but for a two-start worm, the true pitch, or "lead," is 3 t.p.i. To cut this pitch on a lathe having an 8 t.p.i. lead screw, the mandrel/lead screw ratio needs to be 8:3. This can be obtained by using a compound train with drivers of 40 and 50 teeth, and driven gears of 25 and 30 teeth, or any conbinations which will give total equivalent ratio. The worm blank may be made in a readily machinable metal, such as brass, as its duty is quite light, and after turning and concentric drilling, may with advantage be mounted on a true-running mandrel to run between centres. The screw-cutting tool is ground to Acme form (29 degrees included angle) and the width at the tip should fit the root of the gear teeth; this is the maximum allowable, as it is often more convenient to use a narrower tool and finish the thread by taking side cuts.

The lathe catchplate should be fitted with two equal-sized driving pins, exactly opposite to each other, for cutting two-start threads. It is most important that the blank should be quite secure on its mandrel, and the carrier must also be firmly fixed, as shifting of either during the entire operation would ruin the work. If desired, a narrow straight-sided tool may be used to gash out the threads before using the forming tool. In either case, the first "start" should be cut almost to full depth in one position before engaging the carrier with the other driving pin, for cutting the second "start." Finishing the threads may be done in alternate driving positions, at the same tool setting.

It may be mentioned that the angle of the wormshaft is determined by the pitch angle of the worm, which in turn is influenced by its pitch diameter. With an *outside* diameter of $\frac{5}{8}$ in., the pitch angle works out at approximately 10 deg. as shown on the drawing, but this may be subject to slight variation. It may be checked by meshing the worm hard against the teeth of the wheel, with its bearing bracket in position. Any discrepancy in the angle can then be detected easily and, if necessary, corrected by filing the underside of the bracket. A gap will need to be cut to clear the worm when it is located at approximately the level of the worm wheel centre, but this is not at all critical. The bracket is located to give close but not tight meshing, and it is secured by two screws from the underside of the baseplate. An extension sleeve is fitted to the wormshaft to carry the handle well away from working parts, and either a ball handle, or any other type preferred, can be fitted. Incidentally, the spherical curves of the handle shown were generated by its own aid, while a temporary handle was fitted.

A short radial slide is secured to the top of the gear wheel; it is intended for adjustment, rather than traversing in the normal sense. Its feed screw is fitted at the side and does not project outside the turning circle any more than necessary. The slide is slotted so that a gauge pin can be fitted in the centre of the pivot bush, and when this is not in use, a cover plate, held in place by a single knurled screw, can be fitted to prevent swarf clogging the slot. A lantern type tool post, with the usual rocker pad for height adjustment, is fitted to the moving component of the slide.

The radial movement provided is relatively small, but is sufficient for its designed purpose, which is to cope with spherical work up to $1\frac{1}{2}$ in. diameter on a $3\frac{1}{2}$ in. lathe. The tool can be rotated through a full circle without fouling of the moving parts, though this is never necessary or practicable.

ERRATA

HOLCROFT VALVE GEAR

Page 274, column 1, line 6. Should read:
Thus when Angle A = 90 deg. *Not 20 deg.*

Page 275, column 2, line 9. Should read:
and $337\frac{1}{2}$ deg. *Not 339 deg.*

Page 275, column 2. First equation should read:

$$OF = \frac{1.620}{3.939} \times .00894 = .0037$$

So OF = 1.620 + .0037 = say 1.624 in.

ELEMENTS OF SPHERICAL TURNING

Part III *Continued from May 19*

by Edgar T. Westbury

THE ROTATIONAL movement of the cutting tool, for generating a true spherical curve, may be in any plane, provided that it obeys the first principle, that the centre line of the pivot must exactly intersect the axis of the work. Many appliances have been made having a horizontal pivot set at the level of the lathe centres, and a tool head equipped with convenient means of rotation and radial adjustment. This arrangement has advantages for certain applications, not the least being that its pivot location can be made positive, thus eliminating the risk of spherical error. It can also be designed in a form which is easily and quickly mounted, without the necessity for removing any of the normal slide rest fittings. The equivalent of height adjustment for the point of the cutting tool can be obtained by the cross-slide movement (which should be locked or clamped during the spherical turning operation) and the lathe mandrel may be run in either direction, according to the tool setting.

In the course of operations to which I briefly referred in the previous issue, I was led to experiment with various designs of appliances with a view to producing a quick-set type of fixture, interfering as little as possible with the use of standard tooling arrangements. The horizontal-pivot appliance seemed to offer a possibility of achieving this purpose, as it could be mounted on the back end of the cross-slide, well out of the way of any but the largest work, and instantly ready when required for use. I already had a rear tool with a detachable head, somewhat similar to that designed by Duplex several years ago, and this was used for the mounting of the spherical turning appliance.

In the original arrangement of this device, the rotating tool head was mounted in a spindle which worked in a horizontal bearing block, designed to be mounted on the pedestal of the toolpost fixture, interchangeable with the existing tool heads, and clamped down by the T-bolt in the slot of the cross-slide. A short radial tool slide was attached to the front end of the spindle, and a worm wheel (again found in the scrap box) fitted to the rear end, for operation by a worm with a vertical shaft and ball handle. The spindle bearing in the block was bored and reamed in situ from the lathe chuck while clamped on the toolpost at right-angles to its normal position. Its height, therefore, was positively set, with no possibility of introducing spherical error, and it was unnecessary to provide a gauge pin in the pivot centre.

The radial tool slide was, as in the previous appliance, of dovetail form, with adjusting gib, but the feed screw could be centrally located, as it did not have to dodge a gauge pin. Neither was it necessary to fit a rocker pad under the tool bit in the lantern toolpost, as the cross-slide provided the means of adjustment. A bracket was attached to the back of the pivot block to provide a bearing for the worm shaft, which was extended to a convenient height for operation by the ball handle. This device, though it started as a makeshift, and never really attained the status of a finished design, served its purpose, and enabled me to produce some accurate work with the minimum expenditure of time and trouble.

Ball handles

Some months ago, at a meeting of the Sutton Model Engineering Club, a question arose about the best method of producing ball handles for machine tools. This led to a discussion on spherical turning generally, and I demonstrated the appliances I had made, together with examples of work produced by their aid. Most of the club members considered that it was not worth while to make an " elaborate gadget " to produce one or two ball handles, and this is obviously true in terms of workshop economics, as applied to all kinds of tool making. But there are many model engineers who will spare no pains to make their workshop equipment as complete and versatile as possible, irrespective of whether they have any urgent need to carry out highly specialised operations. Very rarely are efforts in this direction entirely wasted, provided that the gadgets they make are practical, and not so elaborate as to absorb considerable time, which might better be devoted to more worthy projects, or what is known as " real model engineering." This is a matter on which each individual must form his own judgment and make his own decision.

Mr Norman Cohen (who, incidentally, has now emigrated to Canada) was interested in these appliances, and after trying out the horizontal-pivot type, decide to construct his own version of it. This proved to be well suited to his requirements and he has made complete detail drawings of his design, which he has given me permission to reproduce. Not only is he a much better draughtsman than I am, but his appliance is much better made and finished than mine, so I have decided to illustrate it in preference to the original type, from which it differs in many minor details.

The general arrangement, next page, shows the complete appliance, and the location and assembly of the parts, to which the various members are allocated; to avoid confusion, therefore, the details are given only their part numbers and *not* further figure numbers. Part No. 1 is the pedestal, which is essentially similar to that of the Duplex rear toolpost, and if this already exists, can be utilised without the need for a specially made component. Cast iron is the most suitable material, but it could be made by brazing two pieces of mild steel bar together if preferred.

The underside of the base is first faced flat and true, and it is then reversed, either in the four-jaw chuck or on the faceplate, with the square part set truly for turning the register spigot and drilling the vertical hole for the main T-bolt. This bolt, and the nut which holds the assembly down, is not shown in the drawings or photographs, but its purpose and location are obvious. Nothing more than the single bolt is really necessary for secure mounting, but a hole for a short bolt is provided in the base flange for further security, but more particularly to prevent the pedestal shifting if the main bolt is slackened for adjusting the head. Instead of two separate bolts, studs screwed at each end may be fitted to a T-strip to engage the slot of the cross-slide, as recommended for the previously described appliance. All finishing operations, such as scraping of the base or seating surfaces, which may affect the height of the pedestal should be completed before proceeding with other components.

The bearing block

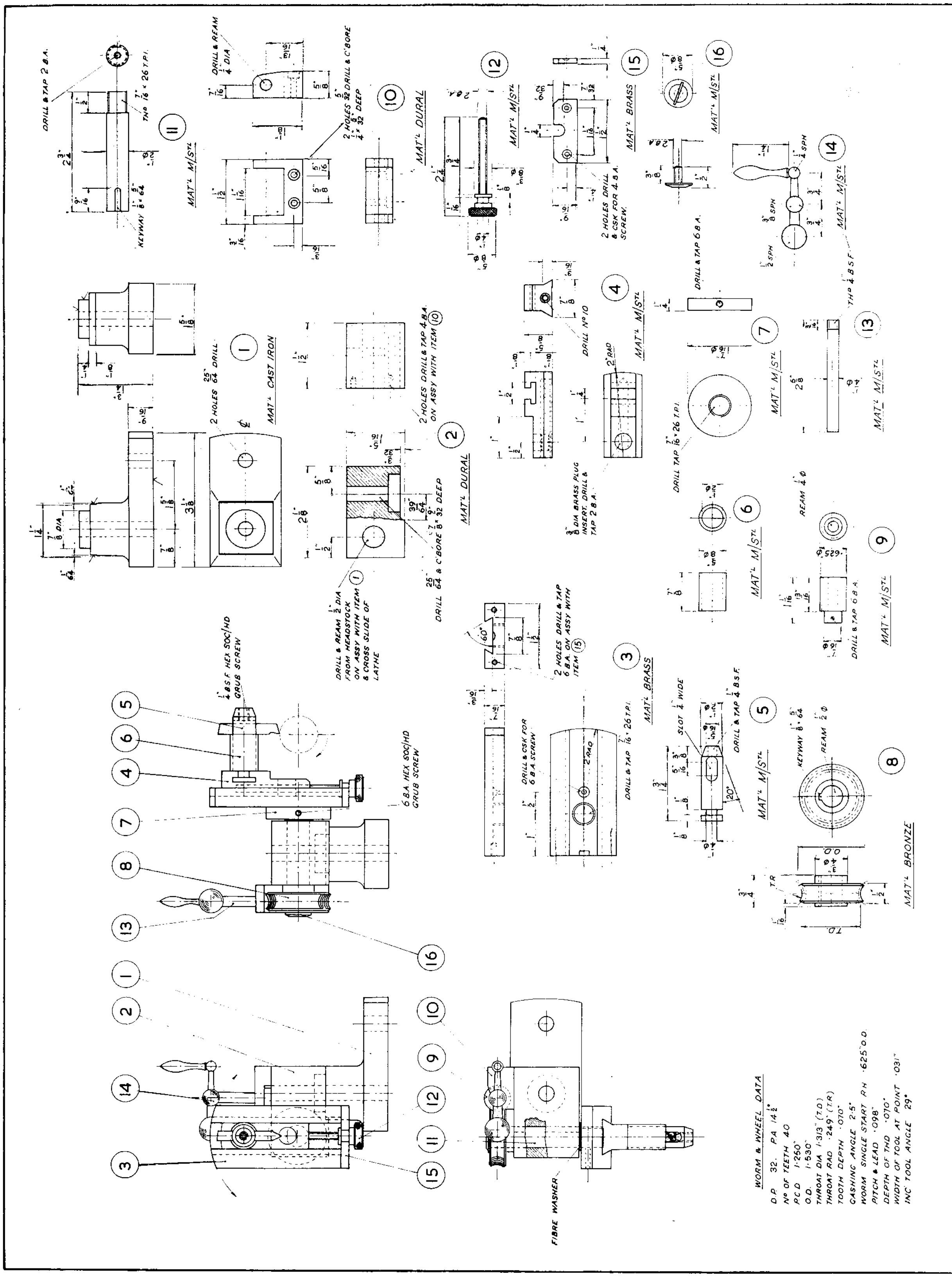
Duralumin is specified for the bearing block, part No. 2, but other materials such as cast iron or bronze are equally suitable. Steel can be used if a bronze bush is inserted to form the bearing. The base surface of the block is stepped to provide a square edge which fits against the machined side edge of the pedestal, to locate the block squarely to the lathe axis when fitted. The seating surface on the underside must therefore be machined by milling or shaping. An alternative method, which may be more convenient, is to face the underside of the block right across, at the same setting as the drilling and counterboring of the vertical hole, and attaching an aligning strip, or fitting a dowel in the top of the pedestal, to provide positive square location. The drilling, facing and counterboring to a close fit on the base spigot can then be carried out at one setting, with the block set up in the four-jaw chuck.

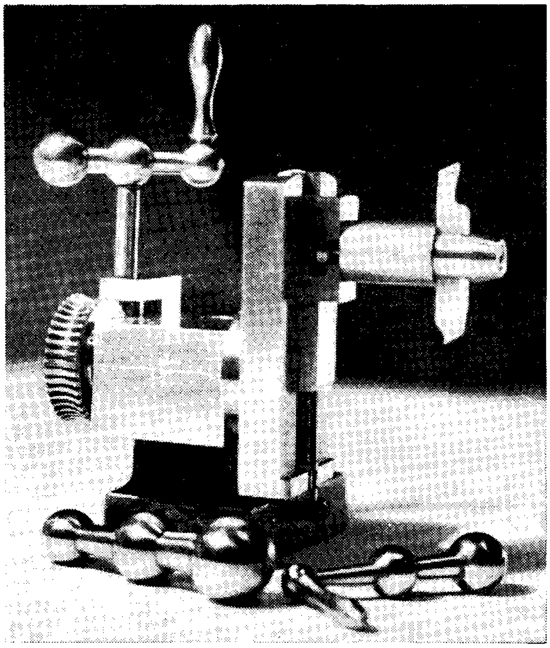
The block may now be mounted on the pedestal and secured by the T-bolt to the cross-slide, with its left-hand face set parallel with the lathe axis for centre-drilling, drilling and reaming the bore of the bearing. This is the critical operation which determines the spherical accuracy of the work produced by the appliance, therefore care should be taken to see that both the pedestal and the block are seated truly on the cross-slide, without any chance of grit or swarf being trapped between their surfaces; errors in height are difficult to correct afterwards. When drilling the block on the cross-slide, with tools held in the lathe chuck, there is a tendency for it to slew round under the applied end thrust, and this should be prevented by backing the work up by a drill pad held in the tailstock. Two or three stages of undersize drilling are recommended and if a reaming size drill is not available, a 31/64 in. drill may be used, followed by a D-bit, which can easily be made from silver steel rod. The end faces of the bearing should be machined by mounting the block on a stub mandrel.

The rotating slide

Suitable materials for the rotating slide member, part No. 3, are brass, bronze or cast iron. It is first machined flat and parallel on both sides by milling, shaping or facing methods; the edges and ends, though of no functional significance, may also be machined for the sake of neatness. The dovetail slot was produced by Mr Cohen with the aid of a vertical-spindle machine, but it could well be carried out by end milling in the lathe, with the work mounted on a vertical-slide. As shown, no provision was made for adjusting play in the slide, but this calls for meticulous fitting, and there is plenty of metal to allow of interposing a gib strip, with adjusting screws. The slideway should in this case be made $\frac{1}{16}$ in. wider on one side (not symmetrically), and a strip of steel $\frac{1}{16}$ in. by $\frac{1}{4}$ in. fitted, as for the slide of the vertical-pivot appliance. For drilling and tapping the hole $\frac{7}{16}$ in. fine thread, to attach the slide to its spindle, it may be mounted on the faceplate, so that positive squareness is ensured.

A piece of mild steel $\frac{5}{8}$ in. × $\frac{7}{8}$ in. × 2 in. long may be used for the radial tool slide, part No. 4, which is machined to dovetail section by the same cutter as that used for the slot of the former component. This is most conveniently done before stepping the top surface, but the $\frac{3}{8}$ in. hole may be drilled to take a bolt for holding the part on the vertical-slide. It is set horizontally, with the under face outwards, and the top and bottom edges milled at one setting by adjusting the slide move-


WORM & WHEEL DATA
D.P. 32. PA 14½°
No OF TEETH 40
P.C.D. 1·250"
O.D. 1·530"
THROAT DIA 1·313" (T.D.)
THROAT RAD ·249" (T.R.)
TOOTH DEPTH ·070"
GASHING ANGLE 2·5°
WORM SINGLE START RH ·625" O.D.
PITCH & LEAD ·098"
DEPTH OF THD ·070"
WIDTH OF TOOL AT POINT ·031"
INC TOOL ANGLE 29°



The spherical turning appliance made by Norman Cohen, with examples of ball handles made with its aid.

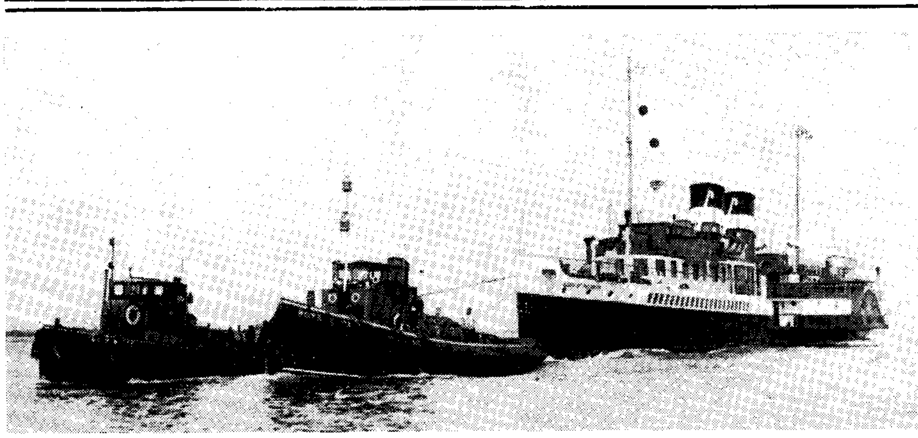
ment. This will ensure that the two edges are parallel with each other.

To mill the slot for anchoring the toolpost, a special T-slot cutter is normally required, but it is possible to file this out accurately enough for practical purposes if the centre channel is first cut to full depth by a $\frac{1}{4}$ in. end mill. The work of removing metal by filing may be reduced if two $\frac{1}{8}$ in. holes $\frac{3}{8}$ in. apart are *first* drilled horizontally through the block, to partially form the base of the slot. Filing is also good enough to shape the step of the slide, if most of the unwanted metal is cut away with a hacksaw; but machining facilities, where they are readily available, should always be exploited to full advantage on work of this nature. A hole is drilled longitudinally through the slide to clear the feed screw, the nut of which is formed in a brass plug $\frac{3}{8}$ in. dia., fitted to the hole already drilled, and cross-drilled and tapped to line up with the screw. This provides a measure of flexibility in alignment, as the nut can swivel or slide in the hole to adjust its position. The sliding surfaces of the two mating parts may call for final fitting by scraping, or the use of a fine file, so that they work smoothly together, and the slide gib, if fitted, is then adjusted to eliminate any perceptible play.

The toolpost, part No. 5, may be made from $\frac{1}{2}$ in. dia. mild steel bar, $1\frac{1}{4}$ in. long, faced squarely on the end, and grooved to fit the T-slot in the slide. It is then chucked in the reverse position, tapered as the end, and drilled and tapped to take a $\frac{1}{4}$ in. BSF screw. The hole may be drilled down as far as the lower end of the cross slot, to reduce the amount of metal which needs to be removed in forming it. End milling, with the work held in a small vice on the vertical-slide, is the quickest method of doing so, but as an alternative, three undersize holes can be drilled and filed out to merge with each other in an elongated slot.

Also in mild steel, the sleeve, part No. 6, is simply a piece of $\frac{5}{8}$ in. dia. bright bar, drilled $\frac{1}{2}$ in. dia. through the centre and faced at both ends. Its length is not critical, as the tool position can be adjusted by the cross-slide. A socketed screw, either with or without a head, can be used to clamp the tool bit, but there is much to be said for the good old-fashioned square-headed screw, made of carbon steel, and hardened and tempered on the point only.

Part No. 7 is simply a mild steel disc, drilled and tapped $\frac{7}{16}$ in. $\times$ 26 t.p.i. (or to match other parts). It is used to back up the rotating slide, and provide the utmost rigidity when locked up as tightly to it as possible and further prevented from movement by a grub screw in the side.



The "Queen of the South" returns for further service. *See page 527.*

ELEMENTS OF SPHERICAL TURNING

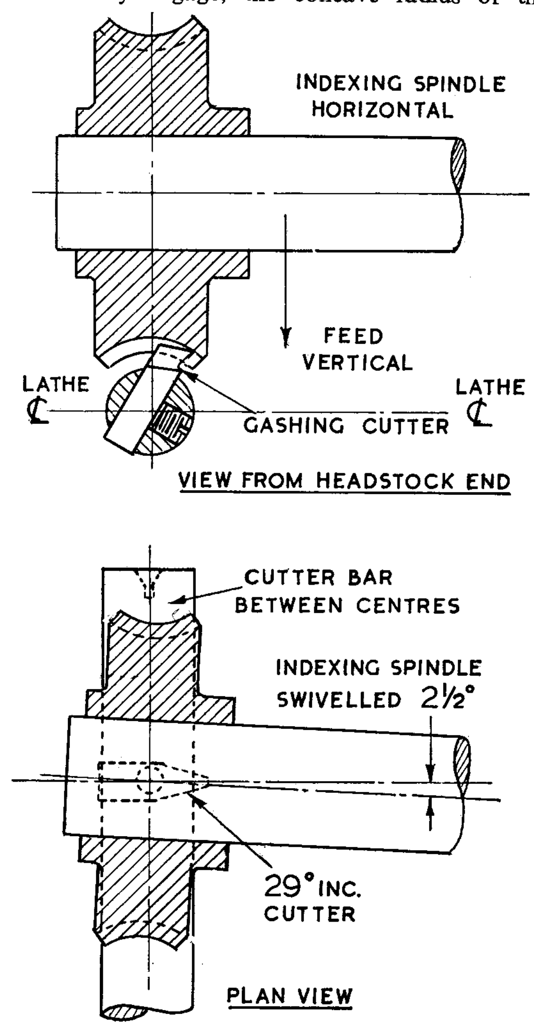
Part IV *Continued from June 2*

by Edgar T. Westbury

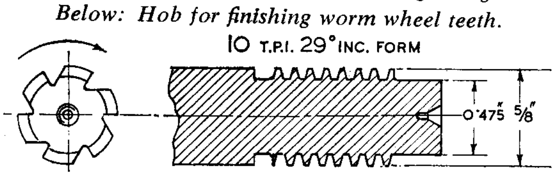
THE SPECIFICATION of the worm and wheel for this appliance (parts 8 and 9) are subject to modification to suit available material. There is considerable latitude in the size of these parts, and the ratio of reduction need not be strictly adhered to. Gearing obtained from breakdown of "surplus" apparatus can, therefore, be used if it is anywhere near the stated dimensions, and a straight-cut spur gear can be substituted for the worm wheel, if the wormshaft is set at the appropriate pitch angle as in the vertical-pivot appliance previously described. A ready-made worm and wheel of 40:1 ratio can be obtained from Bonds o' Euston Road (Cat. No. 7/33), the dimensions of which are larger than those stated on the drawings but within the permissible limits. This particular item has the worm machined integral with the shaft; it is possible that a worm bored to fit a separate shaft may also be available, but if not, it is only necessary to modify the wormshaft bracket (part No. 10) and its location on the bearing block (part No. 2).

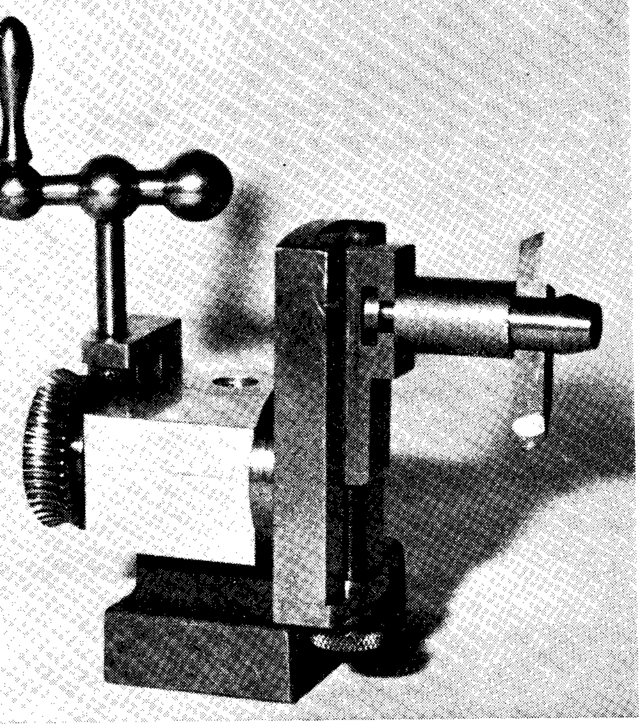
Mr Cohen decided to make the worm gearing himself, and has taken pains to work out the details for machining the essential parts. There is a good deal of unnecessary apprehension about the problems of cutting gears, in general, and worm gearing in particular. It is perfectly true that if gears are required to run at maximum efficiency such as for power transmission, where maximum ratio of output to input is essential, both the design and production must be accurate within very close limits. But when the object of the gearing is simply to translate the speed and direction of control movement, and the duty is very light, approximate accuracy of tooth form and other factors is sufficient for all practical purposes.

Most worm wheels are "throated," that is, made with a concave periphery to increase the contact area of the teeth of the wheel in mesh with the worm; but this is not absolutely necessary, and there are many examples to be found of worm wheels with flat crowns in dividing gear and other machine tool applications. In any case, true contact of the worm and the teeth of the wheel can only be maintained over a limited width. Little if anything can be gained by making the throat of the wheel engage more than 90 deg. of the worm thread. All throated worms must be designed to suit the diameter of the worms with which they engage, the concave radius of the



Right: Set-up of worm wheel blank for gashing teeth.
Below: Hob for finishing worm wheel teeth.





Mr Cohen's spherical turning appliance. Note the worm gear.

throat being equal to that of the root of the worm thread, plus clearance allowance. If the teeth are cut by a hobbing operation, the throat can be left slightly oversize, as the hob will produce the exact contour required.

It is generally advisable to make the worm first, as it can be used as a gauge for meshing with the wheel. The specified pitch is 0.098, and as the worm has a single start, this is also the " lead," at which the thread is cut. The nearest approximation to this which can be cut on a normal screw-cutting lathe is 10 t.p.i., which is close enough for this purpose. A narrow gashing tool may be used for cutting the thread nearly to its full depth, but a carefully ground form tool with sides at an included angle of 29 deg., and a width of 0.031 in. at the tip, is required. A narrower tool may be used if, after cutting to full depth, the sides of the threads are shaved to produce the width, by adjustment of the top-slide. The operation will be facilitated if a material of good machining quality is used, and ample lubrication by cutting oil or soluble emulsion is supplied.

Having turned the worm wheel blank to external dimensions, it should be mounted on a mandrel for cutting the teeth. There are various divergent opinions on how this can best be done with limited equipment; it is often said that worm gears can quite easily be cut by using an ordinary screw tap as a hob, running in the lathe, and mounting the blank to turn freely on a vertical spindle at centre height. When fed into cutting contact with the tap, the blank will rotate at its natural rate, and cut the teeth progressively to the required depth—at least that is the theory, and it is sometimes known to work, on worm wheels in which neither the pitch accuracy nor the number of teeth are of very great importance.

I do not recommend attempting to cut the teeth in this worm wheel by the above method for these reasons: first, it is not generally possible to engage the hob to full depth and, therefore, it will start cutting on a larger diameter than the designed pitch circle. As a result, rotation of the blank at its natural rate will tend to produce a larger number of teeth than required, and not necessarily an *exact* number, so that there is a risk of double-tracking or uneven indexing of the teeth. The use of an ordinary screw tap of Whitworth or similar thread form will produce teeth of excessively wide pressure angle, though this may be acceptable for some light duties. But the wide fluting of a standard tap may cause their threads to lose contact with those of the blank for parts of the revolution, giving still further cause for mis-tracking or mutilation of the teeth.

In my experience, and in that of Mr Cohen, the best way of cutting the teeth of worm gears, in the absence of proper gear hobbing machinery, is first to gash the teeth to near finished depth by individual indexing, and then finish them by freely floating the blank against a hob of the same diameter, tooth form and pitch as that of the worm to be used. The hob may, therefore, be cut at the same setting as the worm, preferably in tool steel which can be hardened and tempered, though mild steel hobs, case-hardened, have been successfully used for finishing one or two worm wheels.

The teeth of the hob, up to about six in number, may be milled or filed, with the cutting faces as near radial as possible. They should be kept fairly narrow, but a little in excess of the thread depth; it is not necessary to space them evenly. Backing-off is hardly possible but a little easing-off of the *crests* of the threads, by honing, is helpful, and the cutting faces should be honed keen with a slip stone.

In order to set up the blank for gashing the teeth, some form of indexing device is required, but this can be of a simple or even primitive nature, such as a spindle on one end of which the blank can be mounted, and a division plate or a 40-tooth change wheel on the other. A detent or latch to lock this in the required positions is necessary, and the bearing for the spindle may be in the form of a block mounted horizontally on a vertical slide. A single point cutter, fitted to a cutter bar between centres, may be used for the gashing operation; its form may be approximately the same as that used for screwcutting the worm, and the depth of cut, applied by the vertical feed, about $\frac{1}{16}$ in. The spindle needs to be set with its axis at the pitch angle of the worm, by swivelling the base of the vertical-slide to an angle of 2.5 deg. to the square position, checked with the aid of a protractor from the edge of the cross-slide.

Some care will be necessary to set the position of the blank centrally, both laterally and crosswise, in relation to the cutter. Exact measurement may be difficult, but after setting by eye as closely as possible a shallow witness cut may be taken on one tooth, and the blank turned into a position where this is readily visible for inspection. When set, the saddle and cross-slide should be locked, and each tooth in turn gashed by feeding the blank vertically, preferably to a positive stop if this can be arranged. The cutter bar is then replaced by the hob, the indexing gear is released so that the blank can turn freely, and the spindle set square with the lathe axis. With the hob fully engaged with the indexed teeth, the lathe is run at moderate speed, and vertical feed applied until the teeth are formed to their finished shape. As the pitch of the worm is very slightly greater than that specified, the teeth of the wheel should be on the minus side in depth rather than otherwise. It will readily be understood that the *circumferential* pitch of the teeth is proportional to the diameter measured on the working pitch line.

It may be thought that a good deal of space has been expended on a component which is hardly relevant to the main subject. The basic principles of spherical turning do not directly involve worm gearing, and it is only incidental to the construction of appliances which have been described. But advice is often sought on methods of cutting worm gears for use in various kinds of small mechanical appliances, and it is hoped that this description will be found generally helpful. There are other ways of making worm gears, some of which may produce higher accuracy or efficiency, but their design may involve the use of formulae, which is not easy to apply in practice with equipment normally available.

The shaft to which the worm gear is fitted (part No. 11) may be made from ½ in. b.m.s. if it can be chucked truly for turning down and threading the end; otherwise it is better to use larger material and machine it all over between centres.

To be continued

JEYNES' CORNER

Continued from page 610

It will be seen that Bourne was experimenting with liquid fuel as early as 1834; he also used steam power for riveting in this year. Here are a few of Bourne's early patents:

1834: Marine engine governor.

1836: Single eccentric reversing link-motion. This, however, did not reverse the lead.

1837: Steam starting and reversing gear for marine engines. Fitted in SS *Don Juan* 1837.

1838: Marine return tube boiler, having forced draught and superheater.

1838: Steam donkey pump for boiler feeding.

1852: Impulse valves.

1852: Balanced crank throws.

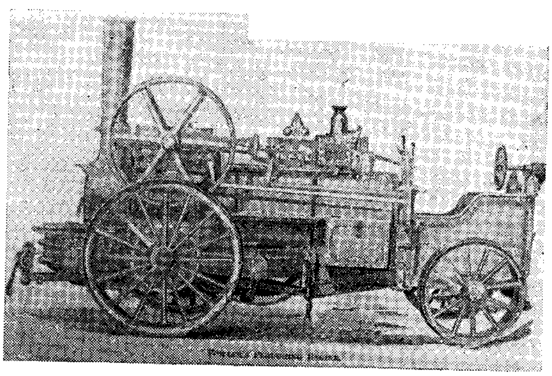
Bourne also initiated the superheating or reheating of the exhaust of the high pressure cylinder of a compound engine, to replace the heat lost by radiation, and produce more power in the low pressure cylinder.

Among the books written by Bourne are: "The Catechism of the Steam Engine," "Recent Improvements in the Steam Engine," "A Treatise on the Steam Engine," "A Handbook on the Steam Engine" and "A Treatise on the Screw Propellor."

Bourne also had something to say about the term Nominal Horse Power: "The uncertainty and varying character of the ratio subsisting between the actual and nominal power is a source of much perplexity, and proposals have been made in consequence to substitute some other unit for the horsepower. In the average class of modern engines (1869) the actual horsepower may be taken at 4 to 4½ times the nominal. The actual and nominal powers of engines, at first identical or nearly so, soon began to diverge; and in time as the pressure of the steam was increased the actual power became twice greater than it had been at first, while the nominal power being an expression of the dimensions of the engine remained the same. The divergence however did not stop here, but has gone on increasing, until in recent engines, the actual power exerted has been in some cases nine times greater than is represented by the nominal power."

In conclusion, I would say that it at once becomes apparent that confusion has existed on this subject for over 100 years. ▣

A Fowler double-drum ploughing engine built in 1867. The late C. E. Shackle built a model of this engine which is now in the Science Museum.



ELEMENTS OF SPHERICAL TURNING

Part V *Continued from June 16*

by Edgar T. Westbury

THE thread should preferably be screwcut to fit the rotating and lock ring slide neatly and accurately. It should be a close working fit in its bearing and adjusted to eliminate end play; if the worm wheel is keyed to the shaft as recommended the large headed screw (part No. 16) will provide endwise adjustment, and a fibre washer may be interposed between the lock ring and the face of the bearing to enable slight frictional resistance to movement to be obtained.

Modification of the wormshaft (part No. 13) and its bearing bracket (part No. 10) may be called for if a different worm and wheel than that specified are employed, but the alterations are obvious, and the bracket only needs to be located against the back of the bearing block so that the worm is in close mesh with the wheel, eliminating backlash as far as possible consistent with smooth and easy working. In the original version of this design, I used a single bearing with a long sleeve extending upwards, instead of a gapped bracket as shown, the object being to use a worm which was machined integral with its shaft. If the specified arrangement with the worm a light press fit on the shaft and grub screwed or cross pinned to it, is employed, the gap in the bracket should be made to fit the length of the worm closely, without end play.

The ball handle (part No. 14) was machined with the aid of the appliance together with other similar pieces of various sizes, such as those seen in the photograph in the previous issue. Some further information on the methods employed for turning these parts will be given later. Cross drilling and tapping the handle to fit the wormshaft and the crank may present practical problems and, in the first case, it will be found worth while to set the piece up on the four-jaw chuck so that the middle ball runs truly. Before starting the hole with a centre-drill, a light facing cut should be taken to serve as a "witness," when any error in setting up will immediately be apparent, and may be corrected by adjustment of the chuck jaws. The cross hole, in this particular instance, should stop short of passing right through the ball, for the sake of neatness, and a plug tap is then used to produce a blind thread to screw tightly on to the wormshaft. A short piece of $\frac{1}{4}$ in. rod, similarly threaded on the end, may be screwed into the ball to assist in the orientation of the piece when drilling and tapping the hole in the end ball from the other side for fitting the crank. If this is not done, it may be found difficult to ensure that the two holes are in the same axial plane, and the finished result may be rather unsightly, to say the least.

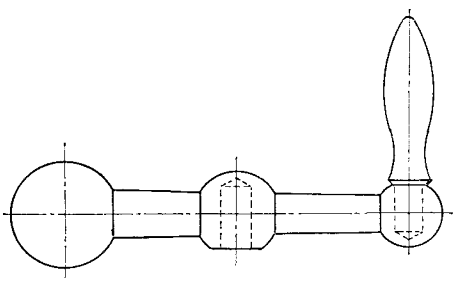
The rotating tool slide is moved by means of a small feed screw (part No. 10) which is quite easily machined from the solid, but it is permissible to make the head separately and pin or otherwise secure it to the shank. Instead of screwing it 2 BA, a $\frac{3}{16}$ in. × 40 t.p.i. thread may be used which, besides being more convenient for screwcutting, would enable the head to be indexed in 25 divisions, each giving 0.001 in. increments of feed. But, as I have pointed out, this only gives accurate measurement of the work being produced when the tool is applied in a truly radial direction, which is not always possible, because of limited clearance between the moving parts of the appliance and the lathe chuck when in action.

A groove is turned in the head of the feed screw to fit closely over the thickness of the keep plate (part No. 15), which is attached to the end of the rotating slide (part No. 3). This has a U-shaped gap to fit the groove diameter of the screw, thus providing positive location in both directions, without the need for a separate thrust collar. After drilling and tapping the fixing screw holes, the plate is located on the end of the rotating slide, with the feed screw in position, in the tapped hole of the radial slide (part No. 4) and the tapping holes spotted through, prior to drilling and tapping.

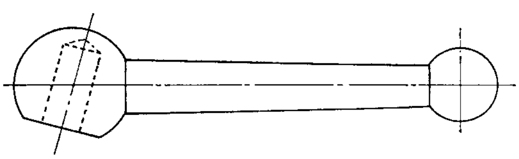
Ball and socket joints

Although the need for precise spherical accuracy is most important in parts such as ball and socket joints, which need to articulate over a universal angular range, many occasions occur in general workshop practice where it is worth while to set up a spherical turning appliance to ensure neatness and general accuracy of the finished component. These include several kinds of fittings for machine tools and attachments within the scope of toolmakers and "gadgeteers." The two examples shown are typical and do not call for explanation. Balanced handles are almost universally employed for slide rest and machine table feed screws nowadays, having superseded the plain crank handles which were once common. Their primary object, when first introduced, was to avoid risk of inadvertent movement under the effect of gravity and vibration, and this is still of some importance when the handles are large and heavy. Exact balance is rarely necessary for small handles, but the shape has become very popular because of ease of manipulation and pleasing appearance.

Clamping levers for turrets and other fixtures are also commonly made with ball ends, to harmonise with the handles, besides combining maximum strength with production facilities. The shape and proportions of the examples shown are based on examination of a number of parts seen on actual machines. Although standardisation of these parts, by firms specialising in their production, has been introduced, there is still a good deal of variation in details. The balanced handle shown has the large ball twice the diameter of that of the small end; the middle ball is intermediate in size, though in some cases the method of attachment to the feed screw, or the fitting of an index dial, may call for modification of its size, and sometimes its shape as well. Small handles are often screwed on to the end of the feed screw and locked by means of a back nut, in which case the centre hole, as shown, does not pass completely through the ball; but in other cases the handle may be secured by a nut or retaining screw on the outer end.



BALANCED HANDLE FOR SLIDE REST



CLAMPING LEVER FOR TURRET

General proportions

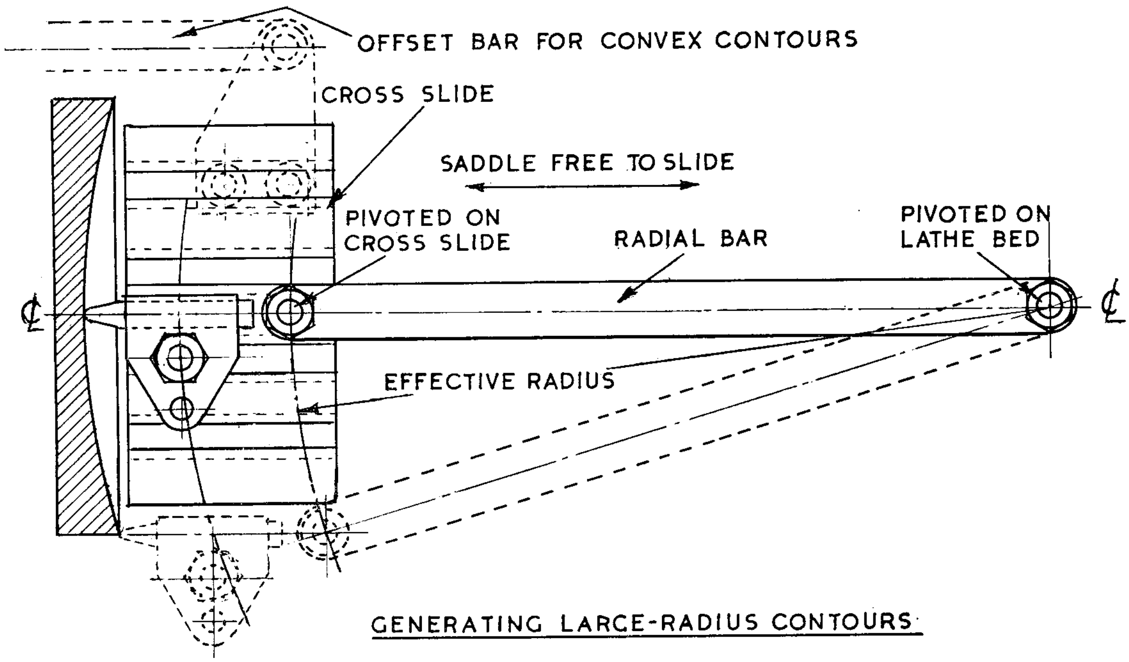
The hand crank has a length approximately equal to the radius of the handle (i.e. half the length between ball centres) and a diameter somewhat less than that of the small end ball. It is necessarily made as a separate part and pressed or screwed in tightly. Unless a contour-forming or copying appliance is available, its shape is best produced by means of hand tools. It is worth while to take pains in shaping it properly, not only on the grounds of appearance, but also for comfort in handling. One often sees rough and slovenly shaped handles, neither the look nor the feel of which give joy to the operator. The shank of the balanced handle should have a taper of about 2 to $2\frac{1}{2}$ deg., total length between ball centres about four times that of the centres ball, and *mean* diameter about half that of the same ball.

For a clamping lever $2\frac{1}{4}$ in. long between ball centres, the large ball may be made $\frac{11}{16}$ in. dia., and the small ball $\frac{7}{16}$ in. dia.; other sizes in proportion. The taper may be 2 to $2\frac{1}{2}$ deg. as before, with a mean diameter of about $\frac{9}{32}$ in. In most cases levers of this type are cross drilled and tapped at an angle which is convenient to give clearance over the fixture and fittings to which it is applied, and unless the length of thread on the clamping bolt necessitates drilling right through, a blind hole is preferable for the sake of appearance. The angle of the cross hole in this example is 15 deg., and for drilling the hole, the large end ball can be held in the three-jaw chuck, protected by a slip of thin soft metal, and inclined backwards at the required angle; this is not at all critical unless demanded by specification, or to ensure uniformity in a number of similar components.

It may be observed in passing that solid integral clamping levers of this kind are not only neat, but also provide maximum strength and rigidity for their intended duty. Levers made in two pieces, with the handle screwed or otherwise attached to the centre hub or nut, obviously have their torque resistance limited by the strength at the point of attachment, which is often relatively weak. A variation of the lever shown, which may be preferred if the radial length is short, is to shape the shank like that of the hand crank of the balanced handle, instead of with a ball end. The area of the clamping surface at the face of the cross hole may be considered too small for ample bearing, but a loose thrust washer may be fitted, and for some purposes it may be advantageous to make this with a spherical under surface to assist self-alignment of the fixture.

Machining procedure

In these, and most other turning operations of a similar nature, roughing out to within about $\frac{1}{32}$ in. of finished shape and size is generally advisable. The slide rest tools may be manipulated for part forming of the contour, but, as the spherical appliance is capable of taking reasonable cuts, it is often sufficient to take the corners off with a 45 deg. chamfering tool. For the balanced handle the taper shank can be turned to finished size, or leaving only a very small amount for subsequent finishing; one advantage of the horizontal-pivot



GENERATING LARCE-RADIUS CONTOURS

appliance, when fitted at the back of the cross-slide, is that the normal front tool can be retained in position without disturbing the angular setting. A tool having angular sides at about 60 deg. inclusive and a small radius on the nose is advised for turning the shank, as sharp internal corners make blending-in of contours more difficult. The two parts of the shank should be machined at the same index setting, so that they form in effect a continuous taper, interrupted by the middle ball.

While it is not impossible to form most of the contours on work mounted between centres, it is generally easier to mount the work in the chuck, without back centre support, and machine as much of it as possible before parting off. The small end ball should be formed on the outer end and, if the amount of overhang should be considered excessive, a little extra length should be allowed so that a small centre may be drilled to take the back centre; this length is turned down to a small diameter and subsequently parted off. Sometimes a small axial hole in the end ball is permissible, such as to take a grub screw to lock the hand crank. If the work can be chucked truly, the turning may be done piecemeal, with only sufficient projecting for the particular part of the operation in hand. After parting off, the large ball may be finished by chucking over the middle ball (again protecting its surface with a soft metal slip or ring) and pushing it back as far as it will go in the chuck. It is generally possible to get within 30 deg. of the centre in the spherical forming of the large ball, so that not much is left to be machined in the finishing operation. Mention has been made of the cross drilling operations on these components, which involve some problems, as it is not easy to drill exactly through the centre of a ball, or to ensure that the hole is drilled at the correct angle, but detailed instructions on these matters are somewhat outside the scope of the present articles.

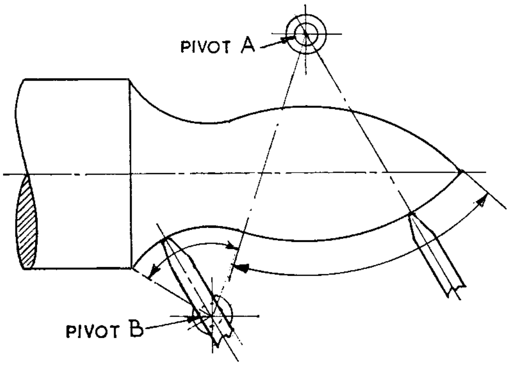
Large radii

Limitations in the radius of adjustment for the tool in any of the spherical turning appliances described may make them unsuitable for dealing with contours of specially large radius. It is, however, possible to cope with these by means of simple devices which follow the same basic principles. Optical instrument work, for instance, often involves the need to machine concave mirrors, also laps and moulds for lens grinding, which have a large radius of curvature. The method is shown in my drawing, in which a radius bar pivoted at its two ends to bolts fixed to the cross-slide and the lathe bed respectively, is employed. In order to produce a true spherical curve, the latter point must be exactly under the lathe axis, and the tool point must be set to coincide with this centre-line when in the middle of the work as shown.

With the saddle free to slide and the cross-slide traversed by its feed screw in the normal way, the swing of the slide bar will cause the tool to move in an arc and produce a contour equal in radius to the length of the bar between its eye centres. In a variation of this device, the cutting tool may be carried in a fixture attached directly to a die block fitted to a slot in the cross-slide. The effective radius in this case will then be equal to the distance from the pivot on the lathe bed to the actual tool point, and therefore will be more susceptible to variation or adjustment that when using an articulated bar of fixed radius. Convex curves may be more difficult to produce in this way as it may be impossible to pivot the radial bar on the lathe bed at the required point unless the work is overhung a long distance from the headstock. In this case, it is possible to use an *offset* radial bar at the back or front of the headstock, provided that this is set exactly parallel to the lathe axis when the tool is in the centre of the work. This arrangement is indicated by dotted lines.

Curved profiles

Sometimes spherical turning appliances can be used with advantage to produce—paradoxically—non-spherical contours involving circular arcs. This cannot be done with the horizontal pivot appliance having a fixed centre height, but the simple vertically pivoted lever device, which has the widest range of adjustment for either internal or external curves, is easily adapted to this kind of work. In my next drawing, the convex curve on the end of the work is produced by setting the tool to a large radius from the pivot A, and the concave curve by setting it to a large radius from pivot B.

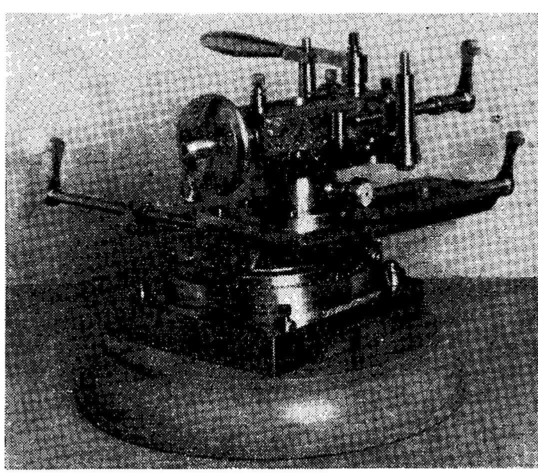


GENERATING NON-SPHERICAL CONTOURS

This principle could be applied to forming the hand crank for the balanced handle, but many turners would consider it unnecessarily complicated. It was, however, employed to advantage in producing a master pattern for use on a copying lathe, where both the dimensions and curvatures were specified within close limits. Where the convex radius is too large to be obtained with an appliance mounted on the cross-slide, the tool may be controlled by a radial bar having its stationary pivot mounted at the back of the lathe bed, and the other on the cross-slide. In this case, the cross-slide must be set to move freely, and the saddle traversed in the normal way, using self-act if desired. This arrangement was employed in a munition factory in quantity production of large shells for forming the nose contour to fine limits.

A compound turning appliance

While on the subject of appliances for spherical turning, mention may be made of an ingenious and elegant device built by Mr. John Pickles, as a part of a set of equipment for ornamental turning. It is intended to be mounted directly on the lathe bed, and its movements provide for many other operations in addition to spherical turning. The square base carries a turntable with a " tangent wheel " or worm gear, the movement of which is controlled by a crank on the shaft extending to the left. With the centre of the base mounted exactly under the lathe axis, spherical curves can be produced by a cutting tool mounted on the radial slide, the handle of which extends to the right. Superimposed on this slide is another component capable of both rotating and radial sliding movement, and also incorporating a bearing for a horizontal spindle. This is fitted with a grooved pulley on its front end, so that it can be driven from an overhead shaft, and a cross-slide carrying a socketed tool holder. It is thus possible to use the spindle for drilling, grooving, fluting and eccentric cutting or " engine turning," on flat, angular or spherical surfaces of work held in the lathe chuck. This appliance, together with a geometric chuck, was awarded the Bowyer-Lowe Cup at the 1958 M.E. Exhibition.


A spherical turning slide rest built by John Pickles.

Although complex movements such as provided for by this appliance are rarely required in machining components in general engineering, they demonstrate how inexhaustible is the range of

Continued on page 652

SIMPLEX

Continued from page 649

rather more than $1\frac{1}{4}$ in. wide, machine this, using the four-jaw, or by milling, to exactly $1\frac{1}{4}$ in. wide, or if the frame slots have already been cut and finished—to a tight fit in the horn slots. Drill all the holes in the horns, noting that the top and bottom holes must not be too close to the ends or there will be no room for the bolts holding the top and bottom stays. Jam the "gauge" into the first horn slot, and clamp the horns, in pairs, to both the frame and the gauge, using two small, and one medium-sized clamps. Run the drill through the holes in the horns and drill the frames. Remove all parts and clamps, take off any burrs, and countersink the outside of the holes in the frames. The rivets required here are $\frac{1}{8}$ in. × 1 in. iron snaphead, and these should be just about the right length as bought.

Feed pump

The most simple method possible to get water into the boiler is probably the single-ram eccentric-driven pump, or an externally fitted crosshead pump. I would have liked to have shown a crosshead pump, similar to that on *Rob Roy* but the Walschaerts' valve gear rather gets in the way. It would just be possible to sling a crosshead pump of small bore underneath one of the cylinders, and drive it by an extension of the drop link or by a separate link bolted to the crosshead. The snag of this arrangement is the large offset necessary, introducing an unpleasant couple. This would quickly cause wear on the crosshead slippers and then on the piston rod gland.

If we use a single ram eccentric-driven pump between the frames, the large bore and stroke necessary to ensure that the pump is always master of the boiler becomes rather a nuisance, and might cause jerky running at low speeds. But reading through a recent article on pumps by Edgar Westbury gave me the idea of using a differential double-acting pump, so that only one eccentric and eccentric rod and strap will be needed.

To be frank, I am not too certain of the *effective* output of the pump shown, so I have purposely arranged for a fairly large bore and stroke. Experienced builders who intend to fit an injector in addition may be well advised to make the throw of the eccentric $\frac{7}{32}$ in., rather than $\frac{1}{4}$ in., which will reduce the angularity of the eccentric rod quite considerably. I should however explain that as the pump has not been drawn exactly to scale, although the dimensions are correct, the eccentric rod appears shorter in proportion to the other components than it really is.

The pump is bolted to a cross-stretcher cut from $\frac{3}{8}$ in. thick b.m.s. by four 2 BA hexagon-headed bolts, though Allen screws would be preferable as there must be no chance of the pump working loose in service.

This cross-stretcher is in turn bolted to the frames by three 4 BA screws each side. That on the right in my drawing should be countersunk, to clear the driving wheel, but the other two may be turned bolts, to ensure a good fit in the frames. In addition, after the bolts have been tightened up, a $\frac{1}{8}$ in. silver steel dowel pin should be put in, a good fit in frame and stretcher, to take some of the thrust of the ram off the screws. There is just room for this between the two bolts.

To be continued

SPHERICAL TURNING

Continued from page 644

operations which can be carried out on the lathe beyond normal turning as generally understood. Lathes designed specially for ornamental turning a century or more ago were often equipped with a galaxy of appliances, few of which, I imagine, were ever properly mastered by a majority of those who used the lathes.

There are many possible variants of the spherical turning appliances I have described, all capable of accurate work provided that they follow the basic principles. I have seen a simple horizontal-pivot attachment used on a capstan lathe for production work; the spindle worked in a square block held in the tool post of the cut-off slide, and the cutting tool, adjustably mounted on its front flange, was presented tangentially to the work. Rotation of the tool head was arranged so that it could be linked to the capstan for self-acting feed.

Modern users of lathes are generally satisfied with straightforward slide movements, which will generally cope with most machining requirements. Many readers may say "these gadgets do not concern me—I shall never need to do spherical turning or other fancy work!" but one never knows when the need for special operations may arise, and when it does, it is always urgent. The "compleat" turner (to borrow a term from Izaak Walton) should always strive to attain a comprehensive understanding of both the possibilities and the limitations of his machine. It was said by Joshua Rose, a well-known 19th century writer on workshop subjects, that "he who is master of the lathe is master of the entire mechanical world." ▣

ELLIPTICAL TURNING – A NEW METHOD

by A. Shackell

THE MATTER of elliptical turning was raised in these pages (issue 3517) in connection with machining the flanges of two-stud stuffing glands. Although elliptical flanges rather than the tangent profile type are not always good scale on a model, when they are needed getting the correct shape can be quite a problem.

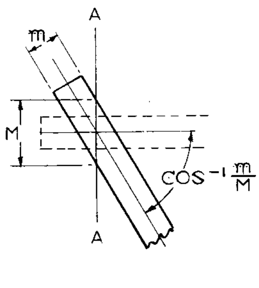
The method I have developed, using an ordinary lathe, is based on the simple fact that an ellipse is the oblique section of a cylinder. I have submitted a specimen gland to the Editor, so he should be able to vouch for the quality of the results. (Yes, indeed — Ed.) One valuable feature of the method is that the cutting and clearance angles of the tool are quite normal, and do not acquire undesirable exaggerations encountered in using an elliptical lathe or other appliance having a similar action, such as a swing-frame copier.

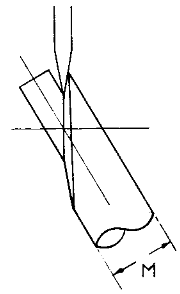
To understand how the method works, it is helpful to consider the solid geometry involved; this is quite simple although its application in this way is apparently not well known. In the diagram at upper left in the drawing, AA represents a very thin plate having a circular hole of diameter equal to the major axis M of a given ellipse. Now if a bar of the correct elliptical section were passed into the hole at right angles to the plate, as shown dotted, it would touch the plate at the ends of the major axis, but could be swung in the plate of the minor axis m through an angle of COS— $\frac{m}{M}$, when it would exactly fill the hole. The significant fact here is that the bar, which is straight, parallel, and theoretically of any length, can be moved lengthwise through the hole in the plate at any angle up to that determined by the minor axis.

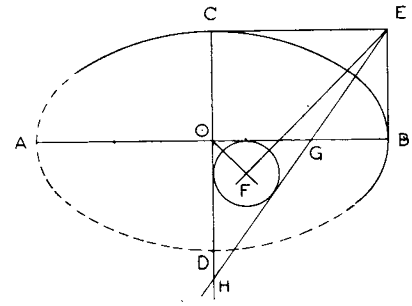
In practice, we just replace the plate by a rotating tool, the path of the cutting point simulating the circular hole, as in the next view to the right in the drawing. This shows the elliptical section being produced from a round bar of diameter M, the major axis, and we come to the set-up shown at lower left, a plan view of the arrangement rigged on a typical small lathe. I think this form of presentation is better than a photograph, because one can select just the elements related to the subject, whereas a camera puts in everything, what is insignificant and even what is confusing. The tool is held in the bar of a boring head, and the gland or other component is carried on the end of a bar clamped in the tool-post, with the top-slide set at the necessary angle. The top-slide is used for feeding the job through the cut, and the boring head to advance the tool for each cut. The view is drawn with the slide in the mid position of its operational travel, when the tool would be cutting only at the major axis of the flange of the gland, and to make things clearer I have added some lines that might be tool marks on the flange.

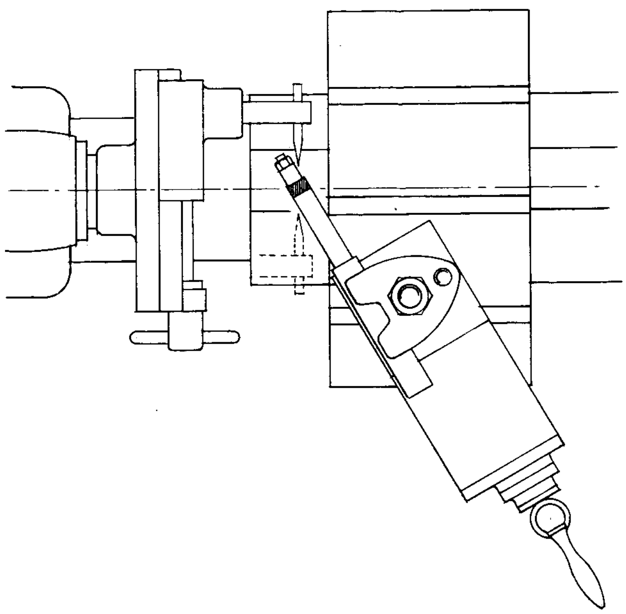
Some notes that should be helpful: The tool must be at centre height when in the horizontal position, with the slide of the boring head also horizontal. The component should be mounted with its major axis vertical and the minor axis exactly at centre height. This last takes care of the vertical alignment; horizontal alignment is achieved by manipulating the cross-slide, the saddle, and the boring head, so that the tool just touches each side of the job when the top-slide is moved to the appropriate positions. Cross-slide and saddle should then be locked. The thing to watch is that the furthest out position needed to complete the cut, the corner of the top-slide must remain clear of the plane of the path swept by the end of the tool bar.

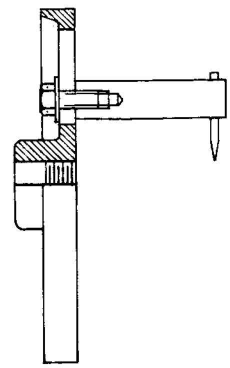
The bar for mounting the component is conveniently made from square section mild steel turned for a suitable length to a diameter slightly less than the minor axis of the finished part, and make no mistake about this: the intermittent cutting action has a strong tendency to dislodge the component, so it must be firmly fixed. Or to avoid any such trouble, the gland can be mounted by screws through the stud holes while retaining the central location. To allow of doing this the bar would not be turned cylindrically, but would need forming to a section slightly less all round than the required ellipse, perhaps being turned to shape and size on the set up for the gland. Another option is to braze a palm on the bar to take the two screws. If you do not have the use of a boring head, a subsitute bar in the form of a pillar bolted to the faceplate, see lower right of drawing, can with care and patience be made to serve, the cut being applied by tapping the toolbit out. Here again it is important that the cutting face of the tool be set truly radial to the lathe axis.











It should be clear from the diagram that the tool is restricted to a narrow V shape, and the cutting tip should have only a small radius; I find that 5 to 7 thou is about right, and of course the feed for the final cut needs to be quite slow accordingly.

For setting the top-slide, just divide the minor by the major axis; this will be the cosine of the required angle. The higher this angle, that is, the greater the difference between M and m, the longer and thinner will be the overhung part of the component support. I would recommend that the ratio of the axis but not much more than 2 to 1 (cosine 60°), which I think makes a good-looking gland, with adequate room for the studs. If the gland or other part is to be made from bar and not from a casting, I would say that the best procedure is to turn a length of the bar to the required elliptical section, then set this with an indicator true in the four jaw, to finish the turning. This way gives the maximum rigidity for the elliptical operation. Rectangular bar could well be used, not only saving material, but conferring a valuable reduction in the total depth of cut at the sides. And naturally, if you don't feel quite confident with the process at first, you will try it on a piece of scrap.

While dealing with ellipses, I propose describing a useful method of quickly finding the optimum radii for drawing the quadricentric quasi-ellipses that are frequenly required in machine drawing. In the figure at top right of my drawing:

Let AB and CD be the major and minor axes intersecting at O.

Complete the rectangle OCEB.

Continued on page 973

The maker's nameplate.

chuck, centres and nineteen changewheels, also plenty of dirt and rust and thankfully, grease.

For those of us accustomed to the proportions of the modern $3\frac{1}{2}$ in. or 5 in. lathe, my vintage lathe $4\frac{1}{2}$ in. by 25 in. between centres makes some startling comparisons. The nineteen changewheels go from 20T x $1\frac{3}{4}$ in. to 120T x $9\frac{3}{4}$ in. diameter. It makes the largest Atlas diecast wheel of 64T x $4\frac{1}{2}$ in. seem like a toy. If lathes were still made this way today model engineering would be strictly for millionaires. Or buy your changewheels on instalments! The 4 TPI leadscrew is over $1\frac{1}{8}$ in. dia. and the four jaw "dog chuck" is of giant proportions for a $4\frac{1}{2}$ in. lathe. Being $10\frac{1}{4}$ in. diameter it can only be used with the bed gap open when the centre height is $8\frac{1}{2}$ in. Incidentally the bridge which closes the bed gap is still such a fine fit it needs very firm tapping into place.

One of the lathe's less endearing features is that the headstock is adjustable and secured by a single $\frac{1}{2}$ in. bolt. It was obvious that this headstock had not been moved in years. The layers of grease and dirt were witness to that. Imagine my surprise when after skimming the face of the dog chuck to remove the worst of the corrosion I found it was not flat. One wonders what work the previous owner turned out. Needless to say, half an hour with a dial gauge soon corrected the error.

But I have not mentioned the make of this lathe, or should I say maker. It still has an attractive and beautifully engraved nameplate, the letters enamelled in two colours:

HENRY B. MASSEY
MAKER
SPALDING

Now I have only come across this form of wording on one other item, a double barrel percussion pistol by Wheeler of Birmingham, circa 1840. Just how old is my lathe?

HOT AIR ENGINE

From page 960

The measurement of the speed of rotation of small engines can be difficult, and my musically-minded son came up with a simple method of doing it. A small sprocket with a known number of teeth is fitted to the crankshaft. With the engine running, a piece of paper is held against the teeth of the sprocket. This emits a musical note which can be identified on the piano. Now the number of teeth on the sprocket is known. (31 on the sprocket I have used). If the note emitted is, for example C♯, this represents 1040 cycles per second. The speed of rotation is therefore $\frac{1040}{31} \times 60 = 2012$ r.p.m.

I hope the design of this engine will prove of interest to other Hot Air Engine enthusiasts and that it will stimulate them to describe some of their ideas and experiments.

References

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Thomas, F. B. (1975) Stirling Cycle Engine. The Laubereau—Schwartzkopff Cam. S.I.M.E.C. Newsletter No. 19, 117.

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ELLIPTICAL TURNING

From page 971

From E and O draw lines at 45° to the axes, intersecting at F.

With F as centre, describe a circle tangent to OB and OD.

From E draw a tangent to this circle, cutting AB at G and CD produced at H.

Then GB and HC are the radii for arcs to make the figure.

Quadricentric figures drawn this way always look nice. Point G is not quite the position of the true eccentric focus, but it can be shown (we won't bother just now) that the point of common tangency, where the arcs meet and blend, is actually on the true ellipse.

DRAWINGS FOR "ROYAL ENGINEER"

LO. 943. Sheet 1. General Arrangement and main frames.

Sheet 2. The boiler.

Price 70p each (inclusive of V.A.T. and post).