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.

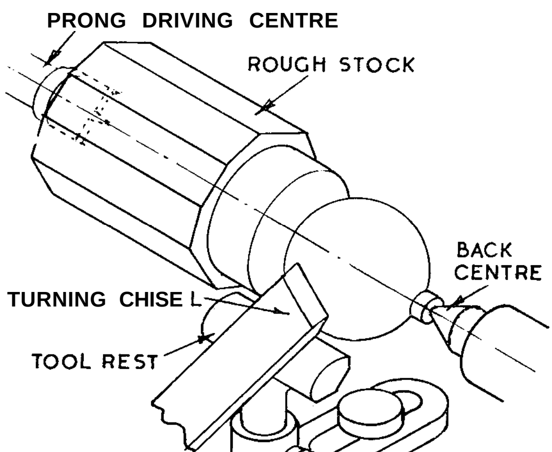
Freehand methods

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.

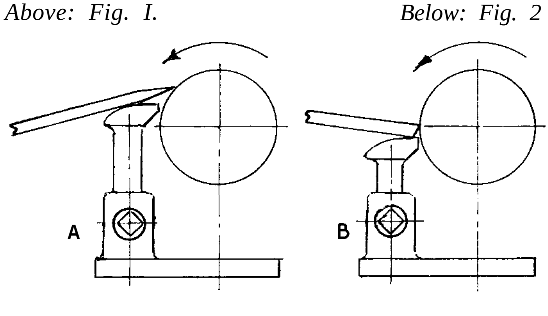
Most spherical contours comprise only a part of a complete sphere, with a supporting stem or stalk. Such parts as balanced handles for machine tools, stanchions, or handrai1 knobs, and ball-ended rods and links are in this category. The production of a complete ball is not often necessary in mechanical 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



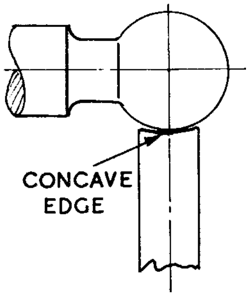
Above: Fig. I. *Below: Fig. 2*



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 iess 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.

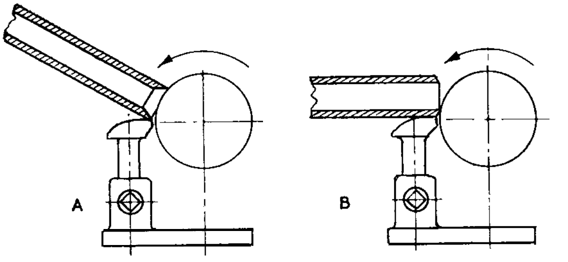


Fig. 4: The use of tubular turning tools on soft and hard materials.

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, out 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 rigbt-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 pant; they may be adapted to check the shape of the neck or stem of the sphere, and also to cope with

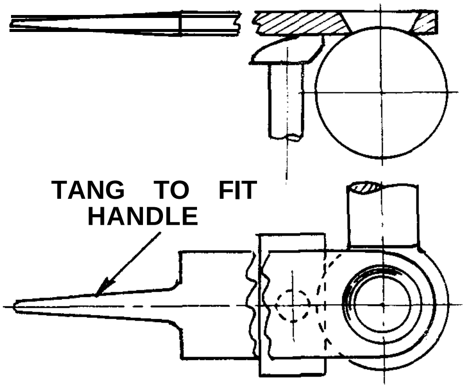


Fig. 5: Flat tool for ball turning.

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.

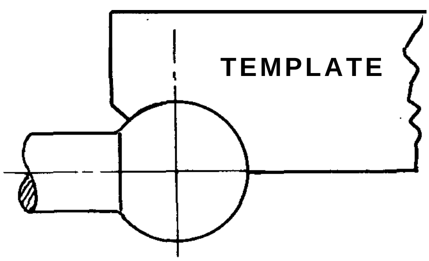


Fig. 6: Use of template to check contour.

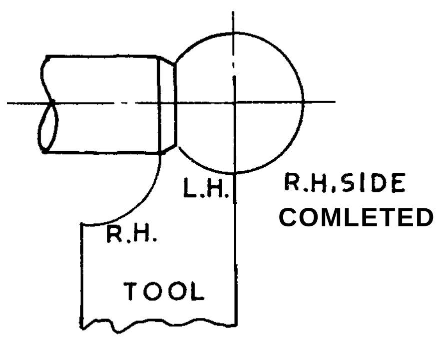
In industrial production, spherical and other contours are often turned by means of form tools mounted in the slide rest in which the cutting edge is of negative shape to that of the article to be turned. The extent to which such tools can be used in jobbing work, however, is rather limited, primarily 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 resharpening is required, they should be ground on the tap 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 Ieft-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 1/2 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 ingenieous 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 mechanical1 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 rigitdity 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 Iocated 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 cylindricall 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.