THE DESIGN OF JIGS AND FIXTURES FOR MACHINE TOOLS.

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The reason for making special tools is to reduce the cost of manufacture; and tools are made more or less elaborate according to the number of parts to be made. The greatest reduction in cost is usually in the shortening of time required for an operation, but another saving is available by simplifying operations so that a semi-trained man may handle work which would otherwise require a tradesman, thus taking advantage of lower wages rates.

A lot of a dozen parts will often pay for some special tools, but if the number is increased to a thousand, fairly elaborate tools will be found profitable, while for a hundred thousand a special machine may be worth while. Really large numbers of similar parts are the exception in this country, so it is proposed to confine our remarks to tools suitable for lots of from a few dozens to a few hundreds in each batch. Even in lots of a hundred at each set up, a tool may do thousands of parts in its lifetime.

Tool design is too wide a subject to treat in all its phases, so remarks will be confined to jigs and fixtures for use when cutting metal in the standard machine tools—the lathe, driller, planer, shaper, miller, and slotter. A jig has been defined as a piece of plant with guides for cutting tools, either with or without locating or clamping features; and a fixture has been defined as a device for locating and holding a part while being cut by tools, such tools being guided entirely by the machine in use; hence a drilling jig or a milling fixture. The definitions are not universally accepted, as setting devices for arc welding are commonly spoken of as jigs.

Cost being the governing factor in manufacture, it is the lowest over-all cost of each part that must be aimed at, and the designer must have an idea of the number of parts a tool is to produce when considering the design. This is usually outside his sphere, but someone must make an estimate of the number required, and the business must take the risk of loss from smaller sales.

Mr. Harnett, of General Motors Holdens, was reported as saying that, after a car design was agreed upon, a major problem arose in the provision of tools, for, no matter how many cars were made, the cost had to be amortised just the same. He said
it was usually considered uneconomical to attempt mass production unless assured of a market for at least 35,000 cars. The gamble lay in judging the market.

In making improved tools for a line already on the market, numbers are more definite, but there is always the risk of a change of design which may reduce tools costing hundreds of pounds to scrap iron.

The ingenuity of the designer plays a large part in making successful tools, as the work comes in great variety, but there are certain broad principles to be followed. Close co-operation between the part designer and the tool designer is advisable, as small alterations in a part often cheapen manufacture considerably. There is also the occasional problem of the part that must be made in small numbers, but in a shape difficult to machine with standard tools. In such cases a good deal of tool making can be profitable in spite of small numbers.

If there are a thousand parts to be made, and if a certain operation when done with standard tools already in stock costs 5/-, there is a sum of up to one thousand shillings available for tools for every shilling that the cost of operation can be reduced, but the job has probably been priced for selling on the assumption that the cost of this particular operation, including tool cost, will be 3/-. It is therefore up to the tool designer to keep down the cost of tools and make them as efficient as possible.

As well as these two most important points of ability to produce and cost, strength, lightness, and convenience are important. Strength is needed to resist distortion, either by cutting tools or clamps, and clamping must be arranged so as not to distort the part. In some cases special precaution must be taken to prevent distortion of the parts by the cutting tools. Thought must be given to develop tools that are as far as possible fool proof, so that indifferent operators may be relied on to insert parts correctly.

Symmetrical parts may be entered several ways, but it is usually possible, with non-symmetrical pieces, to provide stops to prevent incorrect setting. In all cases there must be sufficient room for chips. This is most important. It is uneconomical to increase the price of a tool seriously to effect small savings, unless large numbers are being dealt with. The designer must, of course, have an intimate knowledge of the machines, standard tools, and processes available for the work under consideration.

The materials used for tools are mainly the commoner metals. Steel and cast iron naturally predominate. Cast iron is very
largely used for bodies of fixtures, but steel castings have much to recommend them where castings are called for. The newer method of arc welding is most economical in many cases, as it eliminates the expensive pattern. In fact, the piece can frequently be made, ready for machining, for the same cost as the pattern, and there is no delay waiting for castings. It also has the advantage that members or inserts of hard steel may be welded solid, instead of hardened pieces being attached by screws or other means. The obvious disadvantage is that when wear does occur it is more difficult to rectify.

Cast iron is a cheap material, and for many purposes it is most economical, but for tools expected to be used repeatedly it is subject to serious abrasion on locating faces, also studs pull out, and set screw holes wear rapidly in the thread. The extra cost of a steel casting is in most cases easily justified, being a very small percentage of the total cost. Steel can usually be made lighter, will stand more abrasion, hold screw threads better, and generally be more satisfactory. For these reasons, a fairly hard grade of casting is preferred. Every job must be considered on its merits, but there is no doubt that the arc-welded frame is frequently the best. The design is more restricted in shape than in using castings, but workable frames can usually be built up from standard sections. Smaller non-cutting tools can frequently be machined from soft bar steel, and if necessary case-hardened, while very small parts, such as drill bushings and locating pads that must be hard, are most economically made of a water hardening carbon steel.

Larger tool bodies that must be handled are at times made of aluminium, but it is usually for big quantities. Bronze and babbit are used for bearings, and white metal is run in for holding parts, but steel in its various grades is the main material.

A sidelight on reasons for construction by different methods may be given. In an American tool design office some years ago instructions were given not to call for patterns if it could be avoided, but to build up tools from cast iron blocks, as listed in the general office standards book, and rolled steel bars. The parts were screwed and dowelled together. The reason given was the high cost of patterns, due to the pattern-makers’ union being strong enough to demand exorbitant wages. This was before the days of general arc welding.

When the tool designer receives a drawing of a part, with instructions to prepare designs for tools for producing it, the first thing to do is to decide the type of operations and their sequence, together with the necessary points for setting in the
various fixtures. For the first operation location must be from
the unfinished surface of the part, especial care being taken to
have the part so set that all subsequently-machined surfaces
will clean up, and that those surfaces remaining in the rough
state will be in the desired positions. As far as possible, location
for subsequent operations should be from previously machined
surfaces, to ensure all finished faces being in correct relationship.

The locating points must be chosen very carefully, and the
clamps and tool pressure arranged to force contact with as many
as possible. Stops not in forced contact should, wherever
possible, be visible, so that the operator has not to depend entirely
on his touch. A most important point to watch is that chips can
be easily removed from the fixture in general, and the locating
points in particular, as small particles adhering to the engaging
faces will cause inaccurate work. It is advisable, therefore, to
keep the locating spots small, allowing ample clearance at all
other places. One large American office lays down a minimum
clearance of \( \frac{3}{8} \) in. between parts in fixtures and unmachined
surfaces of the fixture body.

Some method of holding the work in correct location must be
used. Methods vary from merely holding the part in position
with the hand, to complicated lever and screw systems for
equalising pressure at different points. Screws are most used,
either as set screws or in conjunction with plain lever clamps,
but cams and wedges are useful at times. A wedge often makes
a cheap and effective grip, but it requires a hammer to drive it,
and the average production operator can cause quite enough
damage without being invited to use a hammer on his tools. A
wedge must be fairly fine in the taper, or it will not grip, so
that any heavy driving causes excessive pressure.

Drilling operations probably offer the simplest and often the
most profitable field for special tools. Everyone conversant with
machine shop work knows what a long time is taken in laying
out holes and drilling to circles. On flat work one part will
serve as a jig to drill the rest, being simply clamped on top of
one or a number of others with bolts and split plates. The next
step is to carefully drill a plate, perhaps thicker than the parts
to be drilled, and caseharden it. A further advance may be made
by boring the holes larger and fitting hardened renewable bushes.
The final step is to attach locating and clamping gear to the
bushed plate. As before mentioned, the number of parts to be
drilled governs the class of jig made. The engine lathe does not
offer so much scope for special tools except in the design of
chucks for holding awkward-shaped parts, though in many
instances special cutting tools show to advantage.
To some extent the same remarks apply to the planer, shaper, or slotter, with the difference that there is no automatic setting of work on centres, and therefore much greater scope for holding devices. The miller, being very largely a production machine, lends itself to special cutting tools, as well as holding fixtures. These cutting tools may be either special combinations of standard cutters or cutters made for a particular operation only.

The foregoing gives some idea of the elements of design, but the practice can best be shown by taking examples in use. Choosing examples is difficult, but an attempt has been made to give variety. As it is almost impossible to convey an adequate idea of a design without some form of illustration, lantern slides have been prepared to illustrate the following:

The first example (Figs. 1 and 2) is a small gear wheel from the familiar German jack. The operations are: Cut-off bar, drill, broach, and mill teeth. The cutting off is done in a circular saw, so that the blanks will be true enough without further finishing on the sides. The drilling is done in a jig having a permanently fixed vertical V under the drill bush and a spring-loaded, serrated cam to hold the blank against the V and prevent rotation. The clamping is therefore practically instantaneous, and, with the assistance of a blow gun to clean the chips from the locating faces, there is little idle time. Broaching is done in a screw-driven machine with a pull broach. The broach has 49 teeth, with a cut of .002 per tooth, and six finishing teeth the same size. It is made of nickel casehardening steel as used for some motor-car gears, and finished entirely before hardening. It has parallel lands $\frac{1}{32}$ in. wide, and can be ground on the front face to that extent. The gear teeth are not standard shape, so that a special cutter is needed. This has been taken advantage of to make the cutter finish the tops of the teeth as well as the tooth space, and eliminate a turning operation. The blanks are held on a square arbor in the index head, ten at a time. The arbor fits in the taper socket of the index head, and the tail centre is brought up to steady it when cutting. When a set is finished the tail centre is set back far enough to clear, the nut on the arbor taken off, and the gears removed one at a time. This gives a stiffer set up than an arbor held between centres, and renders unnecessary its removal from the machine each time for unloading and loading.

A point that may be stressed here is the necessity of keeping everything as stiff as possible, especially for cuts of any width. If a tool could be moved exactly in the desired path and the work held absolutely still, the result would be perfect machining.
and very long tool life. The absolute is unobtainable, but the
difference between a stiff set up and a springy one is seen in the
poorer quality of work produced and in greatly increased tool
wear. This holds for all ordinary cases, though spring tools
have a definite but very small niche. If either the work or the
tool is springy, it is frequently necessary to reduce speed to
prevent chatter, but even if that stage is not reached the disor-
tion will show in poorer finish and increased tool sharpening.

The next example (Fig. 3) is a tool made owing to the great
difficulty of the operation with standard tools, small lots of
parts only being anticipated. The part belongs to a safety
friction lowering device, and carries a thread of ten inch lead
with eleven starts. Diameter is ten inches, and length $\frac{3}{4}$ in.
The machine designer showed good reasons for the shape, so it
had to be made. The first one was cut in the lathe by man power,
with a lever on the chuck to get the necessary small rotation
per thread, and a change gear wheel, with a multiple of eleven
teeth, was worked into the train so that it could be taken out of
mesh and turned the required amount between the threads. The
worst trouble was that to cut ten inch lead the lead screw had
to rotate 20 times as fast as the spindle. A handle on the lead
screw was tried, with negative results. The threads were cut at
the cost of much labour, and not too smoothly.

The special tool comprises a short, heavy, vertical shaft in a
cast iron bush, which has a clamping flange at the bottom and
locating places for the part at the top. The lead was given by a
groove of the required angle, covering about 90 degrees of the
spindle, and a round gunmetal plug with an end formed to
engage the groove. This plug was fitted through a hole bored in
the cast iron bush part, and fastened with a set screw. The
lead groove was made of the acme form, so that wear could to
some extent be taken up. An arm was attached to the top of
the vertical shaft. To this arm was attached the tool post, and
a link for connecting to the ram of a shaper to get the required
oscillation. The tool post was in the form of a very small
clapper box, with the hinge pin working in a slot, so that the
clapper box could be fed by a screw lengthways to the extent of
the slot. This saved making a slide, and for the limited travel
required worked excellently. Feed was by hand on the moving
tool post, and an adapter ring, with eleven holes, took care of the
spacing of the threads. In cutting the nuts the tool post was
reversed, and fed from the centre outwards, a different adapter
holding the part.

We will now take a very common need, that of drilling a pin
hole through a round bar. A large number of pivot pins are
cut from round bar and fastened with a cotter pin through each end. The simplest jig for the purpose is a hole drilled in a piece of steel, and a cross hole to guide the drill. Apart from the disadvantage of fitting one side of bar only, chips cause a lot of trouble, and a drill broken halfway through is a calamity. A V block with a drill bush holder supported centrally over it gives exact location sideways. An adjustable stop is easily arranged to locate the hole from the end of the pin, and if two holes at exact distance apart are required a movable pin is provided to engage the first hole drilled. The only clamping necessary is to keep the part against the end stop until the drill is entered and to prevent the part lifting as the drill is withdrawn. A simple lever on top of the part is sufficient, it being held with one hand while the drill is fed with the other.

It may be remarked here that drilling jigs with one hole only should in general be bolted in position under the drill so that no further handling on setting of the jig is needed, and screws or levers can be operated without it being necessary to hold the jig. It is also desirable to use a design that does not need the drill bush to be moved in loading the jig. If the bush is in a hinged cover, the drill must be lifted high enough to clear it for each loading.

The next example is a lathe chuck. The problem was to set a winding drum true with a ratchet cast at one end of it. These could be set in the standard independent four-jaw chuck by using chalk and plenty of time. But when an attempt was made to use a three-jaw chuck, there was trouble owing to some of the castings being oval, $\frac{1}{8}$ in. bigger one way than the other. A radial inaccuracy of half that amount was permissible, but if one jaw of the three-jaw chuck got on the major axis and the other two near the minor axis, it would run out too far altogether. A little thought showed that an ellipse will be chucked true if engaged at four points equally spaced, with each opposite pair at the same distance from the centre, and that it does not matter whether the jaws are near the ends of the major and minor axes. The trouble was got over by making a four-jaw chuck with each opposite pair working in unison, but independent of the pair at right angles. The work was done in a boring lathe with a heavy four-jaw chuck permanently fixed to the spindle, and it was found that there was room in the rather large screw and jaw slots to put two right and left hand screws, at right angles to each other, and crossing in the centre. These screws operated jaws fitted in the slots, and a thrust piece in the centre engaging collars on the screws kept them in position. After assembling, the jaws were bored to the required diameter and casehardened.
The next consideration is the lay out of the whole machining on a part of unusual shape. It is a rocker or tumbler from a ratchet and lever jack, in which two pawls oscillate in the two grooves. The part is drop forged with the grooves to size, and the other surfaces must be machined in correct relation to them. The first operation is to provide locating holes in the round end and a centre in the square one. For this purpose the part is clamped vertically in a jig on two rounded projections that fit into the two grooves (Fig. 4). The jig has a flat face at top and bottom, with two drill bushes arranged over the two projections at one end, and a bush for a centre drill at the other. Two holes are then drilled to meet the grooves, and a centre is drilled in the other end. The jig is used loose on the table of a two-spindle drill, having a ½ in. drill in one spindle and a combination centre drill in the other. The two holes are used as locating holes for succeeding operations and as oil holes in the finished jack.

Turning is done next in an engine lathe. A round block with two suitably located taper pegs is set in the chuck. These pegs serve as live centre and driver. The other end rests on the tail centre in the usual way, and turning is done with standard tools in the tool post.

Following this, the groove is cut across the end in a heavy drilling machine. This groove later engages a bar stop to limit the oscillation. Four parts are placed in as many vertical holes arranged round the centre of a block, and are set to a gauge having pins that engage with the locating holes (Fig. 5). Two set screws per hole clamp the parts securely. The cutter is in the shape of an end mill, with teeth, slightly narrower than the width of the groove to be cut, projecting on the face, and so arranged that the inside radius gives the correct curve. A pin on the upper face of the holding block guides the cutter. After feeding to depth, each of the parts is turned 180 degrees, and the cutter fed down again to finish the other side of the groove. The convenience of the driller over a vertical miller is in the rapid lift of the spindle for loading and unloading.

The square is machined in a vertical miller using straddle mills over a constantly revolving circular table, on which twelve pieces are held in pairs in a fixture, with their square ends inwards (Fig. 6). The operator unclamps a pair as they come to the front, removes a finished one, puts the half-finished one in its place, inserts a rough one along side, and reclamps, six squares being finished at each revolution of the table.

The last machining operation is the drilling and counterboring of the central hole, which is done in a simple jig; then the part is ready for burring and casehardening.
The pawls that engage with the last considered part have angular ends that presented some difficulty in holding for machining. The parts, as they come from the dies, have a thick fin up to ¼ in. long on the end, so that there is a fair amount of metal to remove, and solid clamping is essential. A pair of pawls is set on a block which has a groove to engage the rounded end, and an angular face for the front of each pawl (Fig. 7). These faces on the fixture are exactly positioned to give the required point angles and lengths of pawls when the end of the pair of pawls is machined parallel to the base of the fixture, and ⅛ in. above the top face. Fastening is by a double clamp operated by a single screw to hold the pawls into the grooves, and by a pair of set screws that keep them against the angular faces. The pawls are alloy steel, difficult to machine, so the work is done in the shaper with an ordinary round-nose tool that is readily sharpened.

Another part of the same material is also handled in the shaper. In shape it approximates an isosceles triangle, having a radius of ⅛ in. on the apex end, and about 2 in. at the other, both struck from the same centre; both curves are machined (Fig. 8). Formed milling cutters seemed the natural method, but a rather extensive trial proved expensive in cutters, so the job was shifted to the shaper and cheaper cutting tools. The part is set in a block that rotates on centres in line with the centre of the desired curves. One centre has a worm and worm-wheel drive. Two tools are used, one approximately on the vertical, and the other on the horizontal centre line, and set respectively at about ⅛ in. and 2 in. away from the centre of rotation, so that one will finish each curve. The vertical and horizontal feeds of the shaper will then adjust one tool and have very little effect on the other. Gauging is by a short straight-edge over faces that are in line with the finished part. The operation is not very fast, but the cutting tool cost is negligible, and the accuracy excellent.

A somewhat similar operation, also on a tough grade of steel, is done in a slotter. The part is a pawl for a ratchet jack, which is not made in large numbers. The pawl has a trunnion at each side, and a machined end in line with them is drop forged close to size, then set in the fixture, so that the inner side of the trunnion engage a pair of vertical grooves, and is held in place by an eye bolt which engages a convenient projection (Fig. 9). The fixture is arc welded from the bar stock, then machined on the bottom with a spigot to fit the slotter table, and the groove for engaging the pawl end is bored from the bottom at the same setting to ensure concentricity. In use the circular feed is used in conjunction with a flat-ended tool.
A milling fixture is next for consideration. The part is a jack pawl again. It is, however, made in larger quantities than the last example, so that six parts are set at once to have a $\frac{3}{8}$ in. wide groove milled. The pawls are set in pairs end to end with a dovetail piece between them and a flat plate clamp set on an angle at the end of each, to hold it down and against the dovetail at the other end (Fig. 10). Three cutters suitably spaced are used, so that six parts are finished at each setting. Cutters are set $\frac{1}{32}$ in. clear of gaps in the centre dovetail piece.

Another milling fixture is used to hold round pins while cutting a flat on each. Being small, the fixture body, also the clamp, is machined from a bar and casehardened. The body is formed with a flat top, on which two pins rest. At one side there is a raised undercut shoulder, and at the other side a similar shoulder on the clamp, which has also a tongue engaging a groove in the end of the body, so that it cannot rise. Tightening the clamp holds the pins firmly on the bottom, ensuring that all grooves are cut to the same depth. A small stop positions the pins endways, and the cutter is set as before $\frac{1}{32}$ in. clear each way of a groove cut in the body of the fixture for that purpose.
A drilling jig, which clamps and locates in several places with one screw, is next considered. It is shown in Fig. 11. The problem is to drill a pair of holes for flat-sided taper locking pins. These holes must break into the sides of the main holes, so that the locking pins can engage. It is necessary to use a filling piece in the main hole when drilling the cross hole, and, to prevent drill breakage, great care must be taken that there is no relative movement between the filling piece and the part being drilled. The filling piece is in the form of a short bar, which is used until it has grooves nearly all over it, and then discarded. The part to be drilled has two lugs, which fit one each side of the central part of the jig, and are covered by correctly placed drill bushes. The filling bar is passed through the holes in the part and securely clamped by the plate on top and a V underneath. The part is centered and clamped by a pair of pins, which are expanded between the two lugs by a taper head on the clamping bolt. Springs return these pins when the nut is slackened. The one bolt thus clamps both parts securely. The jig body is a steel casting, but if designed to-day would probably be arc welded. The working parts are case-hardened pieces fitted to it.

The last example is a drilling jig (Fig. 12) for a casting which has holes in the top and bottom and one side. The holes must be at right angles to the previously machined bottom face; so the jig is provided with machined pads to engage this face, and a pair of studs and a cross clamp to secure the part, also side stops for locating. The jig is arranged with top and bottom faces machined true with the locating pads, and large enough to give stability when drilling. It also has legs on the side opposite the one having side drill bushes, so that it may be turned on to them for these holes. The body is entirely arc welded from standard bar sections.

In concluding this brief outline of one phase of a very large subject, the writer would stress the smallness of the area covered. As previously mentioned, the paper has been restricted to a small group of machines and to small quantity production only.
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