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CUTTING TOOLS
WORKED BY
HAND AND MACHINE

ROBERT H. SMITH

MANUALS OF TECHNOLOGY.

EDITED BY

PROF. AYRTON, F.R.S., AND R. WORMELL, D.Sc., M.A.

CUTTING TOOLS

WORKED BY

HAND AND MACHINE.

WITH

14 FOLDING PLATES AND 51 WOODCUTS.

BY

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CASSELL, PETTER, GALPIN & CO.
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PREFACE.

THIS book does not pretend to be a descriptive treatise on tools. It does not enumerate all the cutting tools in use, nor does it explain all the details of construction of the machines referred to in it. To do so, indeed, would require very much larger space than is at our disposal, and, for other reasons, would be beyond the aim of the book. Such a descriptive treatise unfortunately does not at present exist in the English language. Meanwhile, Hart's "Werkzeugmaschinen," published in Leipzig, is the best collection of detailed descriptions of machine tools for wood and metals; while Hartig's "Versuche ueber die Leistungen der Werkzeugmaschinen" is still the only book to which one can refer for trustworthy information regarding the horse-power required to drive these machines. The former is chiefly a collection of beautifully-executed illustrations, showing all the details to scale, and, indeed, having all leading dimensions in millimetres marked on in figures. But, having been published in 1870, it is already much out of date. Before that time there were to be found in the German workshops numerous examples of the machines made by the best tool-makers of France, England, and America, and the constructive details of these were studied eagerly, and copied with an exactitude sometimes disconcerting to the original designers. Since then, great advances have been made in England and America, perhaps more especially in the former country. Hence, although a fairly complete technical description of hand and machine cutting tools, bringing the various manufactures really up to date, would be of the greatest interest and utility, yet the rapid progress of design in this direction would ensure its soon falling out of date, unless it were being continually revised. This object is carried out on a necessarily small scale in Shelley's "Workshop Appliances," which, so far as it goes, is a very useful book. Holtzapffel's "Mechanical Manipulation and Turning" is too ancient to be of great utility to modern artisans or manufacturers.

Hartig's work supplies very valuable data from which to judge of the requisite power to drive tools. Unfortunately, he seems to have been led away by the idea that the cutting force varies in simple proportion to the depth of shaving. This idea is wholly erroneous. It seems first to have received definite expression in certain mathematical papers published in the appendix to the later editions of Holtzapffel's works. These papers are singularly apt illustrations of the extremely vicious results of the attempts occasionally made by mathematicians to interpret Nature by algebraic formulas alone, without the aid of experiment. The author fully believes that mathematical theory is the only ultimate possible way of perfectly describing fully-developed scientific knowledge, but it is worse than useless for anyone to dabble in mathematical theory before becoming thoroughly and intimately acquainted with all the *facts* of the subjects obtainable by experiment and observation. In consequence of the above error, Hartig has divided the work done in each of his experiments by the *volume* of material cut away, and thus obtains what he calls a "constant," but what is in reality a most delusive variable.

The aim of this work is educational, and at the same time it is intended as an attempt, at least, to begin the elevation of the art of tool-making from its present entirely empirical to a more scientific position. It has, however, been found possible to make only brief and general references to the principles of strength and stiffness that ought to govern the proportioning of the various parts of machine tools. So far as the author knows, no attempt has yet been made to apply methods of exact calculation to the design of the leading dimensions of this class of machines. It is clear that to enable tools to do good work their dimensions must be regulated so as to ensure *stiffness* and not *mere strength*, while hitherto, in attempts to apply scientific calculation to engineering design, the rules for strength have been much too commonly and indiscriminatingly followed, to the neglect of STIFFNESS. It is probable that there will continue to be an unfortunate tendency in this direction, because so long as a machine has *strength* it "will do," that is, it will serve its purpose after a fashion, without leading to positive catastrophe; whereas it is only those who trouble themselves about refinements which are too often considered superfluous, who recognise that it is *usually* only in so far as a machine combines *stiffness* with strength that it *does well.* Again, it would be impossible within the present limits of this book to develop detailed rules for the proper dimensions of the machines dealt with. The author also regrets that he has been unable to extend the experiments referred to on pages 173 to 181 in time for the publication of the present edition. Hartig's experiments on this subject have already been mentioned. In the "Proceedings of the Royal Society" for December, 1881, Mr. A. Mallock has described a series of interesting observations on lathe turnings made in the Mechanical Laboratory at Cambridge, and has given the most careful, but still incomplete, analysis of the cutting forces in front of the tool edge that has yet been published. In the author's experiments, carried out in the spring of 1881, the cutting force was measured in the most direct manner, and with very little probable error. The plotted curves, showing the results of each series of experiments, have almost invariably the same character, but this character seems to be so peculiar that no algebraic formula has yet been found to represent it. The author hopes shortly to extend these interesting experiments in the Mechanical Laboratory of the Mason College, and trusts that the law connecting the force with the depth and breadth of the shaving removed will be ultimately discovered. It is evidently upon the magnitude of this force that all proper calculations made in designing the machine must be based.

The chief object of the book, however, is educational. It is intended to guide the mechanical student into a correct scientific way of thinking about tools, so that he may be able, aided by practice, to judge *intelligently* whether a tool is good or bad, to criticise its details, and eventually to design new tools scientifically. It is of comparatively little importance that he should know whether the tool is in accordance with the pattern adopted by this or that maker.

To succeed in this aim as the author would wish, *accuracy* and *particularity* are both essential. In all purely technical subjects, such as that of which this work treats, *minutiæ* are of very great importance. For the purpose of training the intellect to deal well with practical things, it is of much more use to think out thoroughly every detail of a single example, than to make a cursory study of the "general principles" of a dozen. It has, therefore, been the author's aim to encourage *thoroughness* in the consideration of the details of the subject. The illustrations taken have seemed to the author those best calculated to give an insight into the general character of tools. As he has deemed it of greater importance to explain fully a few than to mention all kinds of tools, it will be found that several classes of cutting tools have not been treated of. The most important omissions are those of screw-cutting tackle and files. In the hope of sustaining, so far as possible, the interest of the student in what to many seems a dry subject, the author has intentionally adopted an easy lecturing style of writing.

Every year the number of men who are more or less acquainted with science, and who have a practical connection with manufactures, is increasing, and every year more use is made of the lessons of science in the processes of manufacture. These laudable attempts are, however, difficult, because the common mode of teaching science is to abstract it from every consideration of utility, and it is even not at all uncommon to hear practical usefulness decried as the basest and most unworthy of motives for scientific research. The author's belief is exactly the reverse: the highest possible aim and sanction of scientific study are the outcome of comfort and happiness to living creatures that results from it, the general amelioration of the conditions of life in the world. The opposite opinion has among others this result inimical to the interests of pure science itself, namely, that in accordance with it the vastest possible field for true scientific observation is cut off from the view of the scientific student. That field exists in the operations of the manufacturer, which are almost infinite in variety, and which vary and progress continuously. This magnificent field of research is watched patiently day by day by millions of intelligent operatives and managers, but in spite of their general intelligence they, as a rule, make no use of their opportunities, because they have either received no scientific education, or else have been taught that science has nothing to do with the common things on which their daily work is expended. If this condition of things were reversed, it is difficult to predict how much more rapid the progress of science might become than it is at present.

There is an innumerable series of parallel but different physical facts, from any one of which the general fundamental laws of physical science may be learnt almost as well as from any other. The operative in each special craft need hardly go beyond the narrow limits of his own trade to get proof of the most fundamental and widest branching laws of Nature, provided he has some guide to lead him right. He may hammer them out on the anvil, or he may mould them in the foundry. If they are brought home to his mind by the facts of his own trade, not only will they gain far greater reality in his conception than if obtained from books only or lecture-table experiments, but at the same time also his work will come to have a far higher and keener interest for him, and the tone of his life will rise from the weariness of drudgery to the healthful enjoyment that is felt in exercising one's higher faculties.

It is partly as a contribution to this mode of extending scientific knowledge that the present book has been written, no less so than in the hope of rendering more scientific the efforts at improvement in cutting tools. This method of teaching science is quite a new one, and there are, therefore, no models to follow. The subject of cutting tools is one of the most interesting that could be proposed to a scientific student. It is curious to think what a very large proportion of the whole energy spent in manufacturing operations is spent in some kind of cutting, or in the very similar processes of tearing and crushing—it is difficult to draw any distinct line between "cutting" and these last-mentioned processes. Even when from cutting operations those only are selected that are in use among engineers, as is done in the present volume, the richness of the field for interesting observation and experiment is quite obvious. If his attempt to explain clearly some elementary matters only leads to some few turners, and planers, and fitters, applying their minds actively to find out something more about what they do every working hour, the author will be quite satisfied with the result of his labours.

The plan of the book being educational and scientific, it has been deemed best to treat wood and metal tools simultaneously, as far as possible, the classification not depending on the material cut so much as upon the mode of cutting.

In conclusion, the author has to acknowledge his indebtedness to the before-mentioned work of Professor Hart for some of the illustrations. For others he has to tender his thanks to various manufacturers who have kindly allowed him to use their drawings. For the careful preparation of these drawings he has to acknowledge his obligation to Mr. Batten; and he wishes also publicly to offer his best thanks to the publishers for the liberal way in which they have incurred the expense of the engravings.

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CUTTING TOOLS

WORKED BY HAND AND MACHINE.

CHAPTER I.

CHISEL-TOOLS FOR WOOD.

1. Relations between Chisel-tools.—It is easy to recognise that there is some considerable resemblance and intimate relation between the modes of action of such tools as the iron wedge for splitting wood, the axe, the adze, the hatchet, the penknife, the paring and mortising chisels, and the spoke-shave.

2. Scientific Classification.—It is the chief object of science to simplify our knowledge of the multitude of forms and modes of action which we observe in the things that surround us, and that we use in doing our work, or enjoy in taking our pleasure, or simply admire through wonder or curiosity. We accomplish this simplification of our knowledge by arranging the multitude of diverse things in groups, throughout each of which there runs a certain amount of similarity. There may be many easily-observed points of difference between the different members of one and the same group, and indeed very often the differences are more observable at first sight than the resemblances. But it is the similarity that reigns throughout each group that is to be the guide or key, not only to the single group itself, but also to the position which that group holds in the general system of grouping.

These similarities, each belonging to one group, must then be placed together, examined, and carefully compared; and this comparison leads to the discovery of underlying principles that are common to all, and which serve to bind the vast mass of diversities all together in one grand whole. This is the simplification that is the aim of science. Science has not yet advanced to such perfection that we should be able at present to include in *one* simplification *all* the things we have opportunity of observing and examining, but that is the goal towards which scientific men work, and they will never rest until it has been reached.

Since these similarities form the lines leading from such complicated ramifications to the most perfect simplicity attainable, it is evident that each resemblance that is to regulate a group must be chosen with the greatest care, and only after the most thorough investigation. It must not rest on mere superficial or accidental likeness. It must be a likeness that is the result of the most important influence that has guided the growth or manufacture of each object. We must look deep into the nature of the objects, therefore, before we can settle how they are to be arranged. Our method must be *rational* investigation of the whole character and mode of action of the things examined and classified. Thus, in scientific study, both learner and teacher must exercise to the fullest extent not only their senses of observation, but also their reasoning faculties.

It is only after long experience in such study that one acquires the power of recognising, among the many comparatively unimportant influences that go to shape things to their final forms, the one or two chiefly important characteristics which reveal their connections with general scientific principles. It is not to be expected, therefore, that the learner can be taught at the outset how to draw out the lines along which the different groups are to be arranged. The plan of the system of classification must be left in the hands of those advanced students who are slowly, but gradually and surely, carrying science forward to greater perfection by their investigations. In the beginning, the scholar must be content to receive from the teacher an explanation of the reasons which guide the formation of each group. These will be supplied in this book by describing as accurately as possible the chief examples in each group, and afterwards drawing attention to the important resemblances reigning throughout each. The student must exercise his reason in recognising these essential similarities; and after he has thoroughly understood the arrangement he will have little difficulty in determining for himself how to investigate and classify any new objects, and, in particular, will be able to deal with the objects with which we are now specially concerned, namely Tools. He should not expect from his teacher simply a certain amount of cut-and-dried information about specific tools. He should expect more than that. He should hope to acquire, from the accurate and rational study of a limited number of common representative tools, the power of investigating for himself any and all kinds of new tools, and even of designing and making new-fashioned tools for new special classes of work that may be required of him.

3. **Wedges.**—The first group of tools to be considered is that mentioned in paragraph 1, which has been so placed on account of its comparative simplicity.

The iron or steel wedges used for splitting open logs of timber are so simple and so well-known as to require but little description. They range from two to five inches wide, and in length up to six or seven inches. For harder woods they should have a gentler taper than for softer timber. They ought to be made parallel in width, but for the sake of greater ease in entering they are often made rather narrower at the edge end. This edge is ground to a much more rapid bevel than the general taper of the wedge. The object of this is evidently to obtain a moderately sharp edge without having a long, thin, weak part at the working extremity of the tool. Several wedges are inserted in the line of the split it is desired to make, the number used being proportioned to the breadth of the split. They are inserted by blows with a hammer, or, if the wood is too hard to permit this, a shallow saw-drift is sawn across the surface along the line of the intended split, and the wedges inserted in this. They are then driven in by blows from a hammer or axe, care being taken to distribute the blows along the row of wedges, so as not to let any one wedge be driven much farther in than any other at the same time.

While the rapid bevel of the extreme edge is entering, no splitting of the wood takes place (Fig. 1). The action of the tool extends only a very small distance from the surface. A very small portion only of the wood is simply crushed. The crushed edges of the timber are, of course, destroyed for all useful purposes. The thickness through which it is crushed and destroyed is very considerably diminished by cutting, in the first place, the saw-drift mentioned above. The farther the point gets into the wood the wider is the area over which the tool crushes the wood beneath it, and the deeper does the crushing extend, because the material, being supported on either side by the wood beyond, can yield sidewise only to a very limited extent, and must suffer the rest of the crushing that is imposed on it in the direction of depth. It would thus be impossible to continue the large angle of bevel to any great distance from the point of the tool. This large-angled bevel must be very short, and beyond it must begin a much more finely-tapered part. This is the true wedge; and, as soon as it gets below the surface sufficiently for its sides to bear well against the timber, the splitting commences.

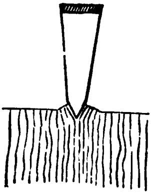

Fig. 1.

When the split has just begun, and also after it has extended some little way down the block, the wedge bears against the top edges only of the split surfaces.

The arrows (Fig. 2) show approximately how it pushes out the timber on either side. Let us now see what is taking place in the portion of the wood beyond the point to which the split has already extended. The two halves cling together in opposition to the force of the wedge that seeks to separate them. Over the surface that is just about to split open, the left-hand half of the wood (marked A in Fig. 2) pulls the right-hand half, B, in the direction shown by the arrow, 2.

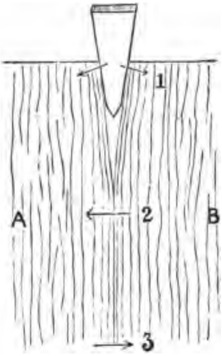

Fig. 2.

We find, then, the block of wood, B, pushed to the right-hand by a force represented by the arrow 1, and pulled to the left-hand by another force lower down, represented by the arrow 2. If these two forces were alone acting on B, it is quite clear that B would begin to turn round right-handedly, like the beam of a pair of scales which is supported by the knife-edge in the centre, and is weighed down by having a weight thrown into one pan without any balancing weight in the other pan. But B, instead of turning round, remains upright while the wedge is being driven in, and it is thus clear that it must be kept in balance by a third force acting on it lower down than the arrow 2, and in the direction shown by the arrow 3. A very little consideration shows that this force 3 can be exerted by nothing but the surface of the half-block A pressing against B in the direction of the arrow 3. While, therefore, the action of the wedge makes the two halves of the block pull away from each other at about the level of the arrow 2 (or, as it is described in mechanical language, throws the timber into *tension* in this part of it), it simultaneously causes the lower portions to push against each other—that is, it throws them into *compression.*

It is evident that the tension is greatest close below the last point at which the two split surfaces have actually separated. From this point downwards the intensity of the tension decreases gradually, until at a certain level it has diminished to nothing. Here the wood is neither in tension nor compression, and beyond this position downwards the compression gradually increases from zero to a maximum intensity at some level depending on the length of the block. The compression then diminishes again the farther one goes from the extremity of the split.

It is clear that the effect of these three forces is to bend the half-block B, the concavity of the bend being to the right-hand side. Fig. 2 shows the top edge only of the split surface bearing against the wedge. Whether this will actually be the case or not in any particular example, evidently will depend on the angle of the wedge, and on the roundness of the curve to which the half-block is bent by the action of the above-mentioned three forces. The block will bend to a sharper curve the softer and more pliable the kind of timber is. The curve will be straighter, on the other hand, the thicker the block is from the line of the split to its outer surface on the right hand. It is found by calculation and by experiment that this last-mentioned thickness of material has a much more powerful influence in stiffening the block, and preventing the curve of bending from deviating much from a straight line, than even the hardness or softness of the wood itself has.

It is easy to see that the distance from the end of the split down to the point at which the tension in the wood (indicated by the arrow 2) has diminished to zero, that is, the length over which the wood is thrown into tension by the action of the wedge, depends altogether upon the curve to which the splitting surface of the half-block is bent. The rounder this curve is the shorter becomes the length of wood thrown into tension, and conversely. Now the whole pull, indicated by arrow 2, that the half-block A exerts on the half-block B evidently depends upon this length over which tension is distributed, and is, in fact, roughly proportional to this length, because the intensity of the tension per square inch of surface increases gradually from zero at the lower end of this length up to just that amount at its upper end necessary to tear one surface quite away from the other. This last maximum intensity of tension is the same for different blocks of the same kind and quality of timber. It is simply the measure of the direct tensile strength of the wood across its grain. The stiffness of the wood, on which depends the straightness of the curve and the length of the surface over which tension is caused, is measured by what is called the modulus of elasticity. As for the exact ratio in which the pull that the two halves exert on each other in clinging together varies with the above-mentioned elements, an approximate theoretical calculation can be made, and this shows that (other things being equal) this pull is proportional to the fourth root of the modulus of elasticity and to the fourth root of the cube of the product of the tensile strength by the thickness from the split to the outside surface.

That is, if E = Modulus of elasticity
T = Tensile strength in the direction transverse to the split
and h = thickness from split to outside surface,
then the pull represented by arrow 2 is proportional to

$$\sqrt[4]{\mathrm{ET}^3h^3}.$$

It varies also, of course, in simple proportion to the width of the split.

It also decreases a little the greater becomes the length of the split from the bearing points of the wedge down to the last torn part of the newly opened surface, but to explain why it does so would lead to more difficult theoretical reasoning than would be proper here.*

---

* The force 1 acts with a moment whose arm increases with the above distance. This moment helps very largely to bend the splitting

This force 2 is balanced by the forces 1 and 3 together. The portion of it balanced by 1 depends on the distance from 2 at which 1 acts, that is, upon the length of the split. The longer this split becomes the smaller does the force 1 become. The same approximate theoretical calculation as is referred to above shows that, roughly speaking, it varies inversely nearly in proportion to the length of the split, and at the same time varies in proportion to $\sqrt[2]{\text{ET}h^3}$. Taking the last term of this expression separately, it is seen that the transverse force which the wedge exerts on the edge of the wood increases in the ratio of the square root of h^3 or the thickness of the piece split off; that is, it increases in a faster ratio than this thickness but not so fast as its square.*

4. Wedge-Action in Cutting Tools.—The object of explaining so minutely the action of a wedge in splitting a block of wood will be soon seen, when we find that a most important part of the action of all cutting tools is quite similar to that of the simple wedge. The results of the above investigation will serve to explain many points which are, at first sight, and taken by themselves, difficult to understand, but in the elucidation of which no time need be lost, now that a clear comprehension of the effect of the simplest of all tools has been gained.

It is to be remembered that the wedge acts in two ways. At first, when the sharp-pointed edge is entering, it causes no splitting, but simply crushes and pushes aside the small quantity of material in close proximity to its edge and into which it penetrates. After it has got a

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fibres, and the curve to which they are bent is sharper the larger is this moment. The sharper the curve in advance of the split, the shorter is the surface exposed to tension. The resulting diminution of the pull 2 leads to a corresponding diminution of the thrust 1, but this diminution of 1 is not in quite so great a ratio as the simultaneous lengthening of the arm with which it acts to exert the moment.

* If, however, the split be extremely short, the point of the tool following close to the point of actual separation of the material, and the pressure of the tool being exerted close to its edge, then this pressure varies more nearly with the ¾ths power of the thickness of the shaving; that is, not quite so fast as that thickness.

certain distance, it begins to cause a split in advance of its edge, in the manner described in detail above.

5. **Mortising Chisel.**—Of the tools named in the first section, that which bears the most resemblance to the simple wedge in the mode of its action is the common mortising chisel. It also is driven forward by blows from a hammer, and the thicknesses of the pieces of wood removed by it being large, it acts to a great extent by splitting. Its edge, however, is made much finer and sharper to give more penetrative capacity, in order that it may cut the fresh surface clean and smooth (in a manner that will be presently explained), and because also it is used to cut transversely to the grain of the wood, in which direction the wood both yields to the penetrating edge and also splits with much greater difficulty than in the direction of the fibre. The fine edge is, of course, more liable to be broken by the shocks of the blows than that of the common wedge, and, therefore, a wooden hammer or mallet is used in order to mitigate the violence of the shocks. One other difference is that the one surface of the mortising chisel is made quite flat, the bevel which makes the extreme edge being put all on one side. This flat surface acts as a guide whereby the tool may be advanced through the wood in a straight line, cutting off all the material lying on one side of that line.

6. **Axe.**—The ordinary woodman's axe (Fig. 3) has no such flat surface on one side. Both sides are rounded off equally, there being no flat bevel on either. The reason of making it so is to allow the workman with greater facility to cut into the wood at any angle he may desire to the surface upon which he is working. The surfaces being rounded so prevent him from obtaining accurate flatness in his work, but for his purpose this is of no consequence. The handle, or shaft as it is called, should be of straight grained ash, and is made from 3 to 4½ feet long. The

Fig. 3.

workman swings the axe round with the full stretch of his arms so as to bring it to the greatest possible velocity at the moment of striking into the timber. As the blade flies backwards past his feet, upwards and forwards overhead, the thick part in which the shaft is fastened runs in advance of the cutting edge, and it is only during the downward stroke after the blade has passed overhead that the workman brings the cutting edge in front by giving a peculiar twist to the shaft. This twist is given in such a direction as to carry the edge through a semicircle lying away from the workman to his right hand, supposing him to be cutting the right-hand side of the timber. The reason that it swings this way and not round the inner semicircle, is not to avoid any risk of accident, but because in extricating the blade from the timber after the blow, the heavy side of the blade naturally falls outwards to the right hand, and this gives the blade a half turn in the opposite direction to that mentioned above. In order, therefore, that there should not be a continuous rotation of the shaft as the blows succeed each other, which would make it difficult or impossible to keep a firm certain grasp of the shaft, the half turn overhead must take place in the direction mentioned. The blade thus oscillates backwards and forwards at the bottom and top of its swing without turning continuously in one direction.

The shaft is made oval, the greatest diameter being in the plane of the blade. The shock of the blow being in this plane, the strength of the shaft to resist breakage requires also to be in the same direction. As great a depth as can be conveniently grasped in the hand is, therefore, given in this plane. By making the transverse thickness smaller this depth can be made greater, because the size that can be firmly grasped in the hand depends more on the length of the circumference than on the diametral size, the fingers accommodating themselves to any desired shape. The oval section also allows the workman to know by the feel in what position he has hold of the axe, and so to direct it that the edge may fall on the wood at the desired angle.

The shaft lies straight in the plane of the blade; but as seen perpendicularly to this plane, it is very considerably bent in such a direction as to lower the extremity when the axe lies in the cut in the wood. The object of this bend is to avoid the awkward and useless raising of the left hand that would be necessary at the moment the blow is struck if the shaft were straight. At this period of the swing the shaft lies, in ordinary work, at only a moderate angle of obliquity from the vertical, and, therefore, its extremity stands high up, and, during the last instant of the stroke, this extremity swings forward rapidly. The left hand which grasps this end portion avoids the necessity of following this awkward movement, by slipping along the bent portion to the extreme end of the handle. This bend is also probably of use in some degree in steadying the tool as it cuts into the timber, and preventing it from heeling over to one side.

Very little advance has been made for a long time past in England in the design of this felling axe, probably because of the comparatively little work that remains to be done by it in this country, the forests having disappeared during the gradual spread of land cultivation for agriculture. In America more modern patterns are used. The blade is made of a superior class of steel, much thinner and lighter, and the edge is sharpened more keenly. It is used with a much swifter stroke than the more ponderous old English axe could be driven with, and, the extra lightness more than compensating for the increased speed, more work is done with it with less fatigue than is possible with the heavy pattern.

7. Hatchet.—The Hatchet is a tool quite similar to the axe for lighter work. It has a short straight shaft, and can be wielded with one hand. What is called a side hatchet has the thickened head for the reception of the shaft end lying all to one side, so as to leave one side quite flat. No bevel is put on the edge on this side, the bevel being wholly ground from the other side. This is used for flattening the vertical sides of posts, etc., but is not a good tool for the purpose.

8. **Adze.**—The Adze has a blade which stands perpendicular to the shaft and to the plane in which it is swung. The surface which is cut by it is thus perpendicular to the plane in which it is swung. The blade, as shown in Fig. 4, is curved in the direction in which it is swung. The object of this is to allow the front surface of the blade to lie flat down on the surface which is being worked, and thus act as a guide to the advance of the cutting edge; and at the same time to allow the end of the shaft, which stands a small distance beyond the front surface of the blade, to clear the surface of the timber. It also allows the tool to be heeled over slightly after being driven into the wood, so as to break off the shaving that has been cut. The dotted line in Fig. 4 is a tangent to this front surface of the blade at its cutting edge. This tangent stands a short distance clear of the end of the shaft. As the edge is worn away and re-ground, this tangent will fall gradually nearer the end of the shaft. The sharp end is made by grinding one bevel only, which is on the inside, that is, away from the timber being cut. If the outside is quite straight crosswise, and regularly curved, this tool is capable of producing very true flat surfaces. It is used both with a long shaft, swung with both hands, and with a short one held in one hand only.

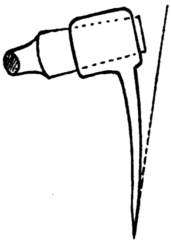

Fig. 4.

9. **Pen-knife.**—The Pen-knife is in every respect similar in form of cutting edge and in action to the axe with a two-bevelled edge, except that it is driven into the material to be cut by a steady pressure, not by a

blow. Being rounded on both sides, it is incapable of producing truly flat surfaces.

10. **Paring Chisel.**—The most perfect instrument of the sort now being described for cutting wood is the ordinary paring chisel. These chisels are made from 6 to 10 inches long, and from $\frac{1}{8}$th of an inch to 2 inches wide. In order to give sufficient strength, the very narrow ones are made extra thick, as shown in Fig. 5, *b*. The length is made greater for the larger widths, but in consequence of frequent re-grinding and re-sharpening, broad chisels of very short length are as often met with in the workshop as narrow chisels are.

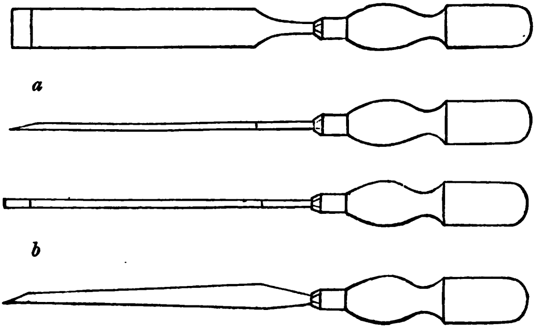

Fig. 5.

In the process of manufacture both faces of the chisel are ground. One of these is ground very carefully flat. The other side is ground to a bevel at the edge, the angle between the bevel and the flat face being about 30°. The wood to be cut is steadied in its position on the bench by the left hand, and the chisel handle is grasped by the right hand. The left shoulder is placed on the top of the chisel handle, and pushes it forward, while the right hand guides and steadies it, the flat face of the blade being always kept towards the workman.

In sharpening the chisel on the oil-stone, some workmen lay the bevelled surface flat down on the stone, so that the whole surface is rubbed on it, but the more common custom is to rub only a small facet, making, with the flat face, an angle 5° or 10° greater than that of the ground bevel. If the chisel has been ground carefully to a fine edge, the first method may be followed with great advantage at the first setting on the oil-stone, but in subsequent re-settings much time is lost by doing so, because of the large surface to be rubbed down. Whatever be considered the proper angle for the facet, it is easy to grind the bevel to an angle smaller than it by a few degrees, and thereby to secure a small sharpening surface on the facet. The advantage of rubbing down the ground bevel at the first setting seems to consist in providing a smooth surface over which the shavings may slide, whereby less force is required to shove the chisel onward. It costs but little trouble to smooth away the roughnesses of the grinding, because these, instead of constituting a complete unbroken surface, are actually merely projections scattered here and there, the total area of which bears a very small ratio to that of the surface on which they stand. The first edge, prepared in this way, stands undulled a considerably longer time than the subsequent edges with the larger facet-angle do.

11. **Grinding Wood Tools.**—In grinding wood tools in general—not only those mentioned in this chapter, but also plane-irons, &c.—it is well to avoid the very common practice of continuing the grinding until a feather-edge is produced. This is a strip across the edge of from one-32nd to three-32nds of an inch wide, which bends over under the pressure of the grindstone when the edge is ground very thin. This feather-edge has afterwards to be removed by cutting with it across the grain of a piece of wood. Its removal means simply the loss of so much of the length of the chisel *unused*. After the feather is taken off, the thickness of the edge left is no less

than can easily be obtained by carefully grinding to the limit that is reached before the bending begins to form the feather. Another advantage of avoiding the feather in grinding is that it allows one to see whether the edge has been ground to a uniform thickness throughout its width. This is impossible when a feather is formed.

12. Setting Edge Tools.—In using the chisel for work that needs to be finely finished, the most common mistake made by beginners is to use it too long before re-setting the edge on the oil-stone. Suppose that half an hour's work shortens the blade, as measured to the exact cutting edge by $\frac{1}{200}$th of an inch. To bring the edge once more to its original keenness requires a certain amount of rubbing on the stone, the amount corresponding to $\frac{1}{200}$th of an inch on the flat face. In ten minutes' work the blade will be shortened by, say, about one-third of $\frac{1}{200}$th or $\frac{1}{600}$th of an inch, and the amount of rubbing to bring back the edge to the original sharpness after this amount of work is not more than one-third of that needed in the first case. Thus, if in the half hour the edge be sharpened thrice instead of once, the total amount of rubbing required will be no greater than that needed at the end of the half-hour if no sharpening has been performed since the beginning of it; while, in the former case, the edge will at no time have become more than one-third as blunt (*i.e.*, the edge no more than one-third as thick) as it is at the end of the half-hour in the latter case. Thus, by having the oil-stone *always* at hand, clean, and in good condition, and by having very frequent recourse to it to keep the chisel edge constantly sharp, a great deal of unnecessary labour is saved, and the work is done more nicely. Of course, this rule cannot be followed unless the oil-stone is always ready to be used; otherwise, much time would be lost in getting it ready so often. This rule also cannot be adopted to so great an extent with, for instance, plane-irons, with which a considerable amount of time is lost in taking the tool to pieces and putting it together again every time the edge is set.

13. **Paring Action.**—The special characteristic of all the tools that have hitherto been mentioned is, that each has a blade which follows the cut made by the edge into the wood, so as to keep the plane of the blade coincident with that of the cut. In consequence of this feature, the material removed by the tool does not need to be thrown off in short lengths, in order to leave the way clear for the advance of the tool. It sometimes gets broken in short lengths, as, for example, in cutting across the grain, but this is not necessary for the passage of the tool, and only results from the excess of brittleness of the material in certain directions. The tool passes between the wrought surface and the material removed, and simply bends this latter aside to a greater or smaller extent. The bending is, in some cases, large enough to crack it in irregularly long pieces, but it is not necessarily broken into separate bits.

The first function of the blade is to act as a support to the penetrating edge, which is pushed forward by it. Its second function is to bend aside the material sufficiently to open a passage for itself. It must be strong enough to perform these two functions simultaneously without risk of being bent or broken. It has a third function—namely, that of guiding the advance of the penetrating edge more or less nearly in one and the same plane.

The function of the sharp edge is to penetrate the material at the desired place and in the desired direction, and it does this simply by crushing a minute quantity of material in front and on either side of it, and pushing it to one side and the other, somewhat in the manner in which water is thrust to one side by a solid body entering it. Its work is facilitated by a transverse tensile strain being put on the material in front of it by the bending action of the blade, and this is more especially the case when the cut is nearly parallel to the grain of the wood.

Let Fig. 6 represent on an exaggerated scale the blade of a paring chisel taking a thick shaving (the thickness of which is exaggerated, proportionally, more than is the rest of the sketch) off a flat surface. Let the small arrows represent the splitting force which the blade exercises against the shaving, and conceive the thickness of the shaving to be divided into three layers, by the dotted lines. We have seen that the splitting force required to tear up a layer increases faster than in the simple ratio of the thickness of the layer. Therefore, the force required to tear up the topmost of the three equal layers from the middle one, is somewhat less than one-third of that required to tear up the whole shaving of triple thickness, if this shaving hold together in one piece. But the pressure exerted by the tool blade on the under surface of the shaving is—a large part of it, at any rate—transmitted through the thickness of the shaving to the upper layers. The whole of it is not so transmitted; part is balanced by the resistance to bending that the undermost layer independently offers, and a second part is in the same way balanced by the second layer. But more than two-thirds of it is transmitted to the second layer, and probably more than one-third is passed on to the third layer. The force, then, that bears against the under-surface of the second layer is *more* than sufficient to tear up the two topmost layers taken together from the undermost layer; and again that which reaches the top layer is probably more than sufficient to

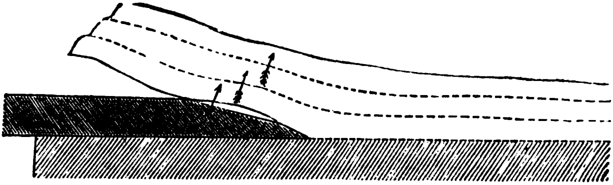

Fig. 6.

tear it up from the middle one. Thus a thick shaving gets split up into a number of different layers of various thicknesses, according to the small differences of cohesive strength between the different fibres. As every one who has used the chisel knows, these splits run often a considerable distance in advance of the tool. They are not always decided splits. But if the shaving be examined carefully when the tool is pressing on it (if necessary with a magnifying glass), it will be found that even when the layers are not actually pulled apart, they are on the point of separating, the delicate fibres being pulled out into a loose tangle. Thus the undermost layer is left very thin and pliable, and is easily dealt with by the sharp cutting edge.

If the material be not very coherent transversely to the fibre, this undermost layer lies closely down on the facet of the edge, and no trace of a decided split, however short, can be found immediately in front of the edge. If, on the other hand, the fibres cohere more strongly together, a small opening is found extending a short distance in front. Now this split, of course, follows the grain of the wood, which is not necessarily the desired direction of the cut. The sharpened edge has, therefore, still to perform its cutting function. It is guided by the flat face of the blade which is pressed against the already cut surface of the wood, and it cuts off and raises from the forward extension of that surface all the wood left by the small split above that same surface. It

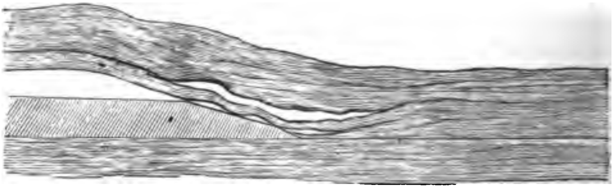
Fig. 7.

is in this case continually beginning new small shavings, just the first minute length of which is separated from the larger shaving above. The free ends of these new layers are so short that they are not perceived without very close inspection. As soon as the new layer is fairly started as a shaving, the little advance-split changes place, and runs underneath the new layer of the shaving.

Fig. 7 will give some idea of this action of the cutting edge, but it would require a still larger scale of exaggeration to show it clearly and exactly.

14. Power required to Pare Wood.—The power required to drive forward a tool of this description depends (*a*) on the quality of the material; (*b*) on the direction of the cut relatively to the grain; (*c*) on the thickness of the shaving; (*d*) on the angle of the tool bevel; and (*e*) on the keenness, or perfection of fineness, of the cutting edge.

Experiments made by the author with a chisel $1\frac{1}{2}$ inch broad gave the following results for yellow pine and mahogany.

1st. Yellow pine plank, well seasoned and straight grained, $1\frac{3}{8}$ inch thick. The chisel-cut taken was the whole thickness of the plank.

(*a*). Cut parallel to the grain. Chisel $1\frac{1}{2}$ inch wide by $\frac{3}{32}''$ thick; $\frac{5}{16}''$ length of bevel; $\frac{3}{32}''$ length of small facet forming cutting edge.

Thickness of Shaving.	Force required to drive Chisel forward.
0·01 inches	14 lbs.
0·03 „	21 „
0·1 „	35 „
0·18 „	41 „

(*b*). Cut at 45° to the grain. Chisel $1\frac{1}{2}''$ wide by $\frac{7}{64}''$ thick; $\frac{3}{8}''$ length of bevel; $\frac{3}{32}''$ length of small facet.

Thickness of Shaving.	Force required to drive Chisel forward.
0·02 inches	28 lbs.
0·03 „	37 „
0·11 „	46 „
0·2 „	78 „

(*c*). Cut perpendicular to the grain. Same chisel as in (*b*).

Thickness of Shaving.	Force required to drive Chisel forward.
0·025 inches	45 lbs.
0·08 „	90 „

2nd. Mahogany of common cheap quality, quite dry.

The same chisel was used as in (*b*). It was found impossible to measure satisfactorily the force required to cut parallel to the grain, because of the irregularity of the splitting.

Cut at 45° to the grain.

Shaving 0·02 inch thick. Force required 57 lbs.

Cut perpendicular to the grain.

Shaving 0·01 inch thick. Force required 61 lbs.

Examining the numbers for yellow pine, cut parallel to the grain, it is seen that the force does not increase nearly so fast as the thickness of the shaving. It was shown that the part of the force which is spent in splitting the material increased faster than this thickness. The above result shows, then, that most of the force in this case is spent not in splitting, but in the penetration of the cutting edge, the power to drive which forward into the wood, as previously described, increases only slowly (if at all) with the thickness. To this latter there is also to be added the friction between the chisel face and bevel and the cut surfaces.

The same may be said of the forces found by experiment necessary for cutting at 45° and 90° to the grain. Here one part of the power exerted is spent in shoving the thin segments, into which it is easily observed that the shaving is half-broken transversely, one over the other perpendicularly to the line of the cut; and this amount of power varies nearly in proportion to the thickness, but it forms only a small portion of the whole power used.

15. Tools for Metal.—No tools similar to those that have now been described are used for the harder metals. Lead, tin, and solder can be cut with a knife or paring chisel, the action being very similar to that of the same tools used on wood.

CHAPTER II.

CHIPPING CHISELS AND HAND PLANES.

1. **Difference from Tools of Chap. I.**—The tools with which the last chapter dealt have all this peculiarity, that the face of the blade lies close down on the surface that is cut, and that the tool has no other guide than the contact of the blade-face with this surface. There is a numerous class of cutting tools which differ from these chiefly and almost solely in having a small angle between the under surface of cutting edge and face of the work.

2. **General Characteristics.**—These have sometimes two bevels, one on each side, and sometimes a single bevel on one side only.

Most of these require to be guided mechanically, so as to cut in a straight line; but at least one—namely, the cold chisel for iron, steel, or brass, is used without any such guide.

3. **Cold Chisel.**—The cutting angle of the cold chisel is smaller than that of other tools for iron, it being ground to from 40° to 70° according to the quality of metal to be chipped. Apparently the sole reason for this is that, it being a hand tool, the power available for driving it forward is strictly limited. The power required is lessened by making the edge keener, but at the same time durability of the edge is to a large extent sacrificed. This is readily recognised by comparing the lengths of cut that can be accomplished by a chipping chisel and

a planing-machine tool before each needs re-grinding. It is doubtful, therefore, whether the angle of the chipping chisel would be the best if the workman's hand-power were unlimited. It is to be remembered, however, that the interruption to the work of the fitter, caused by his having to re-grind his chisel, is not of nearly so much importance as the stoppage of a planing-machine, or other power-tool, for the re-setting of the tool-edge. In the one case, only the man's time is lost; in the other, the machine as well as the man is for a certain time prevented from doing productive work; and this is equally true whether the machine is left standing while the man goes and re-dresses his tool, or whether it is stopped only long enough to change the tool, the re-dressing of the tool being handed over to another workman whose special duty it is to re-grind and make all the tools of the shop as wanted. Probably if no expensive loss of time occurred in changing tools very frequently, it might be found more economical to use keener edges for lathe and planing-machine tools than are used at present. It seems certain that a less amount of power would be needed to perform the cutting with such tools, *provided they were kept keen.*

There is, however, a certain cutting angle for each quality of metal below which it is impossible to use a chipping chisel. The edge will be either broken or completely blunted with only one or two blows if it be ground too keen, and this, too, without these one or two blows accomplishing any appreciable amount of work. Thus, in order to ensure its edge lasting a *useful* length of time, the fitter has to grind his chisel in accordance with the quality of the metal he has to work, the proper angle being greater for the harder and tougher sorts.

4. Chipping Hammer.—Chipping hammers vary in weight from 1¼ to 2 lbs. The best weight is 1¼ or 1½ lb., according to the size and strength of the workman. A workman can more usefully employ his strength—that is, he can get more work done with a given expenditure of time and strength—by hitting hard and swiftly with a light hammer than by hitting sluggishly with a heavy one. The difference is here analogous to that previously mentioned between the light American axes and the old-fashioned heavy English ones. The arm should be swung from the elbow, not from the shoulder. The latter swing would exhaust the body more, and would give a less steadily guided motion to the hammer. The edge of the chisel should be kept moist, either by wetting it in the mouth or by dabbing it on a piece of waste soaked in oil.

5. Guidance of Chipping Chisels.—The angle at which the chisel must be held to the worked surface in order that it may run neither in nor out but continue cutting a shaving of equal thickness depends on the toughness of the material, on the keenness of the chisel-edge, and on the thickness of the shaving. A thick, stiff shaving presses the chisel-edge downwards into the material with great force. The chisel must be held closer down to the surface; the tougher the material, the smaller the cutting angle of the chisel, and the thicker the shaving. It would be futile to attempt to express mathematically the dependence of the right angle upon these different quantities. Even with prolonged experience, one can only make a very roughly-approximate estimate at starting. The proper angle is always found out as the work proceeds by feel, and by watching how the chips come off. After two or three blows, a good fitter sees what the right angle is, and practice gives him the power of keeping so exactly to this correct angle that he can produce a fairly smooth and accurately flat surface with the chipping chisel alone. When he comes to a place where thicker chips have to be taken off, because of unevenness of the outside "black" surface, he instinctively alters slightly the inclination of his tool, so as to prevent the stiffer shaving driving it below the level of the surface he wishes to produce.

This keeping exactly to a level surface in chipping is perhaps the most curiously delicate operation in the whole range of tool-cutting. It is the result of the balance between the downward component of the force of the blow, of the resistance of the material to the advance of the penetrating edge which may be taken as directed along the centre-line of the chisel, and of the oblique downward pressure of the shaving (which resists being bent upwards) upon the higher portion of the upper bevel of the chisel-edge. The mathematical expression of this balance would be an equation of great complexity.

6. Penetration by Chisel Edge.—The character of the penetration of the extreme edge into the metal differs from that of the wood chisel into the wood (as explained in the last chapter) only because metal partakes more of the characteristics of a *fluid* than does wood. Under great pressure almost any metal, if not hardened by fire or by chemical admixture with non-metallic substances, can be made to flow or ooze from one shape to another like a viscous fluid, such as treacle or soft mud. As the chisel-edge is thrust forward, it to a certain extent compresses the metal immediately in front of it, but probably the material makes way for its passage chiefly by this flowing movement, and the greater part of the resistance it offers to its advance is a viscous resistance. This fluidity of the material accounts for there never being any splitting in advance of the tool-edge, as there is in wood. Such splitting hardly ever occurs in chipping, even with bad laminous iron.

7. Wood Hand Planes.—Wood Hand Planes have, like the chipping chisel, a thin blade, the under surface of which is held up at a certain small angle from the surface being worked. This angle varies from 10° to 25° in planes intended for the commoner softer timbers and for the harder and more cross-grained sorts. The upper face of the blade is ground flat, there being a bevel and small facet on the under side only. This bevel is ground at an angle of from 20° to 25° to the upper face

—that is, the length of the bevel is from three to a little less than two and a half times the thickness of the blade. The small facet may have an angle from 15° to 10° greater than this, so that the upper face lies at from 45° to 60° from the surface of the work.

In all the planes used by joiners, except some few for special work, such as moulding, the "plane iron," or

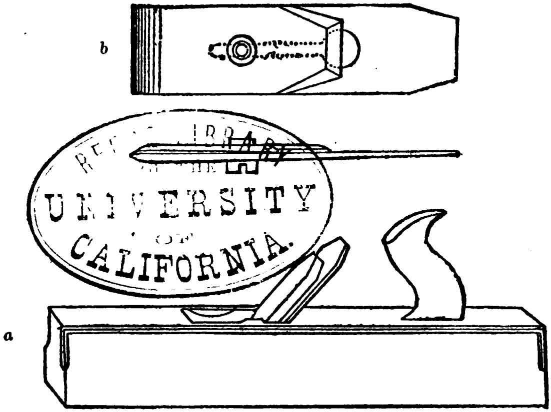

Fig. 8.

blade, is stiffened by having a second "top iron" screwed down on its flat surface. This bears against the flat face only at its two ends, and, being itself thin, presses against the edge with a yielding springy force; the spring, however, being a very stiff one. The edge of the top iron is placed close to the cutting edge—the closer the finer the shavings are desired to be—and this springy pressure it exerts prevents, or very greatly deadens, "chattering," that is, unsteady bending before the always-varying resistance of the material cut. This bending can take place only between the cutting edge and the top of the bevel, at which latter point the iron is supported by resting on the "stock." Above this point also it is held firmly by the wedge, which is driven in to fasten it in its place in the stock (see Fig. 8). The top-iron also serves another purpose, which will be explained farther on.

The stocks of the longer planes are made of wood. Those of the shorter planes are also most usually made of wood, but iron stocks are becoming common for them in America, and to some extent are already used in England. The edge of the slit in the sole of the wooden stock wears away with the passage of the shavings past it, and after a time leaves this slit too wide. This is rectified usually by letting in a small flat plate of hard wood screwed down to the sole. A brass plate is occasionally inserted, and of course this wears much longer; but it is not advisable, because of the difficulty in getting the surface of the brass exactly co-planar with that of the wood part of the sole. When the sole needs to be re-stripped, the brass must be removed, the wood stripped, then the brass re-screwed in place and filed down level with the fresh surface of the wood. A still more important disadvantage, however, under which wooden stocks labour in comparison with iron ones, is that the wooden sole gradually loses the perfect flatness of its surface from the warping of the wood, from unequal wear in different parts, and from "scoring," *i.e.*, being grooved by being accidentally driven over nail-ends. The iron surface having been made once true, remains so always.

The Jack Plane, Fig. 8, for rough, heavy work, has a stock of about 14 inches in length. The iron is ground with a slightly-rounded contour, so that the plane really ploughs out broad, rounded furrows. The top iron is set back from the edge about $\frac{1}{16}$ inch.

The Trying or Half-Long Plane is 20 to 22 inches long, and the Long Plane about 26 inches. These have the edge ground straight across, rounded off only a little at the corners, and the top iron should not be more than about $\frac{1}{64}''$ back from the cutting edge.

The Smoothing, or as it is sometimes called, Hand Plane, is made of various lengths up to 8 inches long and is used on as many different classes of work.

There are also various small planes for hollow work. An extremely useful form of iron-stock plane is shown in Fig. 9. It has a flexible sole-plate, which can be screwed up to any radius of curvature.

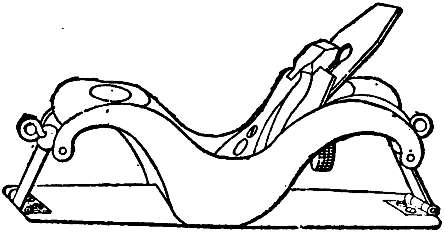

Fig. 9.

8. Guidance of Planes.—We have here quite a peculiar sort of guidance for the cutting motion of the tool. Consider a trying-plane in the middle of its stroke, both the front and hind ends of the stock lying on the plank, that is, neither overhanging the end of the plank.

Behind the tool the surface has been cut down by the thickness of a shaving. In front of the edge of the iron it remains still uncut, and, therefore, higher than the hinder portion. The flat sole is, therefore, tilted slightly upwards, the forward end being the higher. If the wood were perfectly hard and incompressible, evidently the sole of the plane would rest on it immediately in front of the iron, and also at the hinder end of the stock, the front end of the sole being raised out of contact with the wood. The cutting edge would then be below the uncut surface in front of it by a depth equal to the distance it projects below the sole-plate, and if this were also the height of the uncut surface above the cut surface where the tail-end of the sole rests, evidently the relative positions of the different parts would be maintained constantly the same as the plane moves forward.

But the wood is not incompressible, and the workman, bearing heavily on the fore-end of the stock, causes the front half of the sole to compress the surface of the wood, so that the forward edge of the sole, instead of being raised clear of the wood, rests upon it. If the hinder end also at the same time rests upon it, it is clear that the portion immediately in front of the iron must be slightly pressed below its natural position, and the cutting edge of the iron also must be a little below the position we first supposed it to have, that is, it lies at a somewhat greater depth below the surface of the wood

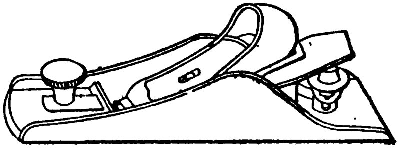

Fig. 10.

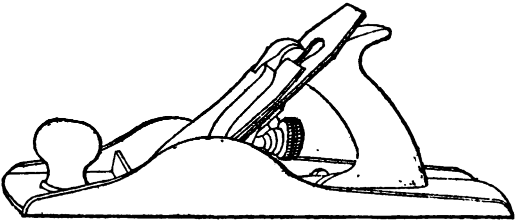

Fig. 11

at the front end of the stock, than does the wood surface at the hinder end of the stock. Both on this account, and on account of the compression of the material immediately in front of the iron (whereby a given *thick-*

ness of shaving means a greater quantity of material), it is clear that there is a tendency for the cut to get a little deeper as the stroke advances. Of course, there is a a limit to this deepening. Either the front or the hinder end of the sole soon stands a minute distance clear of the wood surface,* and the depth of shaving cut is simply that of the projection of the edge of the iron below the sole, increased slightly in proportion to the pressure exerted by the workman. The real bearing is evidently over the surface, extending only a small distance in front of the iron.

It may be asked, then, what is the advantage of having a long sole for trueing up. The answer is, of course, that in the above explanation the uncut surface was assumed to be already truly flat, and it showed that so long as an equal pressure downwards was exerted, the planing would not bring the surface out of truth. But if there be unevennesses, however minute, that is, even if their height be only a fraction of that of the cutting edge beyond the sole-plate, then when the tool is over the hollow parts the whole or the greater part of the pressure is borne at the ends of the sole, while the iron either does not cut at all, or removes only an extra thin shaving; when, however, it is over a high place, the full pressure comes on the part of the sole near the iron, and this latter takes its full cut, thereby reducing the unevenness.

It is evident also that, if he choose, the workman can plane a hollow by pressing first lightly, then heavily, and again lightly, until he lifts the plane entirely off the plank. In this way, he can reduce any high portions he discovers by the application of a straight-edge.

The pressure put on the material immediately in front of the iron greatly conduces to the clean cutting of the surface. It prevents splitting and tearing of the wood in advance of the tool.

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* Chiefly the hinder end, because the iron does not cut a track the full width of the sole-plate, which therefore cannot descend to the bottom of this track without being heavily pressed.

There is always a tendency to "plane round," *i.e.*, to make the ends of the board lower than the centre. This is because at either end of the stroke one of the ends of the sole is free of the wood, and therefore the iron always takes its full cut. In the middle of the stroke it takes its full cut only at the high places. To counteract this tendency, no downward pressure should be put on the stock at the beginning and end of the stroke.

9. Difference between Wood Plane and Paring Chisel.—The chief difference between the mode of cutting of the plane iron and that of the paring chisel previously explained in detail has already been pointed out, namely, that the wood in front of it is kept firmly pressed down so that it cannot split far in advance of the edge. This splitting is further prevented by the shaving being broken or rather half broken through as soon as it leaves the surface. In examining a shaving from a plane, lines or small ridges are seen running parallel and crosswise, close to each other. If the plane is in good condition and the wood be of even texture, these ridges are spaced the one from the other at very regular distances. These are the above-mentioned lines of half-breakage. If the shaving be bent over, it always cracks along one of these lines. They are seen more easily on thick shavings than on thin, and are farther apart on the thick ones.

This cracking of the shaving is effected when the shaving slides up the edge of the top iron. Holtzapffel seemed to think that this was the chief and indeed the only function of the top iron. This idea cannot be taken as being by any means correct. It was probably occasioned by the fact that the top iron of the trying plane is placed much closer down on the cutting edge than that of the jack plane, while at the same time the lines of cracking in the shavings from the trying plane are much closer than on those from the jack. But this will be found to result from the greater thinness of the shavings and from the narrower mouth of the former. To test this point, the author closely examined the shavings from a jack and from a trying plane, the mouths of both of which were narrow (the planes being nearly new) and exactly equal. The top iron of the trying plane was put close down to the cutting edge, while that of the jack was set back nearly an eighth of an inch. When both planes took exactly the same thickness of shaving from the same piece of wood, no difference of any kind could be discovered between the shavings from the two, even when examined with the aid of a powerful Codington lens. The cracks were exactly the same distance apart in both. When either plane was set to take a slightly thicker cut than the other, the difference immediately showed in the spacing of the cracks, this being greater the thicker the shaving whether this came from the jack or the trying plane.

This proves that the chief object in putting the top iron close down to the cutting edge in the trying plane is to keep this edge perfectly steady, so that it may not yield more or less according to whether it cuts over a high or a hollow place. The main object is not the more immediate breaking of the shaving.

When an old jack plane with the sole worn so that the mouth was $\frac{1}{4}''$ wide in front of the cutting edge, was used in these experiments, and when very thick shavings were taken, the spacing between the lines of breakage agreed more with the distance of the top iron edge back from the cutting edge than with the width of the open mouth.

When there is a wide mouth to the plane, the setting back of the top iron conduces to splitting in front of the tool, and in the jack it is set back with this avowed intention because, as has been previously explained, splitting is by far the easiest mode of removing the surface of the wood.

CHAPTER III.

MACHINE PLANES FOR WOOD.

1. Velocity of Cutting.—The speed with which hand-planes cut wood is necessarily very limited, a great velocity not being possible to the arm of a man simultaneously with the exertion of considerable power, or even without such exertion. A cutting edge, set as it is in such a plane, could not cut off the shavings cleanly and smoothly at this low velocity, if the sole of the stock did not forcibly compress the material just in advance of the cut.

But if the velocity of cutting be very greatly increased, the necessity for applying this holding down pressure close to the tool edge disappears, because the advance of the tool may be made swifter than the speed at which splitting can possibly take place. This is what is done in wood-planing machines driven by steam or water power.

In these, plane irons precisely similar to those used in hand planes, except that they are without any top iron, are held by screws in grooves cut in a block which revolves at such a speed as to make the cutting velocity of the tool-edges from 4,000 to 6,000 feet per minute, the slower speed being suited to the harder qualities of timber.

2. Classes of Machine Planes. — The revolving spindle on which the cutter block is fastened is, in one class of machine, placed horizontally and in another vertically. In all these machines the surface of the wood to be operated on is placed horizontally; or, where different surfaces at right angles to each other are to be worked simultaneously, the largest and most important of them is horizontal. When the spindle is vertical, therefore, the cutter-block takes the form of a disc whose face is parallel to that of the wood to be cut. This class of machine is very little used at the present day, but for heavy work which does not require fine finishing it is very effective in rapid cutting. In suitable recesses in this disc are placed the cutting tools, their cutting edges being horizontal and lying along radii of the disc. They are set and held in place by screws, and to furnish room for these set screws the whole disc is made hollow, a cover-plate being placed over it to prevent the screw-heads and other projecting parts catching the dress or limbs of the workman. A machine of this sort is illustrated in Fig. 12. The face of the disc stands clear, of course, of the wood, because at this high velocity the friction between the two, if they touched, would not only necessitate the loss of an enormous amount of power, but would also generate so much heat as to burn the wood and cause the bearings of the spindle to run dry of oil, and thus get destroyed.

3. Vertical Spindle Machine.—The bevel of the tools in this and the other machine is somewhat shorter than that of the iron of the hand plane; that is, the cutting angle is made larger to give the edge greater strength against the occasional sudden extra resistance caused by unevenness of the uncut surface or by knots. The angle at which the blade is set to the plane of the work is also made greater, namely, about 55° or 60°.

The bearings of the vertical spindle are fixed in the frame of the machine, and do not move. The timber to be cut is passed underneath the revolving disc upon a table, to which it is clamped and which is forced forwards by mechanism. This mechanism usually consists in a toothed rack screwed on the under-side of the table, into which gears a wheel on a horizontal shaft driven by a pinion on another parallel shaft. Both shafts lie underneath the table, and on the latter are placed a fixed and two loose pulleys, round which run, side by side, two belts from the counter-shaft of the machine. One of these belts is "open," and the other "crossed." By

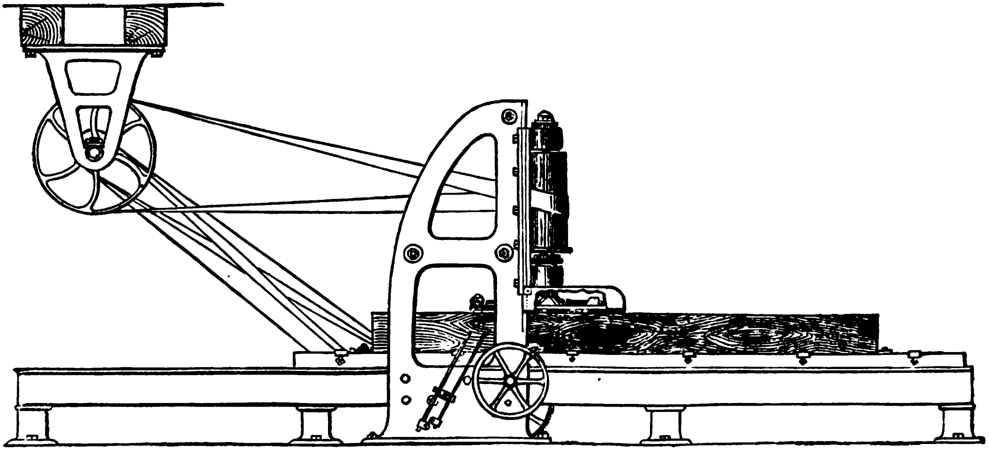


Fig. 12.—Wood Planing Machine (old pattern) by Ransome and Co.

means of a lever and a double fork the positions of these belts can be shifted, so that either of them can be made to run on the fixed pulley, while the other runs on a loose pulley. According as the open or crossed belt runs on the fixed pulley, the table is driven forwards or backwards.

4. Calculation of Feed.—If the cutters are arranged on a circle of 2 feet diameter, the speed of the spindle should be about 1,000 revolutions per minute, so as to give a cutting velocity of between 6,000 and 7,000 feet per minute. If the timber is fed up at the rate of 20 feet per minute, the front boundary-line of the cut surface will advance $\frac{20}{1000} = \frac{1}{50}$ foot = 0·24 inch, or about $\frac{1}{4}''$, each revolution of the disc. If there be just two tools on opposite sides of the circle, each will take a cut of only $\frac{1}{8}$ inch wide; and if there be four tools, the width of cut of each will be just $\frac{1}{16}$ inch. The actual rate of feed with such machines is often considerably below 20 feet, and is never more than 40 feet per minute, and it is, therefore, apparent that a broad cutting edge is not necessary, and that all the *work* is done by the corner of the planing-iron farthest from the centre of the disc. Thus, with 20 feet of feed and four tools on the disc all the work would be done by the outer $\frac{1}{16}$ inch of the breadth of the chisels, and if these chisels were 1 inch wide, it is evident that each spot on the planed surface is swept over by the cutting edges 16 times during the passage of the front side of the disc, and again 16 times while the back side of the disc passes forward over this part. The first 16 sweeps take place, say from left to right, and the second 16 sweeps are in the reverse direction. The surface is therefore very thoroughly worked over, and if it is not left quite smooth and flat, the fault will be in the bad and irregular setting of the chisels, or in the unsteady, trembling revolution of the spindle and its disc. The disc, being a somewhat heavy casting, must be very carefully turned, so that it may be perfectly balanced in order to avoid unsteadiness in its motion;

and also with the same object the upright bearings must be made particularly long (so as to wear well), and the brackets in which they are inserted particularly strong and stiff.

5. Importance of Correct Setting of Chisels.—If one chisel is set a little lower than the others, or if it is set so as to have its outer corner not quite so far from the disc-centre, it is clear that it will do little or no work. Therefore, very exact setting of the chisels is absolutely essential in order to make the machine work up to its proper capacity. It is also clear that, if the timber be not fed along a line which is *exactly* perpendicular to the axis of the revolving spindle, the disc-cutters will reach farther towards the wood either on the front half of their revolution than on the back half, or *vice versa*. If this line is the slightest degree inclined one way, the cutters will rise quite clear of the planed surface on the back half of their circular path, and a valuable series of finishing grazing cuts will be quite lost. If it is in the least inclined the other way, the cutters at each passage through the hinder part of their revolution will leave a scar or scratch. These scratches will be distant from each other by the amount of feed per revolution of the disc—for example, $\frac{1}{16}$ inch in the case taken above. It is, therefore, of very great importance that the spindle should be set with perfect exactitude perpendicular to the slides on the bed along which the table travels. To attain this accuracy, the only practicable method is to provide means of adjusting the bearings of the spindle after the machine is bolted down to the foundation, and to keep them in adjustment after they begin to wear. Such means are not difficult to provide, but this point has not been hitherto attended to in the design of these machines. Probably on account of this difficulty in setting, and the unsteadiness inseparable from long standard brackets subjected to the variable side-thrust mentioned hereafter, this machine has now gone much out of fashion.

6. The Cut on Vertical Cylindrical Surface.—In each new cut the material has not only to be removed from the horizontal surface which is planed, it has also to be separated from the farther advanced portions of timber to which the tool does not yet reach. This separation takes place over a vertical cylindrical surface. If the tools used are only chisels with *horizontal* cutting edges, this separation is left to be done by *tearing* simply. Now this would be wasteful of power, and, besides, would introduce danger, and at times certainty, of leaving ragged torn holes and marks underneath the tooled surface. This vertical surface, therefore, ought to be *cut*; and this becomes more especially important if the machine is for heavy work. This can be done by fixing a small vertical knife (*i.e.*, with a vertical cutting edge) immediately in front of each chisel. The work that has to be done by such a knife is extremely light, and the knife may, therefore, be made a very thin blade which merely slices out the circumferential boundary of each new annular shaving that is removed. It is, of course, important to set this knife, so as not to cut below the surface tooled by the chisels. The same object may be attained by rounding off the outer corner of each chisel with a round resembling that put on the corners of a jack-plane iron, only shorter and sharper. This arrangement is, however, not so economical in power, and has in no other respect superior advantages. The material is taken off in a series of very thin broad shavings (the breadth being equal to the length of the round) instead of in one thick shaving of very small width.

Messrs. Ransome & Co., in the machine illustrated on p. 34, effect the same object by having in advance of the horizontal-edged finishing chisels a number of gouges, which rough out the surface and do all the hard work. They have six tools in the disc, four of which are gouges, and two finishing chisels. The gouges are simply pieces of cast-steel tube, the ends of which are ground to sharp-cutting edges. This form of gouge has the very great advantage of being readily turned round through a small angle when the part of the edge last used has become blunt. Thus a fresh bit of cutting-edge (what is in fact a new tool) is presented for work, and the machine can thus be run for a very long time without being stopped for the sake of taking out and re-grinding the cutters.

7. Cross Strains through the Machine.—The cutting-sweep of the tools is *across* the length of the log operated upon, and, therefore, *across the grain*. This is an advantage for heavy, deep cutting, as it precludes the possibility of splitting along the fibre in front of the tools. Thus, this style of machine is specially adapted for heavy rough work.

The resistance to the cutting is also, of course, *across* the centre-line of the table. This throws a heavy side-stress both on the bed and on the standard which supports the bracket and bearings for the vertical spindle. These must be designed so as to give ample strength and *stiffness* to resist not only breakage, but also any sensible *deflection* or harmful vibration in the direction of these forces. At the same time this stress resisting the cutting action being mostly crosswise results in the force required to feed up the timber being comparatively small. This is another reason why this machine is specially suited for heavy work.

8. Pitch of Chisels in Horizontal Spindle Machines.—In wood-planing machines with the rapidly revolving spindle lying horizontally, the timber passing underneath parallel to the axis of the spindle, the cutting chisels are screwed into recesses in a cylinder the axis of which coincides with that of the spindle. The chisel edges are parallel to this axis, and they must have a width at least as great as that of the planks to be planed.

Their bevel and angular pitch to the surface they have to plane is about the same as those last mentioned. Being used for lighter cuts, the pitch might safely and with advantage be made less, but the arrangement of four

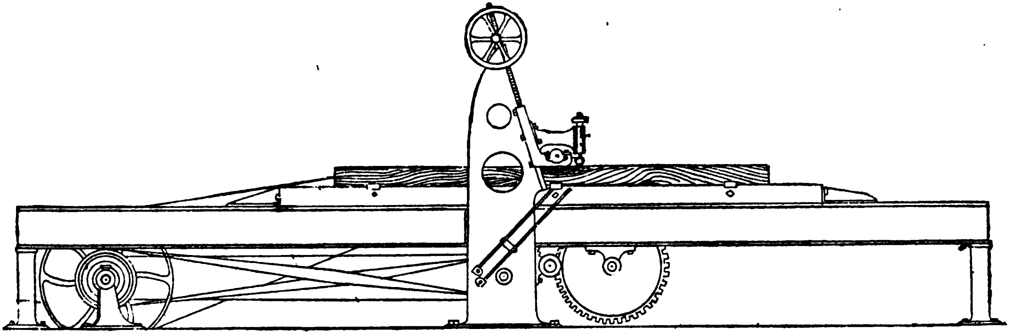


Fig. 13.—Wood Planing Machine with Horizontal Cutter-Block, by Ransome and Co.

chisels in grooves cut in a small cylinder of some five or six inches in diameter would be impossible at a smaller angle to the tangent.

9. Ransome and Co.'s Wood-planing Machine.—A machine of this sort by A. Ransome and Co. is shown in Fig. 13. The block that carries the cutters is of cast steel. The edges of the cutters being set at from 2½″ to 3″ from the centre of the spindle, the rate of revolution of the block should be about 4,000 turns per minute in order to give a cutting speed of 6,000 feet per minute. This is about the highest speed at which it has hitherto been found practicable to run a spindle without the bearing becoming hot. Fig. 14 shows to a larger scale than that of Fig. 13 the cutter block with its spindle and bearings.

The bearing is made of the hardest gun-metal. It is of essential importance to get the two bearings with mathematical accuracy exactly in line with each other. The brasses should, therefore, be first carefully fitted in their seats in the sliding head-stock, and then, the covers being firmly bolted down, they should be bored out in a boring lathe with one setting only for the two.

10. Steadying Roller.—In Fig. 13 may be seen a small roller in front of the cutter block. The object of this is to press down the plank firmly on the table and prevent it "chattering." Obviously this holding-down pressure is not applied at a point so close to the cutting-tool-edge as to be of service in preventing splitting, as is the sole of a hand-plane. Its object is to prevent vibration. This would occur if it were not for the roller, because the cutting-edges have a motion which is mostly forwards in the horizontal direction, but which has also a small upward component. This latter has a continual tendency to lift the plank up from the table.

11. The Feed.—In the machine illustrated, the plank is fastened to a travelling table, which is then fed forward by chain or rack gearing, the speed of feed being capable of variation.

In other similar machines there is what is called a "roller" feed. That is, the plank to be planed is passed between two rollers, either or both of which are driven in rotation by toothed or belt gearing. These two rollers grip the plank between them, and this is pushed forward by them as they rotate. In Ransome's machine, shown in Fig. 13, a roller feed arrangement may be mounted on the travelling table, which is then thrown out of gear.

If the plank be fed forward at the rate of 20 feet per minute and the spindle make 4,000 revolutions per minute, the advance per revolution will be $\frac{20}{4000} = \frac{1}{200}$ ft. = 0·06 inch. If there be two blades in the block the depth of each cut will, therefore, be 0·03 inch, and with four blades it would be no more than 0·015 inch. This is just the thickness of a shaving that can be easily taken with a jack plane, and in consequence of the combination of this very small depth of cut with the very high speed of cutting, these machines plane up wood surfaces with a high degree of smoothness and "finish."

Here again it is of the greatest importance to set the different blades all exactly at the same distance from the centre line of the spindle. If this be not carefully done, not only will one blade do nearly all the work, but also the planed surface will be found covered with a regular series of minute transverse waves or ripples.

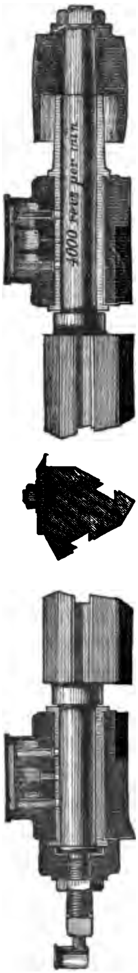


Fig. 14.—Cutter Block and Spindle for 14-in. trying-up Machine.

The reason of this is evident. Each time the high-set blade comes into operation it makes a deeper cut than the others, and also the wood travels forward a small distance in each interval between such deep cuts.

12. Moulding Blades.—By "profiling" the edge of the blade, that is, by shaping it, not straight, but so as to fit exactly like a template to the outside of any desired curved or angled section, grooves, tenons, mouldings, &c., can be cut on the plank at the same time as its surface is planed up. Sometimes, when one set of cutters is operating upon the flat upper surface of the timber, the sides are being simultaneously grooved, or tenoned, or beaded, by other cutters driven on vertical spindles placed at either side of the machine.

13. Tenoning and other Machines.—There is a large class of tenoning, tongueing, grooving, beading, matchboarding, dove-tailing, machines, &c., which are all constructed on very much the same principle as that of the last described. Their appearance is often much complicated by their being arranged with several different tools to do as many different kinds of work, all mounted on the same framing.

In America, where so much more timber is "converted" than here, and where manual labour is much more expensive, the designs of such machines show frequently great ingenuity and skill in arrangement of parts, and until lately their workmanship was probably superior to ours; but during the last ten or twelve years great advance has been made in the excellence of manufacture of wood-working machinery in Europe, and those built in England and France cannot be surpassed in arrangement, solidity, and superior workmanship. In this class of machinery, more than in any other, first-class workmanship, most especially in the spindle bearings, is of immense importance in ensuring clean, true work, and in giving *durability* to the machine itself.

CHAPTER IV

SAWS AND MILLING MACHINES.

A CLASS of machine-tools very much resembling in principle that dealt with in the preceding chapter, includes saws for wood, saws for iron, and milling machines for metal.

1. Difference from Machines of Chap. III.—Saws for wood of the commoner and older sorts differ from the tools described in last chapter, in having their cutting chisels made all solid together in one piece. This distinction, however, can no longer be made as a general one between saws and other machines, because it is quite common now to have "inserted" teeth, in large modern circular saws. There remain two essential distinctions, which separate saws for wood and iron from planing machines, but which do not apply to milling machines. These are, firstly, that the object of the tool is not to flatten and true up a surface, but to *separate* a block of material into two distinct parts; and, secondly, that in consequence of this being the object, the teeth and blade on which they are set are made as *narrow* as they can possibly be made consistently with their having sufficient strength to resist breakage. To obtain a maximum of strength with a minimum of width of face, the thickness of the tooth or cutting chisel, measured in the direction of the cutting motion, is made as great as practicable.

2. Saving of Timber by Thin Saws.—By making the width of face small, two objects of very great importance are attained. In the first place as small an amount of material as possible is converted into saw-dust and thereby almost entirely wasted. This waste in saw-dust does not appear at first sight to be of extreme importance when one watches only a few planks being cut. But when one considers that this waste is repeated millions of times in the course of a year in a single saw-mill, the absolute necessity of economy in this direction becomes evident enough. If, for example, a 14-inch square log is to be converted by sawing into $\frac{5}{8}$ inch planks, if the saw cut away $\frac{1}{16}$ inch only between each plank, 20 planks will be got from the log; if it cut $\frac{1}{8}$ inch away only 18 boards $\frac{5}{8}$ inch thick can be got out of it; and if $\frac{3}{16}$ inch be lost in saw-dust, then only 17 boards will be obtained. Thus in the first case about 9, in the second 17, and in the third about 23 per cent of the timber is lost in the shape of saw-dust.

If these logs were 12 feet long, then in the first case, there being 21 cuts, each 14 inches deep and $\frac{1}{16}$ inch thick, there will be more than $1\frac{1}{2}$ (exactly $1\frac{17}{32}$) cubic feet of timber converted into saw-dust for every log. In the second case there would be $2\frac{3}{4}$ cub. ft. lost; and in the third $3\frac{15}{16}$ cub. ft. would be the waste in saw-dust.

If now we suppose that a single saw-frame cuts up 50 of these logs per day, and works 250 days per year, the losses per year in the above three cases would be 19,150, 34,350, and 49,150, cubic feet of timber per annum. Taking this at the price of 2/- per cub. ft., which is a fair average for yellow pine, we find that the above three yearly losses are represented in money by £1,915, £3,435, and £4,915. This example serves to show the extreme importance of saving by making as little saw-dust as possible.

3. **Saving of Power by Thin Saws.**—Secondly, it is almost self-evident that the power required to drive the saw becomes greater in simple proportion to the width of the cut it takes. To save horse-power in the steam or water driving engines also, therefore, thinness of the saw-blade is of the greatest utility. Even in hand-saws, the difference in fatigue to the workman is very speedily recognised by any one who tries saws of different thicknesses on the same wood.

In the hand-saws used in England the cutting stroke is a push outwards from the shoulder of the workman. This mode of using the tool has been perpetuated by the Anglo-Saxon race in the United States, Canada, and the British Colonies. The blade of the saw is thus thrown in *compression*, and in order that it may have sufficient stiffness to prevent it buckling, it requires to be made far thicker than if it had to transmit the same force in tension only. This liability to buckle is illustrated by lads beginning to learn to saw, who not unfrequently injure a saw-blade by the unsteadiness of the thrust they give to it, which leads to the teeth catching on one side of the cut and a sharp bend or even a crack being caused in the blade. As it is almost impossible to remedy such an injury perfectly, the saw becomes permanently damaged. On this account chiefly, also, English saw-blades for hand work are (and require to be) made of a much better quality of steel than would otherwise be necessary.

In Germany, Italy, and most of the European Continent, as well as throughout the chief peoples of Asia, hand-saws are used in tension, the cutting stroke being a pull towards the chest of the worker. In consequence, the blades are made very much thinner than those of English saws, less material is converted into saw-dust, and less exertion is required for a given rate of cutting.

The English method, however, has this advantage, that a man standing upright can exert a considerably greater force in thrusting forward with his arms than he can in pulling inward. This is still more the case if he leans forward *over* his work, because he can then throw a large portion of his *weight* on the saw handle to drive it forward. The result is, that if an English carpenter be pitched against an equally strong German carpenter, each armed with his own tool, the Englishman will saw through as great, or possibly a greater, length of the same thickness as the German will. But the Orientals *sit* to this sort of work, and, planting the feet against the log being sawn, pull outwards by the contraction of all the muscles of the body. As is well known to us from our familiarity with the English style of rowing, this is by far the most powerful attitude into which the human muscular system can be thrown. Thus, unless the peculiar shape and position of his work compels, say, the Japanese carpenter to assume an awkwardly cramped position, he is enabled, with his thin, broad, saw blade, to get through his work with far less fatigue and with greater rapidity than an Englishman can.

Thin saws worked in tension, being extremely pliable, are more likely to make a cut that is not quite straight. The thick saw-blade of English or American make has superior stiffness, and, therefore, superior guiding power to keep the advance of the cut always in the same straight line, but this superiority in guiding power is again neutralised by the fact already mentioned of the thrust tending to bend the blade, while the pull on the thin saw tends to straighten its blade.

4. Frame, Band, and Scroll-band Saws.—In hand and machine *frame* saws, the thin blade in tension is almost universally used, as also in *band*-saws. The superiority of the thin blade is recognised in France, where the majority of machine-saws used is of the band-saw class. In *scroll-band* saws the thickness and narrowness of the band permit the saw to cut out corners and holes of extremely sharp curvature.

5. Circular Saws.—Rotating *circular* saws, on the other hand, are intermediate between the thrust and the pull saws. In them we may imagine successive radial segments of the circular blade to act as spokes of a wheel, and the cutting teeth to be driven through the wood by these spokes. The direction in which they are driven is perpendicular to the spokes, which are, therefore, on the whole, thrown neither into tension nor compression, but are simply *bent.*

6. Forms of Saw-teeth.—In all hand-saws and in most machine-saws the teeth are made solid with the blade. There is a great number of different shapes used for the teeth, some of which are found better for cutting across the grain, and others for "ripping" in the direction of the fibre, some more especially suitable for hard, and some for soft wood. Fig. 15 shows seven different common forms of teeth. The first four shapes are for cross-cutting—*a* receiving the special name "peg" tooth, and *b* that of M tooth. The fifth (*e*) is suitable for ripping soft wood, and, when made of a smaller size, for sawing iron; *f* is one of the shapes commonly used in sash-sawing machines, in which logs are converted into planks; *g* is a form suitable for a circular saw.

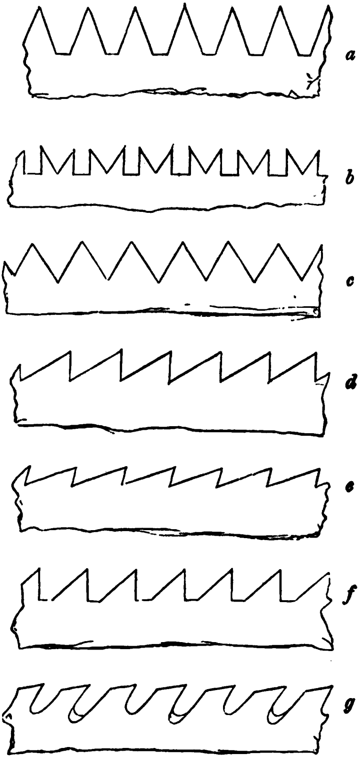


Fig. 15.

In Figs. 16 and 17 are shown several forms drawn to an enlarged scale, and showing the "set" of the teeth.

7. Setting Saw-teeth.—"Setting" is the bending of successive teeth alternately to one side and the other. The purpose of this is to make the width of the cut greater than the thickness of the blade, so that the blade may pass to and fro without much friction. Greater power being required for cross-cutting than for ripping and the cut surfaces—composed, as they are, of bundles of fibres perpendicular to the surface—being less yielding than those parallel to the grain, a large amount of set is given to cross-cut saws, and very little to ripping saws. The

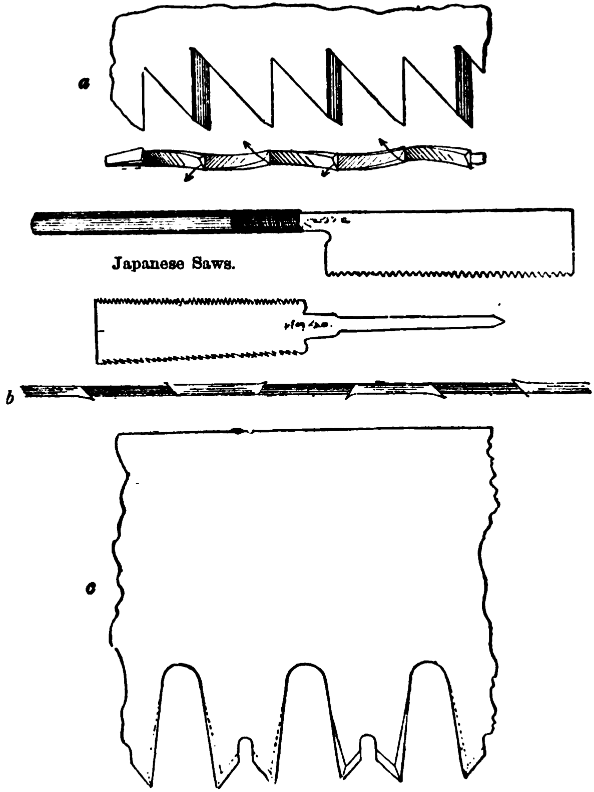
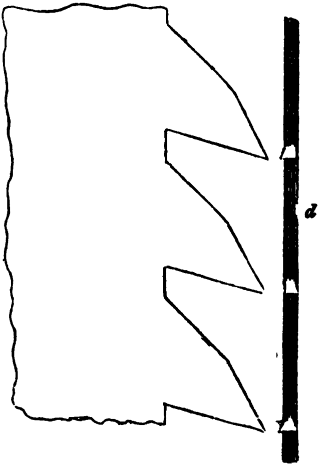


Fig. 16. (*a*, *b*, *c*.)

setting is best performed by striking down alternate teeth upon a small anvil specially made for the purpose.

When all the teeth that have to be set to one side are struck down, the saw-blade is turned over, and the others are struck down to the opposite side. The teeth are, however, more commonly set over by means of a specially constructed pair of pliers upon which there is a stop which, as the pliers pull the tooth over, comes in contact with the blade and thus regulates the angle through which the tooth is bent to the side. In filing the teeth to sharpen them, care must be taken to bevel the edges of alternate teeth opposite ways, and in the subsequent setting equal care must be taken to bend each set of teeth towards the side of the blade for which it has been sharpened—that is, so that the sharp bevelled edge will lie outwards on the side to which the tooth is bent. The



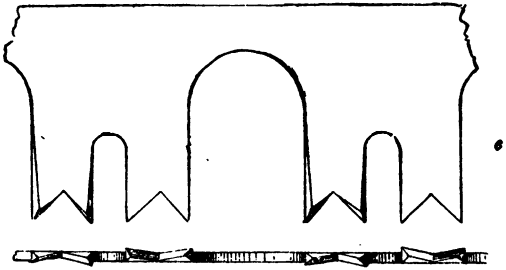


Fig. 16. (d, e.)

M tooth is intended to cut both on the forward and backward strokes. The opposite sides of the M are, therefore, bevelled in opposite directions. The result is shown in *b*, Fig. 16.

The above method of setting is the commonly adopted one, and is called "spring" setting. Another style is what is called "spread" set. In this the tooth is not bent, but has its extreme point hammered, or "swaged," so as to become broader than the thickness of the blade. This is more suitable for ripping than for cross-cutting.

If the set is in excess of what is really needed, evidently the "kerf" becomes so wide as to allow the saw-blade to lean a little to one side from the direction of that portion of the cut already made. This leads to the saw cutting out a curved surface instead of a straight one.

8. Inserted Teeth.—In Fig. 17 *f* shows a form of tooth for a circular saw in which both spring and spread set are used. The latter is so arranged as to spread the point all to that side of the blade towards which the tooth is bent. In the same figure, *g* and *h* are two forms of "inserted" teeth that have of late become much used in America. They are used only in circular saws. The mode of fixing them in place is sufficiently evident from the diagram. The advantages of the inserted teeth are, that if a few teeth are broken they can be replaced easily, so as to make the saw once more as good as it was originally; that the diameter of the saw is not reduced by repeated filing in sharpening; that the teeth may be tempered much harder than the rest of the blade; and that the separate teeth being all individually forged and ground to gauge—*i.e.*, to one exact pattern—they are of necessity all exactly alike in size and shape.

The last point is a specially important one. If any tooth in a saw-blade does not stand so high as the general level of the others, evidently it can do no work, and might as well be non-existent. If, on the other hand, its point is too high, it becomes buried too deep in the timber, and either will be rapidly worn and blunted, or else will be broken off altogether. Until it is injured in one of these two ways, it prevents the neighbouring teeth coming into proper action.

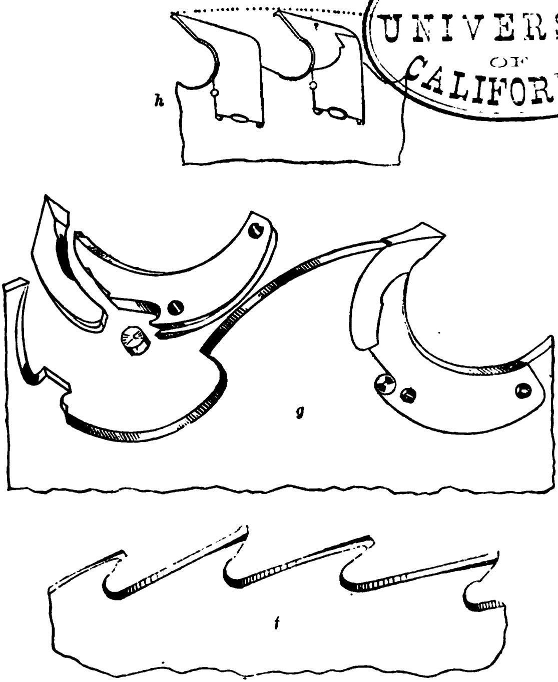


Fig. 17.

9. **Sawdust Space.**—If a saw has a cutting stroke of length L, and the spacing between successive teeth be l, then, in the length L, the number of teeth will be $\frac{L}{l}$. If, in this single stroke, the bottom of the cut be

advanced a distance, d, the thickness of the shaving removed by each tooth is $d \div \left\{\frac{L}{l}\right\} = l\,\frac{d}{L}$.* If the thickness of the plank which is being cut is less than the stroke of the saw (as it usually is), the volume of material cut away in one stroke by a single tooth equals the width of the kerf (*i.e.*, a little more than the thickness of blade), multiplied by the thickness of the timber and by the depth of shaving. If the thickness of the timber be called T, this volume will be $l\,\frac{d}{L}\,T \times$ width of kerf.

Now, while any tooth is passing through the timber, this amount of material reduced to saw-dust has to be stowed away in the notch between this tooth and the next tooth in front of it. Reduce the area of this notch to a rectangle standing upon the line drawn between the points of the two successive teeth—that is, find the mean depth of the notch, so that its area may be represented by this mean depth multiplied by l. Then, making an allowance for the greater bulk of the saw-dust per unit of weight than of the uncut wood, we should evidently have this:—

Mean depth of notch $= \frac{d}{L}\,T \times$ percentage allowance for greater bulk of saw-dust.

Now, other things being equal, of course the depth of cut increases proportionately with the length of stroke, so that $\frac{d}{L}$ would be found always to have the same value for long and for short strokes. But if one supposes the forward pressure put on the saw to be always the same, then this ratio of depth of cut to length of stroke will be smaller for harder woods, and greater for more easily cut woods. On the same supposition it will be smaller the greater is the thickness of the timber to be cut through; that is, it will be *inversely* proportional to T.

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* This is not mathematically exact. Each tooth advances along a line, inclined to the line of the saw by an angle whose sine is $\frac{d}{L}$. The exact thickness of the shaving is, therefore, the above multiplied by the cosine of this angle, but, the angle being extremely small, its cosine differs very little from unity.

Thus the quantity $\frac{d}{L}T$ is approximately a constant quantity so long as the same quality of timber is being dealt with in the same way. We infer from this that the mean depth of the notch between the teeth would be the same for widely spaced and for closely spaced teeth, so long as the percentage allowance for difference of bulkiness between the saw-dust and the uncut timber is taken the same. Thus, if deeper notches are used with more widely spaced teeth (as is always the case) this means that for them a greater percentage allowance is made than for closely spaced teeth. The chief reason for this is to be found in the fact that the larger saws are meant for heavier work, that the feed pressure applied to their blades is greater, and that, in consequence the saw-dust is coarser. Thus for these the ratio $\frac{d}{L}$ is made greater in consequence of the greater feed pressure, and the allowance for increased bulkiness of the material when converted into saw-dust is also greater on account of the coarseness of this latter.

The above calculation has been made on the supposition that the length of stroke is greater than the thickness of the timber cut. In sash saws, where large logs are cut up into planks, this is not always the case. If it be not so, then to get the volume of wood cut off per stroke by each tooth we must evidently substitute L, the stroke, for T, the thickness of the log. We would then get instead of $\frac{d}{L}T$ simply $\frac{d}{L}L = d$, and the rule would be that the depth of notch should be simply proportional to the depth of cut taken per stroke, being made greater than the latter depth in a certain ratio indicating the allowance made for increased bulkiness of the saw-dust.

In an example quoted from American practice by Grimshaw, a sash saw had the spacing between the teeth 1¼″. The stroke was 19″ and the length of the saws 54″, so that timber at least 30″ thick could be taken in. The maximum depth of cut per stroke for soft wood was

1″, the minimum for hard wood being ⅜″. The depth of the notch was 1¼″, the same as the spacing. The *mean* depth, of course, was much less, probably not more than about half the extreme depth, or about ⅝″. This being much less than the maximum cut taken per stroke, we infer that the depth of notch was much too small; and, indeed, it is difficult to imagine where the saw-dust was packed away if the depth of cut (1″) reported be not one of those pleasant exaggerations in which American engineers occasionally indulge. If so heavy a cut as 1″ per stroke were to be taken, the depth of tooth should have been made much greater, and the spacing at the same time proportionately wider.

10. Cutting Speed and Feed.—Circular saws are made to cut usually at the speed of about 9,000 feet per minute, but in America it has been found practicable to use one-and-a-half times that speed. Saws running at the higher speeds are ground so as to make the thickness of the blade at the periphery considerably thinner than at the centre. The object of this reduction at the edge is to obtain as little weight as possible at the points where the velocity is highest, in order to reduce the risk of breakage by centrifugal force, and at the same time to obtain as thin a kerf as possible. At such high velocities the periphery vibrates rapidly from side to side through a small range, the consequence being that the kerf cut is much wider than the breadth of the faces of the teeth. The greater thickness at the centre is required for strength. The resistance to cutting acts perpendicularly at the end of the radius, and the maximum bending stress upon the material of the blade is close to the point of attachment to the spindle. On account of the great centrifugal force given by these high speeds, the greatest care must be taken in using inserted "planer-bit" teeth to secure them with absolute safety. If they were not perfectly secure, they would fly out with such violence as to kill any man who was struck by one.

For the same peripheral velocity, however, the centrifugal force is *less* the larger the diameter is. It is, in fact, inversely proportional to the diameter. It is only half as much with a double diameter. It is on this account chiefly that a greater peripheral velocity may be given to large saws than to small saws, and it is by the employment of saws of very large diameter that the Americans are enabled to cut at such a high speed. These large saws, however, are suitable only for rough work on account of the wobbling vibration set up.

A saw cutting with the peripheral speed of 9,000 feet per minute can be fed forward at a rate varying from 30 to 100 feet per minute, according to the nature of the work done. If the feed is 60 feet per minute, then the advance will be $\frac{60}{9000} = \frac{1}{150}$ foot = ·08 inch for every foot of peripheral movement. If the distance from point to point of the teeth is 2 inches, *i.e.*, 6 teeth to the foot, the depth of cut for each tooth is evidently $\frac{\cdot 08}{6}$ = ·013, or $\frac{1}{77}$ inch only. At the rapid feed, 100 feet per minute, that is about $1\frac{1}{7}$ mile per hour, the depth of cut is no more than ·022 or $\frac{1}{45}$ inch.

The very rapid feed that can be employed with saws in good order upon the softer qualities of timber is, therefore, by no means surprising, when considered in connection with the very high peripheral velocity. Of course, for cross-cutting the feed cannot be nearly so rapid. Evidently, other things being equal, the more rapid the feed is the more economically, as regards power expended, is the work done. The thicker the shaving, the smaller is the number of cuts to be taken to get through a given length, and the less also, therefore, is the total area of the cut surfaces perpendicular to the plane of the saw-blade. The two opposing surfaces that are cut by the side edges of the teeth parallel to the saw-blade have, of course, the same amount whatever be the rate of feed, so that there is largely increased rate of doing work with the more rapid feed, but the increase is not in so great a proportion as is the greater quantity of timber sawn in a given time.

11. **Horse-Power.**—The power required for sawing depends very greatly on the condition in which the teeth are kept. It is the worst possible economy to spare labour in keeping the teeth sharp, to their true shape, and all equally high. Saws are most commonly re-sharpened by hand-filing, but they can be more expeditiously and more uniformly dressed by one of the numerous special machines made for the purpose, in which the teeth are ground by a revolving emery disc. Circular saws have to be dismounted, and taken to the sharpening machine. In order to save time, it is necessary to have different blades for the same machine, so that it need not stand idle while one blade is being re-dressed. In view of the economy effected by keeping the teeth *constantly* in good condition, it would probably be well worth while, in mills where much work is done, to have arrangements whereby a small emery-wheel, driven by a rubber band, as a hair-dresser's brush is driven, could be used to dress up the teeth of circular saws without its being necessary to dismount them.

The horse-power required for sawing machines varies with the feed, and the horse-power actually supplied to them in common practice depends greatly on the character of the duty to be performed. If the saw is infrequently used, only sufficient power is supplied to enable the work to be done at a slow rate of feed, because in this case the loss of time involved in the slowness of feed is of little importance. But if the saw is used for a constant special duty, if, for instance, it is specially constructed and used for the production of railway sleepers from the rough logs, or for the conversion of heavy timber into planks, since such work goes on continuously, ample power is given to the saw to enable it to be used to its full capacity. The following examples are given on the authority of Grimshaw.

GANG SASH SAWS, OR SAW FRAMES.

Number of Saws.	Length of Blade in feet.	Width of Blade in inches.	Gauge of Blade, B.W.G.	Stroke in inches.	Number of Strokes per minute.	Feed per Stroke in inches.	Horse-power used.	Width of Double Belt.	Diameter of Pulley in inches.	Height of Teeth in inches.	Spacing of Teeth in inches.	Width of Kerf in inches.	Capacity in one day of 10 hours.
21	3½	7	13	20	300	⅝	70	24	48	1	1⅛	3/16	80 M
30	5	7	11 12	22	200	⅝	35	16	42	1¼	1¾	3/16	35 M

BAND SAWS.

Width of Blade in inches.	Gauge of Blade, B.W.G.	Diameter of Saw Pulley in inches.	Revolutions per minute.	Feed per minute in feet.	Horse-power used.	Width of Single Belt in inches.	Diameter of Driving Pulley in inches.	Height of Teeth in inches.	Spacing of Teeth in inches.	Width of Kerf in inches.	Capacity in one day of 10 hours.
4	18	60	400	25	12	8	30	½	1½	1/16	10
5	16	72	350	30	15	10	30	1	2		20

CIRCULAR SAWS.

Kind of Teeth.	Diameter of Saw in inches.	Gauge at centre.	Gauge at Rim.	Number of Teeth.	Spacing of Teeth.	Revolutions per minute.	Feed per revolution in inches.	Width of Kerf.	Horse-power used.	Width of Double Belt.	Diameter of Driving-Pulley in inches.	Capacity in one day of 10 hours.
Solid . .	56	5	7	48	3⅝	600	3½	¼	30	10	24	12
Inserted .	72	6	8	72	3⅛	680	12	¼	80	18	23	50
Solid . .	60	4	8	64	2 15/16	850	6	¼	80	20	30	55
Inserted .	60	6	7	34	5½	400	2	¼	25			10

All the above saws—sash, band, and circular—were used on pine with the above speeds, feeds, and horse-powers.

12. **Cold-iron Saws.**—There is a class of machine tools which, although in external appearance as different as possible from wood saws, are really constructed on essentially the same principle so far as the cutting tool is concerned. These are milling machines for iron, steel, and brass. Intermediate between them and wood-sawing machines are circular saws for metal, and these have more apparent resemblance to the wood saws than milling machines have. Small circular saws of one to three inches in diameter are much used for cutting the slits in heads of screw-nails and metal screws, and also for making slits in various metal articles in the smallware trades. The cutting speed of the teeth is very much smaller than that of wood saws. It is greater for brass than for iron, and greater for iron than for steel. No lubricant is used with brass or cast-iron, but with steel and iron oil or soap-and-water are used in order to keep the tool and the work cool.

13. **Hot-iron Saws.**—Saws are also used for cutting iron bars to the lengths desired. Except for the smallest sizes, it is necessary to heat the iron to a red heat. The heating softens the iron, and, of course, makes it much more easy to cut it, so that bars and plates two or three inches thick can be cut without destroying the saw teeth. In saws intended for heavy work, the saw is arranged to run through a trough of cold water, in order to keep it cool, and prevent it from losing its temper.

14. **Milling Machines.**—Milling machines, as has already been said, are in many respects very different from wood saws. The difference is partly, of course, due to the difference of the materials worked upon, which require a slower cutting speed and greater power. It is also in great part due to the general difference of object. Whereas the saw has for its purpose simply to divide one mass of material from another, the milling machine has for

its purpose the shaping and finishing plane and curved surfaces to the various desired forms. In this it is perfectly analogous to the wood-planing machines, from which it differs in having the cutting tools not inserted but solid with the cutter-block. The cutter-block, or milling wheel, is simply a disc of greater or smaller thickness, and from one up to five or six inches in diameter, on the periphery of which are cut small teeth. If a plane surface has to be cut, the toothed surface of the milling wheel is cylindrical. If notches are to be cut to special forms, such as, for instance, the interspaces between the teeth of wheels, the contour of the axial section of the milling wheel is shaped accordingly, so as to fit exactly into the recesses to be cut out.

This small sharp-toothed milling wheel is rapidly revolved and moved gradually from point to point over the whole surface that is to be operated upon. At any one instant it operates upon only one line of what will be the finished surface, the length of this line being that of each of the cutting teeth. In order to bring the cutter successively over all the different portions of the work, two "feed" motions are necessary. These feeds must produce relative motions between the cutting axis and the work, and, so far as the mathematical result is concerned, it is a matter of indifference whether the work is held fixed and the cutter-spindle moved over it, or whether the bearings of the spindle are immovable, while the work is made to move under the cutter revolving in them. The one of the two feeds must produce relative motion perpendicular to the axis of the spindle, either in a straight or in a curved line, according to the character of the surface to be produced. The other feed is in a direction perpendicular to the first, usually parallel to the axis of the spindle, and always in a plane passing through this axis. If both these feeds are rectilinear the surface produced is plane. Any shape of surface may be produced by a suitable combination of these feeds, and the revolving cutter-tool is usually guided to cut out any desired shape by means of a "copying" bar, the form of which corresponds to that desired in the finished work, and along which one bearing of the cutter-spindle is made to slide.

Fig. 18 shows a milling machine for plane work. The spindle, upon which the cutter is fixed by means of a strong washer and nut, has upon its end a small three-stepped cone. This is driven by a belt direct from the counter-shaft overhead. The spindle revolves in two conical bearings. These bearings are not made conical in order to take any axial thrust. The actual axial thrust is always small, and it is supported at the flat bearing *b*, specially provided for the purpose at the back end of the spindle, and which can be screwed up for re-adjustment from time to time. The object of making the principal bearings conical is simply to allow of the spindle being drawn back by the adjustable screwed collars after the brasses have worn a little, so as always to have the spindle fitting quite closely in these brasses, and thus to avoid the slightest unsteadiness in its rotation.

These bearings are placed in a headstock, which is bolted fast to the framework of the machine. The axis of the spindle, therefore, always occupies the same position. The work is fastened firmly to the cast-iron table T. This table has two faces, to suit different shapes of pieces to be bolted to it. The one is horizontal and parallel to the spindle axis. The other hangs vertically like a curtain on one side of the horizontal face. Such a combination of two plates cast in one and intended to bolt work to, is called in the technical language of tool-makers an angle plate, and in this instance it is a right-angle plate. Both faces are perforated with series of rectangular holes, through which are passed the bolts used for clamping the work down.

15. **Machine Vice.**—A very convenient appendage to such a table for small work is what is called a machine vice, an example of which is shown in Fig.

19. This vice is bolted to the table, and the work fixed in it. The work has usually to be cut on two, three, or four different faces, and has, therefore, to be several times unfastened and re-set. To do this by simply unscrewing the vice and re-screwing it, is very much simpler than to loosen all the clamping bolts required to hold the work steadily by direct fastening to the table. There is, however, one disadvantage in the use of such a vice. If two surfaces have to be milled exactly parallel to each other, after one of them has been finished, the work must be fixed with this finished surface close and accurately pressed down on the horizontal face of the table, or on some face accurately parallel to this. If it is fixed in an ordinary vice, during the tightening of the jaws there is always a tendency to lift one or more corners of the work out of contact with the plate upon which it has been laid. To obviate this, Messrs Tangye have introduced a very ingenious vice, in which, by the act of tightening up, the jaws are forced downwards through a small distance and scraping on the sides of the work during this motion, draw down the work with them so as to ensure its close bearing upon the accurately horizontal surface beneath.

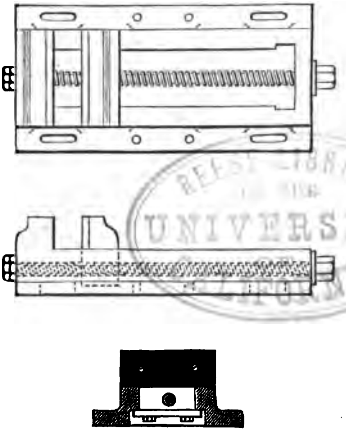

Fig. 19.

This kind of table and machine vice is also used in exactly the same form in shaping machines to be hereafter described, and very similar ones are used in slotting and in drilling machines.

16. Mechanism of Milling Machines.—The table slides up and down in dove-tailed grooves on the vertical face of the plate P, which is seen in Fig. 18 attached to the front of the frame. It is raised and lowered by means of a nut and screwed spindle. The spindle is vertical, and has on its upper end a small bevel wheel gearing into a similar bevel on the inner end of a short horizontal shaft. This shaft projects beyond the front edge of the horizontal table an inch or so, and is squared at its outer end for the reception of a hand-crank box-key, whereby the workman may turn the screwed spindle so as to raise or lower the table at pleasure. In some machines a rack and pinion take the place of the screw and nut, but the arrangement shown is in every way more satisfactory, the difference of cost between the two being inappreciable.

This vertical motion is not one of the two feed-motions previously referred to. It is more properly a "setting" motion, whereby the work is brought (by hand) to the required height. If, however, the surface has to be gone over more than once, the table has to be raised between the cuts by the above-described apparatus, and the amount by which it is so raised would be quite properly called "feed."

The vertical plate P slides horizontally (carrying the table with it) along the dove-tailed slides cast on the face of the frame. The plate carries a nut which gears with a leading screw actuated at one end by a ratchet wheel and pawl. The pawl can be reversed so as to traverse the table in either direction, or it may be thrown out of gear altogether, and the leading screw actuated by hand. When it is in gear the table receives a slow regular traversing feed, the amount of which per revolution of the cutter is constant. By using a larger or smaller ratchet wheel, or by altering the throw of the pawl, the rate of feed per revolution of the cutter can be changed. The pawl is attached to a slotted lever which is oscillated by an eccentric and eccentric-rod.

The throw of the pawl, and consequently the number of teeth on the ratchet wheel it passes over in each throw, is regulated by the position in the slot of the lever of the point of attachment of the eccentric-rod.

The second feed motion, which is horizontal and perpendicular to that last described, is obtained by making the table "compound;" that is, of two parts, the one lying on the top of the lower and sliding on it. The sliding motion is produced by a nut and screw actuated by a detachable crank handle fitting on the squared outer end of the screw-spindle.

This second feed motion is seldom or never actuated by the machinery, but almost always by hand. In the small sizes of milling machines both feeds are usually hand-moved, although a machine feed in the one direction is extremely convenient.

Much of the work done on milling machines is cylindrical, or prismatic, in general outline. First one small strip of the surface parallel to the axis of the cylinder or prism is milled, and then in succession, other exactly similar strips, at equal distances from the axis, are operated on. Such work is conveniently fixed on a mandril or otherwise, and placed between centres accurately perpendicular to the cutter-spindle. These supporting centres may be on separate brackets, each bolted independently to the table, or they may be both on one casting which has a resemblance to the fast headstock of a lathe, this casting being similarly bolted down. The traversing feed being put in motion, the cutter will plane off a surface parallel to the line of feed, and, therefore, if the centres have been carefully set, accurately parallel to the line of centres. Between each successive cut, the mandril is revolved on the centres through any desired small or large angle. During each cut it must be firmly prevented from revolving. This may be simply managed by fastening a small toothed wheel on the mandril, and arranging a spring-catch to wedge in between any pair of teeth corresponding to the desired position of the work on the mandril. For instance, if the work to be done is cutting out the teeth of change, or other wheels, a wheel is fixed on the mandril with either the same, double, treble, or any multiple of the number of teeth in the wheel to be cut; and by setting the spring-catch in the proper positions, the division of the wheel to be cut will be accomplished with the same degree of accuracy, *i.e.*, the pitch will have the same uniformity as is found in the wheel used as a gauge, or "copy." A more accurate method of obtaining the same division is by fixing on the mandril a "dividing plate." This is simply a flat plate with a number of small holes drilled in it, corresponding accurately to given aliquot parts of the circle, and into which holes fits a little peg-stop passing through a hole in the centre-bracket. If the desired division of the circle is very simple—for instance, if it is desired to divide it only into, say, 2, 3, 4, 6, 8, 12 parts—the holes are often placed in the cylindrical periphery of the dividing plate; but if the division desired is to be complicated, so that the necessary holes are very numerous, the holes are placed in its flat face, and for important work such a dividing plate should be made of hard gun-metal or of phosphor bronze, in order to minimise the wear of the holes by the frequent insertion of the stop. By arranging the holes on four or five concentric circles, sufficient room for them is obtained without making their diameter very small, and without making the dividing plate inconveniently large.

17. Cutting Speed and Rate of Feed in Milling Machines.—The beautifully fine and smooth surface obtained by properly conducted milling is the result of using a high cutting speed and an extremely small thickness of shaving. For finishing cuts, a cutter of about 9″ in circumference, or $2\frac{7}{8}$″ in diameter, should be run at about 60 revolutions per minute to cut tough wrought steel, about 80 for wrought-iron, 120 for ordinary cast-iron, and from 140 to 160 for the various qualities of gun-metal and brass. For smaller cutters the rates of revolution are proportionately larger. These rates correspond to the cutting speeds given in the following table :—

Steel	45	feet per minute.
Wrought-iron . . .	60	,, ,,
Cast-iron . . .	90	,, ,,
Gun-metal . . .	105	,, ,,
Brass	120	,, ,,

These speeds are intended for very light finishing cuts. For heavy cuts, the speed must be reduced to about one half these amounts. Ordinarily, the speed cone by which the spindle is driven has just three steps, which may be taken to correspond with the proper speeds for steel, cast-iron, and brass.

The rate of feed in the direction of cutting varies for ordinary work from 40 to 70 revolutions of a four-inch cutter per inch of feed. This, of course, gives shavings of extreme thinness. For example, the circumference of a four-inch cutter being 12½, and there being about five teeth per inch of circumferential length, the number of teeth in the cutter is, say, 62, and the advance in the coarser of the above two-feed motions corresponding to the passage of one cutting tooth over the surface is $\frac{1}{40} \times \frac{1}{62} = \frac{1}{2480}$ of an inch; while that in the finer feed is only $\frac{1}{70} \times \frac{1}{62} = \frac{1}{4340}$ of an inch.

The rate of feed employed always depends on the character of the work done. The power that can be delivered through the belt friction on the cone limits the rate of feed. The maximum possible within this limit is inversely proportional to the length of the cutting edge of each tooth, because the longer this is, the more power is required for the cut.

Again, the rate of feed that may be used depends greatly upon the shape of the piece of material that is being cut, whether this is or is not so shaped as to offer a stiff resistance to the pressure of the cutter upon it. The quicker the feed, the greater is this pressure, and the greater is the tendency of the material to *bend* out of the way of the cutter. If it does bend appreciably, the track cut out by the tool will not be a true reproduction of the shape of the tool. For instance, in cutting teeth of fine pitch on small wheels, the tooth that has been last cut is apt to spring to one side under the tool pressure, if the feed be not very cautiously managed; and this is more especially the case if the material be brass.

The feed must also be regulated according to the state of the cutter. If this be blunt, it cannot cut so fast as if it were freshly sharpened. Also, if some of the cutting teeth do not stand so high as the rest they will not perform so much work as the others, and may even do none at all. This throws more work than their fair share on the others, and the rate of feed must be lessened to suit the capacity of the most severely used of the teeth. Cutters very frequently become injured by careless usage in this way, even when they are originally made quite perfect. The workman often sets them on the mandril slightly eccentrically, so that only one half of the circumference actually does any work, and this side becomes more rapidly worn than the other. The cutter then loses its circular shape, and cannot afterwards be made to cut evenly by re-dressing and sharpening. The maximum of injury of this sort is that of the breakage of a number of the teeth. The cost of making or of re-sharpening and dressing cutters being very considerable, milling wheels are usually used for a long time after they have begun to get broken. The rate of feed possible with them is the less the more they are broken.

18. Sharpening Milling Cutters.—The only satisfactory common method of sharpening the teeth of solid milling cutters is to use the file. To allow of this the cutter needs to be softened in the fire, and this having been done, it ought to be re-turned to give it once more its accurate circular shape. When the teeth have been properly dressed up, it must be re-hardened in oil, or in an admixture of salt and flour in water. The process of re-dressing being thus a long and expensive one, it is extremely important to harden the cutter, so that it will stand the work, and remain in good condition for a long time, and therefore no tempering is resorted to. The process of hardening without tempering, and so as not to produce such great hardness as to cause brittleness, and also and more especially so as to avoid the correct circular shape being destroyed in the process, is a very difficult one, requiring delicate manipulation and much experience. During dipping the cutter should be kept rapidly revolving round its axis.

Mr. George Hookham, of Birmingham, has recently applied Tilghman's sand-blast to the sharpening of milling cutters. The results of his experiments were highly successful, a set of cutters in very bad condition, with many teeth half broken, being re-sharpened to a condition almost as good as when they were new and unused. Each cutter was simply placed loosely on a rod held horizontally a little below the centre of the sand-blast, so that this impinged on the faces of the teeth, and kept the cutter revolving like a small mill. As this process does away with the necessity of softening and re-hardening, it is likely soon to come into general use.

19. Face-plate Chuck with Milling Cutters.—Milling machines are sometimes used with a face-plate of special construction, screwed on the end of the spindle in place of the ordinary circular cutter. In the face of this plate is a series of small square holes, arranged at equal distances round a circle concentric with the plate. In these small holes are placed small cutting tools, all exactly alike and similar in shape to the tools to be afterwards described as used in boring and cutter-bars. A milling face-plate of this sort is shown in Fig. 20. If the work is traversed crosswise, the tools will produce a finely finished plane surface. If the work is not traversed, but simply fed up in the direction of the axis of the cutter-spindle, a circular groove will be cut of the same shape as the tool edge. If the face-plate have different circular series of holes in which the tools may be fixed, circular grooves of corresponding different diameters may be cut. Circular ends of pieces or plates may also by the same means have their outer edges moulded to any desired profile, by shaping the edges of the tools accordingly. The inner edges of annular plates may likewise be moulded in the same way. All the small tools must be shaped exactly alike, and require to be set uniformly with the greatest care, in order that each should stand out from the surface of the face-plate precisely as much as all the others, and thus do its fair share of the cutting.

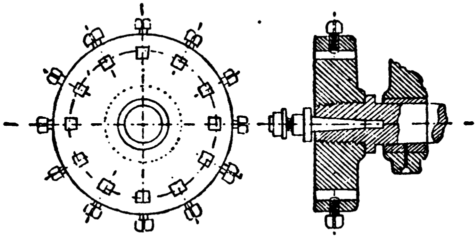

Fig. 20.—Milling Machine Face-plate.

20. Cutting Angles.—The cutting angles of these tools, and of the teeth of the solid circular cutter, may with advantage be made as keen as is possible consistently with the retention of sufficient strength and depth of tool. The angle is from 70° to 80°, and the angle of relief, *i.e.*, the angle between the back of the tooth and the face of the work, about 10°.

21. Traversing Headstocks for Milling Machines.—In many milling machines of large size the work is bolted to immovable tables, while the headstock carrying the cutter-spindle is traversed by a feed apparatus in two rectangular directions over the work.

22. Improved Milling Cutter.—The accompanying woodcut (Fig. 20) shows the special design of milling cutter used by Messrs. Smith and Coventry, the different diagrams giving examples of the various forms it may take. The chief peculiarity is that the pitch of the teeth is much larger than in other designs. This enables the spaces to be made large enough to admit the edge of a thin emery wheel, and thus the teeth can be sharpened by grinding the *faces only.* The shape of the teeth in profile is thus better preserved. The maximum cutting speeds recommended with these cutters are:—Cast-steel, 15 feet per minute; Cast-iron, 18 feet ditto; Wrought-iron, 25 to 80 feet ditto, if well lubricated; Brass, 60 to 80 feet ditto.

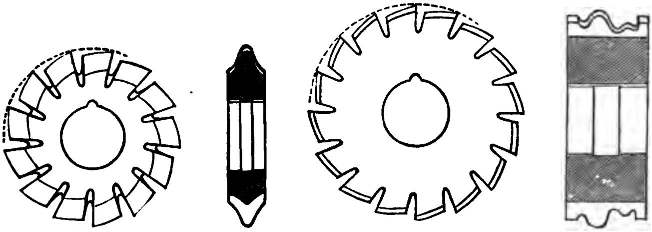

Fig. 20.—Milling Cutter Tools.

CHAPTER V.

PLANING, SHAPING, AND SLOTTING MACHINES.

1. Planing Tools for Metal.—The next simplest class of tools is that of planing tools for metal—a class which is very comprehensive, and the members of which have certain points of resemblance with the later mentioned of the previous class. Planing tools differ from milling tools chiefly in that they work at a much slower rate, take much heavier cuts, require consequently to be much stronger, and, therefore, are nearly always used singly, and not in series as those of the milling machine are. The principal machines included in this class are—Planing machines proper, Shaping machines, and Slotting machines.

Planing machines proper are for comparatively large-sized work, and in them the tool is usually held fixed, while the work is made to move under it in a horizontal direction.

In Shaping machines the work is of smaller size, and the tool performs the cutting stroke while the work is held immovable. The stroke is here also in the horizontal direction.

In the Slotting machines the size of work has the same range as in shaping machines, the tool also makes the cutting stroke, but the stroke is vertical.

2. Fixture of Tool or Work.—The distinction between the fixture and movability of the work and tool, or *vice versâ*, however, is not consistently carried out in any one of these machines. For instance, in the planing machine, while the main cutting stroke is, as abovesaid, performed by the work, both the traversing feed-motion and the feed perpendicular to the cut surface are performed by the tool. On the other hand, in slotting machines these conditions are exactly reversed, the feed-motions being always motions of the work and not of the tool. In shaping machines, in which the main cutting stroke is obtained by a movement of the tool, the feed motions are sometimes given to the table on which the work is fixed, and sometimes to the headstock carrying the tool.

3. **Action of Planing Tools.**—Of these three machines the thickest shavings are obtained from the first, and therefore it is on this machine that one can most readily study the special character of the cutting action of planing tools.

This action is very different from anything that has yet been described.

The first observation that one naturally makes in taking up a shaving from a planing machine is the very high temperature to which it has been raised during the process of being cut off. It becomes so hot that it cannot be held in the fingers immediately after it has been separated. The next fact to be noticed is, that the length of the shaving is very much less than that of the surface. It is quite easily seen, even at first sight, that shortening has taken place, but owing to the shaving being broken up into a great number of small fragments of irregular size and shape, the surprising amount of this shortening is not readily recognised at once. If, however, the small bent, twisted, and curled pieces are each carefully measured, and the length each would occupy if bent straight again calculated; and if these lengths for all the small shavings produced at one stroke of the machine be added up, and their sum compared with the length of the metal surface which they covered before removal, the great difference cannot fail to astonish any one who has not before made a similar exact comparison. In the case of some rolled bar iron that was examined in this way, the author found that the length of the shavings was sometimes less than half that of the uncut surface.

The whole of this shortening is not due to simple compression of the material in the direction of the stroke. A large portion of it, however, is due to this, and it is readily perceived that the form of the tool is such as to lead to the greatest amount of compression that the material will stand before giving way altogether by crushing. In order to support without breakage or injury the severe stress that is put upon it, the tool point needs to be made very strong. This means that the angle between its front and back surfaces, the line of intersection of which forms the actual cutting edge, must be made large. Since the back surface must stand clear of the material to be cut, the front surface is unavoidably perpendicular, or almost so, to the direction of the cutting motion. This is the surface which exerts the force that removes the shaving, and it is evident that it cannot, being at right angles to the plane of division, exert any appreciable pressure that tends *directly* to *lift* the shaving upwards from the cut surface, that is, to *tear* it off by direct tension perpendicular to that surface. The force it exerts is wholly, or nearly wholly, parallel to this surface, and the result is that the material of the shaving about to be separated is simply shoved forwards. This results in its very severe compression in this direction. As it is pushed forwards, it is compelled to slide over the layer lying immediately underneath, from which it is thus separated by *shearing* and not by *tensive* tearing. But so far this action would result in a mere accumulation of material heaped up in front of the advancing tool. The amount of this accumulation, before a regular shaving is formed and broken off, varies with the kind of material operated upon, being greater the softer and more ductile that material is. The mode by which this crushed layer is raised up and thrown to one side has still to be explained. The material immediately in front of the tool is stressed in all directions, and on the different planes or sections that may be imagined lying at different inclinations to the face of the tool, there exist stresses of different intensities and of different kinds. On sections parallel to the tool face the stress is wholly compression, and there is a greater intensity of compression on these sections than on any others. On sections parallel to the cut surface, on the other hand, the stress is wholly shear, and it is on these sections that occurs the maximum shearing stress. On other sections inclined to these two, and lying in the right angle between them, the stress is of a mixed character, being partly shear and partly compression. The intensity of neither shear nor compression is so great on any of such sections as on the first-mentioned rectangular surfaces, but their combination is such that at some inclinations the strength of the material to cohere together is more severely taxed than at either of these two latter where the compression and shear exist separately and singly. At one certain inclination the tax on the strength of the material reaches a maximum, and, of course, it is along this surface that the actual rent or destructive crippling of the shaving takes place. This extends diagonally upwards and forwards from the under to the upper side of the shaving. The small part of the shaving being formed in front of the tool is forced to slide up this inclined section of most complete disablement. It is thus made to ride on the top of the material in front of it, and is forced out of the way of the advancing tool. If the material be very ductile, no actual visible rent may take place, the metal being only excessively stretched in the immediate neighbourhood of the above-mentioned section.

The angle at which this plane of collapse, as it might be termed, is formed must evidently depend on the ratio of the shearing and compressive stresses on the two principal sections; and this ratio depends again on the relative ultimate shearing and compressive strengths of the material.

For the removal of the shaving it is not absolutely necessary for distinct separation to occur along the inclined sections. The absolutely necessary shear is confined to the horizontal surface which is the path of the tool edge. This latter shear progresses continuously from point to point, but on the former sections the splitting is intermittent, the split surfaces being at short irregular distances from each other, and the material between them being merely twisted severely but not actually rent.

Fig. 21 represents the result of this action. The dotted horizontal line shows the line along which the tool edge is about to advance. The ragged lines across the shaving represent the inclined surfaces along which splitting has taken place. In the position shown one of these splits has just occurred along the line *bb′*. This may not be a perfect split; that is, the shaving may not actually break off along this line, but may adhere by a few of its still unbroken fibres to the material lying to the right hand, out of which the continuation of the shaving will be formed. But, although not actually broken off, the material is so crippled that the cohesion along the line *bb′* is very feeble, and as the tool advances further, the layer *aa′b′b* offers little resistance to the tool, and is pushed forward along with the rest of the shaving above it, without dragging along with it any of the material immediately underneath and to the right hand of the line *bb′*. The point *b′* thus becomes pushed above the still undisturbed surface at the extremity of the line *cc′*. Just before the split along *bb′* took place, the pres-

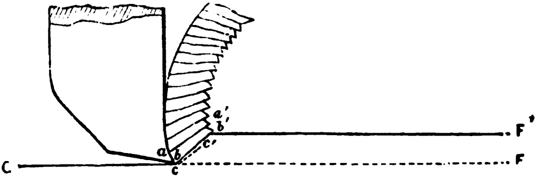

Fig. 21.

sure of the tool was transmitted upwards from the small surface ab of application along the layer $abb'a'$ in such a way that it was fairly distributed along the line bb' and spent in producing shear along this line. Just after the crack has occurred, there being no longer any appreciable shearing resistance along this line, the whole effort of the tool becomes concentrated at the point c. It produces shear for a minute distance along the line c F, and severe compression on all the material in the neighbourhood of the point c, and along all the lines lying within the angle $c'c$F, or rather within the space $b'bc$F. This material is bound by cohesion to that lying below the line cF, and this bond is not overcome until some portion of the surface cF is actually shorn through. Thus the metal close in front of c being pushed forward, drags forward along with it the metal immediately below it. If this continue long before the dragging force is destroyed by the shearing through of the first part of cF, it is evident that a small perpendicular crack would appear underneath the tool in the cut surface, which of course it is desired to leave as smooth and free from flaws as possible. Such cracks do actually appear if it is attempted to plane across the laminæ of rolled plates of inferior quality where the laminæ have not been well welded together. This cracking, if it occur, or tendency to cracking, is evidently the result of *tension* across vertical sections perpendicular to the cutting stroke. If the shearing strength along cF, that is, along horizontal sections in the direction of the cut, be less than the above tensive strength,* these vertical cracks will not appear. The tendency for them to appear increases with the thickness of the shaving, and decreases with the sharpness and keenness of the tool.

The latter tendency can be easily understood. The

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* Or, more properly, if the ratio of the former to the latter strength is below a certain magnitude, which may be made the object of mathematical calculation, but which it is unnecessary to investigate in a book of the present elementary character.

break along *bb′* having just occurred, and the surface *ab*, therefore, no longer offering any resistance to the motion of the tool, the whole resistance is that offered by the very small surface *bc*. This surface at the first instant is very minute, and gradually increases in extent until the next break occurs. The intensity of the resistance offered per unit of area cannot be greater than the crushing strength of the material; and, therefore, the whole area being very small, the total force exerted by the tool must be correspondingly small at the first instant after *bb′* has been broken. This small force is partly transmitted along the line *cc′*, but only a fraction of it goes in this direction, because it spreads out in all directions radially from *c*. A very short crack may be caused along *cc′*, but it cannot extend far, because at only a minute distance along *cc′* the force is wholly exhausted in producing shear on this section. Thus at this time no part of the force finds its way as far on the line *cc′* as the upper surface near *b′*. This, therefore, remains undisturbed in shape or in position, and the point *b′* of the previous layer of the shaving rises above it so as to produce the ragged upper surface that is observed on these shavings. At the same time it is to be noted that the layer *bcc′* is severely crushed in the direction *cc′* in the neighbourhood of *bc*, and that the intensity of this compression diminishes as the distance from *bc* towards *b′* increases. This crushing is naturally associated with bulging in the transverse direction, that is, in the direction of the line *cba*. The bulging, or extension, in this direction diminishes gradually from a maximum at the tool side *abc* of the shaving to zero at the upper side *a′b′*. Now the result of stretching one surface of a bar while the opposite one is kept at its original length is to *bend* the bar. This is the cause of the shaving curling up.

As the tool progresses, the surface *bc* on which it presses becomes larger, the force exerted increases, the thickness of the layer *bc* becomes greater, so that this layer has greater strength to transmit the force forward towards the upper side of the shaving, the transmission of the force reaches farther in this direction, and the strain on the metal near the upper side becomes greater and greater. Still, as the force is generated at *bc*, and is expended gradually in producing shearing strain along the surface *cc′*, the compression is always greatest at the face of the tool, and always diminishes to zero near the point *b′*. The shearing strain close to the point *c* on the plane *cc′* is developed to its full extent almost instantly after the breakage along *bb′*; it then extends gradually to successively higher points on the line *cc′*, until it reaches the outside of the metal; but at this point it never reaches nearly so great an intensity as it does at the base of this same line, and the intensity diminishes gradually from the base to the outer extremity of it. The severity of the shearing stress is measured with, at any rate, some approach to accuracy, by the angle through which the material becomes twisted.* Now the line *bc* originally lay along the line G*c*. Thus the angle between *cc′* and *cb*, or between *bb′* and *ba* was, before the cut was taken, equal to G*cc′*, and has now been reduced to *acc′*. The whole of the material lying on that side of the shaving next the tool is twisted through this large angle. The amount of twist suffered on the other side is comparatively small, as may be recognised by observing the points of the ragged edges on this side. The angle of these edges is not much greater than what was probably the original angle between the upper surface *b′*F′ and *b′b*, or, what is the same thing, the angle *c′c*F. The average twist throughout the thickness of the shaving may, therefore, be taken roughly as equal to half the angle G*ca*. The power expended in performing this twist forms a large portion of that required to drive the tool for-

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* This is the correct measure of the strain, and according to Hooke's law, *Ut Tensis sic Vis*, the stress is proportional to the strain. This law, however, is approximately accurate only for very small strain, while the strains dealt with above are very large: are, in fact, the ultimate strains the material is capable of standing without breakage.

ward, and another large portion is that absorbed in producing the compression already explained. It is to be noticed that both of these amounts of work are done upon the under layer of the shaving along the line *c*F, and are absorbed in altering its shape and density, and that comparatively little is similarly spent in the upper layer along the line *b*′F′. It is this absorption of energy that produces the great rise of temperature, and, therefore, we find that this under surface of the shaving is very much hotter than the other, the latter being heated chiefly by conduction from the former.

The amount of shearing work to be done is evidently less the smaller is the angle G*ca*, that is, the keener the tool is. Also, since the shearing and the compressive stress decrease from a definite maximum at one side to zero or nearly zero at the other, and since the work done is proportional conjointly to the intensity of the stress and the quantity of metal stressed, it is easy to see that more power is needed the greater is the thickness of the shaving. It does not follow that it is in simple proportion either to the angle G*ca*, or to the depth of cut. The ratio of increase with these quantities can only be satisfactorily determined by actual experiment. This has not as yet been done for planing tools for metal, but in a later chapter will be given the results of a long series of experiments made by the author to determine these points for turning tools. Planing tools have a very similar action, but it is impossible to say that the laws of variation are exactly the same in the two cases.

4. Friction between Shaving and Tool.—One other source of expenditure of power in the process of cutting is the friction between the shaving and the face of the tool resisting the motion of the former as it slides up the latter. The speed with which the sliding takes place is less than the cutting speed, in the same ratio as the shaving is shorter than the planed surface. This ratio depends on the angle *c*′*c*F. The outer ragged side of the shaving is, as has already been said, very little compressed in the direction bb', and very little, if at all, bulged out transversely to this direction. The material is here comparatively unstrained, although it has more appearance of being crushed and torn than at any other part of the shaving. It is very nearly in its original condition. The ratio of the length of this side of the shaving to the length on the line $b'\mathrm{F}'$, along which it lay before being lifted by the tool, is therefore simply the ratio of the thickness of the layer $a'b'$ to the corresponding length along $b'\mathrm{F}'$. This ratio is that of the line $b'c''$ to $b'c'$ in Fig 22, where $b'c''$ is drawn parallel to the face of the tool ab. The angle $b'c'c''$ equals $b'b\mathrm{F}$, and the angle $b'c''c'$ equals abb', which is 180° minus the sum of $b'b\mathrm{F}$ and $ab\mathrm{G}$. Since the sides $b'c''$ and $b'c'$ are proportional to the sines of the angles opposite them in the triangle $b'c'c''$, and since $\sin [180° - (b'b\mathrm{F} + ab\mathrm{G})] = \sin\ (b'b\mathrm{F} + ab\mathrm{G})$, we find that the ragged side of the shaving is shorter than the planed surface in the ratio

$$\frac{\sin b'b\mathrm{F}}{\sin (b'b\mathrm{F}+ab\mathrm{G})}$$

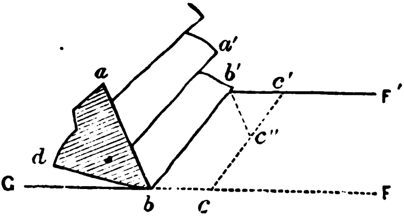

Fig. 22.

The inclination of $b'b$ depends on the stiffness of the metal being cut, and on the direction of the thrust of the tool, and this direction depends on the inclination of ab. Thus the above ratio depends wholly upon the stiffness of the metal, and on the shape given to the tool.

The thrust of the tool is not at right angles to the face of the tool, but is inclined to this face at the angle whose tangent is the coefficient of friction between the tool and the shaving. This tangent probably varies from $\frac{1}{10}$ to $\frac{4}{10}$ according to the lubrication that is applied. If the lubrication is not good, then unless the angle $ab\text{G}$ is made much less than 90°, it is probable that the direct thrust of the tool will actually press the shaving downwards instead of helping to lift it up. Tan $23° = \frac{4}{10}$, so that if this were the frictional coefficient, the angle of the tool-face, namely $\text{G}ba$, could not be more than $90° - 23° = 67°$ in order that the tool-thrust should not be directed downwards, *i.e.*, below the horizontal line. 60° is a commonly used angle for the edges of tools for wrought iron, and as 6° or 7° is ample for the angle of relief, *i.e.*, between the line $\text{G}b$ and the under surface of the tool, it is probable that in these planing tools the thrust is nearly horizontal if no lubricant be used.

If, however, the friction be reduced to a minimum by injecting a lubricant between the shaving and the tool-face, the thrust of the tool may with sufficient accuracy be calculated as the requisite horizontal thrust divided by the sine of the angle $ab\text{G}$. If P represent the required horizontal thrust, and f be the coefficient of friction, then the whole friction on the tool face will be

$$\frac{f\text{P}}{\sin ab\text{G}}$$

The amount of work done in overcoming this friction during the advance of the tool through unit length is thus:

$$\frac{f \sin b'b\text{F}}{\sin ab\text{G} \sin (b'b\text{F} + ab\text{G})} \text{P}$$

The whole work done in the same time is P, and the ratio of the work lost in friction to the whole work is

$$\frac{f \sin b'b\text{F}}{\sin ab\text{G} \sin (b'b\text{F} + ab\text{G})}$$

In order to make this friction as small as possible, it is advisable in the first place to make f small, of course, and secondly to make angle $b'bF$ small, and angle abG large. But it must be remembered that the above formula is only approximately true so long as f is small, and that by making abG large we may make P large, that is, increase the whole work done, although at the same time diminishing the proportion of it spent in friction.

As an example, take the case already cited, in which the angle abG was about 80°, and the shaving only half as long as the planed surface. This would correspond to an angle $b'bF$ about 28°, or rather less than 30°; and the fraction

$$\frac{\sin b'bF}{\sin abG \sin (b'bF+abG)} = \cdot 507.$$

The coefficient of friction was in this case probably about $\frac{3}{10}$, so that the work done on friction would be a little more than 15 per cent of the usefully applied work.

5. Lubrication and Cooling.—The importance of diminishing as far as possible the friction is not confined to a direct saving of power. A large proportion of the heat generated in the cutting operation is due to the friction, and the consequent rise of temperature not only destroys the temper of the tool (if, at any rate, it is allowed to rise to excess) but it also makes the metal more difficult to cut. The tool gets rapidly blunted, and soon requires greatly increased power to drive it beyond what is needed while its edge is still keen.

Recently experiments have been made with great success on the effect of making a jet of soapy water impinge at a high velocity (produced by high pressure in the supply pipe) upon the point of the tool, and directed from behind the tool forwards to the point. The effect was that a very much faster rate of cutting was found possible without dulling the tool-edge than had ever been attained before. In ordinary lubrication, with the liquid falling in front of the tool, there is little or no chance of the lubricant ever reaching the cutting edge, because the shaving closely pressed down on the tool-face is moving in the opposite direction to that in which it is endeavoured to introduce the fluid. It can thus be effective only as a *cooling* agent, and not really as a lubricant. When, however, it is injected with considerable force from behind, there is in the first place no obstacle whatever to its reaching the cutting point, and once there it seems to be carried up the tool-face along with the shaving which is in course of formation.

6. Angles of Tool-edge.—The greater the angle of the tool-edge, the larger is the amount of power spent in breaking the shaving in fragments; the smaller this angle is made, the larger the power spent in friction. At a certain angle, which for all materials is found to be between 50° and 80°, the thrust becomes a minimum. According to numerous experiments made by the German, Hart, the angle *ab*G should be 54° for wrought iron, 55° for cast iron, and 66° for gun-metal; and the same authority gives for the angle of relief *db*G 3° for wrought iron, 4° for cast iron, and 3° for gun-metal. Hart also says that the same angles are best for all depths of cut and for all qualities of tool-steel.

These angles are from 5° to 10° less than are commonly used in England, and for very heavy cuts on the planing machine still larger angles are considered advantageous. The larger angles are employed in order to give greater strength to the tool, and to prevent the edge becoming so rapidly dulled as it would be with the above keenness.

It very considerably improves the cutting power of a tool for metal to rub the edge smooth upon any ordinary hone after grinding it. If an emery-wheel is used for grinding tools, it is very important to have a constant stream of water over it, otherwise it is extremely difficult to avoid taking the temper out of the ground edge.

It is not simply the bottom front edge of the tool that cuts. A most important part of the cutting is done at the *side* of the tool. This is easily seen from Fig 23, which represents the face of the point of a planing tool and the cross-section of the work.

The dotted line shows the cross-section of the shaving being removed. All round the cutting edge, both on its horizontal and on its nearly vertical parts, the hinder surface of the tool should slope away at an angle of 3° or 4° from the cut surface. Thus, if the point were a true circular arc, as seen in the front view, Fig. 22, the back ought to be part of a true cone. The front also ought to be hollowed out to a true conical shape. It would, of course, be impracticable to do this all round on both right and left hand, but as the tool cuts only on one side, it is unnecessary to do it on more than the horizontal lower edge and on the one vertical cutting side. It is impossible with ordinary or simple grinding apparatus to produce the desired *true* hollow conical surface, but it is not difficult to produce a sufficient approximation to it.

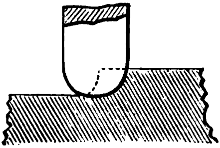

Fig. 23.

Considering, however, that an accurate approximation to uniformity of cutting angle all round the cutting-edge is quite unattainable by any ordinary or possible means at the disposal of a workman in an engineering establishment, it is not a little remarkable that the best cutting angles for different materials should have been discussed so keenly as they have been, and that authors and experimenters should be so positive in stating to a single degree what is the best angle, without even mentioning whether they refer to the angle at the bottom of the tool or to that at the side. The tools that are commonly used, and presumably have been used in these experiments, are *flat* faced, and in this case not even a rough approximation to equality between the angles at different points of the cutting edge is mathematically possible.

For broad finishing cuts the formation of the lower part of the edge is of most importance. For medium cuts every part is of equal importance, and for heavy cuts the side of the tool is of very considerably greater importance than the other, because the greater part of the length of the cut as seen in cross-section lies at the side and because the bending of the shaving takes place more nearly perpendicularly to the side portion of the cut surface than to the horizontal portion.

7. Tool-holders.—The tools that have been most commonly used until now are solid square bars of steel, the lower end being forged to the desired shape and ground. These are fastened by one or two set-screws in the front part of the tool-box, an example of which is shown in Fig. 24, A B, the arrangement in this instance being suitable for a planing machine of large size.

For such solid tools have recently been substituted to a large extent tools made of small pieces of steel inserted in what is called a *tool-holder*. Of these there is a great variety of patterns, some of which will be noticed in a later chapter in connection with lathes. Of those suitable for planing machines, the best seems to be that shown in Fig. 25. A small flat piece of steel, of tapered section, of about $1\frac{1}{4}''$ in depth and of $\frac{1}{4}''$ thickness at the bottom and $\frac{9}{16}$ at the top, is inserted in a groove of the same shape at the bottom of the wrought-iron bar of square section, which is the *holder*. This tool-steel of tapered section is now very largely manufactured for machine-tool purposes, and can be got of excellent quality. The groove is made slightly larger than the size of the steel, so as to allow for small irregularities in the size of the latter. The steel is set forward to the desired position by means of the set-screw *a;* which also takes the thrust of the cut. It is also clamped firmly sidewise in the groove by means of the set-screw *b*. As the steel is shortened by re-grinding, its edge is maintained in the same position by advancing *a*. In the diagram the edge is shown considerably in advance of the vertical centre-line of the shank of the holder. For some classes of work, where there is danger of the tool springing into the cut, this would be disadvantageous, but it can be simply avoided by using a shorter piece of steel than that shown, and setting it farther back in the groove, the front lower corners of the holder at the sides of the groove being cut away, so as to leave the face of the cutting tool free for the ascent of the shaving.

The advantages of these tool-holders are evident. In the first place, a very large unnecessary expenditure of costly tool-steel in the formation of the shank is avoided, the whole holder being of forged wrought iron. Secondly, the tool point can be removed for re-grinding with much greater ease and rapidity; and thirdly, this small piece of steel can be treated on the grindstone or emery wheel with far greater facility and exactitude than a large and clumsy piece. There is also the very important advantage that there is no forging, re-hardening, and re-tempering required with this style of tool. The steel of tapered section is supplied to the workshops in long bars. Short pieces are obtained from the bar simply by nicking and breaking off cold. These pieces are then ground, hardened, and tempered. If carefully used, they need never be again tempered until the time when they

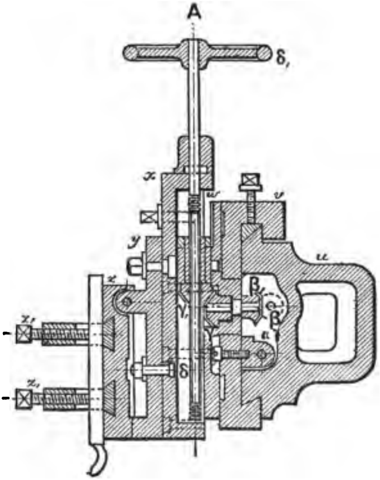

Fig. 24A.—Vertical Section of Planing Machine Tool-box.

have been so often re-ground for sharpening that they have become too short to be of further use. The tempering of such small pieces is also much more easily and accurately performed than is that of the points of long bar-tools.

8. **Tool-box.**—In Fig. 24 the binding straps *z,z,* are tightly dove-tailed into the front of the tool-box. Each contains one clamping screw. In Fig. 28, page 95, which shows a similar tool-box for a shaping machine, the only modification of this part is that the screws, instead of passing through separate binding straps, penetrate a projection cast on the front piece of the tool-box.

This front piece, marked *z*, is hinged on a long horizontal bolt seen clearly in the sectional plan B, Fig. 24. It swings loosely on this hinge, so that the tool-point may be drawn forwards, although it cannot be pushed farther back than is shown in the figure. The object of this is to allow the point to be slightly raised during the back stroke when no cutting is being done, so as to press only lightly against the surface. If it were kept rigidly down against the metal while going backwards, the rubbing action would slightly bend over and dull the cutting edge. Even with the above hinge arrangement, the rubbing that still takes place under the pressure caused by the weight of the tool and the swing flap in which it is screwed is injurious to the edge, and some tool-makers put a balance-weight on this flap, which has the effect of tilting it up during the back stroke, so as to entirely clear the tool edge of the work, while the resistance to the cut brings it down to its proper cutting position during the forward stroke. The tool edge must be prevented by a stop from being raised by the balance-weight to a greater height above the surface than the depth of the cut, otherwise it would not catch the metal at the beginning of the new cut in its forward motion.

The plate *y* to which *z* is hinged rests on the front vertical face of the plate *x*. It is fastened thereto by two bolts seen in the vertical section. The lower bolt forms an axis round which the whole plate *y* can be swivelled in front of *x* through a certain limited angle. This is possible in consequence of the upper bolt passing through a circular slot whose centre coincides with the lower bolt. By tightening the upper bolt the plate may be fixed in any desired position. The object of this circular motion is to make it possible to throw the tool-point to one side of the tool-box so that no part of this latter will interfere with the planing of vertical faces on the work. If the tool-point were not thrown to one side in this way, then the top edge of the vertical face on the work to be planed could not be higher than the bottom edge of the tool-box.

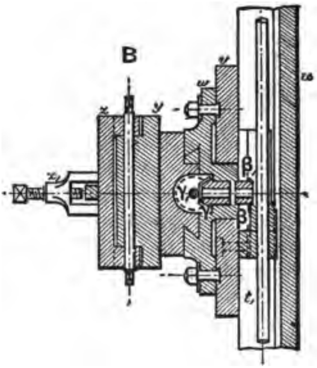

Fig. 24B.—Horizontal Section of Planing Machine Tool-box.

There passes vertically through the plate *x* a spindle, δ, screwed with a square thread, and having on its upper end a hand-wheel, $\delta_{,,}$ by which it can be turned. This screw gears in a gun-metal nut which has bearings on the plate *w* which prevent it (the nut) moving along *w* in the direction of the screw. These bearings, however, allow the nut to rotate, and at its lower end there is formed on the nut a small mitre-wheel, γ. This gears along with the similar mitre-wheel $\gamma_{,,}$ fixed on a horizontal freely-rotating bolt at the other end of which gears the other pair of similar mitre-wheels, β_1 and β. This last, β, slides along a horizontal shaft extending to the side of the planing machine, and is forced to rotate along with this shaft by having a feather sliding in a groove cut on the shaft throughout its whole length. If this shaft does not turn, the nut on the screwed spindle δ cannot turn, and if the spindle be then turned by hand by means of the wheel at its upper end, the spindle will rise in front of the plate *w*, and will, by means of the collar near the top of it, lift *x*, *y* and *z* and the tool along with it. In this motion, the plate *x* is guided rectilinearly by a straight dovetailed groove with internal wedge-shaped packing-strips. If, on the other hand, the hand-wheel be held steady and prevented from turning, then by turning the long grooved shaft from the side of the machine the gun-metal nut will be turned, and the result will be, as before, to raise the whole front portion of the tool-box. This latter mechanism is worked mechanically by a ratchet-wheel and pawl, moved once for each stroke of the machine, so as to give a self-acting feed to the tool in the vertical direction.

The small horizontal pin on which the mitre-wheels γ and β_1 are fixed, rotates inside another pin of large diameter and concentric with it. This larger pin forms part of the casting of the circular plate *w*, and it fits in a round hole in the rectangular plate *v*. Round this pin the former plate may rotate in face of the latter one. It is fastened in any desired position by the four clamping T-headed bolts, two of which are shown in the horizontal section. The slide plate *x* with its feed-spindle δ can, therefore, be fixed at any inclination to the vertical, so that the feed may be in the proper direction to plane any oblique surface on the work.

Finally, the rectangular plate *v* slides horizontally on the plane front surface of the hollow beam *u*, the cross-section of which is seen in the vertical section of Fig. 24, and again to a smaller scale on Fig. 26, Plate II. This beam stretches transversely over the table from side to side of the planing machine, so that the tool-box may be brought into any transverse position over the table. The sliding motion to effect this is actuated by a long horizontal screw, α, lying in the hollow face of the beam, and directly underneath the grooved shaft that drives the before-mentioned mitre-wheels. This transverse feed-motion-screw is worked at its one end by a ratchet and pawl which is made to have one throw per stroke of the machine, and the extent of which throw, *i.e.*, the number of ratchet-teeth moved over by the pawl, and consequently the fraction of a turn made by the feed-screw, is regulated by the point of attachment on the slotted pawl-lever of the connecting-link which works it.

The tool-box for a shaping maching, or for a small sized planing machine, as shown in Fig. 28, is arranged on precisely the same principles, and differs only from that already described in its having fewer adjustments, and therefore consisting of fewer parts, and being throughout much simpler in construction.

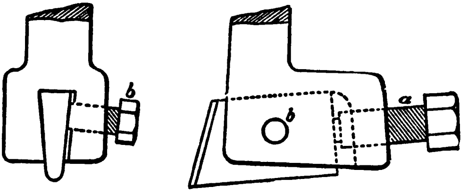

Fig. 25.

9. Quick Return Motion in Planing Machines.—In all planing machines proper the tool is kept fixed during the stroke, and the work is moved underneath it. This movement is a back and forward oscillatory one, and in the common form of the machine cutting is done during one half of the oscillation. The speed of cutting being from 15 to 20 feet per minute only, each half oscillation occupies a considerable fraction of a minute; and as the time occupied by the back-stroke is wasted, this back-stroke is made to take place at a threefold or fourfold faster rate than that of the cutting stroke. The means by which this is managed may be seen in Fig. 26. This shows (A) a longitudinal section, and (B) a vertical cross-section, of a planing machine, with a maximum stroke of 3 metres (10 feet) capable of planing a surface 1 metre (3 feet 4″) wide on a piece of a maximum depth of 1 metre.

The table on which the work is bolted is marked *c*. The surface of this is perforated with a large number of rectangular holes, through which the clamping-bolts for the work are passed. This table has two long ridge-like feet stretching its whole length, and by these it rests in two v-shaped grooves formed in the top of the bed-plate. Along these grooves the table slides, being actuated by the spur-pinion *i* gearing in the toothed rack, *k*, which is screwed to the under side of the table. The pinion *i* is keyed on a transverse horizontal shaft, on the outer end of which is also keyed a larger spur-wheel, *h*. This wheel gears into two different pinions g_1 and *g* on different centres. The first g_1 drives the wheel *h* during the backward non-cutting stroke. It is either keyed or cast on the end of a long hollow boss, that runs loose on the shaft upon which the three pulleys d d_1 d_{11} are mounted. This boss is in one piece with the nearest of these three pulleys d_1. The driving belt runs over these pulleys, and is shifted from one to another by means of a fork moved by a rod and bell-crank lever, actuated by stops bolted to the under side of the edge of the table. These stops can be bolted in any desired positions, to suit the stroke that is needed for the particular work to be performed. At each end of the stroke the bell-crank lever is struck and thrown through a certain angle by one or other of these stops, and this movement throws the driving belt from the pulley d_1 over the pulley d_{11} (which runs also loose on the shaft) on to the pulley *d*, or *vice versa.* When the belt is on d_1 it drives the table through g_1 *h*, *i* and *k*. When, during the cutting stroke, the belt is on *d*, its motion is transmitted to the table by a much more circuitous route. This pulley is keyed on the shaft which passes through the hollow boss of d_1 and

g_1, and runs transversely under the table to the opposite side of the machine. About the centre of the machine there is keyed on this shaft a pinion *e*, that gears into a wheel *f*, keyed on a third shaft lying a little lower down. This third shaft passes towards the pulleys to the outside of the machine, and has keyed on its end the pinion *g*, which has already been mentioned as one of the two pinions gearing with the wheel *h*. By this roundabout method, with two reductions of speed at the pair of wheels *e* and *f*, and at the pair *g* and *h*, the motion and power are transmitted to the table on which the work is bolted. The number of teeth in the wheel *f* is thrice that in the pinion *e* in the special example in Fig. 26, and the pinions g_1 *g* are of the same size, so that the back-stroke takes place at a speed thrice faster than the forward stroke.

10. Acceleration of Momentum at Beginning of Stroke.—The table and the work upon it together having a very considerable weight, they possess a large amount of momentum even at the slow rate of 17 feet per minute, and cannot, therefore, be reversed in their motion quite suddenly. It is partly in order to allow a brief interval of time to elapse between the instant at which the driving force applied by the belt is taken off the pulley d_1 which moves the table backwards, and the instant at which the same force is applied to the pulley *d* which moves it in the reverse direction, that the loose pulley d_{11} is placed between them. Also, when it is desired that the machine should stand still while the counter-shaft is running, the fork is so placed as to keep the belt upon the loose pulley.

No mass can attain even a small velocity quite instantaneously, and in this case we have a very large mass, which therefore requires two or three seconds to acquire the full velocity of the stroke, even when urged to it by the full power that the belt is able to exert through the friction between it and the surface of the pulley. At the begining of the stroke, therefore, (whether backward or forward) the belt slips a little, and there is a gradual quickening of the speed of the table as the slipping of the belt becomes less and less. Also, during these first instants, all the driving power is used up in producing this acceleration of velocity. There is none left for cutting the material. It is thus needful to make the stroke of the table several inches longer than the length of cut desired, and the stops must be adjusted so as to give this extra length of stroke.

11. Reversible Tool-holders.—Even with the above arrangement for quickening the speed of the non-cutting stroke, there is still, of course, a large portion of the time of the machine unproductively spent. In order to do away with this objection, Sir Joseph Whitworth has for many years past constructed his planing-machine tool-boxes so that at the end of each stroke the tool is turned through two right angles round a vertical axis, and is thus thrown into position to cut on the succeeding stroke in either direction. The tool is clamped in a vertical cylindrical tool-holder, which revolves inside a hollow cylinder made to fit it on the front of the tool-box. Cords attached to the tool-holder and passing over pulleys, actuated by the stops in a similar manner to that in which they shift the fork, reverse the tool. The table is made to move at the same speed in both directions. This arrangement, however, although introduced and approved by the most celebrated tool-maker in the world, has never come into extensive use, and in fact there are inconveniences about it which make the workmen very averse to use it.

Another system of reversible tools recently introduced is more likely to be found practically advantageous. In this there is, as in the common system, a hinged flap-plate on the front of the tool-box, in which the tool is clamped. The tool is made with two oppositely directed and exactly similar edges, the bottom surface of the tool joining these edges being at right angles to the centre-line of the tool-holder, so that when this centre-line hangs vertically the two edges are exactly on the same level. On one stroke the tool swings backwards from this vertical position through an angle equal to the proper angle of relief for the under surface of the tool-edge, that is, through 3° or 4°. It is prevented from swinging farther than this exact amount by abutting against the bearing surface provided on the rigid part of the tool-box. On the opposite stroke it swings to the opposite side of the vertical to an angle of the same amount, and is there supported by a similar abutment facing the former one. In this simple way, the tool, actuated by the resistance to the cut itself, is automatically brought at the beginning of each stroke into the correct position for cutting in the direction of that stroke. Fig. 27 shows a tool-holder constructed on the same principle as that of Fig. 24, but modified to provide the two opposite cutting edges. An obvious objection to this method is, that both the cutting edges must necessarily lie in front of the point of suspension at the hinge and still more in advance of the point of abutment on the tool-box. If the tool-box and tool-holder be made sufficiently rigid, however, this is not a serious objection for most classes of work.

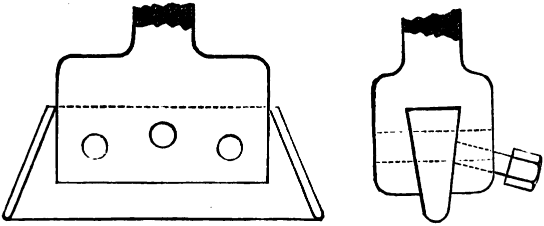

Fig. 27.

If instead of the tapered section of tool-steel a parallel-sided section were used, then the tool-holder might be fixed rigidly, and the requisite rocking motion of the tool in reversing its direction of cutting might take place round the central pin jointing it to the bottom of the bar-holder. In this case the bottom of the groove in which the steel is inserted would be bevelled 3° or 4° on each side of the central pin, and the whole horizontal thrust on the tool would be transmitted through this pin. To preserve steadiness, it would also be necessary that the vertical sides of the groove should be planed out accurately parallel, and that the tool-steel should be ground accurately parallel and to fit the groove.

The objection to this and the previous arrangement for a back cutting stroke is, that it is troublesome to grind the two cutting edges of the tool so that the forward and backward cuts will be of precisely the same depth. If these two edges are not exactly at the same distance from the point of suspension, or not at exactly equal distances to right and left of the vertical line through the above point when the tool is pressed against its abutment on the one side and the other, the two cuts will not be accurately of the same depth.

12. Systems of Driving Planing Machines.—As above mentioned, the ordinary system of driving planing machines is through a pinion gearing into a rack screwed to the under side of the table. Each pair of teeth in the pinion and the rack first comes into contact near the point of the rack tooth. The point of contact gradually slides from this point up to near the root of the rack tooth. The pressure exerted between the two surfaces therefore varies slightly in direction, at first having a vertical upward component, and at last being wholly horizontal or nearly so. This produces a minute irregularity in the planed surface, because of the driving force being variable both in amount and in direction. The vertical component at first contact between each pair of teeth relieves a part of the bearing pressure on the guide grooves, and in consequence of the unavoidable elasticity of materials of construction, this has the effect of lifting the table to a minute degree. To avoid the small imperfections due to these causes in the plane surfaces produced, Sir Joseph Whitworth has endeavoured to obtain a continuously steady driving force by discarding the rack and pinion, and substituting for them a screw and nut. The nut is fixed to the under side of the table at the middle of its length.

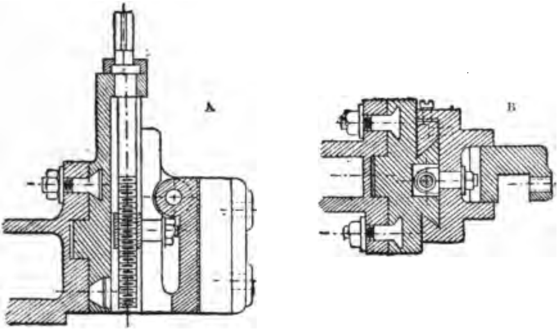

Fig. 28.—Vertical (A) and Horizontal (B) Sections of Shaping Machine Tool-box.

The long leading screw lies along the centre line of the machine in plan, and stretches the whole length of the maximum desired stroke. This construction is much more expensive than the rack and pinion. Sellars, of Philadelphia, the excellence of whose machine-tools is hardly surpassed by those of any other maker, has adopted a combination of a rack and a screw. His screw shaft lies diagonally underneath the table, and a small portion in the centre of its length only is screwed. A rack is screwed as usual to the bottom of the table along the longitudinal centre line. The teeth of this rack are slightly oblique, like those of a worm-wheel. The degree of obliquity is such that at the touching point between the tooth rack and the screw-thread the two surfaces lie in the same direction. It would be as easy to produce this coincidence of the touching surfaces with the teeth perpendicular to the length of the rack. But owing to the friction between these surfaces, the pressure between them is not perpendicular to them, but inclined at a small angle to that perpendicular direction. The obliquity of the teeth is so chosen that the effect of the friction is to make the driving effort be directed approximately in the direction of motion during the cutting stroke. On the return stroke no cutting is performed, only small pressure is exerted, and it is not of great consequence whether it is much oblique to the motion or not. In this arrangement the expense of a long leading screw of large diameter is avoided, and the design is certainly ingenious, but it is difficult to admit that it possesses advantages that make it superior to that of the ordinary rack and pinion. A peculiarity of the gearing is, that the point of contact between the worm-thread and the rack-teeth moves to and fro from side to side of the rack with an oscillatory motion.

13. Shaping Machines.—When the surface to be planed is short, and the piece of work of which it forms a part is of small size, a shaping machine is used in preference to a planing machine. In this the tool is driven forwards and backwards the length of the cutting stroke, while the work is fixed. Fig. 29 shows a side-view of one so designed. The tool-holder forms the outer end of a ram of rectangular section, which slides in a massive guide-box of the same internal section. In a very common form of the machine this ram is driven by a short connecting-rod from a disc crank keyed on a shaft at the back of the machine. On this shaft is the cone pulley upon which the driving belt runs from the counter-shaft overhead, and, there being ordinarily three steps on this pulley, the machine can be driven at three different speeds.

In the machine shown in Fig. 29, however, the ram is jointed to the upper end of an oscillating slotted lever, the fulcrum of which is situated near the level of the ram. In the slot in this lever slides a block bored and bushed for the insertion of the crank pin on a disc crank that revolves on one side of the lever. The shaft which carries this crank lies somewhat below the middle of the height of the lever, and is geared into by a pinion on a shaft carrying the driving cone-pulley. The cutting stroke is performed during the lower half of the crank's rotation, and the back stroke during its upper half. During the former semi-revolution the crank pin is at a greater distance from the fixed fulcrum of the lever than during the latter. The upper extremity which is jointed to the ram being always at the same distance from the fixed fulcrum, the result is that the forward cutting stroke is much slower than the backward non-cutting stroke, the ratio of the whole length of the lever to that part of it lying between the fulcrum and the crank pin being much smaller during the former than during the latter. This is called a "quick return motion," and was first introduced into shaping and similar machines by Sir Joseph Whitworth. Its object is to save part of the lost time in the non-cutting stroke. The form in which Sir Joseph Whitworth uses it is more compact than that shown in the illustration. In this latter the crank pin does not pass above the fulcrum of the lever, and the lever is consequently long. In the Whitworth machine a second disc with a slot in its face takes the place of the lever, and the crank pin block slides freely along this slot past the centre of the disc. The second disc has its centre placed higher than that of the first, and drives the ram by means of a crank pin and a connecting rod.

The work is either bolted to the table or clamped in a vice bolted to the table. This table is a compound sliding table similar to that of the milling machine already described. The bracket on which it rests slides horizontally along dovetailed guide surfaces that form part of the vertical front face of the standard of the machine. This traversing motion is effected by means of a leading screw worked by a ratchet-wheel and pawl. The pawl is on a small slotted lever, driven by a light connecting rod from a crank pin on that end of the driving shaft opposite to that of the main crank disc. This crank pin is fixed in a T groove across the face of a small crank disc. The rate of this traverse feed can be altered by shifting the end of the connecting-rod in the slot of the crank disc. The ratchet-wheel is coupled to the leading screw spindle by means of a friction cone-clutch. The cone is upon a screw cut on the spindle, and is grasped in the hand by a milled head. A very small fraction of a turn is sufficient to throw it in or out of gear. When it is out of gear, the feed-screw can be turned by a hand-crank placed upon the end of the spindle, which is squared for this purpose. The traversing feed is occasionally given to the head carrying the tool and driving shaft and crank, instead of to the table on which the work is fixed, but the arrangement described is the most common.

14. Circular Shaping.—It is frequently desired to plane portions of cylindrical surfaces in the shaping machine. In machinery there occur frequently cylindrical surfaces which are not complete circumferentially. At one part of the circumference the metal protrudes beyond the cylinder radius. Such surfaces cannot be cut by continuous motion in the lathe, and the plan of rotating the lathe through a part of a revolution and then pulling it backwards, is extremely clumsy and tedious, and it is difficult to produce good work by means of it. The most important examples of this kind of work are the bosses at the ends of cranks and levers. The part of the boss standing above the web is turned in the lathe, and the rest may be finished in the shaping machine if it is of such a size as is admissible. The boss is clamped between two cone mandrils on a spindle whose axis is parallel to the stroke of the tool. Each stroke of the tool thus cuts a straight line on the cylindrical work parallel to its axis—such a line as is called in mathematical language a generating line of the surface. The spindle on which the work is clamped is in gear with the ratchet and pawl feed motion, and is thus rotated through any desired small angle once for every stroke of the tool. The connection between this spindle and the ratchet motion is by means of a shaft parallel to the leading screw and connected with it by spur gearing, and a worm and worm-wheel on this shaft and the spindle itself. This is called the "circular motion" of the shaping machine.

15. Slotting Machines; Tool-box.—The slotting machine is intended for the same class of work as that done on the shaping machine, but in which it is more convenient to place the surface to be planed vertically instead of horizontally. As in the shaping machine, the invariable arrangement is that the cutting stroke is made by the tool, not the work. The line of motion of the tool is invariable, so that all the desired feed motions are performed by the table on which the work is fixed.

Fig. 30 contains five views of a slotting machine of good ordinary construction. A is a side elevation; B, a front elevation; C, a section parallel to the plane of A through the lower part of the frame and through the table; D, a transverse central section through the table; and E, a section through the driving gear *k* and *m*.

The machine shown is designed for a maximum stroke of 11 inches. The whole height of the machine is 6 feet 7 inches. It is driven through the cone pulley *h*, with four steps which give four different speeds, *i.e.*, four different numbers of strokes per minute, suitable for various metals and for various lengths of strokes. If the counter-shaft be run at 120 revolutions per minute, these different speeds are 13, 23, 39 and 69 double (*i.e.*, up and down) strokes per minute. With the lowest of these speeds and the greatest stroke, the average linear velocity of the tool would be 2 × 11 × 13 inches = 286 inches = 24 feet per minute. But, as will be explained, the downward cutting stroke is made more slowly than the upward non-cutting stroke, *i.e.*, there is a "quick return motion." The tool during its cutting stroke has thus an average velocity of about 21½ feet, and during its up-stroke a velocity of about 28½ feet per minute.

The tool is fixed in the lower end of the long upright casting, *b*. The projection in front of this casting, seen best in A, has a vertical square hole through it, in which the tool is gripped by the six set-screws, b_1. It is thus connected rigidly to the casting *b*, and since this latter is immovable, except in a vertical line, the tool is not relieved during its up-stroke from close contact with the cut surface. In this respect the slotting machine of ordinary design is at a decided disadvantage as compared with the shaping machine. The difference results from the fact that in the latter machine gravity acts perpendicularly to the direction of the stroke, and, therefore, the weight of the hinged tool-holder is easily available to keep the tool in close contact with the metal without much pressure during the back stroke, whereas this is impossible in the slotting machine of ordinary design, whose stroke is in the same direction as that of gravity. In order that the weight of a hinged tool-holder in a slotting machine should act in the same way as in the shaping machine, the hinge would need to stand farther out in front of the frame than did the centre of gravity of holder and tool that hung from the hinge. This would bring the hinge so far forward as to prevent it from passing below the upper edge of the work, and thus the length of cut would be limited by the length of the tool. A cranked tool might be used to overcome this difficulty, but the weakness introduced into a tool-shaft by a long crank would be a decided objection.*

In some of the more expensive slotting machines a hinged tool-box is used, which is pressed in one direction by a spring, and is shifted slightly in position at the end

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* The centre of gravity of the hinged part can be thrown back by a counterbalance weight on a small side lever.

of each stroke by a small cam shaft that is oscillated by striking pallets fixed on the frame.

For cutting outside faces on work, there would be no difficulty in arranging a hinged tool-box with the tool inserted in a horizontal hole and projecting horizontally so as to clear the hinge. This system would be clearly inadmissible for slotting an inside surface in a confined space, such as a key-way in a wheel-boss; but in such work it is in any case a necessity to use a tool so long that it will project downwards beyond the bottom of the tool-holder rather more than the length of the cut to be taken, because the tool-box itself cannot usually enter the confined space. There seems, therefore, to be no good reason why a hinged tool-box should not be used in which there are two recesses for the insertion of tools, one of these horizontal for outside work, and the other vertical for inside work. The horizontal tool would have its cutting edge farther from the frame than directly underneath the hinge, and the tool-box would have its abutting surface during the cut higher than the hinge.

16. **Mode of Driving.**—In Fig. 30, the already-mentioned casting, *b*, slides up and down in two dovetailed grooves with packing strips forming the extremities of the two horizontal brackets projecting from the standard frame. It is driven up and down by means of the connecting-rod, *n*. The lower end of this is on a crank pin which is bolted in a radial T groove in the face of the circular disc, *m*. This is shown distinctly in Fig. E, where the crank pin is lettered m_1. It is formed with a T head that fits the groove, and can slide along it when the clamping nut is loosened. The pin can thus be fixed at any position in the groove so as to be at different distances from the centre of the disc. This disc is keyed, and rotates along with the shaft *g*, Fig. E. According to the distance of the crank pin from the axis of rotation, the stroke of the slide *b* and of the tool held in its lower end is varied. The shifting of the position of the crank pin in the groove

can only be accomplished when the machine is not in motion. The driving shaft should be pulled round until the groove lies horizontally, as in this position the pin can be moved in it without the necessity of raising or lowering, except through a very small height, the heavy slide, *b*.

The shaft, *g*, lies in a bush, marked *l* in Fig. E, which is screwed fast to the standard. This bush has an enlarged eccentric end, which forms the fixed axis round which the spur-wheel, *k*, revolves; *k*, therefore, rotates about an axis higher than that round which *m* turns. In the back face of the disc *m* is cut another radial groove, along which is free to slide a small square block fitting the groove. This block is driven by a crank pin fixed in the wheel *k*, and entering a hole in the centre of the block. This connection between *k* and *m* is seen clearly in the section E, where the crank pin in *k* is lettered k_1; *k* drives *m* in rotation by this connection, and during the revolution the crank pin and block k_1 slide backwards and forwards in the groove because of *k* and *m* not revolving about the same centre. The rotation of *m* is, therefore, not uniform, being faster when the pin k_1 is nearer its centre, and slower when farther away. During the slow half of its revolution, the tool is descending and doing its cutting work. During the fast half of the revolution it is being lifted and is doing no work. This is the "quick return," and is the same as was mentioned as the system adopted by Sir Joseph Whitworth in shaping machines.

The spur-wheel *k* is driven by the pinion *i*, which is keyed on the same shaft as the driving cone pulley.

17. Table and Feed Motions.—The construction of the table of the slotting machine is somewhat complicated, but is shown clearly in Figs. A, B, C, and D. There are *three* feed-motions to be given to this table. The first is rectilinear and parallel to the axis of the driving shaft. The leading-screw by which this feed is effected is marked *v* in the section C, and

its cross-section, and the nut in which it gears and which is screwed to the under side of the plate *c*, are seen well in Fig. D. The end bearings of this screw are in the base-plate of the standard frame. As it rotates the nut travels along it, and carries with it the whole of the compound table composed of the superimposed plates *c*, *d*, and *e*. The outer squared end of this screw-spindle bears the spur-wheel u_1, which gears with the spur-wheel *u* on the parallel shaft *t*. This wheel *u* is not keyed on *t*, but is connected to it by means of a feather and slot. When it is drawn back along the slot it is put out of gear with u_1, and the shaft *t* does not then drive the feed-screw *v*. At the other extremity of *t* is a pair of mitre wheels gearing it with the short upright hollow shaft *r*. This revolves loosely on the lower end of the vertical shaft q_1, and is driven by q_1 through a pawl, *r*, on a lever keyed to q_1 and a ratchet wheel keyed on top of the short hollow shaft. The shaft q_1 is oscillated by a lever *q* keyed on its upper end, and jointed by a connecting link p_1 with a lever *p*. This lever has on its other end a small pin and roller which runs in the cam groove *o*. This groove is cut in a casting fixed on the end of the spindle *g*, already mentioned as being that along with which the driving disc *m* revolves. Thus the feed-screw *v*, when it is put in gear by tightening the nut upon the wheel *u*, receives a small fraction of a turn for each stroke of the tool.

The second feed motion is also rectilinear, and is perpendicular to the first. It is given to the second plate *d* of the compound table sliding on the lowest plate *c*. The feed screw for this motion is marked y_1 in the diagrams, and has its end bearings in the plate *c*, and its nut is bolted to the under side of *d*. A side view of this screw is seen in Fig. D, and a cross section in C. Figs. A and D show how it is driven by the shaft *t*. Along this latter slides the mitre wheel *w*, which is rotated by having a feather fitting in the key-slot, which may be seen (Fig. A) extending nearly the whole length of *t*. A bracket on the carriage makes the mitre wheel travel with it. This mitre gears with the other mitre w^1 on a short shaft inserted in this bracket, and having on its other end the wheel x. The wheel x gears with the wheel y on the end of the feed-screw y_1. It can be put in or out of gear in the same way as has already been described for the first feed-motion.

The upper plate *e* is capable of rotation about a vertical axis. In this rotation it moves on the horizontal upper face of the plate *d* which is made in three pieces immovably bolted together, and has a circular recess turned in it that forms the guide for the top plate in its circular motion. This is the third feed motion. It is called the "circular motion," and its object is to facilitate the slotting of cylindrical surfaces. The feed is actuated by the spindle z_1, with the spur-wheel z on its end gearing with the wheel x. Either or both of the wheels z and y can be drawn back on their spindles so as not to be in gear with x. When they are desired to be in gear they are pushed forward. The spindle z_1 has on it a worm, and drives it by a feather sliding in a longitudinal slot. This worm gears into a worm wheel cast on the lower part of the table *e*, which thus receives a uniform small circular feed per stroke of the tool.

The table cannot be moved vertically upwards or downwards. The adjustment of the height of the tool to the work it has to cut is effected by bolting in a higher or lower position in the slot of the slide *b* the block by which this slide is driven by the upper end of the connecting rod *n*.

18. Improvements in Planing Machines.—There is given in Fig. 30* an illustration of a very good form of planing machine by Smith and Coventry of Manchester. One special feature in the design is that the slide bearings of the table are flat instead of being **V** grooved as usual. A fitting strip at one side can be set up by set-screws so as to make an accurate fit to steady the table side-wise, and to take up the side wear. Also a tappet motion connected to the tool-box by cord gearing gives the tool a positive lift of small amount at the end

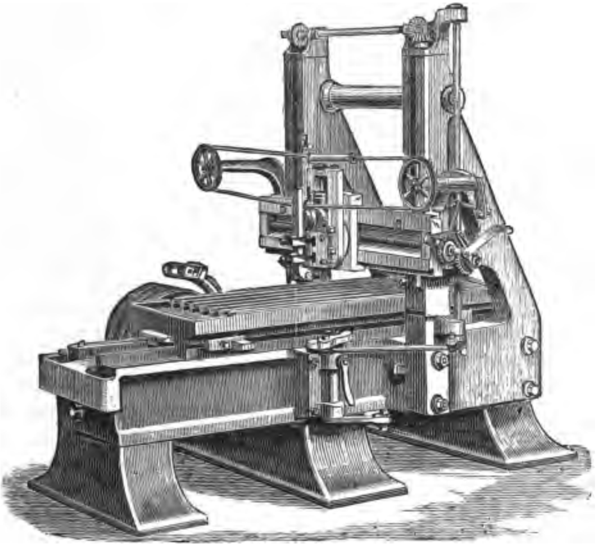

Fig. 30*.—Planing Machine (Smith and Coventry).

of the cutting stroke which effectually prevents any rubbing at all between the tool and the work during the back stroke.

CHAPTER VI.

LATHES.

1. Primitive Lathes.—The Lathe is so important a machine-tool, does such a variety of work, and has so many different forms, that it requires a chapter to itself. It is by far the oldest machine cutting tool, and its early history is very interesting to those who think it profitable to trace the development of machinery in its infancy. The first form which it assumed in Europe may still be seen at work in Japan and other Asiatic countries, where very useful and ingenious, although not very accurate, work is performed by its help. The rotation of the spindle is not continuous. It makes a certain number of revolutions in one direction during which the tool cuts, and then this motion is reversed through the same number of turns while the tool stands idle. To mechanics who are now so familiar with the crank and connecting-rod linkwork for producing continuous rotation, it may seem at first sight surprising and absurd that the machine should remain for long in such a condition that during half the time it was in motion it did no work; but it must be remembered that the three kinds of planing machines described in the last chapter are even now in very much the same state of advancement, and that it is not at all improbable that even the next generation of engineers may look upon our present planing machines as being as antiquated and absurdly wasteful of time as these primitive lathes appear to us now.

2. Geometrical Character of Turned Work.—The surfaces cut in lathes are all surfaces of revolution: that is, the finished work has a geometrical axis which has this property, that if sections be imagined to cut it perpendicularly and at all positions along it, the lathe-cut peripheries of all these sections are circular. The diameter of the circle may vary in any manner, so that a longitudinal section taken through the above geometrical axis may have any shape, its bounding lines being either straight and joining at sharp corners, or being curved in any manner, or being any combination of curved and straight lines.

The work being fixed to the rotating spindle of the lathe, and the cutting tool being held steadily against it, the axis of the lathe spindle becomes the above geometrical axis of the work, and the tool cuts out the circular peripheries of the transverse sections. In order that the tool should cut successive peripheries, it must be moved parallel to the axis of rotation. In order that it may cut circles of different sizes at different parts, it must be moved nearer or farther from that axis—that is, perpendicularly to it. These two motions of the tool are called feed motions. They may be combined in any ratio, and this ratio may be kept constantly the same or may vary from point to point. The ratio may vary from zero to infinity: that is, the reciprocal of zero. If a shaft has to be turned truly parallel—*i.e.*, of the same diameter throughout its length—the feed motion perpendicular to the axis must be zero, and its ratio to the longitudinal—or, as it is technically termed, *traversing*—feed motion is zero. If a surface of the work has to be faced truly flat and perpendicular to the axis, the traversing motion must be zero, and the ratio of it to the perpendicular—or, as it is called, *surfacing*—motion is zero, while the ratio of the latter to the former is infinitely great. If the two motions are combined in a ratio remaining constantly the same, the surface is turned to a conical shape. This shape is referred to as having a *straight taper*. If the two are combined in a ratio that constantly changes, then a surface is produced that is curved longitudinally.

3. Hand and Power Mechanism.—The rotational motion of the lathe spindle is always produced by means of some sort of mechanism. The feed motions are given to the tool in the simpler class of lathes directly by hand, and in the more complicated by mechanism which can be worked either by hand or by the same power that rotates the spindle.

In lathes for turning wood the feed is nearly always given directly by hand. The exceptions are some lathes specially constructed for the manufacture of one particular article in large quantities, such as reels and bobbins for winding cotton, linen, or silk thread upon. In these there being no variation in the successive feed motions to be given to the tool, there is an immense saving of time in guiding these mechanically, and in limiting their extent by stops. Thus the required shape is given with certainty, without the necessity of much—or, indeed, hardly any—thought on the part of the workman, and, therefore, is accomplished with extreme rapidity and consequent cheapness.

In general wood turning, however, an infinite variety of shapes is desired, and the constant change of requisite feed motions for the tool demands the unremitting attention of the turner. There are two special considerations, depending on the character of the material, that cause the direct hand guidance of the tool to be more convenient than mechanical guidance. The first is that the quality varies much more largely and more rapidly from point to point in timber than it does in any metal. When the turner comes to a knotty or cross-grained portion, he must alter the manner of holding the tool to suit the different texture. The tool is keen-edged, and correspondingly weak. To avoid the risk of breaking it, it must be delicately managed. The alterations in texture are reached more suddenly in dealing with wood than with metal, not only because the differences lie closer together, but also because the cutting speed is very much greater, and the tool, therefore, passes from one spot to another more rapidly. The second consideration is that, in consequence of this high cutting speed and of the softness of the material, the whole work is performed much more quickly and the necessary successive changes of position and direction of tool feed motion follow each other much more rapidly than in metal turning. There is greater advantage, therefore, in the *handiness* of direct hand guidance of the tool than there is in the greater accuracy of mechanical guidance.

4. Tool-rest for Wood Turning.—Fig. 31 shows the hand tool-rest for a wood-lathe.

(*a*) is a side view looked at parallelly to the lathe spindle axis; (*b*) is supposed to be seen perpendicularly to the same direction. The horizontal bar, from four to ten inches in length, has an overhanging section. On this the tool is firmly held down with the left hand, while the right grasps the end of the wooden handle. In roughing out a gouge is used—that is, a tool formed as if made by bending a strong flat chisel into a semi-cylindrical channel shape. The right hand traverses the tool-point by sweeping it through a small angle round its resting-point on the rest as a pivot, then pushing this resting-point a short distance along the rest, and repeating these movements alternately. This plan allows the tool to be held more firmly down on the rest than if the point of support of the tool were continually pushed along. In finishing, however, a broad flat chisel with a straight cutting edge is used, and evidently, in giving the traversing feed to this tool it is necessary to keep the cutting edge always exactly parallel to the axis of rotation in parallel work, or to the surface of whatever work is being cut. To do this, the chisel must be moved always parallel to itself, and, therefore, the above oscillatory feed motion cannot be given to it, but it must be slid along the rest gradually and continuously.

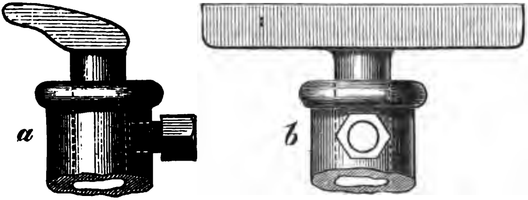

Fig. 31.

5. Tools for Wood Turning.—Among the tools used for lathe turning is the gouge already mentioned. The bevel to produce the cutting edge is ground on the outside, and at a somewhat greater angle than that used for paring-gouges and chisels. Sectionally, it is of small size, both inside and outside being fashioned to small radii. The end is ground so as to give a cutting edge, not square across the length of the tool, but sharply pointed to an oval curve. Deep cuts of very short axial length may thereby be taken, and a large amount of material turned off without the need of running the tool backwards and forwards frequently. Finishing cuts are hardly ever taken by means of a gouge, and, in fact, it is impossible to cut the surface with this instrument so as not to leave a series of small ridges between the cuts. The turning-chisel is ground with a bevel on each side, therein differing from the paring-chisels formerly described. It also is much thicker and stronger than these, and has a larger cutting angle. The edge is usually ground obliquely to the length of the blade, and chisels with various breadths and various degrees of obliquity of the cutting edge are used. The advantage of this obliquity is in facilitating the cutting out of sharp corners and in "cutting in"—*i.e.*, in taking a cut straight into the wood in a plane perpendicular to the axis of rotation. The best finishing tool for wood turning is an old paring-chisel, which has been by use worn down short to the upper end of the blade where it is tolerably thick and strong and void of spring. In using this in order to take just the last cut, it is a useful practice, after carefully sharpening the edge on the oil-stone, to turn up a minute feather edge by drawing a gouge blade once or twice with considerable pressure across the cutting edge of the chisel.

A flat-faced chisel may also be used very effectively in cutting in, with the flat face next the surface which is to be preserved. In doing so, the flat face must be carefully held obliquely inclined to that side of the vertical away from the edge that must be preserved as the finished one.

6. Tool-rest for Metal Turning.—A tool-rest for a lathe for metal turning is a much more complicated structure. It consists of a series of plates, one on the top of the other, on the topmost of which the tool is firmly clamped by a flat piece pressed down on it by screws. The plates slide one over the other with dovetail groove slide surfaces. It is therefore called a *slide-rest*; and because the motion given to the tool is compounded of the sliding motions of the plates one over the other, it is called a compound slide-rest.

The grooves along which free sliding takes place are all rectilinear. One set is placed perpendicularly to the other, and they are usually placed so that one is parallel, and the other perpendicular, to the centre line of the lathe. But it is sometimes desirable to give the tool an oblique feed motion without having recourse for that purpose to a combination of two simultaneous motions, and therefore provision is made for turning the upper portion of the rest round a vertical axis, so as to set the slide at any inclination to the lathe bed.

There are two classes of such rests, according to whether or not it is desired to have the feed motions not only mechanically guided, but also propelled by lathe power, and not by hand power. When this power propulsion is applied, there are again two subdivisions, according to whether both the traversing and the surfacing feeds are actuated by power, or only one of them. The word "self-acting" is inserted in the name of the lathe to indicate this power propulsion of the tool in its feed motions. Thus we have self-acting traversing (or sliding) lathes, and self-acting traversing and surfacing lathes.

When these self-acting arrangements are introduced, it is still necessary for the workman to have power to move his tool either way through a small range by hand for the purpose of setting it, or for manipulating in a rapid convenient manner any short, bevelled, or rounded part of the surface to be wrought. To meet this need the slide surfaces are duplicated, the main slides driven by power being at the base of the rest, while at its top two short slides at right angles to each other are introduced, these being worked solely by hand. Between the upper and the lower pairs comes the circular grooved slide surface, by which the upper slides may be set so as to work obliquely.

An example of the more complicated of the ordinary styles of slide-rest will now be described. The simpler kinds contain merely portions of this form, one or other, or both, of the self-acting slides being dispensed with. With the disappearance of each set of slides there disappears also, of course, the whole train of mechanism that drives it.

7. **Mechanism of Slide-rest.**—Fig. 32 shows a slide-rest of this class. F is a section parallel to the bed of the lathe, and E is a cross-section.

The topmost piece is a bracket-formed plate. This is held down to the plate n_1 by a stout bolt, round which it may be swivelled into any position by slackening the nut. Underneath the projecting part of this the tool is laid and fixed down firmly by two square-headed screws, and as this piece may be swivelled as mentioned, the tool may be set at any horizontal angle with reference to the other parts.

The plate n_1 slides over the plate n underneath it, the pair of guide surfaces being dovetailed in the usual way with a bevelled packing strip. The motion is effected by a screw and nut, the former having its bearings in the upper plate n_1, and advancing along with it, while the nut is set in the plate n so as to be immovable in it. The screw at its front end, where it is easily accessible, has its end squared for the reception of a crank handle by which the workman turns it. This motion in the ordinary position of the slide-rest is perpendicular to the rotational axis of the lathe. This is the motion most frequently required by the turner to set the tool in to take the desired depth of cut, to withdraw it at the end of a cut in order to slide the whole rest to the other end of the work for the purpose of beginning a new cut, or to withdraw it quickly from its work in case of anything going wrong. For this reason, this slide is placed highest. The least weight rests upon the topmost slide, and it is therefore the most easily moved.

The plate *n* now slides by a similar pair of dovetailed surfaces over the plate *m*. This motion is parallel to the lathe spindle, and it is effected also by a screw and nut. The nut is bolted to the under-side of the plate *n*, and the screw has its bearings in *m*. This screw is squared at its right-hand end, and is worked by hand, similarly to the upper one.

The plate *m* is deeper than any of the others. Its top part is elongated in the direction of the sliding of *n*, and its lower part is flat and circular. The latter fits over a similar surface turned on the upper side of *l*. In two holes in this circular part are fixed two bolts, with hexagon nuts on their upper ends and with dovetailed heads at the lower ends. These pass into two circular concentric slots of similar section, shape, and size, and cut out in the under part of *m*. By this means the whole of the rest lying above l_1 may be swivelled round the short pin seen in the middle of *m*, and clamped in any position by the two bolts already mentioned.

The lower plates l_1 and *l* are larger in size than the others, and give a greater extent of motion, one along the surface of the other. As may be observed in the cross-section, the nut is bolted to the higher of the two plates l_1, and the screw is placed in the lower one, *l*. This screw, marked z_1, is a long one, about twice the breadth of the bed of the lathe. There is thus a long range of motion obtainable on this slide. At the end of the screw in front of the lathe the screw spindle is square, so that it may be turned by hand by means of a crank handle. It is driven mechanically by a spur-toothed pinion *z* upon its extremity at the back of the lathe. This pinion is not keyed fast on the screw spindle, but may slide along it the length of the teeth, and drives the spindle by a feather fitting a key slot in the spindle.

On an extension cast on the pinion is a clutch groove, which is embraced by a fork on the end of the rod z_{11}, seen in the plans B and G, and in end view in H.

This rod extends to the front of the tool-rest, from which position the workman can push it forward, and thereby slide the pinion z along its shaft. In one position the pinion is in gear with the spur-wheel u, driven by the worm t, which is rotated by a feather lying in a long groove in the shaft s. When it is not desired that the transverse slide-screw z_1 should move, the pinion is pushed out of gear with u. The shaft s extends the whole length of the lathe, and is driven at the fast head-stock end by means of spur gearing and a narrow belt running over a pair of small stepped cones. Since this belt is apt to slip on the cones to a small and irregular amount, it is evident that the above mechanism is incapable of giving an exact and constant ratio between the "surfacing" feed of the slide-rest and the rotation of the spindle in the fast head-stock, and of the work that is being turned. The maintenance of exact constancy in this ratio is, however, not of importance.

The shaft s runs, as has been said, the whole length of the lathe-bed, as may be seen in the plan B. As the slide-rest moves along the bed into new positions, it is necessary that the worm t should move with it. It is therefore compelled to slide along the key-slot in the shaft by a fork bracket bolted on the rest "saddle," this fork embracing the boss of the worm.

8. Along with the boss of the worm-wheel u is keyed a spur pinion, marked v. This pinion gears with the wheel w, seen in Figs. G and H. The wheel is fastened by a feather sliding in a key-slot to a short hollow shaft, on the other end of which is keyed the pinion x. It is also pinned to a rod which lies in the interior of this hollow shaft and is continued to the front of the slide-rest. By means of this inside rod the wheel w may be pushed back so as not to be in gear with the pinion v, when also the pinion x will

therefore not be moved by the rotation of the shaft *s* with the worm *t*; *x* gears with the toothed rack *y*, which is bolted on brackets, seen in the cross-section E, to the back cheek of the lathe-bed. Thus when *s* is in motion, and also in gear with *x*, this pinion travels along the rack, and since the shaft on which it is keyed has its bearings in the saddle of the slide-rest, the latter is carried along the bed, or "traversed."

The self-acting traverse motion is slightly irregular, not only on account of the above mentioned slipping of the belt driving *s*, but also because the teeth of a rack are never spaced with exact mathematical uniformity. But for ordinary parallel turning it gives a perfectly sufficient degree of constancy to the feed motion, and a much higher degree than could be obtained by hand. There is one important advantage in having this gear driven by a belt. In roughing out work in the lathe, the depth of cut always varies to a slight extent, owing to the irregularity of the outside surface of the casting or forging that is being turned. There are also here and there variations in the hardness of the metal to be cut. On both these accounts the resistance to the cutting action of the tool varies during the traversing motion of the tool. Now, when a place is reached at which the resistance would be greater than elsewhere with the same rate of feed, it is, of course, desirable that the rate of feed should be diminished, so as to reduce the width of shaving cut, and thereby decrease the resistance to cutting. The frictional driving of the feed motion by a belt tends towards this equalisation of cutting effort, because the belt slips slightly, and the more so the greater is the strain put upon it.

When very exact regularity in the traversing feed is desired, as in screw-cutting, another mechanism is used, which will be described presently.

9. The mechanism described in the last paragraph is in many respects clumsy. In order to throw the pinion *z* and the wheel *w* out of gear, they have to be slid along their respective shafts, and to do this, in the one case at least, an extra rod with a fork is required. It is also to be noticed that *u* is a worm-wheel, and that this is made to gear with the pinion *z*. The teeth of both of these must be made oblique in order that they may gear at all, and even when placed at the same angle of obliquity in both pinion and wheel, the teeth of the latter cannot be made to fit well *both* the worm *t* and the pinion *z*.

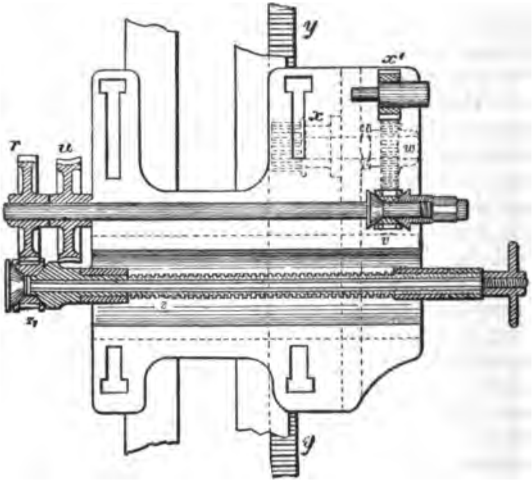

Fig. 33.

The design shown in Fig. 33 is a great improvement and simplification of the necessary mechanism. The diagram shows the saddle in plan, with the top slides removed, and with the lathe bed and the rack *y* broken off. The latter is secured to the front side of the bed, and the pinion *x* (seen dotted) exerts its driving pressure on the rack much more nearly in a direct line underneath the cutting point of the tool, where the resistance to motion is generated, than in the former design.

The worm-wheel *u*, which gears into the worm *t*, not shown in the figure, is keyed fast on the shaft which runs to the front of the saddle. Near the front end of this shaft there is formed a cone, which fits into an internal cone cut in the boss of the pinion *v*, and another similar cone stands on the opposite side of this pinion, fitting into a similar recess in the front end of the boss. The pinion and the latter cone both run loose on the shaft, except when, by means of the large nut seen at the end of the shaft, the external and internal cones are tightened and locked together by friction. The friction-cone coupling takes the place of the sliding of the spur-wheels on their feathers, and the tightening or loosening of the cones is effected by a very small rotation of the clamping nut. The putting the self-acting rack feed into and out of gear is by this means made very much more handy and expeditious. The importance of this advantage is not limited to the saving of a little trouble on the part of the turner. If the workman has to turn a parallel length on his work which joins on to a flat surface perpendicular to the axis of rotation, he must exercise the greatest care in turning the last portion of the parallel run close to the corner, because if he goes the least distance too far he may spoil the flat face, and break his tool as well. With the mode of engagement shown in Fig. 32 there is always a risk of the teeth sticking so hard together when they are in gear that the first effort of the workman will not be sufficient to disengage them. The turner cannot afford to run this risk at the last instant of the parallel cut, and he must, therefore, throw the self-acting feed out of gear when his tool is still at some considerable distance from the corner, and must finish the cut up to the corner by hand feed with the top slide. This process is altogether clumsy and wasteful of time; and although the hand feed at the last small fraction of an inch from the corner cannot be dispensed with even with the friction-cone engagement, still the latter is so much more certain and rapid in its action that a great deal of time is saved by means of it.

The pinion *v* gears into the wheel *w*, seen dotted underneath the saddle, and this is keyed on the same short shaft as the pinion *x*, which engages with the rack *y*. Another small pinion, x^1, is fixed on a bolt with bearings in the saddle, and with its outer end squared for the reception of a crank handle; x^1 gears into the wheel *w*, and being turned by hand, traverses the slide-rest along the rack.

On the same shaft that carries the worm-wheel *u* is also fixed the wheel *r*. This drives the pinion z_1, which runs loose on the screw-spindle *z*, except when clamped to it by a friction-cone coupling similar to that already described. In this case the outer cone forms the end of a rod which runs through the screw spindle, this being bored out hollow to admit its passage. The other cone is formed on the end of the hollow screw spindle. The interior rod projects at the front of the saddle, and has its end screwed for the reception of a long nut, rotated by a small hand wheel and cut in the boss of this wheel. By screwing this nut up, which has its flat bearing on the front end of the hollow screw spindle, the spindle, with its cone at its other extremity, is pushed back, while the rod with the opposing cone is drawn forward, so that the pinion z_1 becomes firmly clasped between the two cones. The pinion being thereby put in gear with the screw *z*, and this working in the nut fastened to the lower side of the surfacing slide, the tool-rest is drawn towards or moved outwards from the axis of rotation of the work by means of the revolution of the worm *t*, driven by the belt at the fast head-stock.

10. Feed Motion for Screw Cutting.—As already said, a more accurate traversing feed is required for screw cutting. This is obtained by a nut fixed to the underside of the saddle of the slide-rest, and gearing in a long screw, called a "leading screw," that runs the whole length of the bed of the lathe. In first-class lathes this screw should be preserved from wear with all possible care. It should, therefore, not form the only self-acting traverse motion, but should be combined with the rack motion described last, and the rack should be used for all work in which great regularity of feed is not necessary.

In Fig. 32, the leading screw, marked *a*, is seen in the front elevation A, in the plan B, and in the sections E and F. The nut in which it gears is best seen in E and F. This nut and the casting in which it is held are split in halves, which may be separated so as to stand clear of the screw, and not be in gear, therefore, with it. They slide up and down in a vertically slotted plate, and the engaging or disengaging motion is given to them by two studs which enter the eccentric curved slots in the circular disc seen most plainly in the front view, A. This plate swivels on a central pin, and is moved through the requisite circular arc by a lever bolted to one side of it.

The nut shown in this figure is of gun-metal set in cast-iron. Gun-metal is still very commonly used for the purpose, but a nut of cast-iron or of malleable cast-iron answers the purpose perfectly if made of extra length. The modern improved custom is also to use only the upper half of the nut. This upper half is all that is required. The use of it alone very much simplifies the mechanism for throwing it into and out of gear, which is reduced to a short hand lever, with an eccentric pin turned on the face of its boss. The upper half-nut also keeps comparatively free of dirt and dust, which readily lodges in the lower half when it is standing clear of the screw. The most important advantage in this improvement is, however, that it renders possible the support of very long leading screws by half bearings on the under part of the surface. These bearings are supported on brackets bolted to the lathe bed or legs, and are bored out to a diameter equal to that of the top of the thread of the screw. The complete nut would not permit of these bearings, because they would interfere with its passage along the screw. Leading screws are of a considerable weight, and when very long, as in lathes designed for the turning of long lengths of shafting, they bend very considerably if not supported at points intermediate between their ends.

11. The best position for the leading screw in the lathe bed is still a matter upon which difference of opinion exists among tool-makers. It is occasionally, but not often, placed at the back of the bed. It is very often put in the hollow space between the back and front slide-surfaces of the bed, as close as is convenient to the front cheek, in order to be protected by the front slide-surface from dirt falling from above, and in order to be as nearly as possible directly under the cutting edge of the tool. It is sometimes said that this position protects the screw from getting dirty. This is a mistaken idea, however, because in consequence of its inaccessible position it seldom or never gets properly cleaned by the lathe man. The sole real advantage of this position is the protection it affords from accidental blows from tools, spanners, &c., falling on it, and from other ill-usage. If the screw is placed in front, as is the commonest and most approved position, it is not infrequently used by thoughtless workmen as a rest in lifting heavy weights from the floor on to the lathe bed, and in this way gets often bent, bashed, and generally ill-treated. The advantage of the front position is its great accessibility for cleaning. It would not appear difficult to arrange so that it should be protected by a projecting ledge or shelf cast on the front cheek of the bed. Such a shelf would also be found very useful for laying tools and spanners upon. These are at present usually found in heaps lying all along the bed, whose surface it is really important to keep free from bruises or defacement of any kind. Besides doing injury to the surface of the bed, these heaps of tools are a continual nuisance in being swept off and thrown

on the floor by the advance of the saddle in its self-acting traverse motion.

12. There still remains to be mentioned the means by which the leading screw is rotated. The chief object of the leading screw is to traverse the slide-rest and tool in the operation of cutting screw-threads. For each revolution of the piece upon which the thread is being cut, the tool must traverse a distance equal to the desired pitch. If the pitch were equal to that of the leading screw, then evidently the leading screw would need to make one revolution for every revolution of the main spindle. If the pitch were to be half that of the leading screw, then the leading screw must revolve once for every two revolutions of the lathe spindle. Whatever be the thread desired, the ratio between the rate of revolution of the leading screw and that of the lathe spindle must be made the same as that of the pitch of the thread to be cut and the pitch of the leading screw. If this ratio between the speeds of rotation of these two shafts be kept with accuracy constantly the same, the thread will be cut to a uniform pitch, or rather its accuracy will be proportional to that of the leading screw. In order to maintain this ratio always the same, the leading screw is driven by the lathe spindle through a train of spur gearing, the teeth of which ought to be cut out accurately in a milling machine to a proper shape, and to a uniform pitch. This train of gearing is mounted on a swivelling plate, or, as it is called, the "radial arm," which pivots round the screw spindle as a centre. It can be swung round this centre and clamped in any position by means of nuts on a couple of studs projecting from the flat surface against which the swinging-plate bears. The studs pass through two segmental slots made in the plate. This plate is seen in the end view, C, in Fig. 32, and is there marked β.

Besides the two arched slots, there are two straight slots made in it. In any position in these straight slots may be bolted two studs, the tightening on the plate taking place between collars on the studs and nuts on their screwed ends. On these studs are placed the wheels of the spur gearing. They are called "change wheels," and a large number of them is supplied with each lathe. According to the speed desired for the screw spindle, one or other pair of these wheels may be placed on the above studs, and the wheel on the screw itself may also be changed. Thus different sizes of wheels being in use at different times, it is necessary to have means of mounting them with their centres at corresponding distances apart, and this is done by sliding the studs along the straight slots into suitable positions. The wheel gearing with that on the screw spindle is first set on the stud in the outer slot, and then that which must gear with this is placed suitably in the inner slot. This latter is brought into gear with the pinion on the lathe spindle, either directly by swinging the radial arm into such a position that the teeth of the two interlock, or else intermediately through the small wheel o_1, of the same size as that on the lathe spindle, with which it always remains in gear. The object of this intermediate wheel is to reverse the direction of motion of the leading screw, so as to draw the slide-rest from left to right instead of in the opposite direction, which is considered the forward direction for its motion. With the arrangement shown in Fig. 32 for this reversal, it is necessary to shift the large radial arm, which is an inconvenient operation. In order to avoid this inconvenience, a small swinging plate with two equal idle wheels gearing with each other is introduced. This can be placed either in such a position that the first wheel in the radial arm is driven through one only of these, or so that it is driven through the pair. In the latter position of the plate on which they are mounted one of the pair gears with the pinion on the lathe spindle, while the other gears with the wheel on the radial arm.

13. Headstock.—Fig. 34 shows the details of the fast headstock of a double-geared lathe. A is a longitudinal vertical section; C is a sectional plan. The chief part is the spindle, or mandril. The right-hand end of this has an axial hole bored in it, slightly tapered, for the reception of a pointed piece of steel, called the "centre." This should be carefully fitted to the hole, so as to be perfectly firm in it, and after the lathe has been completely fitted up and put in working trim, the centre must be turned in place. This ensures that it will run absolutely true, with an accuracy that could not be obtained by any other method. Two small holes are made in the work at opposite ends of the axis round which it is desired to turn it. Into these holes are inserted the "centre" on the fast headstock, and the similar centre of the loose head-stock shown in D.

The work is thus suspended between these two points, and is free to rotate about the line joining them. It is carried round with the rotation of the mandril by means to be presently mentioned. The cutting tool turns the work to a surface of revolution, all the centres of whose circular sections lie upon the line joining these centres. If, now, the object is to be turned to the cylindrical shape, or, as it is termed in the workshop, "parallel"—referring to the parallelism of the sides of its sections through the axis—the tool must be traversed so as always to stand exactly at the same distance from the line between the "centres" in the two head-stocks. If it does not do so, the diameters of the various sections will not all be accurately equal. The slide-rest is guided in its traversing motion by the "bed." Hence arises the necessity for having the outside edges of the bed, which form the surface that guides the slide-rest, very exactly parallel to the line joining the two centres. This is accomplished, not of course by cutting the bed to suit the centres, but by fitting the tongue-shaped projection on the bottom of the movable head-stock that enters and slides in the groove of the bed, so that the centre on this headstock will stand above the edges of that groove in a precisely similar position to that occupied by the centre on the fast head-stock. The two centres must stand exactly the same vertical height above the flat upper surface of the bed, and exactly the same horizontal distance measured perpendicularly to the bed from either edge of the inside groove. These inside edges also must be exactly parallel to the outside edges of the bed. Thus this adjustment of the movable head should be the last thing done in the manufacture of the lathe, the turning of the mandril centre being the second last operation.

14. Centre-point.—It is often stated, in books and elsewhere, that the exact angle of the conical points of the centres is of great importance for accurate work. The writer does not recognise any importance in exactitude in this matter. The *best* angle certainly varies with the kind and quality of the material turned in the lathe. The considerations which determine that *best* angle in any special case are the following. The pressure exerted by the cutting tool on the work has two components: one of these is perpendicular to the axis of rotation, and is due to the rotation of the work; the other is parallel to this axis, and is due to the traversing feed. These pressures are for the most part transmitted to, and borne by, the centres. The bearing surface here is small, and, therefore, the material in the centre hole of the work is gradually crushed proportionally to its degree of softness. As soon as it is appreciably crushed, the work hangs slightly loose between the centres, and it becomes impossible to turn true work until the centres are tightened up once more. Now this crushing and wear of the material in the centre holes are produced by both the above components of the pressure. The vertical pressure will be better resisted the more acute is the angle of the steel centre, because in that case its sides will be more nearly perpendicular to this component of the whole pressure. But at the same time the material will be less favourably situated to resist the axial pressure component, because the surface will be very oblique to the direction of that thrust, and the conical steel point will penetrate into the metal like a keen-edged wedge. Any change in the angle of the cone is thus advantageous with reference to one component of the pressure, and disadvantageous with regard to the other. The best angle is that with which the combined advantages with reference to the two are found to be a maximum. It must evidently depend to some extent on the softness of the material being wrought, and also on the ratio between the two components of the pressure. This ratio depends again on the nature of the material, and also still more on the ratio of the amount of traverse-feed given per revolution to the depth of cut. It also depends to a large extent on the form given to the cutting edge of the tool, and the manner in which this is held. As these elements of calculation vary greatly in the work of the same lathe, and even during the process of turning one piece of metal, it would be futile to attempt to construct a rule for the best angle for the cone of the centre that would be generally true.

In order to diminish this wear at the centre-points, it is, however, very important to make the centre holes of the same degree of conicity as the centres, so that the two surfaces will bear fairly together. These holes are commonly made by driving in a "centre punch" with a hammer. This may be a convenient practice for small work, but it is a bad one in any case if the workshop contains facilities for drilling the holes. The centre punch has its point always more obtuse than the farther back portion of its conical surface. The result is that either the punch does not make the hole deep enough, and the lathe centre itself has to complete its formation, whereby too much pressure is brought on its extreme point, or else the centre punch must be ground to an acuter angle than that of the lathe centre, and the surface of the hole it stamps in the work does not conform to that of the lathe centre, and a fair bearing is not obtained.

None of the pressure should be borne by the extreme point of the centre. In order to avoid this, it is necessary to drill a small hole deeper than the centre-point is intended to penetrate. The outer end of this hole is then to be counter-sunk to the right angle to fit the centre. The small drill and the counter-sinking drill may conveniently form parts of the same tool, which may be used in a hand-brace, or may be inserted in a specially constructed "centring" machine.

The forging or cast-iron piece to be turned has usually an irregular outer surface, and although at some parts a considerable depth of metal has to be removed in order to reduce it to the desired size, at other places there is an extremely small quantity to be taken off. At these places, where the metal in the rough condition is "scrimp," it would be impossible to turn off the whole of the outer skin, so as to leave everywhere a clean-cut surface, if the above centre holes were not placed correctly with extreme exactitude. A misplacing of the centre by $\frac{1}{64}$ inch would reduce the diameter to which it would be possible to turn up the scrimp section by $\frac{1}{32}$ inch. With the centre punch it is seldom that the workman can make the hole as exactly as is necessary in the correct position without making a correction in the first hole he makes. He punches the holes as nearly right as he can judge by eye; he then places the piece in the lathe, and by slowly turning it, and holding a piece of chalk steadily so as just to touch the side farthest from the centre of rotation, he discovers in which direction he must correct his centre hole in order to get a nearly uniform chalk mark all round. He then removes the piece from the lathe, and alters the hole as required by driving the centre punch to one side or the other. This process evidently must result in a hole that is neither regular in shape nor in the hardness of the metal round about it. The metal on that side to which the punch has been last driven is more compressed than the rest. On account of this difference and the irregularity of shape, the hole will

not wear evenly during the subsequent turning. The position of the centre will gradually shift, and it will be found impossible to produce perfectly true work.

The centring machine above mentioned finds the true exact centre of the rough surface mechanically. The end of the bar is placed in a concentric chuck with four jaws, and these are screwed down upon it simultaneously. The centring drill, which is made to run exactly true with the jaws of the chuck, is then brought forward, and bores the hole without possibility of error in the exact centre of the largest circle that can be turned on the part gripped in the jaws of the chuck. In the case of bar iron, the ends are the important parts to get well centred. If when these are exactly true other parts of the bar are found to run untruly, they are to be corrected by bending the bar by striking it with a hammer on an anvil or some other solid resisting surface. The centring machine is not, however, applicable to pieces of large size. In the turning of shafting and spindles of all sizes it is a very valuable tool.

15. The mode of driving the work when it is placed between the centres, and other methods of fastening it in the lathe, will be presently described.

16. Parallel and Conical Bearings in Headstocks.—In Fig. 34, A and C, it will be seen that the mandril of the fast headstock runs in parallel brass bearings. These brasses are split horizontally, and the upper halves are held down by cast-iron caps, bolted to the standards of the headstock by studs and nuts. As wear occurs, these can be tightened up by screwing down the nuts. The end-pressure due to the traverse feed is partly delivered by a collar on the mandril to the face of the right-hand pair of brasses. The greater portion of this axial pressure is intended, however, to be borne at the left-hand end of the mandril. In the sectional plan C are seen two horizontally placed pillaret studs attached to the left-hand standard of the head-stock, and both at the level of the mandril centre. Across the extremities of these is bolted a small cast-iron bridge. The mandril thrusts upon this bridge through the intervention of a steel pin that is passed through it and is placed so that its centre-line is a continuation of that of the mandril. This bearing-pin has its ends screwed, and is clamped by two nuts, one on each side of the bridge. By turning these nuts in either direction, the pin can be set forwards or backwards to the right amount, so as just to bring the collar on the front end of the mandril into contact with the brasses without allowing any large amount of pressure to be borne by these brasses.

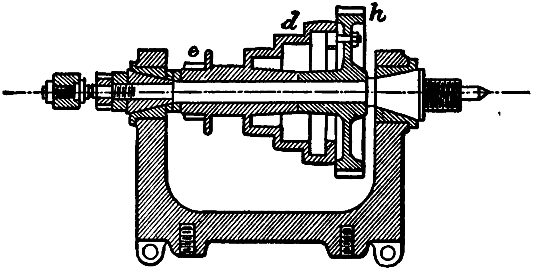

Fig. 35.

The mandril is kept from moving forwards axially by two nuts that are placed on a screwed portion of it, immediately behind the left-hand brasses. These nuts are screwed gently against the brasses, and tightly against each other.

Fig. 35 shows another system that is very commonly adopted for the mandril bearings. Here the bearings are conical and in solid brass bushes. There is here no utility in having a bolted-down cap over the brasses, so that these are simply placed in holes bored to fit them in the solid tops of the headstock standards. The wear is "taken up" by thrusting the cone of the mandril farther into the hollow cone of the brass. In the example shown, the two cones at the two ends are oppositely inclined. It must, therefore, be possible to draw the two cones on the mandril nearer each other as wear proceeds. The one is, therefore, made solid on the mandril, while the other slides loosely on a parallel portion at its back end which is screwed. On this screw there are two nuts, by means of which the sliding cone is pushed forward until the two cones fit closely into their brasses. A small part of the end feed pressure is borne by the conical surface of the front brass, but the main portion of it is borne at the extremity of the mandril by a steel bearing-pin, in a bridge exactly similar to that described in Fig. 34.

The two cones are not necessarily inclined oppositely as in this example. If, however, they are inclined in the same direction, that at the left-hand end must be made small. Its largest diameter cannot be larger than the smallest diameter of the other cone, in order that the spindle may be passed through the solid brass for this latter and put in place. This results in the screw for the nuts behind the left-hand brass being very small, as also the end of the mandril which rests against the pin for taking the axial thrust.

The construction (Fig. 35) with conical bearings is considerably less costly than that with parallel split bearings in Fig. 34. Opinion as to the relative merits of the two constructions independently of cost is divided. There is a common idea that the mandril runs truer in conical bearings when equally well finished as the others. The writer has, however, been unable to find any rational ground for this opinion. If the wear at the axial-thrust bearing pin takes place at the same rate as that at the conical bearings, then there may be an advantage in these after wear has taken place. This bearing pin can also be set back from time to time, as the wear of the brasses proceeds. But it must not be overlooked that the pressure on the brasses is constantly in one direction, so that the wear of these does not merely make them larger, but results in their becoming *oval.* To make them true once more, it is necessary to take them out, and either to re-bore them or to bring them back to the circular form by scraping. The same has to be done with parallel bearings, but not so often, because these can be tightened up in the direction of wear by the cap-bolts. Also when re-scraping at last becomes necessary, it is more readily performed on the split than on the solid brasses.

It is probable that the conical solid bearings are to be preferred, on account of cheapness, for small lathes, while in large lathes the parallel split brasses are decidedly the better.

17. Double Gear.—Upon the mandril in the fast headstock is mounted a stepped cone pulley. A belt from a similar stepped cone pulley on the "counter-shaft" overhead drives this. The overhead pulley has its large diameter directly above the small diameter, and its small diameter directly over the large end of the lathe pulley. The belt may be put upon any pair of the "steps." When it runs from a large size above to a small size on the lathe, the lathe pulley runs faster than the counter-shaft, and *vice versâ.* Thus for one and the same speed of the counter-shaft as many speeds may be obtained for the lathe pulley as it has "steps." In Fig. 34 there are five speeds, and in Fig. 35 there are four. If this variation of speed be considered sufficient for the purposes to which the lathe is to be applied, the pulley is keyed to the mandril, and drives it directly. In this case there are no other wheels about the headstock, and the lathe is said to be "*single geared.*"

In the lathe shown in Fig. 34 this number of variations of speed is doubled by the addition of extra toothed gearing, and the lathe is said to be "*double geared.*" In this case the cone pulley is not keyed to the spindle, on which it runs loosely. On the small end of the pulley is keyed a spur pinion, marked *e* in the sectional plan C and vertical section A. In plain bearings in the side of the headstock is placed a horizontal bolt, upon which revolves a hollow cast-iron shaft, having keyed to its ends the spur wheel *f* and the spur pinion *g*. This bolt can be shifted in position so as to stand nearer or farther away from the cone pulley. When placed in its nearer position, the teeth of *f* engage with those of *e*, and the teeth of *g* engage with those of the spur wheel *h*, which is keyed on the mandril on which the cone pulley revolves loosely. The cone pulley thus drives the wheel *f* at a slower rate than itself in the ratio of the number of teeth in *e* to that in *f*, which ratio is in the example shown $\frac{24}{70}$; and this being keyed on the same shaft as *g*, drives *h* and the lathe mandril at a still slower rate in the ratio of the number of teeth in *g* to that in *h*, or in this example in the same ratio again $\frac{24}{70}$. Thus the mandril runs slower than the cone pulley in the ratio $\frac{24}{70} \times \frac{24}{70} = \cdot 117$. With the belt on the five different speeds of the cone, five rates of slow revolution of the mandril are obtained.

When the bolt, or back shaft, as it is termed, on which are fixed *f* and *g* is moved to its position farther away from the cone pulley, these fall out of gear with the pinion *e* and the wheel *h*, so that the rotation of the pulley has no effect in moving *f*, and *g* does not interfere in any way with the motion of *h*; *h* can now be fastened to the cone pulley by means of the belt seen in figure A. The pulley then drives *h* and the mandril at the rate at which it runs itself. Thus, by again shifting the belt, five new speeds are obtained different from the previous five. The largest step on the cone has a diameter of about 16½ inches, and the smallest one of 4⅝ inches. As the sizes of the cone on the counter-shaft overhead are the same, the fastest of these speeds is faster than the slowest in the ratio $\frac{16\cdot 5 \times 16\cdot 5}{4\cdot 6 \times 4\cdot 6}$ = about 13. If the fastest of these speeds be combined with the double gear, which reduces the speed in the ratio ·117, calculated above, the resulting speed of the mandril will be 13 × ·117 = about 1½ times the slowest speed obtainable in single gear. Thus the two sets of speeds overlap each other, and the dimensions of the example are so arranged as to give two different methods of approximating to any desired medium speed. This is not entirely without utility. The medium speed in single gear causes less frictional waste of power, because of the spur gearing not being in action. On the other hand, in the use of the double gear for the medium speed, the belt passes over the surface of the larger end of the lathe pulley, and gets a better hold of it. At the same time it passes over the smaller end of the driving pulley overhead, but here the belt is somewhat tighter than on the lower pulley, in consequence of its own weight. This difference in tightness is slight, but a very small increase in tightness is sufficient to enable a considerably greater driving pull to be transmitted by the friction between pulley and belt.

The actual speeds of the lathe mandril in the example shown in Fig. 34, when the counter-shaft runs at forty revolutions per minute, would be approximately:

In single gear, 11, 22½, 40, 71, and 142½ turns per minute.

In double gear, 1½, 2½, 4½, 8½, and 16½ turns per minute.

18. The back shaft on which *f* and *g* (Fig. 34, C) are mounted is approached and receded from the cone pulley by having its ends turned eccentrically. By rotating the eccentric ends through half a turn in their fixed cylindric bearings, the centre line of the shaft is shifted, since that of the eccentric ends maintains its position unaltered. These ends are shown in C. It will be observed that while the left-hand end is solid in one piece with the shaft, the right-hand end is, on the contrary, a separate loose piece. This is necessary because the ends are made larger in size than the main body of the shaft, while this has to be passed through the ends of the hollow shaft, into which it is made to fit. It would be impossible to put the pieces together if both ends were larger than the intermediate part fitting the hollow shaft.

19. Loose Headstock. — In D we have a vertical longitudinal section through the movable headstock, or poppet-head. This can be shifted along the bed of the lathe into any position, so that longer or shorter pieces may be supported between the centres. The bolt, passing downwards through its centre, clamps it to the bed in any desired position by means of a small cross-bridge spanning the under side of the shears in the hollow space between the cheeks of the bed.

After clamping in this way, a further longitudinal motion can be given to the centre-point by means of the screw which is seen in the diagram to be attached to the small hand-wheel at the right-hand extremity of the poppet-head. The object of this wheel is to turn the screw. The screw is prevented from longitudinal motion by collars—of which one is formed by the boss of the hand-wheel keyed on it—on each side of a plate screwed fast to the end of the headstock. The steel centre is fitted in a tapered hole in the end of a cylinder, which may slide out and in in the interior of the head which is bored to fit it. A longitudinal groove, or key slot, is cut in this cylinder, and a feather in the casting fits in this slot and prevents the cylinder from turning. At the inside end of the sliding cylinder is a nut, into which the screw enters. Since the nut cannot turn, it must advance along the screw when this latter rotates, and thus the point is moved out and in.

20. As before explained, for parallel turning it is very important that the centre in this movable poppet-head should stand in exactly the same position relatively to the edges of the bed as does the centre in the fast headstock. If it stands a little to one side of this correct position, then the ordinary traversing motion of the slide-rest results in a smaller section being turned at the one end of the traverse than at the other, the difference in the diameters of the two end sections being twice the difference between the positions of the two centres, measured relatively to the bed. Advantage is frequently taken of this fact for slightly taper turning. For this object the movable poppet-head is purposely put backward or forward out of its true position by an amount corresponding to the degree of taper required. Some poppet-heads are for this purpose made of two parts, the lower being a flat plate on which the upper part may slide to a small extent. It is made to slide the desired amount by set screws and is then clamped in position. This construction is strongly disapproved by many good makers of tools because of the risk of the poppet being carelessly left set to one side, when work may be spoilt by its being forgotten to set it back to its central position for parallel turning. It is also a troublesome operation to set it again in this central position with the needful accuracy.

21. Modes of Driving and Chucking Work.—The front end of the spindle in the fast-head is screwed for the reception of various "*face-plates*," "*chucks*," and "*drivers*."

In Fig. 36 *a* shows a "driver" of the kind most commonly used. It is simply a small solid plate screwed on the mandril, and having firmly fixed in its face, near the edge, a strong projecting pin. The figure *b* represents what is in technical language called a "carrier." This is a cross-piece, to be fixed on the bar or other work to be turned. It has through it a hole of oval, or rather, egg-shaped, form. The bar is put through this hole, and is screwed down tight into the smaller end of this hole. In consequence of the tapering egg-shaped form of the hole, one size of carrier will admit, and hold fast, bars whose sizes differ considerably. The size of the bar being

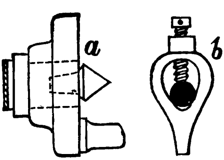

Fig. 36.

greater than that of the circle to which the small end of the hole is formed, it rests on two points at the sides of the hole. The end of the screw comes on a third part of the circumference of the bar, which is thus securely gripped between these three points. This carrier being placed at the extremity of the work, where it rests on the centre in the mandril, one or other end of the carrier catches on the projecting bolt of the driver, and by this means the rotation of the mandril is communicated to the work. The part of the work on which the carrier is fixed is ordinarily in the rough condition and, owing to the inequalities of the surface, a large amount of power can be transmitted by this fastening. When a similar carrier is used upon work that has already been turned, the driving effort is exerted wholly by means of friction, and on this account the thick end of the carrier, which forms the nut for the clamping screw, must be made longer than the usual length of a nut of corresponding diameter, in order that the bolt may be screwed down very fast without risk of stripping the threads. The carrier should either be forged or made of malleable cast-iron.

Sometimes the driver has two projecting prongs on opposite sides of its disc. If these are fixed immovably, it will be found that the opposite ends of the carrier seldom both catch on the prongs because of the two ends of the carrier not being alike. A bearing may be got on the pin at the small end of the carrier, so that this as well as the opposite pin should share the driving work, by slipping over it one or more short ferrules as packing between it and the carrier end. A number of pieces of ferrule of different thicknesses may be kept by the lathe ready to hand.

In Clements's driver the two prongs are upon a front plate, which may slide a short distance on the face of the plate screwed on the mandril. The prongs may thus be thrown to one side by an amount just necessary to let them both catch equally on the work, and in this position the front plate bearing these prongs is clamped by a couple of studs and nuts to the plate behind it. These drivers are a good deal used, but they do not appear to possess any superiority of merit that compensates for their extra complication and cost. Instead of a "driver" proper, a face-plate, with a bolt fixed in one of its holes so as to project from the face, may be used and does equally well.

22. Driving by Face-Plates.—The above carriers are made of various sizes, but never of such a size as to admit of their application to work of more than three or four inches in diameter. When the piece is larger than this, and is placed between the centre-points, it is usually driven by bolts, fastened so as to project from a face-plate such as that shown in Fig. 32. Such large pieces of work have ordinarily some projecting parts, either internal or external, which serve as abutments against which these bolts may thrust.

When the work has no great length in proportion to its diameter, it is not usually supported between the centres, but is secured rigidly to the mandril by either a face-plate or a "dog-chuck." The face-plate is simply a large circular disc screwed on the end of the mandril, and with a large number of square holes and rectangular slots cast in it. Through a convenient number of these holes are passed bolts, by which, with the help of clamping-plates, the work is firmly secured. This mode of securing it is especially convenient when a central hole has to be bored out in the lathe, and when flat surfaces perpendicular to the axis of rotation and of greater radial width than can be reached by the projecting length of the tool-shank, have to be cut. The movable headstock is slid back so as to be out of the way, and so as to allow the slide-rest to be brought near the centre of the bed.

When two such parallel surfaces have to be turned, the piece is bolted to the face-plate, in the first place, in its rough condition, and as nearly as possible in the correct position. The one face is then turned. This flattened surface is next bolted to the face-plate; and if this latter be truly perpendicular to the mandril, the second face may now be turned, with the certainty of getting it accurately parallel to the first provided it is made flat—that is, neither hollow nor round. This latter result is attained if the slide along which the tool-rest travels be accurately perpendicular to the mandril. It is evidently of the greatest importance to have the surface of the face-plate to run perfectly true. To ensure this it is in the first place necessary that it should screw on the end of the mandril quite tightly. The external and internal screws of the joint must, therefore, be made very carefully to fit each other. In the manufacture of the lathe after this fit has been attended to, the face-plate should be screwed in place, the lathe driven as it will be in after use, and the face-plate turned up in the lathe itself. This finishing of the face-plate in place is the only method by which it can be got true. In the course of time and use the thread of the screw may get slightly bent or otherwise injured, the fit between the face-plate boss and the mandril collar may get worn, and the metal of the plate may warp slightly. To re-true the face-plate, it should, in the first place, be bolted with its face against the face of another face-plate, either on the same or another lathe that has been ascertained to be true, and the back face of the boss should be trued up. The front face of the mandril collar should then be re-turned, and finally the face-plate screwed against it in the ordinary position and re-turned.

Two or three face-plates of different sizes should be furnished with every lathe that is intended to do a variety of work. For very large lathes they are the almost exclusively employed means of fixing the work. Those of these large lathes that are used chiefly for plane surfaces are called "face-lathes," and have generally only one large face-plate, which is kept permanently fixed to the mandril. Such a large face-plate may be seen in

Fig. 38 (Plate VII.), which represents one of 7 feet 6 inches in diameter.

23. Driving by Jaw-Chucks.—A third way of fastening the work to the mandril is by means of "dog-chucks." These are used for the same sort of work as are face-plates, but are only suitable for moderately small sizes.

The commonest form is the 4-jaw chuck, an example of which is shown in Fig. 34. There are four radial screws in the face-plate, marked *k′*, and seen in the figs. A and B. Near the edge of the plate the shafts of these screws are squared down, so that they may be turned by the application of a box key. They are prevented by a collar from moving radially, and each passes through a large nut that may slide to and fro in a radial slot, but is prevented by the sides of this slot from turning. The rotation of the screw thus forces the nut inward towards the centre, or *vice versa*. The nut forms part of a piece that projects from the surface of the plate in the form of a miniature staircase of two, three, or more steps. There being four of these on two rectangular diameters of the plate, the work is gripped between the four of one series. There are also sometimes one or two steps on the part of the jaw farthest from the centre, in order that the work may be grasped by an internal surface. The cylindrical faces of the steps directed towards the centre, as also the outer cylindrical faces, are ribbed, so as to grip more securely on the work. These pieces are called the "dogs," or "jaws." Each may be screwed in independently. The ribbed surfaces should be either faced with steel, or at any rate case-hardened, because the gripping pressure applied through them rapidly wears the ribs down, after which they cannot be depended on to hold securely. The gripping pressure is applied only, and not maintained, by means of the screws. From the back of each nut a stud stands out behind the face-plate. This stud being screwed, a strong washer and a nut serve to clamp the dog in any position on the plate to which it may be brought by the radial screw.

Similar chucks are made occasionally with two dogs only, and more frequently with three. If the cutting power proposed to be applied can be transmitted by the frictional grip of three dogs, this arrangement is more scientific, as well as cheaper, than that with four, three being all that are needed in order to keep the work centrally in place.

These dog-chucks are, of all methods of fastening the piece to be turned, the most unsatisfactory. There is a continual tendency to drag the piece out of the jaws forwards. The cutting pressure of the tool does not only tend to hinder rotation. Its moment to hinder the rotation of the mandril is equal to the product of the force by half the diameter of the section being turned. But the force also exerts another moment, tending to lift the right-hand end of the work bodily up—that is, tending to rotate it round a horizontal axis passing along the face of the jaw-chuck. This moment is equal to the cutting force multiplied by the horizontal distance by which the point of the tool stands from the jaws. At each instant its effort is exerted to tear the work out of the jaws at the lowest point, and to push it farther in at the topmost part of the chuck. Each jaw comes alternately to the top and bottom, and the above action results in each part of the work being pushed in and pulled out with very considerable force once per revolution. The consequence is that the grip which the jaws have of the metal is gradually loosened, the work may shift in position, and not unfrequently the turner finds that it has done so in the middle of his operations, so that the latter half of the parts he has turned are not concentric or coaxial with the former half. He has then to loosen his chuck, re-set the piece, tighten up the jaws once more, and go over the whole work a second time in order to true it—if, indeed, he does not find that he has already cut so much material off as to leave him nothing, or insufficient to enable him to make this correction.

These jaw-chucks have one other defect, in that it is difficult to get the face of the work to lie close against the flat face of the jaw. The flat faces of all the three or the four jaws are turned together, so as to form one accurately plane surface perpendicular to the axis of rotation upon which it is intended that the work should be in close contact. But when the jaws are tightened on the work, any little irregularity on the cylindrical surface that is thus grasped leads to one or both sides being slightly thrust forward, so that the two faces which are desired to be together are separated by a small space. Thus two accurately parallel faces cannot be turned in a chuck of this sort as they can on the face-plate as explained above.

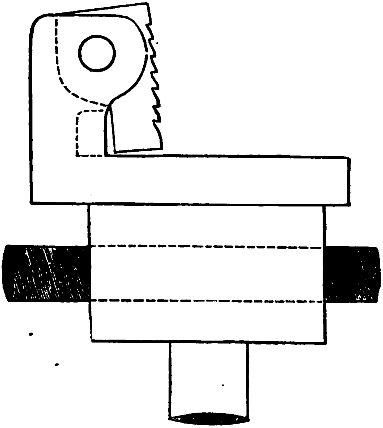

Fig. 37.

The construction shown in Fig. 37 has been designed to rectify these faults as far as possible. The ribs on the jaw are slightly pointed towards the face of the plate, being shaped like the teeth of a saw, so as to hold the work better in the direction most needed. The jaw is made in two parts, the one with a nut and clamping stud and shaped like the common jaw, the second hinged to this and forming the gripping face, or actual jaw. This second part is wholly made of steel, and being of small size, is inexpensive and can easily be renewed if the teeth become broken or worn away. Behind the foot of this smaller piece there is inserted in a recess drilled in the larger one a small block of india-rubber or a small spiral spring. This throws the hinged part into the oblique position shown in the diagram, so long as there is no pressure applied to the toothed face. The upper back edge of this part rests against the back of the recess in the hinge casting, and the jaw is thus prevented from being thrown out by the spring to any greater inclination than that shown in the figure. When the jaw is screwed down on the cylindrical surface of the object to be gripped, the spring is crushed back, and the jaw recedes to a position perpendicular to the plate. In this backward motion all the teeth have a small component movement towards the plate. Since they are at the same time always bearing harder and harder on the work, and are becoming to a minute degree pressed into and embedded in its surface, they effectually prevent any risk of the work separating farther apart from the plane face than it has been set, and, on the contrary, draw it down close on that surface with very considerable force.

24. Concentric Jaw-Chucks. — The jaw-chucks of which a description has been given in the last paragraph, all have their jaws, or dogs, moved independently by separate screws. The jaws themselves, therefore, are of no use for the purpose of centring objects in the lathe. This must be done by trial and error, the error being discovered by running the lathe with the work clamped in the chuck and marking it with chalk to show the high places, and the correction being applied by screwing one jaw outwards and the opposite one inwards to the same extent. This process occupies some time; and if the lathe is used for odd jobs, each of which takes only a short time to finish, or for work which has to be frequently taken out of the chuck and re-set in it—as, for example, in turning pins which are to be exactly fitted in the lathe to the holes in which they are to be inserted—there is expended in this centring operation a considerable and wasteful proportion of the whole time spent in the work. In such circumstances a chuck in which all the jaws are made mechanically to move simultaneously out and in from and to the centre by precisely equal amounts is of very great advantage. Such a chuck is called a concentric jaw-chuck. If the jaws are once placed so as all to lie accurately in one cylindric surface whose axis coincides with that of the lathe spindle and of the chuck, then the jaws may be moved together to any other distance from the centre, and they will still be accurately in one and the same cylindric surface concentric with the mandril. The jaws themselves, therefore, will bring any object clasped in them to coincide axially with the mandril. The work is thus mechanically centred.

There have been invented many forms of chucks of this description. The different jaws have to be connected by one or other kind of gearing, and this complication in the construction makes the chuck not only expensive in first cost, but also very apt to get broken if not used with special care. These disadvantages, however, do not by any means counterbalance the great saving in time attained by their use in the class of work above mentioned. But they are not suitable for large lathes, and, therefore, have never been made except of a small size.

The pattern that is at present the most favoured—and will continue to be so until something new and simpler has been invented—is Weston's American Scroll Chuck. This consists of four plates, which are put together so that three of them are immovably attached to each other and form one rigid piece, in which there is a deep circular groove. In this groove the fourth plate fits, and can revolve. This revolving plate has a square-thread spiral cut on its face. In front of this spiral there are cut three radial grooves in the face of the chuck, and in these slide out and in three stepped jaws. These are prevented from falling forwards out of the grooves by feathers running radially along the edges of the grooves. The back or interior surface of each jaw has formed on it several square teeth which fit into the spaces between the successive turns of the thread of the spiral. When the spiral plate is revolved without any corresponding rotation of the jaw-plate, the jaws, being in gear with the spiral through their teeth, are compelled to move radially, and all move by the same amount.

The jaws of this and the other previously mentioned chucks are too large to admit of their coming so close together as to grip pieces of very small diameter. A special chuck, called a drill chuck, is required for this purpose. It is a concentric chuck, and does not differ in principle from that last described. Its jaws have very narrow faces, and the whole instrument is of small size. It is suitable for use in small lathes.

25. Function of Lathe Bed.—The bed of a lathe has two functions. In the first place, it bears the slide-rest and the two headstocks. The cutting thrust on the tool is delivered to the bed by the bottom plate of the slide-rest, and is transmitted by it horizontally to the points at which the headstocks stand. Between these two latter points the bed acts as a beam, loaded at a point intermediate between its supports. The dimensions of the section, of which the depth is most important, need not be calculated with reference to strength. The depth chosen is always enormously in excess of that needed to prevent breakage from the tool-thrust. Considerations of *stiffness* rather than of *strength* ought to regulate this depth. For accurate work it is evidently necessary that the bed should not yield in the minutest perceptible degree to this force. If it did, the position of the tool would sink, and regularity of the diameter cut would not be maintained. The fact that the piece of work being turned is nearly always pliable to a greater degree than the bed, and that, therefore, inaccuracy is more to be feared from the spring of the work than from the spring of the bed, is no good reason for making the bed weak enough to have appreciable spring. The spring of the work is unavoidable; it occurs as a necessity of the shape required to be given to the work; that of the bed is avoidable, and there is the more reason to avoid it because the other source of error is inevitable.

The other function of the bed is to guide the tool-rest in its traversing motion. It is necessary that this guidance should keep the motion of the saddle very exactly in one straight line throughout its whole length, and that this line should be accurately parallel to the line between the steel centres. It is of the greatest importance, therefore, to have the upper surface of the bed quite plane, and the edges perfectly straight. These are not only planed very carefully in a planing machine, but are also scraped up true throughout their whole length. The vertical edge is necessarily very limited in depth and therefore does not present a large wearing surface. It is well worth considering whether this edge may not with advantage be made considerably deeper than is at present usual. The under oblique surface of the dovetail projections also partake in the work of guidance. Their straightness and exact flatness require to be attended to as carefully as those of the other finished surfaces of the bed. If the thickness of this dovetail be not exactly uniform from end to end of the bed, or if the angle which its lower surface forms with the upper horizontal surface be not maintained precisely regular throughout the same length, the result is that the dovetailed groove of the saddle that spans the groove and should clasp it with the proper degree of tightness, will fit tightly at some places and loosely at others. If this is so, the straightness of the guidance is inevitably lost, and it is thus evident that the careful formation of the under surfaces of the dove tail edges of the bed is as important as that of any other part.

26. Size of Lathe; Gap-Lathes.—The size of an ordinary lathe is stated by the vertical height of the steel centre-points above the flat upper surface of the bed. If this surface be continued underneath the work, it is evident that the diameter of the work cannot be greater than double this height. Indeed, no portion of the work underneath which it may be necessary to bring the saddle of the slide-rest can be of so great diameter. In this case the largest possible diameter is less than the above by twice the thickness of the plate forming the saddle. This does not imply, however, an impossibility of operating upon parts of the work of greater diameter than this, because the cutting-edge of the tool may be made to project to either the right or left of the rest, so that it may cut on a part that does not lie over the saddle. The tool being held so that the saddle does not interfere, the size of the object turned may be twice the height of the centres above the slide-surface of the bed; or it may be even greater than this, if part of the bed be cut away so as to allow the work to come below its upper line.

Lathes whose beds are shaped in this way are called "gap"-lathes, because there is an opening or gap between the part of the bed on which the fast headstock stands and that on which the slide-rest moves.

Between these two parts the bed is bent downwards in the shape of a crank. The bed is continued of its full depth throughout this cranked portion, so that the whole retains nearly all the stiffness it would have if it were not so cranked. The gap is 6 to 16 or 18 inches wide, according to the size of the lathe. The length of the large part of the work is limited by the width of the gap, and its size may be twice the height to the centre from the bottom of the gap. When the gap is not required, it is filled up by a bridge-piece fitted carefully to the planed edges of the gap, and bolted down securely to the under part of the bed. If the bridge-piece is made to fit very exactly, and is properly fastened, it strengthens the bed so that it may be as stiff as if the gap did not exist; but this will not be effected if there is the minutest degree of slackness in the fitting of the piece.

27. **Break-Lathe.**—In this last construction the continuity of the bed is maintained from end to end, although the straightness of its top surface is sacrificed to the gap. When the size of the work is to be so much greater than the height of the centres that the depth of the gap would be inconvenient, the bed is made in two pieces, each of which is bolted on a shallow base-plate on the ground. The one part is fixed permanently at one end of this lower plate, and carries the fast headstock; the other may be shifted nearer or farther from the first, so as to leave the space between them narrower or wider. This construction is referred to by the name of "break-lathe." On the second right-hand portion of the bed stands a movable poppet-head and a slide-rest, to which can be given a self-acting traverse feed motion by means of a longitudinal shaft near the level of the ground. The shaft is slotted throughout its length for the reception of a feather upon a pinion which slides along it, and forms the connection between it and the gear, actuating the feed motion. By means of this gear, not only a traversing, but also a surfacing, feed may be obtained.

28. **Face-Lathe.**—In what are termed "face-lathes" the work operated on has only a small axial length, so that the length of traverse feed required is not more than can be given by the motion of the upper upon the lower part of the slide-rest itself. At the same time, a large extent of surfacing motion is required to be given to the tool. In these lathes, therefore, the bed for traversing the slide-rest upon is discarded altogether. Fig. 38 (Plate VII.) shows such a lathe. A very large face-plate, in the example illustrated 90 inches in diameter, is mounted on the mandril, about 8 inches in diameter, of

a correspondingly large headstock. This is secured by four large bolts to a strong base-plate of about 8¼ inches deep. This plate extends no farther than the front of the headstock. In front of this lies a second base-plate, which is marked *p* in the diagrams A, B, and C. It has only a small breadth in the direction of the axis of the mandril, but stretches parallel to the face-plate a distance of 10½ feet to one side of the centre. In the direction of its length it has three pairs of undercut grooves planed in its surface, which receive T-headed bolts by which to fix in any desired position the bottom plate of the slide-rest. The slide-rest is a high massive pile of five pieces, movable one over the other. The lowest of these stretches over two of the three pairs of grooves. It may stand over the space between the second and third pairs of grooves, or may be shifted into the space nearer the face-plate between the first and second pairs. It is moved along these grooves to any desired distance from the centre of the face-plate by hand with the assistance of a crow-bar. This lowest plate is marked q_1, and on its upper surface is a pair of grooves at right angles to the direction in which it is movable. In these lie the T-heads of bolts which fasten the second piece q_2 to q_1. This piece is moved by hand along these grooves to any desired distance from the face-plate, and clamped in that position by the bolts. It has a height of 16 inches. Its upper surface is a horizontal circular table, on which the third plate q_3 rests. In q_3 are circular grooves which allow it to be slewed round so that the slides above q_3 may run at any specified angle to the surface of the face-plate. The upper part of q_3 is a long dovetailed slide, in which the screw r_1, gives a surface feed motion to the plate *r* that lies above q_3. This plate *r* has a similar, but much shorter, slide at right angles to that on q_3, and a screw having bearings in *r* gives traversing motion to the uppermost plate *s*, upon which is clamped the tool in the usual manner. The two upper slides may be worked by hand, or may be made self-acting by a ratchet-wheel and pawl. The pawl is oscillated by a chain which hangs from a short lever on an overhead rocking shaft. The shaft extends along the roof of the workshop to over the hindmost end of the headstock. Here a small disc crank, with its crank pin in a radial slot, so that it may have different throws according to its position in the slot, drags downwards once per revolution of the mandril the end of a chain attached at its upper end to a second lever on the rocking shaft.

In the surfacing bed-plate *p* the space between the two further pairs of grooves is filled up by a strong web of iron. That, however, between the first and second pairs, and partly directly underneath the face-plate, is left open. Underneath this open space in the base-plate is dug in the foundation a trench, in the form of a quarter circle. This space is left open, in order to admit of flat objects of great diameter, such as large fly-wheels, being turned. Pieces of twenty feet diameter can be taken in the lathe illustrated.

The two base-plates of this lathe ought to be placed upon a solidly-built foundation of concrete, and bolted down firmly to it, in order that both may at first be placed accurately level, and thus have the plane of the second parallel to the axis of the mandril, and that they should maintain this relative position permanently. If the adjustment of the one plate to the other be disturbed by the sinking of part of the foundation, then the traversing slide remains no longer perpendicular to the face-plate, and it becomes a very troublesome job to turn a surface truly cylindrical.

29. Treble Gear.—This lathe is "treble-geared": that is, with the belt running upon any given step of the cone pulley, the face plate may be run at each of three different speeds, according to the arrangement of the spur-wheels and pinions. As there are five steps on the cone, there are, therefore, fifteen speeds at which the lathe may be driven. The cone runs loosely on the mandril, and at its large end there is a spur-wheel, which is keyed on the mandril. The pinion on the back shaft being slid along this shaft so as to be out of gear with this wheel, the wheel may be bolted directly to the cone pulley, and thus the fastest of the three speeds is obtained. The second is obtained through the pinion *f*, cast in one piece with the cone, gearing into the toothed wheel *g*, and the pinion *h* gearing into the wheel *i*, which must now be unbolted from the cone pulley. On the back of the face-plate is bolted a large internal spur-wheel, marked *n*. Into this gears a pinion *m* on the end of the shaft *d*. This shaft lies below the shaft *c* carrying *g* and *h*. Its level is seen in the side and end views A and B. At its back end it bears the wheel *l* that engages with the pinion *k*. This latter is keyed on the back shaft *c*. The pinion *m* can be put in or out of gear with the large internal toothed wheel by sliding it along the shaft, there being a key slot in the shaft and a feather in the pinion. When it is in gear, *h* must be out of gear with *i*, and this latter must also be unbolted from the cone pulley. This arrangement gives the slowest speed of rotation, and is suitable for turning very large diameters.

It may be observed that the bearings of the mandril of this lathe are unsplit conical ones, and that the end thrust is taken by a steel pin in the bridge, bolted to the back end of the headstock in the manner previously described.

30. Wheel-Lathe.—Fig. 39 shows a lathe specially constructed for turning the tyres of locomotive and waggon wheels. A is a side and B an end view. It will be seen that there are here two slide-rests, the two wheels being fixed on their axle before being put in the lathe and the tyres being turned up simultaneously.

There are no face-plates to this lathe. The ends of the wheel axle are clasped in cone chucks, which are then bolted to the bosses of the spur-wheels l and l_1. These occupy the usual place of face-plates. These outside spur-wheels are driven by the pinions k and k_1 on the shafts i and i_1. These carry the wheels h and h_1, gearing with the pinions g and g_1. The latter are keyed on a shaft f_1, that stretches the whole length of the bed. In the centre of its length the shaft f_1 carries keyed to it a toothed wheel f, and this engages with a pinion on the end of a shaft d_1 that lies from the centre of the length of the bed to the left-hand end of it. At this latter end there is keyed upon d_1 the three-stepped cone pulley d, on which the driving belt runs.

The mandrils bear two small wheels that drive the similar wheels r and r_1. These have discs with radial slots in their faces, and a crank-pin fixed at the suitable positions in these slots actuate a chain feed-motion similar to that described for the lathe mentioned and illustrated in Fig. 38.

There are other forms of lathes constructed for special purposes, but those already described are sufficient to illustrate the chief modifications to which this important machine tool is subjected. The lathes specially made for internal turning, or "boring," are described in a future chapter. The next chapter will treat of the cutting tools used in the lathe and some of the smaller appurtenances of the machine.

CHAPTER VII.

CUTTING TOOLS FOR LATHES.

1. Point of Application of Tool.—The points of lathe tools are applied at the level of the centre points. The tool requires to be held at a certain angle to the direction of the cut—that is, to the tangent to the circular section being formed. There is no special difficulty in placing the tool at such a desired angle

whatever be its position above or below the centre level, and it would also be easy to fix it in a tool-box in any such position. But the slide of the tool-rest being level, when the tool is advanced towards or withdrawn from the line of the centres, it is evident that the tool point remains always at the same level; and if it is at one distance, a certain amount, say, below the centre, then it will be always below it by that same amount. In consequence, if in one position it is set so as to be perpendicular, or at any other definite angle to the cut, that angle would not be maintained, but would become smaller when the tool is advanced so as to cut a circle of smaller diameter. If it is set right for one size of section, it will not be right for any other size. This variation, however, does not take place if the tool is placed at exactly the level of the centre. It is in order to avoid the extreme inconvenience of altering the setting of the tool anew for each new size it has to turn that it is placed at the centre level, and not, as is frequently imagined, because this particular point of the section is in any essential way specially suited for the application of the cutting thrust.

When the diameter of the work is large it makes no appreciable difference in the cutting whether the tool is a small distance higher or lower than the centre, because on a large circle a small height corresponds to only a very small angle; but for small work a very little error in the setting of the tool to the correct level makes a very considerable difference in the angle between the tool and the work, and makes a correspondingly great difference in the cutting capability of the tool.

2. Since the edge is placed in this position, evidently every part of the surface which it is at any instant cutting stands vertically at that instant. The angle, therefore, between any surface of the tool and the vertical is its inclination to the direction of the cut, and the inclination of any such face of the tool to the horizontal is the same as the angle between it and the normal to the cut surface. It is simpler to speak of these inclinations

to the vertical and horizontal, but in what follows it must be remembered that the angles referred to are those made with the cut surface and its normal, and that if, for any special reason, the tool be placed higher or lower than the centre level, the phraseology used in subsequent paragraphs becomes literally incorrect.

3. Cutting Face; Top and Bottom Rake.—In all lathes, with one exception,* the surface being cut moves vertically *downwards*, so that each portion of material about to be separated in the form of a shaving lies *above* the tool. The upper surface of the tool edge is, therefore, that which forces the shaving aside, and it is in consequence called the "cutting face" of the tool. The chief point of importance in the formation of the tool is the angle which this cutting face makes with the horizontal, and this angle is technically termed the "top-rake" of the tool. There are curious differences between different metals in this respect, some of them in being cut requiring much more top-rake in the tool than others. Different amounts of rake are also desirable, according to the depth of cut taken on the same metal.

The angle between the under surface of the tool that slopes downwards from its cutting edge and the vertical is what Holtzapffel termed the "angle of relief," and is very commonly referred to as "bottom-rake." The only object that there is in cutting away the under surface of the tool in this way, and not leaving it vertical, is to avoid its rubbing against the cut surface and thereby causing unnecessary frictional resistance to the motion of the lathe and the generation of injurious heat. It may be shown that with ordinarily-shaped tools the cutting point exerts a very considerable horizontal pressure inwards as well as a vertical pressure. This is easily proved experimentally by loosening the collar on the screw of the surfacing slide so that the tool-rest may be

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* That of Whitworth's, in which two tool-holders on opposite sides of the work are used, the one tool being placed, as it were, upside down.

easily pushed in or out. If the lathe be started and a cut be taken in this condition, the tool is immediately pressed outwards by the work, so that the depth of the cut rapidly diminishes to nothing.* The amount of the radial pressure thus illustrated depends on the amount of the top-rake, the pressure being less the greater this is. The radial pressure crushes the material inwards to a minute extent. This springs outwards again immediately it has descended below the cutting point, and the result is that for a very small distance below this point the surface is not actually vertical, but is inclined outwards from the vertical. If it were not for this, a much smaller angle of relief than is necessary would be sufficient. Professor Hart of Carlsruhe, whose work on machine tools contains the best descriptions of this class of machinery that has yet been published in book form, gives as the proper angles of relief 4° for cast-iron, and 3° for wrought-iron and gun-metal. The above-mentioned projection of the surface under the point of the tool extends, of course, for a minute distance only, and this angle of relief is by no means *necessary* throughout the whole depth of the tool. But if the surface be ground to a straight bevel, it is impossible to give the requisite angle to the top part of it without giving it throughout the whole depth. There is no harm in grinding the surface hollow, whereby less rake is given to the lower part of it where it is not needed and more to the top, and this method of grinding is often employed by workmen. There is, however, no advantage in it, because the additional amount of metal left at the bottom in no way strengthens the tool.

No more bottom-rake should be given than is just necessary to avoid friction between the tool and the work. The solid angle of the tool edge, which is called

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* This is so with tools whose cutting angles are upwards of 50° or 55°. With a larger amount of top-rake, however, there is often an opposite tendency exhibited, namely, for the tool to run into a deeper cut.

the cutting angle, equals a right angle minus the sum of the angles of top and bottom rake. Thus the cutting angle becomes less the greater either rake is made, and the tool edge becomes weaker with the decrease of the cutting angle. As has been proved mathematically in Chapter V., when treating of planing tools, the greater the top-rake is made the greater becomes the frictional pressure of the shaving on the cutting face of the tool; but it is certain that within pretty wide limits the whole thrust necessary to drive forward the tool is less the larger the top-rake is. This angle is, therefore, made as large as possible consistently with getting a cutting angle such as will give sufficient strength to the edge. It is for this reason that the bottom-rake must be made as small as may be.

4. Cutting Angle.—Hart gives, as the result of a long series of experiments, 51° as the best cutting angle for wrought-iron, the same for cast-iron, and 66° for gun-metal, these angles for lathe tools being the same as have already been given for planing tools. He says that the best angle is the same for all depths of cut. This last statement does not, however, accord with the writer's own experiments, nor with common practice in workshops, where a somewhat greater amount of top-rake is always thought advantageous for the heavier cuts. As will be seen afterwards, the cutting force varies with the depth of cut in such a way as to show that it is probable that there is a special rake most suitable for each depth of cut.

Hart's experiments were directed towards finding the angle that gave the least force required for cutting without reference to the endurance of the tool edge. In taking account of the due importance of getting the edge to stand well without becoming dull, it is found necessary to make the cutting angles larger than the above amounts. The power required to cut is increased very greatly by dulness of the edge; in fact, such dulness simply means the wearing away of the accurately sharp edge, so that the real cutting angle becomes very much larger than the apparent angle. As it is impossible to be perpetually removing the tool for the purpose of sharpening it, it would be absurd to start with an edge such as will rapidly become blunt, even if it has the angle which is proved to be best, because it will rapidly lose that angle and be converted so as to have an angle much worse than would be left after the same amount of work if at starting the edge had been made not quite so keen. The actual cutting angle commonly used on wrought-iron and steel for heavy cuts is, therefore, 10° or 12° greater than the above, while for cast-iron it is best made a few degrees still greater.

If the cutting angle be 65° and the bottom-rake 3,° these leave 22° as the angle of top-rake. These are probably about the best angles for ordinary roughing-out work in wrought-iron and steel, while a few degrees larger cutting angle is suitable for cast-iron, and about 80° for brass. In finishing, the angles are often left unchanged, but a better result may be obtained by increasing the cutting angle in each case by from 5° to 10°.

5. Faulty Formation of Cutting Face.—It would be very easy to obtain whatever amount of top-rake is desired at every part of the cutting edge if the cutting edge were simply one straight line. This is approximately the case with tools used for taking finishing cuts. The depth of shaving is here very small, and its breadth comparatively large. All except a very small length at the forward corner of the edge is parallel to the finished surface of the work. But it is not so when deep cuts are being taken. Fig. 40 represents the plan of a tool

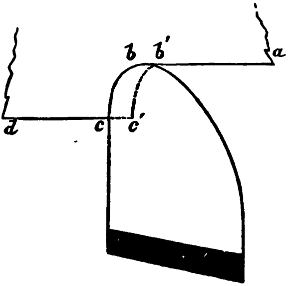

Fig. 40.

point that is being traversed to the left-hand and has cut along the line *ab*, the depth of shaving being the distance between the lines *dc* and *ba*. The section of the shaving being removed is shown between the full line cbb^1 and the dotted line cc^1b^1. The portion of the cutting edge that is in operation is the curved line cbb^1. The length bb^1, which equals the amount of traverse-feed per revolution of the work, is parallel to the finished surface b^1a, and the portion corresponding to bb^1 (*i.e.*, of which bb^1 is a plan) of the surface in the act of being cut is vertical and parallel to the axis of rotation. The portion of this surface near *c*, however, is vertical and perpendicular to the axis of rotation. Between *c* and *b* there is a series of strips of this surface that are all vertical, but have all shades of inclination to the axis of rotation. Suppose, for the sake of simplicity of statement, that *bc* is the quadrant of a circle, then the cut surface immediately below it forms a quadrant of a vertical cylindrical surface of circular section. The under surface of the tool should be equally inclined at all points of the cutting edge to this cylindrical surface, namely, at an angle of 3°. It should, therefore, be ground to the form of a cone, the angle at whose apex is twice 3°, or 6°.

There is no difficulty in so grinding this under surface at 3° to the horizontal plane at every point of the cutting edge, whether this be circular or of any other shape. Similarly the upper face of the tool should be inclined at 25° to the horizontal plane at every point of the edge, and if this be circular, the result would be that the upper face should be shaped as a hollow cone whose apex angle is $(180°—2 \times 25°) = 130°$. This is impossible to perform accurately by any process of grinding or other means of renewing the sharpness of the edge. But it is to be observed that only the front and one side of the plan of the point are employed as cutting edges, and that the hollow upper face need not be conical all round. If one quarter of the hollow cone were formed, the rest of the surface to the right-hand side might be left open, sloping downwards as a continuation of the left-hand conical part. A trough of this sort that will give approximately the quarter-cone surface on the cutting side can be ground out on a small-sized emery-wheel with a round edge.

Such an upper surface is not often given to their turning tools by workmen, but it is to be strongly recommended, and many intelligent turners produce a hollowed top-face that is in effect not greatly different from that described. The trough they give the tool has curvature in one direction only, this being the fault of the grindstone or emery-wheel being too large in diameter, since the proper double curvature can only be produced on a wheel of very small size; and it has, besides, the other fault of being ground too straight across the tool, as seen in plan, instead of obliquely at an angle of from 30° to 60° to the tooled surface according to the shape of the point in plan.

6. Side-Rake.—These remarks apply to all lathe tools with rounded points, or "round-nosed" tools, as they are called. All such tools are gradually traversed in one direction or the other, and, therefore, the cutting portion of the edge is confined to the front part, parallel to the work and to *one side.* The tool *never* cuts on *both sides* of the front part.

The angle of inclination to the horizontal of the part of the cutting face lying immediately behind the front of the edge is called the *front top-rake*; that of the portion sloping away from the side of the edge is called the *side top-rake.*

If the cutting face be ground flat, with its plane parallel to the centre line of the lathe, there can evidently be no side-rake on the tool. Such a tool is very disadvantageously formed for a deep cut and a traversing motion. This form is much used, however, especially for finishing cuts. Evidently it may be traversed equally well in either direction. It may be termed a "front tool."

Tools with side-rake can evidently be used each with a traverse in one direction only. A tool ground for a traversing motion towards the left-hand cannot be used with a motion towards the right-hand. Side-rake must, therefore, be distinguished as left-hand and right-hand, the former being that in a tool whose side cutting edge lies to the left-hand of the tool, and whose left-hand edge is, therefore, higher than its right-hand edge.

A tool without any side-rake not only cuts much worse at its side edge, but also requires a large amount of force to move the slide-rest in its traversing motion so as to make the tool feed forwards. A tool which is given the full due amount of side-rake, on the contrary, requires very little power to drive it onwards in its traversing motion, and a correspondingly small amount of wear takes place in the self-acting feed-gear, whether that be a rack and pinion or a leading-screw and nut. In a book entitled "The Complete Practical Machinist," by Mr. Joshua Rose, an American mechanic, it is said that sufficient side-rake may be given to a tool to cause it to feed itself into its cut—*i.e.*, to require no force to be applied to the slide-rest to draw it along the bed.

7. Straight-edged Tools.—Straight-nosed tools, as distinguished from round-nosed, are those whose cutting edges are straight lines. The edge may be a single line, and this line may be either horizontal or inclined to the horizontal, and in either case the line must lie in a vertical plane parallel to the line of centres. For finishing, a single straight-line edge, very slightly inclined to the horizontal, is very suitable. The effect of the inclination of the edge on the sectional shape of the shaving is the same as if the edge were very slightly rounded, *i.e.*, to an extremely flat curve. The cutting face slopes slightly downwards to the right, besides slanting backwards for top-rake, and thus the shaving is thrown off easily, curling over to one side. The under front face (that to which bottom-rake is given) should not be ground so as to be parallel to the line of centres, but should lean a little towards it on the right-hand side, the effect of this being to keep the edge in the vertical parallel plane above-mentioned from which it would deviate if this were not done.

The edge may also be made up of two straight lines. The angle between them is very various in actual tools. Tools for cutting screw-threads are given the angle desired in the groove between the threads. Other tools are specially formed for cutting out rectangular corners, and in them the angle between the two parts of the edge is made 3° or 4° less than a right angle, so as to enable the point to get into the exact corner without both the edges cutting simultaneously. These corner tools are usually required to be bent round in a horizontal plane to the right or left hand for opposite situations of the corner, and they are called right and left hand tools according as they are bent right or left.

Sharp-pointed tools with two straight edges meeting at the point are sometimes used for plain cutting with a traversing feed. The surface cut by such a tool is evidently a V-threaded screw. There does not appear to be any advantage in this form. Both edges cut. Professor Willis investigated the geometrical properties of such a tool with a flat upper face, with the result of showing it to be impossible to combine fair cutting angles with sufficient strength. The whole value of Professor Willis's investigation lies in this negative result: he recommends the above form of tool, but on mistaken grounds. The objection to it is that there is a back cutting edge as well as a forward one, which makes it impossible to use side-rake. This fault in the tool is removed by grinding off the sharp point (which is in any case sure to become worn away rapidly) with a small straight or slightly-rounded facet, of a breadth rather more than the greatest traverse feed to be used with the tool. The cutting edges then become one of the oblique sides only and the facet, and, the other edge becoming then of no use, side-rake may be applied. If the symmetrical form of the tool is to be preserved so that it may be used with a traverse in either direction, then the advantage of having the right cutting angle at some portion of the edge must be sacrificed.

8. Side Tools.—When a large plane surface perpendicular to the line of centres is to be turned, the tool is clamped in the rest with its shank at right angles to the surface. This is possible so long as a cylindrical continuation of the work standing out from the plane surface does not interfere with the tool-rest moving into position, so that the tool may reach the inner portions of the plane. At this inner corner, however, the tool-rest could not be advanced sufficiently near the centre, and recourse must be had to a "side tool" clamped in the rest, with its shank parallel to the plane turned surface. This is a tool with its end set out to one side, so that a straight side-cutting edge may be formed on it, which may operate on a surface from which the body of the tool stands clear by a small distance. The cutting edge may be made long or short, according to the work to be done. It stands radially along a horizontal diameter of the plane surface being wrought, and all the rake required is side-rake. All faces of collars on shafts, etc., and similar work, must be treated so. If the collar is not deep, an ordinary right or left hand corner tool may be sufficient; but if it is a large one with a broad surface, side tools must be used with which to finish off the plane faces.

9. Springing of the Tool.—It has already been said that if the tool be not held firmly up towards the work it will "run out of its cut." It will do so, at least, unless an excessive amount of top-rake has been put upon it. There is, however, an opposing influence which sometimes tends to make the tool cut deep when it meets with any extra resistance. This is the pliability of the tool itself. If the tool bends, its edge shifts its position relatively to the work and moves to a greater or smaller distance from the centre of the work, according to whether the direction of its motion lies within or without the periphery of the section being turned. As the edge stands at the same level as the centre of the work, it follows that if the centre about which it moves in consequence of the bending of the tool lie above the horizontal diameter of the work, the edge will be thrown farther from the centre, and will cut a section of larger size than is intended. If, on the other hand, it be below this level, bending of the tool will cause the edge to move inwards—to "spring into the work," as it is called—so that the section cut will be too small. If the bending cause the edge to move round a centre on the same level as the centre of the work, then for a very small amount of bending the effect will be almost nil, and large amounts of bending cause less variation in the turned section than if this centre of movement be situated anywhere else.

In order to ensure that the tool should rather spring out than into the cut, it is recognised as a principle that the cutting edge should not stand higher than the top surface of the shank. To obtain the upward slope giving top-rake, it is therefore necessary to have the front portion of the top surface hollowed or cranked. This is very commonly attained by simply grinding out a portion of the top of the straight shank. This is quite satisfactory in a very stiff tool; but if the shank be not strong, the process evidently leaves the weakest part, round which bending must occur, underneath the hollow, *i.e.*, at a point below the level of the edge, which will, therefore, not spring as desired.

With the same object in view, the front end of the shank is very frequently forged in the shape of a crank. This results in the edge being considerably lower than the top of the body of the shank. Such a tool, therefore, whenever it bends at all, springs outwards. Several different forms are given to the cranked end, all, however, having the same object, but chiefly differing in the amount of pliability given to the tool. Some, such as, for instance, an upward cranked tool for finishing cuts on brass, are purposely designed to be pliable and give way before differences in the resistance.

In general, however, it is very valuable to remember that what is of chief importance is to keep the tool edge constantly at the same distance from the centre of the work, and that for this purpose it is much more efficacious to ensure that the tool will not bend at all appreciably than to ensure that it will bend in any particular direction. To produce accurately true work, it is best to make the tool in the first place as stiff as possible, and after that is provided for attention may be turned towards the problem of arranging that whatever small amount of bending is absolutely unavoidable should move the edge in a vertical line.

10. Tool-holders.—In a previous chapter the great advantages of using small pieces of steel inserted in the extremity of a stout iron bar as tools were explained in the case of planing-machines for metal. These advantages have been more extensively recognised in their application to lathe work than in any other application probably because there is much more lathe work done than machine work of any other kind. The iron tool-holders with small inserted tools have, therefore, become very common in turning, and several patterns of tool-holder are extensively sold.

The first form that had wide practical success was Smith and Coventry's "round steel tool-holders." Fig. 41 illustrates this design. The tool-holder is a stout bar of square iron which is cranked at its forward end. At the front end of the crank, immediately behind the point, is bored a hole of small diameter downwards through the whole thickness of the iron. This hole is oblique to the vertical, slanting backwards and downwards, and also either from right to left, or *vice versâ*. In this hole is inserted a short round bar of steel, which is the cutting tool, and whose diameter is very slightly less than that of the hole. The upper end of this is ground off obliquely, so as to give an elliptical section. This section forms the cutting face, and the cutting edge is the highest sharp corner of the ellipse. The tool is, therefore, a round-nosed one. The piece of steel is fixed at the proper height by a small steel set-screw passing through one side of the extremity of the iron holder and entering the hole. This screw pinches the tool-steel against the opposite side of the hole. When the tool is re-ground, it is pinched in a slightly higher position than previously, so as to make up for the shortening of its length and keep the edge at exactly the same level as before. The object of the lateral inclination of the hole and of the tool inserted in it, is to give the same effect as that obtained by bending the shank of a solid tool to one side or the other. The tool thus acts as a side or corner tool. A pair of tool-holders is, therefore, necessary, one left-handed and the other right-handed, with the hole for the insertion of the steel-tool correspondingly inclined.

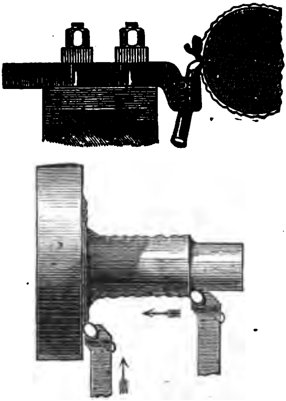

Fig. 41.—Smith and Coventry's Round Steel Tool-holder.

These tools are found to cut very well indeed, but with a deep heavy feed the pinch-screw does not hold the steel sufficiently firmly to withstand the strain, and the steel is therefore apt to slip downwards a little, thereby causing inaccuracy in the work, which may easily be overlooked if the slipping takes place gradually. In the diagram (Fig. 41) it will be observed that between the upper front edge of the holder and the hole the supporting metal is necessarily very thin. This is a decided fault in the design because it is here that the chief pressure has to be sustained. Consequently it is found in practice that this thin strip of metal bursts sooner or later, and it then becomes impossible to hold the tool up to its work steadily.* These faults do not affect the efficiency of the instrument for light work; and, therefore, the great simplicity of the tool, its cheap form, and the ease with which it can be re-ground and renewed when worn out, make it very suitable for small lathes and for finishing cuts.

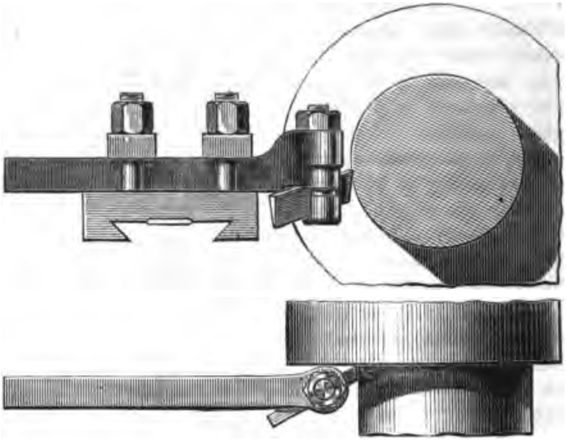

Fig. 42.

Smith and Coventry have more recently brought out another tool-holder which possesses many advantages over their earlier patent. This is shown in Fig. 42. In it the shank is again of square section. Its front end is forged into the shape of a short vertical cylinder or

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* In Messrs. Smith and Coventry's own works these defects are said not to have been felt, probably because their workmen have been more carefully instructed in the proper mode of using the tools, and have had a more prolonged experience in their use than has been gained elsewhere. Messrs. S. and C. prefer these tools to their swivel tool-holder.

boss. Through this is drilled a vertical hole of about one-third the diameter of the outside of the boss. Through this hole is placed a bolt, its head being below and a nut above the boss. Through the centre of the bolt, immediately over its head, is cut a vertical rectangular slot, and through this is passed the small piece of steel of tapered section that performs the cutting. The thickness of the top of this steel is greater than its thickness at its lower side, in such a proportion that the two sides slope towards each other at an inclination of about 6°. An example of the dimensions has already been given in Chapter V.: namely, depth $= 1\frac{1}{4}''$, top thickness $= \frac{9}{16}''$, bottom thickness $= \frac{1}{4}''$. Other sizes have the same proportional dimensions. When this is held upright, each side is inclined at about 3°, the proper angle of relief for the under surface of a metal-cutting tool. In order to ensure that the steel is held upright, a notch is cut centrally across the upper face of the head of the bolt of the proper width to allow the thin under side of the tool-steel to enter it. Over the tool, and between it and the under surface of the boss of the holder, comes a strong washer, and across its lower face is cut a diametrical notch of just the right width to admit the top of the tool-steel. These two notches prevent the possibility of the steel leaning to one side of its upright position. They are cut so as to have one side higher than the other. The tool-steel lies, therefore, with its upper face inclined to the horizontal, the notches being cut so that this inclination is a good average value for the ordinary top-rake required. The forward end of the steel is ground to any desired shape of cutting point, and the steel can be swivelled along with the bolt and washer, so as to stand at any horizontal angle with the axis of the work, while the shank of the holder itself always remains perpendicular to that axis. When the tool has been set in the desired position, all the parts are tightly bound together by screwing up the nut on the top of the boss. The same tool-holder can be used right and left hand, or the steel may be set to act as a front tool. The great advantage which this and no other tool-holder possesses is that the steel may be set so readily to any exact horizontal inclination, according to the peculiarities of shape of the work being operated upon. The shape of the steel used for the tool gives it great strength and stiffness, and allows it to be ground with any desired rake with facility. The clamping arrangement is neat, compact, and perfectly trustworthy; and, altogether, it is probable that a better tool-holder for the lathe cannot be designed. It has one defect, namely, that when great side pressure is put on the tool by a heavy cut the tool is apt to be swivelled round slightly by this side force, and so to cut deeper into the material. This may easily be remedied, without sacrificing the horizontal angular adjustability, by ribbing the upper surface of the washer and the under surface of the boss against which it is clamped, after the manner of a rose-drill.

Fig. 43 shows a third tool-holder, made by Tangye Brothers. It is similar in principle to that last described, but differs from it in several points. The tool-steel used is of the same shape, and it is held in a rectangular vertical slot. The slot is, however, made in the solid boss forming the extremity of the shank, there being no loose bolt passing through this. The steel is clamped in this slot by a wedge or by a set-screw that penetrates vertically through the boss. There are three such slots through the boss, which intersect each other in the vertical axis of the boss. One is directed straight forward, and when the steel is placed in this it acts as a front tool. The two others are equally inclined to the right and left of the central slot. When the steel is placed in either of these, it becomes a right or left hand side tool. These slots are inclined to the horizontal in the same manner as in Smith and Coventry's, at the angle of average top-rake required. The superiority that Messrs. Tangye Brothers claim for this design is that the whole holder being in one solid piece, with the exception of the small clamping-wedge or set-screw, there is greater solidity and less liability for the tool to shift its position horizontally if undue cutting stress be thrown upon it, than in Messrs. Smith and Coventry's system. They maintain that two side positions of the tool are amply sufficient for all work, and that a slight variation of the horizontal inclination of the side tools can be obtained by clamping the shank obliquely in the tool-rest. The writer thinks, however, that the variability of this inclination obtained in the previously described holder is of great advantage, and the method of clamping is also decidedly more secure.

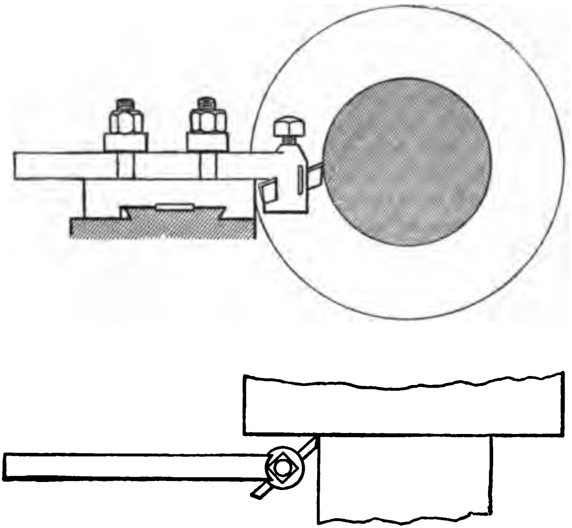


Fig. 43.

11. Springing of the Work.—The inaccuracy in the work caused by the springing of the tool has already been mentioned. The same kind of inaccuracy results if the piece being turned bends in consequence of the pressure applied to it by the tool.

It was shown that if the shaving were at every point of the same thickness and offered the same resistance to cutting, the tool would always be bent by exactly the same amount, and would, therefore, still cut a truly circular section in spite of its springing. In the same manner, if the resistance to cutting remained uniformly the same from point to point, and if the work be symmetrical round its axis from end to end so that it bends equally easily in all directions, then as it rotates the bending would take place in a plane that maintained always the same position relatively to the lathe bed and rotated relatively to the work at a uniform rate, and the amount of the bending would from instant to instant remain the same. If this were the case, the section turned would still be truly circular. In consequence, however, of the work being not truly cylindrical, to begin with, a thicker and more resistant shaving must be taken off one side than off the other. The work bends, therefore, more at one part of its revolution than at another, and the result is that the section cut is not a circle truly concentric with the axis of rotation. In taking the second cut, therefore, there is still an inequality in the thickness of the shaving to be taken from opposite sides. The same difficulty, therefore, occurs a second time, but the resulting error after the second cut is not nearly so great as that after the first cut, not only because the variation in bending has been greatly reduced by the first cut, but also because the second shaving taken off is not nearly so thick, and therefore not so resistant, as the first was, and thus the whole amount of bending is much smaller than it was before. By successive approximation, therefore, the truly circular section is at last obtained. In order to produce very accurate work, it is sometimes necessary to take two or three finishing cuts.

12. Back Steady-Rest.—There is still another way, however, in which the bending affects the work. Any force applied near the centre of a beam bends it much more than does the same force applied near its point of support. The cutting effort of the tool, therefore, bends the work much more when the slide-rest is nearly midway between the centres than when the tool acts close to the ends of the work. If the tool be traversed in a line accurately parallel to the axis of rotation, the result of this is that the size of the section cut near the middle of the length will be greater than that of the end sections, so that the work produced is not truly cylindrical. This effect is also reduced by gradually diminishing the depth of successive cuts, *i.e.*, by taking "finishing" cuts. But in long and slender pieces, such as shafts, the error produced in this way would be so large, and would require so many repeated cuts to get rid of, that it is necessary to provide other means of avoiding it. This is effected by the use of what is called a "back steady-rest." A stiff upright bracket is bolted to the back of the saddle of the slide-rest, and is, therefore, traversed along with the tool. This carries at its top a bearing, which can be adjusted in position so as to support from behind shafts of larger or smaller size. The bearing consists simply of a block of cast-iron, with an internal right angle formed in its front side, in which angle the turned shaft lies. The one side of the angle lies vertically over the shaft, so as to prevent its rising before the tool pressure. The other leg of the angle supports the shaft at the back extremity of the horizontal diameter, and prevents its yielding horizontally. The support is not applied directly opposite the tool, but as short a distance behind it as possible on the portion that has already been cut. In starting from one end, the workman turns a short length before adjusting the steady-rest, the bending at the end being so slight that no support is needed. He thus gets a short length turned down to the required diameter, and, the rectangular bearing being set to this, it continues, travelling behind the tool, to be in exact adjustment so long as the diameter of the section cut remains the same.

A considerable amount of frictional resistance arises at this bearing, and it should be kept continually well lubricated. Such steady-rests are not usually, but they ought to be, supplied with a drip-oil or soap-water can for the efficient lubrication of the bearing.

13. Capstan Tool-rest and Hollow Mandril.—A very convenient modern form of tool-rest for special work, called a "capstan" rest, may be mentioned here. This is a thick cylindrical plate in the place of the ordinary top plate and tool clamps of the slide-rest. In the periphery of this disc is a number of square holes, in which differently shaped tools may be fixed by set-screws through the top of the disc. The plate, with the tools thus fixed in it, can be swivelled round into as many positions as there are tools, and is caught and held in these positions by a spring catch entering a corresponding series of notches in the plate. Thus, any one of the set of tools may be brought to the front, and used on the work. Such a rest is extremely convenient when a large number of copies of an object of small size is to be manufactured, and the turning of which necessitates or is facilitated by the successive use of several tools. Each of the copies occupies only a small time in actual turning, and if to the time thus actually utilised were to be added that needed to take out of the rest one by one every tool needed in the series of operations, and to insert each in turn, the proportionate waste of time would be very great. This is obviated by the above tool-rest. Without it, time may be economised by performing one of the operations on a large number of the copies; then changing the tool, and proceeding to the second operation on the same number again; and so on. But this necessitates the taking of each object out of the lathe and putting it in again many times. There is the same objection to having the various operations performed by different men at different lathes, the article being passed on from one hand to the next. In some instances the waste of time is not the only objection to such a method. If, for instance, a number of pins of any special pattern have to be turned, these are best made in a "hollow mandril" lathe. The rod out of which the pins are to be manufactured is passed through the hollow mandril, and chucked so that a short length of its end only projects. This is operated on successively by the various needful tools fastened in a capstan rest, the last of which, when the pin is finally complete, cuts it off the end of the rod. The rod is then drawn farther through the hollow mandril, gripped once more, with the exact required length projecting (measured by the end being drawn up to a stop-gauge), and the process repeated. For such work two of the tools invariably needed are a roughing-out tool and a cutting-in tool. Then there may be a tool for finishing parallel parts and another for finishing flat faces. Other tools may be wanted to round off, or shape to any given profile, different corners, for which purpose it is convenient to have special profiling tools made whose edges are cut to fit to the exact contour desired. These tools, being difficult to make and to re-sharpen, should not be made to do any heavy duty, but should be used only to finish off with, the shape having been got approximately with roughing-out tools. Hollow mandril lathes are useful for a great variety of purposes, and their efficiency is greatly increased by being provided with capstan tool-rests. These rests have been chiefly introduced by Messrs. Smith and Coventry.

14. Boring Collar.—A long object that for ordinary outside turning would be placed between the centres, sometimes requires to have a hole bored along its axis from one end, and it may be convenient to do this in the lathe. As in this case the centre of the work is not available for its support (because the tool is operating at this point), a special support is needed. This is supplied by a strong stiff plate bolted to the bed of the lathe at just the right distance from the fast headstock to admit the object to be bored between the steel centre on the mandril and a hole bored in the plate. The centre of the hole is placed so as to lie in line between the centres on the two headstocks. The hole is made of the size of the end of the object, and is chamfered or counter-sunk so as to provide a conical bearing for that end. The object running in this conical bearing is at once kept to the centre, and end pressure is also supplied similar to that exerted by the steel point of the poppet-head. If the object may have a short length turned down so as to leave a shoulder, it is better to have the hole in the centre plate parallel, and to allow the shoulder to bear against the surface of the plate. There is sometimes, however, not sufficient metal for this. For example, if a number of long tubes of thin metal are to have the ends faced off, and perhaps the interior bored out for a short length for the insertion of a socket of some sort, or perhaps to have their interior ends screwed in the lathe, a plate of this sort with a conical bearing is the only method of supporting them, unless a loose collar be clamped on the end temporarily.

Such a centre plate has been given the name of "boring collar." Attention should evidently be paid to keeping it well lubricated.

15. Chasing Tools.—All screws that are required to be accurate are, as has been previously mentioned, cut by traversing a single pointed tool shaped so as to fit into the grooves desired to be left between the rounds of the thread, the traverse feed motion being made strictly uniform by being operated by a carefully made "leading screw." The requisite traverse motion may, however, be given to a hand tool by the pressure between the tool and the work itself. The under surface of the tool is composed of two nearly vertical faces meeting in a sharp edge that is pressed into and becomes buried in the work. This edge is inclined laterally to the vertical, at the inclination the thread is desired to have to the cross section of the screw, and, sliding in the groove which the tool itself cuts, guides the advance of the tool along a spiral line always having this same inclination. Such tools are called "chasing tools." In order the better to keep the inclination and, therefore, the pitch of the screw uniform, several cutting points one behind the other are given to the tool. The inclination of the leading edges is to the right or left according as the screw is to be a left-handed or a right-handed one. Chasing tools are made both for outside and inside screws, the former having their edges placed on the shank like a front tool, and the latter having them placed on the side parallel to the length of the shank, so that the shank may be held parallel to the axis of rotation and pass into a narrow hole.

There is always considerable difficulty in starting the cut with these tools at the exact right inclination. It is impossible to produce accurate screws by their means; but for the majority of screws no great accuracy is required, and for them the work produced by chasing tools is quite sufficiently good. As, however, much simpler and more rapid means of producing such screws — namely, by "dies" — are usually at hand, chasing tools are very little used in modern workshop practice.

16. Experiments on Cutting Pressure on Tool-point in Lathe.—As has already been said, the cutting force required in lathes varies rapidly with the depth and breadth of shaving turned off. One large portion of the power consumed by a lathe is expended in overcoming the friction of the journals, in bending the belts whose stiffness resists their motion round the pulleys, and in driving the traversing gear of the slide-rest. The chief point of scientific interest, however, is to discover that part of the power actually spent in the removal of the shaving. To find how this varies with the depth of cut, with the breadth of the traverse feed per revolution, and with the velocity of cutting, the writer carried out a series of experiments at his works in London, in which he was assisted by Messrs. Charles Hambly and George Hunt, turners by trade. A Smith and Coventry's swivel tool-holder was used in these experiments. Measurements were taken under 240 different conditions as to cutting speed, depth of cut, and amount of traverse feed. One hundred and twelve of these experiments were made in cutting cast-iron, 64 in cutting forged steel, and 64 on bar-iron. Two tools were used on the cast-iron, the first tool made proving to have been tempered too soft. The second tool was ground to exactly the same shape and cutting angle as the first, and was hardened in salt water. It lasted very well, not requiring to be re-sharpened throughout the whole of the remaining experiments on cast-iron, 64 in number. Nearly all the rake was put on the side of the tool, which was shaped with a round nose suitably for a moderately heavy cut. The cutting face was ground so as to leave an angle of top-rake on the side of 24°. One and the same tool was used throughout the 128 measurements on iron and steel. Nearly all its rake was on the side, the angle of top-rake being 46½°, and the edge being round-nosed. This tool was hardened by being quenched right out in water in which salt and wheaten flour were mixed, and without any subsequent tempering. It stood remarkably well, not requiring any sharpening throughout 112 experiments, in each of which it cut a length of shaving corresponding to about 1¼ inch traverse on a mean diameter of 2⅜ inches. Its edge then slightly broke in taking a cut 0·14 inch deep on wrought-iron of inferior quality with a good deal of dirt in its texture. The tool was then re-ground to the same form as before, and lasted well for the remaining 16 experiments, in each of which a cut 0·14 inch deep was taken on the same wrought-iron.

The cast-iron operated on was of good soft quality, such as is usually termed pulley-metal. The diameters cut were 16⅝ inches, 7 inches, and 3¼ inches. The measurements taken from the two larger diameters were slightly irregular; but, so far as could be judged, the difference in diameter made little or no difference in the force required for cutting, other conditions being the same.

The steel used was tough, a waste crank-shaft forging of 2⅝ inches diameter being used.

The wrought-iron was common bar of inferior quality, the diameter being 2¼ inches.

Throughout all the experiments the tool was carefully kept in the same position in the swivel tool-holder, and all the cuts were taken without any water or other lubricant being applied to the tool point.

The tool-holder had a $\frac{5}{16}$ inch hole drilled through its shank parallel to the axis of the work, at a short distance from its front end. A steel pin was driven through this, fitting tightly in the hole. A wrought-iron block had a deep groove cut in it, of exactly the width of the shank of the holder, and of slightly greater depth. This was drilled across the groove, the holes at each side being made a loose fit on the steel pin. The tool-holder being inserted in the groove of this block, and the pin driven through, the tool-holder was free to rock on the pin as a horizontal axis, but was prevented by the sides of the groove from having any lateral motion relatively to the block. The block and tool-holder thus connected were placed in the tool-rest of a 14½ inches centre double-geared lathe, and bolted down with the ordinary tool clamping-plates. The tool-holder was still free to rock on the pin through a small vertical arc, limited by the spaces over and under the top and bottom of the shank and the surfaces of the plates of the tool-rest. These latter spaces were then filled up by two small steel plates filed accurately parallel, and to such a thickness that they could be both slipped into their places at the same time, and could be moved easily to and fro, but at the same time prevented any vertical oscillation of the tool-holder.

The back end of the tool-holder had two holes drilled and tapped in its upper side, and by these there was bolted to it a long iron bar. This bar was graduated in suitable divisions, like a scale-beam, and heavy and light weights were hung on it, by which the pressure brought on the tool point was accurately balanced. A small cranked bracket was fixed to the rest, so as to stand over the scale-beam, and the unbalanced weight of the scale-beam and tool-holder was suspended from this bracket by means of a spiral spring that could be screwed up to any tension and length. Before any weights were hung on the beam, and without contact between the tool and the work, but after the tool had been placed in its right position in the tool-holder, this spring was screwed up until the holder was floated accurately in its horizontal position, the accuracy of this adjustment being tested by feeling whether the two small parallel steel plates moved to and fro with equal ease. This adjustment was frequently tested during the course of the experiments, and could be made with great delicacy.

When an experimental cut was begun, before sufficient weight was put on the beam to balance the pressure the tool was held up to its work by the clamping-plate of the tool-rest, so that the pressure exerted by it on the tool-holder kept the upper of the two loose steel plates tight so that it could not be moved to and fro. The heavy weight being adjusted on the bar to balance the pressure approximately, a small weight was then moved along the bar until this upper plate just became loose. If the weight were moved beyond its proper position, the lower "feeling plate" became tight. The weight was placed exactly so that the upper and lower plates moved to and fro with *equal* ease. With the very heavy cuts the trembling produced by

PLATE X.

the pressure caused these plates to feel tighter than when no cut was being taken, but after a little practice it was always easy to set the weight so that the one offered precisely the same amount of resistance to motion as did the other. With loads on the tool point up to about 200 lbs., a difference of 2 lbs. on the point was easily felt by this means. With 600 or 700 lbs. the possible error was not more than 3 lbs., and with the greatest load used, namely 920 lbs., it was no more than 5 lbs.

17. Influence of Cutting Speed on Cutting Pressure.—Each cut taken was taken at four different speeds, ranging from the slowest speed of the lathe to the fastest at which the lathe was capable of making the desired cut. As some of the shavings taken off were heavier than was suitable for the lathe, the highest speeds in some of the experiments are considerably below what would be practicable in a larger lathe under similar conditions of work.

The speed at which the cast-iron was cut varied from 14 down to 2½ feet per minute. Steel was turned at speeds ranging from 6 to 1·3 feet per minute, and wrought-iron at from 9½ to 1½ feet per minute.

The pressure was measured in all cases at each speed. The result showed that there is a slightly increased force required for increased cutting speed, but that the increase is very trifling. This increase is very curiously constant for all conditions of cutting, for deep and shallow cuts, for broad and narrow shavings, and for all the three metals experimented upon. The increase of force corresponding to the alteration from the slowest to the fastest speed averaged about 25 lbs. and ranged irregularly from 15 to 35 lbs. In one case only was it as great as 40lbs., and in two cases as small as 10lbs.

18. Comparative Resistance to Cutting in Different Metals.—The following examples will illustrate the difference between the three metals operated upon.

	Number of Experiment.	Pressure on Tool point. lbs.	Traverse Feed. Inch.	Cutting Speed. Feet per Min.	Depth of Cut. Inch.
C. I. .	53	176	·0385	13	·03
W. I.	181	190	·0385	9·6	·03
Steel .	149	430	·0385	5·8	·04
C. I. .	69	252	·0385	12·7	·05
W. I.	213	470	·0385	9·1	·06
Steel .	165	680	·0385	5·1	·06

These numbers show that while for both thin and moderately thick shavings forged steel takes from 2 to 2⅓ times as much power to cut it as does cast-iron, wrought-iron takes very little more than cast-iron for shallow cuts, and rather more than 1½ times as much for cuts of about $\frac{1}{20}$ inch deep. In fact, for broad thin shavings it was found that cast-iron required more cutting force than wrought-iron.

19. Influence of Variation of Traverse Feed on Cutting Pressure.—The variation of the pressure along with the rate of feed per revolution—that is, with the breadth of the shaving—is very decided. The annexed table will show this.

It may be observed at once from this table that the force on the tool does not increase in nearly so rapid a ratio as the breadth of the shaving. There is the same series of feeds in all the examples quoted in the table, namely, ·0303, ·0385, ·0555, and ·0606. The last is exactly double the first of the series. The ratios of the last three to the first are 1·264, 1·833, and 2. The successive differences are ·0082, ·0170, and ·0051. The ratio between the lowest and highest forces is generally about 1½, although sometimes a little less, and in one case considerably more, this latter being that of the medium cut on steel. The second difference in the feeds

	Number of Experiment.	Pressure on Tool point. lbs.	Traverse Feed. Inch.	Cutting Speed. Feet per Min.	Depth of Cut. Inch.
Cast-iron.	65	228	·0303	12·7	·05
	69	252	·0385	12·7	·05
	73	288	·0555	12·7	·05
	77	340	·0606	12·7	·05
	97	510	·0303	11·1	·135
	101	620	·0385	11·1	·135
	105	690	·0555	11·1	·135
	109	775	·0606	11·1	·135
Wrought-iron.	177	165	·0303	9·6	·03
	181	190	·0385	9·6	·03
	185	215	·0555	9·6	·03
	189	250	·0606	9·6	·03
	209	435	·0303	9·1	·06
	213	470	·0385	9·1	·06
	217	530	·0555	9·1	·06
	221	570	·0606	9·1	·06
	225	630	·0303	7·9	·14
	229	760	·0385	7·9	·14
	233	810	·0555	7·9	·14
	237	920	·0606	7·9	·14
Steel.	129	185	·0303	6	·02
	133	215	·0385	6	·02
	137	250	·0555	6	·02
	141	315	·0606	6	·02
	145	365	·0303	5·8	·04
	149	430	·0385	5·8	·04
	153	480	·0555	5·8	·04
	157	665	·0606	5·8	·04
	161	615	·0303	5·1	·06
	165	680	·0385	5·1	·06
	169	705	·0555	5·1	·06
	173	810	·0606	5·1	·06

is double the first, but in no case does the corresponding second difference in the forces nearly equal double the first difference. The third difference of the feeds is less than $\frac{1}{3}$ the second, but in nearly every case does the third difference in the forces greatly exceed the second difference. Thus the ratio between the increase of the force and the increase of the feed at first diminishes, and then again very rapidly increases. This is shown clearly by the diagrams in Fig. 44. These curves form a complete graphic record of the experiments on each of the three materials, and are arranged specially to show the variation of the cutting force with the breadth of shaving. The force in pounds is measured horizontally from the left-hand side of the diagram to the scale marked on the edge. The corresponding breadth of shaving—that is, the parallel feed per revolution—is measured vertically upwards, the scale being marked along the side of the diagram. All the curves are shaped more or less like an S. They first bend upwards, and then bend with an opposite curvature.

20. Influence of Variation of Depth of Cut on Cutting Pressure.—The same table will illustrate the mode of variation of the cutting force with the thickness of the shaving. This would be more clearly exhibited by a fuller extract from the original record of the experiments, but space will not allow of the insertion of more. It is, however, still better represented to the eye by the curves drawn in Fig. 45, which are plotted from the same results as those shown in Fig. 44, but are so arranged as to show directly the relation between the depth of cut and the pressure on the tool. The pressure is here measured horizontally, as in Fig. 44, and to the same scale. The depth of cut is measured vertically to the scale marked at the side of the figure. The law of variation is exactly the converse of that in Fig. 44. At first the pressure increases at a more rapid rate than the depth, and then the rate of increase gradually falls off, until it becomes less than that of the depth. The curves are, therefore,

PLATE XII.

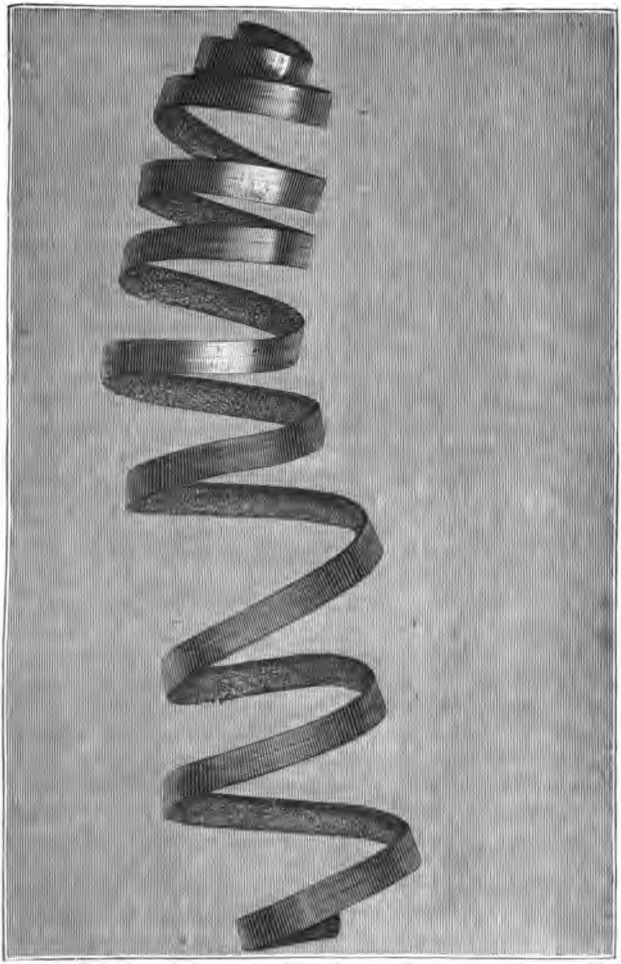


Fig 46b.—WROUGHT-IRON SHAVING. *(After a Photograph.)*

S-shaped once more, but the direction of the two bends is reversed from those seen in Fig. 44.

The sum of the breadth and depth of the shaving is approximately equal to the length of the portion of the cutting edge of the tool that is in action—that is, the length of cut being taken at each instant. From an examination of the curves, it is seen at once that the force does not vary in simple proportion to this quantity, nor in proportion to any single constant power of it.

21. Photographs of Shavings of Cast-iron, Wrought-iron, Steel, and Gun-metal.—Fig. 46, A and B, shows a series of photographs taken from lathe shavings. In the first series the material is cast-iron; that of the second is wrought-iron; that of the third, steel; and that of the fourth, gun-metal. They show well the manner in which the cutting forces break up the shavings in layers, and show also the marked differences that exist between the different metals in this respect. Fig. 46, B, is a large-sized shaving of wrought-iron.

CHAPTER VIII.

BORING AND DRILLING.

1. Boring and Turning.—There is a distinction made in technical language between the turning of outside and that of inside surfaces. The latter is called *boring.*

The differences between boring and outside turning all result from the contracted character and peculiar position of the space in which the boring tool must be held.

If the diameter of the inside surface being bored is large, then the conditions under which the shaving is cut and broken off are the same as for a plane surface. The tool edge stands at the level of the centre, and the direction of the surface on which it operates is vertical at the cutting edge. If the diameter be large, the small quantity of metal lying on the surface immediately above the tool point, through which the pressure exerted by that point is distributed and which is severely crushed and twisted, stands to a very close degree of approximation accurately vertical. If, however, the diameter be small and the crushing pressure be supposed to penetrate upwards the same distance as in the previous case before it becomes dissipated in breaking the shaving, it is evident that this small length of surface is no longer accurately vertical. At its lower end it is vertical, but at its upper end it leans inwards towards the centre so as to make an angle less than 90° with the horizontal diameter. Comparing pieces of different small diameters, and always taking the same small depth of crushed material in all of them, clearly the average inclination from the vertical will be greater the less is the size of the hole. Now, this lessening of the angle between the metal affected by the tool pressure and the horizontal diameter is evidently equivalent to a lessening of the angle of top-rake of the tool, and results in greater difficulty of cutting in small holes than in large ones, the shape and position of the tool point being supposed the same in the different cases. This difficulty cannot be overcome by setting the edge of the tool a little lower than the centre, because if this be done a greater amount of bottom-rake must be given to the tool, in consequence of the inclination of the surface to which the point would be applied. This bottom-rake is, as has been already explained, made as small as it may be consistently with preventing pressure on the surface under the point of the tool, and thus the above increase of it would be quite necessary. This would lessen the cutting angle below its proper value and thus weaken the edge.

The tool is, therefore, maintained at the exact level of the centre, and in consequence of the above difficulty it should be given a little more top-rake than the ordinary outside turning tool. The cutting angle thus becoming keener and weaker, it is impossible to take such heavy cuts in boring small holes as those taken in outside turning.

Again, when the hole is small the surface of the work underneath the tool rapidly bends towards the tool, so that if the tool be not of very small depth or given excessive bottom-rake, its lower face must be ground-curved, so as not to catch the side of the hole at its lower edge. This rounding off of the bottom corner of the tool does not in the least affect its cutting action, and does not materially lessen its strength.

2. Difficulty of Supporting the Tool in Face-plate Boring.—We here go on the supposition that the work is rotated and the tool held fixed. This is not always the case, as will be mentioned immediately; but if it is so, the rest upon which the tool is fixed cannot stand opposite to it, *i.e.*, in the same plane perpendicular to the centre-line of the lathe as the tool. The lower part of the rotating work interferes with the possibility of any straight vertical support from the tool down to the lathe bed. The tool must, therefore, be held in a tool-holder clamped horizontally in the slide-rest and parallel to the line of centres. This projects into the hole. If the hole be a deep one, the bar tool-holder must be correspondingly long; and, in consequence of the "over-hang," it is proportionately difficult to hold the tool perfectly steady and to prevent it springing. The bar must, therefore, be made as stiff as possible. When the hole is small, there is often difficulty in getting room enough for a bar of sufficient stiffness. This over-hang of the holder is another circumstance preventing heavy cuts being taken in boring small diameters, the jarring of the tool with a heavy cut preventing it cutting truly and rendering breakage of the edge easy.

The point of the tool must, as in turning, be shaped suitably for the work to be done. A round nose with side-rake is the best for roughing-out. If a sharp inside corner has to be bored out, the tool must have a correspondingly sharp-angled point. The tool is best made of a small piece of steel wedged into a bar-holder, but boring tools for small work are frequently made with the point solid in one piece with the shank, the shank being of tool-steel and having its end forged to a crank shape so that the cutting edge stands out to the left-hand side of the bar.

3. **Boring Bar.**—When the work is of large size it is much more convenient to give the rotational movement to the tool than to the work. This is the arrangement in the majority of boring operations. The tool, a small piece of steel, is fixed to a long bar, termed a "boring bar" which is placed between the lathe-centres and driven by a carrier and driver as if it were a piece to be turned in the usual manner. The work is fixed on a table that slides along the bed exactly as does the ordinary slide-rest. This table may have parallel under-cut grooves in its surface for the insertion of T-headed bolts by means of which the work is clamped in place. The feed motion is given to the table and the work upon it by a leading screw or a rack and pinion. Such boring is frequently done in an ordinary lathe when the saddle of the slide-rest is used as a table to which to fix the work. In workshops where much of such boring has to be done there are always some lathes specially constructed for this class of work. These are called *boring lathes*, or "boring machines." The chief peculiarity of these lathes is that the centres stand at a great height from the bed in order that large-sized work may be admitted, and that no provision is made for the attachment to the mandril of face-plates or jaw-chucks. The boring bar is very commonly coupled to the mandril by a split cone coupling.

The small boring tool ought to be well supported at no great distance from its point. For holes under four or five inches the bar may be made of large enough diameter for the tool to have a bearing at its outer surface, sufficiently near the edge. For medium-sized holes there may be placed on the bar a thick strong cylindrical plate like a piston, in the circumference of which the tool is inserted in a hole. Such a holder is convenient as it may be shifted along the bar to any position suitable for the work. It may also have several tools placed at different points on its circumference on a spiral line (one tool being axially a small distance in advance of the next). This allows of a correspondingly quicker feed being given to the work, and also equalises the cutting pressure in different directions, so that there is very little tendency for either the work or the boring-bar to spring. At the same time, however, it must be noticed that if the different tools are not set so that all their cutting edges are precisely equi-distant from the axis of the bar, the bored surface will be found with a number of spiral grooves of small depth cut in it. To set the tools so accurately as to avoid this result perfectly is somewhat troublesome, and if several cuts have to be taken off the surface a new setting of the tools is required for each.

When the hole to be bored is several feet in diameter, a strong cross-beam of iron is firmly attached to the boring-bar, and on the end of this beam is mounted the holder in which the tool is inserted.

4. Boring Large Cylinders.—Large cylinders, when their walls are not very thick, are so heavy that when lying on their sides they bend slightly out of the true cylindrical shape. It then becomes difficult or impossible to bore them out truly in that position. Cylinders over six or seven feet in diameter are, therefore, much better held vertically when being bored. The boring-bar is placed upright, its journals revolving in bearings in stiff iron beams, supported in the walls of the workshop. It would in this case be inconvenient to give a vertical feed-motion to so heavy a piece of work, and the boring bar is given a slow upward or downward motion simultaneously with its rotation, the tool point thus following a spiral path of small pitch.

5. Double-boring Machines.—There are frequently two cylinders to be bored parallel to each other in the same casting, as, for instance, in double cylinder engines of small size. Then if the two cylinders of a double cylinder engine are cast in two separate pieces, it is well first to plane and fit together the surfaces by which the two are to be joined and bolt them together, and after this is done, to bore them. It is thus easier to ensure accurate parallelism between the cylinders. For such work an extremely convenient boring machine is constructed with two boring bars driven simultaneously at the same rate, the two being connected by a cross shaft and bevel gearing. The two bars may be drawn apart so as to stand at any exact required distance from each other, this distance being that desired between the centres of the cylinders. The gearing between the two must then be adjustable.

In such a double boring machine it is better that the two tools should revolve in opposite directions, because then at each instant the horizontal components of the two cutting thrusts will balance each other, and there will be the less tendency towards shifting of the work by the loosening of the bolts holding it down to the slide-carriage.

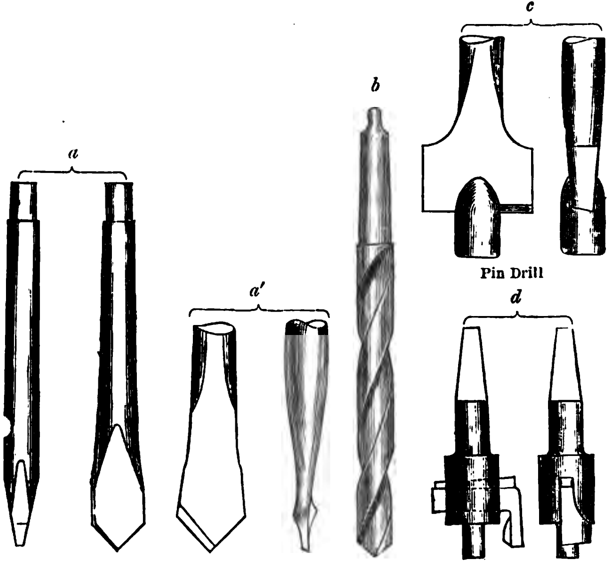
6. Drilling and Boring.—Drilling is another method of forming inside cylindrical surfaces. Like boring, drilling may be performed either vertically or horizontally. The former is the common direction in which drilling machines act. Horizontal drilling is not unfrequently done in the lathe, the drill being fixed in a chuck and rotated with the mandril, while the work is fed up against it by being pressed by the centre in the poppet-head.

In drilling, the rotational motion is invariably given to the tool (the method being adapted for holes of small size), and the feed-motion is usually, but not always, given also to the tool.

As the words are ordinarily understood, there are two characteristic distinctions between drilling and boring. In the latter operation the hole is already roughly made in casting or in forging the piece, and the cutting tool has only to reduce the irregularities of the surface and to make the hole of the exact required diameter, it being left in the rough somewhat smaller than its finished size. In drilling, on the other hand, the hole is cut out of a solid piece, so that the material removed in the shape of shavings corresponds to the full volume of the hole. In the second place, in boring the tool operates on a cylindrical surface only, which is parallel to the axis of rotation, while a drilling tool acts chiefly, and almost solely, upon a flat or conical surface which lies across the axis of rotation. Another distinction may be found in the fact that while drills have always two cutting edges acting on opposite sides of the axis, a boring-tool has ordinarily only one which cuts at each instant on one side alone of the hole. A further important difference lies in the modes of guidance, as will be apparent from what follows in section 9.

7. Drilling Tools: Defects of Ordinary Forms.— Fig. 49 (Plate XIII.) shows a common form of drilling machine. A horizontal driving shaft rotates the vertical spindle *k* by means of the pair of mitre wheels *g* and *h*. To this spindle the drill is fixed in the socket k_1, and, the work being fixed on the table *v*, the spindle is fed downwards as the hole is drilled deeper.

The drill is a straight piece of round steel, shaped suitably at its lower end to perform its work of cutting out the bottom of the hole. Various forms are illustrated in Fig. 47. The commonest, because the most easily made, is represented by *a*. The shank is forged out to a flat blade, which is usually made a little wider at its lower extremity than above it. The bottom edge is diamond-shaped, the two sides being equally inclined to the horizontal by an angle that, among drills for different purposes, varies from 50° to 30°, the most common being between 40° and 50°. These two inclined edges are the cutting edges, and are bevelled so as to prevent their narrow flat faces rubbing against the conical cut surface of the metal operated on—that is, so as to give a small "angle of relief." The rotation given to the drill is always right-handed, looking towards the work. The two cutting edges are, of course, on opposite sides of the flat blade, and the bevels, or back-rakes, given to them are correspondingly ground in opposite directions. With a straight flat blade, it is impossible to give any front-rake to the edges, because the faces must stand vertically. In fact, if the thickness of the blade is made, as is usual,



Pin Drill

Flat-pointed.

Flat point, with twisted edges.

Morse Twist Drill.

Cutter Pin Drill.

Fig. 47.—Drills for Metal.

somewhat thinner at the point than higher up, these faces lean slightly towards the horizontal, and the rake becomes negative. The same result—namely, negative rake—is further produced by the fact that the edge must necessarily be not in a radial plane, but in a plane passing to one side of the centre by half the thickness of the blade. The size of the hole, and, therefore, the radius to which the surface of the work is curved, being small, this half-thickness represents a not inconsiderable angle, and this difficulty effectually prevents the cutting edge being formed favourably for good cutting. This kind of drill is, therefore, perhaps, the most defective of all cutting tools as regards the relation of the requisite driving power to the amount of material removed. The defect increases in magnitude the larger is the ratio of the thickness of the blade to the diameter of the hole, and it is thus greater in drills for small holes, because it is practically impossible to reduce the thickness of the blade in proportion to its width.

There is still another defect in this drill. Since the two cutting edges already referred to pass at a small distance from the centre of the hole and from each other, there is left a small central core of metal that is never touched by them, and cannot, therefore, be cut out by them. Supposing the centre of the blade to lie accurately in the centre of the hole, the diameter of this central core equals the thickness of the blade. It is actually cut away by the short edge that crosses from one face to the other at the point of the blade, this edge being the intersection of the two narrow surfaces lying behind the main cutting edges and to which the back-rake has been given. The line of this short edge is perpendicular to the axis of the drill, and the surface it cuts is, therefore, not conical, like the rest of the bottom of the hole but flat and also at right angles to this axis. If the side edges be ground at 45° to the axis, the cutting angle of this short edge is 90°, and it is situated very unfavourably for cutting because the two faces intersecting in the edge are equally inclined to the surface cut. The front-rake is negatived by the large angle 45°, and the back rake is also 45°, an angle that is for this purpose very unnecessarily large. To cut at all with so badly-formed an edge, it is necessary to force the edge downwards into the metal with great pressure, and the removal of the material takes place more by bruising and abrasion (by what has often been called scraping) than by clean cutting. It is thus evident that the severest duty performed by the drill is thrown upon the point of the diamond, and it is found in practice that this part of the edge gets most frequently and rapidly blunt.

This last defect may be to a great extent remedied by grinding or filing a small half-round groove on the opposite faces of the blade to the right and left hand side of the point edge, as is illustrated in Fig. 48. Here the main cutting edges are *d e* and *c h;* the cutting edge of the central core is *c e.* The two halves of this edge at *c* and *e* cut simultaneously in opposite directions—the half at *c* cutting to the right-hand, and that at *e* to the left-hand, in the position shown in the diagram. To the left-hand of *e* and to the right-hand of *c* are filed two small notches, extending with a gradually diminishing depth a short distance up the respective faces of the blade. The effect of these notches is to make the front faces of the cutting edge *c e* perpendicular, or nearly so, to the metal they cut. They at the same time, however, somewhat weaken the central portions of the edges *d e* and *c h.*

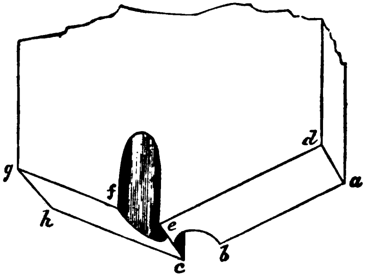


Fig. 48.

8. Twisted Drills; Morse Twist Drills.—In this common form of drill the cutting faces are inclined by less than 90° to the surface of the work in front of them. This angle ought to be much more than 90°; for wrought-iron it ought to be about 117°. This inclination might be attained by bending forwards the two edges in opposite directions when the tool is being forged. Doing so would prevent the possibility of re-grinding the edges many times without re-forging the tool; it would make the proper grinding of the tool a difficult matter even the first time; and the bending at the forge would so weaken the material that the drill would most probably be unable to stand any but the lightest work. The end of the drill treated in this fashion would have a twisted shape, as shown in (*a′*) Fig. 47. The above objections are wholly obviated by making the twist continuous for some distance up the shank. This is what is done in the Morse twist drill, shown in *b*, Fig. 47. The blade is made thick and strong, and is carefully and accurately cut by machinery to the form of a double-threaded spiral. The inclination of the spiral to the axis is the front-rake of the tool. As the tool point is re-ground farther and farther back, the two cutting faces are always found at the same inclination. An extra advantage is that the shavings being pressed against the sides of the hole and suffering from this contact frictional resistance to being carried round with the rotation of the drill, are forced to slide up the two grooves of the spiral, and the hole is thus easily kept clear of the metal cut away. With the ordinary drill the difficulty of getting out the shavings is a great hindrance to the work, especially with cast-iron. On these accounts the Morse drills are decidedly the best that can be used, even although in first cost they are considerably more expensive than those of the ordinary shape. They do not, however, alter the inefficient character of the short edge lying cross-wise between the faces and by which the central core is scraped out. In this respect the Morse is slightly worse than the other because of the increased thickness and consequent increased length of the cross-edge, whereby the diameter of the central core is left larger. The other advantages, however, greatly outweigh this disadvantage, which may probably to some extent be overcome by notching the back edges in the way described in the last section. In the Morse, the file, however, could not be used for making such notches because its use would involve softening the steel in the fire, and it would be a little difficult to grind them satisfactorily.

9. Guidance of Drilling Point: Centring.—The guidance of these pointed drills is such as not to be rigidly exact, and therefore requires careful manipulation. Suppose the drill has already penetrated a short distance into the material so that the top of the cutting edges is below the surface; a portion of the parallel walls of the hole has already been formed, and against these bear the vertical parallel edges of the blade of the tool; these edges are narrow, and do not present a good bearing surface. So far as they do give lateral support to the drill, they tend to maintain its axis from instant to instant during its downward motion in the same exact line as that which it occupies at each instant, which line is determined at each such time by the precise position of the lower end of the drill and by that of the socket at the bottom of the spindle in which the shank of the tool is inserted. The line in which this socket is fed downwards is the vertical centre line of the spindle, and if the bottom end of the tool be not accurately in the same line, then the centre-line from top to bottom of the drill will change continuously during the downward feed, always departing more and more from the vertical, this being possible because the shank is not held perfectly rigidly in the socket. The consequence is that the cutting end of the drill follows a curved line, the curve being modified and made flatter than it would otherwise be by the guiding resistance of the vertical edges of the blade bearing against the walls of the hole. But these latter edges are sharp enough to cut in an imperfect way, and the effect of the above action is that they cut away the walls of the hole on one side, leaving it of an oval section. In the Morse drill the lateral edges are made truly cylindrical and are much broader than in ordinary flat drills, so that they give much more effective guiding support to the tool and cause less risk of ovalness.

From the above may be seen the great importance of ensuring that in beginning the hole the drill should "run true," that is, that the centre of its lower end should lie accurately in the continuation of the centre line of the spindle. The centre here spoken of is the centre of the width from edge to edge. It will appear from what follows that the extreme point of the cutting end must coincide accurately with this centre, and that this point, therefore, must "run true," so as to appear motionless during the revolution of the drill.

The pressure against the conical surface at the bottom of the hole is much greater than that at the sides. The latter may be called accidental, and is practically *nil* when the hole has been started fairly and is fed down truly in the centre line. The former is the cutting pressure of the two edges. It has a vertical component equal to the force exerted in applying the feed. The horizontal part of the force on each cutting edge may be divided into two parts, one perpendicular to and the other along a radius of the cone. The radial components at the two opposite edges are oppositely directed, and push the drill oppositely, each towards the centre. If these are exactly equal in magnitude, the point of the drill is maintained in balance, and there is no tendency to push it out of the straight line along which it is fed. If, however, the one radial force is at any moment greater than the other, the point is pushed in that direction and its progress downwards becomes curved. Such inequality in the two pressures may arise either because of want of uniformity in the surface being cut—

for instance, because of a hole in the surface on one side, or because of there being on one side a patch of harder metal than on the other—or because of want of symmetry between the two edges of the tool. If the want of balance is produced by the first cause, the excess of force is always in one direction across the hole, depending on the location of the hole or patch of hard metal, and it continues until the metal in which these are situated is all cut away in the form of shavings.

Advantage of this is taken in centring the hole when commencing it. A circle is drawn round the desired centre, and larger by about $\frac{1}{32}$ inch than the hole to be bored. "Centre dabs" are put upon this circle, because the line is generally obliterated by the dust, sometimes mixed with oil, which is caused by the drilling. Four "dabs" are quite sufficient for holes up to $\frac{7}{8}$ inch in diameter, and it is for very large holes only that more than six are needed. Another dab is put in the centre, and this one ought to be at least as wide as the thickness of the point of the drill, so that this point may enter it and be steadied by it. When between half and three-quarters of the length of the cutting edges has entered the metal, the drill is withdrawn, and the shavings or dust blown or wiped aside; the conical hole will then be found nearly always to be not quite concentric with the circle as indicated by the dabs. A narrow, round-nosed chisel, called a "centring chisel," is then used to cut a groove on that side of the cone towards which it requires to be "drawn" in order to become concentric with the circle. The drill is then fed down again a very short distance, and when it has cut to the bottom of the groove made with the chisel, it is once more raised and the hole examined. The depth of the groove should be made larger the more the hole requires to be "drawn," and if its size has been skilfully proportioned in this way, there will be no occasion to use the chisel a second time; but if, on raising the drill the second time, the hole is still found eccentric from its true position, it must be drawn once more by using the chisel, and the operation must be repeated until the hole has been moved to its exact right position.

It is to be noticed that it is only during the sinking of the oblique cutting edges below the upper surface of the work that this process is possible. As soon as the parallel walls of the hole have been commenced, the effect of the chiselled groove becomes very small, in consequence of the guidance afforded by these vertical walls to the sides of the drill. Care must therefore be taken to finish the centring operation before the cutting edges have wholly entered. If, when they have penetrated nearly up to their upper ends, the hole is still found considerably eccentric, the whole of that side of the conical hole towards which the point is to be moved must be chiselled away, so that the drill may be rapidly drawn over. The chiselled groove is a great deal more effective if made close down at the point of the cone than if made high up on its side, because near the point a groove of a given width means the cutting away of a much larger proportion of the whole circumference than higher up where the diameter is larger, and consequently means that the inequality of pressure on the two sides of the point is maintained during a much larger fraction of the whole revolution of the drill.

If the inequality of pressure be due, not to irregularity in the conical surface on which the drill presses, but to want of symmetry in the drill itself, there are three cases that may arise. The two edges may be both ground at exactly the same angle to the axis, but the point where they meet may be nearer one side of the blade than the other, so that one cutting edge is longer than the other. In this case the drill will be guided wholly by the point, and a hole larger in diameter than the breadth of the blade—of, in fact, a radius corresponding to the *longer* of the two cutting edges—will be formed. A second kind of dis-symmetry occurs when, the point being precisely equi-distant from the two vertical sides of the blade, the cutting edges are ground at different inclinations to the horizontal. When this is so, that edge with the greater horizontal inclination never comes in contact with the metal, and consequently the point of the drill is continually being pushed with great force towards this non-cutting edge. The direction of this push is continually rotating, and, therefore, the result is not to draw the hole in any one direction but to cause the drill axis to rotate round a conical surface of small angle and the point, therefore, to cut out a flat circular surface perpendicular to the axis of a slightly larger diameter than the thickness of the drill. The hole will thus be bored to a somewhat larger diameter than the size of the hole, and it is also evident that the motion will be unsteady and the diameter of the bore not accurately constant.

When the two faults above mentioned are combined, the inclinations of the two edges being unequal and also the point being eccentric, the motion of the drill is still more unsteady and the result still more unsatisfactory.

All the remarks of this paragraph apply to Morse twist drills as well as to flat drills. In the former the guiding influence of the walls of the hole after the cutting edges have sunk below the surface is greater, and that of the cutting edges less, than in the latter.

10. Other Forms of Drills for Metal.— In Fig. 47 *c* shows a third kind of drill, called a pin-drill. Its use is the formation of flat counter-sinks, in which the heads of bolts or of flat-headed screws may lie. The hole for the body of the bolt being bored, the projecting central plug of the drill enters this, its size being such as to be an easy fit in the hole. Behind the plug, or pin, stand two wing cutting edges perpendicular to the axis of the hole. For each size of bolt a separate drill is required, the ratio of the diameter over the extremities of the cutting wings to that of the central pin being slightly larger than the ratio of the size over the angles of the nut to the diameter of the screw.

In *d* is illustrated a very similar tool, also used in the drilling machine. The wing cutting edges here consist of a loose cutter passed through a rectangular slot near the lower end of a wrought-iron "cutter bar," which is fixed in the socket of the spindle. The cutter is held tightly in the slot by a small wedge.

In these last two tools it is important that the two edges should lie exactly in one horizontal plane. If they do not do so, one of them will alone do all the work. In the cutter bar, if the top and bottom of the slot be slightly rounded, so that the cutter may be tilted through a small angle without slackening the wedge, the pressure on the cut surface will ensure that both edges cut equally. If one lies lower than the other, it bears all the pressure, and, there being none on the opposite end of the cutter, this edge is pushed upwards until the pressures at the two ends balance. The two edges should also be precisely equally long. If the pin, or lower end of the bar, does not quite fit the hole in which it runs, a piece of thin sheet brass, or of brass tube split down one side, may be put round it to make up the difference of sizes, and ensure steadiness in the motion.

11. **Lubrication in Drilling.**—In drilling cast-iron no lubricant of any kind is used, and brass is treated in the same way. The shavings from these materials usually break in minute fragments, which, if they were mixed with a sticky liquid, would form a paste that would be difficult to remove from the hole, which rapidly gets filled up so that the rotation of the tool is impeded. As was mentioned also in the chapter on lathes, these materials are most easily cut "dry," independently of the difficulty in getting rid of the shavings. Wrought-iron and steel, on the other hand, must be drilled with a plentiful supply of oil or soap and water. The writer does not know of any authoritative explanation having been given of the reasons why these materials require such different treatment, but it seems probable that the difference arises simply from the facts that a much larger amount of power is required for the cutting of wrought-iron and steel than for the others, and that most of the energy so

expended is converted into heat, which is apt to overheat the tools. This explanation is not entirely satisfactory, however, because if one feels a drill after it has been working on cast-iron for a few minutes, and then again after it has been working the same length of time on wrought-iron supplied to the usual extent with oil, he will find that the drill point is much hotter in the former than in the latter case.

12. Construction of Drilling Machines.—In Fig. 49 (Plate XIII) the driving gear of the vertical spindle is best seen in the section A. The driving belt runs on the stepped cone-pulley *b*. This runs upon, but is not keyed to, a horizontal shaft with bearings in the standard. On the boss at the large end of the pulley is keyed a pinion *c*, and behind this lies a toothed wheel, *f*, keyed to the shaft. The pinion may be bolted to the wheel, and when this is done the shaft is rotated at the same rate as the pulley. There is also a side shaft, corresponding to the back shaft of a lathe, on which are mounted a wheel to gear with the pinion *c* and a pinion to gear with the wheel *f*. These, being mounted on a stud in an eccentric bearing, can be thrown forward into gear or backward out of gear. When in gear, the bolt fastening *c* to *f* must be slackened and pushed out of the way, and the shaft gets a reduced motion from the pulley through the two pairs of pinions and wheels. There being four steps to the cone, there are eight speeds possible to the spindle. The vertical spindle is driven from the horizontal shaft by a pair of bevel pinions, *g* and *h*, the latter of which has a feather sliding in a key-slot in the spindle, which is thus permitted to move up and down without the driving connection being interfered with. The work either rests loosely on, or is bolted to, the grooved table *v*. This is a sliding table, having a nut, γ, bolted to its under side, into which gears the screw β. By turning this screw by a hand-crank set upon its squared end, the upper table can be drawn farther or nearer the standard. It rests upon a bracket, *u*. This is hinged to the vertical plate *t* by a strong hinge, the two bolts of which are seen in the front view B. By swinging the table round this hinge, a motion is given to it transverse to that given by the screw, and thus any number of exact spots of a piece of work bolted on the table can be successively brought under the drill and operated upon without unbolting it. On the lower portion of the front of the frame are two vertical slide surfaces, like those of the bed of a lathe, and on these moves up and down the plate *t* on which the hinge is made. It is clasped to the vertical slides by the ordinary dove-tailed groove and wings, with a triangular fitting strip at one side. In bearings in the plate *t* lies a short horizontal shaft bearing at its one end the pinion *z*, which gears with the rack *a* that is bolted to the frame. By the rotation of the pinion the table is thus lowered or raised. The short shaft has at its outer end the worm-wheel *y*, actuated by the worm *x* and the hand-wheel *w*.

13. Different Designs of Table.—Many other designs are in common use for the purpose of giving the table freedom to move under the drill in two horizontal directions. One good arrangement is to use—in place of the slide, nut, and screw of Fig. 49—a circular table swivelling round a large-sized vertical bolt in the hinged bracket. The table, having been rotated into the desired position, is clamped by a set-screw bearing on the side of the bolt.

Again, instead of the vertical hinge in the plate *t*, the standard frame of the machine is made with two legs, the front one of which is in the form of a pillar. The table bracket is then formed at its inner end as a cylinder, and the cylinder embraces the pillar, so that the table can swing round the latter: the pillar and cylinder forming, in fact, a large-sized hinge.

The table is sometimes raised and lowered by means of a screw and nut, but the rack and pinion are to be considered better. The rack should never form part of the frame-casting, because its teeth are apt to be broken.

It should be a separate casting, fixed to the frame by screws. It can then easily be removed and a new one put in its place if it should get broken.

If the table be not clamped to the frame-slides by bolts, the downward pressure of the drill, along with the weights of the work and of the table itself, are apt to cause the rack-pinion to rotate slowly and allow the table to sink. This may be perfectly avoided, however, without the use of clamping-bolts, by the use of a pinion of only two teeth. These teeth consist of two steel pins projecting from the face of a small disc. This is keyed to a shaft whose centre line lies in the plane of the pitch lines of the teeth of the rack. When one pin-tooth lies in a space between two teeth, the other tooth lies directly underneath it in the space beneath. The line of pressure on the faces of the teeth being thus vertical, and passing through the centre line of the shaft, there is no tendency to rotation in the two-toothed pinion, and there is no risk of the table slipping downwards even when unclamped.

14. **Arrangement of Feed Gear.**—The downward feed of the spindle and drill-tool is given by the hollow screw *r*. The pinion *h* is keyed to a long bush, *i*, in which the spindle *k* slides, *h* being revolved by a feather and slot. The bush *i* also encases the lower part of the screw *r*, but this screw does not rotate. Its lower end bears against a shoulder on the spindle *k*, and part of the upward thrust of the spindle is delivered to the screw by this shoulder. Above this point the spindle is turned down to a smaller diameter and passes upwards through the hollow screw to its top, where a couple of lock-nuts form a collar covering the upper end of the screw. The spindle can thus rotate freely in the screw without carrying it round with itself, but it must move up and down along with the screw. On the top of this latter is screwed a cap, r_2, through which passes a steel set-screw, with a flat point bearing against the upper end of the revolving spindle. This is

intended to take the main part of the feed-thrust, so as to relieve the pressure on the shoulder lower down.

The screw *r* works in the long cast-iron bush r_1, which is fixed in the frame. This bears a feather that enters a longitudinal groove cut across the threads of the screw, and so prevents the screw from turning, but permits its vertical motion. In a bearing in the frame immediately above this lies a nut, which can rotate, but is prevented by collars from moving vertically. It forms the boss of the wheel *q*, and the revolution of this wheel moves the screw *r*, and with it the spindle *k* and the tool, up or down as is desired; *q* gears with the pinion *p* on the top of the upright spindle *e*, seen in the front view, B. At the lower end of this spindle is a hand-wheel by means of which a hand-feed can be given to the drill. The hand-wheel can be coupled to a worm-wheel that lies immediately above it by a small cone-clutch, tightened up by a screw and hand-nut underneath the wheel. When thus bound, the worm-wheel can drive the feed-spindle; otherwise it runs loose upon it. The worm-wheel, in its turn, is driven by a worm *n*, and this is rotated by a narrow belt running over the small cone-pulleys *l* and *m*.

15. Other Arrangements of Feed Gear.—A great variety of feed motions for drill-spindles has been invented. That described above, although the most common, seems by no means the best, involving as it does an unnecessarily complicated construction.

It is easy to avoid any need of having the feed-screw hollow. A rotating joint between its lower end and the top of the spindle is easy to arrange so that the screw may be able to lift the spindle as well as to press it downwards. Fig. 50 shows one such arrangement. *k* is the spindle, as in the previous figure, and *r* is the feed-screw, which is now solid. The two bear against each other on their flat ends at *e*, through which all the feed pressure is delivered. To lift the spindle there is the collar *a* screwed on the lower end of *r*, and kept in place by the lock-nut *b*; *a* is put over the reduced end of *k*, and two lock-nuts, *c* and *d*, screwed on the top of *k* form a collar by which *a* can lift the spindle. For the sake of compactness, *c* and *d* are made circular, and are screwed up by a prong-key entering holes in their flat surfaces, the lower one *d* being held fast while *c* is tightened down on it by a pin inserted in a hole in its peripheral surface and passed through a hole in *a* from the outside. In putting the pieces together, *a* is first put over *k*, *d* is then screwed down to its proper position, which is such as to allow *a* to revolve quite freely round *k*, and then *c* is tightened down on *d*. *b* is next screwed up to the top of its run on *r*. Then *a* is screwed on *r* until *k* is drawn to bear closely on the under surface of *r*; *b* is lastly screwed down again tight upon *a*. The screw *r* is prevented from rotating by a feather fixed in the frame-bearing.

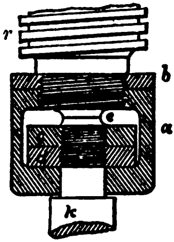


Fig. 50.

Another plan consists in making the feed-screw in one solid piece with the spindle. The nut is capable of revolving in its bearing in the frame, being prevented from vertical motion by collars. When it rotates at the same rate as the spindle, the latter receives no feed motion. If, however, the rotation of the nut be hindered by the application of a frictional resistance to its motion, the spindle moves in the nut, and receives a feed motion proportional to the difference of rates of revolution of the spindle and of the nut. The feed pressure being transmitted through the thread of the screw to the nut, this thread requires to be made square and strong to withstand wear. Its pitch cannot, therefore, be a fine one. Since the motion of the drill is a very rapid one, and because of the largeness of the pitch of the screw, the difference between the speed of rotation of the nut and that of the screw-spindle must be very small in order to give a slow feed motion. The feed pressure, after being transmitted from the thread on the spindle to that of the nut, is delivered by the nut through its collars to the frame. There is thus a certain amount of frictional resistance to the rotation of the screw inside the nut, and, again, a certain amount resisting the rotation of the nut in the hole in the frame. Supposing that the nut moves with equal freedom on the screw and in its bearing in the frame when no feed pressure is applied, then there will be the same amount of friction caused at the collars as at the threads of the nut, both being caused by the same pressure—namely, the feed pressure. But the friction at the collars acts at a greater distance from the axis than does that at the threads of the screw and has consequently greater leverage to resist sliding motion. Thus, if extra means were not adopted to prevent its being so, the nut would always remain immovable in its bearing, and the screw would revolve in the nut. This difficulty can, however, be obviated by the simple expedient of splitting the lower portion of the nut. The split portion becomes slightly pliable, so that the two halves may be drawn together by the application of a suitable force. Being drawn together by two bolts, they are tightened down on the screw, and thus cause an extra resistance to the motion of the screw in the nut, independently of any feed pressure. This ensures that the nut will rather turn in its bearing than that the screw should turn in the nut. To cause the screw to feed down through the nut, extra frictional resistance must be applied to the outside of the nut on a groove pulley cut on the nut for that purpose, by a brake-collar or strap controlled by hand. The rate of feed is proportional to the amount of brake friction applied. On account of the rapidity of the motion and the large pitch of the screw, the brake friction must be applied delicately and with a reduced leverage. To draw the drill upwards out of the work, the nut must be made to revolve faster than the spindle. This can be effected by means of four small bevel friction-wheels or pinions. One of these three is cast in one piece with the nut at its upper end. A second is placed on the screw, with the bevel downwards and at a higher level than the nut, and is rotated by the screw, by means of a feather in the pinion and a slot in the screw. This pinion is prevented from shifting vertically by collar bearings in an extension of the frame. The first pinion is smaller than the second. They are thrown into gear with each other by another pair of similar bevel friction-wheels, cast in one piece and running on a horizontal stud. One of these nearest the spindle is of the same size as that on the top of the nut. The other, standing behind it, is larger than the latter, but smaller than that rotating along with the screw. These can be pushed back on the stud away out of contact with the first pair, but when they are advanced towards the screw they come simultaneously in gear with the first two mentioned, with the desired result of the nut being driven faster than the spindle, which is consequently raised with a rapidity dependent on the ratio of the diameters of these bevel pinions.*

One more feed arrangement may be briefly mentioned, on account of its being frequently used. The upper part of the feed-spindle is separate from the lower, and does not rotate. On one side of it is cut a toothed rack. A pinion gears with this, the rotation of which lifts or lowers the spindle. A worm is keyed on the same horizontal stud that carries the pinion, and a worm-wheel gearing with the worm is carried at the top of a vertical rod which is rotated by a hand-wheel fastened to its lower end. An example of this gearing is seen in Fig. 51.

16. Radial Drilling Machine. — In the drilling machine already described the line of the axis of the drill-spindle is immovable, while different parts of the work may be brought under it by moving the table. When the piece to be drilled is very large and weighty

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* The arrangement here described has not yet, at the date of publication of this volume, been tried in practice.

it is more convenient to be able to move the drill-spindle into different positions over the work. This is accomplished in the radial drilling machine shown in Fig. 51. A heavy upright standard, *a*, seen in section B, is firmly bolted to the foundation. In bearings in this lies the shaft *e*, with a cone driving-pulley *f*, and at its front a bevel pinion *g*. In front of the standard are two vertical guide surfaces, on which slides a massive hinge-plate *b*. This has a rack bolted to it by means of which it can be elevated or lowered by the toothed pinion μ. The shaft upon which this pinion is mounted is turned by a worm-wheel and worm, seen in the side view A, the worm-shaft being rotated by a hand-wheel.

At the top and bottom of *b* are two large cylindrical bearings, in which lies the large pin end of the canti-lever gantry *c*. The whole of this projecting beam, or "radial arm," can thus be swung round these bearings, and the drill, being mounted on it, is carried with it into any desired radial position. Along guide surfaces on the beam slides a plate *d*, seen in A and in the section C, and on this an ordinary drill-spindle is mounted in the manner the details of which are clearly shown in A. Between the upper and lower hinge-pins the vertical portion of *c* is shaped as a hollow half cylinder. In this portion stands the shaft *i*. This is driven by the bevel-wheel *h*, and it again by *g*. The shaft *i* is slotted thruoghout the whole of its height, and slides upwards or downwards with *c* through the boss of *h*, in which there is a feather fitting into the slot. The horizontal part of the beam *c* is recessed in its front face between the two slide surfaces, as seen in section C. In this recess lies a screw, gearing into a nut fastened to *d*, and moved by a hand-wheel ρ at the extremity of the arm. By this screw the drill may be moved farther from or nearer to the frame *a*. The bevel *k* at the top of the shaft *i* drives a similar bevel on a short hollow bush. This drives the telescopic shaft *m n*, on the end of which is the pinion *o*, gearing with *p* on the drill-spindle. The drill-spindle itself drives a pair of small bevels, which actuate the feed-motion cones. The latter, by means of the worm w on the same shaft, operates the shaft x_1, the worm y, and the pinion α that gears into the rack β, and lifts it and the spindle along with it.

17. Multiple Drilling Machine.—It is frequently desired to drill a large number of holes with the centres of all in one straight line. It saves much time if the machine used has a number of parallel drill-spindles which can all be brought into operation on the work simultaneously. Such machines are called multiple drills. The different drilling heads are all geared together by being driven all from one horizontal shaft by means of bevel-wheels. For general work they ought to be capable of being shifted to different distances apart, to suit the desired pitch of the series of holes. Frequently, however, these multiple drills are constructed for a special duty, in which the holes to be drilled are all spaced alike, and in this case there is no need of being able to adjust the drills relatively to each other.

18. Slot Drilling.—Slot drilling is a mode of making key-way grooves in shafts, or similar recesses. The drill has two straight edges perpendicular to the axis, so that the bottom of the hole cut out is flat. The vertical side edges are also made keen and sharp so as to cut easily. The drill is sunk a small depth only underneath the surface, and the work is then traversed horizontally underneath it, the side edges of the drill cutting out a longitudinal groove. If the work be traversed in a straight line, the groove cut is straight, and a circular or any other groove may be cut by giving the work a corresponding motion. The depth of cut being small, the operation has to be repeated many times, the number of backward and forward traverses made by the work being proportional to the depth of groove desired. Slots for the insertion of keys or feathers in shafts, and slots on shafts in which feathers slide, are best cut out in this way. These slots are sometimes of very considerable length, and on that account the sliding-table on which the work is bolted must be long, and have a long range of motion. When the length of the slot exceeds the possible travel of the table, one portion of the slot is first finished, and the work then shifted and re-bolted to the table in a new position, care being taken that the new position is in exact line with the former one, so that the slot shall be continued precisely in the same line.

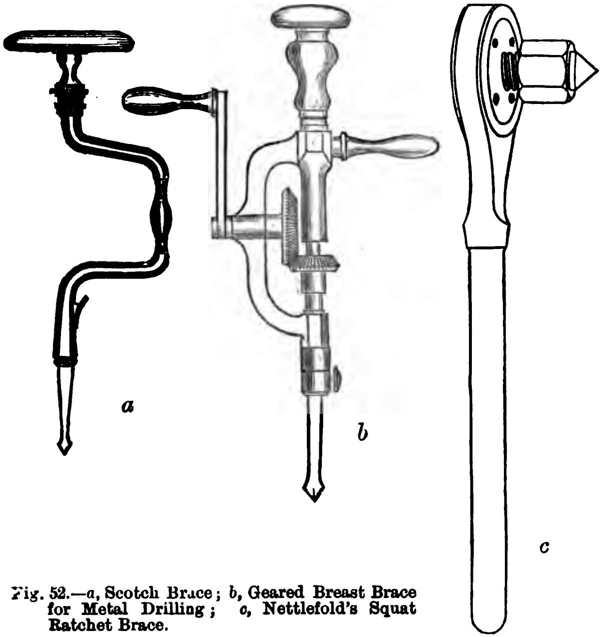

Fig. 52.—*a*, Scotch Brace; *b*, Geared Breast Brace for Metal Drilling; *c*, Nettlefold's Squat Ratchet Brace.

19. Hand Drilling in Wood and Metal; Hand Braces; Ratchet Braces; Bow Drill.—Metal is also often drilled by hand, but, except for small sizes of hole, the process is a tedious one because it is difficult to keep up by hand a sufficient speed of rotation to give the proper linear cutting speed to the edges, this being so on account of the small diameter of the mean circle on which the edge operates. Hand-drills for metal are sometimes placed in braces of the same construction as those used for wood. This is shown in *a* of Fig. 52. The drill is clipped in a socket by a spring catch in the lower end of the brace, the middle portion is cranked and driven in rotation by the right hand, and on the upper end is a loose semi-spherical knob, by pressing against which with the breast the drill is driven forwards. Such an instrument is

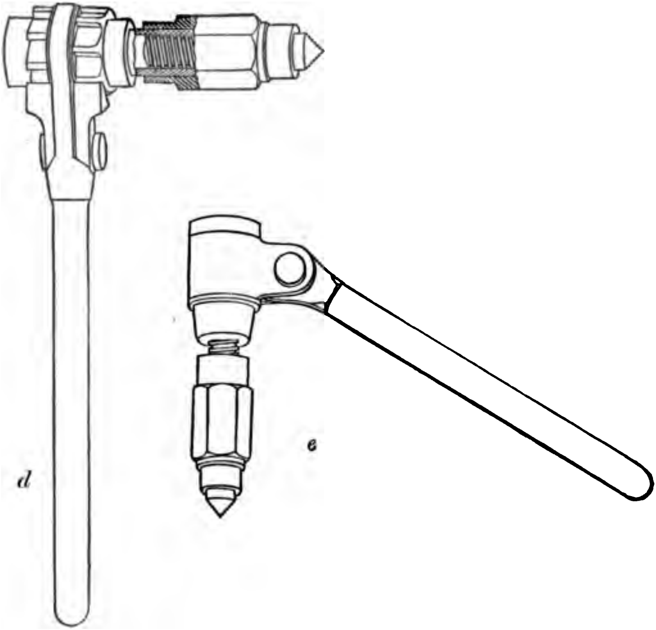

Fig. 52.—*d*, Nettlefold's Ratchet Brace ; *e*, Nettlefold's Swivel Brace.

called a breast-brace. The knob is usually of wood, and for work on wood the crank is also frequently made of wood. Fig. 53 shows several wood drills, or "bitts," as they are technically termed, the forms of which are sufficiently apparent from the illustration without further description. In Fig. 52, *b* shows a breast-brace used with metal drills. The bevel wheels are rotated by the crank handle at one side, while the handle projecting on the opposite side is used to steady the brace and prevent its frame from turning round. In *d* (p. 208) is shown a "ratchet brace" of the most common construction. This is used in conjunction with a cramp, against an arm of which (or sometimes against an overhanging portion of the work) the steel centre at the top of the brace has its bearing. This is upon a long nut, which is gradually unscrewed from the screw which lies between it and the lower portion of the tool. In proportion as the nut is unscrewed the drill-point is fed downwards. The lower cylindrical part rotates independently of the screw and of the handle. The drill is fixed in the socket formed in

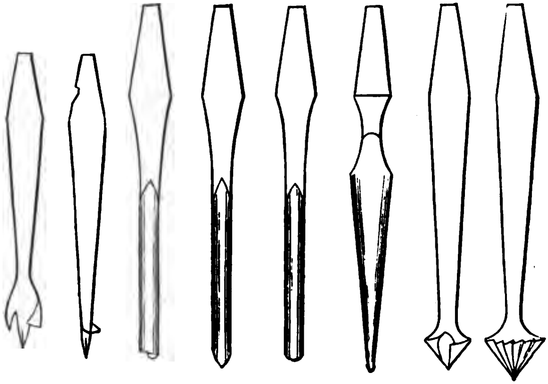

Fig. 53.—Brace Bitts for Wood.

this part, and a ratchet-wheel engages with a spring pawl upon the end of the handle. This handle is swung backwards and forwards, with the result of giving the drill a continuous slow rotation in one direction. Very many designs for ratchet braces, in which one or other form of automatic friction-clutch is substituted for the ratchet wheel and spring pawl, have been patented. The illustration, *c*, p. 207, shows what is called a "squat" ratchet-brace, the parts being so arranged that, while a fair range of telescopic expanding motion is obtainable, the whole length of the instrument is small, and it can be used in confined spaces; *e*, p. 208, illustrates another special form of brace convenient for drilling in confined spaces. The handle may be swivelled up or down. These patterns are manufactured by Messrs. Nettlefold, of Birmingham.

The "bow drill" is a tool used by clock and small instrument makers, and is suitable for very small holes only. The cord of a bow is given a couple of turns round a groove pulley mounted on the socket holding the drill. By drawing the bow backwards and forwards, an oscillatory rotation is supplied to the tool.

CHAPTER IX.

PUNCHING AND SHEARING MACHINES.

1. Similarity between Punching and Shearing.—Shearing machines might well have been described in an earlier portion of this work, on account of the fundamental and simple character of the cutting action that constitutes a shear. But in the series of tools that have been already described, the sequence from chapter to chapter, starting from the simplest tools in which the *other* fundamental kind of cutting—namely, tearing—was chiefly operative, has been so natural that no place has been found before this to consider shearing pure and simple.

In the scientific sense of the word, *shearing* includes *punching.* In the two tools for shearing and punching the cutting actions are of precisely the same sort. This scientific connection finds curious expression in the fact that the two tools are frequently, and indeed usually, combined in one. But they are quite as distinctly different machines, as, for instance, are a planing machine and a turning lathe, in which also the cutting actions are of the same sort, and only different in so far as they are affected by the shape of the work being formed. They are more different than are planing, shaping, and slotting machines. The difference between them is simply that shearing machines, like planing machines, cut plane surfaces, while punching machines, like boring lathes, cut inside cylindrical (or approximately cylindrical) surfaces.

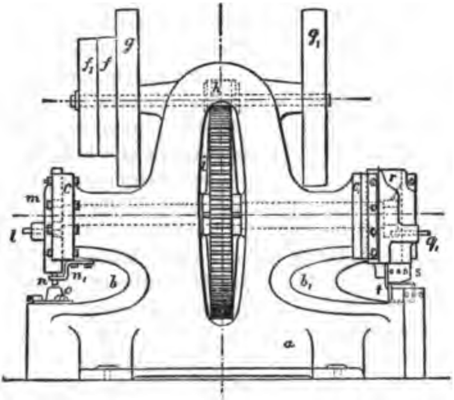

Fig. 54, A.—Side View of Punching and Shearing Machine.

The machines themselves will first be described, and afterwards the cutting actions of the tools will be considered more minutely.

2. Combined Punching and Shearing Machine.—This machine is shown in Fig. 54, A, B, and C. The general arrangement is seen in the side and front views A and B, and the construction of the internal parts in the section C. The frame of the machine is a heavy casting, *a*, of high and elongated form, in the two ends of which are two deep horizontal recesses, *b* b_1. In the right-hand one, as seen in C, is bored a vertical hole, about half an inch larger than the largest size of hole intended to be punched, and on the planed surface at the upper end of this hole rests the cast steel die *o*. This is pyramidal in form, and has a vertical hole through it, the top of which is bored exactly circular to a diameter slightly larger than that of the punch *n*. The lower portion of the hole in *o* is made a little larger in order to allow the round block of metal that is punched out of the plate operated upon to fall down freely without frictional resistance. The punch *n* is a short, nearly cylindrical, piece of steel, which is slipped into a tapered socket in the slide *m*. The punch corresponds in size with the die, and for each punching machine there must be a set of dies and punches for all the sizes of holes desired to be punched. The sizes in such a series usually increase by sixteenths of an inch in English machines. The bottom part of the punch is very slightly tapered for a short distance, so that the lowest diameter is the largest, and the higher portions of the tool can pass without friction into the holes formed by the lower edge. This upward narrowing is continued a small length only, the upper part of the punch being tapered in the contrary direction, in order to gain a larger, and consequently less

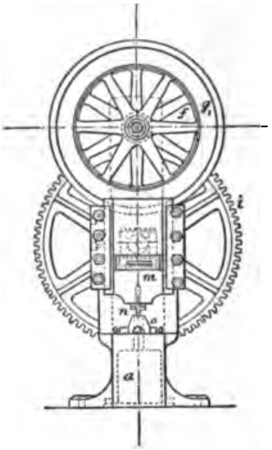

Fig. 54, B.—End View (Punching end) of Punching and Shearing Machine.

severely stressed, section for the body of the tool, and also in order that the upper part of all the punches of smaller size should fit the socket made in accordance with the diameter of the largest of the series. The die *o* is held in place by three horizontal set-screws, by means of which it can be set with accuracy vertically underneath the punch, which at the bottom of its stroke should enter the die by about $\frac{1}{64}$ of an inch. The plate to be punched is laid horizontally resting on the die *o*, and its edge may be pushed back as far as the back of the recess *b*, or any distance less than this at which it is desired to place the hole. The punch is forced down by the slide *m*, and it fits so tightly in the hole made in the plate that in rising again its friction lifts the plate upwards. In order to free the plate of the punch, it is kept from rising more than a short distance by the pronged guard *n* fastened immovably to the frame at n_1. This guard is placed at such a height that it admits between it and the die the thickest plate that it is intended ever to operate upon. The casting *m* in which the punch is placed moves up

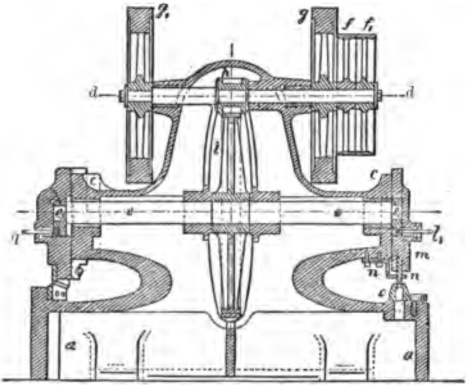

Fig. 54, c.—Longitudinal Section of Punching and Shearing Machine.

and down a dove-tail grooved slide, formed of a flat vertical surface and strips screwed on as seen in the end view. In *m* there is a broad rectangular slot cut, in which works a square block fitting the slot vertically, but shorter than it horizontally, so that it may have in the slot a to-and-fro motion equal to the required vertical stroke of the punch—*i.e.*, two or three times the greatest thickness of plate to be dealt with. In the square block is a cylindrical hole into which enters an eccentric pin e_1, turned on the end of the shaft *e*. As this shaft turns the eccentric pin actuates, through the block, the slide *m* in its up and down motion. It will be observed that the lower edge of the slot in *m* consists of a separate small plate, to which is screwed the handle l_1. By this handle the plate can be pulled forward into a recess made for it in the front part of *m*—*i.e.*, farther than the front end of e_1 and of the square block. In this position it leaves the slot in *m* of a square shape, and of such size that e^1 and the square block may perform their circular motion without driving *m*. By this means the handle l_1 serves to throw the punching end of the machine "out of gear." The slide then remains in its mean position, being held at that level by the friction in the guide-grooves. In order that its weight may not make it fall in spite of this friction, it is often linked to a horizontal lever lying over it with a fulcrum on the frame and a counter-balance weight at its inner end. A small hole may be seen in the section C bored obliquely through the upper part of *m*. This hole is continued down through the top half of the square block. Its object is to lubricate through it the sliding surfaces of the block and of the eccentric pin e_1.

3. Shearing Machine.—The shearing machine is at the other end of the shaft. It has a gap, b_1, of equal depth in the present example to that of the punching end. The shearing consists in cutting one portion of plate from the other along a straight line, and this is done in exactly the same way as that in which an ordinary pair of scissors acts. The shearing blades are flat stout plates of steel, marked *s* and *t* in the side view. These are fastened by countersunk screws, the lower one to the frame of the machine and the upper one to the slide *r*, which is similar and similarly moved up and down by the shaft *e* to the slide *m* that actuates the punch. There is an eccentric pin e_2, the square sliding block surrounding which can be thrown out of gear by drawing out the handle q_1. The shear blades are placed so that the plane of the face of the one coincides with that of the opposed face of the other. The edges are straight, and are ground so as to give a cutting angle of slightly less than 90°. The edge of the lower blade is horizontal: that of the upper one is inclined to the horizontal at a small angle, so that the shearing action commences at one end and proceeds gradually towards the other.

In the machine illustrated the shear blades are not perpendicular to the length of the frame, that is, to the shaft *e*. The object of this is to facilitate the cutting of the ends of plates obliquely. The back of the gap b_1 is placed obliquely at the same angle. Since the bearing surface of the slot in the slide *r*, in which the eccentric and block work, must be perpendicular to the shaft, the slide *r* takes in cross section a nearly triangular shape. The centre of the thrusting surface of the eccentric block should be placed vertically over the middle of the shear blade edges. The weight of this slide is often counterbalanced in the same way as already described for the punching end of the machine.

The commoner arrangement is to have the blades at right angles to the shaft. In one very convenient arrangement, illustrated in Fig. 56, the blades are fixed to separate disc castings bolted on horizontal circular faces on the frame and on the lower end of the slide respectively. These can be shifted round and clamped in position at any desired inclination to the shaft.

4. Driving Mechanism.—The shaft *e* is supported at two bearings at its ends and at two others near its centre in bosses cast in the frame. Between these bosses comes a large spur-wheel. This is driven by the upper shaft *d* by means of the pinion *h*.

The shaft *d* also is supported in bearings in the frame, the boss on the right-hand side being extended close up to the pinion *h*, because this is the driving end of the shaft, *i.e.*, the end through which the driving effort is transmitted. The effort is transmitted from pinion to wheel through the surfaces of the teeth in contact. The force twists the two shafts, the twisting force or moment being that which produces the desired rotation. The same force, however, bends the shafts. This bending, although unavoidable, is not *desired* and, in fact, is injurious. It is, therefore, reduced to a minimum by placing the bearing as close as possible to the mean point of application of the force which is in the centre of the length of the pinion. The design of the machine would be still better than as in the drawing if the boss on the left-hand side in c also came close up to the pinion. All shafts in machinery should be prevented, as far as possible, from bending by placing the bearings as near as they can be arranged to the places of application of transverse force. The bending results in waste of energy, in the form of vibration and heating of the shaft, and it is still more injurious in unduly wearing the edges of the journals, and in thereby wasting a still further quantity of energy in heating the journals.

At the end of the shaft there are two pulleys, *f f′*, one loose and the other fast, by a belt running over the latter of which the machine is driven. When it is not desired to run it, the belt is shifted by a fork overhead on to the loose pulley.

On this upper shaft there are two fly-wheels g and g_1. These are necessary on account of the great variation in the resistance. During the upward stroke of the tools no work is done except in overcoming the friction at the sliding surfaces, and in lifting the weights of the slides *m* and *r* if these are not counterbalanced. It is only during a fraction of the downward stroke that work is done, the size of the fraction depending on the thickness of the plate that is being shorn or punched. During this small time the effort required is greater than can be exerted by the belt, through its frictional connection with the pulley over which it runs. The deficiency is made up during the rest of the revolution. Energy is delivered by the belt to the pulley at a tolerably uniform rate throughout the whole revolution of the shaft *e*. While none of it is being spent in cutting, this energy has the effect of slightly increasing the speed of the moving parts —*i.e.*, additional kinetic energy, or energy of motion, is stored up in them. The heavier these parts are the greater is the quantity of additional kinetic energy corresponding to a given increase in velocity, and, therefore, in order that the whole energy delivered to the machine during the non-cutting period of the stroke may be stored up in this way without involving a large variation of speed, the heavy fly-wheels are added. During the cutting, when the supply of energy by the belt is insufficient to meet the demand, the fly-wheels give up once more the kinetic energy stored in them, helping the belt to drive the punch or shears through the plate.

As mentioned already, the stroke of the punch is made much greater than the greatest thickness of plate to be perforated. The object of making it so is partly to allow a larger portion of the revolution for the storing of energy in the above-explained manner, and partly—perhaps chiefly—to allow an interval of time between the successive entrances of the tool into the plate sufficient to permit the workmen to shift the plate correctly into the new positions for the next holes. The forked guard over the plate enables them to do this with considerable exactitude when the holes are previously marked out with chalk, and with practice it can be done very rapidly.

5. Whitworth's Driving Gear.—Many variations are adopted by different makers in the modes of making the driving connection between the eccentric pins on the shaft *e* and the slides. The design used by Sir

Joseph Whitworth is a good one. Fig. 55 shows this. The shaft (in end view) is marked *e*, and the eccentric pin e^1. The block in which e^1 is inserted takes a triangular form *k*, shown clearly by the shaded edge. The slide *l* has cut in it a triangular slot, corresponding in general shape to *k*, of the same depth but wider by an extra breadth equal to the throw of the eccentric so that *k* may rock to and fro in it at its top end. The rounded lower corners, *o*, of the two triangles are curved to the same radius, and the one rocks inside the other through a very small arc only. The upper edges, *p p p*, are curved to the same centre as these lower corners, so that the block *k* always fills the slot vertically, whether it be upright, as in the figure, or thrown to one side. The chief advantage of this design is that while on the upward stroke, when little pressure is being exerted between the block and the slide, this small pressure is exerted at the surfaces *p p p*, where the maximum sliding motion occurs between the two, and on the downward stroke, when intense force is being transmitted, the pressure is at *o*, where only very small sliding motion occurs. Loss of energy by friction is thus avoided.

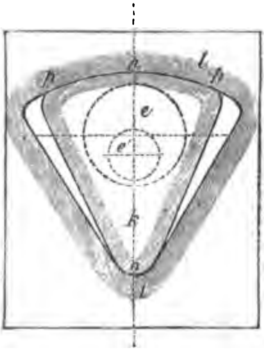

Fig. 55.

6. Hydraulic Punching and Shearing Machine.—In the machine thus driven by a belt and an eccentric pin there are two faults. One has already been explained—it is the necessity of storing up energy to develop an extra great rate of working for a minute period; the other is that there can be no variation of the length of stroke to suit different thicknesses of plate. These defects do not exist in the Hydraulic Punching

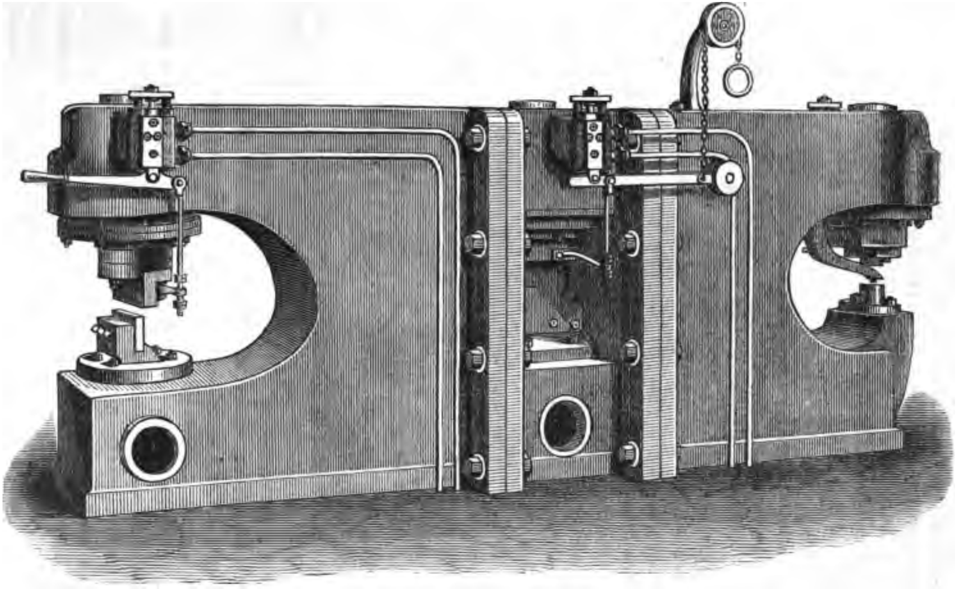

Fig. 56.—Tweddle's Hydraulic Punching and Shearing Machine.

and Shearing Machine, shown in Fig. 56, which is designed and made by Mr. Tweddle. Here an hydraulic cylinder stands directly over each of the two tools for shearing and punching. The plungers of these cylinders take the places of the slides in the before described machine, the tools being directly inserted in their lower ends. The full power required for penetration of the material is obtained by the water pressure acting on the large surfaces of these plungers, and this force acts through a distance only equal to the stroke of the tool. This stroke also is variable for different thicknesses. As already stated, the shears may be clamped at any angle to the centre line of the frame. The water is admitted for each stroke through a valve actuated by a hand-lever, and at the end of the stroke an escape-valve opens automatically, and the plunger, being counterbalanced with an excess of weight, is drawn upwards to be ready for a new stroke. The supply-valve being opened by hand, the interval between each stroke may be made whatever is necessary for the setting of the work correctly in position.

Small portable punching machines could easily be made on this principle, to be slung by chains into position for any odd work on large structures, such as bridges and ship work.

7. **Multiple Punching Machine.**—The principle of multiple punching does not yet seem to have been introduced into practice. This might be done with great advantage. A series of sockets might be placed in the lower edge of the slide to hold as many punches with a corresponding row of dies underneath them, both series being adjustable to any pitch desired. Beyond the forward end of the row of dies there would be fixed a gauge-peg, simultaneously adjustable with the dies to the same pitch from the last of the dies. When one set of holes had been punched by one stroke of the machine, the last hole so punched would be slipped over the gauge-peg, and this would ensure the succeeding stroke making the next set of holes at the right distance from the former set.

8. Mode of Rupture by Simple Shear.—The action of the shearing blades upon the plate is very simple. This is in consequence of the cutting angle being less than 90°, whereby it is ensured that the surface of the plate rests wholly on the edges of the top and bottom tools. The cutting edges sink slightly into the plate, the surfaces of which are compressed over a strip of very narrow breadth. The force is exerted through a slice of material of this breadth, of depth equal to the thickness of the plate, and of length equal to that of the portion of the blade that is in action at any instant. This portion of material is subjected to intense shearing stress—that is, the portion of it at one side is forced to slide over that at the other. Such sliding is called "shearing strain." It may take place to a considerable extent without actual rupture occurring, as when a piece of material is *twisted.* In the present case it is carried so far that the two opposite surfaces part company, and the plate is separated in two pieces. The cut is a comparatively clean one, because the shearing stress has been so localised within such narrow limits. Outside the minute breadth mentioned above, the material remains almost wholly unstressed, and, therefore, there is no chance of the surface of rupture wandering more than the smallest perceptible distance from the plane connecting the edges of the top and bottom blades. The broken surface is slightly ragged, but is quite flat.

It is to be observed that the whole force of the rupturing action is exerted through *as small* a section of the blade-material as of the plate, and as this latter is broken it is only owing to the superior strength of the steel of the blade that the operation is at all possible.

9. Mode of Rupture in Punching.—The shearing out of a cylindrical portion by the punch would be exactly similar to that described above, giving an even breakage if the cutting edges of the top and bottom tools were made with cutting angles somewhat less than 90°. In order that they should be so, the upper surface of the die would need to be coned, and the under surface of the punch hollowed to a cup-shape, as in Fig. 57. The edges so sharpened, however, would be difficult to maintain, there being no easy means of re-grinding them when blunted. The top of the die is made flat instead, and some makers make the face of the punch slightly convex instead of concave. The result is that severe pressure is distributed through an annular portion of the plate the inside diameter of which is much smaller than that of the tool, while its outside diameter extends considerably beyond the circumference of the hole in the die. The first effect of the application of the punch is the crushing of the top of the plate within the circle of the hole about to be formed and to a small depth beneath the surface. In sinking, this portion of the material drags downwards with it the surrounding portion outside the circle. This cannot be dragged downwards far, because the plate is supported underneath, and, in fact, it can sink only in so far as it also becomes compressed. It, therefore, resists the downward force by sheer stress over the vertical cylindrical surface, and the material becomes violently twisted throughout a certain radial distance. It is to be observed that these actions do *not* extend through the whole thickness of the plate (unless this is very thin), but at the beginning reach only to a certain depth from the surface. The downward compressing force inside the circle gradually expends itself in producing shearing forces that are transmitted laterally to the outside of the circle. When a certain depth has been reached, at which the sum of the laterally transmitted shearing forces equals the total downward thrust of the tool, the vertical compressive stress is reduced to zero. Above it the strain increases until the shear over the lateral walls of the crushed portion becomes so great that rupture takes place. The rupture occurs along the lines where the

Fig. 57.

stress has been greatest, and these are nearly but not quite vertical. The broken surface is thus conical, the apex of the cone being above. The angle of this cone depends conjointly on the character of the material, on the difference between the die-hole diameter and the punch diameter, on the plate thickness.

After this rupture, these vertical surfaces, which were previously clinging together, cease wholly to transmit force laterally. The whole of the thrust applied at the upper surface by the punch is now transmitted down to the bottom of the breakage, and the part above this point proceeds to act on the part below it in the same way that the punch-tool itself acted upon the upper portion, the action differing in that the lower face of this plug has no defined cutting edge, and that the thrust is more evenly distributed over this face than it was originally over the face of the punch. The whole process above described now re-commences; a similar set of forces is developed at a lower level under only slightly altered conditions, and then on a new short conical surface the shear-strain increases until rupture again takes place. If this second rupture does not carry the breakage wholly through the plate, the process is repeated a third time, and occasionally a fourth time. The successive ruptures do not take place along the same conical surface, each broken surface lying inside the mathematical extension of the one above it. The short conical shorn surfaces are connected by small, very ragged circular shelf-surfaces, which are called "burrs," and which are a great inconvenience in the subsequent process of riveting the plates together.

The action of the cutting edge of the die on the under surface is quite similar to that explained above as taking place at the upper surface.

10. Error in the Ordinary Calculation of the Strength of Punches.—It will thus be seen that, except in the case of thin plates, where no burrs are discovered inside the punched holes, the operation of cutting through the plates is not an instantaneous one, nor one in which all the different parts of the surface are cut simultaneously. The whole is done bit by bit, and the stress on the tool is correspondingly relieved. The strength of the tool to do its work has been usually calculated as if it had to exert a thrust sufficient to overcome the resistance to shear-rupture of a surface equal to the circumference of the hole multiplied by the *whole thickness* of the plate. By this theory a certain thickness is calculated, beyond which the punch must have insufficient strength to pierce the plate. The above explanation shows, however, that such a calculation must be wholly erroneous, and would give a much smaller limiting thickness than the true one. The resulting error is partly counterbalanced by the additional error made in assuming that the thrust of the punch is uniformly distributed over its horizontal section. It is actually to a great extent concentrated at its edges, and this concentration evidently greatly diminishes its effective strength and the depth of material which it can pierce without itself breaking. It is probably to avoid this concentration of the stress at the edge that Sir Joseph Whitworth and other makers have made the under surface of the punch slightly convex.

11. Relation between Shearing and Punching and other Cutting Machines.—The action of shearing and punching is a true cutting action, although it is of a rough character, and the above explanation will greatly assist in the right comprehension of the mode of cutting in planing machines and turning lathes. The greatest difference between the two really lies in the effect of the keener cutting edge of the latter, and the smaller thickness of the layer of material removed by them, whereby the cutting stresses and strains are more effectually localised. The remaining difference between the cases consists in the altered ratio in which shearing, tensive, and compressive forces are active in producing the separation of the part which has to be removed.

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