words, at the smallest cost, — and if the best class of work is also desired, it seems certain that a twist-drill, with all the accuracy which can possibly be imparted to it in its manufacture, and with the greatest care employed in the re-sharpening, is the only instrument which can be employed.

About a quarter of a century ago both Sir Joseph Whitworth and the late Mr. Greenwood of Leeds made some twist-drills, but it is to be presumed that a large amount of success was not achieved with them, and for some reason the system was not persevered with. After that period the Manhattan Fire-arms Company in America produced some beautifully-finished twist-drills. Though the workmanship in these was of a superior description, the drills would not endure hardship. It was found that the two lips were too keen in their cutting angles, and that they were too apt to drag themselves into the metal they were cutting, and finally to dig in and jam fast, and twist themselves into fragments. Mr. Morse then took the matter up, and by diminishing by about 50 per cent. the keenness of the cutting lips of twist-drills made a great success of them. He used the grinding line, AB, Fig. 29, and an increasing twist. In such a drill, of the standard length, and before it is worn shorter by grinding, the twist is so rapid toward the lips that the angle they present, or what has been already referred to as the angle of the cutting surface, is very nearly the same as that which the writer had previously established for cutters cutting metals, as in Fig. 21.

If however the angle of twist is made to increase towards the lips, it will of course decrease towards the shank, as in Fig. 29, The shorter the drill is worn, the more obtuse the cutting angle becomes, and the less freedom will it cut with: supposing of course that, when the drill was new, the angle was the most efficient. Suppose this decrease of twist were carried still further by lengthening the drill, a cutting angle of 90° would eventually be arrived at. The old common style of drill usually has such a cutting edge which is so obtuse as not to cut the metal sweetly, but on the contrary to have more of a tearing action, and thus to put so much torsional strain on the drill that fracture is certain to take place, even if what the writer would now consider a moderate feed was put on by the drilling machine.

It is therefore obviously advantageous to adopt from the first the best cutting angle for all twist-drills, and to preserve this same angle through the whole length of the twisted part, so that, however short the drill may be worn, it always presents the same angle, and that the most efficient which can be obtained. This cutting angle is easy to fix, and becomes an unalterable standard which will give the best attainable results. This has been adopted at the Gresley Works Manchester, and of course applies to both lips.

A common drill may "run," as it is usually termed, and produce a hole which is anything but straight. This means that the point of the drill will run away from the denser parts of the metal it is cutting, and penetrate into the opposite side which is soft and spongy. This is specially the case in castings; where, for instance, a boss may be quite sound on the one side, while the other side, being next to a heavy mass of metal, may be drawn away by the contraction of the mass in cooling, so as to be very soft and porous. In such cases it is perfectly impossible to prevent a common drill from running into the soft side. This sort of imperfect hole is most trying to the fitter or erector; and if it has to be tapped, to receive a screwed bolt or stud, is most destructive to steel taps. The taps are very liable to be broken, and an immense loss of time may also take place in attempting to tap the hole square with the planed face. A twist drill, on the other hand, from its construction, is bound to penetrate truly, and to produce holes which are as perfect as it is possible to make them.

The next important step in twist-drills has been to fix a standard shape and angle of clearance for both lips, which should also give the best attainable result. This angle might be tampered with if the re grinding were done by hand, and too much or too little clearance might easily be imparted to the drill from want of sufficient knowledge on the part of the workman. If too little clearance, Fig. 30, or in some cases none at all, is given to the drill, the cutting lips then cannot reach the metal, consequently they cannot cut. The self-acting feed of the drilling machine keeps crowding on the feed until either the machine or the drill gives way. Usually it will be the latter.

Again if too much clearance is given, Fig. 31, the keen edges of the lips dig into the metal, and embed themselves there, and of course break off.

Fig. 32, is drawn exaggerated, in order to show the ill effect of grinding one lip of a drill longer than the other. It is found that the centre point P of the drill will be kept, by the pressure of the feed in the direction shown by the arrow, in the centre of the hole which is being drilled. Then there is a long lip and a short one sweeping round the hole drilled will therefore be in diameter twice the radius of the longer lip R, or larger by the distance D than the size of the drill itself. This is very undesirable. A much graver defect, arising from this incorrect grinding, is that the drill can only penetrate into the metal it is boring at about half the speed it ought to attain if it were accurately ground. For each lip can only take a certain thickness of shaving per revolution, and if this maximum thickness were taken by the two lips they would remain comparatively uninjured. But the portion C of the long lip would have a double cut upon it (the other lip not cutting at all at this outer portion of the conical hole): hence it would not stand such usage, and would either rapidly blunt itself or would break.

The grinding line A B, Fig. 29, was introduced in the United States, to assist the operator in keeping both lips of the drill identically the same. To arrive at this however is more than can be accomplished by hand-grinding, as not less than three points have to be carefully watched, namely:—

1st. That both lips are exactly the same length;

2nd. That both have the same clearance angles;

3rd. That both make the same angle with the centre line on the body of the drill.

If these are not attended to, the drill lips may for instance be both ground so as to converge exactly to the grinding line at the point or centre of the drill, and may still be of such different lengths and angles as to produce very bad results in drilling.

Much ingenuity has been expended on machines for the grinding of the two lips with mechanical accuracy. The one which has been the most successful in the United States has three motions, ingeniously combined with each other. So many motions however entail complication, and this, added to a system of holding the drill which was not sufficiently reliable, failed to produce the extreme accuracy it is requisite to impart to the two angles.

The grinding line too is found to be more or less a source of weakness. It is therefore advisable to dispense with it if possible; and where a good twist-drill grinding machine is used, the grinding line is seldom or never looked at, and in that case is useless. If it is still desirable to have grinding lines (as in some cases where the hand grinding has to be relied upon), they should be made as faint as possible, and not cut deeply into the thin central part of the drill, so as to weaken it.

A simple and efficient twist-drill grinding machine was so much needed that within the last three years the write., aided by his firm, has designed one. The twist-drill in this machine has only one motion imparted to it, to produce the two lips of each drill as perfect facsimiles of each other and with the desired amount of clearance. Many of these machines are now at work. That the drills ground by them are accurate is proved by the holes drilled being so nearly the size of the twist-drill itself that in many cases the drill will not afterwards drop vertically through the drilled hole by its own gravity; in other words, the hole is no larger than the drill which has drilled it. It is not generally known that this is the most severe test which can be made of the accuracy of re-grinding, and of the uniformity of all parts of the twist drill.

One of the smallest-sized machines is exhibited. The largest machine grinds drills of 3 in. diam.; and there are intermediate sizes.

The whole of the drilling in many establishments is now done entirely by twist-drills. Since their introduction it is found that the self-acting feed can be increased about 90 per cent.; and in some engineering works the feeds in some machines have been increased by fully 200 per cent., and consequently three holes are now being drilled in the same time that one was originally drilled with the old style of drill and with old machines.

It may be interesting to give a few results out of numerous tests and experiments made with twist-drills.

Many thousands of holes ½ in. diam. and 2¾ in. deep have been drilled, by Smith and Coventry's ½-in. twist-drills, at so high a rate of feed that the spindle of the drilling machine could be seen visibly descending and driving the drill before it. The time occupied from the starting of each hole, in a hammered scrap-iron bar, till the drill pierced through it,