large. In their highest development they fulfil what are termed "universal ” functions (fig. 50), that is, they are capable of grinding both external and internal cylinders, plane faces, tapers, both of low and high angle, and the teeth of various kinds of tools and cutters. These machines occur in two broad types. In one the axis of the revolving wheel is traversed past the work, which revolves but is not traversed. In the other the reverse occurs, the work traversing and the axis of the wheel with its bearings remaining stationary. Equally satisfactory results are obtained by each.

In all external cylindrical grinding, when the work can be rotated, the piece being ground rotates in an opposite direction to the rotation of the wheel (fig. 51, A). In all small pieces ground internally the same procedure is adopted (fig. 51, B). Incidentally, mention should be made of the fineness of the fitting required and attained in the construction of the spindles which carry the wheels for internal grinding. The perfection of fitting and of the means of adjustment for eliminating the effects of wear in the ordinary spindles for external and internal grinding is remarkable. The spindles for internal work have to revolve at rates ranging from about 6000 to 30,000 times in a minute, yet run so truly that the holes ground do not depart from accuracy by more than say 1/5000 to 1/10000 of an inch. Yet so long as the work can be revolved no special complication of mechanism is required to ensure good results. the revolution of the wheel and the work is mutually helpful. The real difficulties arise when the work, on account of its mass or awk- wardness of shape, cannot be revolved. The principle embodied in machines designed to deal satisfactorily with such cases, though much diversified in detail, is the application of the planet device to the grinding wheels. That is, the wheel spindle rotating at a high speed, 6000 or 7000 revolutions per minute, is simultaneously carried round in a circular path, so that its axis makes about 25 or 30 revolutions per minute (fig. 51, *C* and *D).* The diameter of the path is capable of adjustment with minute precision within wide limits to suit bores of different diameters. The periphery of the grinding wheel which lies farthest from, its axis 01 revolution sweeps round in a path the diameter of which equals that of the bore to be ground. These machines are now used largely for grinding out the cylinders of gas and petrol engines, valve seatings, the bushed holes of coupling rods, and similar classes of work. Many of them have their spindles set horizontally, others vertically.

Allied to these are a relatively small but important group of machines used for grinding the slot links of the slide-valve gear of locomotive and other engines. The slot is mounted on a pivoted bar adjusted to the same radius as the slot to be ground, and the slot is moved relatively to the wheel, so producing the required curves.

în another direction much development has taken place in the practice of grinding. the increasing use of the milling cutter has been the occasion for the growth and high specialization of the cutter grinding machines. It is essential to the efficiency of such cutters that regrinding shall be done without drawing the temper, and this can only be effected by the use of an abrasive. In the early days of their use the temper had to be drawn to permit of filing and rehardening effected with its inevitable distortion.

Cutter grinding machines must possess universality of movements to deal with the numerous shapes in which milling cutters are made ; hence they often resemble in general outlines the universal grinding machines. But as a rule they are built on lighter models, and with a smaller range of movements, because the dimensions of cutters are generally much smaller than those of the ordinary run of engineers’ work which has to be ground. Frequently a single pillar or standard suffices to carry the mechanism. In an ordinary universal tool grinder all the teeth of any form of cutter can be ground precisely alike (fig. 52). excepting those having irregular profiled outlines, for which a special machine, or an extra attachment to an ordinary machine, is necessary. But little of this is done, because in such cases, and in many others, the faces of the teeth are ground instead of the edge. This idea, due to the firm of Brown & Sharpe, may seem a trifle, but nevertheless to it the credit is largely due for the economies of cutter grinding. The principle is that in the “ formed cutter," as it is termed, the profiles of the teeth are not struck from the axis of revolution, but from another centre (fig. 20); grinding the tooth faces, therefore, has no effect on the shapes of the profiles, but only lessens the tooth thicknesses. Designed originally for the cutters for the teeth of gear-wheels, it has long been applied to profiles which involve combinations of curves. The pitching of the teeth is effected by a strip of metal, or tooth rest *a* (fig. 52), on which each successive tooth rests and is coerced during the grinding. If teeth are of special form the traverse movement of a spiral tooth along the rest ensures the required movement.

Besides the cutter grinders used for milling cutters, reamers and screwing taps, there are two other groups of tool grinders, one for twist drills only and the other for the single-edged tools used in lathe, planer, snaper and other machines. Both these in their best forms are of recent development. the machines used for grinding twist drills embody numerous designs. Hand grinding is practically abandoned, the reason being that a very minute departure from symmetry on the two cutting lips of the drill results inevitably in the production of inaccurate holes. It is essential that the two lips be alike in regard to length, angle and clearance, and these are embodied in the mechanism oí the grinding machines. But formerly in all these the drill holder had to be moved by hand around its pivot,. and one, lip ground at a time There are now some very beautiful machines of German manufacture in which the necessary movements are all automatic, derived from the continuous rotation of a belt pulley. The drill rotates constantly, and small amounts are ground off each lip in turn until the grinding is finished. The other group for grinding single-edged tools is a very small one. The correct angles for grinding are embodied in the setting of the machine, with the great advantage that any number of similar tools can be ground all alike without skilled attendance.

Lying outside these broad types of machines there is a large and growing number designed for special service. The knife-grinding group for sharpening the planer knives used in wood-working machinery is a large one. Another is that for gulleting or deepening the teeth of circular saws as they wear. Another is designed for grinding the cups and cones for the ball races of cycle wheels, and another for grinding the hardened steel balls employed in ball bearings.

Emery grinding is dependent for much of its success on a plentiful supply of water. Dry grinding, which was the original practice, is hardly employed now. The early difficulties of wet grinding were due to the want of a cementing material which would not soften under the action of water. Now wheels will run constantly without damage by water, and they are so porous that water will filter through them. Improvements in the manufacture of wheels, and the increased use of water, have concurred to render possible heavier and more rapid grinding without risk of distortion due to heating effects. In the best modern machines the provisions for water supply are a study in themselves, including a centrifugal pump, a tank, jointed piping, spraying tube, guards to protect the bearings and slides from damage, and trays to receive the waste water and conduct it back to the tank.

There are two points of view from which the modern practice of grinding is now regarded—one as a corrective, the other as a