both to drive and cut the blank in an ordinary machine. When worms are not produced by these methods the envelope cannot be obtained, but each tooth space is cut by an involute milling cutter set at the angle of thread in a universal machine, or else in one of the general gear-cutting machines used for spur, bevel and worm gears, and only capable of yielding really accurate results in the case of spur-wheels.

The previous remarks relate only to the sectional forms of the teeth. But their pitch or distance from centre to centre requires dividing mechanism. This includes a main dividing or worm-wheel, a worm in conjunction with change gears, and a division plate for setting and locking the mechanism. The plate may have four divisions only to receive the locking lever or it may be drilled with a large number of holes in circles for an index peg. The first is adopted in the regular gear-cutters, the second on the universal milling machines which are used also for gear-cutting. In the largest number of machines this pitching has to be done by an attendant as often as one tooth is completed. But in a good number of recent machines the pitching is effected by the move­ments of the machine itself without human intervention. With spur-wheels the cutting proceeds until the wheel is complete, when the machine is often made to ring a bell to call attention to the fact. But in bevel-wheels only one side of the teeth all the way round can be done; the attendant must then effect the necessary settings for the other side, after which the pitchings are automatic.

As a general rule only one tooth is being operated on at one time. But economy is studied in spur-gears, by setting several similar wheels in line on a mandrel and cutting through a single tooth of the series at one traverse oí the tool. In toothed racks the same device is adopted. Again, there are cases in which cutters are made to operate simultaneously on two, three or more adjacent teeth.

Recently a generating machine of novel design has been manu­factured, the spur-wheel hobbing machine. In appearance the hob resembles that employed for cutting worn-gears, but it also generates the teeth of spur and spiral gears. The hob is a worm cut to form teeth, backed off and hardened. The section of the worm thread is that of a rack. Though it will cut worm-wheels, spiral-wheels or spur-wheels equally correctly, the method of pre­sentation varies. When cutting worm-wheels it is fed inwards per­pendicularly to the blank; when cutting spirals it is set at a suitable angle and fed across the face of the blank. The angle of the worm thread in the hob being about 2½°, it has to be set by that amount out of parallel with the plane of the gear to be cut. It is then fed down the face of the wheel blank, which is rotated so as to syn- chronize with the rotation of the worm. This is effected through change gears, which are altered for wheels having different numbers of teeth. The advantage is that of the hob over single cutters; one hob serves for all wheels, of the same pitch, and each wheel is cut absolutely correct. While using a set of single cutters many wheels must have their teeth only approximately correct.

VI.—Grinding Machines

The practice of finishing metallic surfaces by grinding, though very old, is nevertheless with regard to its rivalry with the work oí the ordinary machine tools a development of the last part oí the 19th century. From being a non-precision method, grinding has become the most perfect device for producing accurate results measured precisely within thousandths of an inch. Ft would be rather difficult to mention any class oí machine-shop work which is not now done by the grinding wheel. The most recent develop­ments are grinding out engine cylinders and grinding the lips of twist drills by automatic movements, the drills rotating constantly.

There are five very broad divisions under which grinding machines may be classified, but the individual, well-defined groups or types might number a hundred. The main divisions are: (1) Machines for dealing with plane surfaces; (2) machines for plain cylindrical work, external and internal; (3) the universals, which embody movements rendering them capable of angular setting; (4) the tool grinders: and (5) the specialized machines. Most of these might be again classed under two heads, the non-precision and the precision types. The difference between these two classes is that the first does not embody provision for measuring the amount of material removed, while the second does. This distinction is a most important one.

The underlying resemblances and the differences in the main designs of the groups of machines just now noted will be better understood if the essential conditions of grinding as a correc- tive process are grasped. The cardinal point is that accurate results are produced by wheels that are themselves being abraded constantly. That is not the case in steel cutting tools, or at least in but an infinitesimal degree. A steel tool will retain its edge for several hours (often for days) without the need for regrinding, but the paticles of abrasive in an emery or other grinding wheel are being incessantly torn out and removed. A wheel in traversing along a shaft say of 3 ft. in length is smaller in diameter at the termination than at the beginning of the traverse, and therefore the shaft must be theoretically larger at one end than the other. Shafts, nevertheless, are ground parallel. The explanation is, and

it lies at the basis of emery grinding, that the feed or amount removed at a single traverse is extremely minute, say a thousandth or half a thousandth of an inch. the minuteness of the feed receives compensation in the repetition and rapidity of the traverse. The wear of the wheel is reduced to a minimum and true work is produced.

From this fact of the wear of grinding wheels two important results follow. One is that a traverse or lateral movement must always take place between the wheel and the piece of work being ground. This is necessary in order to prevent a mutual grooving action between the wheel and work. The other is that it is essential to provide a large range in quality of wheels, graded according to coarseness and fineness, of hardness and softness of emery to suit all the different metals and alloys. Actually about sixty grades are manufactured, but about a dozen will generally cover average shop practice. With such a choice of wheels the softest brass as well as the hardest tempered steel or case-hardened glass-like surfaces that could not possibly be cut in lathe or planer, can be ground with extreme accuracy.

Plane surfacing machines in many cases resemble in general outlines the weIl-known planing machine and the vertical boring mill. The wheels traverse across the work, and they are fed vertically to precise fractional dimensions. They fill a large place in finishing plane surfaces, broad and narrow alike, and have be- come rivals to the planing and milling machines doing a similar class of work. For hardened surfaces they have no rival.

Cylindrical grinders include many subdivisions to embrace external and internal surfaces, either parallel or tapered, small or