only one way in which irregular forms can be produced cheaply and interchangeably, and that is by controlling the movements of the tool with an object of similar shape termed a “form” or “ former,” as in the well-known copying lathes, in the cam grinding machine, and in the forming adjuncts fitted to vertical spindle milling machines, so converting those into profiling machines. The prin- ciple and its application are alike simple. An object (the form) is made in hardened steel, having the same outlines as the object to be milled, and the slide which carries the cutter spindle has a hardened former pin or roller, which is pulled hard against the edges of the form by a suspended weight, so causing the tool to move and cut in the same path and in the same plane around the edges of the work. Here the milling machine holds a paramount place. No matter how many curves and straight portions may be combined in a piece, the machine reproduces them all faultlessly, and a hundred or a thousand others all precisely alike without any tentative corrections.

Plano-millers, also termed slabbing machines, form a group that grows in value and in maps and capacity. They are a comparatively late development, becoming the chief rivals to the planing machines, for all the early milling was of a very light character. In general outlines the plano-millers closely resemble the planing machines, having bed, table, housings and cross-rail. The latter in the plano- ιniller carries the bearings for the cutter spindle or spindles under which the work travels and reciprocates. These spindles are vertical, but in some machines horizontal ones are fitted also, as in planers, so that three faces at right or other angles can be operated on simultaneously. The slabbing operations of the plano-millers do not indicate the full or even the principal utilities of these machines. To understand these it must be remembered that the cross-sections of very many parts which have to be tooled do not lie in single planes merely, but in combinations of plane surfaces, horizontal, vertical or angular. In working these on the planing machine separate settings of tools are required, and often successive settings. But milling cutters are built up in “ gangs ” to deal with such cases, and in this way the entire width of profile is milled at once. Horizontal faces, and vertical and angular edges and grooves, are tooled simυltaneously, with much economy in time, and the cutter profile will be accurately reproduced on numbers of separate pieces.. Allied to the plano-millers are the rotary planers. They derive their name from the design of the cutters. An iron disk is pierced with holes for the insertion of a large number of separate cutters, which by the rotation of the disk produce plane surfaces. These are milling cutters, though the tools are single-edged ones, hence termed “ inserted tooth mills.” These are used on other machines besides the rotary planers, but the latter are massive machines built on the planer model, with but one housing or upright to carry the carriage of the cutter spindle. These machines, varied considerably in design, do good service on a class of work in which a very high degree of accuracy is not essential, as column flanges, ends of girders, feet of castings, and such like.

V.—Gear-cutting Machines

The practice of cutting the teeth of gear-wheels has grown but slowly. In the gears used by engineers, those of large dimensions are numerous, and the cost of cutting these is often prohibitive, though it is unnecessary in numbers of mechanisms for which cast wheels are as suitable as the more accurately cut ones. The smallest gears for machines of precision have long been produced by cutting, but of late years the practice has been extending to include those of medium and large dimensions, a movement which has been largely favoured by the growth of electric driving, the high speeds of which make great demands on reduction and trans­mission gears. Several new types of gear-cutting machines have been designed, and specialization is still growing, until the older machines, which would, after a fashion, cut all forms of gears, are being ousted from modern establishments.

The teeth of gear-wheels are produced either by rotary milling cutters or by single-edged tools (fig. 49). The advantage of the first is that the cutter used has the same sectional form as the inter- tooth space, so that the act of tooth cutting imparts the shapes without assistance from external mechanism. But this holds good only in regard to spur-wheel teeth, that is, those in which the teeth lie parallel with the axis of the wheel. The teeth of bevel-wheels, though often produced by rotary cutters, can never be formed absolutely correctly, simply because a cutter of unalterable section is employed to form the shapes which are constantly changing in dimensions along the length of the teeth (the bevel-wheel being a frustum of a cone). Hence, though fair working teeth are obtained in this way, they result from the practice of varying the relative angles of the cutters and wheel and removing the material in several successive operations or traverses, often followed by a little correction with the file. Although this practice is still commonly followed in bevel-wheels of small dimensions, and was at one time the only method available, the practice has been changing in favour of shaping the teeth by a process of planing with a single-edged reciprocating tool. As, however, such a tool embodies no formative section as do the milling cutters, either it or the wheel blank, or both, have to be coerced and controlled by mechanism outside the tool itself. Around this method a number of very ingenious

machines have been designed, which may be broadly classed under two great groups—the form and the generating types.

In the form machines a pattern tooth or form-tooth is prepared in hardened steel, usually three times as large as the actual teeth to be cut, and the movement of the mechanism which carries the wheel blank is coerced by this form, so that the tool, reciprocated by its bar, produces the same shape on the reduced dimensions of the wheel teeth. The generating machines use no pattern tooth, but the principles of the tooth formation are embodied in the mechan­ism itself. These are very interesting designs, because they not only shape the teeth without a pattern tooth, but their movements arc automatically controlled. A large number of these have been brought out in recent years, their growth being due to the demand for accurate gears for motor cars, for electric driving, and for general high-class engineers’ work. These are so specialized that they can only cut the one class of gear for which they are designed— the bevel-wheels, and these in only a moderate range of dimensions on a single machine of a given size. The principal bevel-gear cutting machines using forms or formers, are the Greenwood & Batley, Le Progrès Industriel, the Bouhey (cuts helical teeth), the Oerlikon, which includes two types, the single and double cutting tools, the Gleason and the Rice. Generating machines include the Bilgram (the oldest), the Robey-Smith, the Monneret, the Warren, the Beale and the Dubosc.

As the difficulties of cutting bevel-wheels with rotary cutters, consequent on change of section of the teeth, do not occur in spur- gears, there are no examples of form machines for spur-wheel cutting, and only one generating planing type of machine, the Fellows, which produces involute teeth by a hardened steel-cutting pinion, which shapes wheels having any number of teeth of the same pitch, the cutter and blank being partly rotated between each cut as they roll when in engagement.

The worm-gears appropriate a different group of machines, the demands on which have become more exacting since the growth of electric driving has brought these gears into a position of greater importance than they ever occupied before. With this growth the demand for nothing less than perfect gears has developed. A perfect gear is one in which the teeth of the worm-wheel are envelopes of the worm or screw, and this form can only be produced in practice in one way—by using a cutter that is practically a serrated worm (a hob), which cuts its way into the wheel just as an actual worm might be supposed to mould the teeth of a wheel made of a plastic substance. To accomplish this the relative move­ments of the hob and the wheel blank are arranged to be precisely those of the working worm and wheel. Very few such machines are made. A practical compromise is effected by causing the hob