MACHINE TOOLS FOR SMALL AND MEDIUM GEARS

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PART I

In Naval Gunnery Equipment gears of a wide range are fitted from small to medium in size. In general, small gears are fitted in predictors, stabilising gears, resetters, etc., in which the gears are lightly loaded but must be accurately cut and meshed ; while medium gears are used in power drives and must also be accurately cut and meshed and in addition must be quiet running and resistant to wear, *i.e.*, the harder the tooth flank the better.

It is useless to expect to cut accurate gears on a cutting machine of unsuitable size or one which is not competently designed, accurately made and adequately maintained. In addition, rather elaborate and comparatively expensive measuring apparatus may be necessary. There is little doubt that some sections of the manufacturing industry in this country catering for Gunnery Equipment were formerly not adequately equipped to produce the wide variety of accurate gears required. This led to undue restriction on the designer on the one hand and the necessary acceptance of sub-standard parts on the other. In recent years there has been a distinct improvement in this respect. There is undoubtedly room for further improvement.

In this article Mr. Gunner has made a wide survey of the gear cutting machine tools and measuring apparatus potentially available. It will be of general interest to all serving technical officers and particular interest to those who are concerned with design and production.

Introduction

In a previous article " The Manufacture of Machine and Instrument Gears at the Admiralty Research Laboratory " published in the May 1947 issue of the *Journal of the Royal Naval Scientific Service*, a passing reference was made to the fact that for the production of Small and Medium Gears in this country, American, German and Swiss machines predominated. Let us examine this matter in closer detail and survey the position, recognizing that while the larger trade gearcutters have always employed a proportion of " own make " machines, the average user must depend entirely on proprietary makes available as stock lines sold in the ordinary way. Since the above article was written, certain changes in the pattern have emerged as a result of the Machine Tool Exhibitions in Chicago and London, but it will take time for these developments to have any appreciable effect.

Small Gears Defined

Over the whole field of gear drives, three broad classes emerge, based partly on pitch as a criterion : (*a*) Machine Gears for real power and heavy load, generally reckoned from 16 D.P. and coarser ; (*b*) Instrument or Fine Pitch Gears, for light power or motion drives, 16 D.P. and finer ; and (*c*) Clockwork Gears, usually associated with a spring-driven escapement mechanism where wheels always drive pinions and the power available at the output end of the train is strictly limited. A rigid definition of these classes is hardly possible, and some overlapping is bound to occur. According to the American Gear Manufacturers' Association fine pitch gears are those of 20 D.P. and finer, while the term instrument gears is in common use for much the same thing, although pitches coarser than 20 (say to 16) are frequently employed in instrument work. This division into fine, medium, and coarse pitch bands, however, takes no account of the actual diameter of the gear in relation to its pitch—a gear of 660 teeth, 40 D.P., 16.5 in pitch diameter is certainly a fine pitch gear, but can hardly be described as a small one, which, in the present context, may be regarded as having a pitch diameter of .25 to 4 in maximum.

In considering small gears for power and motion drives in instruments, apparatus, and light precision engineering, 16 D.P. seems to be a kind of turning point, being a fair average for maximum capacity of a number of small gearcutting machines of various types examined. At the other end of the scale, the practical limit of fineness is 60-100 D.P. for spurs and helicals, 40-60 D.P. for bevels and worm gears. The finer pitches in the range should be avoided wherever possible ; designers tend to call for high tooth numbers and very fine pitches, resulting in longer cutting times and increasing the difficulties of measurement and control over tooth form.

The extensive use of metric module as a basis of pitch definition reflects our long-standing dependence on Continental machines, hobs, cutters, and standards for small gears. The diametral pitch notation is now extending to the smaller ranges ; for example, small bevel gears made in this country—using American machines and standards—are calculated on D.P., and there seems to be no good reason for the use of two systems, inch and metric, side by side. Although the term module is commonly associated with millimetres, there is also the inch module (reciprocal of D.P.) which has its advocates and is used to some extent.

Medium Gears Too

This class may be taken to include gears for general engineering and machine-building, machine tool applications, automotive transmissions and so on. Here again a precise definition is elusive—all these things are relative. What we have in mind, however, is a group ranging from say 4 to 12 in diameter in pitches up to 6 D.P. or thereabouts. For our present purposes, therefore, we may consider Small and Medium Gears as those coming within a pitch range of 6-100 D.P. in diameters from the smallest up to about 12 inches. All the usual types are encountered, viz., spur, helical, worm, straight and spiral bevel, and hypoid gears. Within recent times, small spiral bevels have been applied to instrument work on an increasing scale, while the introduction of the Gleason No. 2 Hypoid Generator opens up entirely new avenues to the designer of precision apparatus.

The most common tooth form used throughout for general work is the 20° full depth involute. Clearance proportions are not standardized at present ; a few variants are .157, .166, .187, .2, .2+.002 in, .25, and .3. These values are in inches for unit D.P. There are also roughing depths for profile grinding, pre-shaving depths, and an assortment of specials to add to the general confusion. The involute is ideal for fire-control instruments, small geared motors, etc. ; gears for dial gauges, gas and electricity meters and electric clock reductions should work equally well with either involute or cycloidal systems, while for spring-driven clockwork mechanism the cycloidal (or some variation of it) may still be preferred.

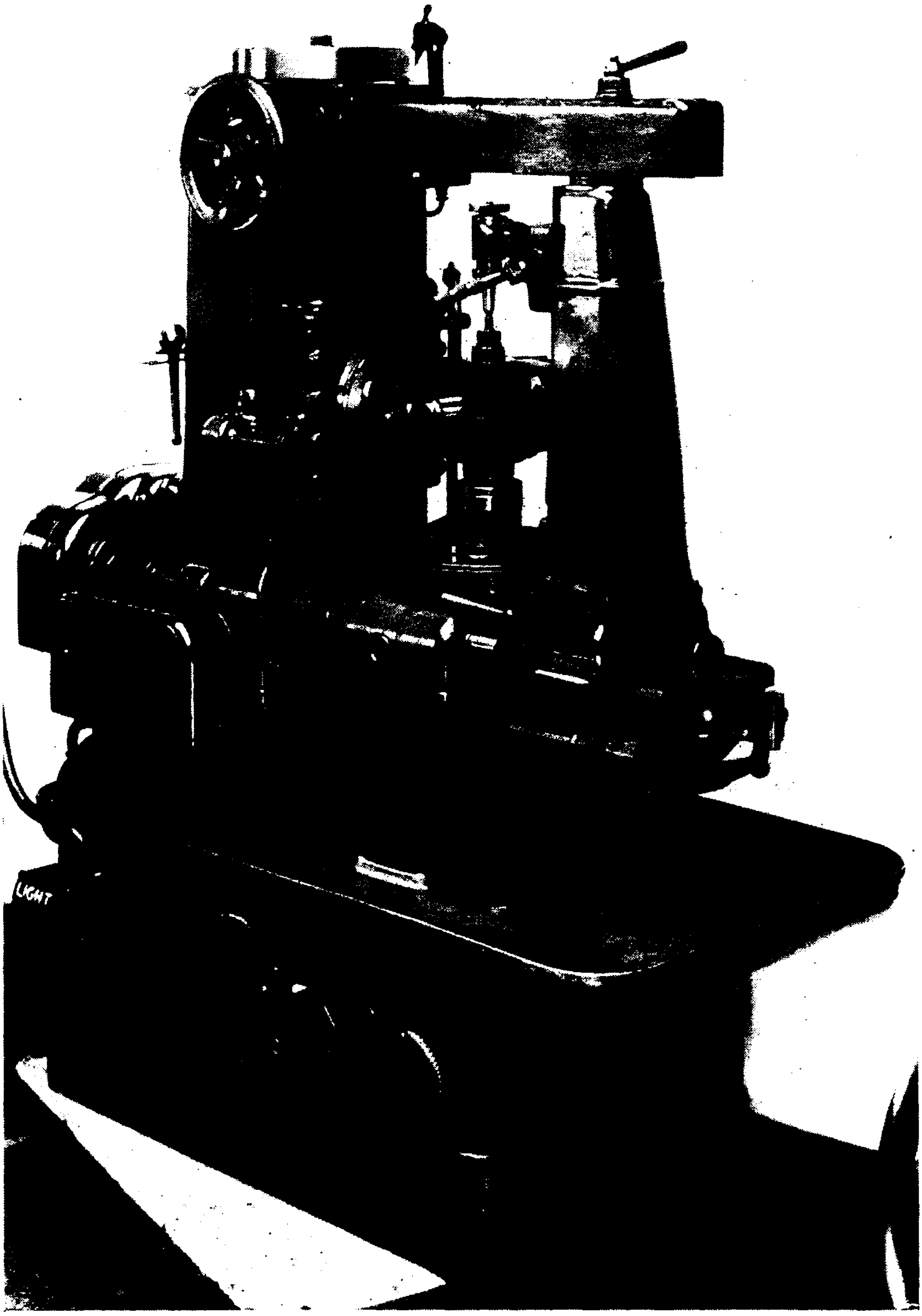

FIG. 1—PFAUTER " RSO " GEAR HOBBER

Machine and Product Accuracy

For Service applications, the smaller gears are usually master elements in predictors, computers, Magslip transmissions, gyro and oil motor controls and the like, while the larger sizes must combine accuracy with power-transmitting capacity. The principal requirement is the ability to transmit uniform motion with the minimum backlash and friction loss. In regard to errors in tooth profile and spacing, runout, etc., accuracy to a higher degree than that normally associated with commercial gears is essential—it follows therefore that the general design and workmanship of the machine tools employed must be such as to ensure the highest accuracy of the product.

Machining Methods

The usual processes for the cutting and finishing of small and medium gears as described above call for the following machine types :—

Hobbing, for spur and helical gears, worm wheels, and spline shafts.
Gear Shaping (*Sunderland system*), for spur and helical gears.
Gear Shaping (*Fellows method*), for internal and external gears.
Rack Cutting, for straight and inclined racks.
Worm Milling, for roughing or finishing worms.
Bevel Gear Generators, straight, spiral and hypoid.
Gear Shaving (*rack and rotary*), for finishing soft work.
Gear, Worm, and Spline Grinding, for hardened work,

together with the necessary hobs, cutters, arbors and work-holding equipment, tool sharpeners, gear testing machines, gauges and measuring devices.

With these introductory remarks setting out the terms of reference more or less precisely, it is proposed to make a start on the business in hand by listing the principal makes of machine used in this country at the present time, with a few notes on each type. Figures 1 to 8 illustrate some pre-war models.

Hobbing Machines

Barber-Colman (American) ; Pfauter (German) ; Mikron (Swiss).

The majority of spur and helical gears are produced by hobbing. Though the gear shaper is responsible for a considerable output of straightforward external gears, it is generally reserved for its own especial field of cutting cluster and shoulder gears, and of course internals, for which (for all practical purposes) it is the only type in existence. The hobbing machines of chief interest here are the Pfauter RS.0 (Fig. 1) and RS.00, Mikron 102 (Fig. 2) and 79, and Barber-Colman Type A and No. 3 Models. All three firms set out to provide a range of first-class hobs, machine relieved or profile ground, for cutting spur and helical gears, worm wheels, chain sprockets, spline shafts, etc., and also special-purpose hob sharpening machines for the proper maintenance of these tools.

A few facts of historical background may be interesting. The original patent for a universal hobbing machine with differential was taken out by Herman Pfauter in 1897, and the factory at Chemnitz founded in 1900 ; in 1939, the Pfauter Works was the largest of its kind in the world.

The Mikron 102 Universal Hobber is the firm's largest machine—it is roughly comparable in size and capacity with Pfauter's smallest. The Mikron firm serve the watch, clock, and instrument industries, their products ranging in size from the No. 102 down to tiny bench models for cutting watch pinions—while the Pfauter manufacturing programme, starting with the RS.000, goes through the whole range of general engineering up to the very largest sizes.

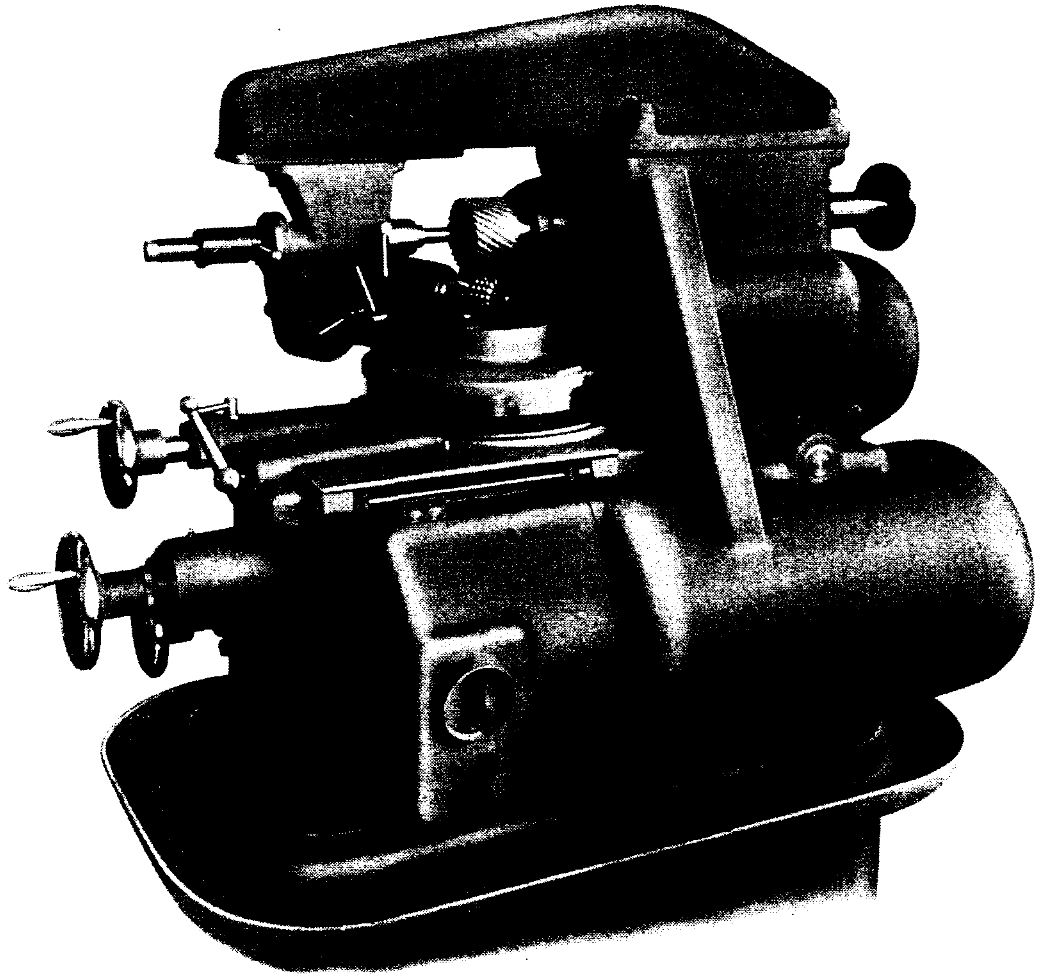

FIG. 2—MIKRON " 102 " GEAR HOBBER

For excellence in design, construction, and general utility these two makes have a high reputation. Considerable numbers of these machines are in use on the Continent and in this country, but to a lesser extent in the U.S.A., where the Barber-Colman and Gould & Eberhardt hobbers hold the field for average work, with special high-production types, *e.g.*, the Cleveland, in the automotive industry.

Gear Shaping Machines

Fellows (American) ; Drummond, Sunderland, Sykes (British) ; Maag (Swiss).

The Sunderland and Maag machines represent the rack-cutter system. The Sunderland horizontal type is probably the best known, although the Maag vertical machine is quite familiar over here. The three others mentioned employ circular gear-type cutters for producing internal or external gears with straight or helical teeth ; this method was originated by Fellows. For external gears, the shaping method allows teeth to be cut close up to a shoulder, where there would be insufficient room for hob run-out. Helical gears can also be produced, but as these necessitate helical cutters and guides for each and every

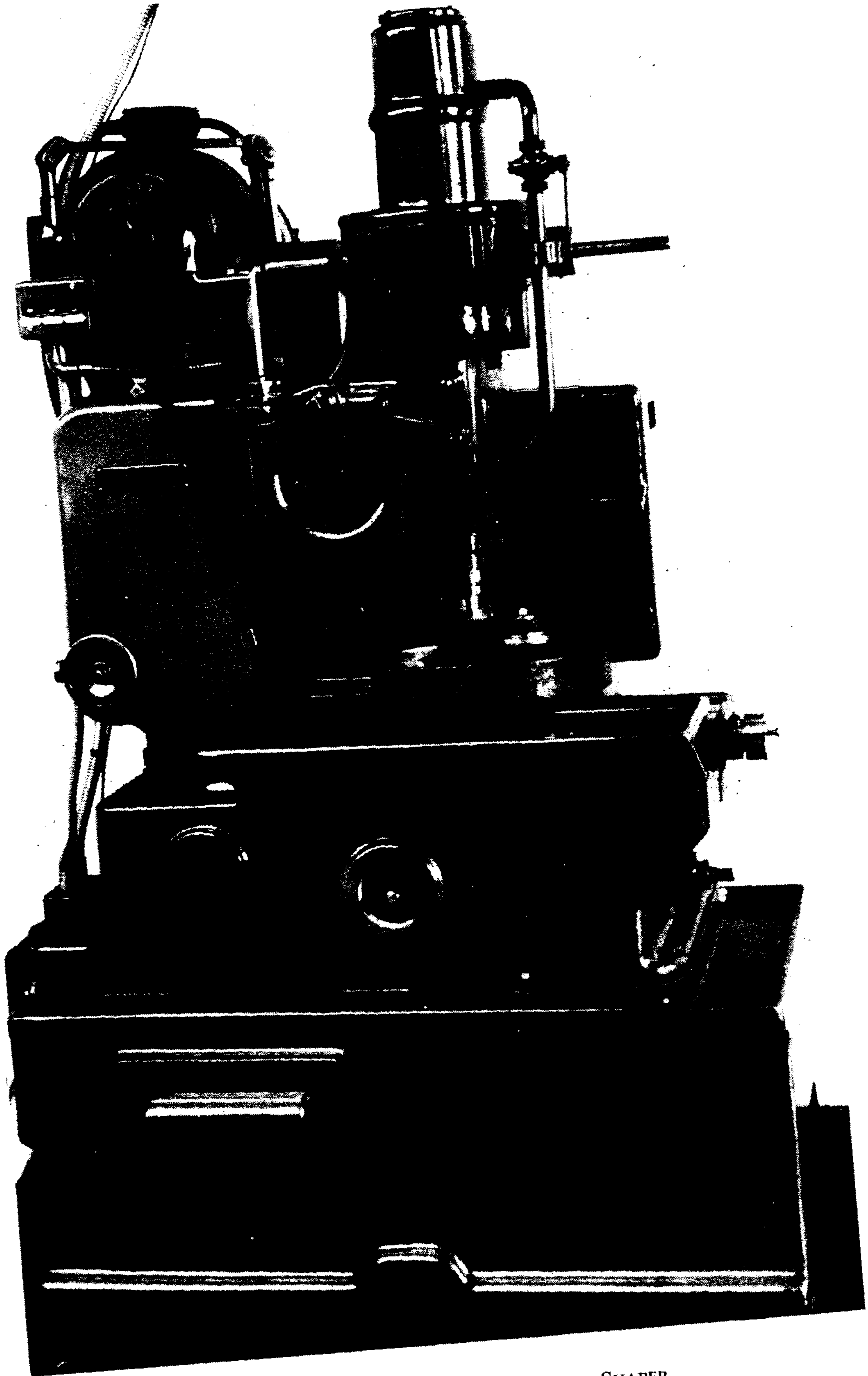

Fig. 3—Drummond (Fellows) Gear Shaper

helix angle and hand, such gears as are required for small-lot production or experimental work are preferably designed for hobbing.

The Fellows Gear Shaper Co. are the principal producers of gear shaping machines and cutters—they also manufacture shaving and lapping machines, thread and hour-glass worm generators (Cornelis principle), gear test equipment, etc. The gear shaper most widely employed is the Type 7, of which Drummond (Fig. 3), Reinecker, and Lorenz machines are variations. The No. 6 series is intended for larger work, while for instrument gears up to 30 D.P. there is the 3 in Fine Pitch Gear Shaper. The recently-introduced Sykes V-6 Small Precision Gear Shaper—shown at Olympia for the first time in September, 1948—fills a need for a machine somewhere between the Fellows 3 in and 7 in sizes ; it has long been considered that a machine with a capacity of say 4 in diameter by 16 D.P. was necessary for the general run of small gears. A companion cutter sharpener for the proper maintenance of small disc and shank cutters is also a requirement.

Rack Cutting Machines

Although straight and inclined racks are very important gear elements, the choice of machines for producing accurate racks economically in the sizes with which we are chiefly concerned is very restricted, probably because, numerically, racks are in much smaller demand than the other gear types. A universal milling machine using rotary formed cutters is still the most common method of rack cutting, one having no special pretensions to accuracy in tooth form or indexing. At one time, in addition to milling machine and shaper attachments for jobbing, there were at least ten special-purpose rack millers available—six American, three British, and one German—but these were mostly for large work or built to specific requirements. Within recent years, Koepfer (Germany) produced an automatic-indexing miller for small and medium racks, but the writer is unaware of a single example at work in this country.

The Fellows gear shaper process is also applicable to rack generation ; it is only necessary to convert the normal rotation of the work into straight-line motion, generally accomplished by an attachment to the gear shaper, though Fellows build a rack-cutting machine (the No. 3-60) for racks up to 60 in long. For fine pitch racks of 20 D.P. maximum, the Mikron 114 Rack Generator, operating on the Fellows principle, will handle work up to 12 in long, 1 in face, 30° inclination either way. It is also possible to cut short racks on a Maag gear generator by putting a Fellows cutter in place of the work and mounting the rack blank in the reciprocating toolholder, where the rack-shaped cutter normally goes. A design point to remember is that all such racks must have an allowance for run-out of the circular cutter.

For more precise applications, hardened racks may be profile-ground on a surface grinder of the type in which the wheel axis may be swivelled parallel with the table motion and the wheelhead traversed across the table, *e.g.*, as used in sharpening surface broaches. An ingenious method of producing precision instrument racks by the thread grinding process is employed by Eastman Kodak, Rochester, N.Y. The machine actually used is a Jones and Lamson thread grinder, mounting a large-diameter drum between the centres ; the drum is provided with a number of equispaced longitudinal grooves, into which the hardened rack blanks, each approximately $\frac{3}{8}$ in square by 10 in long, are secured. The blanks project a little above the surface, the threads being ground from the solid. The lead of the machine is set to correspond with the desired helix angle—for inclined racks, tooth-by-tooth indexing is eliminated. Straight racks are also possible by grinding a number of annular grooves, spacing being

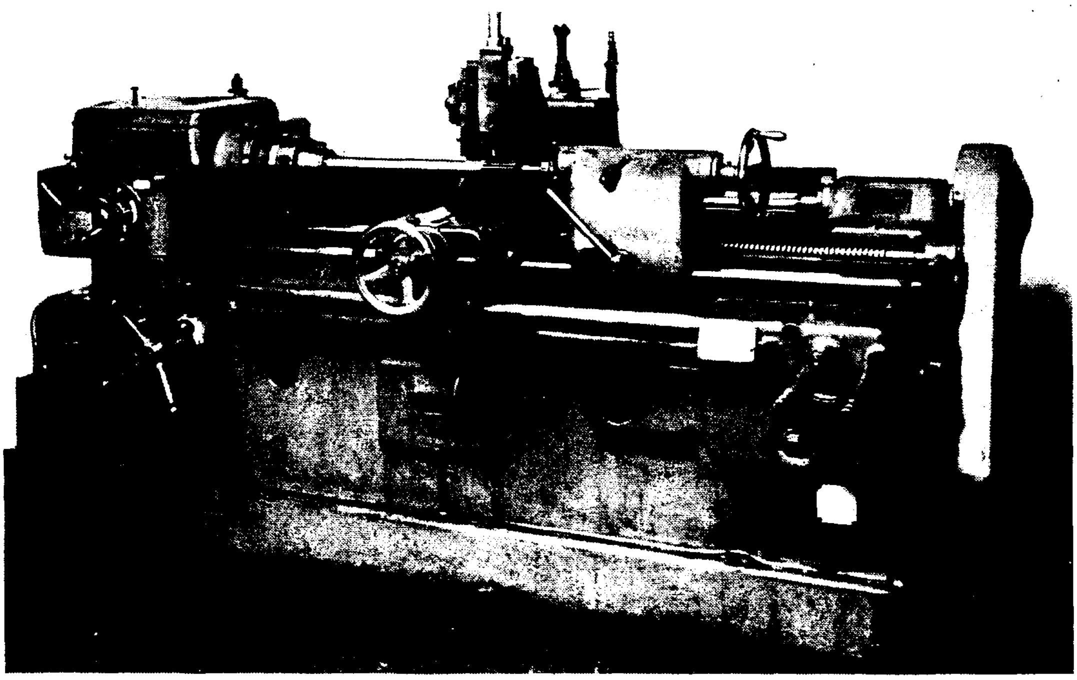

Fig. 4—Wanderer " 31.L " Hobber and Thread-miller

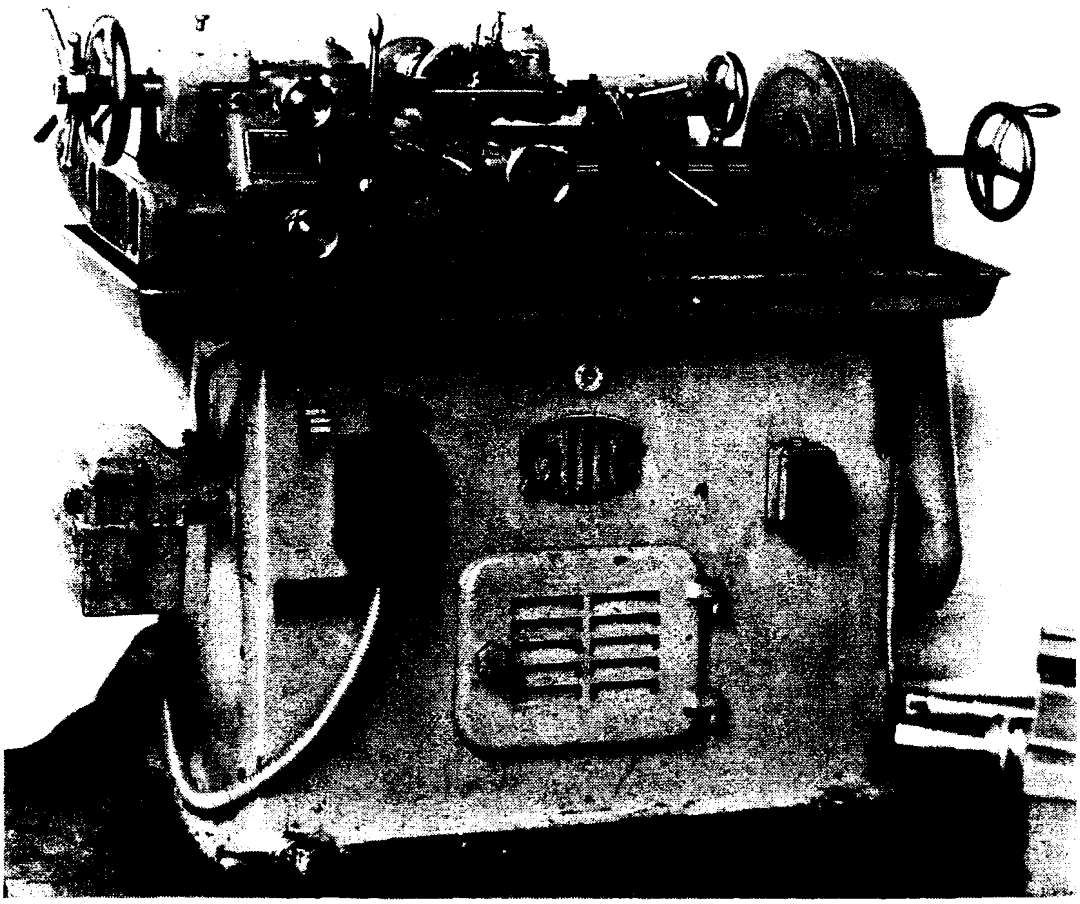

Fig. 5—Hille " FB.O " Thread-miller

accomplished by gauge blocks or other means. The slight crowning effect produced is an advantage rather than otherwise.

Threadmilling Machines

Pratt and Whitney (American); Hille, Wanderer (German); Mikron (Swiss).

These are for milling the threads in single or multi-start worms, which may be finish-cut and used in the soft as they leave the machine, or roughed out prior to hardening and profile-grinding. The first three makes are used extensively in Europe. The Wanderer 31.L (Fig. 4) Series—differing only in length between centres—is extremely useful for thread, worm, and spline milling or hobbing; The Hille FB.0 (Fig. 5) and F.C.1 types are on the same general lines but suitable for smaller work, while the Mikron (104 is the ideal machine for the smallest worms as used in meters and instruments. Mikron also offer an automatic cutter sharpener for the disc cutters used in the 104 Threadmiller; the same machine takes care of the hobs for the Mikron hobbing machine range.

Bevel Gear Generators

Gleason (American); Heidenreich and Harbeck (German).

Dealing first with straight-tooth machines and omitting the original Bilgram, the best-known examples of the modern two-tool generator are the Gleason 12 and 3 in models, and the Heidenreich and Harbeck KH.15 (Fig. 6), a useful intermediate size with a nominal capacity of 6 in diameter. Many of these machines are at work over here.

For spiral bevels we have the Gleason No. 16, the No. 7 (Fig. 7), and the 3 in sizes. The Gleason 16 Spiral and Hypoid Generator is the standard machine in the automotive industries for the production of car, truck and tractor axle drive gears, while the two smaller models are adapted for medium and small work respectively. Face clutches and couplings of the "Curvic" type may be produced on the No. 16 and No. 7 machines. The 3 in size is intended for small spiral bevel gears, a commonplace in the U.S.A. but a comparative novelty on this side of the Atlantic; there are in fact only about half-a-dozen 3 in spiral generators in use here. The new No. 2 Spiral Bevel and Hypoid Generator exhibited at Olympia is designed to produce small hypoids—gears with offset axes—up to 4½ in diameter by 16 D.P. in addition to the usual spiral bevel on-centre variety.

Spiral bevels bear the same relation to straight bevels as helical gears do to straight spurs—they give the same gradual engagement resulting in smooth quiet running. As cut by the Gleason face-milling process it is usual to make the tooth curves of mating teeth of slightly different curvature, giving a controlled zone of contact, which has important practical advantages. The Klingelnberg face-hobbing spiral bevel machine, principally used in Germany, has a tapered hob, which by suitable modification enables a localized bearing to be obtained.

The Gleason Works at Rochester was established in 1865, and is to-day the largest factory in the world devoted exclusively to the manufacture of bevel gear machinery. Their first commercially practical bevel gear planer was built in 1874; this was followed, in 1905, by the development of the modern form of two-tool straight bevel generator; and the first commercially successful spiral bevel machine appeared in 1913. The introduction of this machine and its application to rear-axle drives led to improvements in automobile power transmission now taken for granted. To-day, the majority of the world's

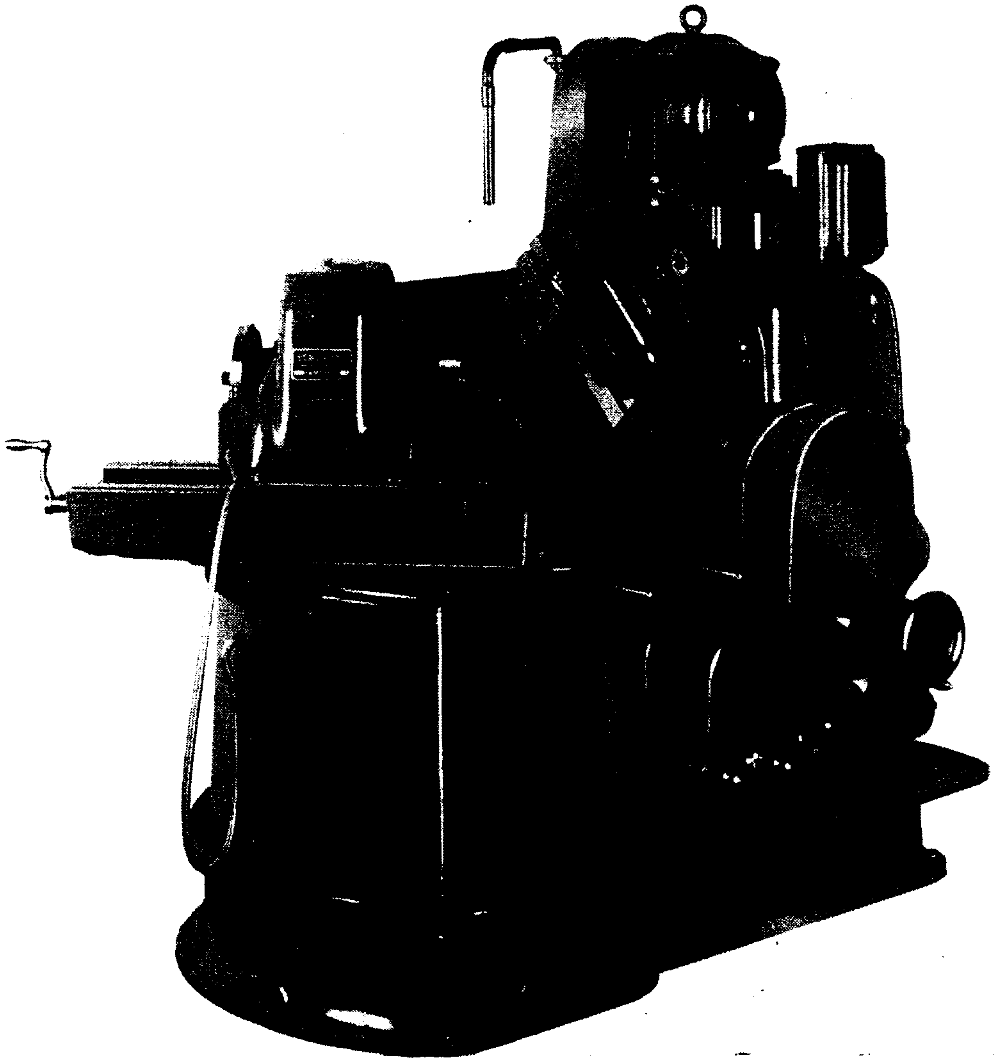

FIG. 6—HEIDENREICH & HARBECK " 15 KH " STRAIGHT-BEVEL GENERATOR

motor transport moves through the agency of Gleason spiral and hypoid gears, with an all-round efficiency leaving little room for improvement.

Gear Shaving Machines

Fellows, Michigan, National Broach (American).

Gear shaving, as a refining process for hobbed or shaped spur and helical gears has long been used in the States, as well as Germany and this country, for finishing car gearbox components prior to hardening. During recent years it has been applied to small instrument gears on an increasing scale. The working principle is now familiar ; the cutter generally takes the form of a hardened profile-ground master gear provided with a multitude of cutting edges running across the teeth. Michigan manufacture both rotary and rack types—in the latter, the cutter is rack-shaped and is reciprocated to-and-fro past the work gear. Recent arrangements between National Broach and Churchill-Redman will enable " Red Ring " machines and cutters to be manufactured under licence here.

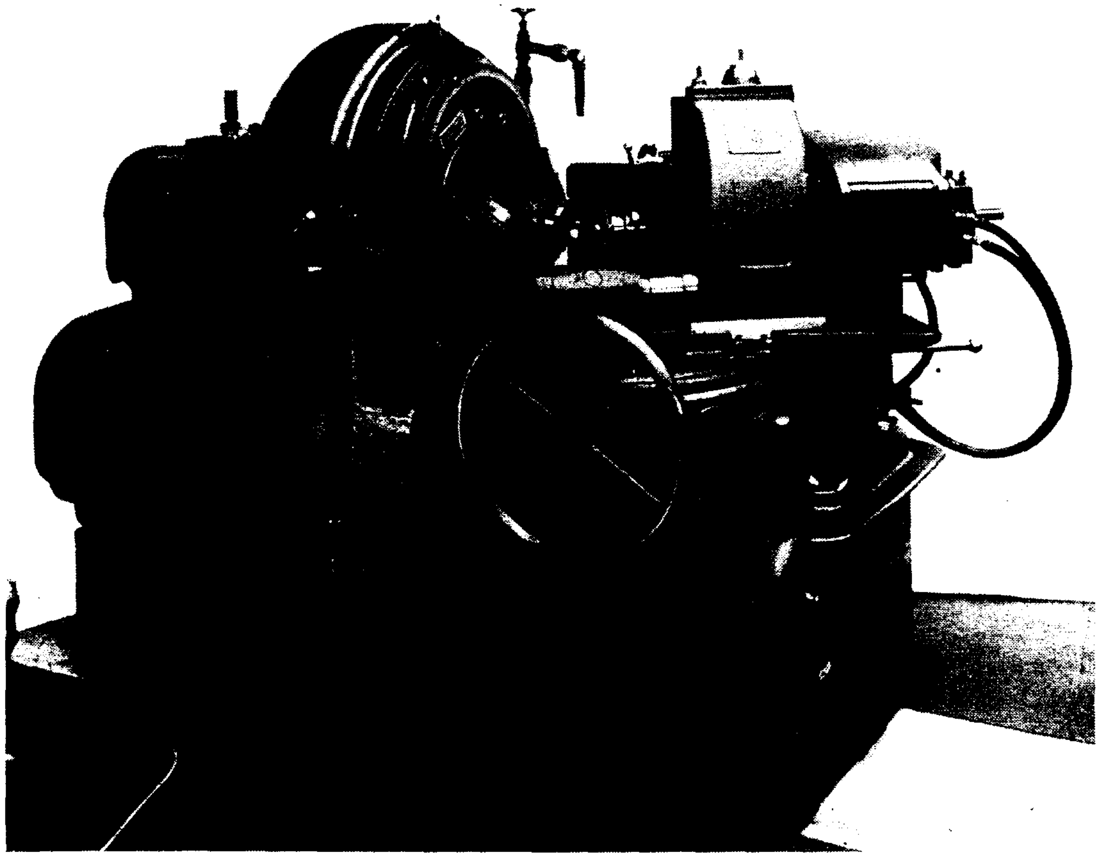

FIG. 7—GLEASON NO. 7 SPIRAL AND HYPOID GENERATOR

Gear Grinders

Orcutt (British) ; Minerva, Maag (Continental).

The first two makes operate on the formed-wheel principle, with direct indexing from divide plates. In the Orcutt system, the wheel is profiled both sides, the truing diamonds being controlled by enlarged formers ; wheel truing on the Minerva is likewise by formers, but by a different mechanical arrangement—as the wheel is formed on one side only, the work must be reversed in the centres. The Minerva is made in various forms in Belgium, France, and Switzerland, and has been copied, but not for sale, in England. Both machines were employed to a considerable extent during the war on aero-engine gears. The HM.24 Spur Grinder is the smallest machine in the Orcutt range, with a capacity of 24 in diameter by 2 D.P. ; for helical gears up to 12 in diameter the HK.4 Helical Grinder is available. The well-known Maag generating grinder (Fig. 8) is made in a range of sizes ; on some models, spur or helical gears may be ground. Other types occasionally met with are Pratt and Whitney, Deutsche-Niles, and Kolb. No comparable British generating gear grinder is available. A fair average for capacity of the above machines would be say 12 in diameter over a pitch range of 4-16 D.P. ; they are all intended for general engineering work, being somewhat larger and heavier than the majority of small gear work demands. The new Reishauer and Coventry Gauge continuous generating grinders have maximum diameter capacities of 9½ and 6 in respectively, pitches from 6-50, and if early hopes are justified the hobbing-grinding principle should be ideal for small work. For grinding hardened spiral bevel and hypoid gears there is only one make in the world—the Gleason. Particular mention should be made of the new No. 7 Spiral and

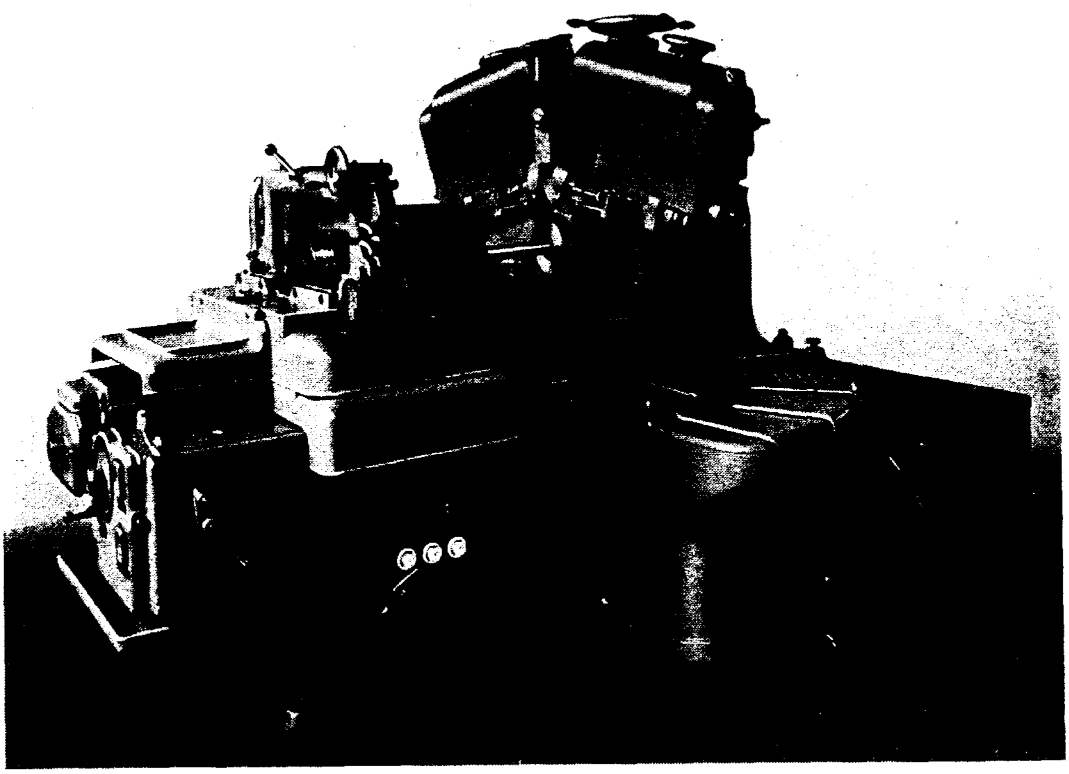

FIG. 8—MAAG "HS.30" GEAR GRINDER

Hypoid Grinder for small and medium gears first exhibited at the Chicago Machine Tool Show in 1947.

Worm Grinders

Remembering our primary interest in small and medium gears, this is a very barren field—only two or three makes are available, most of the machines being built in comparatively large sizes. A considerable number of thread grinders, some of which are capable of limited application to small worm grinding, are in use—these include Jones and Lamson, Excello, Matrix, Newall, Lindner, Reishauer, Société Genevoise, etc., most of them thread grinders pure and simple. There is a real need for a fully-automatic worm grinder for single and multi-start helical involute worms up to 2 in diameter, and also for a larger model, say up to 4 in maximum capacity, for general engineering work.

Spline Grinders

These are by Orcutt and Churchill—both British. The Orcutt is made in two sizes, 20 and 36 in between centres ; the Churchill in 20, 32, and 60 in Both have hydraulic table motion. The Orcutt is available as a combination machine for straight splines and small spur gears. As a gear grinder, the familiar Orcutt formed wheel method is retained, the spline trimmer being replaced by an involute trimmer having form plates of 3 : 1 or 6 : 1 ratio. Incidentally, the only machine known to the writer capable of grinding straight or helical splines is the Fitchburg (American) ; helical splines are used for example in some automotive transmissions, and may offer advantages in special constructions.

Factory Machines

These are special machines for hob relieving and profile grinding, Fellows cutter profile grinding, Gleason spiral cutter relieving, shaving cutter serrating, index plate grinding, master wormwheel hobbing and checking, etc. Most of them are built in the machine makers' works to specific requirements, but a few proprietary makes are in use, *e.g.*, Reinecker, Hille, and Michigan relieving lathes, Monarch hob relieving grinder, and Safag hob and cutter manufacturing machines.

Hob and Cutter Sharpeners

Proper maintenance of these expensive tools is essential for retaining their original accuracy and enabling them to produce the maximum amount of accurate work. Every time a hob is sharpened it is virtually re-made, and if inferior sharpening methods are tolerated the skill and care expended on it during manufacture is mostly thrown away. Further, poor sharpening may considerably reduce tool life by removing useful material unnecessarily. Special-purpose sharpening machines for practically every requirement are available, but are not employed to the extent they should be. There is a balance between production per regrind and the cutting life of the tools ; if they are allowed to run too long, more material must be removed in sharpening to restore them. The B & S reminder " Keep Sharp " stamped on every cutter was well chosen. Given the use of a modern automatic machine they can be brought back to proper operating condition quickly and easily, leaving no possible excuse for neglect. In all good hob sharpeners, helical-fluted hobs are positively guided for flute lead (hydraulic machines by sine bar mechanism, mechanical machines by lead screw and change gears or master screw), a distinct improvement on the finger-in-the-flute " toolroom " method, while flute to flute indexing is by precision divide plates.

Hob Sharpeners. These are by Barber-Colman, Chatwood, Klingelnberg, Pfauter, and Mikron. The B-C No. 6-5 Hydraulic Hob Sharpener is suitable for wet or dry grinding of steel or carbide hobs, has variable wheel speed, adjustable table stroke, automatic indexing and feed. Lead control is by sine bar. The Chatwood, a British machine introduced in 1947, has mechanical drive. For maintaining radial cutting faces on high lead angle hobs as used for worm gear cutting, both Barber-Colman and Chatwood employ a type of generating dresser in which the truing diamond is carried in a frame mounted between the centres in place of the workpiece. The diamond is moved across the wheel face by hand, while the diamond carrier moves in a helical path corresponding to the flute lead. This device was originally patented by Candee and Richmond (Gleason Works) in 1927.

In the Klingelnberg GW.20 Hydraulic Hob Sharpener the hob remains stationary while the wheel is traversed through the flutes—an inversion of the usual arrangement. For small straight-fluted fine pitch hobs the redesigned Mikron 121 Automatic Hob Sharpener is useful, though it is restricted to hobs of small lead angle. Between this little machine and the larger ones mentioned above (some of which take hobs up to 10 in diameter) there is room for a fully-automatic small precision universal hob sharpener with a maximum capacity of 3 in diameter.

Rack-Cutter Sharpeners. Parkson sharpening equipment is supplied for servicing the Sunderland gear planer cutters. One machine grinds the flat surfaces of spur and helical cutters, a separate machine being provided for lipping and chamfering the tools for double helical gears. The Maag WS-2 is for flat and hollow-grinding of spur and helical cutters.

Fellows Cutter Sharpeners. Fellows make a special machine—the 4S—for helical cutters. Spur cutters are usually sharpened by " toolroom " methods ; satisfactory as far as it goes, but no substitute for a proper machine. Such a machine, to handle disc, hub, and shank cutters from the very smallest sizes (as required for the Mikron 117 and Sykes V-6 small precision shapers) up to a maximum of 3 in diameter is still awaited.

Gleason Cutter Sharpeners are provided as companion machines to the Gleason line of straight and spiral bevel generators. There is the No. 12 Straight Cutter Sharpener, the No. 7 Spiral and Hypoid Sharpener, and the No. 13 Spiral and Hypoid Sharpener for the largest Gleason face mill cutters. Revacycle straight bevel cutters may be sharpened on the No. 13 using addition equipment. All these are precision machines.

Measuring and Test Equipment

The measurement and testing of gears is a subject in itself. For the manufacture of accurate gearing a wide variety of measuring apparatus is necessary, ranging from comparatively simple workshop types for controlling production on the shop floor to elaborate inspection and standards room equipment. The principal makes are Fellows, Gleason, Michigan, Orcutt, Parkson, Maag, Mahr, and Zeiss. A complete check of a gear involves measurement of pitch, profile, tooth thickness, runout, and lead ; these elements may be measured individually or in combination. A common method of quality control is to check the first few gears from the cutting machine by rolling test against a master or sample gear known to be accurate, *i.e.*, comparator methods. For a more detailed analysis, investigation of machine errors, etc., single elements, such as pitch, profile, and so on are examined by appropriate means.

Instruments which have been developed for these purposes include : Variable Centre-distance Rolling Testers (Fellows, Parkson, Maag, Mahr) ; Involute Checkers (Fellows, Michigan, Orcutt, Maag, Mahr, Zeiss) ; Pitch Measuring Instruments (Gleason, Maag, Mahr) ; Helix Angle and Lead Checkers (Michigan, Orcutt, Maag) ; Tooth Thickness Gauges, optical (Zeiss), and micrometer screw, Wildhaber's method (Mahr, Reishauer) ; and Universal Measuring Machines (Maag, Zeiss).

Checking Spur and Helical Gears. Assuming the hobbing or gear shaping machines to be in proper operating condition, the user is largely in the hands of the hob or cuttermaker for good results. Here accuracy begins. Among stock machines to assist the tool manufacturer are the Illinois " Toolgraph " Hob Lead Checker, the Loewe Universal Hob Measuring Machine, and, from the Michigan range, Hob Lead, Hob Contour, and Hob Sharpening Checkers. In the larger gear plants, items such as hob-sharpening checkers are valuable in the toolroom on maintenance account, since, as previously explained, correct sharpening is essential for consistent results.

For cut gears, the rolling test commonly applied is a useful guide to quality. Modern rolling testers are electrically driven and auto-recording by mechanical or electrical means ; the Fellows " Red Liner " for automatic gear inspection is all-electric. The composite check gives the combined effect of errors in runout, pitch, profile, pressure angle and thickness, variations in centre distance as the work gear rolls against a master gear being indicated or recorded. The ability to interpret the results and correctly assess the quality of the workpiece comes with experience.

Involute and lead checkers are, of course, used in connection with cut gears, but for gear grinding they form indispensible adjuncts to the grinding machine. Why the difference ? Because, in hobbing, most of the accuracy is " stored in the hob" which has been subjected to all manner of exacting tests during manufacture, while the lead (given a reasonably accurate machine) is dependent only on change gear calculations. In gear grinding, the wheel is formed on the machine, and the simplest way of proving wheel shape is to take an involute check ; also the lead, in this case, depends on the exact angular setting of a slide, which is best proved by a lead check on the gear.

Among involute checkers the Fellows, Maag, and Carl Mahr versions are probably the best known. The Fellows 12M is motor driven, indicating and recording (electronic recording device), and employs a master involute cam ; base diameter setting is by gauge blocks. The Maag PH-60 is arranged to test involute, lead, helix angle, runout, and surface finish (by using a sharp-pointed stylus at the highest magnification, 1000 to 1). Involute is by individual base discs—fundamentally simple and accurate. Carl Mahr No. 889 has individual base discs for each and every gear, while the No. 890 has stepless adjustable base diameter from a Bilgamband linkage ; the Zeiss involute instrument is on similar lines. Considerable design effort has been expended on these constructions, which embody workmanship of a very high order.

Bevel Gear Testing. While it is necessary to measure and check single bevel-gear elements in development work and in the analysis of machine errors, experience has shown that for day-to-day production the best method of testing bevels is a running test. Special machines to simulate operating conditions have been designed by Gleason Works and are furnished in a range of types and sizes for every bevel gear application. The No. 4 Angular Bevel Tester is for small straight or spiral instrument gears of any shaft angle ; a larger machine, the No. 6, will handle hypoids in addition. The No. 13 Universal Tester is for running tests on bevel, spur, and worm gears—a useful machine for jobbing or experimental work in the medium size field. Other more highly specialized machines for the automotive industry include the 17A Spiral and Hypoid Tester and Lapper. For measurement of individual gear errors there are the Tooth Spacing and Concentricity Test Instruments and, for cutter setting, the Cutter Truing and Cutter Angle Testing Devices. Altogether there are more than ten machines and instruments in the range.

Worm Gear Testing. Holroyd worm gear inspection equipment comprises three machines ; a Centre Tester, for checking centre distance, tooth bearing, and backlash ; a Worm Profile Checker ; and a Pitch, Division, and Lead Checker. It would have been possible to combine the functions of all three in a single machine, as exemplified in the David Brown No. 12A Worm Gear Tester, but there are advantages in the separation ; the centre tester, for example, is most useful near the worm wheel generator, the worm profile checker accessory to the worm grinder, while the pitch, division, and lead instrument finds its place in the standards room.

General. Of the fifty-odd known varieties of gear measuring and test equipment manufactured at the present time, ten are of British make. The position regarding two small items—master gears and measuring rolls—is typical. While practically every other type of standard or gauge is available, these essential accessories are not listed except by American, German, or Swiss firms. Master gears are difficult and costly to make, so they are often dispensed with, reducing considerably the value of centre distance testers. Logically, a buyer of test equipment would expect the maker to supply master gears to go with it, but in practice the user is left to find his own. One difficulty arising at the outset is the lack of recognized standards of accuracy to which master gears should conform, unless we adopt the specification of the American Gear Manufacturers' Association. No comparable British Standard exists. The A.G.M.A. Standard (approved by the American Standards' Association) lays down limits and tolerances for master gears in the size range applicable to the automotive and machine-building industries ; a standard for fine-pitch master gears is in course of preparation. Remeasuring rolls, Van Keuren, Mass., list complete sets of gear measuring rolls guaranteed to 25 millionths of an inch for size, graded, boxed, and sold complete with tables ready for use. Such enterprise is to be commended. There is no good reason to continue with odd bits of drill rod and similar makeshifts while this useful and inexpensive material is available.