Module 2 - GEARS

Lecture 5 - GEAR MANUFACTURING

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5.1 INTRODUCTION

Gear manufacturing can be divided into two categories namely forming and machining as shown in flow chart in Fig 5.1. Forming consists of direct casting, molding, drawing, or extrusion of tooth forms in molten, powdered, or heat softened materials and machining involves roughing and finishing operations. They are discussed in the different sections of this chapter.

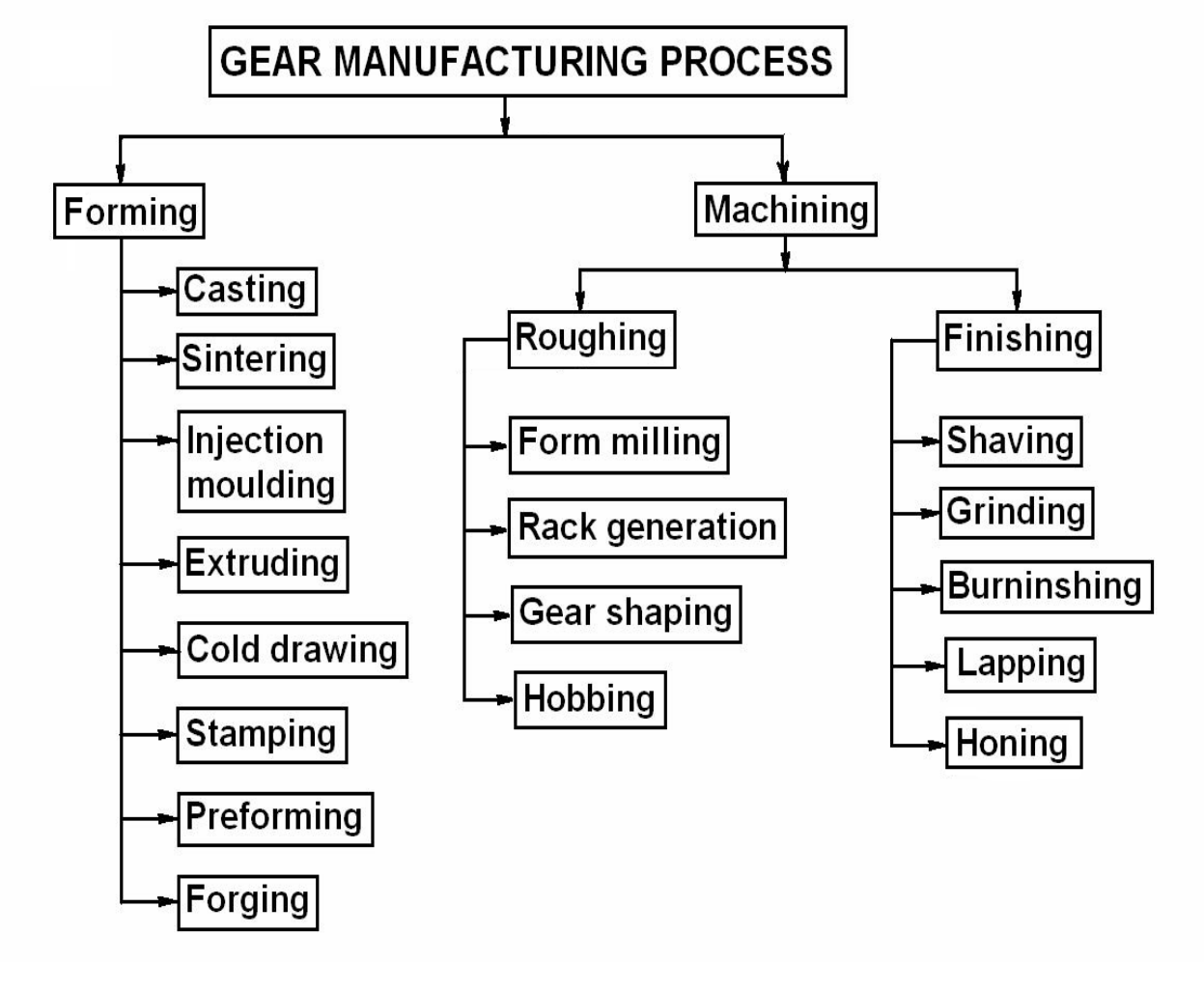


Fig 5.1 Categories of gear manufacturing process

5.2 FORMING GEAR TEETH

Characteristics: In all tooth-forming operations, the teeth on the gear are formed all at once from a mold or die into which the tooth shapes have been machined. The accuracy of the teeth is entirely dependent on the quality of the die or mold and in general is much less than that can be obtained from roughing or finishing methods. Most of these methods

have high tooling costs making them suitable only for high production quantities. The various forming techniques are discussed below in detail:

5.2.1 Casting

Sand casting, die casting and investment casting are the casting processes that are best suited for gears and are shown in fig 5.2. They are explained in the following sections:

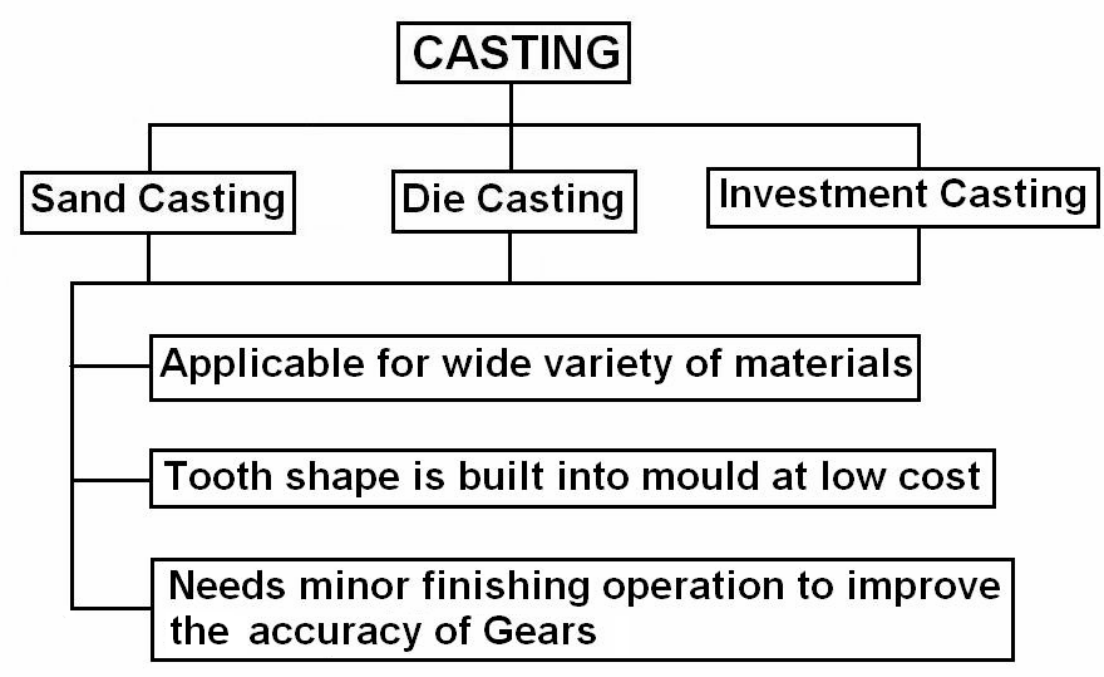


Fig.5.2 Casting processes

5.2.1a Sand Casting

Characteristics:

The characteristics of sand cast gears are,

- Cheaper low quality gear in small numbers
- The tooling costs are reasonable
- Poor Surface finish and dimensional accuracy
- Due to low precision and high backlash, they are noisy.
- They are suited for non- critical applications

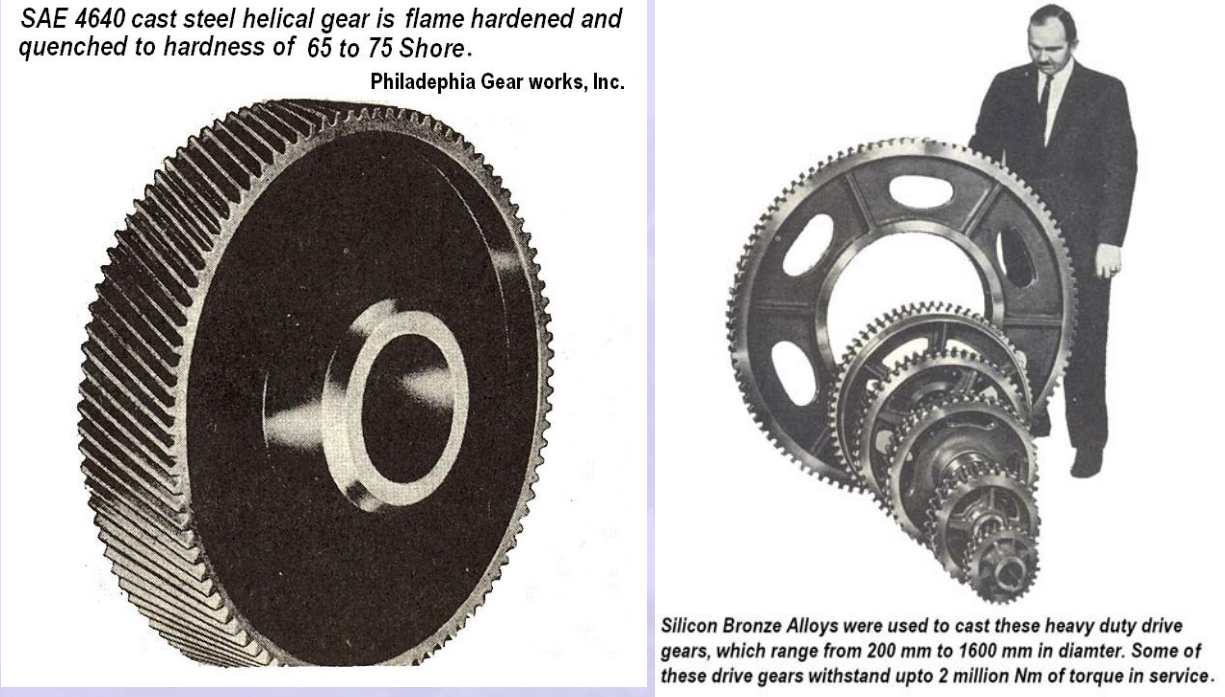
Applications: (without finishing operation)

Sand casting is used for gear manufacture which are used in variety of applications such

as for toys, small appliances, cement-mixer barrels, hoist gearbox of dam gate lifting mechanism, hand operated crane etc.,

Materials:

The materials that can be sand cast are C I, cast steel, bronzes, brass and ceramics. The process is confined to large gears that are machined later to required accuracy.



(a) **(b)**

Fig 5.3(a) SAE 4640 cast steel helical gear, (b) Silicon bronze heavy duty drive gears from 200mm to 1600mm diameter

5.2.1b Die casting

Characteristics:

The characteristics of die cast gears are,

- Better surface finish and accuracy (tooth spacing and concentricity)
- High tooling costs
- Suited for large scale production Applications:

Applications:

Gears that are die cast are used in instruments, cameras, business machines, washing machines, gear pumps, small speed reducers, and lawn movers. Fig. 5.3 shows gears that

are manufactured by die casting.

Materials:

Materials used to manufacture these gears are zinc, aluminium and brass. The gears made from this process are not used for high speeds and heavy tooth loading. They are normally applied for small size gears.

5.2.1c. Investment casting or lost wax process

Characteristics:

The characteristics of gears that are manufactured by investment casting are,

- Reasonably accurate gears
- Applicable for a variety of materials
- Refractory mould material
- Allows high melt-temperature materials
- Accuracy depends on the original master pattern used for the mold.

Materials:

Tool steel, nitriding steel, monel, beryllium copper are the materials that can be investment casted for the manufacture of gears. The process is used only if no other process is suitable since production cost is high. Fig 5.4 shows a wire twister stellite gear which mates with a rack made by IC. Complicated shape makes it economical to produce by investment casting process.

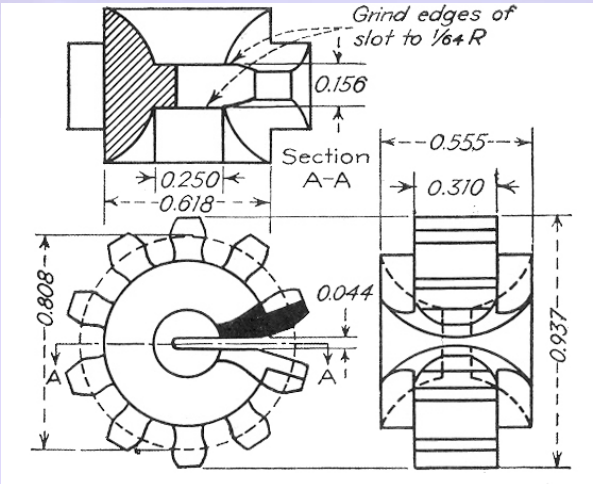


Fig. 5.4 Complicated shape of gear manufactured by Investment casting

5.2.2. Sintering or P/M process:

The powder metallurgy technique used for gear manufacture is shown in fig 5.5.

Characteristics:

- Accuracy similar to die-cast gears
- Material properties can be Tailor made
- Typically suited for small sized gears
- Economical for large lot size only

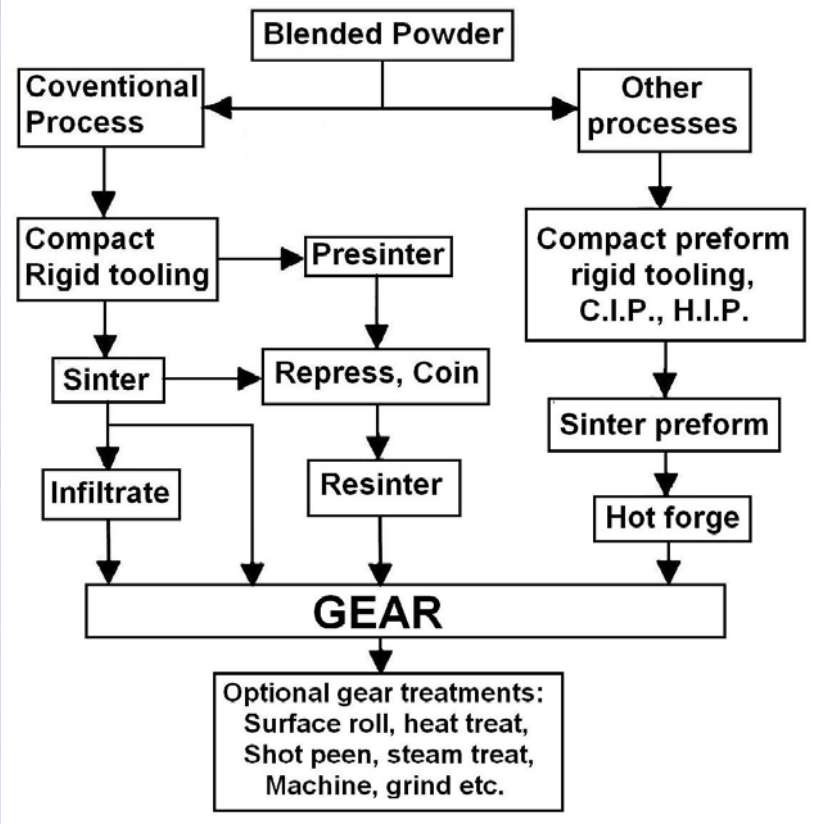


Fig 5.5 Process chart for P/M gear manufacture

As shown in Fig 5.6, for the components manufactured by P/M technique, secondary machining is not required. Fig 5.7 shows cluster gears, different types of gears that can be combined and keyways can be built-in.

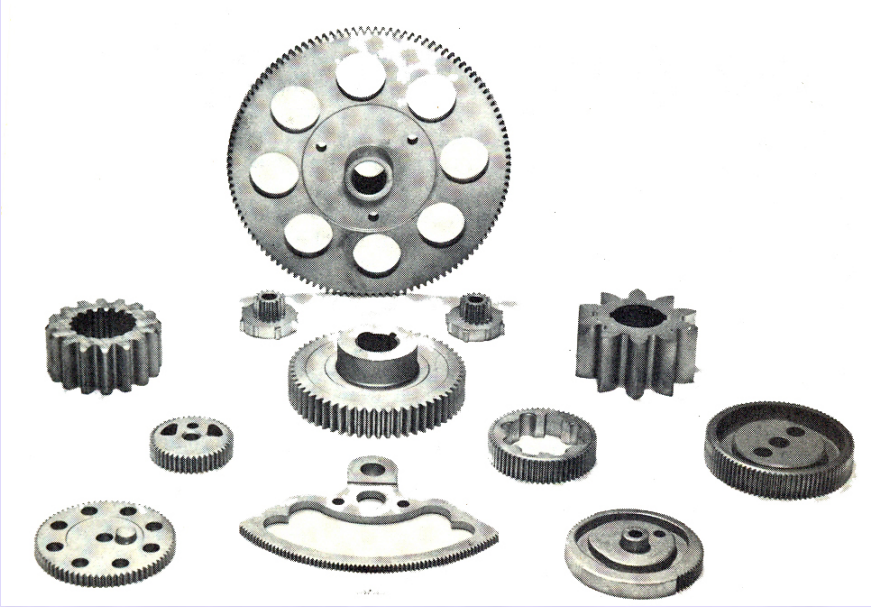


Fig. 5.6. Components manufactured by sintering



Fig 5.7 Cluster gears, combination of gears and gears with key ways

Fig 5.8 shows helical gears and combination of gears made by P/M or sintering process. Material utilization is more than 95% in this manufacturing process. The material utilizations of forged and sintered processes are shown in Fig 5.9.



Fig 5.8 Helical gears and combination of gears

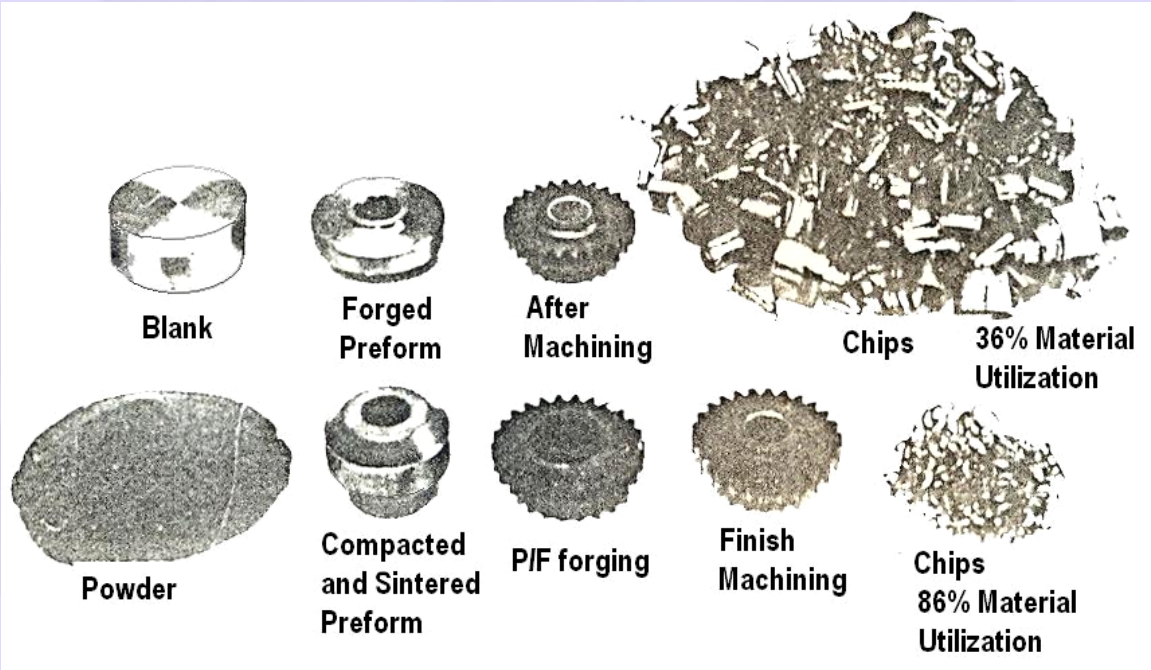


Fig. 5.9 Material utilization of forged and sintered processes

Fig 5.10 shows the P/M gear production by hot forging process and the manufactured components are shown in fig 5.11.

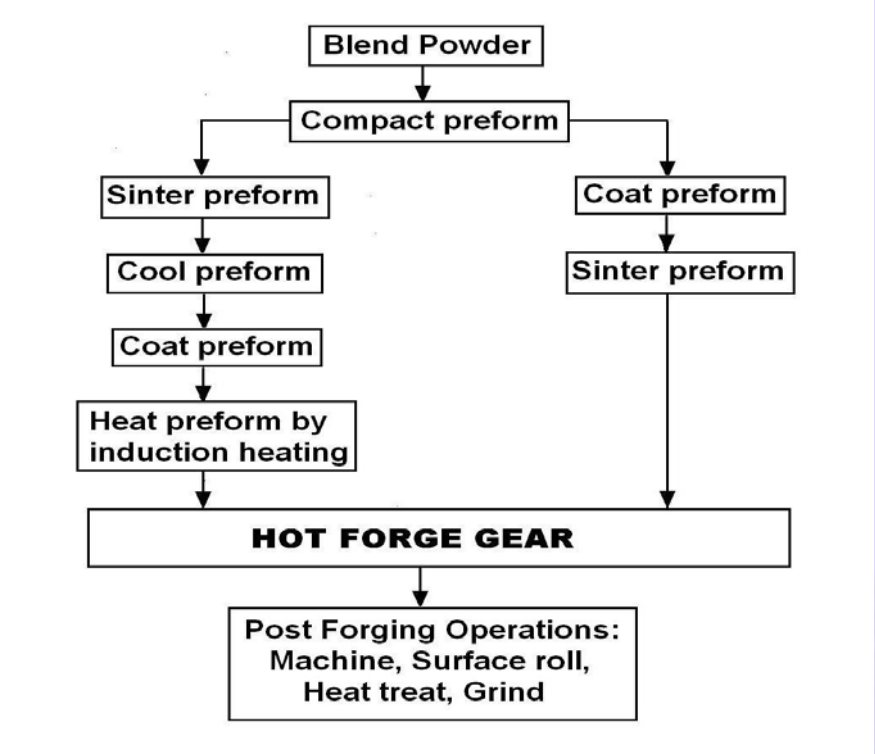


Fig 5.10 P/M gear production by hot forging process



(a) (b)

Fig 5.11 P/M gears by hot forging process

5.2.3. Injection Molding:

Injection molding is used to make nonmetallic gears in various thermoplastics such as nylon and acetal. These are low precision gears in small sizes but have the advantages of low cost and the ability to be run without lubricant at light loads.

Applications:

Injection molded gears are used in cameras, projectors, wind shield wipers, speedometer, lawn sprinklers, washing machine. They are shown in fig.5.12 and 5.13.

Materials:

The materials for injection molding components are Nylon, cellulose acetate, polystyrene, polyimide, phenolics.

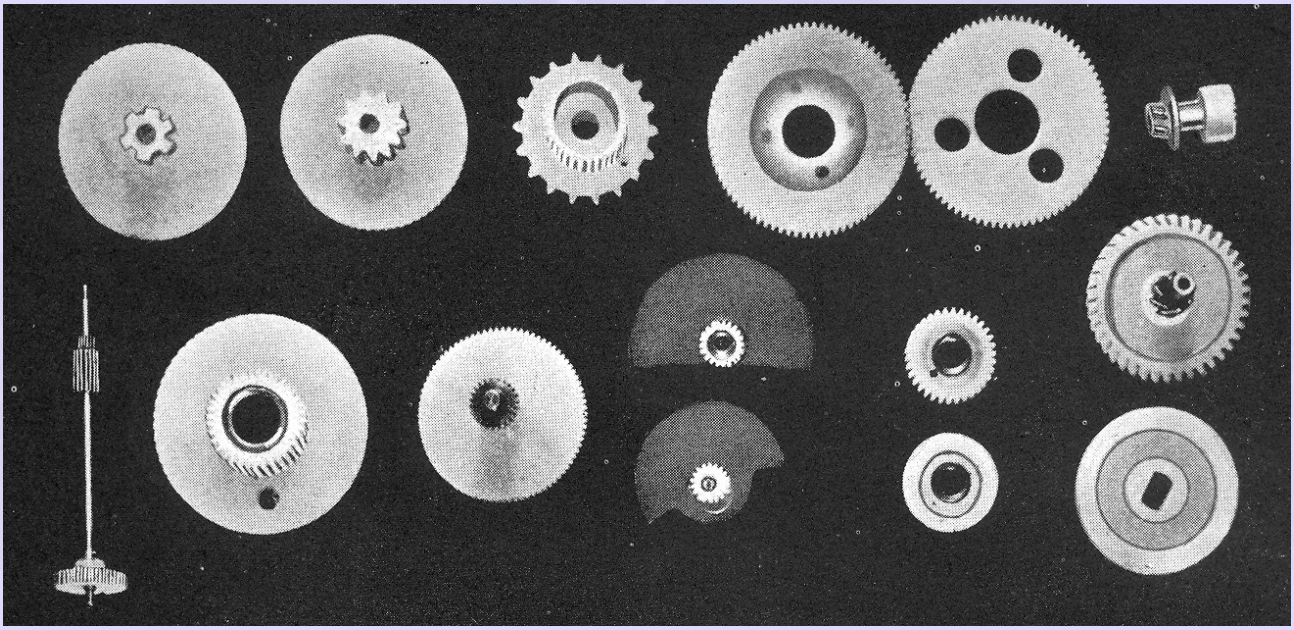


Fig. 5.12 IM camera gears

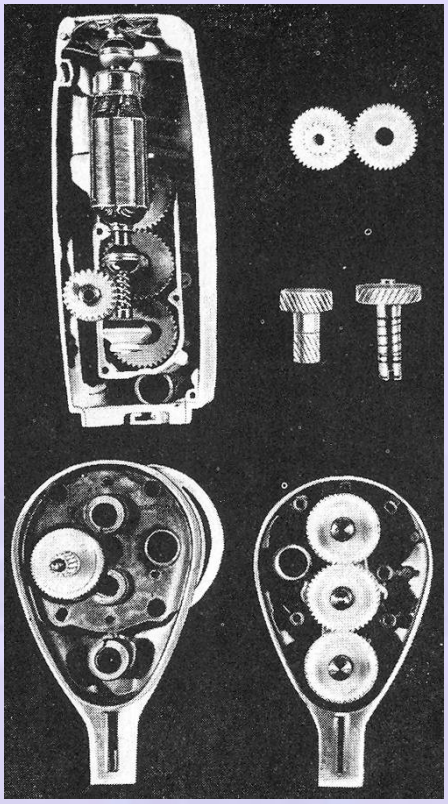
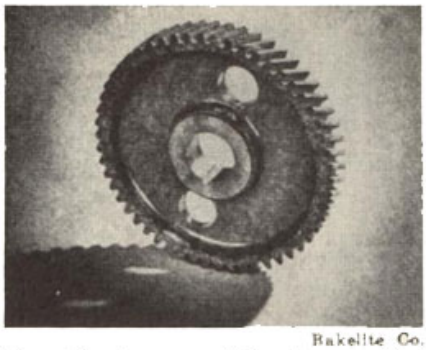
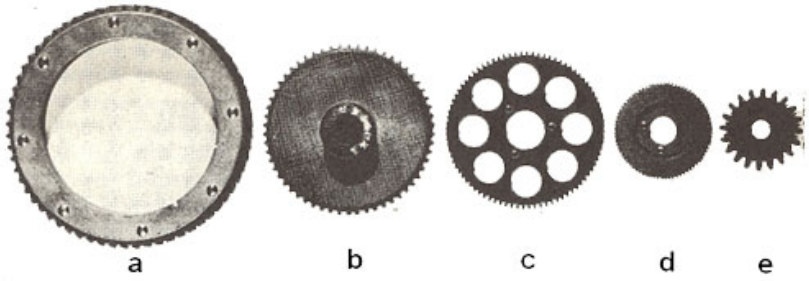


Fig 5.13 Food mixer



Bakelite Co.

Phenolic-glass moulding is specified for engine timing gear because of its high strength and impact resistance.



Quaker City Gear Works; Synthane Corp

Cotton-base phenolic laminate gear (a) with structural brass plates is used in voice recording instrument. Cotton-base gear (b) is used in noiseless elevating equipment. Fabric-base gear (c) is used in electronic instruments. Nylon fabric laminate gear (d) is part of motion picture sound projector. Similar gear (e) is used for television set control.

Fig 5.14 Compression molded gear

5.2.4 Extruding

Extruding is used to form teeth on long rods, which are then cut into usable lengths and machined for bores and keyways etc. Nonferrous materials such as aluminum and copper alloys are commonly extruded rather than steels. This result in good surface finishes with clean edges and pore free dense structure with higher strength. Table 5.1 shows various

extruded sections along with their number of teeth, outside diameter, pitch diameter, root diameter, pitch and tooth thickness.



Fig. 5.15 Extruded gears

Materials:

Aluminum, copper, naval brass, architect-ural bronze and phosphor bronze are the materials that are commonly extruded.

Applications:

Splined hollow & solid shafts, sector gears are extruded and various gears are shown in fig 5.15.

Table 5.1 Specifications of various extruded sections

Typical Extruded Sections

	Number Teeth	Outside Diameter	Pitch Diameter	Root Diamter	Pitch	Tooth Thickness
	18	1.241	——	0.972	16	0.098
	7	1.487	1.062	0.775	6	0.261
	8	0.985	0.800	0.544	10	0.157
	7	1.430	——	0.712	6	0.261
	15	2.020	——	1.588	8	0.1963
	9	1.325	——	0.920	14	0.196
	16	1.285	——	0.985	15	0.112
	8	1.150	——	0.750	Tolerance = 0.010	
	12	1.8	1.5		8	CP = 0.3927
	11	1.8	——		1.265 hole drawn to 1.215	
	6	Segment for Easy washer, body 0.720, radii 1/32 in.				
	12[1]	5.25	4.38	3.625	Tolerance = ± 0.034	

[1]Aluminium

The progression in the formation of a gear blank by cold forming is shown in fig 5.16 and the stages in the extrusion of a gear is shown in fig 5. 17.

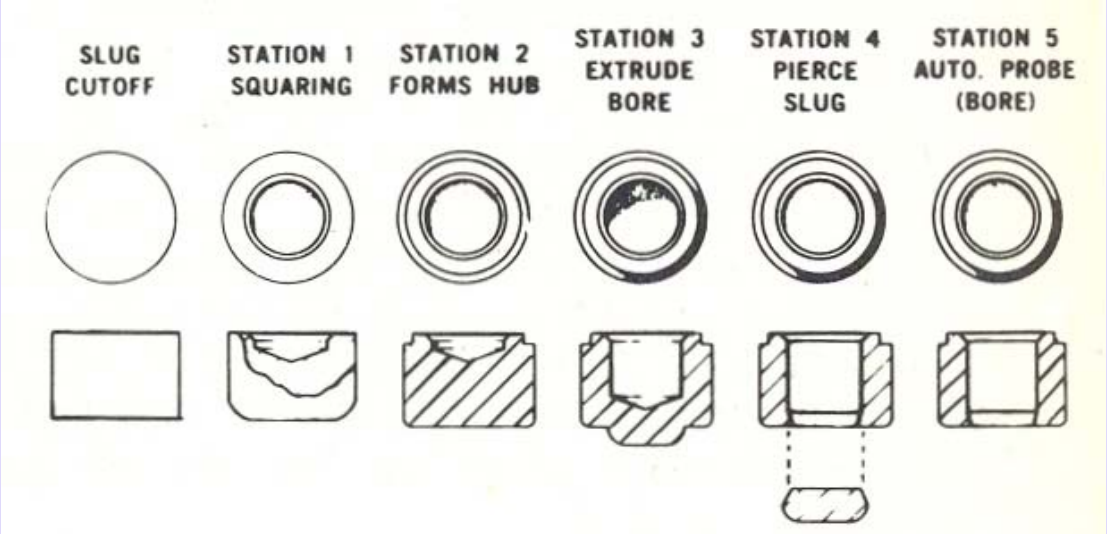


Fig 5.16 Progression of a cold formed gear blank

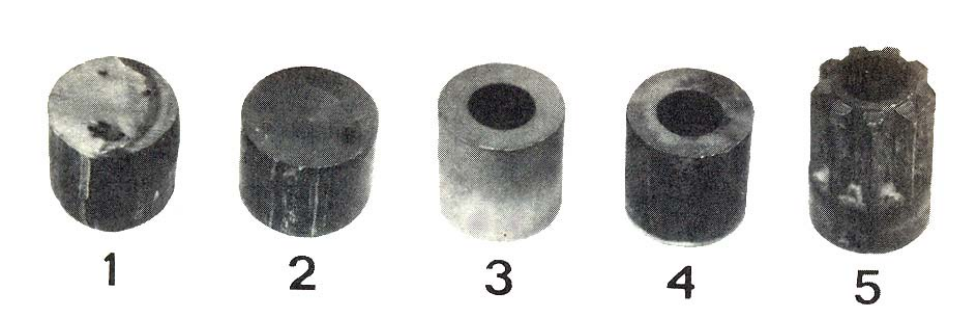


Fig 5.17 Stages in extrusion of a gear

Helical gears manufactured by extrusion are shown below in fig 5.18.



Fig 5.18 Helical gear made by extrusion

5.2.5. Cold Drawing:

Cold drawing forms teeth on steel rods by drawing them through hardened dies. The cold working increases strength and reduces ductility. The rods are then cut into usable lengths and machined for bores and keyways, etc.

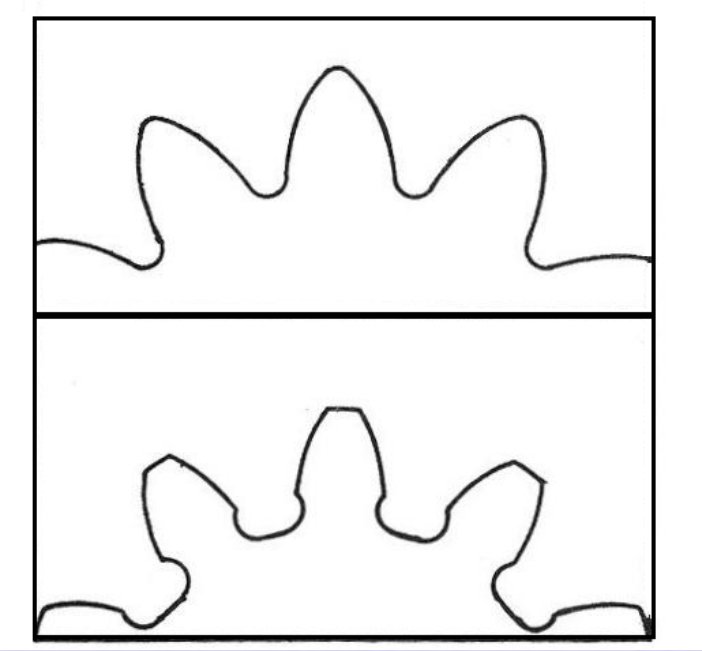


Fig 5.19 For cold drawing, the 11-tooth pinion below is enlarged by AGMA-ASA standard to the form above, avoiding undercut and giving radius rather than sharp corners

5.2.6. Stamping:

Sheet metal can be stamped with tooth shapes to form low precision gears at low cost in high quantities. The surface finish and accuracy of these gears are poor.

Applications:

Stamped gears are used as toy gears, hand operated machine gears for slow speed mechanism.

5.2.6 a Precision stamping:

In precision stamping, the dies are made of higher precision with close tolerances wherein the stamped gears will not have burrs.

Applications:

Clock gears, watch gears etc.

5.2.7. Preforming

For close die forging the feed stock has to be very near to the net shape and this is obtained by performing. This is explained by flow diagrams both in sinter forging and precision hot forging.

5.2.8 Forging:

The steps in forging process are represented in fig 5.20 and the forged gears are shown in fig 5.21.

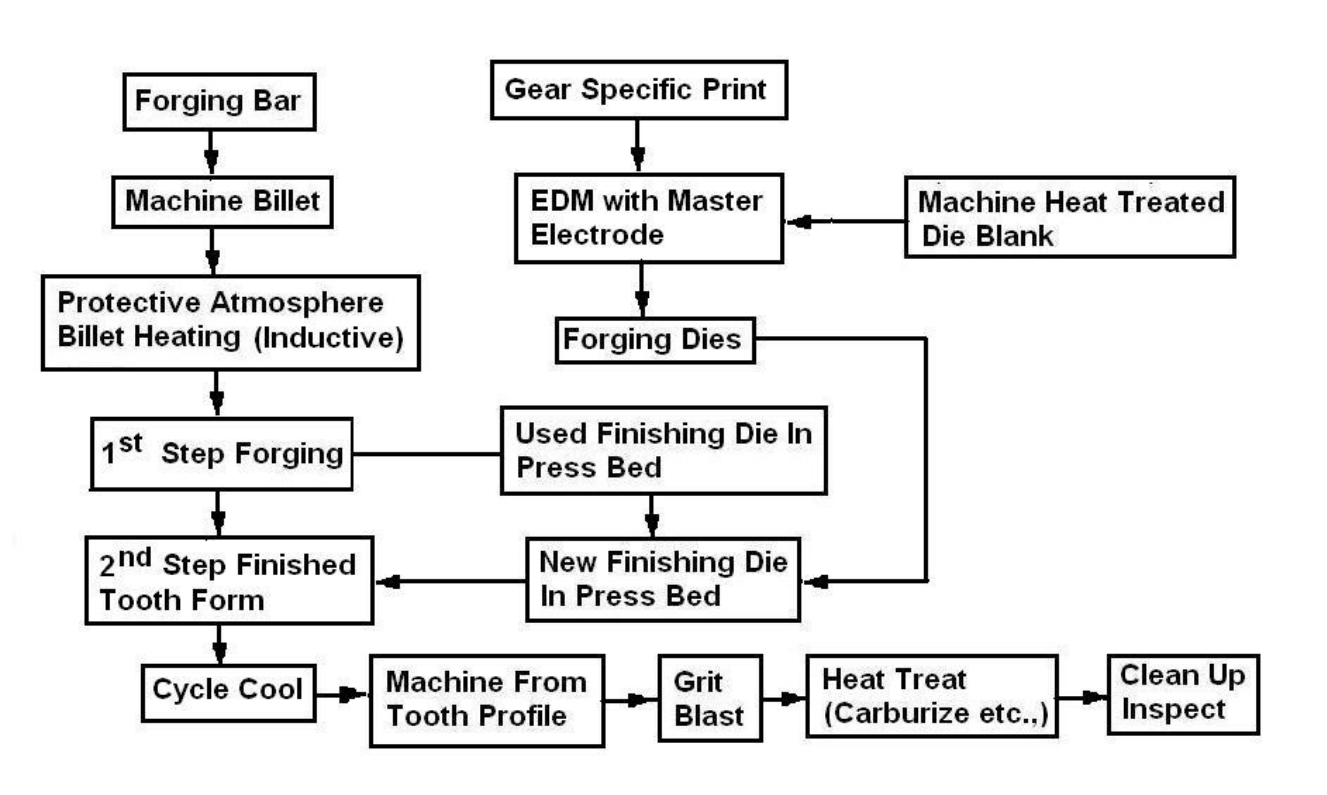


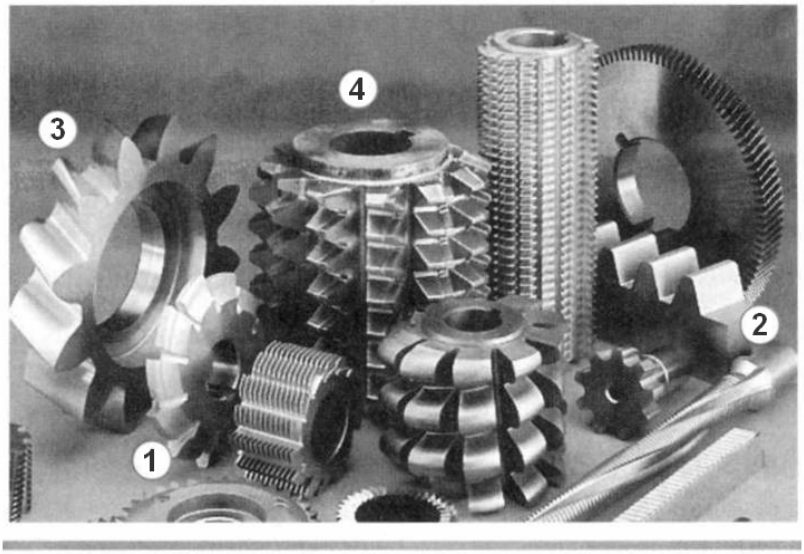
Fig 5.20 Procedure for forging of gears



Fig 5.21 Various forged gears

5.3 MACHINING

The bulk of power transmitting metal gears of machinery are produced by machining process from cast, forged, or hot rolled blanks. Refer fig 5.1 for classification of machining processes. Roughing processes include milling the tooth shape with formed cutters or generating the shape with a rack cutter, a shaping cutter or a hob cutter which are shown in fig 5.22.



A collection of Gear-Cutting Tools: 1—Disc type Milling Cutter, 2— Rack Cutter, 3— Shaper Cutter, 4—Hob Cutter.

Fig 5.22 Various gear cutters

Despite its name, the roughing processes actually produce a smooth and accurate gear tooth. Only for high precision and quiet running, the secondary finishing operation is justified at added cost.

5.3.1 Roughing processes:

Roughing process consists of forming, generation, shaping and hobbing processes. By this method gears are made to an accuracy which is more than adequate for the slow speed operations. These processes are dealt here.

5.3.1.1 Form milling:

Forming is sub-divided into milling by disc cutters and milling by end mill cutter which are having the shape of tooth space.

5.3.1.1a Form milling by disc cutter:

The disc cutter shape conforms to the gear tooth space. Each gear needs a separate cutter. However, with 8 to 10 standard cutters, gears from 12 to 120 teeth can be cut with fair accuracy. Tooth is cut one by one by plunging the rotating cutter into the blank as shown in fig 5.23.

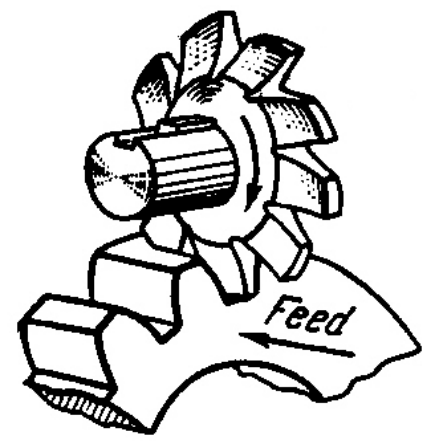


Fig 5.23 Form milling by disc cutter

5.3.1.1b Form milling by end mill cutter:

The end mill cutter shape conforms to tooth spacing. Each tooth is cut at a time and then indexed for next tooth space for cutting. A set of 10 cutters will do for 12 to 120 teeth gears. It is suited for a small volume production of low precision gears. The form milling by end mill cutter is shown in fig 5.24.

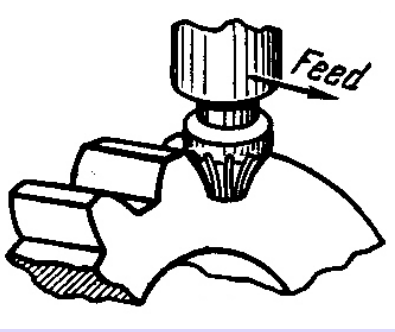


Fig 5.24 Form milling by end mill cutter

To reduce costs, the same cutter is often used for the multiple-sized gears resulting in profile errors for all but one number of teeth. Form milling method is the least accurate of all the roughing methods.

5.3.1.2a Rack generation:

In rack cutter the tooth shape is trapezoid and can be made easily. The hardened and sharpened rack is reciprocated along the axis of the gear blank and fed into it while gear blank is being rotated so as to generate the involute tooth on the gear blank as shown in fig 5.25.

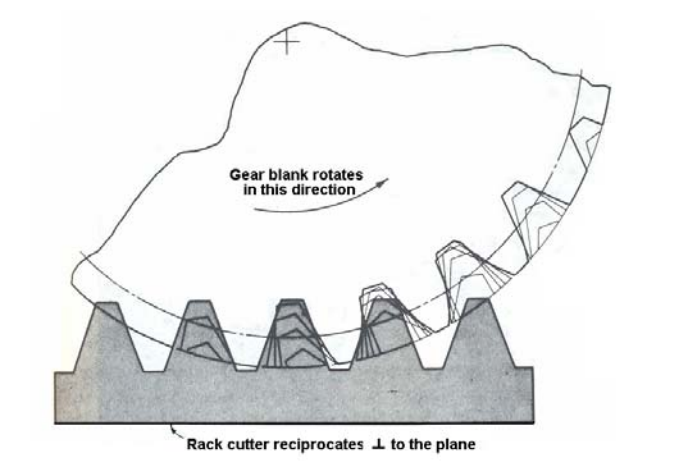
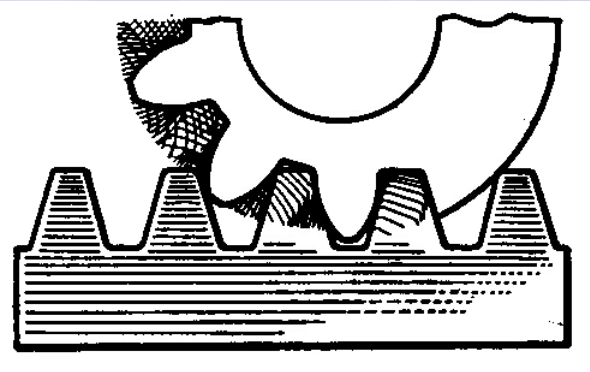
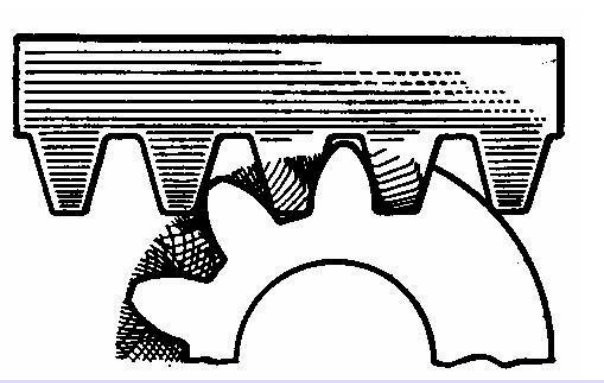


Fig 5.25 Generation of involute tooth on gear blank

The rack and gear blank must be periodically repositioned to complete the circumference. This introduces errors in the tooth geometry making this method less accurate than shaping and hobbing.



(a)



(b)

Fig 5.26 (a) (b) Rack generations

The process is limited to small gears since the length of the rack has to be equal to circumference of the gear at pitch diameter. The generation of spur gear by planing is shown in fig 5.27.

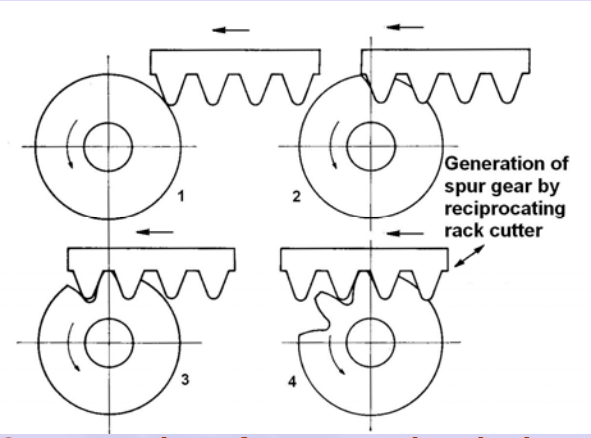


Fig 5.27 generation of spur gear by planing

5.3.1.2b Gear shaping:

Gear shaping used a cutting tool in the shape of a gear which is reciprocated axially across the gear blank to cut the teeth while the blank rotates around the shaper tool. It is a true shape-generation process in which the gear-shaped tool cuts itself into mesh with the gear blank as shown in fig 5.28. The accuracy is good, but any errors in one tooth of the shaper cutter will be directly transferred to the gear. Internal gears can be cut with this method as well.

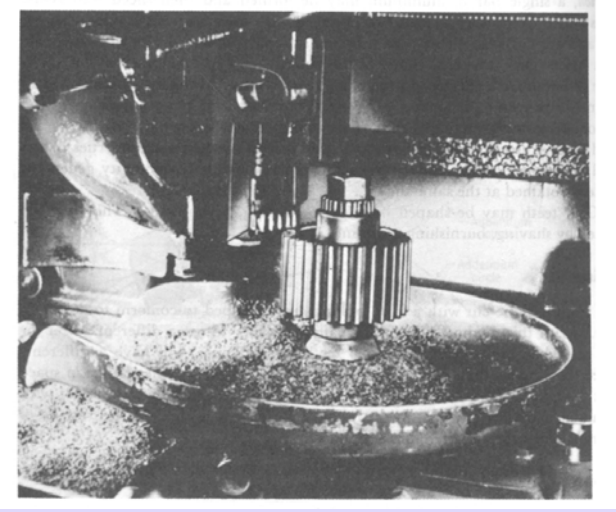


Fig 5.28 Gear shaping

5.3.1.2c Hobbing:

Hob teeth are shaped to match the tooth space and are interrupted with grooves to provide cutting surfaces. It rotates about an axis normal to that of the gear blank, cutting into the rotating blank to generate the teeth as shown in fig 5.29.

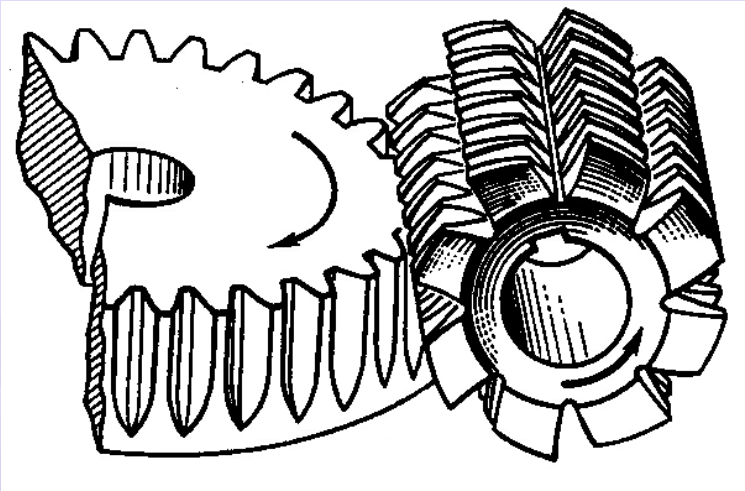


Fig 5.29 Hobbing

It is the most accurate of the roughing processes since no repositioning of tool or blank is required and each tooth is cut by multiple hob-teeth, averaging out any tool errors. Excellent surface finish is achieved by this method and it is widely used for production of gears.

5.3.2.2 Finishing Processes:

When high precision is required secondary operation can be performed to gears made by any of the above roughing methods. Finishing operations typically removes little or no material but improves dimensional accuracy, surface finish, and or hardness. The various finishing processes are shown in fig 5.1.

5.2.2a Shaving:

Shaving is similar to gear shaping, but uses accurate shaving tools to remove small amounts of material from a roughed gear to correct profile errors and improve surface finish. Shaving operation is shown in fig 5.30.



Fig 5.30 External gear being shaved

5.2.2b Grinding:

In grinding, a contoured grinding wheel is run over machined surface of the gear teeth using computer control. With a small amount of metal removal high surface finish is obtained. Fig 5.31 shows grinding operations and dressing of the wheel.

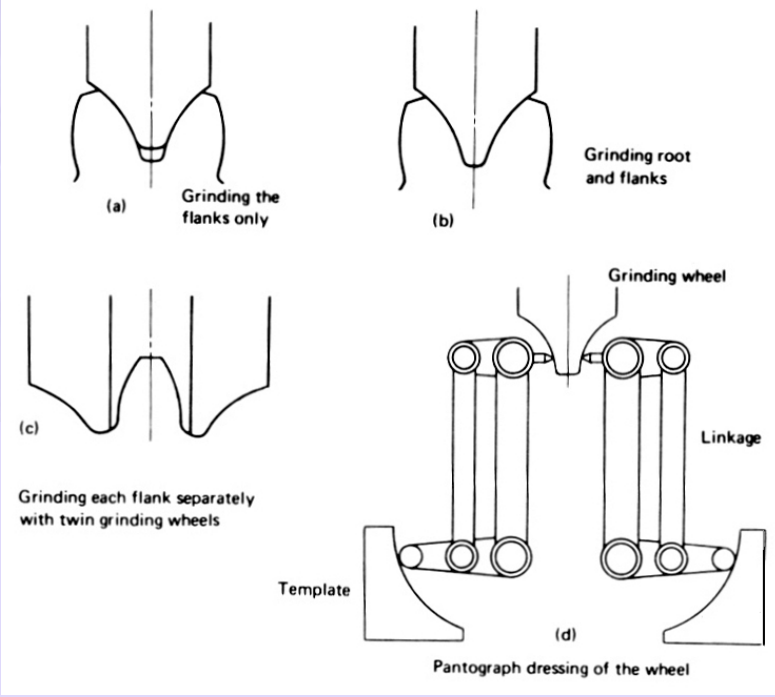
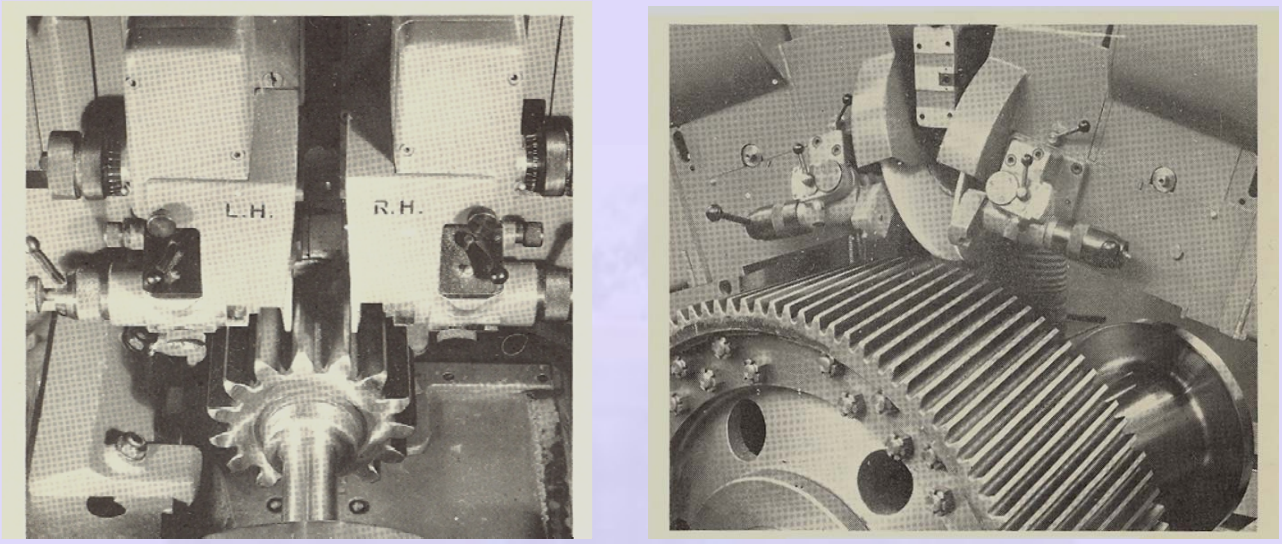


Fig 5.31 (a) Grinding the flanks only, (b) Grinding root and flanks, (c) Grinding each flank separately with twin grinding wheels and (d) Pantograph dressing of the wheel

Grinding is used to correct the heat-treatment distortion in gears hardened after roughing. Improvement in surface finish and error correction of earlier machining are added advantages. Grinding operation for gears can be done by profile grinding or form grinding as shown in fig 5.32 and 5.33.



(a) (b)

Fig 5.32 (a) Maag zero pressure angle profile grinding and (b) Maag profile grinding

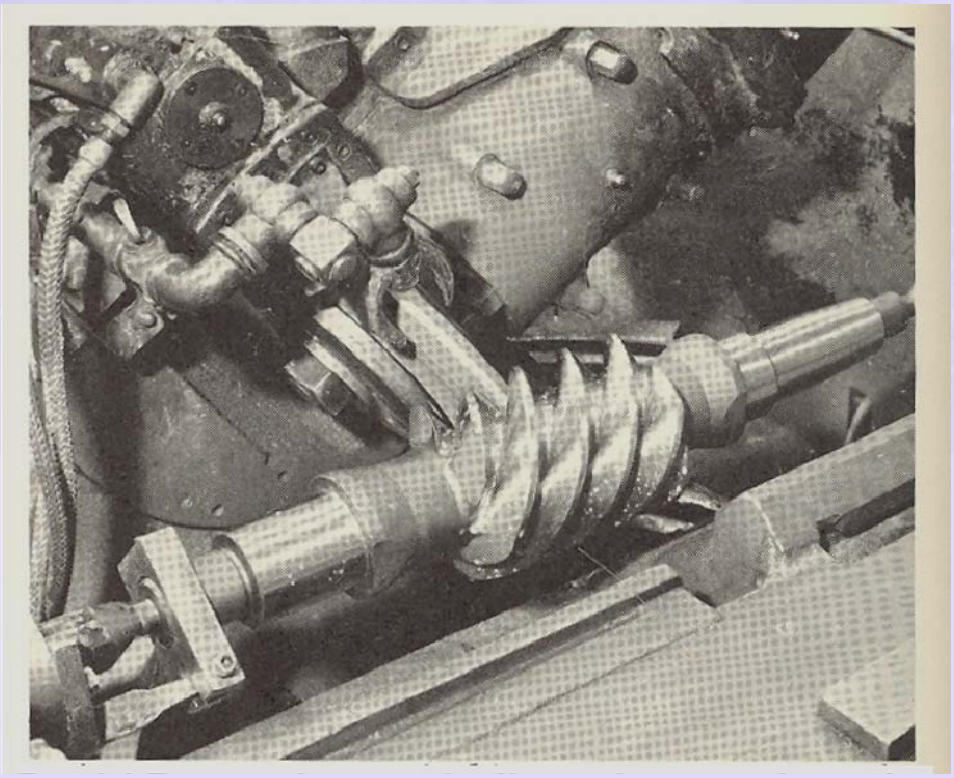


Fig 5.33 David Brown form grinding of worm threads

5.2.2c Burnishing:

In burnishing, a specially hardened gear is run over rough machined gear. The high forces at the tooth interface cause plastic yielding of the gear tooth surface which improves finish and work hardens the surface creating beneficial compressive residual stresses.

5.2.2d Lapping and Honing:

Lapping and honing both employ an abrasive-impregnated gear or gear-shaped tool that is run against the gear to abrade the surface. In both cases, the abrasive tool drives the gear in what amounts to an accelerated and controlled run-in to improve surface finish and the accuracy. Fig 5.34 shows lapping operation for bevel gears.

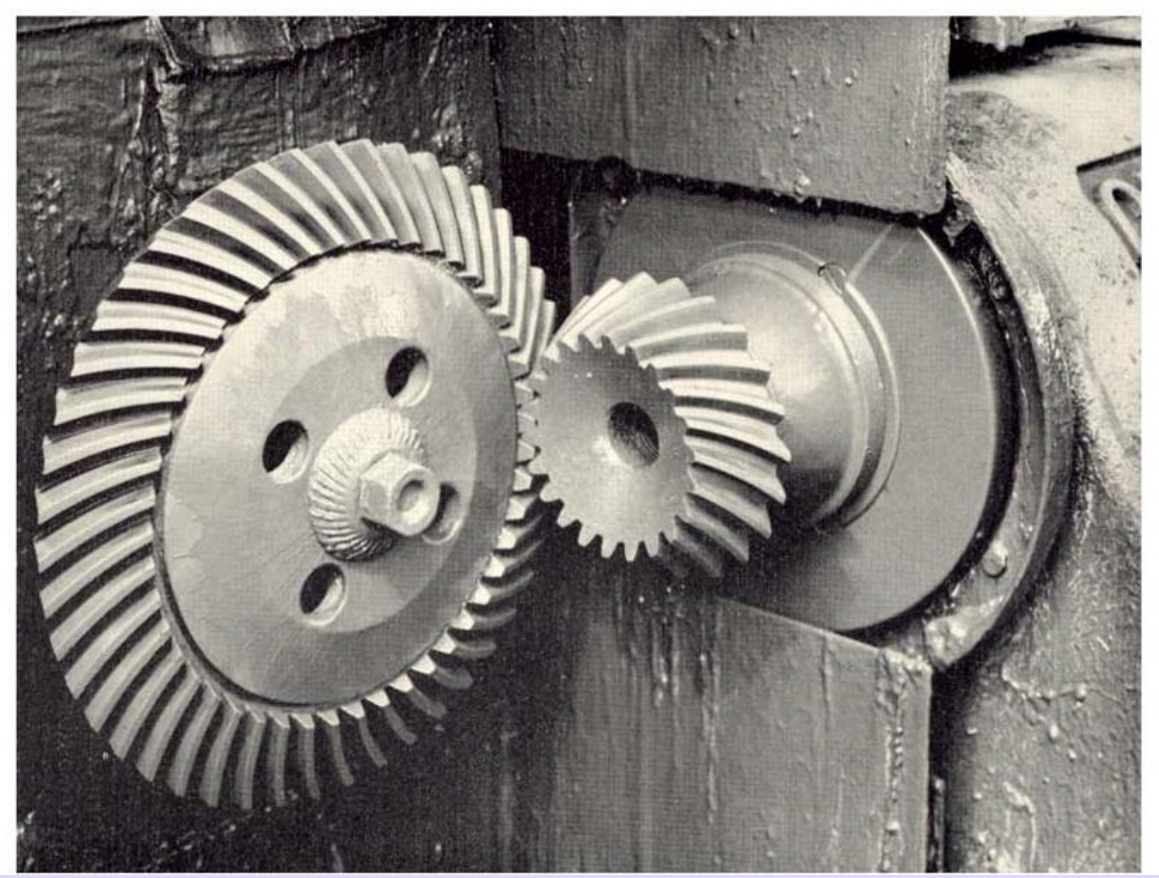


Fig 5.34 Special bevel gears being lapped

5.3. Quality of the Gear:

The quality of gear gives its accuracy, dimensional and profile which dictates the suitability of gears for different operations.

Various standards for assuring the quality of gears are,

- The AGMA standard 2000-A88 defines dimension tolerance for gear teeth and a quality index Qv that ranges from the lowest quality 3 to the highest precision 16.

- DIN 3962 defines quality index in another way. Highest quality is assigned number 1 and the lowest quality is assigned number 12.

Based on the machining/production techniques the accuracy of gears varies viz., with the pitch error, profile errors and surface finish, the Q_v varies. These errors give rise to vibration in the gears and affect their smooth running. Consequently the gear quality limits their speed of operation. The various gear manufacturing processes and the corresponding dynamic load factors at various speeds are depicted in Fig. 5.35. The limiting speeds and dynamic load factors for various quality of gears is shown in Fig. 5.36

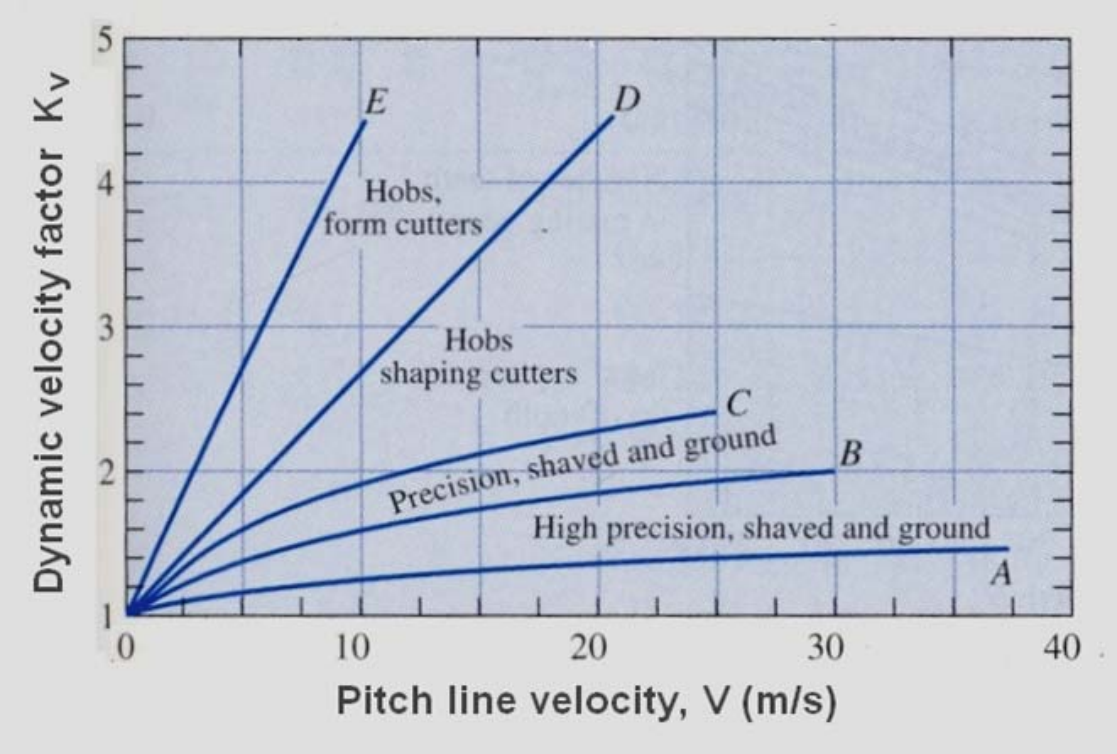
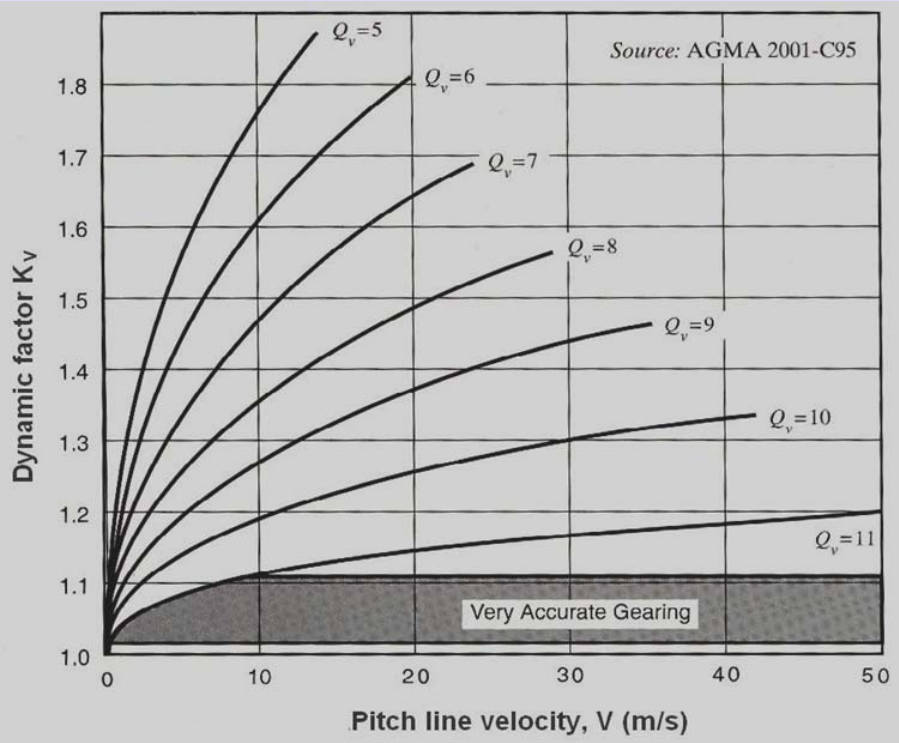


Fig. 5.35 Various gear manufacturing processes, their operating speed limits and dynamic load factors



(b)

Fig. 5.36 Gear quality, their limiting speeds and dynamic load factors

Table 5.2 Allowable velocities and applications of gears of various accuracy grades

DIN accuracy grade	Peripheral velocity m/s		Field of Application
	Spur gears, up to	Other gears, up to	
6th (gearing above and normal accuracy)	20	31.5	High-speed drives, indexing mechanisms
7th (gearing above and normal accuracy)	12.5	20	High-speed and medium-load drives or vice versa
8th (gearing above and normal accuracy)	8	12.5	Drives of general engineering
9th (gearing above and normal accuracy)	5	8	Low-speed drives of low-accuracy machinery

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