Advanced Diploma in Engineering and Technology

EAL
EMTA Awards Limited

VRQ3

Maintenance of Mechanical Systems

Unit 29

(Gear Drives)

NEATH PORT TALBOT COLLEGE
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NPTC

Gear Drives

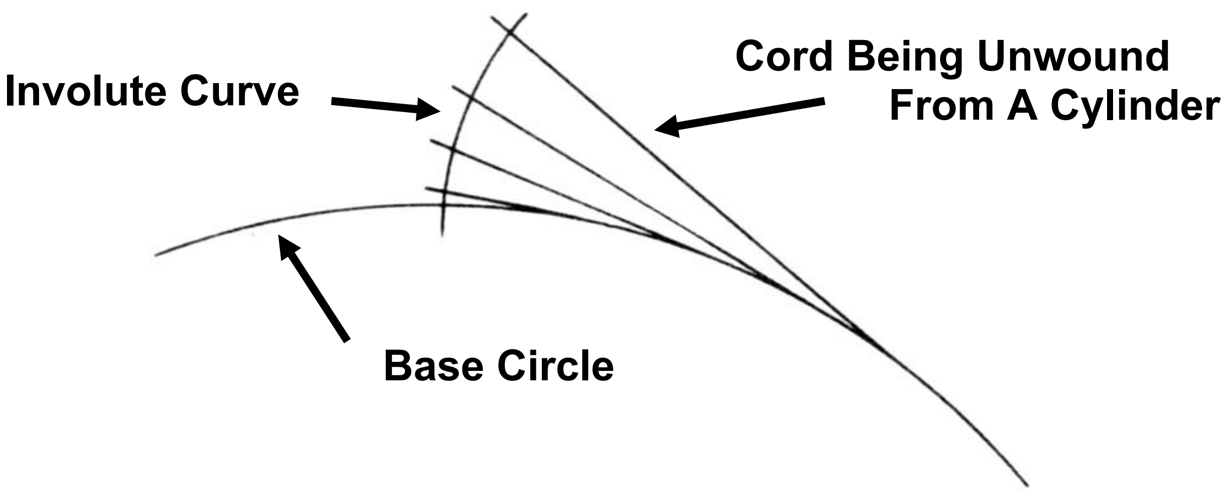
Gear drives are used to transmit power from one machine to another where changes in speed, torque, direction of rotation or shaft orientation are required. They may consist of one or more sets of gears depending on the requirements. In most cases the gears are mounted on shafts supported by an enclosed casing which also contains a lubricant.

Most gear drives in use are speed reducers. They reduce the speed of shaft rotation between driver and driven machines and, at the same time, produce a corresponding increase in torque. The recent increased use of high-speed machinery, such as centrifugal compressors, has also generated a need for speed increasers.

Principles of Operation

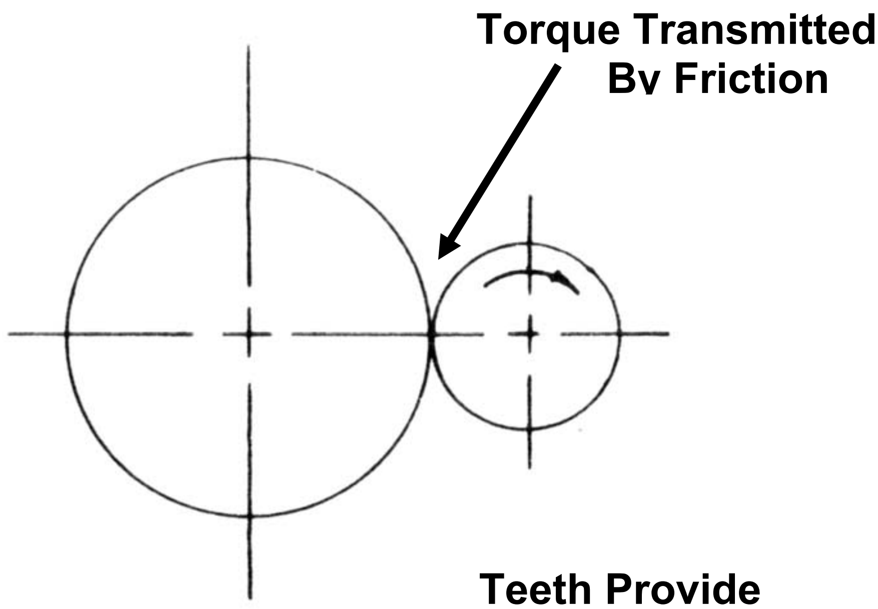
A gear is a form of wheel with teeth machined around the outer edge which allow it to engage with another similar wheel or rack.

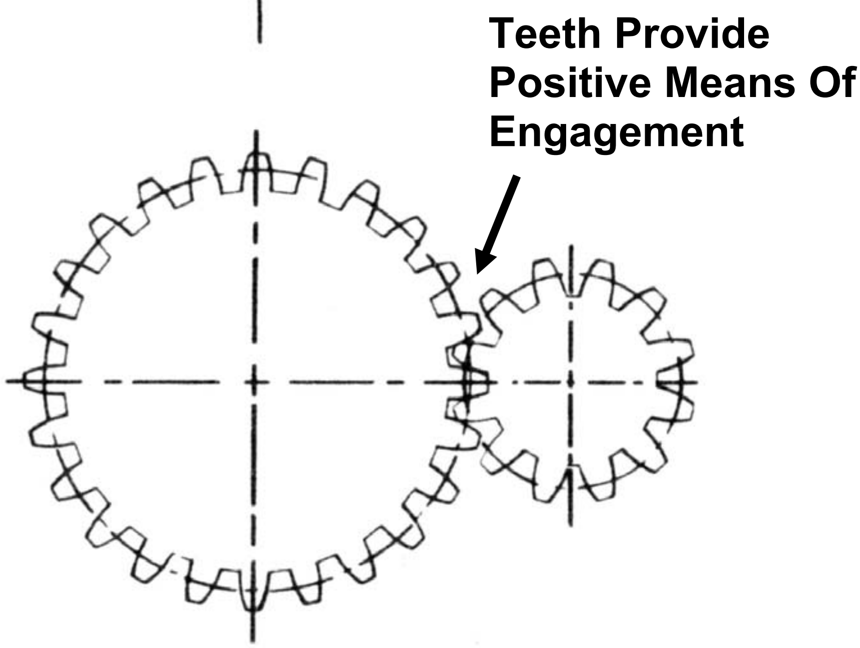
The most important features of a gear are the tooth profile or cross-sectional shape, and the number of teeth. In modern gears the tooth profile is based on an involute curve which is the shape produced when a line is traced by a point on a cord which is 'unwound' from a cylinder as shown



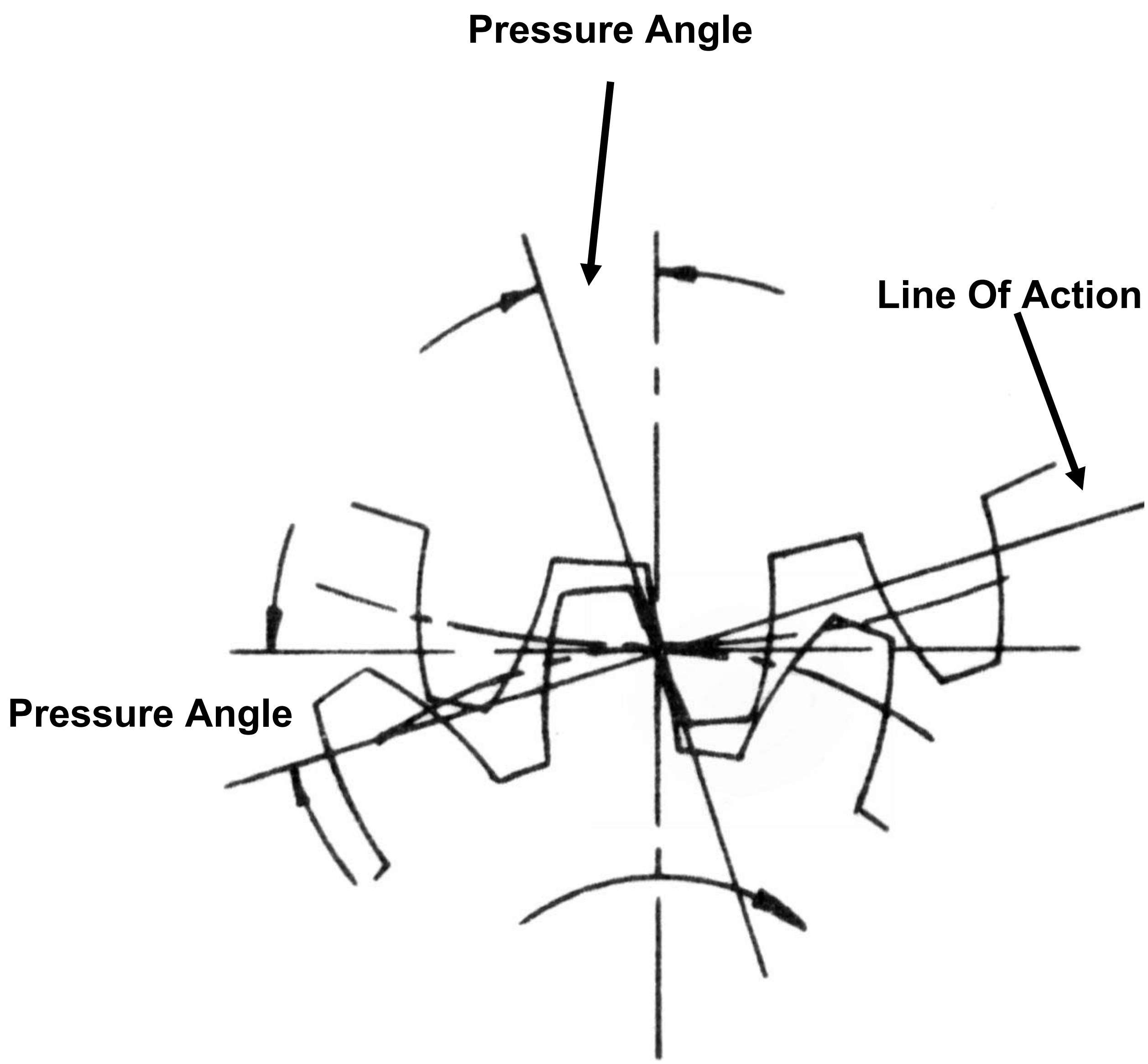
The advantage of the involute form is that when two gear teeth mesh together a constant velocity ratio is maintained with the minimum of sliding and the maximum of rolling action of one tooth against another. This feature helps to reduce wear and extend the life of the gear.

In order to understand the geometry of gears it is useful to imagine the simplest form of gears is two plain discs which touch tangentially. If sufficient friction exists between the surfaces in contact then there is no need for special teeth to be cut. However, there is limit to the torque that can be transmitted by friction and so teeth are cut into the outer edges of the discs to provide s of positive engagement as shown below:



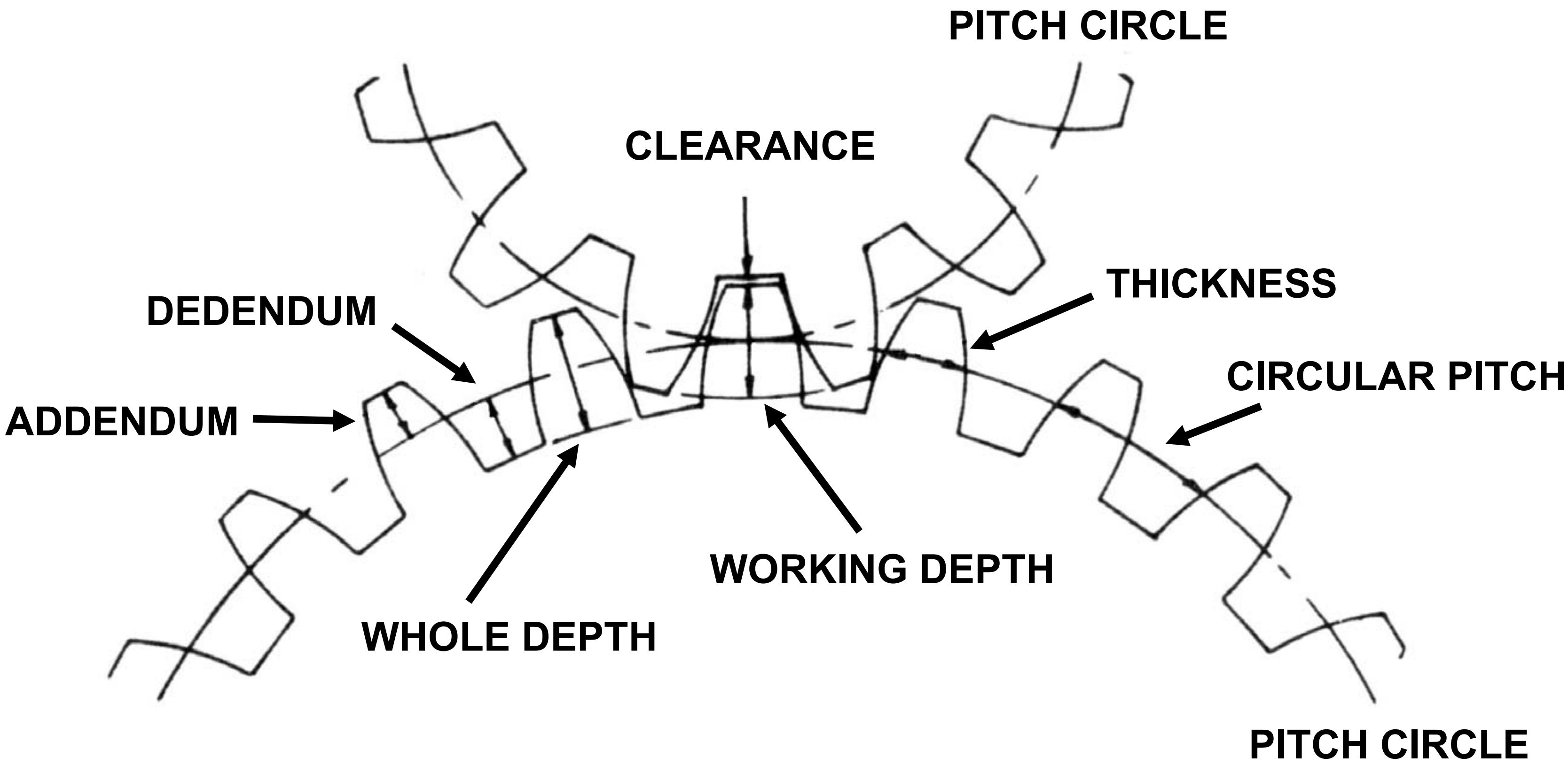


The imaginary circles on which the gears are cut are called the pitch circles, and the pitch circle diameter is the major dimension on which gear geometry is based. The other important dimension is the pressure angle. This is the angle between the tangent to the pitch circle and the line of contact of two mating teeth as shown below:

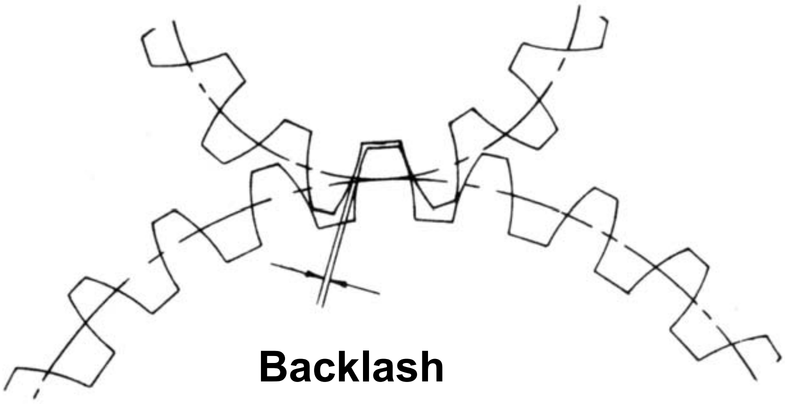


If two gears are to mesh properly they must have the same pressure angle. Standard pressure angles of 14.5^0 and 20^0 are used with 20^0 being the most common.

All explanation of the terms used to describe the geometry of a circular gear is shown below:



In practice, gears are cut to provide running clearance between mating teeth. This is known as backlash.



Backlash

The characteristics of mating gears are often described by the term, diametral pitch. This term refers to the ratio of the number of teeth to the pitch circle diameter of the gear and reflects the size and shape of the teeth. Hence two mating gears must also have the same diametral pitch as well as the same pressure angle.

There are several ways in which diametral pitch can be calculated.

$$\text{Diametral Pitch} = \frac{\text{number of teeth}}{\text{pitch circle diameter}}$$

$$\text{Diametral Pitch} = \frac{\pi(3.142)}{\text{circular pitch}}$$

$$\text{Diametral Pitch} = \frac{\text{number of teeth} + 2}{\text{outside diameter}}$$

The speed relationship between two mating gears depends on the number of teeth on each gear and can be determined as follows:

$$\text{speed of driven gear} = \text{speed of driver} \times \frac{\text{no. of teeth on driver}}{\text{no. of teeth on driven}}$$

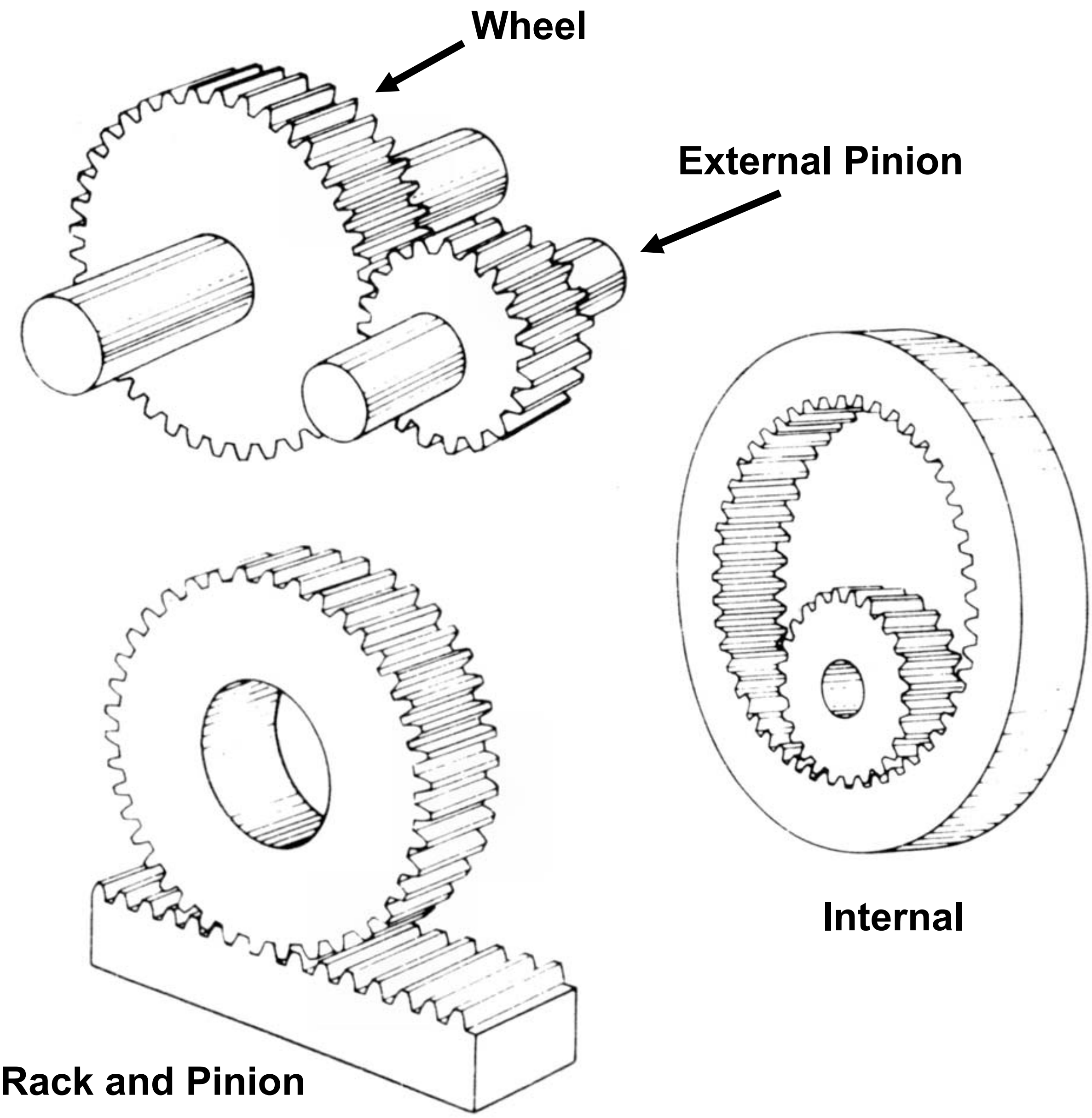
Exercise

Types and Arrangements

The following types of gears are in common use.

Spur Gears

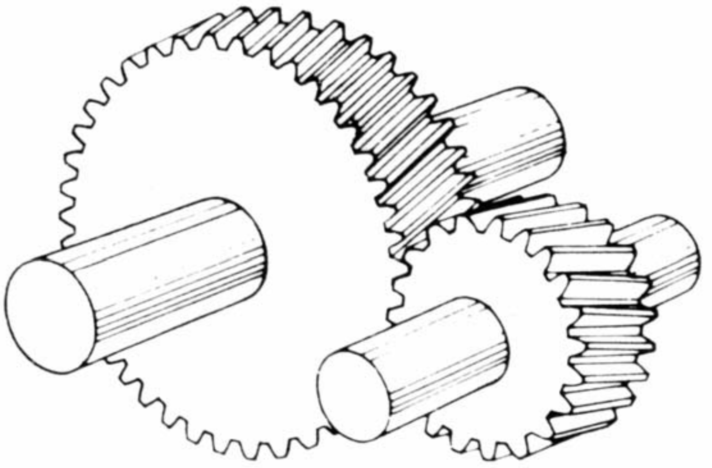
The spur gear is the simplest type of gear and has teeth cut parallel to the axis. Spur gears may be used as external or internal gears or as a rack and pinion as shown below:



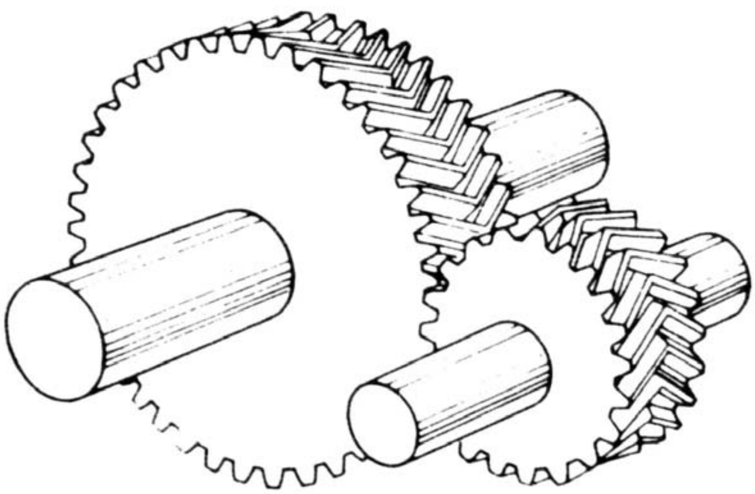
Spur gears are used to transmit power between parallel shafts operating at moderate speeds. They are simple to manufacture, do not develop end thrust and are the preferred type to be used where practicable. It is conventional to refer to the large gear as the wheel or bull gear and the smaller as the pinion.

Helical and Herringbone Gears

Helical gears are also used o transmit power between parallel shafts but have the teeth cut on an angle.

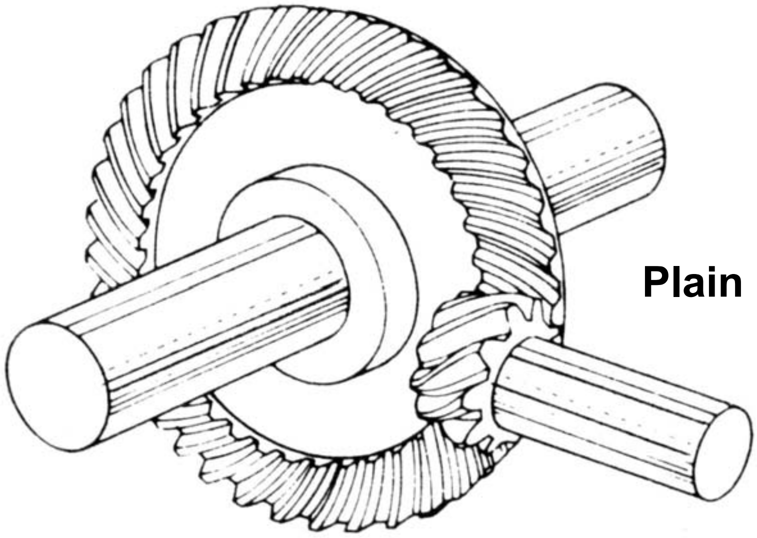


The advantage of this design is that several teeth are in mesh at the same time and this results in greater load carrying capacity and smoother operation. Because of the angle of the teeth, helical gears produce end thrust which must be carried by the shaft bearings. This can be overcome by the use of two rows of opposed helical teeth in a 'herringbone' arrangement as shown below. Herringbone gears are generally not recommended when externally applied end thrust is present or when operating speeds are very high because of the tendency for one helix to carry most of the load.

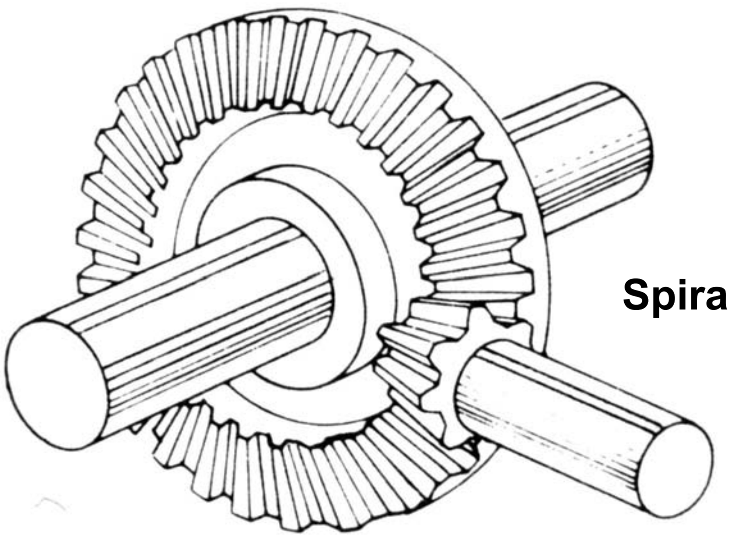


Bevel Gears

Bevel gears are used to transmit power between two intersecting shafts, normally at right angles. The teeth on bevel gears may be plain or spiral as shown below:



Plain Bevel

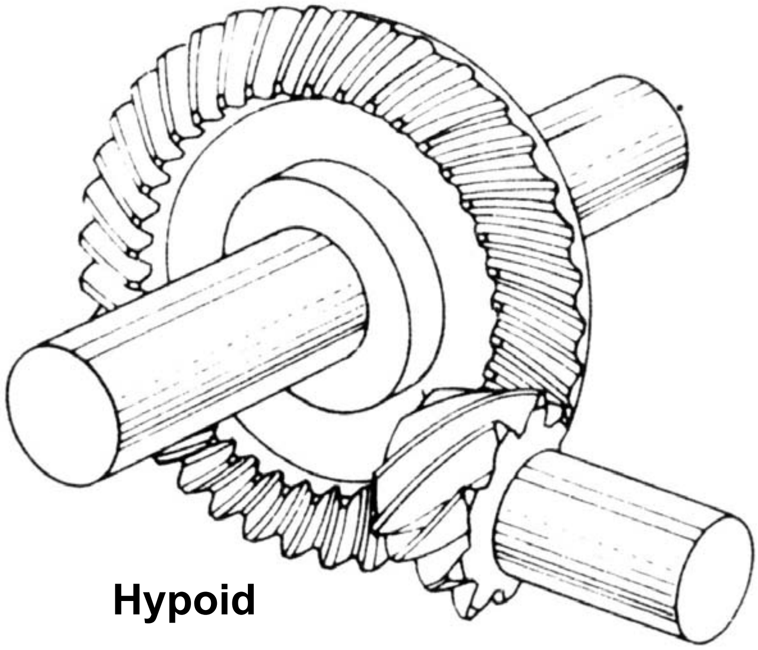


Spiral Bevel

Spiral bevel gears distribute the load over several teeth, in the same way that helical gears do for parallel shafts, and hence give smoother operation.

Hypoid Gears

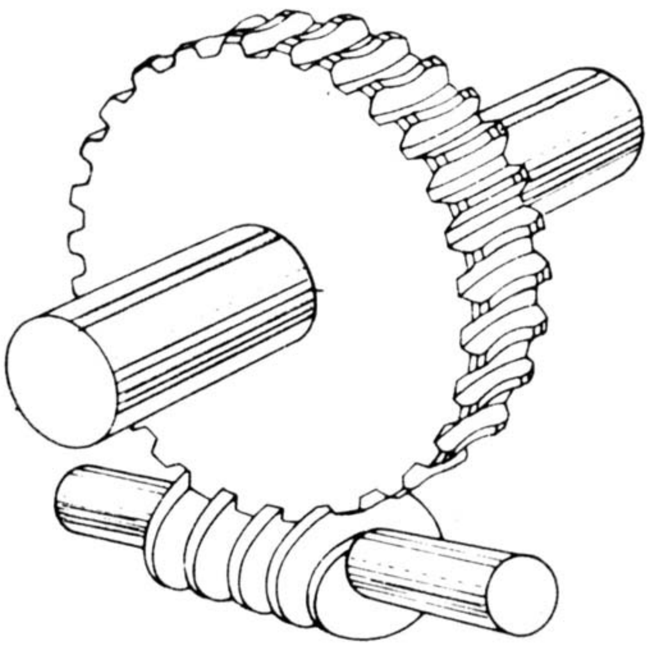
A variation of the spiral bevel gear is the hypoid gear which is designed to transmit power between two non-intersecting and non-parallel shafts.



Hypoid

Worm Gears

Worm gears are designed to transmit power between two non-intersecting shafts at right angles as shown below. They are used when high ratio speed reduction is required. The worm bay be cut with one or more threads and must be of the same hand as the wheel.

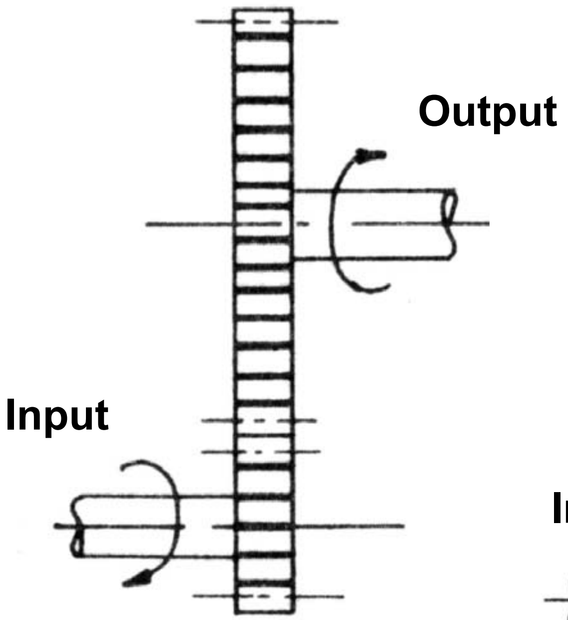


Worm

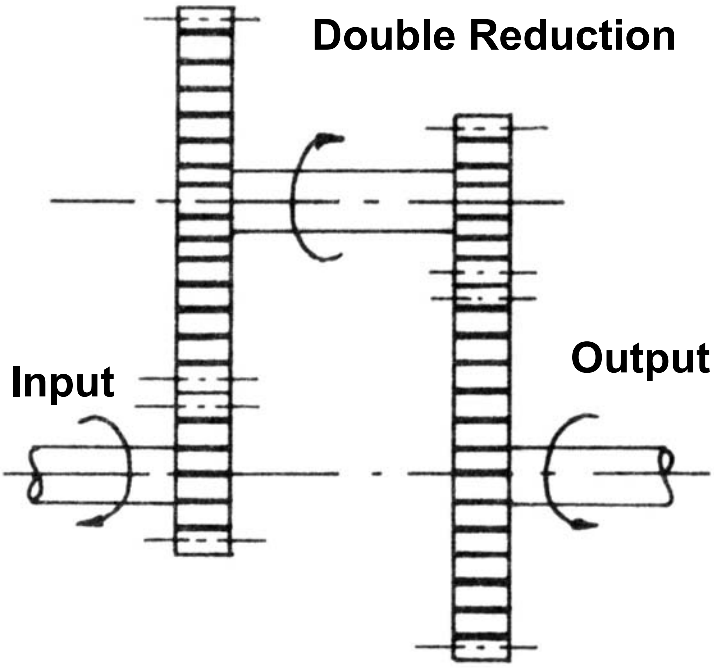
Whatever types of gear is employed, the arrangement may involve one or more pairs of gears depending on the degree of speed reduction required ***(see below).***

Most gear drives are mounted in fully enclosed casings but large ring gears may be installed as open gears with a suitable guard arrangement.

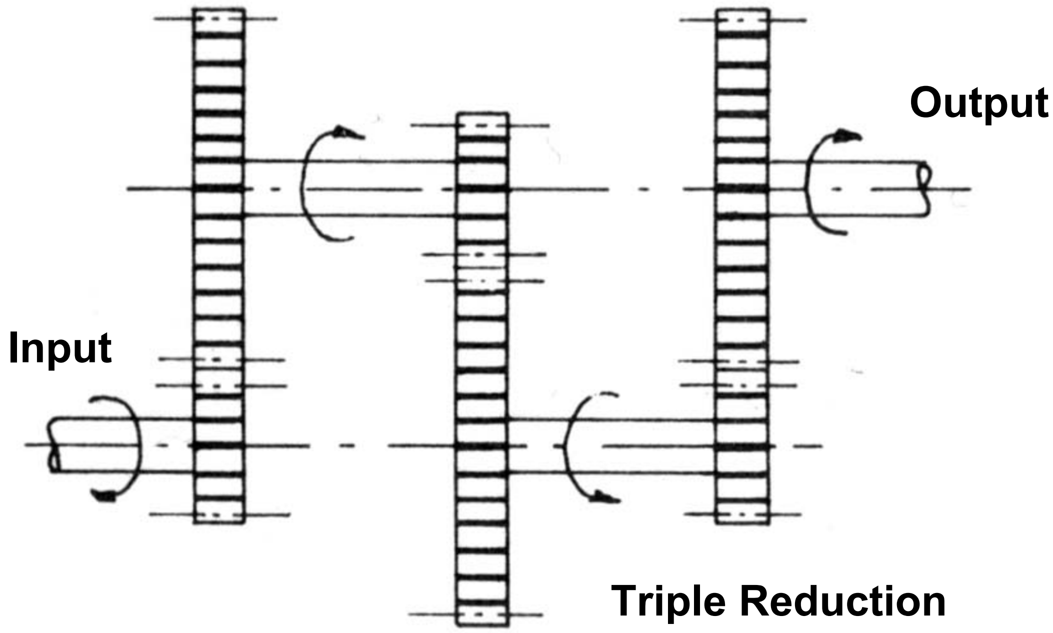
Gears are generally made from steel or cast iron and are surface hardened in order to increase the wear resistance.



Single Reduction



Double Reduction

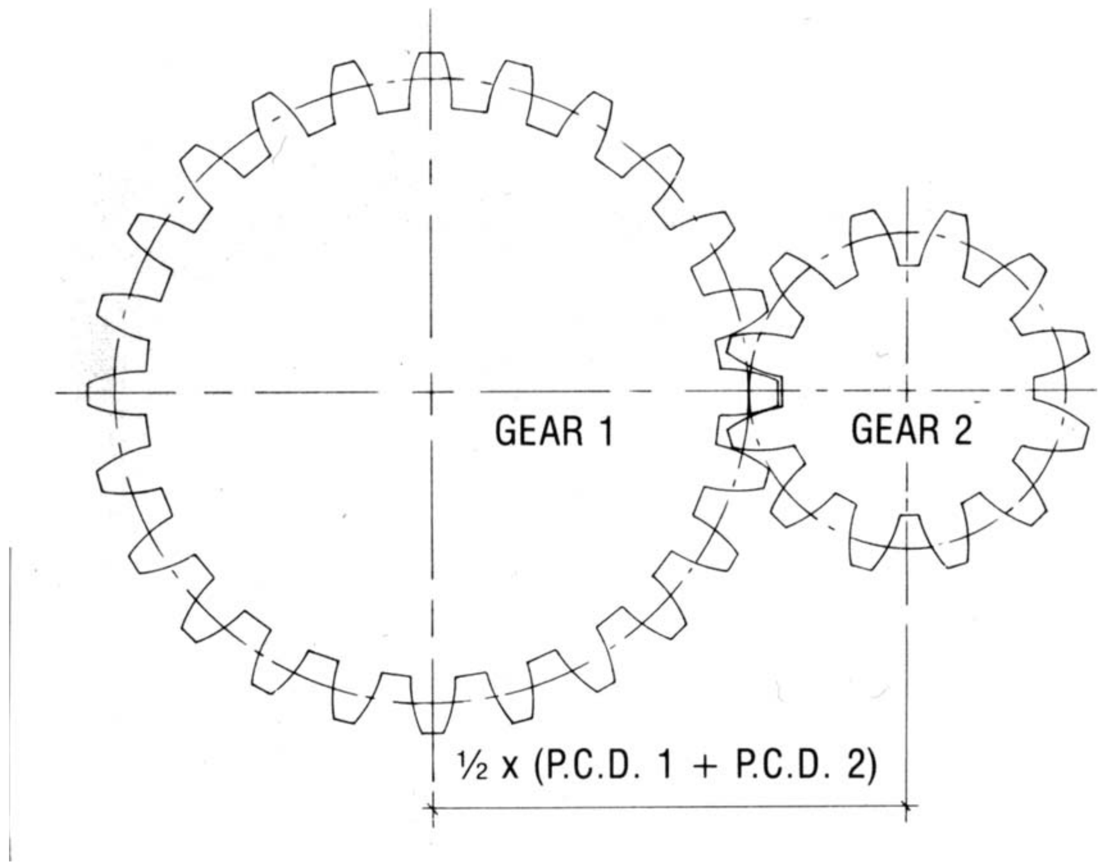


Triple Reduction

Alignment

In most gear drives the alignment is determined by the machining of the casing and the bearing housings and under normal conditions the gears should be automatically aligned. Care should be taken when mounting a gear box to ensure that not distortion of the casing occurs when the mounting bolts are pulled down. Excessive wear and run-out in the bearings will results in run-out and wear of gear teeth and should be rectified as soon as possible.

When gears are open, or installed in such a manner that adjustment of the relative positions is possible, either the centre distance between the gears or the backlash between the teeth can be measured. The centre distance between two gears in proper mesh should be equal to half the sum of the pitch circle diameters of the gears ***(see below).***



If it is more convenient to measure the backlash this can be done using feeler gauges. Care must be taken, whenever the relative position of gears is adjusted, to make sure that the shafts remain parallel so that the gears run true. Parallel alignment of gear tooth faces can be checked by applying marking blue on the pinion teeth and then turning the gear wheel over by hand. The contact pattern on the gear wheel teeth should be even across the face.

Lubrication

Most gear boxes contain a reservoir of lubricating oil in which the lower halves of the gears are submerged. As the gears turn they pick up lubricant which protects the teeth during contact. If maximum gear life is to be achieved the correct lubricant must be used and the correct operating level must be maintained in the sump or reservoir.

A gear box should be checked from time to time for leaks and these should be corrected as soon as possible.

The products of gear tooth wear will collect in the reservoir along with any other contaminants which enter the gear box casing. It is therefore necessary to change the lubricant at regular periods as recommended by the manufacturer. This is particularly important during the run-in phase of the machine when the rate of wear-debris production tends to be relatively high.

Gear boxes that are pressure lubricated are normally fitted with a filter and this must be changed or cleaned periodically.

Open gears are usually lubricated by a sump in which the bull gear runs. If the atmosphere is dusty then a large build-up may develop on the gears and it must be cleaned off from time to time.

Failure Patterns

Like all machine elements which involve relative motion between lubricated components there are a number of ways in which gear failures occur.

Operating Symptoms

The symptoms of gear malfunction found during operation are relatively few in number are easily detectable.

Noise

Even when gears are in good condition they produce a significant amount of noise. This is because of the continuous impact of the gear teeth as they mesh with each other and it will vary with speed and torque transmitted. Every gear combination and gear box has its own distinctive running sound when it is operating satisfactorily and familiarity with that sound will assist the maintenance technician in detecting deterioration in the running condition. Gears in good condition should produce a constant hum with a relatively smooth tone. Once the gears begin to deteriorate, or some malfunction in their operation develops, this noise will change. The sound may become much rougher which could indicate that the gears are not properly in mesh or that they are out of alignment. Misalignment may also cause a rhythmic or pulsating sound to develop. When the surface condition of the gear teeth begins to deteriorate, due either to wear or other factors, the sound of the gears tends to increase in pitch and develops into a whine.

Whatever the nature of the sound, whether it be a growl or a whine, the more it increases the more it is an indication of malfunction of the drive assembly. It is not possible to be precise about the nature of the sound that may emanate from a particular problem and the above description can only be considered as a general guide. Increase in noise level, however, can always be treated as positive evidence of a change in the condition of a gear drive.

Vibration

The nature of gears makes it inevitable that their operation is accompanied by a certain amount of vibration. As with noise levels, this will vary according to the type of gears and the speed and load transmitted. An increase in vibration levels will occur when condition deteriorates or a malfunction develops. The most likely causes of an increase in vibration level are shaft misalignment and teeth running out of mesh. This may occur because of faulty assembly or deterioration in the condition of the shaft support bearings. Wear and deterioration of the tooth surface condition, unless they become excessive, are less likely to cause an increase in vibration levels.

Overheating

Generally speaking, overheating of a gear drive is likely to be due to overload or inadequate lubrication and is more likely to occur with closed gear boxes than open gears. Serious misalignment or running out of mesh may also cause an eventual increase in running temperature. These conditions should be detected from the change in noise and vibration levels before this becomes significant.

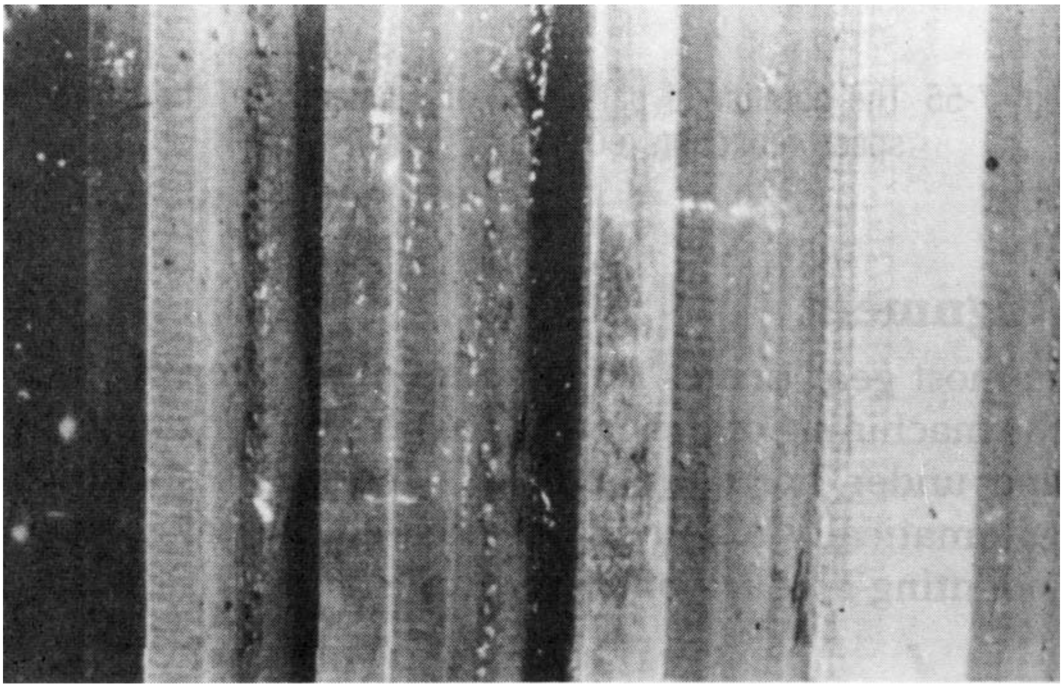
Symptoms Found on Inspection

Once the external evidence of gear drive malfunction becomes significant then the unit must be shut down and examined so that further evidence can be gathered and cause of failure determined.

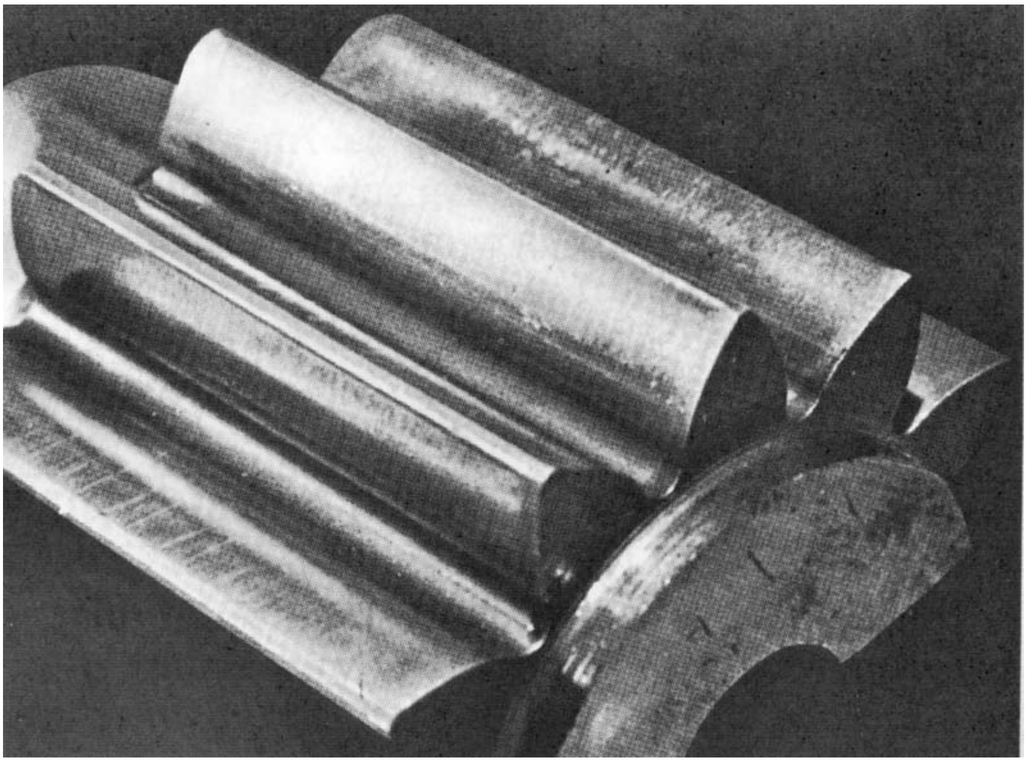
The following patterns of failure are those most commonly encountered:

Wear

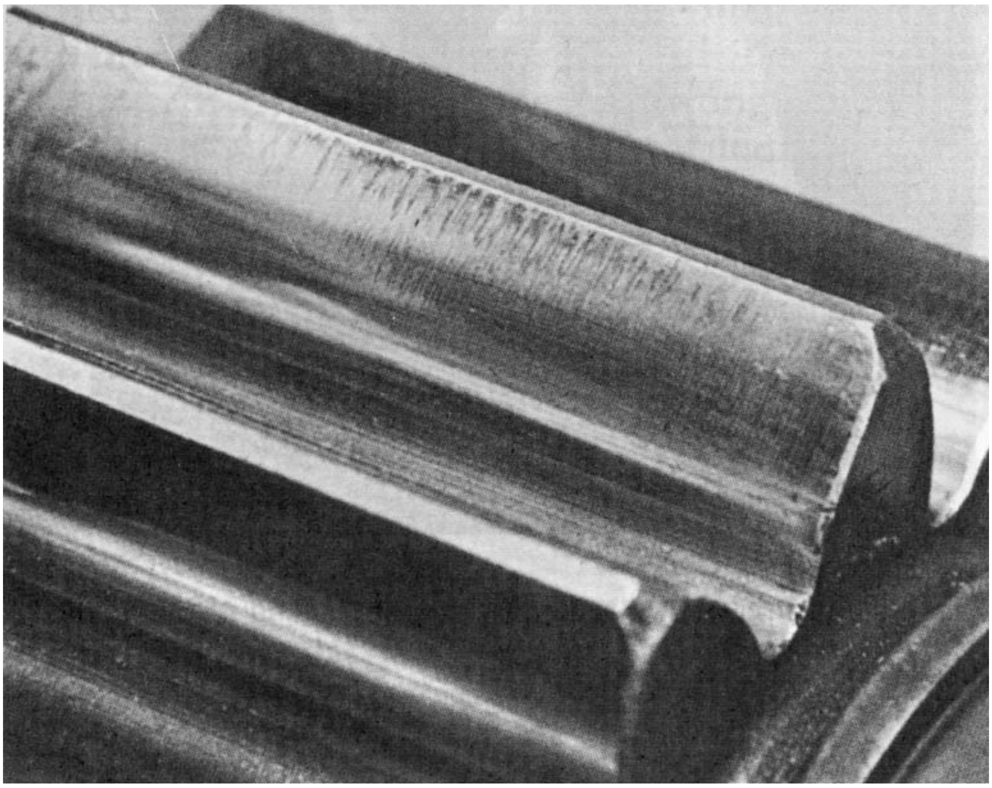
There are various ways in which gear tooth surfaces can wear. In the early stages of gear life, surface irregularities often cause pitting along the pitch line which later disappears when the gears wear in.



Normal wear occurs because of metal-to-metal contact between mating teeth and under light to moderate loads will appear as shown below:



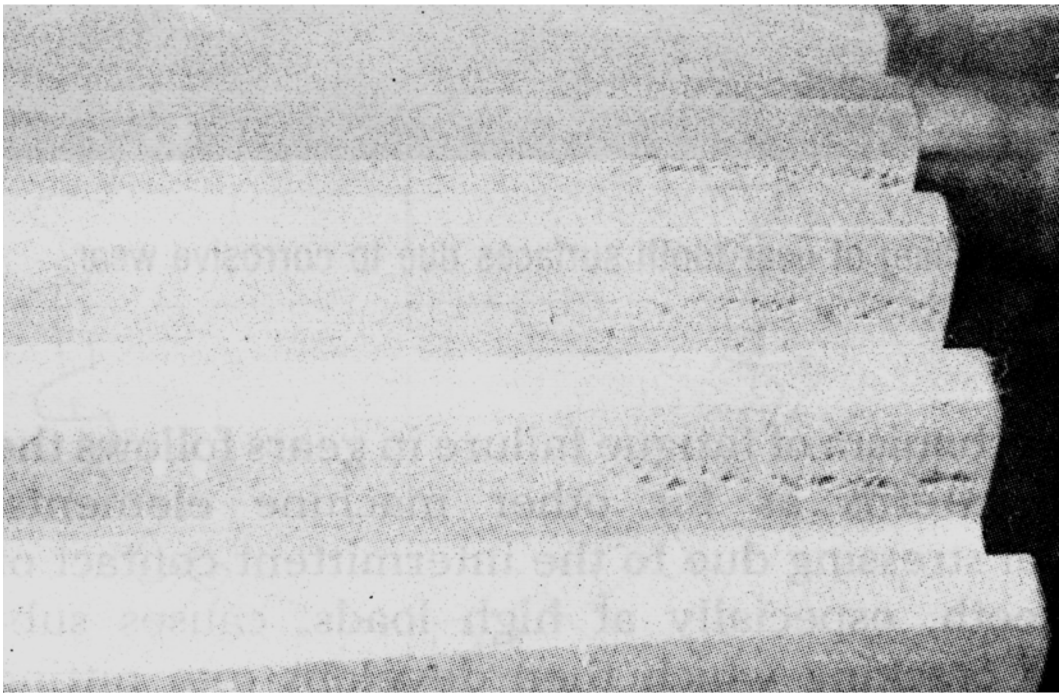
At higher loads and speeds the adhesion and welding of surfaces that takes place, due to the failure of the lubricant, becomes more extreme and the wear pattern that develops is known as scoring as shown below.



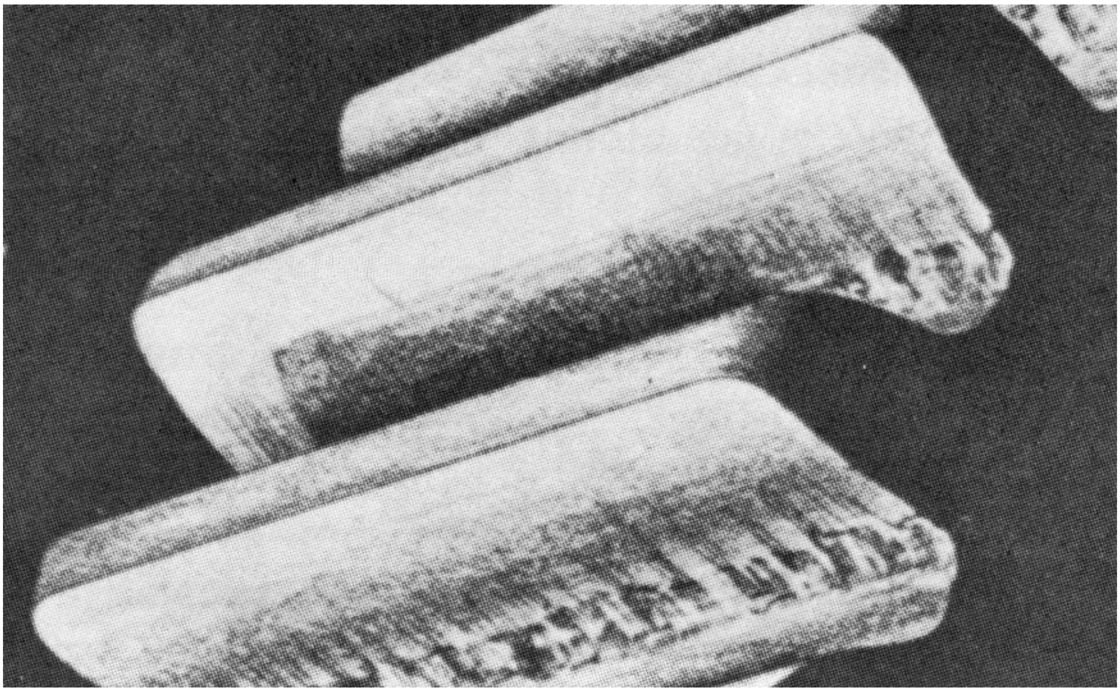
The most extreme form of this failure mode is known as galling.

When foreign particles such as dirt and grit are present abrasive wear patterns, similar in appearance to scoring, may develop.

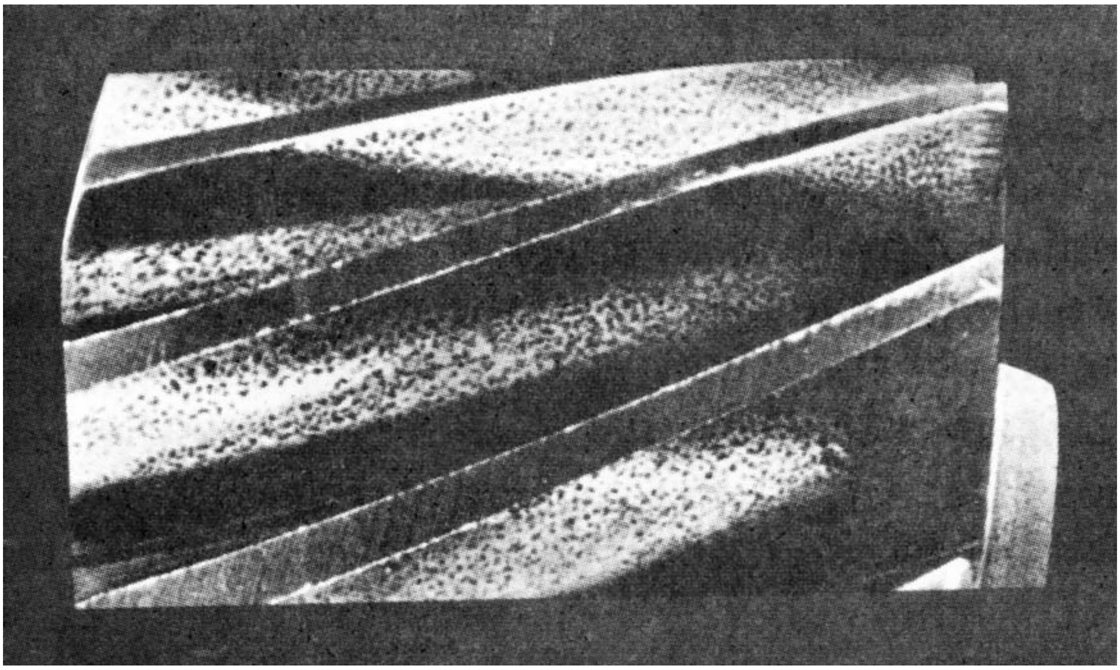
The wear patterns that develop due to misalignment and running out of mesh will have quite specific characteristics regardless of the nature of the type of wear. Misalignment will cause an uneven wear pattern to occur across the tooth face as shown below.



Running out of mesh will cause either undercutting of tooth faces due to interference ***(see below)*** or a shift in the location of the wear pattern towards the tips of the teeth.

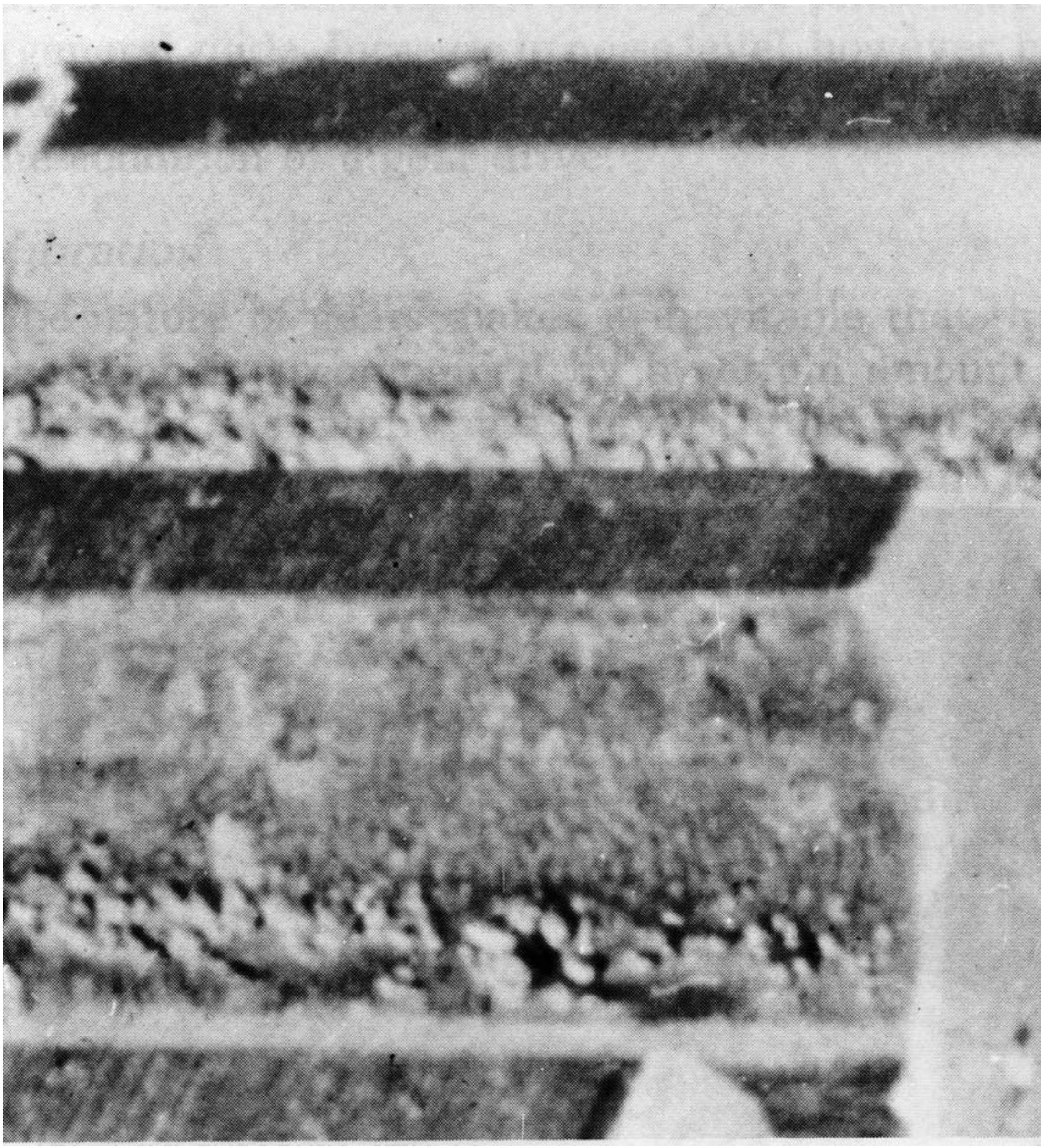


It is also possible for corrosive wear to occur due to chemical attack from either contaminated lubricant or an additive. This will be evident by etching, not only of gear tooth surfaces, as shown below, but also of other gear surfaces.



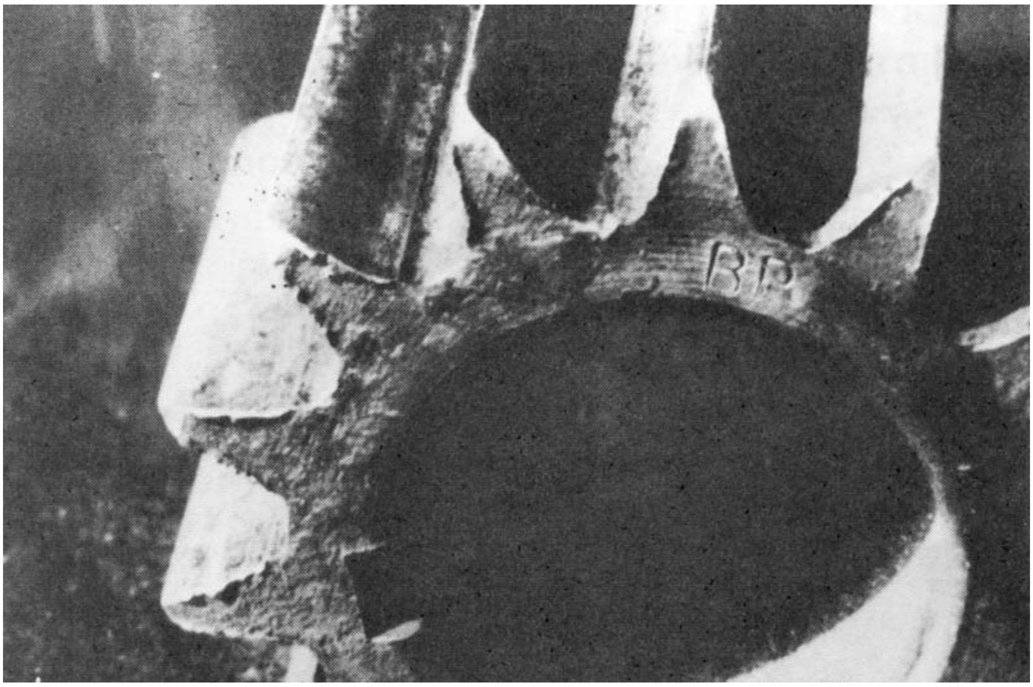
Fatigue

The mechanism of fatigue failure in gears follows the same patterns as for other machine elements. Cyclical stressing due to the intermittent contact of gear teeth, especially at high loads, causes subsurface cracking which then develops into pitting and spalling as shown below.



Plastic Flow

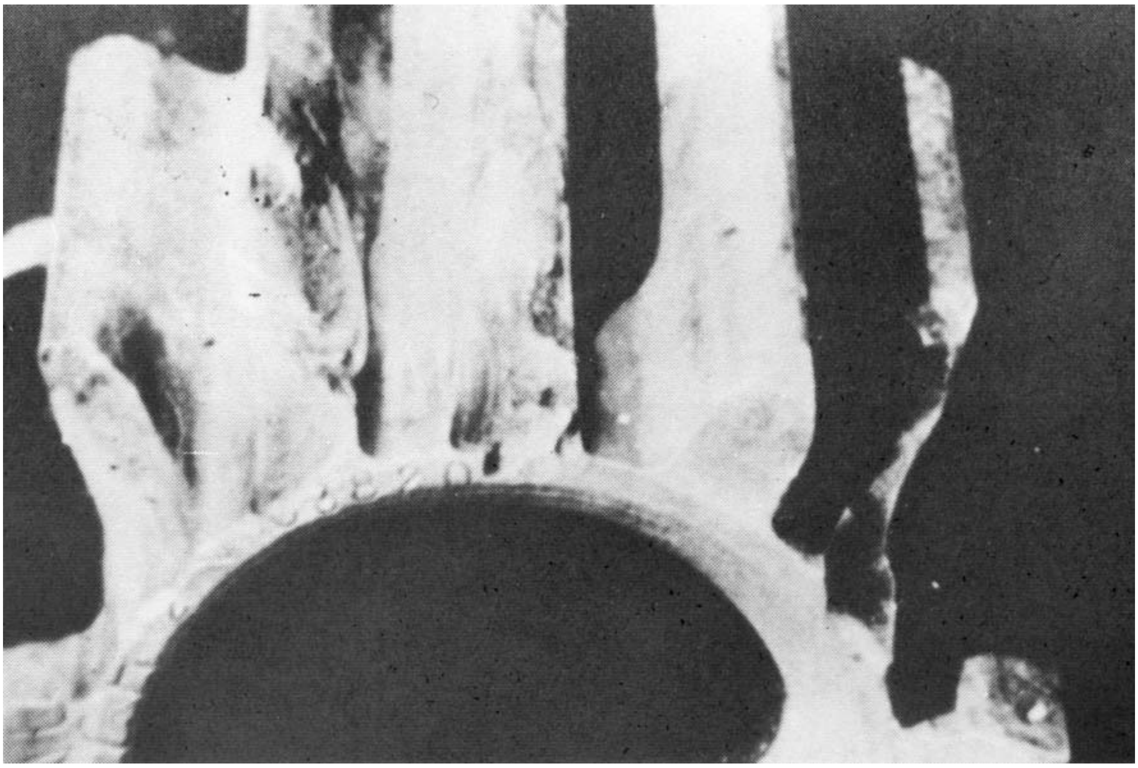
Deformation of gear tooth surfaces due to the effect of heavy loading is referred to as plastic flow or cold flow. This is more likely to occur with case-hardened gears. The surface metal of the gear teeth flows under load and the effect is often described as rippling, ridging, rolling or peening.



Tooth Breakage

If regular inspection is carried out then complete or partial breakage of gear teeth should rarely occur. When it does happen there will usually have been some weakening of the teeth due to a condition that has been present for some time. Once the gear breaks it usually becomes inoperable. The two principle causes are fatigue and heavy impact loads. Fatigue failure is often associated with the presence of a stress raiser such as a quenching crack or some surface defect such as a notch or a tool mark.

Tooth Breakage



Causes

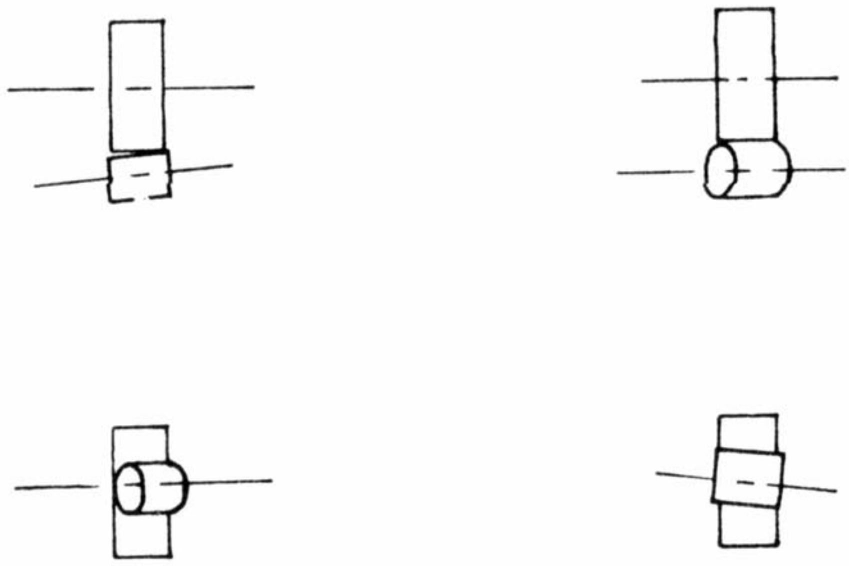
Inadequate Lubricant

The operation of gears is vitally dependent on an adequate supply of the correct lubricant and if this is available gears should give almost unlimited life. If the wrong lubricant is used or if lubricant is allowed to deteriorate then the gears will begin to wear. It is also important that lubricant replacement is carried out according to the manufacturer's recommendations. Additives should be carefully selected to suit the particular operating conditions and lubricant supply systems, including filters, should be properly maintained.

Misalignment

There are two different ways in which gears may be misaligned. They may be

out of parallel or ***out of plane.***



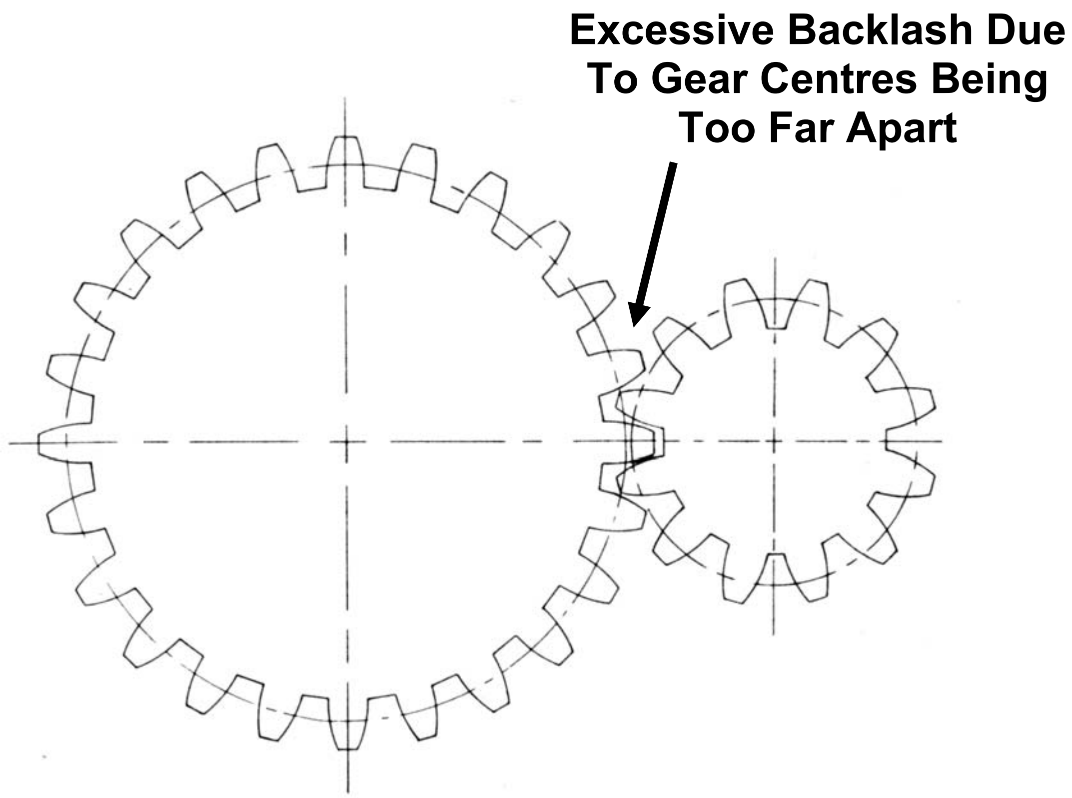
Out Of Parallel **Out Of Plane**

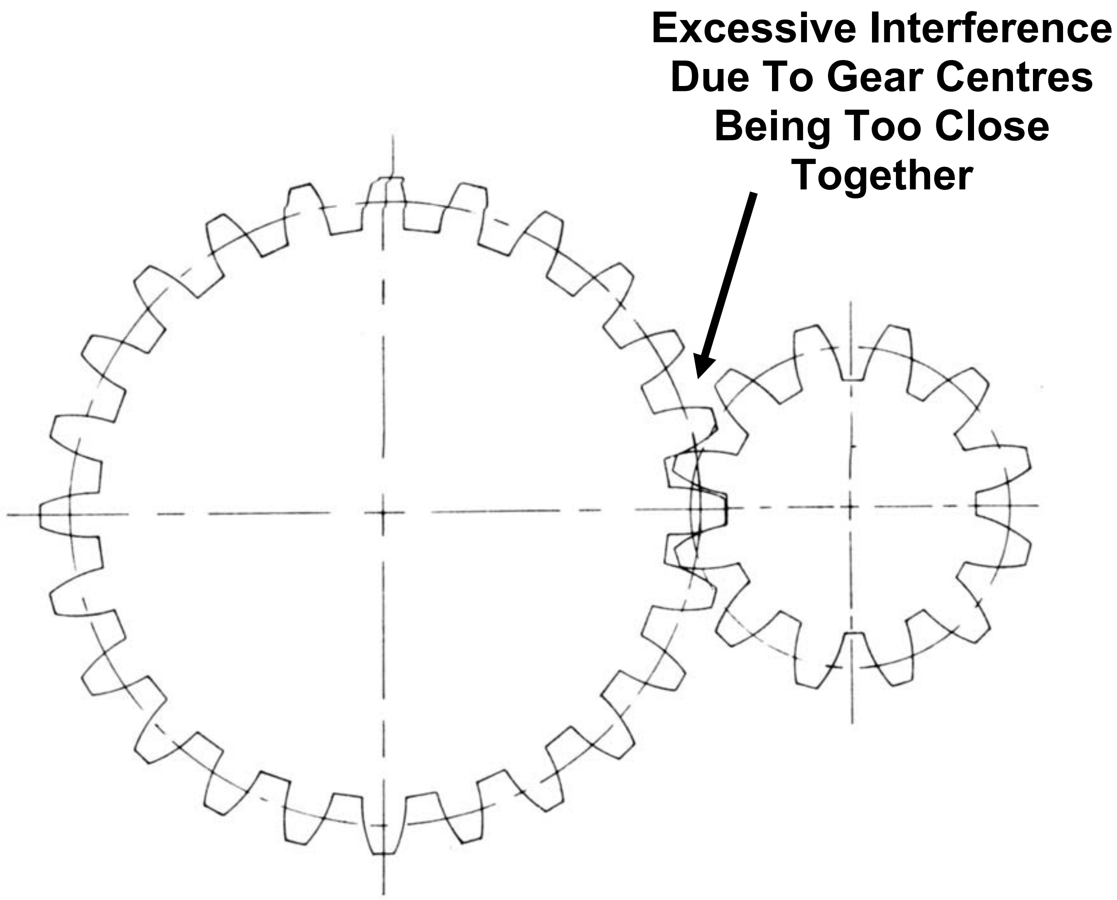
The uneven wear patterns referred to previously are produced by misalignment and if the condition is allowed to continue then tooth breakage may eventually occur.

Out of Mesh

If the gears are set up so that the pitch circles are not touching each other then they can be considered to be out of mesh.

If the centre distance between the gears is too small and there is insufficient backlash then interference occurs and the tip of one tooth tends to dig into the root of the mating tooth and produce excessive wear. This will cause rapid deterioration of the gear condition and may result in excessive noise and vibration. If the gears are set too far apart the backlash will be excessive and wear will occur close to the tips of the teeth which may even break from the impact. Noise and vibration will also increase due to the large amount of backlash.


Excessive Backlash Due
To Gear Centres Being
Too Far Apart


Excessive Interference
Due To Gear Centres
Being Too Close
Together

Overload

Speeds and loads which exceed design limits and high impact loads will accelerate wear processes and lead to the likelihood of premature failure. Heavy spalling or galling and tooth breakages are the usual consequences of overload conditions. The design limits of the drive should be checked and the unit operated to the manufacturer's instructions.

Contamination

The contamination of gear lubricant due to the presence of dirt, dust or other abrasives will increase wear rates and cause scratching of tooth surfaces. Particles of wear metal or chips of broken teeth will also cause significant damage. Careful attention should be paid to the condition of seals and filters and the regular replacement of lubricant if contamination is to be avoided.

Moisture

The presence of moisture in a gear box may cause rusting to develop. In order to avoid moisture due to condensation build-up, special breather arrangements may be required whereas ingress of moisture from other sources should be prevented by the oil seals.

Lubricant Breakdown

If lubricants are not replaced regularly they may deteriorate to the point where harmful acids may form. If corrosion is detected then lubricant analysis may be required to establish whether any change in properties of the lubricant has occurred. The effect of lubricant additives on particular metals should also be considered and the lubricant manufacturer consulted for advice.

Gear Systems

Before starting to work on any drive, the drive must be completely isolated from its power supply. If necessary, the 'permit to work' procedure must be followed.

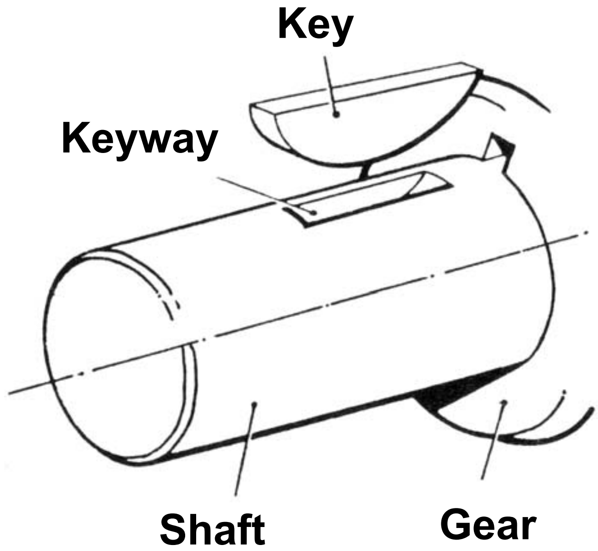
Installing and Adjusting Gears

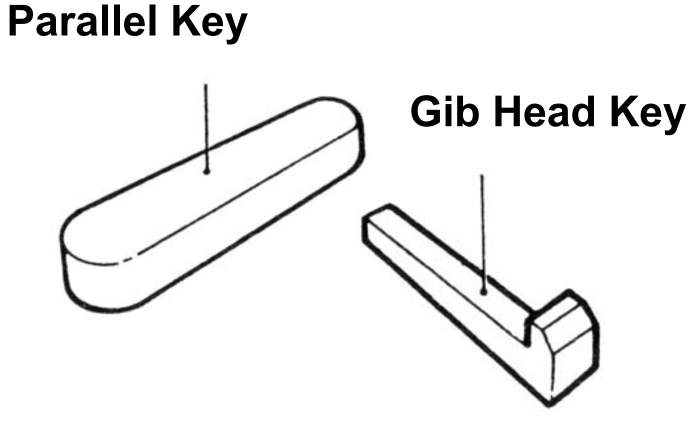
Gears must be installed with:

- the correct backlash.
- the maximum contact between the teeth across their width.
- the correct depth of engagement.

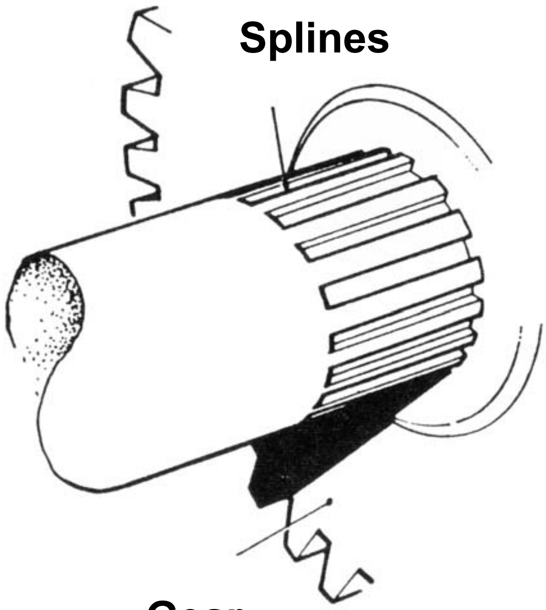
Methods of Securing Gears

A variety of keys are used, depending on the application.

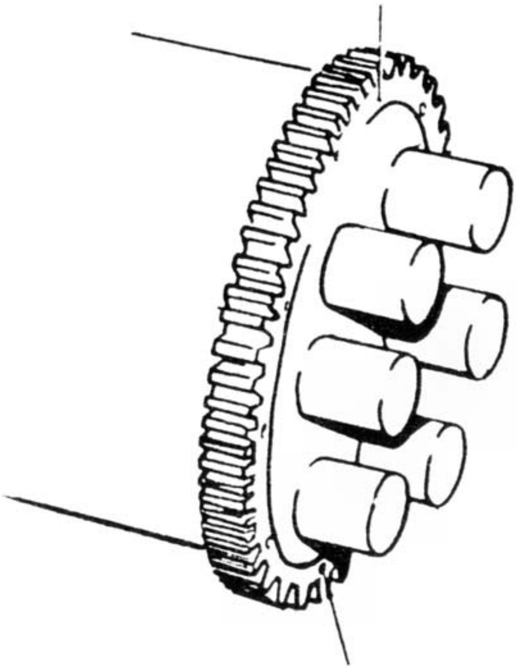




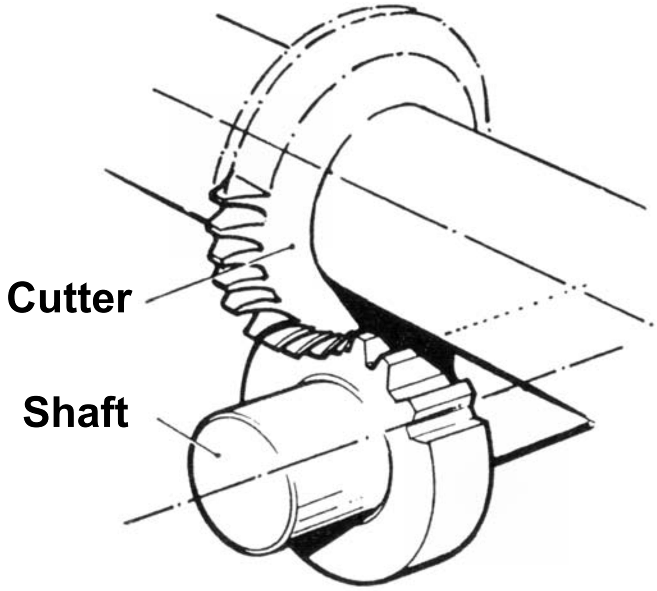
Splines are used normally for gears that have to transmit greater power than gears secured by keys.



Set screws and dowels are used to secure large gear rings.

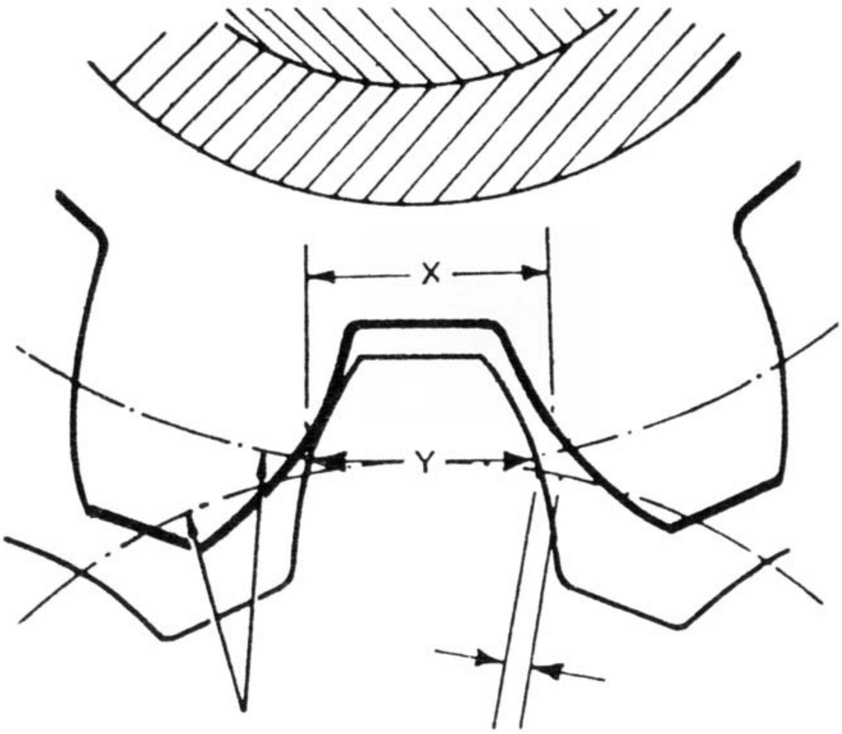


Small gears are sometimes cut directly into the shaft.



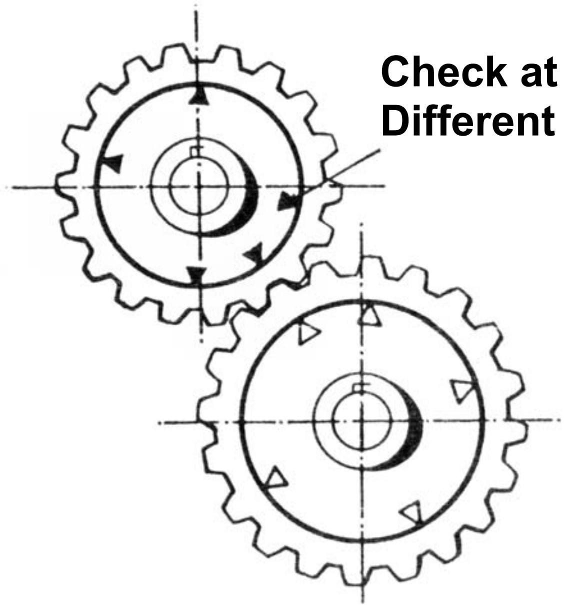
Checking Backlash

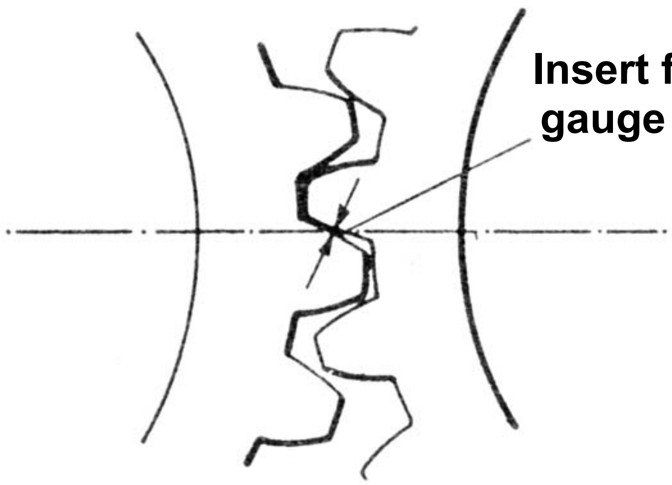
Backlash is the amount by which the width of a tooth space **(x)** exceeds the thickness of the engaging tooth **(y)** on the pitch circles.



A large backlash is used when the gears are required to be free-running and slow wearing, eg, the gears in a drill. A small backlash is used when the gears are required to transmit movement accurately, eg, the gears connecting an indexing device. The backlash is affected by the gears haft centre distance. If this distance is adjustable, the backlash can be adjusted.

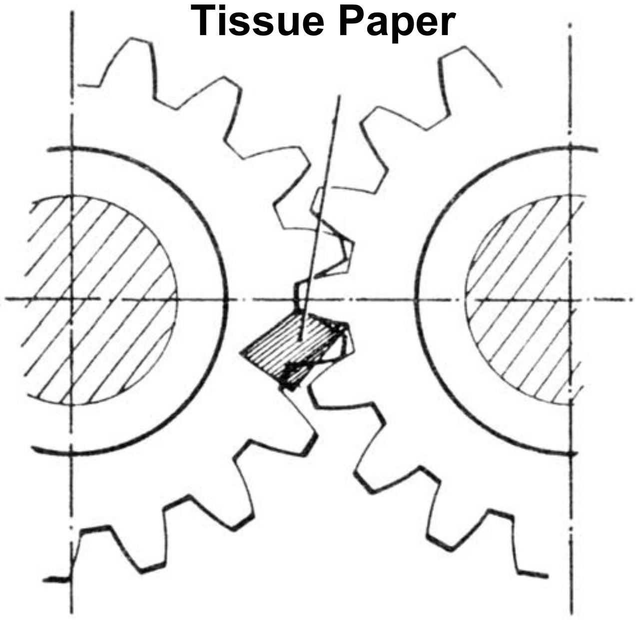
Backlash should always be measured by meshing the gears at several points and taking the average reading.



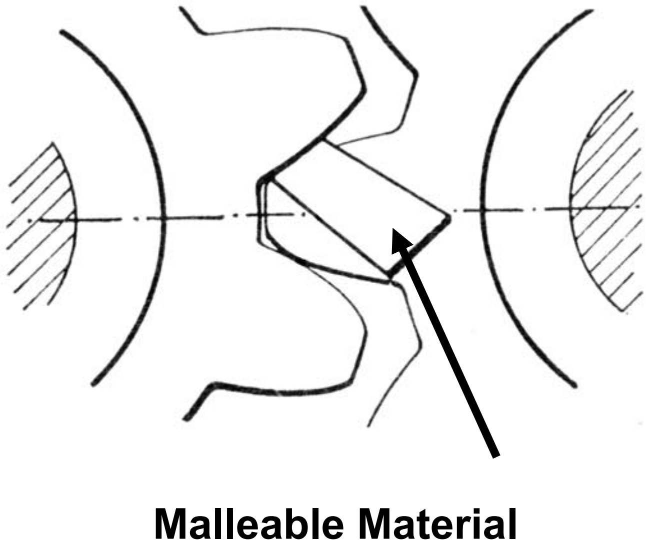


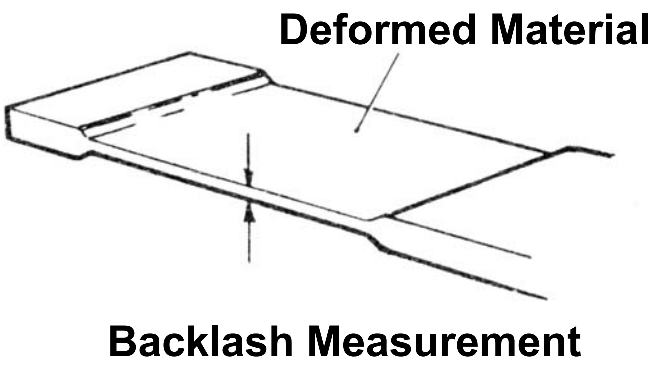
On large gears the backlash can be measured by fitting feelers between the meshing gear teeth when they are on the centre line.

Thin sheet materials can be used as gauges instead of feeler gauges. Hold the material against the back face of one gear tooth and rotate the gears to pass the material through mesh. If the material is not damaged, the backlash is greater than the thickness of the material.



To measure the backlash accurately a sheet or wire of malleable material, softer than the gears, may be used, eg, lead or soft solder may be used for steel gears. Hold the material against the back face of one gear tooth and rotate the gears to pass the material through the mesh.

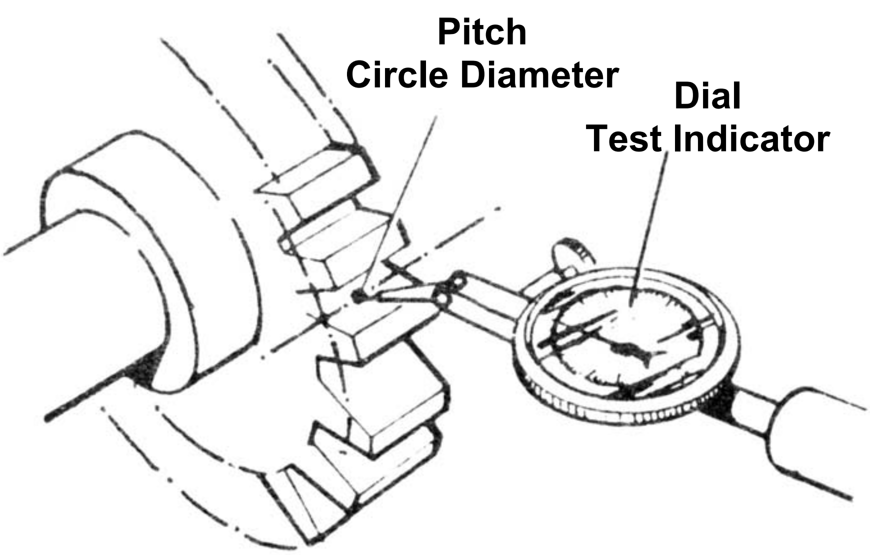




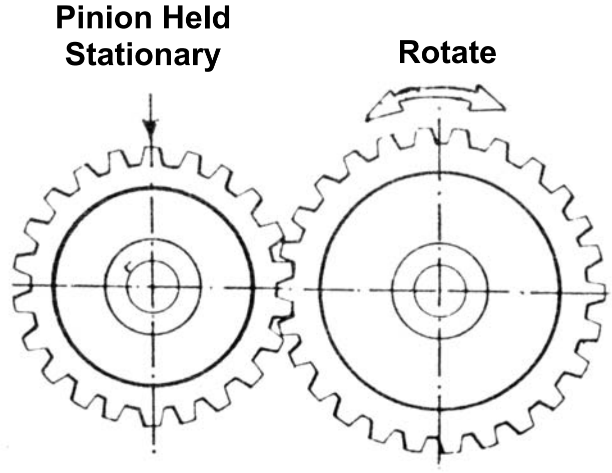
The material will be deformed. Measure the thickness of the material to find the backlash.

To Rock the Gears

- set up a dial test indicator to measure along a tangent to the gear wheel at the pitch circle diameter.



- Hold the pinion stationary and rotate the gear as far as possible in both directions.

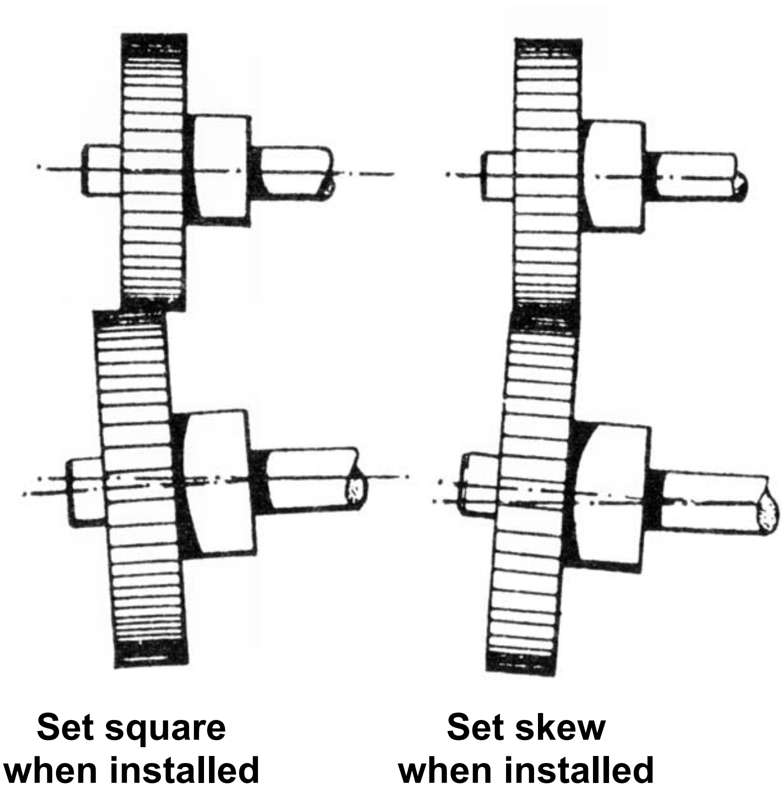


- The backlash is the difference between the maximum and minimum readings of the dial test indicator.

The backlash can be estimated by holding the pinion stationary and feeling how far the gear can be rotated.

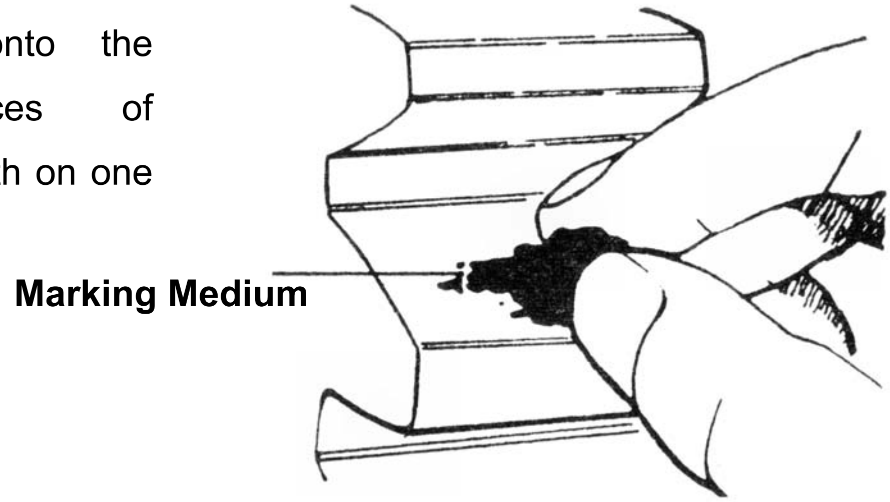
Checking Contact Between Gears

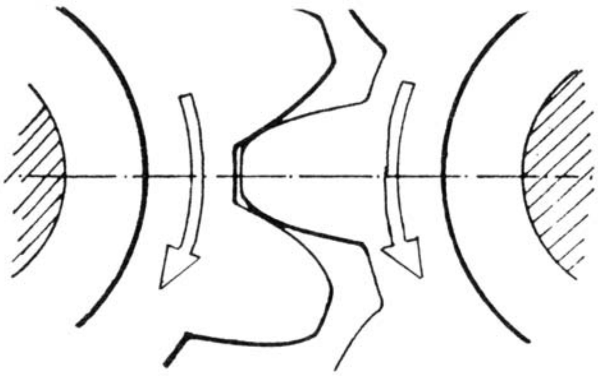
Gears must be installed so that the load is taken across the full width of the teeth. If the gear shafts are designed to deflect under load, it may be necessary to allow for this deflection by installing the gears off centre.



When Using a Marking Medium

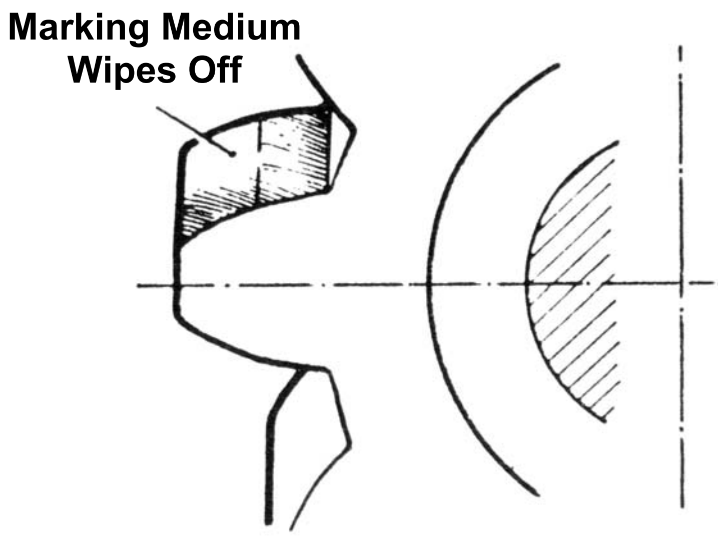
- smear marking medium onto the driving faces of several teeth on one gear.



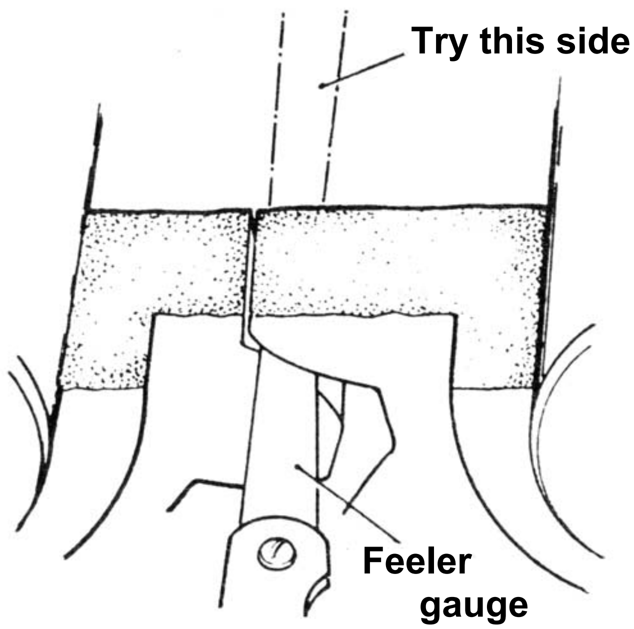


- Slowly rotate the gear so that the marked teeth mesh.

- Examine the marking medium. If the teeth are not in contact for their full width the marking medium will have been wiped off one side of the tooth more than the other.



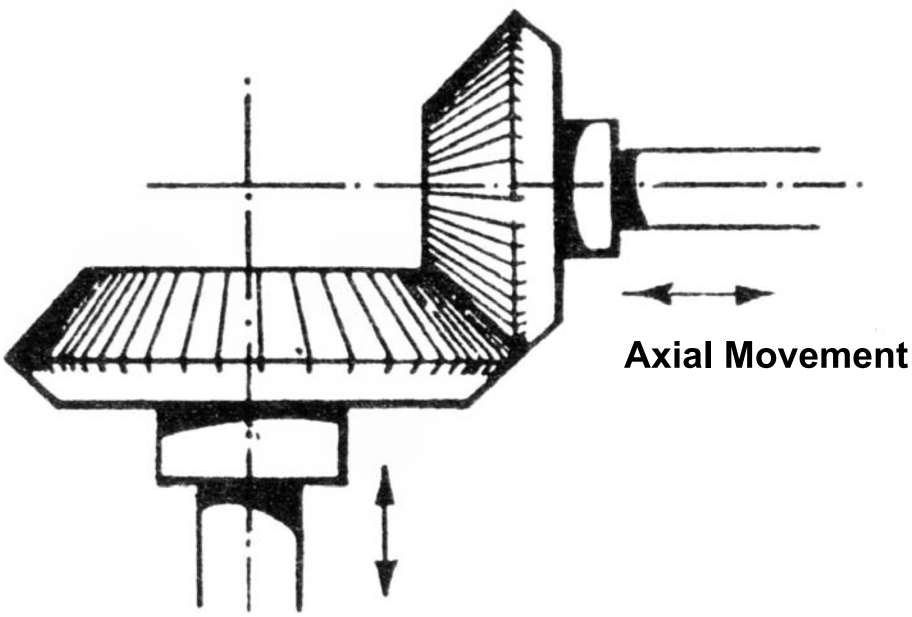
Feeler gauges can only be used when the backlash is large.



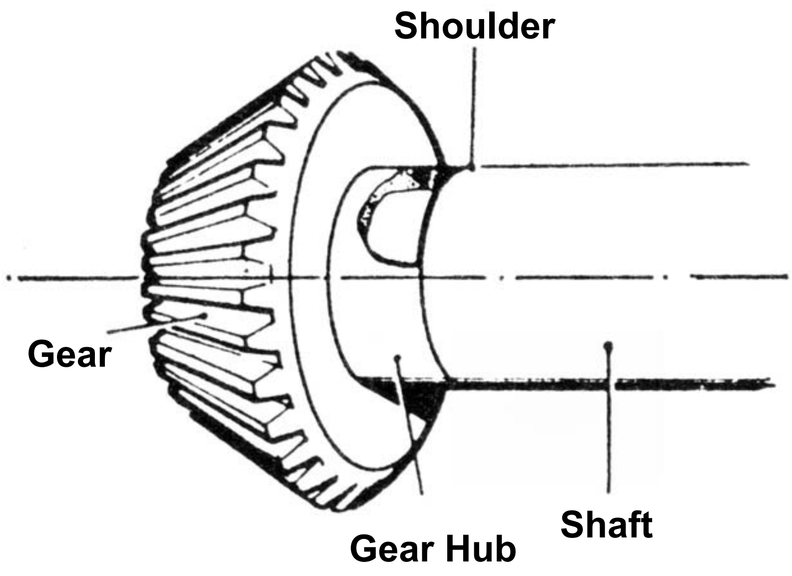
Compare the clearance each side behind a pair of meshing teeth. The clearance is equal if the gears are mating correctly.

Fitting Bevel Gears

The backlash in, and mating of, bevel gears is varied by axial movement of the shafts.

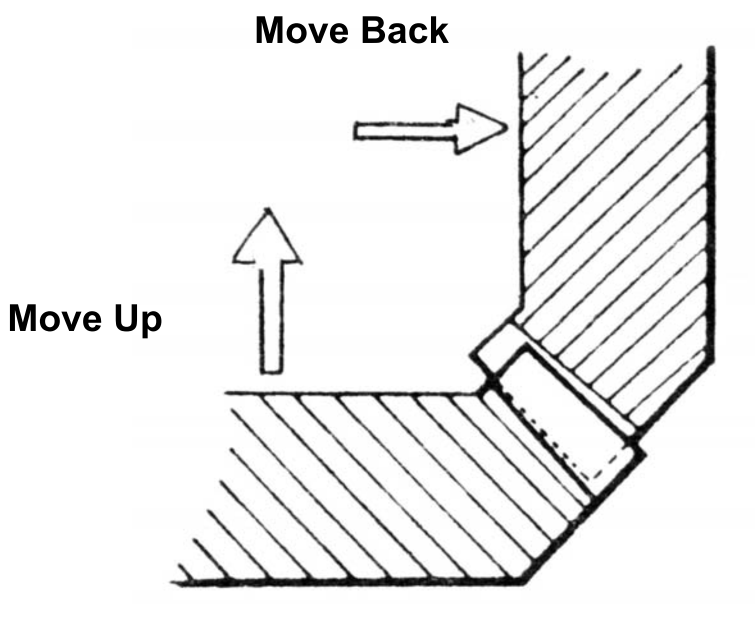


When fitting the gears to their shafts, make sure that the hubs are hard against the shoulders of the shaft.

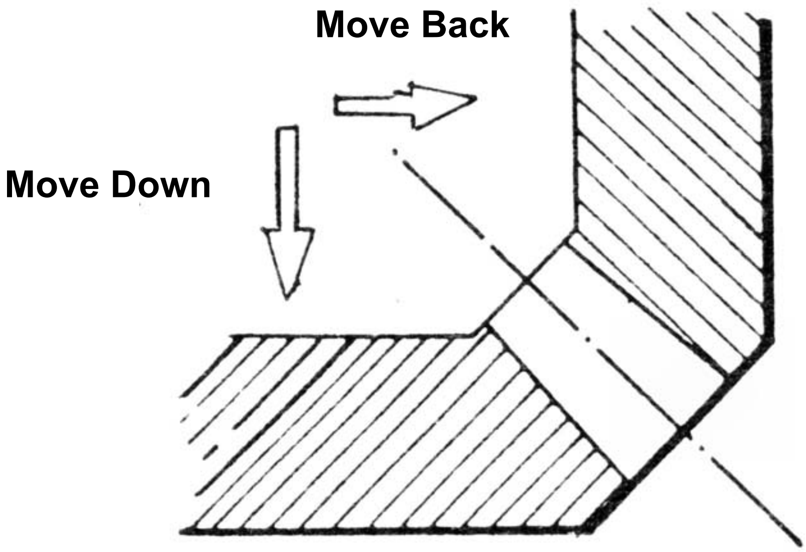


When fitting the shafts into the gear case, make sure that:

- the gears are mating full across the teeth: if necessary adjust the position of the gear wheels.



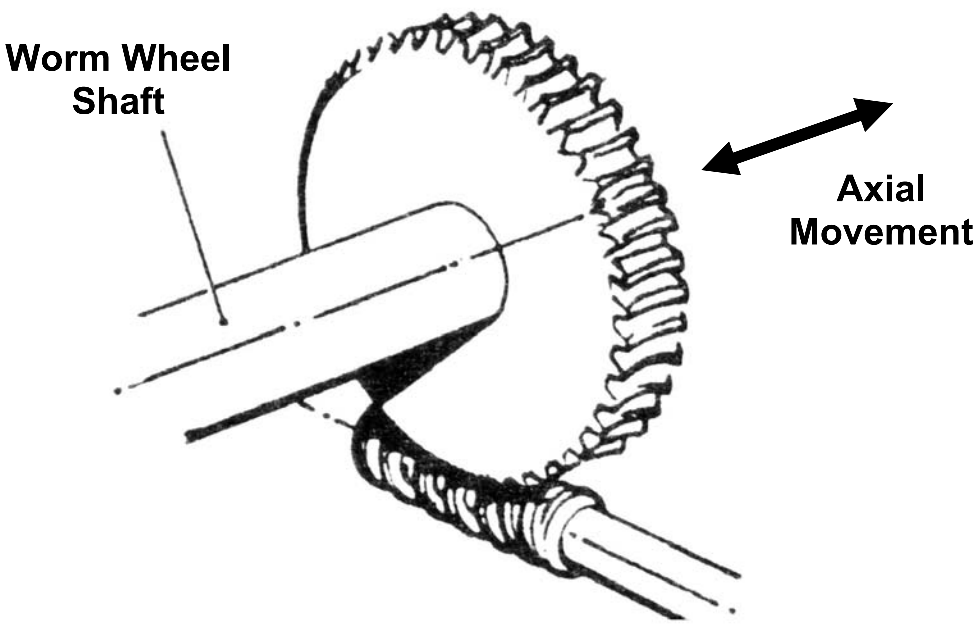
- The gears have the required backlash; if necessary adjust the positions of both gears equally.



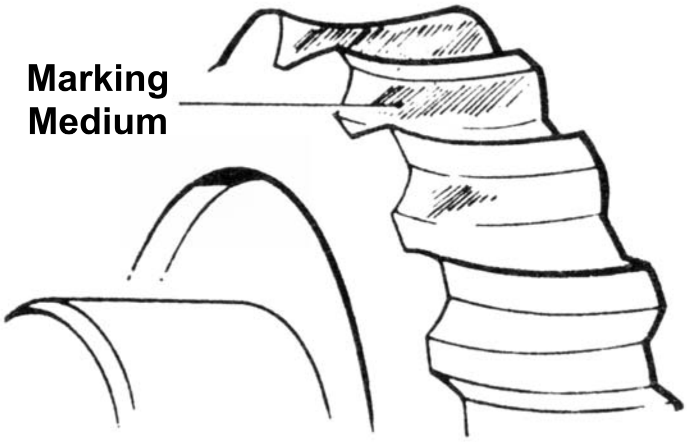
Adjustments can be made by shimming behind the gears or machining down the shoulders on the gears.

Fitting Worm Gears

The contact between the teeth must be central on the worm wheel. This can be varied by axial movement of the worm wheel shaft.

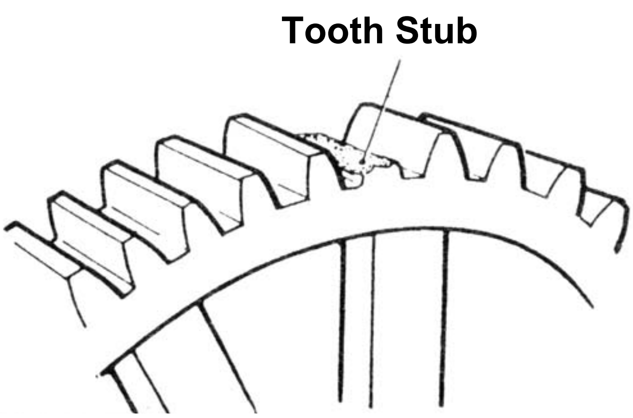


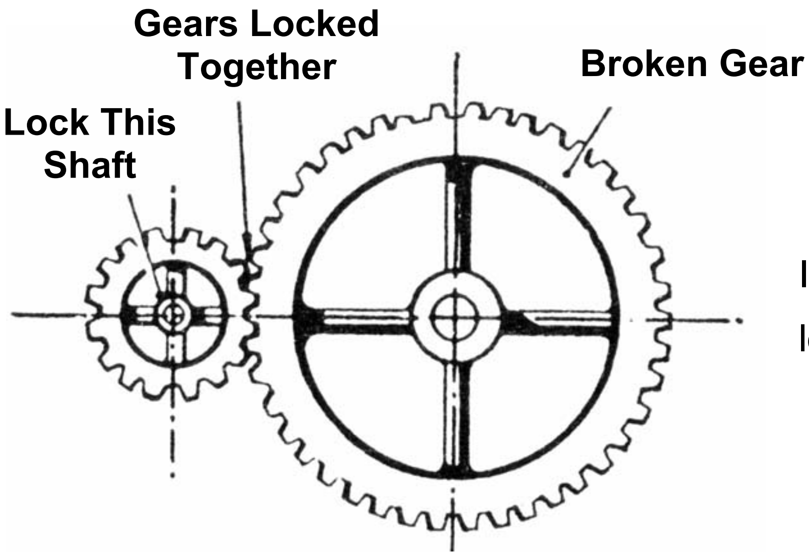
When fitting the shafts into the gear case use a marking medium on the worm to check that the worm is mating with the centre of the worm wheel teeth. If necessary adjust the position of the worm wheel shaft.



Replacing a Gear Tooth

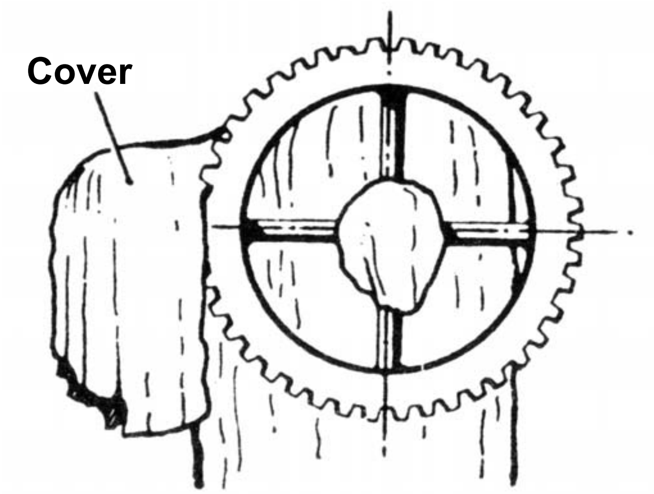
Rotate the gear so that the stub of the tooth is accessible, if possible on the top.





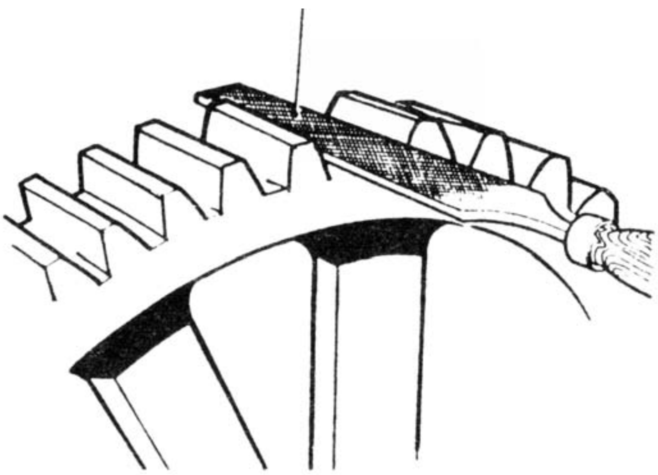
If the gear rotates freely, lock it in position.

Cover any exposed machine parts to prevent metal chippings or fillings falling into them.



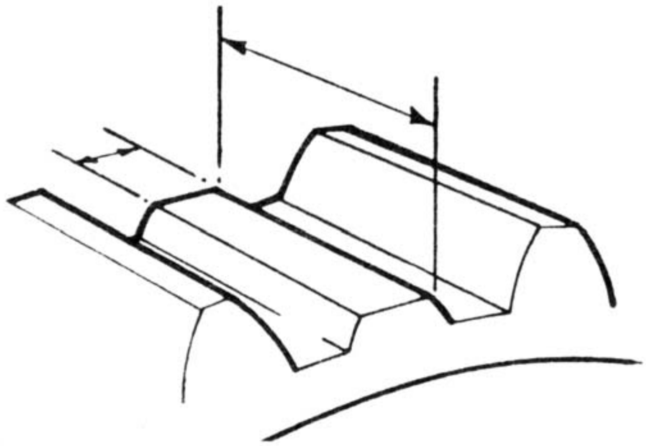
Fitting the Studs

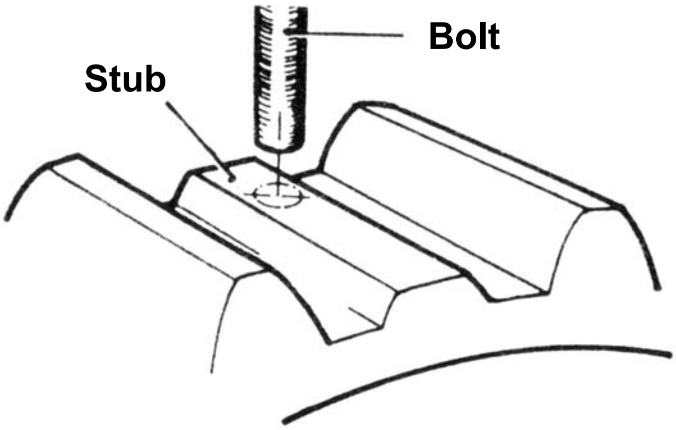
A new tooth may be fitted by keying, but the most common method is fitting studs and welding around them.



File the tooth stub to give a flat sound surface for drilling. Take care to avoid damaging adjacent teeth.

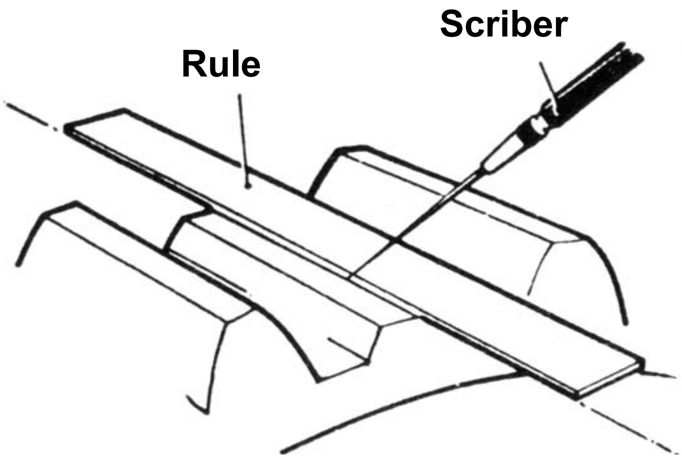
Measure the width and length of the top of the stub.

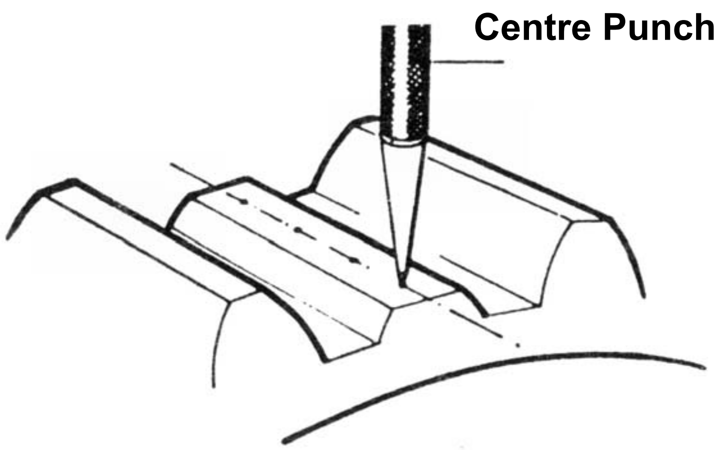




Select a bolt size so that the diameter is as near as possible to the width of the stub. If the tooth is to be built up by welding, ensure that the bolt material is ***'weldable'.***

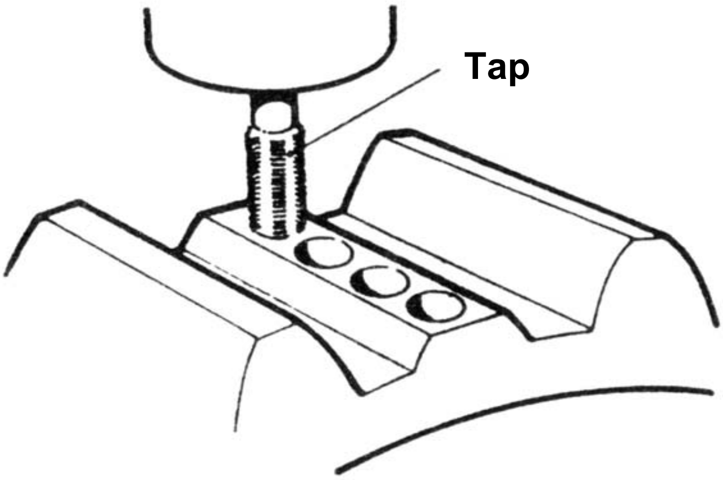
Scribe the centre line on top of the stub.

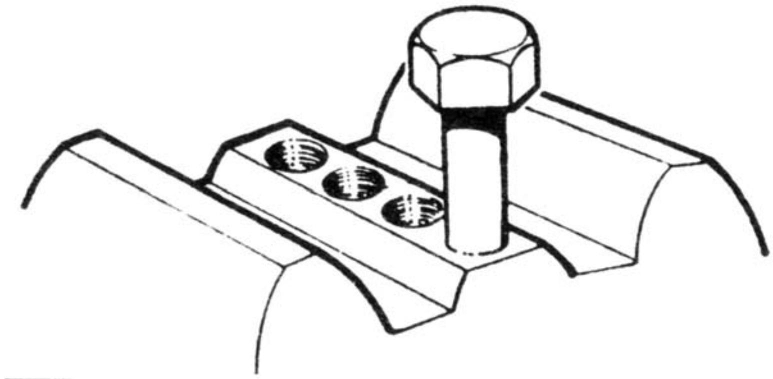




Mark the centres for each bolt on the centre line. Space the hole centres evenly along the centre line so that the bolts will be just clear of each other.

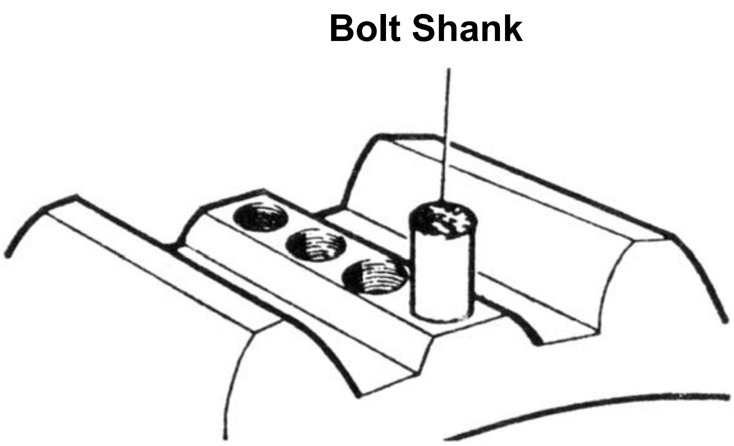
Drill and tap the holes for the bolts. The tappings should be just deep enough to hold the bolts securely without weakening the hub.

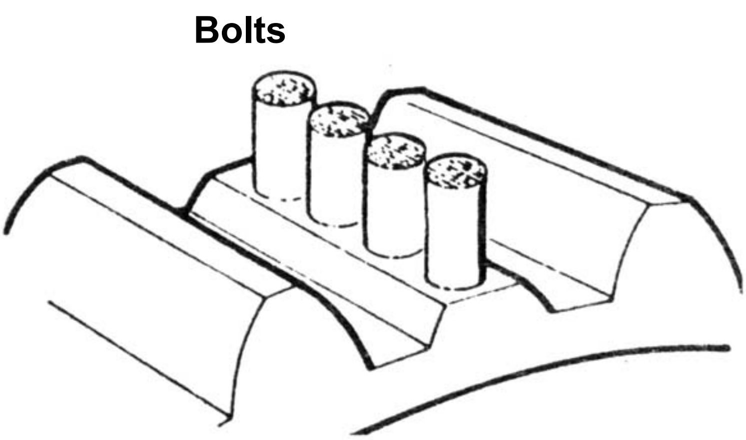




Fit one bolt and tighten it securely so that it will not unscrew while it is being filed.

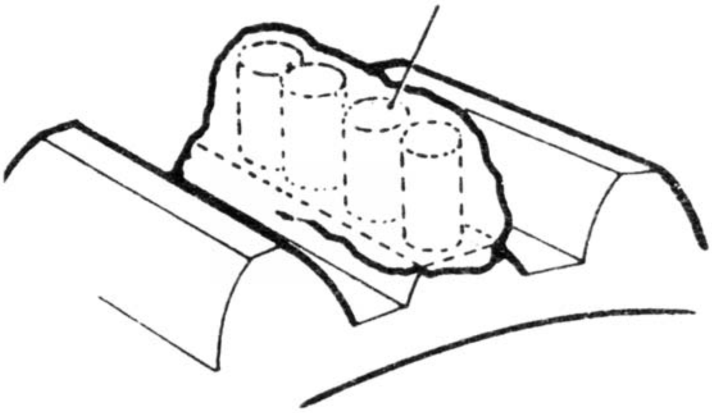
Saw off the head of the bolt so that the shank is slightly higher than the teeth.



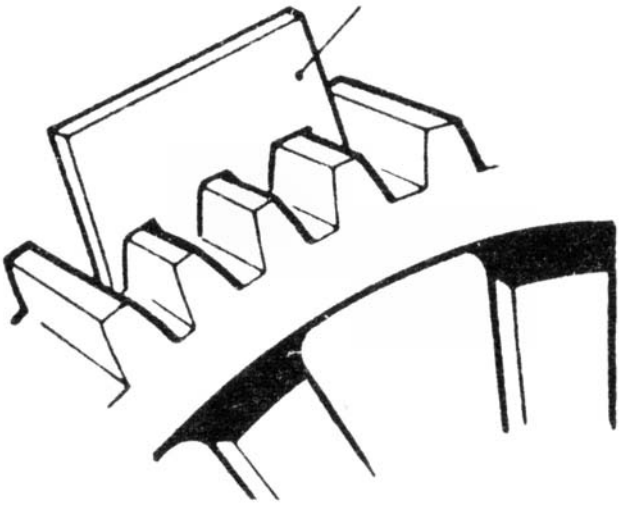


Fit the remaining bolts in the same way.

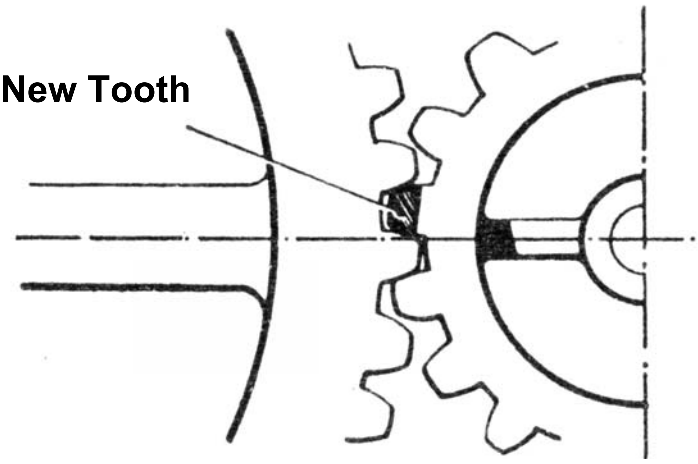
If the tooth is to be built up by welding, apply weld until the build up material is proud of the tooth profile.



To File the Tooth to Shape



- Prepare a metal template to the shape of three of the good teeth.
- File the new tooth to the shape required, checking it with the template. Make the new tooth parallel to the existing teeth beside it.



Free the gear wheel and rotate it so that it meshes with the other gear to check that the gears mesh smoothly.

Remove any high spots shown upon the tooth.

Start the machine and check that the gears run quietly.