MAYDAY
GEARBOX REPAIR

GEAR FAILURES

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ANALYZING GEAR FAILURES

Gear failures can have many causes, but these causes are often interrelated. Occasional failures, especially those that occur in the early hours of operation, are usually caused by factors related to metallurgy, heat treatment processes, design or manufacturing procedures. Other failures may be caused by repeated overloading, which is usually associated with the machine's treatment by the operator. The majority of failures, however, are the result of factors which can be controlled and corrected—such as misalignment, insufficient lubrication, abrasives in the oil, and even the use of non-recommended lubricants.

Pinpointing the cause of gear failure is not always easy. The damaged gear in the shop will not be neatly labeled like the pictures in this publication. Sometimes several forms of failure may occur and overlap on the same gear. Don't look at just one tooth but at the whole gear, not just at one failed gear but at all the surrounding gears, and other related parts of the machine. In almost every case, a sound basic knowledge of the individual types and causes of gear failures, coupled with a close, careful inspection, can lead o a satisfactory explanation of the failure.

IMPORTANCE OF LUBRICATION

Proper lubrication helps prevent gear failures. Proper lubrication includes (1) using only the recommended lubricant, (2) keeping the oil clean and free of foreign material, and (3) maintaining an adequate lubricant supply.

The selection of a lubricant is based on the type of gear, type of load, speed, operating temperatures, input power, and reduction ratio. This decision must be left to gear lubricant specialists, particularly with today's power-transmission gears, greater loads, higher speeds, and the variety of special additives and properties of lubricants. Always check the Lubrication and Maintenance Guides for the recommended lubricants.

Oil serves basically the same function with gears as with other moving parts: to clean, to cool, and to lubricate or prevent metal-to-metal contact, thereby reducing friction and wear. Many gear failures result from improper or inadequate lubrication, and you will want to keep this fact paramount in your mind as you analyze failures.

HEAT TREATMENT TERMS

Some gears are "case-hardened"; others are "through-hardened". These are heat-treating processes used to harden metal, relieve its stresses, refine its grain structure, or otherwise change its properties. A general acquaintance with some of the terms and purposes of heat treatement is necessary to understand gear failures.

In case hardening, only the surface is hardened. This process results in the desirable combination of a hard "case" for wear resistance and a softer "core" for toughness. The case-hardening processes are carburizing, nitriding, and flame and induction hardening. In carburizing, carbon is added to the surface of the gear. In nitriding, nitrogen is the hardening agent. And in induction hardening (generally used to harden only a section or sections of a gear) heat is generated by electrical induction. The choice of heat-treating processes depends on the application of the gear, content of the steel, and the desired results.

In through-hardening, also called direct hardening, a gear is heated to a specified temperature and then quenched (cooled quickly) in a liquid or gas. A tempering operation (reheating at a lower temperature) usually follows, to toughen and relieve stresses. A through-hardened gear will have nearly the same hardness in the center as on the surface.

GEAR TOOTH TERMS

Some geometric terms have been assigned to certain points and areas on gear teeth. The gear tooth profile (Figure 1) is the shape or outline of the tooth seen from the end. The top or upper edge of the tooth is called the tip land, or simply tip. The fillet, or root fillet is near the bottom of the tooth where the profile or outline moves out horizontally. The pitch circle is between these two extremes (tip and fillet). The point of the circle which touches the edge of the tooth profile and extends the length of the tooth surface is the pitch line. The pitch line is rarely midway between the fillet and the tip; it can be either high or low on the tooth. Its position is usually determined by the gear ratio. On final drive pinions, for example, it is low. If the pitch line is low on one gear, it will be high on the mating gear. The pitch line can usually be identified by some discoloration and a slight difference in surface texture. Gear teeth mesh with a rolling-sliding action as they transmit force. When the pitch lines meet, there is only rolling. As the gears continue to turn so contact occurs above or below the pitch lines, the

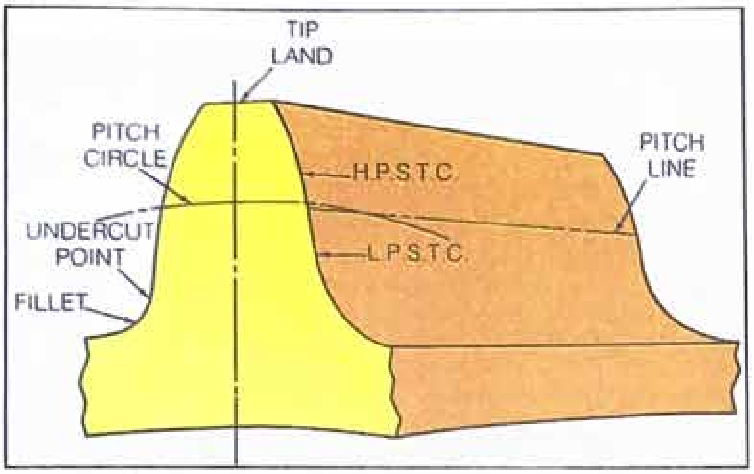


Figure 1. Gear tooth profile

rolling sliding action resumes.

Three other points on the gear tooth profile are important (1) the lowest point of contact, (2) the lowest point of single tooth contact (L.P.S.T.C.) and (3) the highest point of single tooth contact (H.P.S.T.C.). The lowest point of contact is either the point of undercut or the lowest point on the profile where the tip of the mating tooth engages.

The lowest and highest points of single tooth contact usually cannot be detected by observation of the surface. The L.P.S.T.C. is usually slightly below the pitch line. It is the point where only one pair of teeth starts to carry the full load. This is an area of high contact pressure, especially on the pinion of a high ratio set. It is often the first area to exhibit pitting. Conversely, the H.P.S.T.C. is the highest point on the tooth profile where one pair of teeth stops carrying the full load. It is usually slightly above the pitch line. The H.P.S.T.C. on the pinion is an important place to look for scoring. (Pitting and scoring are discussed in separate sections later.)

MILD AND USUALLY HARMLESS FAULTS

Sometimes gears are replaced because suspicious marks are misinterpreted as the beginning of a failure. It is important to be able to recognize these marks so gears are not discarded needlessly. Some of these harmless marks are caused by manufacturing processes and others by reactions with lubricants or by minor metallic flow.

MANUFACTURING BLEMISHES

1. Hob Marks. This initial cutting operation produces longitudinal marks which can be seen on some gears in the root area. Normally, these marks are removed from the surface by a finishing operation such as shaving. Occasionally, the finishing operations do not remove all the hob marks. The longitudinal gouges that remain (Figure 2) are not desirable, but only in rare instances do they contribute to gear failures.

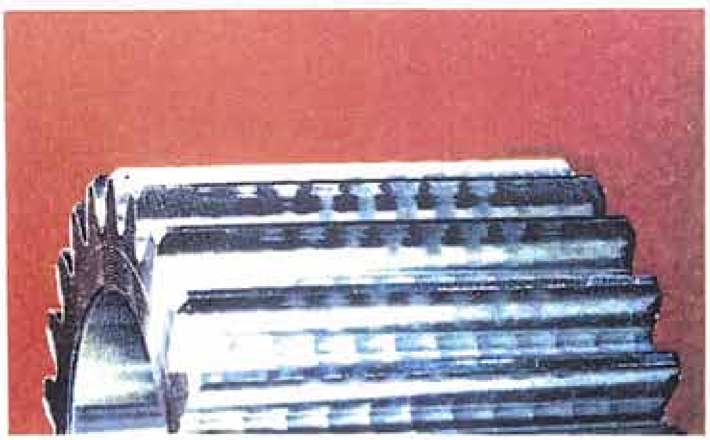


Figure 2. Hob marks

2. Shaving Marks. Shaving is the final machine operation for the majority of gears. Shaving often leaves distinct diagonal marks. Deep, widely spaced markings generally indicate that there are chipped or broken teeth on the shave cutter, but they present no real danger to the capacity of the gear. Figure 3 shows shaving marks which are particularly pronounced near the tip of the gear. These marks can be distinguished from healed-over scoring marks by the fact that they are diagonal, while scoring marks are vertical.

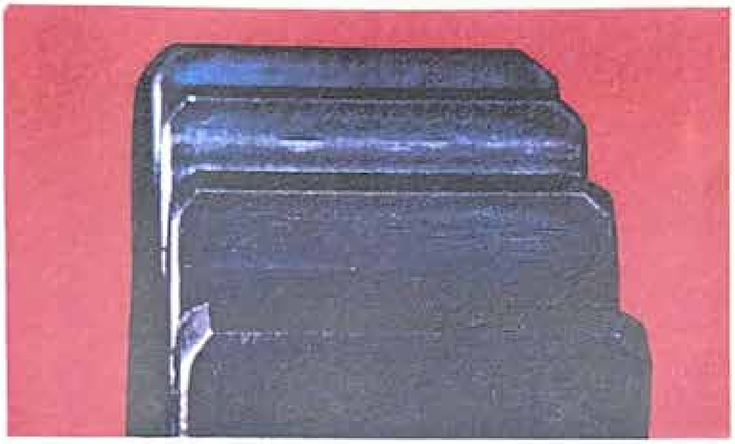


Figure 3. Shaving marks

3. Lipping. Another usually harmless fault, but one which is often mistaken for an indication of harmful plastic yielding or plastic wear, is "lipping", shown in Figure 4. Lipping is caused by the use of a dull shaving cutter in the finishing operation. You must be careful to distinguish between harmless lipping and the type of lipping which does indicate metallic flow during operation. Look carefully on both the forward and reverse sides of the tooth. In harmless lipping, the "lips" are formed to the same height on both sides. In plastic yielding there will be a ridge on the most often or heaviest loaded side of the tooth and there may be evidence of metal flow along the ends of the tooth. The "lips" at the tip will be of uneven height.

Figure 4. Lipping.

4. Heat Treat Mottling. A peculiar spotty mottling is sometimes formed during the heat treatment of carburized gears. Such mottling results from the conversion of oxides back to iron during the heat treat process. This mottling does not contribute to gear failure.

5. Quench Cracks. In some induction-hardened gears, very small quench cracks can be seen at the ends of the teeth. These cracks, usually located at the bottom of the fillet, rarely extend more than 1/16" from the edge. They are not considered harmful because of the low stresses in this area.

LUBRICANT OR CORROSIVE PITTING

Lubricant or corrosive pitting is illustrated in Figure 5. It is characterized by a large number of very small pits, evenly distributed over the working surface of the gear. These pits are caused by the moisture affinity of some additives in Extreme Pressure (EP) oils or some other unusually corrosive medium. Although pits of this type could be a potential danger after long operation, it is unlikely that harmful pitting starts from any of these small etch marks.

Figure 5. Lubricant or corrosive pitting

MINOR METALLIC FLOW

1. Surface Rippling. Figure 6 is a good illustration of this usually harmless phenomenon. A rippled surface is magnified 50 times in the inset. Although it may appear that serious metallic flow has taken place, careful metallographic inspection shows that this is not necessarily so. These ripples are a form of wear of tolerable proportion but do indicate that the gear is operating near its maximum load limit. Rippling occurs only above the pitch line of the teeth.

2. Marbling and Polishing. A gear that has been run for only a short period, perhaps less than an hour at moderate speed, often displays many small highly polished areas. These are areas of initial metallic contact and represent

Figure 6. Surface rippling.

part of the beneficial breaking-in process. Continued operation under the same conditions will result in a complete polishing of the contacting surface. Although such polishing will not lead to a serious failure, it does represent normal wear.

FRACTURES

The most serious form of failure, is the actual breaking of the tooth. There are two major types of breaks, or fractures; static fractures and fatigue fractures. If a tooth breaks after only a few cycles of very heavy load, the result is a static fracture. If it breaks after many cycles of load, it is a fatigue fracture.

STATIC FRACTURE

A fracture following one or a very few high load cycles will often exhibit a hump on the compression side. See

Figure 7. Static fracture.

Figure 7. This hump is a severe plastic shear area characteristic in many cases of static fractures on gears and other parts as well. The longer a gear runs before a failure, the smaller the hump will be. Eventually a point is reached when the hump is no longer evident. The fibrous uniform texture of the fracture and the absence of any sign of progressive damage are further indicators of a static fracture.

FATIGUE FRACTURE

A fatigue fracture can often be recognized by the presence of "beach marks". These are elliptical marks on the fracture surface. They radiate from a central point which was the nucleus of the failure. They are the result of recurring loads heavy enough to enlarge a crack but not heavy

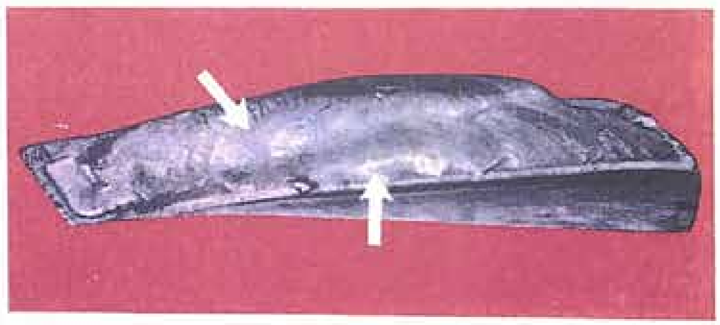


Figure 8. Fatigue fracture (gear tooth)

Figure 9. Fatigue fracture.

enough individually to break the tooth off. For example, during a tree stump clearing job the operator of a bulldozer may ram a rock quite hard, causing a severe shock loading on the pinion and bull gear teeth. If a crack starts and then continues to grow slowly until the tooth finally breaks, the failure will be a fatigue-type fracture. Beach marks result from normal cycle loading in field operation where the crack propagation is sporadic, depending upon the load which causes it and the time between such loads. Figure 8 shows a gear tooth from a fatigue fracture. Notice the elliptical shaped beach marks on the surface of the tooth. However beach marks do not always appear with fatigue fractures on gears. Figure 9 is an example of a fatigue fracture where beach marks can not be seen. This happens with many fatigue fractures in gears because the root area of the gear is not tough enough to allow beach marks to form, or the rate of crack propagation was so rapid that beach marks never formed.

It is impossible to name a number of cycles which differentiates between static and fatigue fractures. Always find out what kind of work the machine was doing before the failure, and include this information in your service report.

MISALIGNMENT FRACTURE

Figure 10 illustrates fractures resulting from misalignment of the gears. In cases of misalignment, the fracture originates at one end of the tooth and occurs on a diagonal line. Beach marks can be seen on the gear teeth. Misalignment is a common cause of broken teeth on spur or helical gears and bevel gears.

Sometimes misalignment is caused by loose bearings. Loose bearings will result in shaft deflection and ultimately in a gear tooth fracture due to corner loading. It is good preventive maintenance to keep the final drive bearings on a track-type tractor in proper adjustment.

Figure 10. Misalignment fracture.

MIDTOOTH FRACTURE

Quite often a tooth will not fracture at the usual highly stressed fillet area but will break at midtooth (above the fillet). There are two types of midtooth fractures: midtooth fractures caused by "case-crushing" or severe pitting, and midtooth fractures caused by gross nonmetallics or inclusions (material faults beneath the tooth surface). Figure 11 is an example of a midtooth failure caused by pitting, and

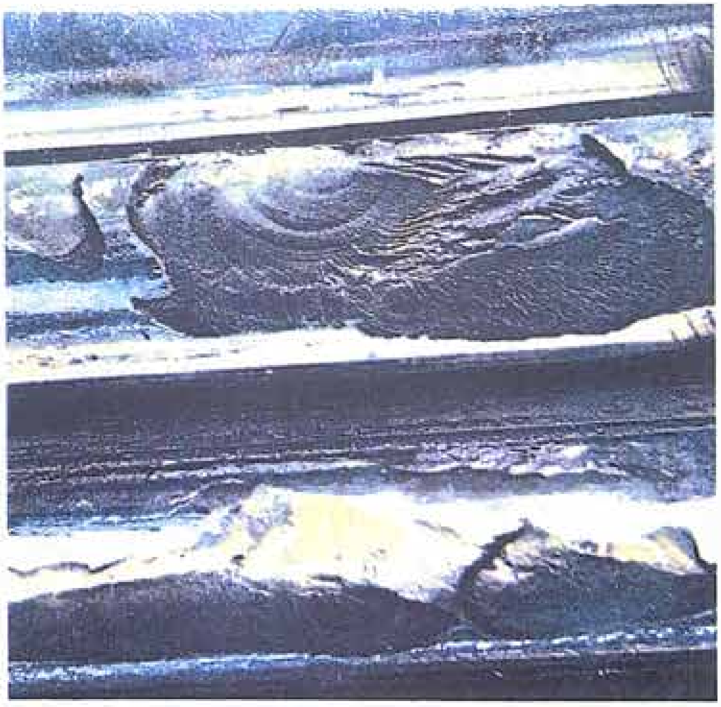


Figure 11. Midtooth fracture caused by pitting.

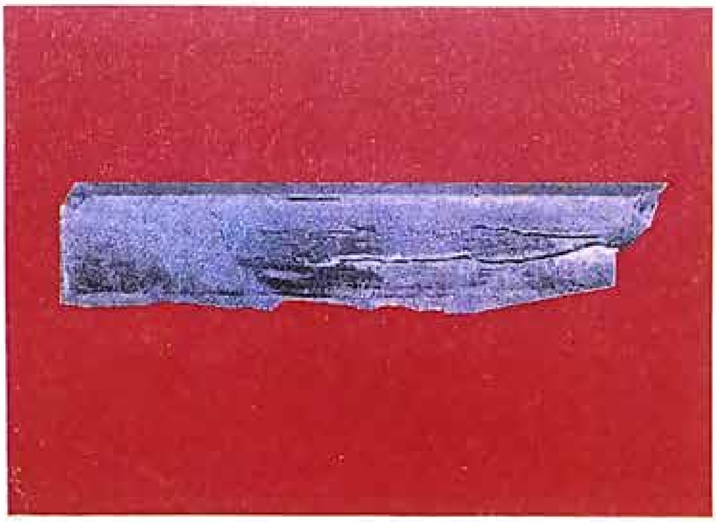


Figure 12. Midtooth fracture (gear tooth).

Figure 13. Midtooth fracture caused by gross nonmetallics.

Figure 12 is an example of a midtooth failure caused by case crushing. Note the characteristic longitudinal mark on the gear tooth in Figure 12.

A midtooth fracture which resulted from gross nonmetallics is illustrated in Figure 13. Note the U-shaped groove formed by the fracture planes in Figure 13.

MULTI-STAGE FAILURES

Quite often a failed tooth will show an uneven fracture pattern which does not clearly indicate any single type of failure. Without looking at the other, unfailed teeth in the area, you may erroneously assume that a high degree of misalignment existed. Often, however, an uneven fracture pattern is a result of a series of causes, or stages of failure, usually initiated by case crushing. A typical sequence of events that might lead to such a fracture is illustrated by the sketches of Figure 14.

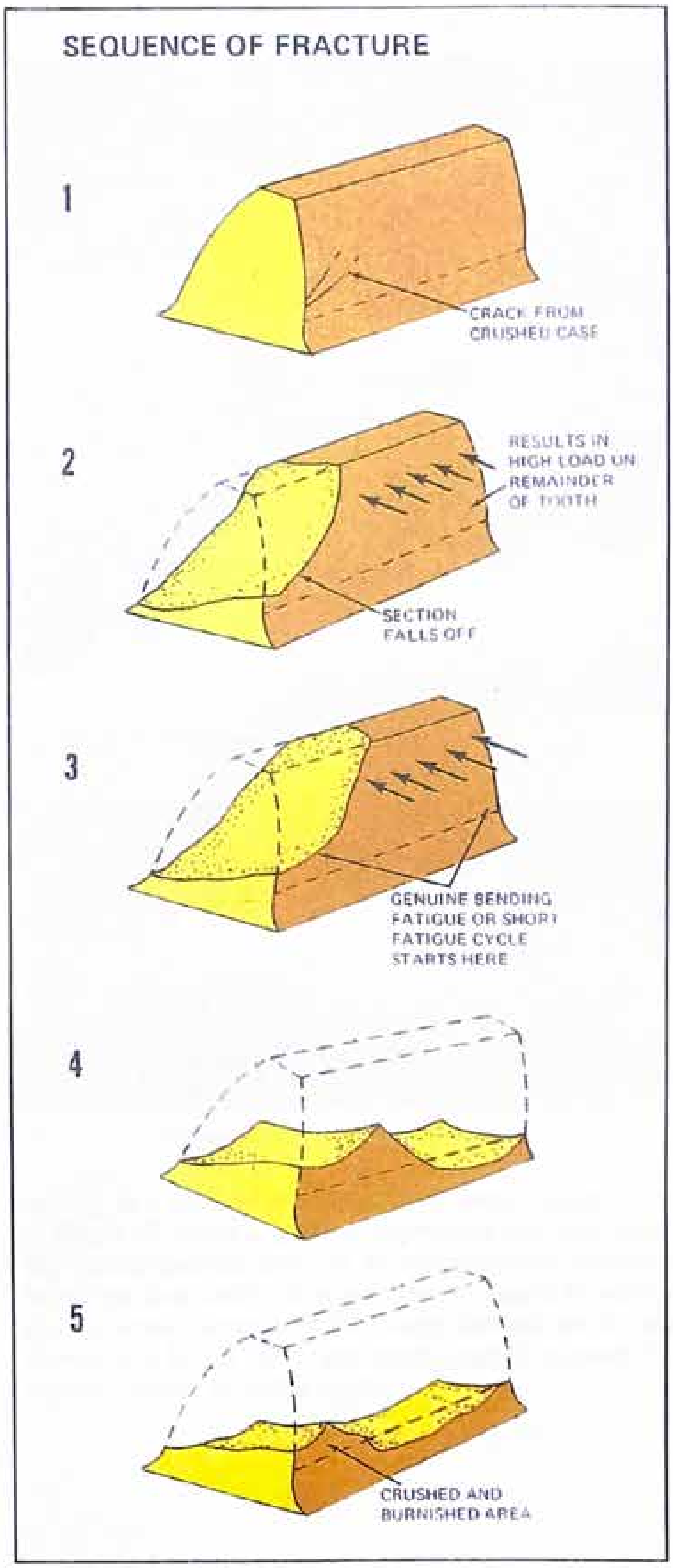


Figure 14. Multi-stage failure.

CASE CRUSHING

Case crushing can be identified in its initial stage by longitudinal cracks on the working surface approximately parallel to the pitch line. See Figure 15. Notice that these cracks do not radiate from a single point of origin on the surface. Case crushing is caused by the failure of supporting core material. In the gear pictured in Figure 15, chips have been knocked out of the tooth to show the core failure.

Figure 15. Case crushing.

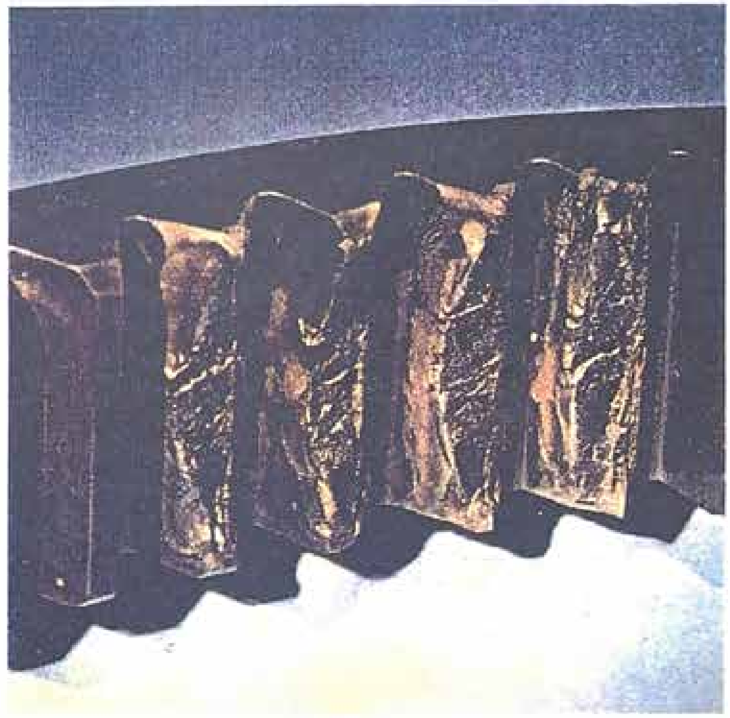


Figure 16. Severe case crushing.

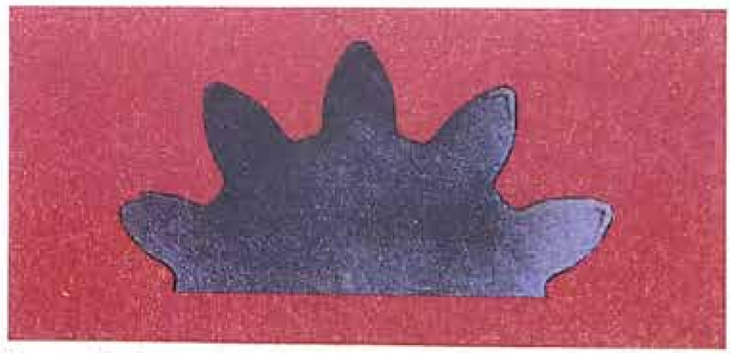


Figure 17. Cross section of gear with core failure.

The progression of a failure from case crushing is very rapid, since much of the core material has been fatigued before the surface cracks appear. For this reason a single tooth may look very bad while the adjoining teeth show no outstanding signs of failure.

Gears with evidence of case crushing should be replaced. If not, the crushing will probably progress very quickly to a point where the surface breaks away.

Figure 16 shows a gear with signs of severe case crushing. Notice that four teeth are almost completely destroyed while the other teeth still seem intact. In Figure 17 a pinion gear is shown sectioned. The cracks beneath the surface reveal core failure. Note that cracks appear beneath the case in almost all of the teeth.

PITTING AND SPALLING

PITTING FOLLOWING WEAR

Pits (little holes) at the pitch line are a sign of wear. This wear in turn is caused by contamination of the oil by abrasives or by low-speed operation at heavy loads. In such "wear", material is removed above and below the pitch line, causing high contact stresses at the pitch line.

That which results from low-speed operation is shown in Figure 18. In this case the low-speed operation was followed by a load which tended to heal or polish over the severe wear marks. A ridge left on the pitch line was gradually being crushed away to result in pitting and spalling. The load fatigues the metal and finally causes particles to break off.

INITIAL PITTING, MACHINABLE HARDNESS GEARS

In initial pitting the pits are about the size of a pin head or smaller. See Figure 19. Gears with small pits can remain in the machine as long as you continue to check them periodically. It usually takes considerably longer for initial pitting to progress into destructive pitting than it took for the pitting to start in the first place. Watch for any unusual accumulation of metal in the oil filter, strainer, or on the drain plug magnet. In the case of high speed gears, the noise level will increase as the pitting or other surface failures get worse.

Figure 18. Pitting and wear.

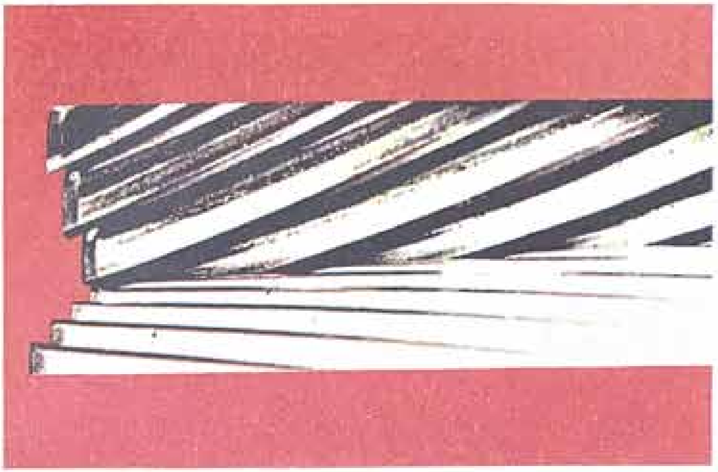


Figure 19. Initial pitting.

Figure 20. Destructive pitting.

Figure 20 illustrates destructive pitting. This badly pitted gear would be noisy in operation. Additional pitting would probably cause the tooth to break because the unpitted areas of the surface would be insufficient to carry the load. This gear also shows a slight discoloration which means it may have become too hot which reduced surface hardness and allowed pitting to start.

Spalling can be the last stage of pitting, or it can occur without previous pitting in case-hardened gears.

PITTING OR SPALLING OF A CASE HARDENED GEAR

Pitting or spalling of a typical carburized and hardened gear is serious. These gears are very resistant to pitting, but if subjected to severe fatigue, are likely to spall. If pitting or spalling does develop on a case-hardened gear, it progresses much faster than on gears of machinable hardness, because undermining or splitting takes place along the boundary zone between the case and the core. In the early stages, these pits are V-shaped, and are usually located below the pitch line of the pinion. With continued operation the pits propagate across the pitch line, undermining the surface (Figure 21). Often the undermining extends under the tip to the unloaded side of the tooth. The undermined areas spall off (spalling is simply an advanced case of pitting, where flakes of metal break off), ruin the tooth profile, and lead to a midtooth fracture. (Figure 22).

Figure 23 shows two gear teeth failed from spalling. Notice the crack in the tooth at the lower left—this crack has gone through the case and progressed upward under it. In the tooth at right, undermining has progressed to the point where the surface has chipped out. The actual start of the failure in both teeth was at the apex (tip or point) or the fan-shaped progression of cracking. The tooth at the left has not flaked out yet, but the fan-shaped cracking is present. The top crack can be seen, but the lower one is not so plain. It starts at the apex and progresses to the left. The fan-shaped area is more clearly defined in the tooth at right, where spalling has occurred.

Figure 24 illustrates the progression of initial pitting into destructive pitting. The center tooth shows how spalling sometimes extends over the tip of the tooth. The pitting has started fairly close to the root of each tooth. If this gear had been run longer, this area would have spalled, too.

The occurrence of pits on case-hardened gears can be the result of excessive loads for long periods of time and insufficient oil film thickness due to too low a lubricant viscosity. Pitting can also be the result of surface decarburization. Surface decarburization is a softening of the surface layer caused by a faulty hardening process during heat treatment. You can usually tell whether the pitting is caused by insufficient hardness by the ease with which you can scratch the tooth surface with an ordinary file. Decarburization can also initiate scoring damage.

Figure 21 Spalling.

Figure 22 Midtooth fracture caused by pitting.

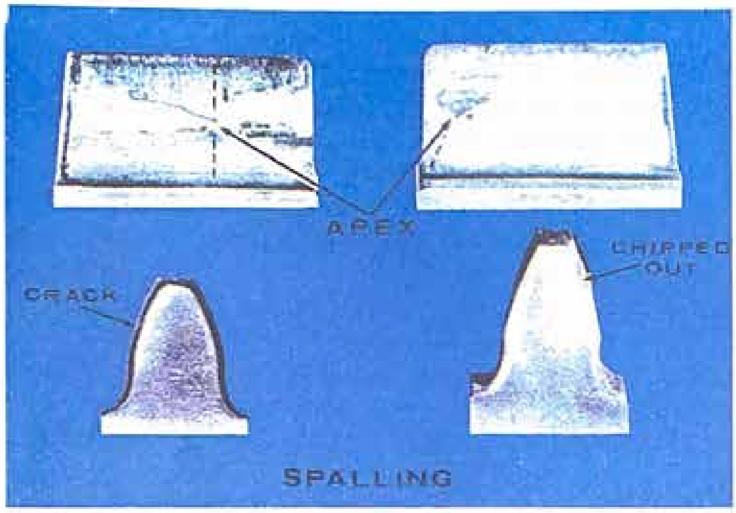


Figure 23. Spalling.

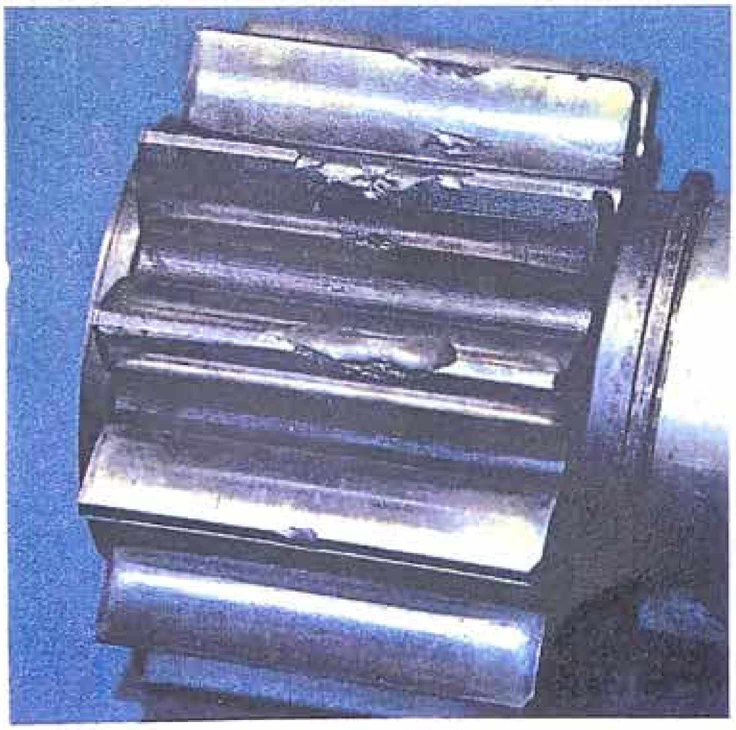


Figure 24. Progression of initial pitting into destructive pitting.

WELDING

SCORING AND GALLING

Welding is a general term describing failures caused by metal-to-metal contact which creates extremely high temperatures and consequent softening of the surface metal. This is sometimes referred to as "picking up stock". Scoring and galling are welding failures.

Superficial scoring, or a light case of scoring, can be identified by the presence of a number of single fine scratches or small patches of seized areas on the tooth surface. These scratches are not considered harmful as long as they remain small. This type of scoring is usually caused by high points or areas on the mating tooth surface. Friction between the mating teeth at these points creates local high temperatures, which prevent the formation of the oil film. In the resulting metal-to-metal contact, the high points are worn away and the load becomes more evenly distributed across the tooth surface. Usually, after this smoothing process, the superficial scoring heals over. In some cases light scoring occurs on parts that have been heavily loaded before they have had a chance to get broken in. This tends to smooth over with continued operation at lighter loads.

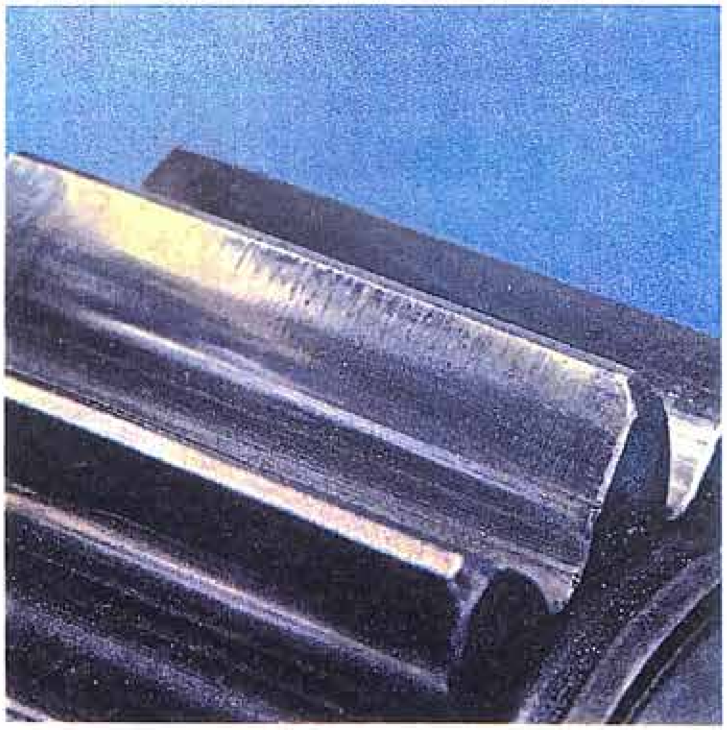


Figure 25. Severe scoring.

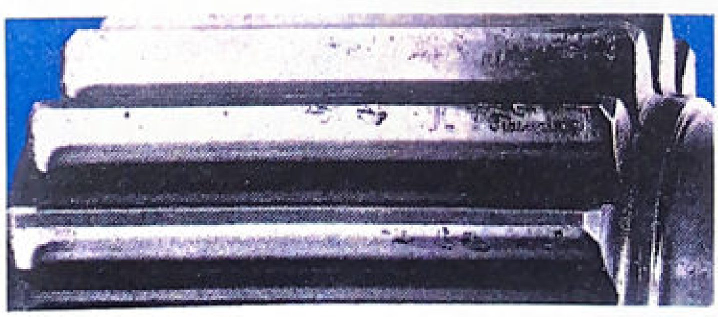
Superficial scoring can also be caused by a temporary ack of lubrication. If the gears continue to run with no ıbrication or with improper lubricants, scoring will progress until the gear is so damaged that it is useless. This tage of surface deterioration is severe scoring. See Figıre 25. Failure of the lubricant can be caused by extreme perating temperatures and high speed and load.

If you look at a scored surface moderately magnified, ou can see fine ridges which appear as shallow, closely paced parallel lines directed up and down the tooth. These lines generally occur above the pitch line on the inion or near the root on the gear. No scoring occurs at the itch line, since no sliding takes place there.

Scoring and the wear associated with it very often lead to erious pitting. Such scoring indicates the failure of the ubricant to protect the surfaces under the high loads or igh speeds imposed. The gear tooth in Figure 26 exhibits itting caused by scoring. The scoring is fairly well healed ver by milder operation and possibly some abrasive wear. But the initial tearing opened up some cracks on the tooth urface, and these cracks developed into pits. Pitting aused by scoring is located either above or below the itch line, depending upon whether the gear is the driver or he driven.

Scoring is particularly serious in an overdrive situation; hat is, where the larger gear is driving the smaller pinion. n this case the direction of propagation of the scoring ction is toward the heavily loaded midtooth area. There is ess chance of healing over or of continued safe operation.

Scoring can develop regardless of the hardness of the ooth surfaces. Scoring which occurs on the teeth of comaratively soft gears (those of machinable hardness, for xample—or through-hardened) may develop into galling. Galling is an advanced case of scoring, a condition in vhich sizeable particles of metal have been torn from the ooth surface.



igure 26. Pitting caused by scoring

WEAR

"Wear" has been referred to several times in the course of describing the different types of failure. Wear is not easily isolated from the other types and causes—in a way, all of them represent wear. First of all, the only "normal wear" on a gear is the initial smoothing and polishing of the working surfaces that takes place in the first hour of operation. This is a beneficial process, usually spoken of as "breaking in" or "running in".

The term "wear" can cover the wear of scoring and galling, abrasive wear caused by foreign material in the lubricant, and plastic yielding of the metal.

ABRASIVE WEAR

Abrasive wear characteristically has a very satiny matte surface appearance. See Figure 27. To detect this, use a mirror to reflect the light from the surface of the gear. You can often see flat, worn areas that interrupt the tooth profile. It begins at the lowest point of single tooth contact, ends at the pitch line, and begins once more at the pitch line to end at the highest point of single tooth contact. The wear follows this pattern because of the high loads in these areas and the degree of sliding taking place. Prominent ridges at the pitch line and near the lowest point of contact identify abrasive wear.

These abrasive wear ridges carry more than their share of the load . . . more than if the entire surface were bearing the load. In any situation where the bearing area decreases but the load remains the same, the unit stress, or pounds per square inch, increases. If you could examine this gear in Figure 27 closely, you would see that the surfaces of the gear teeth have been worn away, leaving a ridge at the pitch line.

In the early stages of abrasive wear, it is sometimes difficult to tell whether there has been a change in the tooth profile. So remember to watch for: (1) a very satiny lapped-in appearance of the tooth surface; and (2) flat spots, which can be detected by reflecting light.

If you find a pitted gear and you suspect the cause of the pitting is abrasive wear, examine all the gears common to the drive train. If all of them have a satiny lapped-in appearance, you can be reasonably sure the cause is abrasive wear. The satiny finish will also appear on the bearing.

Whenever you notice a satiny lapped-in appearance on gears, find out if the filter elements have been changed at the prescribed interval. If not, impress upon the user the

Figure 27. Abrasive wear.

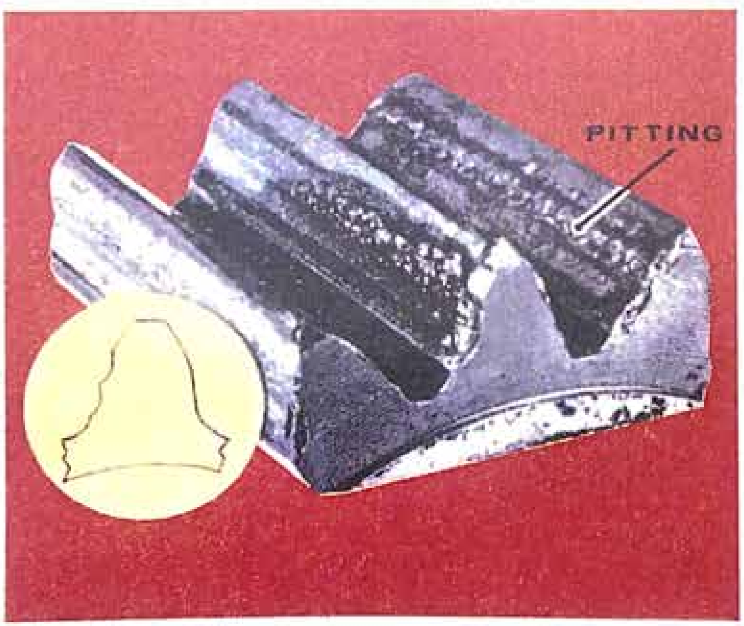


Figure 28. Advanced stage of abrasive wear.

need for proper maintenance. Also, check to see if there is sediment in the gear compartment. If so, the compartment and the lubrication system must be flushed clean of any foreign material.

Figure 28 represents an advanced stage of wear. It is a typical example of what very small quantities of abrasives in the oil can do. The wear is extremely severe from the L.P.S.T.C. to the pitch line, and again from the pitch line to the H.P.S.T.C. Note that the wear is not confined to one area of the tooth face but extends the full width. The reason for this wear pattern is that the sliding action between mating gear teeth occurs above and below the pitch line. Abrasives in the lubricant act as a lapping compound.

PLASTIC YIELDING

Plastic yielding is a severe flow of surface material generally resulting in lip ledges forming on the ends and/or tips of the gear teeth. These lips are usually of uneven height.

Figure 29. Plastic yielding.

Plastic yielding may occur on gears subjected to heavy continuous loading or to gears subjected to intermittent heavy loads which act like hammer blows. An example of the latter type are engine timing gears, which have been subjected to vibratory loads or dynamic loads with severe impact. It sometimes occurs on gears of low hardness . . . very rarely on hardened gears. If plastic yielding does occur on a hardened gear, it is the result of poor heat treatment. Figure 29 shows this type of extrusion of metal surfaces.

Important Points to Remember in GEAR FAILURE IDENTIFICATION

PITTING

Pitting is identified by small pits in the tooth surface below the pitch line. Watch for any unusual accumulation of metal in the oil filter, strainer, or on the drain plug magnet. In the case of high speed gears, the noise level will increase as surface failures progress beyond the initial stage.

CASE CRUSHING

Case crushing occurs most frequently on the larger gears—such as final drive pinions, or bevel gears and pinions. Check for longitudinal cracks in working surface of the tooth.

SPALLING VS. CASE CRUSHING

Sometimes spalling can look like case crushing. However, spalling is identified by flaked out areas and does not have the characteristic longitudinal cracks across the face of the tooth that identify case crushing.

SCORING AND GALLING

Scoring is normally the result of the failure of the lubricant, or just simply a lack of lubricant. It is evidenced by small patches of seized area. Galling is an advanced case of scoring.

ABRASIVE WEAR

Abrasive wear is identified by a satiny lapped appearance and irregular tooth profile. Since it is caused by foreign material in the lubricant, check for sediment in the gear compartment regularly.

PLASTIC YIELDING VS. LIPPING

Do not confuse plastic yielding with harmless lipping. In plastic yielding, the lip will be more prominent on one side of the tip than it is on the other. In lipping, the lips will be of equal size on both sides of the tooth tip.

TOOTH BREAKAGE

Misalignment is a common cause of broken gear teeth. It is identified by diagonal fractures at the ends of the teeth. One of the causes of misalignment is loose bearings. It is particularly important to make sure that final drive bearings on track-type tractors are in proper adjustment.

Other tooth breakages include static fracture, fatigue fracture, and midtooth fracture. Static fracture is identified by a hump on the compression side of the fractured surface. Fatigue fracture is identified by beach marks on the fracture area. Midtooth fracture is identified by either a "fish-eye" pattern around an inclusion, or by a crack running downward from a pitted area to the opposite side of the gear tooth.

The chart on Page 15 may serve as a quick review of the types and causes of failure we have discussed here and as a ready reference for future use.

GEAR FAILURE SUMMARY

FAILURE	TYPE	DESCRIPTION	COMMON CAUSE
Mild and Usually Harmless Faults Page 3	Hob Marks	Small longitudinal gashes interrupting shaved work surface, or remaining because shaving was omitted.	Lack of clean-up during shaving or omission of shaving operation.
	Shaving Marks	Diagonal machine marks on work surface . . . generally most pronounced near tip.	A machining mark, not detrimental
	Lipping	Lips protruding above the tip of the tooth from both working surfaces . . . somewhat resembles plastic flow but harmless lips are of even height.	A machining mark, not detrimental.
	Heat Treat	Spotty appearance.	Results from conversion of oxides back to iron during heat treatment of carburized gears.
	Quench Cracks	Very small cracks at ends of teeth in fillet area.	Result from induction hardening process.
	Lubricant or Corrosive Pitting	Large quantity of very small pits evenly distributed over working surface.	1. Corrosive tendency of some EP oils. 2. Excessive moisture and condensation.
	Surface Rippling	Has the appearance of retarded metallic or plastic flow.	Normal cycle loading causes these to develop. Considered beneficial to lubrication on low speed gears.
	Marbling and Polishing	Small, highly polished areas on a gear run for a short time.	Caused by initial metal-to-metal contact. Normal sign of "breaking in".
Fractures Page 5	Static Fracture	Very often characterized by a hump on the compression side of the fractured surface.	Produced by one or a few high load cycles . . . severe shock application.
	Fatigue Fracture	Often, but not always, accompanied by "beach marks".	Normal cycle loading during field operation or steady continuous loads.
	Misalignment Fracture	Fracture originates at one end of the tooth and proceeds diagonally.	1. Shaft deflection caused by loose bearings. 2. Improper installation.
	Midtooth Fracture (usually fatigue-type)	The breaking occurs above the fillet area.	1. Case crushing. 2. Gross nonmetallics or inclusion (material fault inside the tooth).
	Multi-Stage Failure	Uneven fracture pattern not clearly indicating any single type of failure.	Results from a series of causes, usually initiated by case crushing.
Case Crushing Page 8	Initial	Longitudinal cracks on working surface.	Failure of core.
	Severe	Total destruction of case, exposing soft core.	Failure of core.
Pitting and Spalling Page 9	Initial Pitting	Small pits . . . size of a pin head or smaller.	1. Pitting following wear caused by: Abrasive in oil (abrasive wear). Low speed operation at heavy loads. Scoring. 2. Pitting of case-hardened gears caused by: Excessive loads for long periods of time. Insufficient oil film thickness. Surface decarburization.
	Destructive Pitting	An increase in number and size of pits . . . advanced to the stage that gears are noisy.	
	Spalling	Flaked out areas.	
Welding Page 11	Superficial Scoring	Single vertical lines or small patches of seized area.	1. Excessive oil temperature. Metal-to-metal contact. Excessive speed. Lack of proper lubricant or inadequate lubrication and cooling. 2. Surface decarburization.
	Severe Scoring	Advanced stage of superficial scoring.	
	Galling	Particles of metal torn from the tooth surface.	Dirt or other abrasive particles in the oil.
	Abrasive Wear	Satiny lapped-in appearance & irregular profile often accompanied by pitting.	
	Plastic Yielding	Severe flow of surface material generally resulting in the formation of lips on the ends and/or tips of the gear teeth. These lips are usually of uneven height.	Inadequate hardness.

List of Illustrations

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