Gear Failure and Its Causes

(Kegagalan Roda-Gigi dan Penyebabnya)

Introduction

New gear design based on : 1. Texbook logic.
2. Practical field experience.

• Correct failure analysis is very important for new gear design consideration, also for improving gear maintenance.

• Therefore, in this session, we will study the kind of gear failure and the cause of gear failure.

ANALISA MASALAH SISTIM RODA GIGI

Perhatikan seluruh power package dan history-nya, khususnya paket tertentu sebelum studi secara detil tentang gear-teeth dan bearing.

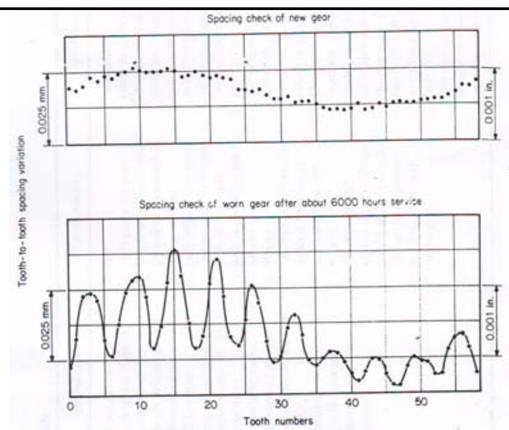
1. PENENTUAN PROBLEM

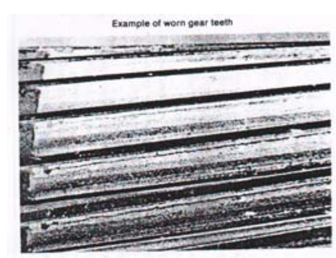
Satu atau beberapa hal ini mungkin dipakai sbb. :

Problem	Consequences
Broken part	Drive system probably inoperable
Abnormally worn part	Drive system probably operable; may be unfit to continue operation for any appreciable time
Abnormal vibration	Drive system probably operable; may be unfit to continue operation for any appreciable time
Abnormal noise	Drive system operable; may be environmental hazard or prone to early failure
Abnormal part temperature; abnormal oil temperature	Drive system may be operable, but in danger of early failure
Serious oil leakage	Drive system operable, but an environmental hazard; may be in danger of early failure
Part seized in its bearings; part moved out of position and jammed with another part	Drive system will not transmit torque; "inoperable" condition may be more apparent than defect which caused it

Contoh kerusakan gigi pada roda gigi kecepatan tinggi.

Kerusakan menunjukan adanya keausan (wear) pada permukaan gigi, kemudian terjadi kegagalan karena gigi patah atau gagal pada bearing.





2. POSSIBLE CAUSES OF GEAR-SYSTEM FAILURE

Beberapa faktor yang dapat menimbulkan kegagalan pada sistim roda gigi (Gear system) :

1. **Perancangan (Design)**
2. **Pembuatan (Manufacturing)**
3. **Pemasangan (Installation / Assembling)**
4. **Lingkungan (Environment)**
5. **Pemakaian (Operation)**

Hal-hal umum yang perlu diperhatikan jika sistem roda gigi mengalami kegagalan :

Design	Manufacture	Installation	Environment	Operation
1. Kind of gear (spur, helical, bevel, worm, Spiroid) 2. Design arrangement 3. Tooth design 4. Gear body design 5. Shaft design 6. Bearing design 7. Casing design 8. Seal design 9. Bolting design 10. Lubrication-system design 11. Vibration criticals known and tolerable	1. Tooth accuracy (profile, spacing, lead, concentricity) 2. Tooth material (hardness, composition, cleanliness) 3. Gears (weld quality or casting quality, fit to shaft, balance, etc.) 4. Casings (bore sizes, bore position accuracy; joint flatness and squareness, oil tightness) 5. Assembly (right parts, correct bolt tightening, fits checked)	1. Foundation (adequate rigidity) 2. Alignment (with driving and driven units) 3. Oil system (clean, all connections made, oil filled properly) 4. Instrumentation (temperature, pressure, flow, vibration OK) 5. Bolting (to foundation, flanges, shaft couplings)	1. Air (adequate for cooling, not polluted with fly ash or chemicals) 2. Temperature (not adjacent to hot equipment, extremes of heat and cold within specification limits) 3. Water (adequate protection against rain water, sea water, swamp water) 4. Housekeeping (spare parts or disassembled parts can be cleaned and protected from rust and corrosion)	1. Break-in (may require oil change after short initial run; may require some running at reduced load before maximum load is applied) 2. Operation (meet specification limits on temperature, oil flow, power rating, etc.) 3. Overload (operate without undue extra loading) 4. Misapplication (high-speed idling, run backward, stall at excess torque, etc.) 5. Starting (no undue starting torque or vibration in starting interval)

INCOMPATIBILITY PADA SISTIM RODA GIGI

Tidak sesuainya sistim lain (diluar sistim roda gigi) dapat mengakibatkan rusaknya sistim roda gigi.

Beberapa contoh ke-tidak-sesuaian dalam sistim roda gigi

Vibration	Misalignment	Reactions	Temperature
1. Gear-tooth meshing frequency breaks turbine blades 2. Reciprocating engine or compressor in trouble with valves or timing. Serious torque pulsations and low-frequency vibration 3. Propeller changed. New vibration mode not tolerable to gear unit 4. Imbalance in heavy gearing shakes light section of turbine	1. Turbine or diesel engine shifts position as it heats up. Drive to gear unit seriously misaligned or out of position axially 2. Foundation shift under heavy driven equipment. Gear casing becomes twisted 3. Thrust bearing wears in prime mover. Axial shift overloads gear thrust bearing 4. Hull of ship or frame of airplane shifts as cargo load changes. Movement too much for gearbox (beyond design allowance)	1. Coupling reactions aggravate gearbox bearings 2. Overhung load on gear output shaft beyond design allowance 3. Imbalance of high-speed impeller overhung from pinion prematurely fails pinion bearings 4. Heavy vibration-absorbing coupling with multiple pads has a pad in trouble. Severe moment applied to gear shaft, leading to gear-bearing and/or gear-tooth failure	1. Heat of engine exhaust puts thermal distortion into gearbox 2. Hot exhaust of engine too close to air-cooled heat exchanger for package oil system 3. Package start-up too quick for thermal equilibrium to be established in gearbox. Bearing seizure due to lack of clearance and/or gear-tooth seizure due to lack of backlash 4. Common oil drain from gearbox overloaded with hot, frothy oil from other system equipment. High-speed gears overheat due to gearbox flooding

IVESTIGATION OF GEAR SYSTEM

Karena ada variasi yang cukup luas yang mempengaruhi kegagalan sistem roda gigi, maka perlu untuk memperhatikan lingkungan nyata sekeliling sistem tenaga (power sistem) yang sedang di-investigasi.

Checklist of Factual Information May be Useful in Investigating Gear Failure

Identification	History	Design and manufacturing	Environment
1. Kind of drive system (identify driving and driven equipment) 2. Serial numbers (of package, of gear unit, of gear or pinion involved) 3. Drawing numbers or catalogue numbers (of gear or pinion involved, of bearings, of couplings to gear unit) 4. Geographic (address of site, identification of building or vehicle for each gear unit) 5. Company names (owner, package builder, gear-unit builder, gear parts makers)	1. Who designed gear unit, and when 2. Extent and nature of development test work 3. Number of similar units built 4. Number of units in service 5. Expected or operating TBO 6. Expected or proven design life 7. When unit was built, and when put into service 8. Load histogram data 9. Frequency of starts 10. Condition of gears at last overhaul or inspection before failure	1. Compliance with AGMA specifications 2. Compliance with other specifications (bearings, couplings, API, ISO, etc.) 3. Kind of heat treatment for gears 4. Method of finishing gear teeth 5. Kind of oil and operating temperature limits 6. Quality plan for geometric accuracy 7. Quality plan for metallurgical control 8. Design drawings of each gear and pinion involved 9. Bearing and coupling design data	1. Weather (typical and extremes) 2. Possible pollutants in air 3. Possible exposure to water, mud, wear debris, etc. 4. Proximity of other machinery (consider vibration, heat, and fumes from nearby machines or process equipment) 5. Nature of foundation or vehicle supporting gear unit 6. Possible damage in storage, in handling, or in cleaning parts

ANALYSIS OF TOOTH FAILURE AND GEAR-BEARING FAILURES

Dalam sesi ini akan difokuskan pada unit roda gigi dan secara detil pada kegagalan gigi roda-gigi (gear-tooth) dan bearing roda gigi (gear bearing).

Nomenclature of Gear Failure

Berbagai macam kegagalan (failure) roda gigi dan klasifikasi (nomenclature) untuk menguraikan kegagalan tersebut telah di-standard-kan oleh AGMA (American Gear Manufacturing Association).

Dokumen terkini, adalah American National Standard (ANS), yang disponsori oleh AGMA dan American Society of Mechanical Engineer (ASME).

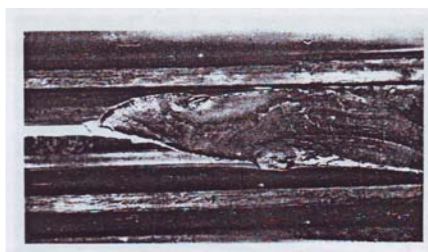
Ada banyak cara (sekitar 18), yang dapat menyebabkan kerusakan pada permukaan gigi roda gigi, dan ada tiga macam patahan gigi roda-gigi. Seorang gear-engineer yang sedang menganalisa gagalnya roda-gigi tidak perlu care terhadap semua item, tetapi hanya care terhadap hal-hal yang sangat mungkin mendekatinya untuk menjabarkan penemuannya.

Hal itu akan memberikan penyeleseian gear failure properly.

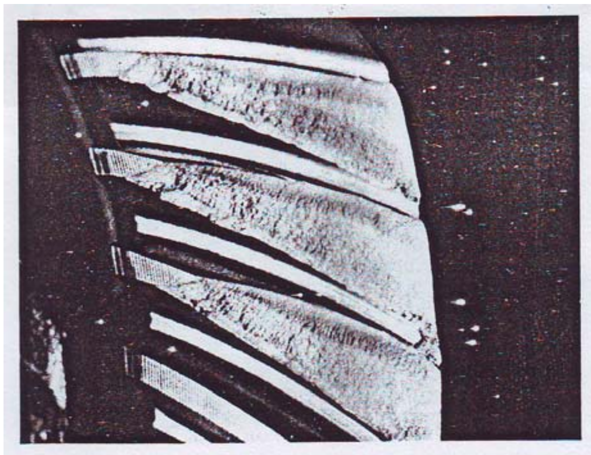
Berikut adalah beberapa contoh gear-tooth failures.

Contoh-contoh tooth breakage (patahan gigi roga gigi)

a) Helical gear, 38 HRC

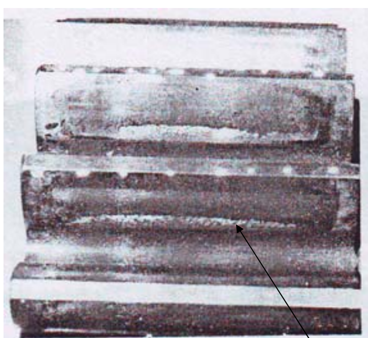


b) Spur gear, 55 HRC

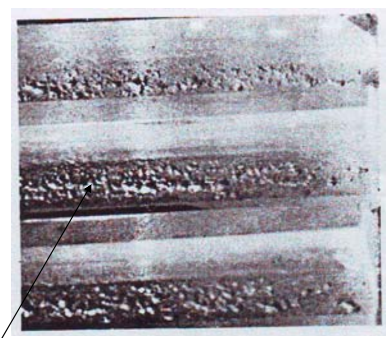


c) Bevel gear, 58 HRC

Contoh kerusakan : macro-pitting

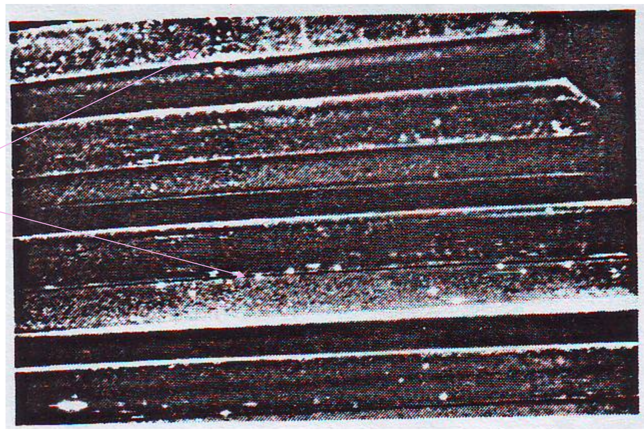


a) Spur gear, 60 HRC



b). Helical gear, 35 HRC

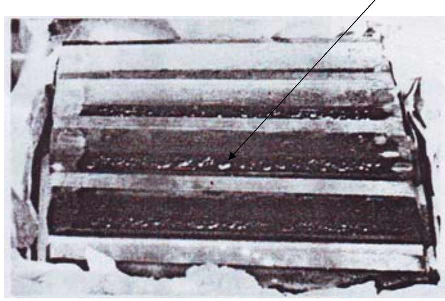
Pitting



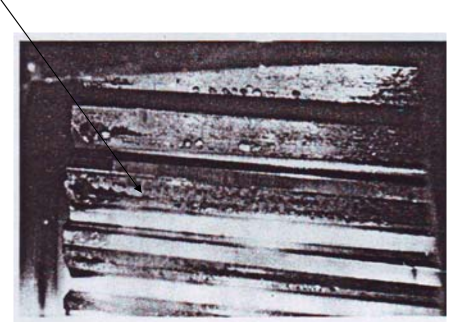
pitting

c) Macro-pitting pada helical gear, 35 HRC

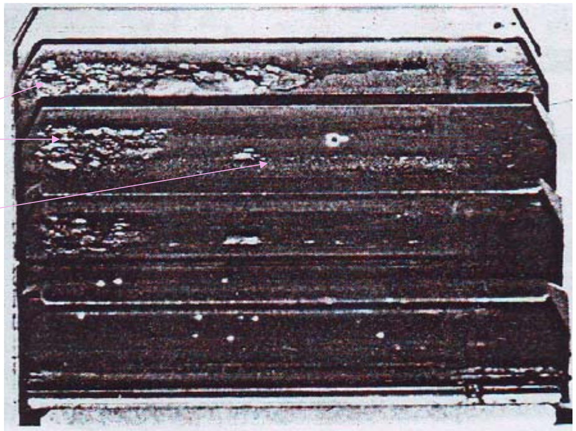
pitting



Gross-pitting pada helical gear, 35 HRC.

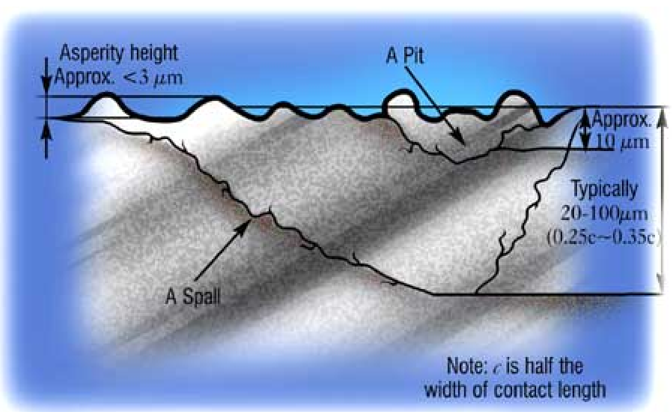


Helical gear, 35 HRC



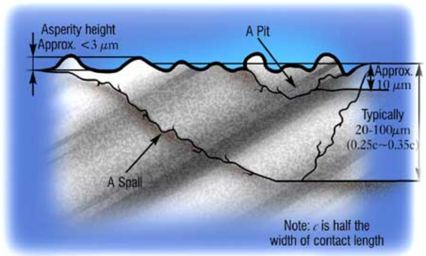
Spur gear, 60 HRC. Menunjukan adanya gross pitting dan spalling.

Pitting and Spalling

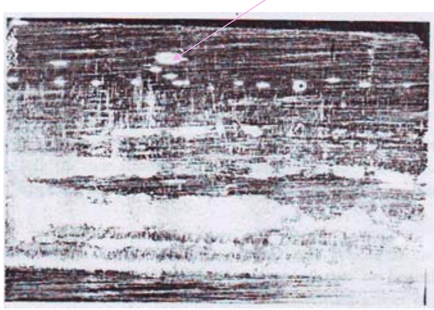


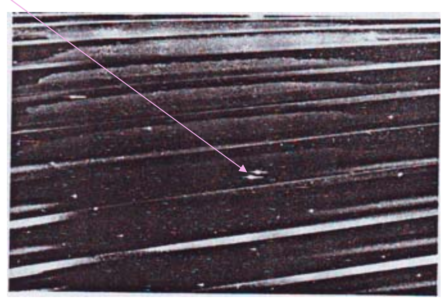
Pitting and Spalling

- Cara mengatasi :
- ✓ Mengurangi beban dan kecepatan sliding
- ✓ Lubrikasi yang bertujuan mengurangi friksi sehingga:
  - Mengurangi tangensial shear dan tensile stress
  - Meningkatkan heat transfer shg thermal stress berkurang
  - Lurikasi yang baik memudahkan dalam mendistribusikan tekanan keseluruh bagian gigi (menghindari lokalisasi panas dan tekanan)
- ✓ Keakuratan surface geometry, dan tingkat kehalusan surface yang tinggi pada gear



Micro-pitting





Micro-pitting, spur-gear, 60 HRC

Micro-pitting, helical-gear, 60 HRC

Micro pitting though as erosion

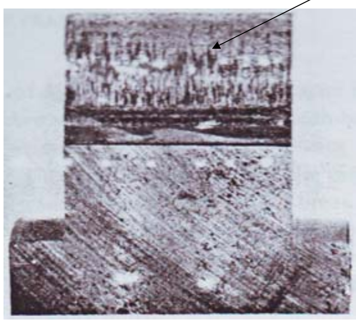
1000 x magnification of section through pits. Micro pitting often precedes macro pitting.

SCORING

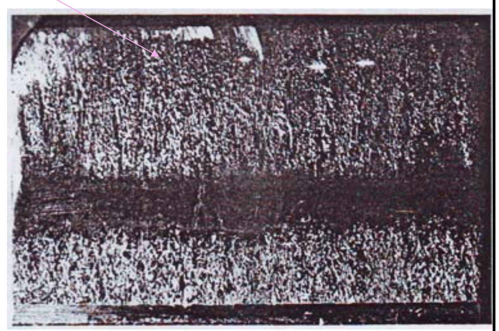
Scoring is surface damage due to accumulated small seizures caused by sliding under improper lubrication or under severe operating conditions.

Contoh pada bearing.

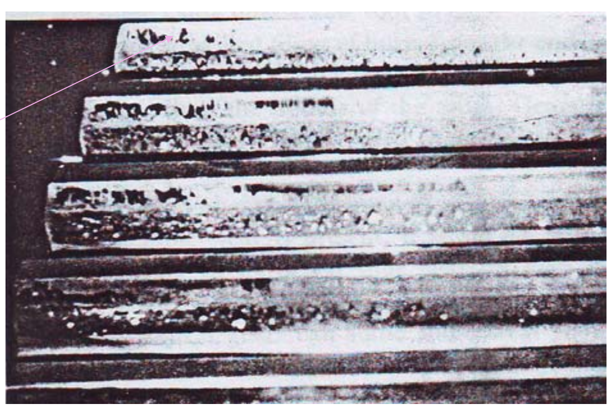
SCORING



Spur gear, 60 HRC



Spur gear, 60 HRC



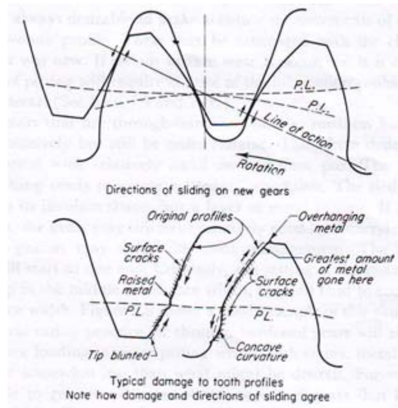
Helical gear, 35 HRC.

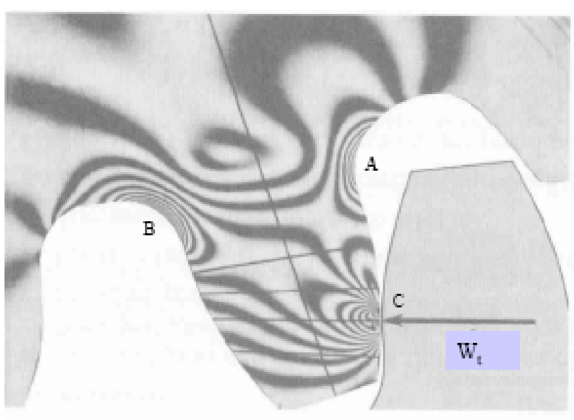
PITTING OF GEAR

Pitting adalah salah satu dari fatigue fracture, yang umumnya terjadi pada range antara 10.000 s/d 20.000 siklus. Umumnya terjadi pada pitch line.

Roda-gigi pinion lebih sering terjadi pitting dari pada gear, karena pinion berfungsi sebagai penggerak shg. arah dari sliding menyimpang dari pitch line.

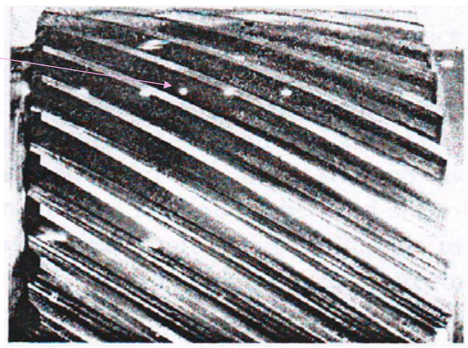
Pengaruh arah sliding pada permukaan gigi roda-gigi ketika mulai gagal karena pitting, wear, plastic flow of metal.





Tegangan pada gigi roda-gigi diambil dengan photo elasticity

Pitting



A misaligned helical gear has pitting which is progressing across face with.

SCORING FAILURE

Scoring merupakan kegagalan pelumasan (*lubrication failure*). Tears (robek) dan scratches (goresan) terlihat pada permukaan gigi. Tidak seperti kegagalan fatigue, yang terjadi setelah banyak siklus, scoring terjadi segera setelah roda gigi baru dioperasikan pada kecepatan dan beban penuh.

Walaupun scoring adalah lubrication failure, tetapi itu tidak dapat menyalahkan lubrication dalam banyak kasus.

Lubrication failure

1. Manufacturing (gear finishing)
2. Design : High hertz stresses and high sliding velocity at the tip of teeth.

→ **Scoring**

Untuk menghindari high hertz stresses dan high sliding velocity, designer harus dapat memilih pitch, addendum yang tepat, dan juga modikasi provil involute.

Ada 4 tempat terjadinya scoring :

1.Ketika ujung gigi gear kontak dengan akar (root) pinion.

2.Pada titik terendah dari single-tooth contact pada pinion.

3.Pada titik tertinggi dari single-tooth contact pada pinion.

4.Ketika ujung gigi pinion kontak akar gear.

Semakin tinggi tingkat kekerasan material roda gigi maka semakin sulit terjadi scoring.

Pada pasangan roda gigi yang menggunakan materials untuk pinion setingkat lebih keras akan menghasilkan score-resistance lebih bagus. Contohnya, case-hardened pinion berpasangan dengan medium-hard gear akan menghasilkan score-resistance lebih bagus dari pada keduanya, pinion dan gear menggunakan bahan yang sama.

Ada dua macam scoring i.e. 1) initial scoring, dan 2) severe scoring.

Initial scoring yaitu scoring terjadi sementara lalu stop.

Severe scoring yaitu scoring terjadi berulang-ulang hingga gigi roda gigi patah.

WEAR FAILURE

Wear means damage caused by use.

Tooth wear : pitting, scoring, tooth breakage, and abrasion.

The regions of gear failure

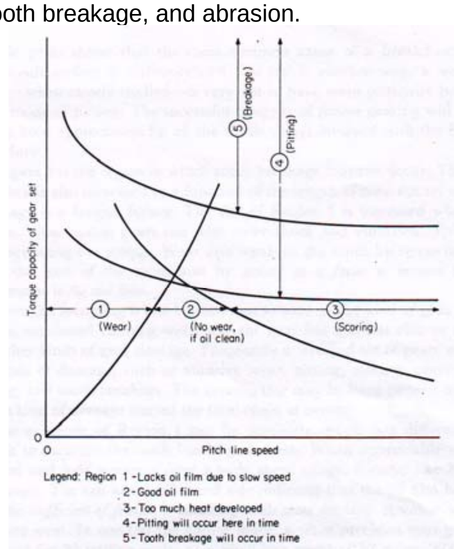
Too thin oil or too rough surface finish will make region 1.

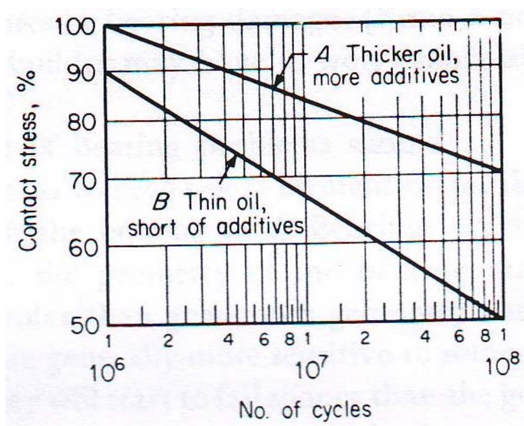
Region 2 is ideal place to run a gear-set.

In region 3, there is rapid failure, since the speed is high enough, so too much heat is developed. Film break down, and scoring or welding.

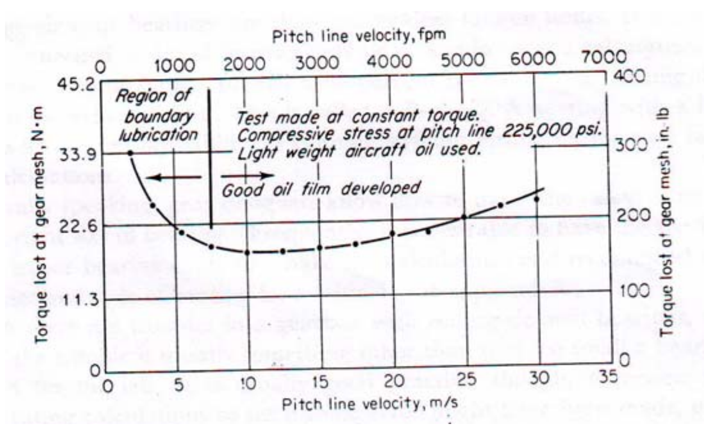
In region 4 pitting occur. It is also enlarged by poor of lubrication condition.

In region 5, tooth breakage occur. This region is increase when wear occur. Wear make gear run with more shock and vibration.





Perubahan secara substantial pada pelumasan akan meningkatkan tegangan kontak ijin dari kurva B ke A.



Friction torque as a function of speed.

Dari hasil test pada spur gear dengan 20 million siklus menunjukan bahwa :

1. Pada pitch line speed 30 m/s (6000 fpm), wear < 2,5 μm (0,0001 in)
2. Pada pitch line speed 5 m/s (1000 fpm), wear menjadi 13 μm (0,0005 in)

GEARBOX BEARING

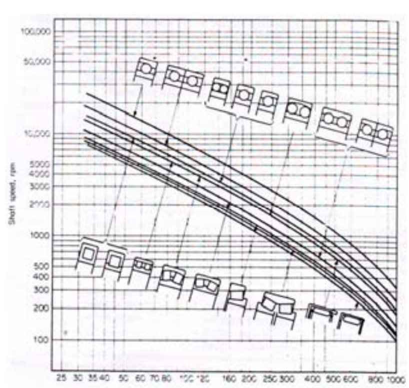
Beberapa macam hal yang keliru (wrong things) yang dapat mengakibatkan masalah pada bearing :

1. Unit (gearbox) bekerja dengan adanya benda luar pada sistim pelumasan (iron filings, sand, dirt, water, acid, etc).
2. Unit bekerja terlalu panas.
3. Unit bekerja pada permukaan jalan kasar, yang dapat menimbulkan kerusakan melalui getaran atau fretting corrosion.
4. Unit bekerja pada getaran tinggi (high vibration).
5. Unit mengalami missaligned.
6. Penggerak unit bekerja dalam kondisi tidak bagus (turbin tidak balance, etc.
7. Kopling yang menghubungkan unit (gearbox) dan alat lainya bekerja dalam kondisi kurang bagus (missaligned, ada moment, thrusts, etc).

ROLLING ELEMENT BEARING

Rolling element bearing meliputi ball, cylindrical roller, tapered roller.

Jika ada masalah pada gearbox dengan roller bearing, penyebab masalah biasanya bukanlah ukuran bearing yang terlalu kecil, tapi karena adanya masalah lainya.



General guide to when speed become critical in rolling element gear-bearing.

Beberapa hal yang perlu diperhatikan dalam investigasi rolling-element bearing :

1. Fit bearing pada poros dan rumah tidak tepat.
2. Bearing tidak terlumasi dengan baik dan terlalu panas.
3. Internal clearance bearing salah/tidak tepat.
4. Bearing mengalami kerusakan pada saat assembly, pengiriman, dan overhoul.
5. Bearing tidak dibuat dengan teknik yang tepat oleh pembuatnya.
6. Benda luar masuk pada bearing.
7. Pemilihan bearing pada gearbox tidak tepat untuk style of rolling element bearing.
8. Akurasi material bearing kutang tepat untuk pemakaian pada keceptan tinggi.

TABLE 7.4 Defects in Manufacture of Rolling-Element Bearings

Kind of bearing	Kind of defect		
	Races	Rolling elements	Cages
Ball bearing	• Curvature not held closely to design • Hardness too low or too high • Grain size too large • Cleanness of steel not up to specifications	• Balls not all round and of good finish • Missing ball • Nicked ball • Hardness too low • Grain size too large • Cleanness of steel not up to specifications	• Broached with a dull or worn broach • Plating defective • Composition of material out of limits
Roller bearing*	• Guide rail at wrong angle • Finish of guide rail inadequate • Clearance of roller in guide rails too small or too large	• Roller end out of square with roller axis • Roller crown wrong or out of position on roller • Roller corners not rounded properly • Roller ends not finished smoothly	• Shape of pocket wrong to fit roller • Pocket clearance too small or too large • Cage blocks oil entry • Cage not guided adequately

*All the items for ball bearings apply to roller bearings.

Analisa kerusakan bearing secara detil dapat dilihat pada bagian lain.

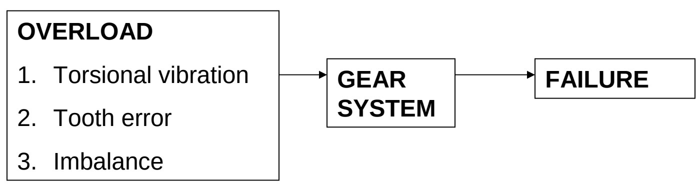
OVERLOAD GEAR FAILURE

Designer biasanya akan memperhitungkan kekuatan roda-gigi berdasarkan daya yang ditransmisikan, tetapi sangan mungkin terjadi torsional vibration pada gear yang akan memberi overload.

Ada beberapa cara untuk mengilangkan torsional vibration, yaitu dengan merubah kekakuan poros, mengurangi inersia benda-benda berputar, merubah amplitudo dan frekwensi vibration.

Tooth error, juga menyebabkan overload karena dengan adanya tooth error, maka kecepatan putar menjadi tidak konstan. Perubahan kecepatan akan menyebabkan momentary overload. Load ini biasa disebut dynamic load.

Imbalance juga akan menimbulkan overload pada roda gigi, maka dari itu gear yang selalu perputar perlu dibalance dengan baik.



LUBRICATION FAILURE

Gear designer biasanya dapat menghasilkan hasil terbaik dengan keduanya yaitu good mechanical design dan good lubrication.

Kegagalan lubrication disebabkan oleh salah satu dari hal-hal sbb.:

1. Lubricating oil tidak mempunyai additive yang tepat atau additive yang cukup untuk menerima load, speed kondition, temperature untuk pemakaian khusus. Koeefisien gesek besar dan aus (wear) biasanya akibat inadequate additive.
2. Lubricating oil tidak mempunyai viscositas yang cukup untuk membentuk oil film pada permukaan yang kontak. Gear kecepatan rendah umumnya perlu viscous film oil dengan good chemical additives.
3. Panas yang diberikan gear tidak dipindahkan secara cukup cepat oleh media lubrication.
4. Wear product dan corrosion pada permukaan gigi tidak dibilas oleh lubrication.
5. Lubricant tercemar oleh dirt, sand, metal particles, sluge, or acids.
6. Sistem lubrication tidak cukup membasahi permukaan gigi sebelum ontak.
7. Lubricant tidak terkontaminasi, tetapi ada kebocoran, penguapan, etc.

Fluids used to lubricate gears.

Fluids	Oiliness	Where used
Petroleum oils	Good	All types of gears except under unusual temperature conditions
Diester	Good	Aircraft and military gears with wide temperature ranges
Polyglycol	Good	Some bronze gears, steel gears at very high temperatures
Silicone	Poor	Some extreme-temperature cases, light load
Water	Very poor	Some nonmetallic gears
Phosphates	Good	Aircraft hydraulic equipment

Viscosity range for AGMA Lubricants.

Rust and oxidation inhibited gear oils, AGMA lubricant no.	Viscosity range,[a] mm^2/s (cSt) at 40°C	Equivalent ISO grade[b]	Extreme-pressure gear lubricants,[c] AGMA lubricant no.	Viscosities of former AGMA system,[d] SSU at 100°F
1	41.4 to 50.6	46		193 to 235
2	61.2 to 74.8	68	2 EP	284 to 347
3	90 to 110	100	3 EP	417 to 510
4	135 to 165	150	4 EP	626 to 765
5	198 to 242	220	5 EP	918 to 1122
6	288 to 352	320	6 EP	1335 to 1632
7 Comp[e]	414 to 506	460	7 EP	1919 to 2346
8 Comp[e]	612 to 748	680	8 EP	2837 to 3467
8A Comp[e]	900 to 1100	1000	8A EP	4171 to 5098

Note: Viscosity ranges for AGMA lubricant numbers will henceforth be identical to those of ASTM 2422.

[a] "Viscosity System for Industrial Fluid Lubricants," ASTM 2422. Also British Standards Institute, B.S. 4231.

[b] "Industrial Liquid Lubricants—ISO Viscosity Classification." International Standard, ISO 3448.

[c] Extreme-pressure lubricants should be used *only* when recommended by the gear drive manufacturer.

[d] AGMA 250.03, May 1972, and AGMA 251.02, November 1974.

[e] Oils marked Comp are compounded with 3 to 10 percent fatty or synthetic fatty oils.

This table was extracted from AGMA Specification "Lubrication of Industrial Enclosed Gear Drives" (AGMA 250.04, 1981) with the permission of the publisher, the American Gear Manufacturers Association, Suite 1000, 1901 North Fort Myer Drive, Arlington, VA 22209.

TABLE 7.8 AGMA Lubricant Number[a,b] Recommendations for Enclosed Helical, Herringbone, Straight Bevel, Spiral Bevel, and Spur Gear Drives

Type of unit[c] and low-speed center distance	Ambient temperature[d,e]	
	−10°C to +10°C (15°F to 50°F)	10°C to 50°C (50°F to 125°F)
Parallel shaft (single reduction)		
Up to 200 mm (to 8 in.)	2–3	3–4
Over 200 mm to 500 mm (8 to 20 in.)	2–3	4–5
Over 500 mm (over 20 in.)	3–4	4–5
Parallel shaft (double reduction)		
Up to 200 mm (to 8 in.)	2–3	3–4
Over 200 mm (over 8 in.)	3–4	4–5
Parallel shaft (triple reduction)		
Up to 200 mm (to 8 in.)	2–3	3–4
Over 200 mm to 500 mm (8 to 20 in.)	3–4	4–5
Over 500 mm (over 20 in.)	4–5	5–6
Planetary-gear units (housing diameter)		
Up to 400 mm (to 16 in.) O.D.	2–3	3–4
Over 400 mm (over 16 in.) O.D.	3–4	4–5
Straight or spiral-bevel-gear units		
Cone distance to 300 mm (to 12 in.)	2–3	4–5
Cone distance over 300 mm (over 12 in.)	3–4	5–6
Gear motors and shaft-mounted units	2–3	4–5
High-speed units[f]	1	2

TABLE 7.9 AGMA Lubricant Number[a] Recommendations for Enclosed Cylindrical and Double-Enveloping Worm-Gear Drives

Type, worm-gear drive	Worm speed[c] (rpm) up to	Ambient temperature[b]		Worm speed[c] (rpm) above	Ambient temperature[b]	
		−10°C to +10°C (15° to 50°F)	10°C to 50°C (50° to 125°F)		−10°C to +10°C (15° to 50°F)	10°C to 50°C (50° to 125°F)
Cylindrical worm[d]						
Up to 150 mm (to 6 in.)	700	7 Comp, 7 EP	8 Comp, 8 EP	700	7 Comp, 7 EP	8 Comp, 8 EP
Over 150 mm to 300 mm (6 to 12 in.)	450	7 Comp, 7 EP	8 Comp, 8 EP	450	7 Comp, 7 EP	7 Comp, 7 EP
Over 300 mm to 450 mm (12 to 18 in.)	300	7 Comp, 7 EP	8 Comp, 8 EP	300	7 Comp, 7 EP	7 Comp, 7 EP
Over 450 mm to 600 mm (18 to 24 in.)	250	7 Comp, 7 EP	8 Comp, 8 EP	250	7 Comp, 7 EP	7 Comp, 7 EP
Over 600 mm (over 24 in.)	200	7 Comp, 7 EP	8 Comp, 8 EP	200	7 Comp, 7 EP	7 Comp, 7 EP
Double-enveloping worm[d]						
Up to 150 mm (to 6 in.)	700	8 Comp	8A Comp	700	8 Comp	8 Comp
Over 150 mm to 300 mm (6 to 12 in.)	450	8 Comp	8A Comp	450	8 Comp	8 Comp
Over 300 mm to 450 mm (12 to 18 in.)	300	8 Comp	8A Comp	300	8 Comp	8 Comp
Over 450 mm to 600 mm (18 to 24 in.)	250	8 Comp	8A Comp	250	8 Comp	8 Comp
Over 600 mm (over 24 in.)	200	8 Comp	8A Comp	200	8 Comp	8 Comp

[a] Both EP and compounded oils are considered suitable for cylindrical-worm-gear service. Equivalent grades of both are listed in the table. For double-enveloping worm gearing, EP oils in the corresponding viscosity grades may be substituted only where deemed necessary by the worm-gear manufacturer.

[b] Pour point of the oil used should be less than the minimum ambient temperature expected. Consult gear manufacturer on lube recommendations for ambient temperatures below −10°C (14°F).

[c] Worm gears of either type operating at speeds above 2400 rpm or 10 m/s (200 fpm) rubbing speed may require force-feed lubrication. In general, a lubricant of lower viscosity than recommended in the above table shall be used with a force-feed system.

[d] Worm-gear drives may also operate satisfactorily using other types of oils. Such oils should be used, however, only upon approval by the manufacturer.

This table was extracted from AGMA Specification "Lubrication of Industrial Enclosed Gear Drives" (AGMA 250.04, 1981) with the permission of the publisher, the American Gear Manufacturers Association, Suite 1000, 1901 North Fort Myer Drive, Arlington, VA 22209.

TABLE 7.10 Typical Vehicle Gear Lubricants

Designation of oil	Viscosity range, SSU			
	At 0°F (−18°C)		At 210°F (99°C)	
	Min.	Max.	Min.	Max.
Motor oil SAE No.				
5W	—	4,000	—	—
10W	6,000	12,000	—	—
20W	12,000	48,000	—	—
20	—	—	45	58
30	—	—	58	70
40	—	—	70	85
50	—	—	85	110
Gear oil SAE No.				
75	—	15,000	—	—
80	15,000	100,000	—	—
90	—	—	75	120
140	—	—	120	200
250	—	—	200	—

THERMAL PROBLEM IN FAST-RUNNING GEARS

Pada gear kecepatan tinggi, gesekan antara udara sekeliling dapat menyebabkan serious overheating.

Spur gear dengan poros paralel dan straigh bevel gear dengan poros tegak lurus mempunyai efisiensi pelepasan panas yang buruk. Tetapi helical gear dan spiral bevel mempunyai efisiensi pelepasan panas yang baik.

Spur gear dan straight bevel gear mempunyai kecepatan max 10 m/s (2000 fpm),

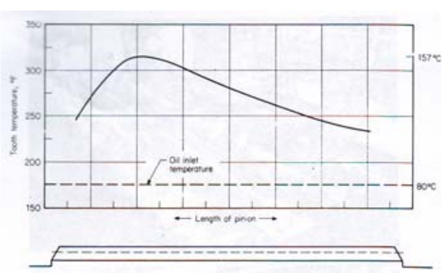


FIG. 7.16 Temperature of pinion teeth across the face width. This is a random example of unpublished test data. Axial meshing velocity exceeded 800 m/s (160,000 fpm).

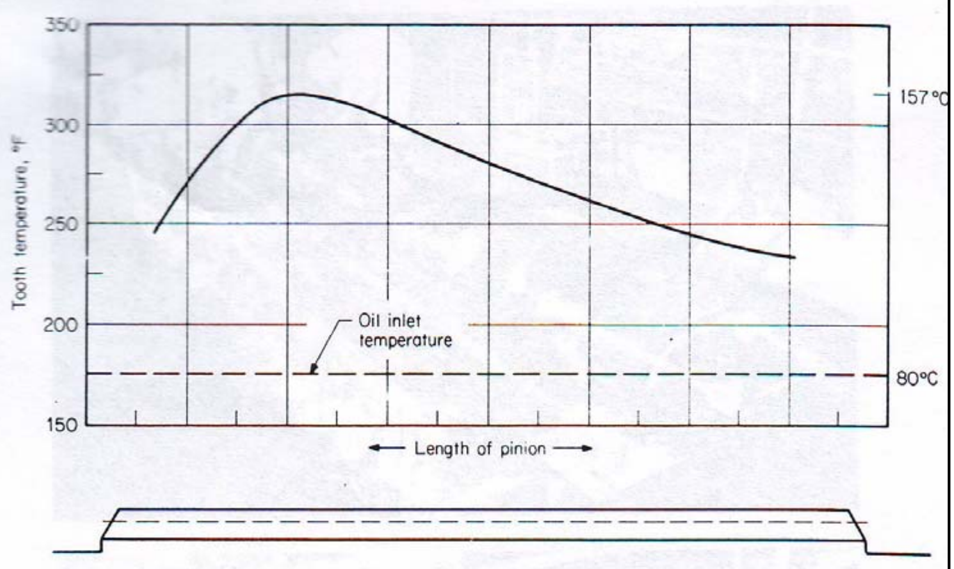


FIG. 7.16 Temperature of pinion teeth across the face width. This is a random example of unpublished test data. Axial meshing velocity exceeded 800 m/s (160,000 fpm).

Kegagalan gearbox dapat dihasilkan dari masalah thermal oleh salah satu dari hal-hal sbb.:

1. Carburized gear teeth mengalami cukup overheating kemudian menjadi lunak,
2. Gear teeth score atau pit karena oil-film breakdown pada gigi overheated.
3. Thermal patern menyebabkan thermal distortion kemudian mempengaruhi seriusly tooth contact pattern.
4. Therma distortion dari casing membuat misaligned pada gear dan/atau bearing.
5. Gear-bearing dari overheated area of casing gagal dari overheating.
6. Beberapa severity dari thermal troubles dapat dilihat pada tabel berikut.

Contoh adanya decoloring pada bearing
karena overheated.

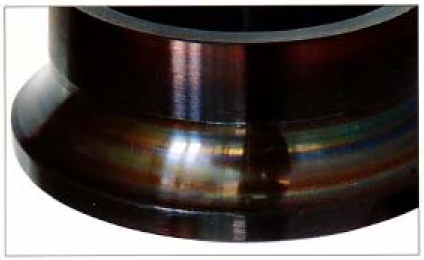


Photo 7-18-1
Part: Inner ring of an angular contact ball bearing
Symptom: Bluish or purplish discoloration on raceway surface
Cause: Heat generation due to poor lubrication

Photo 7-18-2
Part: Inner ring of a 4-point contact ball bearing
Symptom: Bluish or purplish discoloration on raceway surface
Cause: Heat generation due to poor lubrication

TABLE 7.11 Severity of Thermal Problems with Helical Gears

Axial meshing velocity V_x		
m/s	fpm	Severity
400	80,000	No trouble except in very large units where thermal distortion may be enough to require correction. (Need good oil-jet system and generous size casing)
500	100,000	Probably no serious trouble. (Need very good oil-jet system and generous size casing for gear sizes)
700	140,000	Probably have some trouble. May be manageable if gears are not too large and thermal distortions are handled by compensations in tooth fit
850	170,000	Usually difficult to handle. Much skill in tooth compensations needed plus special quality of lubricant
1000	200,000	Probably impractical to handle even with utmost design skill

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850	170,000	Usually difficult to handle. Much skill in tooth compensations needed plus special quality of lubricant
1000	200,000	Probably impractical to handle even with utmost design skill

TABLE 7.12 Relation of Helix Angle to Meshing Velocities

Tangential meshing velocity		Axial meshing velocity							
		10° helix		15° helix		30° helix		35° helix	
m/s	fpm	m/s	fpm	m/s	fpm	m/s	fpm	m/s	fpm
100	20,000	567	113,000	373	75,000	173	35,000	143	29,000
125	25,000	709	142,000	467	93,000	217	43,000	179	36,000
150	30,000	851	170,000	560	112,000	260	52,000	214	43,000
175	35,000	992	198,000	653	131,000	303	61,000	250	50,000

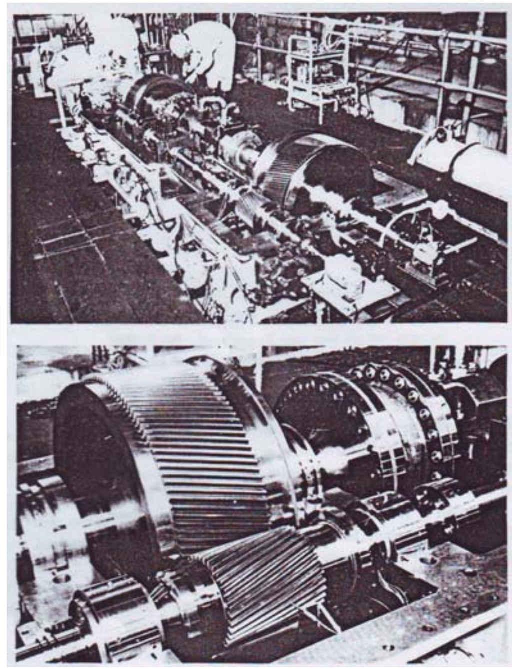

FIG. 7.17 Test gears and test bed arrangement for ultra high speed gear testing. *(Courtesy of Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan.)*

Failure Mode and Effect Analysis of Gearbox

Hierarchy	Failure Mode / Failure Cause	Operational Phase	Local Effects	Next Higher Level	End Effects	Fault Detection	Compensating Provisions
1	Bearing failure	Misalignment in bearing while installation	Clearance between meshing gear teeth increases	Increase in temperature within gearbox	Bearing failure	Sound, smell and visual indication. Improper performance of gearbox	Check for misaligned bearings and mounting misalignment in motor during maintenance hours
2	Wear and tear of gears	More metal-to-metal contact between gears. Increase in clearance between meshing gears	Increase in temperature within gearbox	Increase in temperature within the gearbox with more metal-to-metal contact over a period of time	Gearbox failure	Sound, smell and visual indication. Improper performance of gearbox	Proper lubrication of meshing gears
3	Failure of seals	Improper lubrication	Inadequate lubrication leads to added temperature on seals. Too much lubrication causes excess fluid pressure and this provides an escape route to lubricating material in system	If temperature exceeds absorption capability of seals, then seals tend to wear off. Seals start leaking due to excess lubrication	Seal and gearbox failure	Sound, smell and visual indication. Improper performance of gearbox	Proper lubrication and change the seals regularly based on maintenance schedule
4	Improper lubrication	When the layer of lubrication between bearing and casing is improper	Inadequate lubrication leads to added temperature on seals. Too much lubrication causes ex-	If temperature exceeds the absorption capability of the	Seal and gearbox failure	Sound, smell and visual indication. Im-	Proper lubrication
			cess fluid pressure and this provides an escape route to the lubricating material in the system	seals, then seals tend to wear off. Seals start leaking due to excess lubrication		proper performance of gearbox	

TABLE 5.8 Trouble Chart

Trouble	What to inspect
Heating	Is unit and fan assembly covered with dirt? Is unit overloaded? Has recommended oil level been exceeded or is level too low? Are couplings in alignment? Have bearings been properly adjusted? Are oil seals or stuffing boxes the cause? Is oil clean or is sludge content high? Have oil filters been cleaned? Is oil pump functioning?
Shaft failure	Check alignment; many shafts fail owing to misalignment. Some troubles are caused by use of rigid couplings. Is an overhung load beyond the capacity of unit? Is unit subject to high dynamic loads or extreme repetitive shocks not previously considered?
Bearing failure	Rust formation caused by high humidity or the entrance of water. Unsuitable lubricant or the lack of a sufficient amount of lubrication. Abnormal loading causing excessive deflection which could result in flaking, cracks, and fractures. Improper adjustment causing abnormal loading if bearings are excessively preloaded, or abnormal bearing and gear wear if bearings have excessive freedom. Depending on bearing type, proper mounting and setting could be critical.
Oil leakage	Check oil seals and replace if worn. Check for housing pressure buildup due to a blocked breather. Check stuffing boxes and adjust or replace packing. Check tightness of drain, level, and other plugs or fittings.
Gear wear	Excessive loads. Incorrect lubrication. Insufficient lubrication. Misalignment due to worn bearing. Backlash may be insufficient. Lubricant carrying foreign matter, e.g., abrasive dirt or particles of worn metal teeth. Excessive temperature. Excessive speeds.
Noise or vibration	Bad alignment. Loose or worn bearings. Insufficient lubrication. Excessive lubrication. Gear wear.