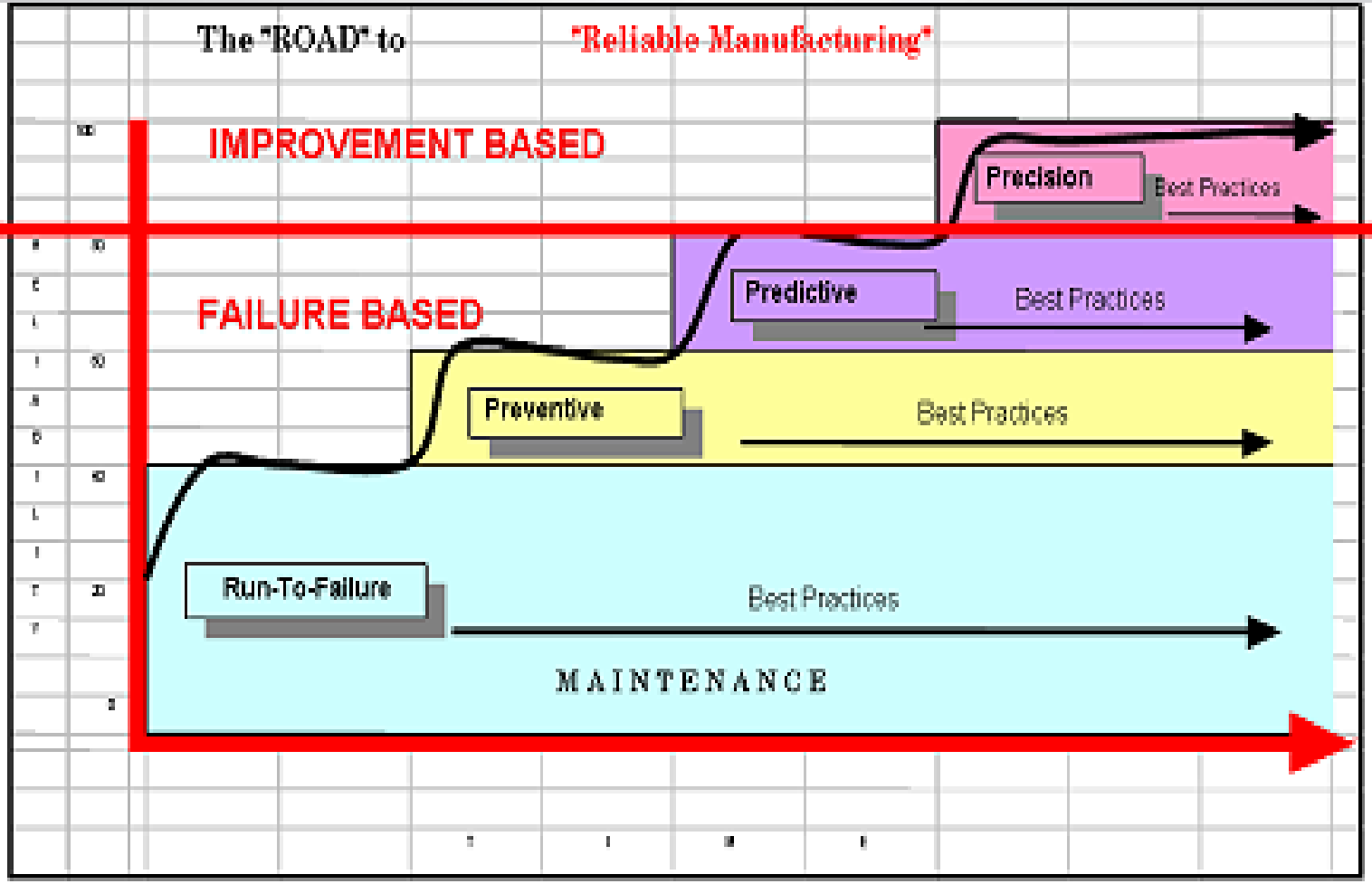
Gear Fundamentals & Failure Analysis

Presenter

Scott Ouellette – Rexnord Industries

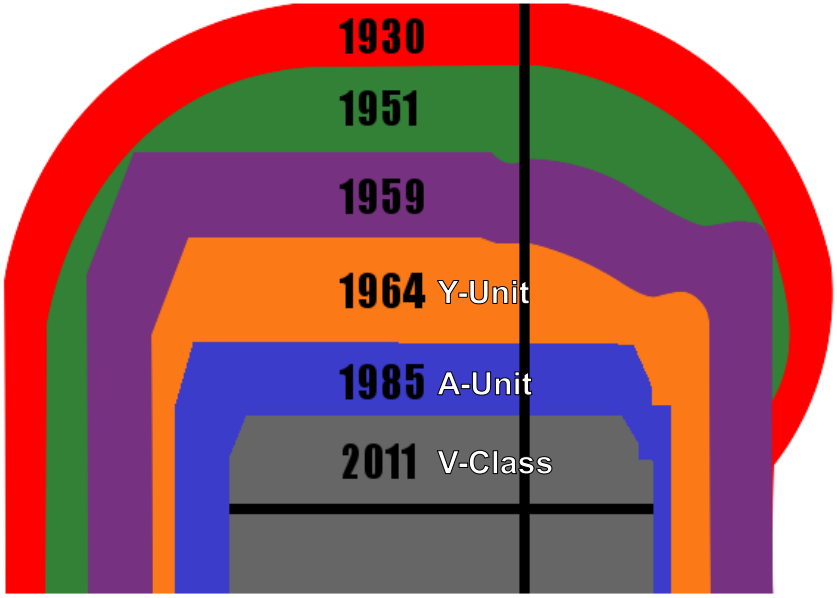
Outline of Presentation Topics

- What is a Gear Reducer and what does it do?
- What are the different styles of gear reducers and the advantages and disadvantages of each.
- Best Maintenance Practices for Gear Reducers
- Some Case Histories of Reducer Failure modes. Most reducer and bearing failures can be traced back to lubrication and load.
- What upgrades and technology enhancements are available that can help extend gear and bearing life.



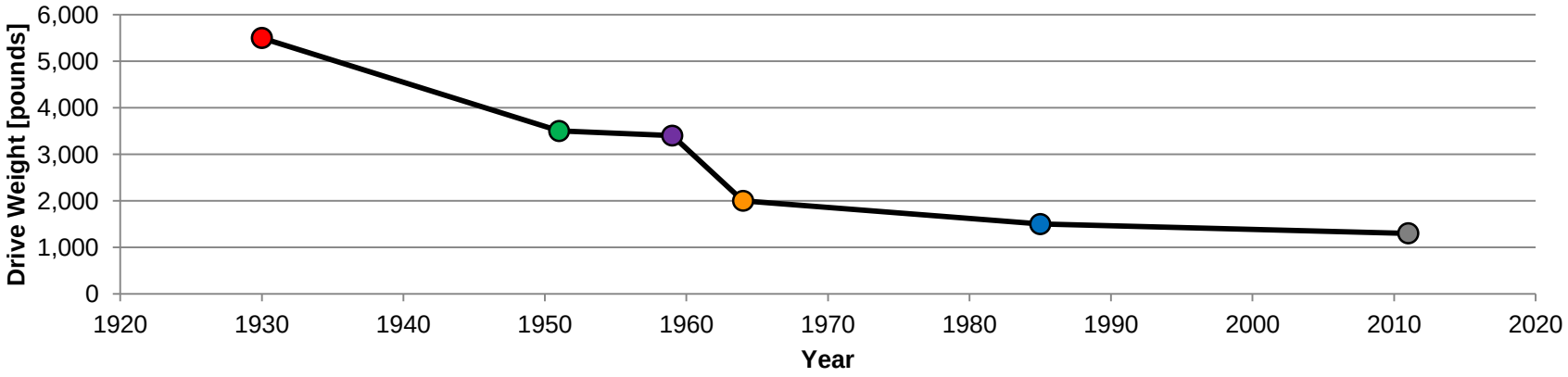
Reactive - run to failure
Preventative- Replace parts often times before useful life is reached.
Predictive - Work on equipment based on predictive analysis tools. Data driven decisions.

Power Density Evolution



200 HP Drive Comparison

Year	Drive Weight	
1930	5,500 lbs	2,495 kg
1951	3,500 lbs	1,588 kg
1959	3,400 lbs	1,542 kg
1964	2,000 lbs	907 kg
1985	1,500 lbs	680 kg
2011	1,300 lbs	605 kg



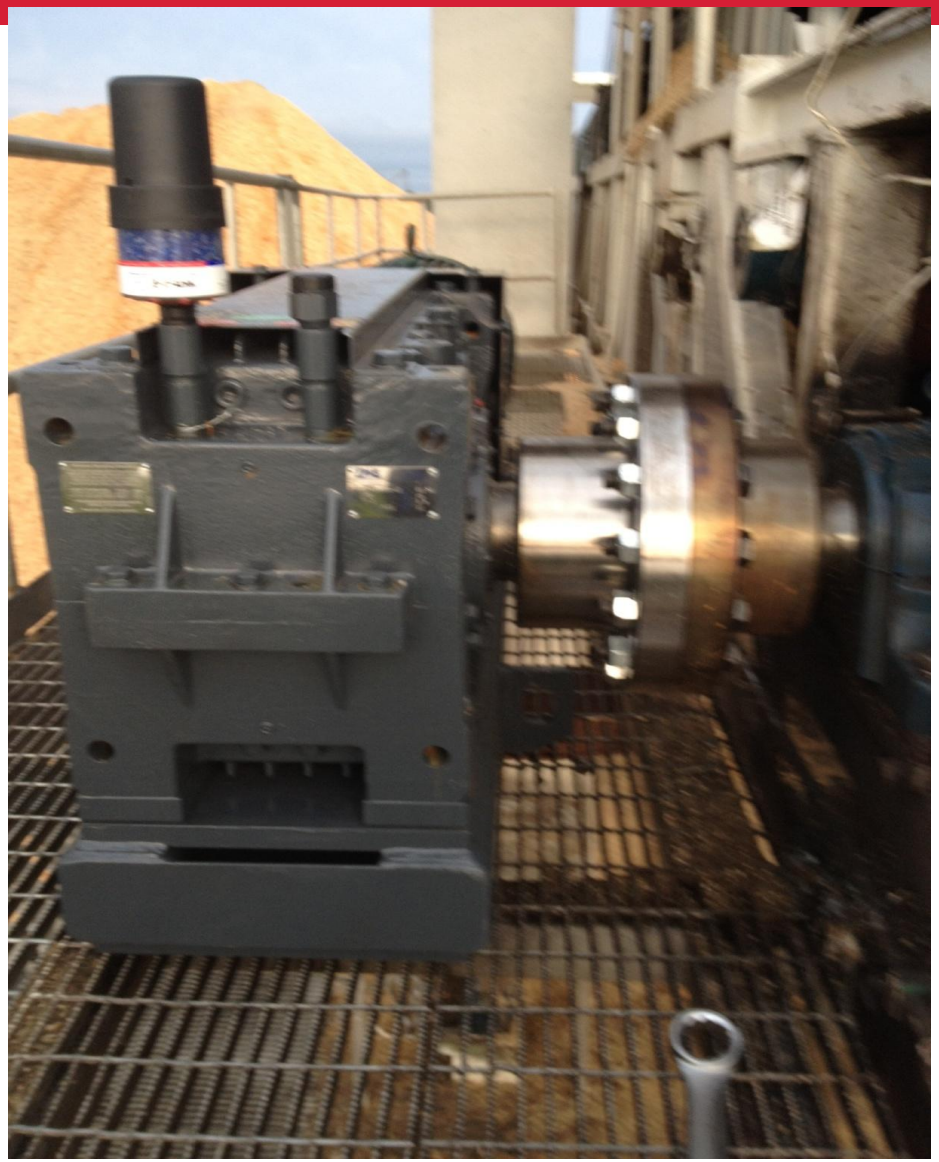
Gear Reducers – High Expectations

- Gear reducers are critical to plant production and tend to have lower service factors than in the past. Both mechanically and thermally! Consequences of failure can be very costly.
- Don’t wait until an alarm trips, catch the trend, order parts, plan the outage. Alarms are generally an emergency point.
- May have to run a lower loads or speeds to prevent severe equipment damage or unsafe condition. Short failure mode or long failure mode
- What level of resources are dedicated to monitor machinery? Maintenance budgets are limited.

Industry and Specification Changes

- Shaft Mounted Reducers and C Face Connections
- Disc Couplings
- Cooling more critical than in the past. More torque for less money.
- Inline Reducers versus Parallel
- Long Life Expectation - Breathers, Oil Sampling, Temperature and Vibration Instrumentation - Remote Monitoring
- Sealing is More Critical
- Long Term Storage
- Warranty
- Worm Reducers Less Popular
- System Torsional Calculations – Growth of VFD’s

Shaft Mounted Reducer



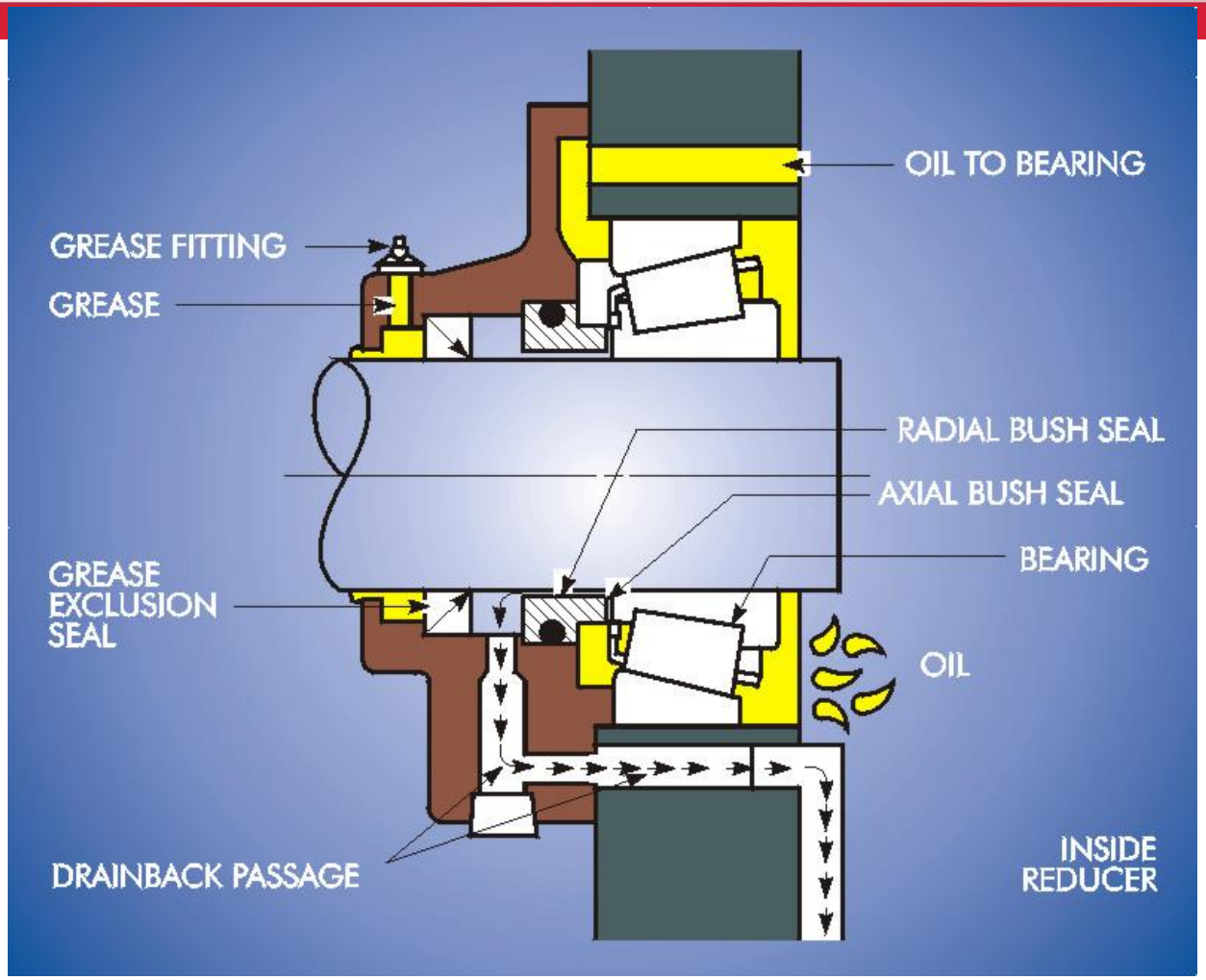
Stacker Drive Reducer with Solid Shaft and Rigid Coupling.

Shaft Mounted Design. No misalignment at low speed shaft and no baseplate or foundation costs.

Falk Magnum Seal Design

- VITON SEALS
- NON-CONTACT BUSH SEAL
- GREASE CAVITY
- DRAINBACK SYSTEM

Leaks are unacceptable in plants today. Zero leaks allowed from reducers due to safety and environmental concerns.



Power Transmission Terminology

- **Torque: Product of the applied force times the perpendicular distance to the center line of rotation. Reducer multiplies motor torque**

- **Mechanical Rating : This is the maximum HP or Torque that a reducer can transmit over a continuous period with damage or failure. A Reducers rating is based on Gearing Strength & Durability, the Housing and Shafting strength and Bearing Life. Capable of 100% overload.**

- **Thermal HP Rating: HP that a reducer can transmit continuously without overheating. The AGMA sump temperature limit is 200 F.**

- **Service Factor: A service factor is a number that is applied to the mechanical rating based on the application, hours of operation, impact loading, experience, and unknown variables. Motor HP x Service Factor = Design HP.**

- **Ratio: A fixed proportion between two like objects. Ratio is calculated by dividing the larger number by the smaller number. Ratios are multiplied or divided.**

- **Efficiency: The loss of mechanical energy due to friction. Energy output is always less than energy input.**

Gear Reducers and Torque Multiplication

$$HP = \frac{\text{Torque (in Lbs)} \times \text{Speed (rpm)}}{63025 \text{ (conv. factor)}} \quad \text{or} \quad \text{Torque (in lbs)} = \frac{HP \times 63025 \text{ (conv. Factor)}}{\text{Speed (rpm)}}$$

A gear reducer does not produce HP, it simply multiplies the motor torque by the gear reduction ratio.

A gear reducer that decreases speed creates a proportional increase in torque.

Gear Reducers and Torque Multiplication

A 1 HP motor at 1750 rpm produces 36 in lbs of torque

A conveyor needs to turn at 17.5 rpm. A reducer with a 100:1 ratio is required. How much torque from the 1HP motor does the reducer deliver at the output shaft?

One way to calculate is by using the formula: $\text{Torque} = \frac{\text{HP} \times 63025}{\text{Speed (rpm)}}$

$$\text{Torque} = \frac{1 \text{ HP} \times 63025}{17.5 \text{ rpm}} = 3{,}600 \text{ in lbs}$$

Or simply take the motor torque and multiply by the reducer ratio:

36 in lbs (1 HP motor at 1750 rpm) x 100:1 ratio = 3,600 in lbs at 17.5 rpm.

Torque is inversely related to speed.

Gear Reducer Design Basics

Gear Reducer Design Basics

Three design ratings that gear reducers are designed around. Lowest of the three rates the gear reducer.

•Durability Rating – Continuous HP that can be transmitted without showing evidence of pitting on gearing.

•Strength rating – How much HP can be transmitted before a shaft or gear fails due to (bending) fatigue or sudden failure. Strength rating is derated.

•Bearing Rating – HP that can be continuously transmitted without showing evidence of spalling or pitting. This is a fatigue rating.

DRIVE MECHANICAL RATING:

- Reducers are designed to accommodate momentary startup overloads of 100% over nameplate rating.

Gear reducers are ideally designed with prime number of teeth to ensure all teeth share the wear evenly. Bad 15T and 25T, better is 16T and 25T. GCD is 1.

Life Equation - ISO

Basic Life $L10 = 1{,}000{,}000/(60*n)*(C/P)^p$

Where

- L10 = number of hours that 90% of the bearings will survive without major pits
- n = Shaft speed (rpm)
- C = Dynamic Load rating
- P = Equivalent dynamic load
- p = Exponent (3.33 for roller 3.0 for ball)
- 1 million revolution basis

Basic Life Equation does not take into account environmental influences on bearing life.

Gear Reducer Requirements

- Extreme Pressure Oils now required in most new reducers. Do not use EP Oil with bronze gearing.
- Synthetic oil is often recommended for better performance. Oil integrity more critical than ever.
- Cooling systems are more critical than ever and are more complex. Some customers require redundant systems.
- Oil leaks are scrutinized more than ever before. Seals must prevent oil leakage over long term.
- Instrumentation Packages are more common and are more sophisticated than in the past. Reducer housings are now predesigned for instrumentation packages.
- Long Term storage is recommended for all reducers.

Gear Reducer Design Basics
ISO vs AGMA Rating Comparisons

- Each Standard drives toward an optimal design for that standard
- AGMA favors larger teeth but fewer teeth on the pinion. ISO favors slightly smaller teeth and pushes toward a 22T minimum.
- AGMA design standard is based on a nominal speed of 1800rpm versus 1500rpm for ISO.
- Generally within 10% of each other but as you get away from the sweet spot of the respective design standard you will get larger differences
- Rulers are slightly different. Not good or bad. Use different calculation methods.

CARBURIZING – Also Known as Case Hardening

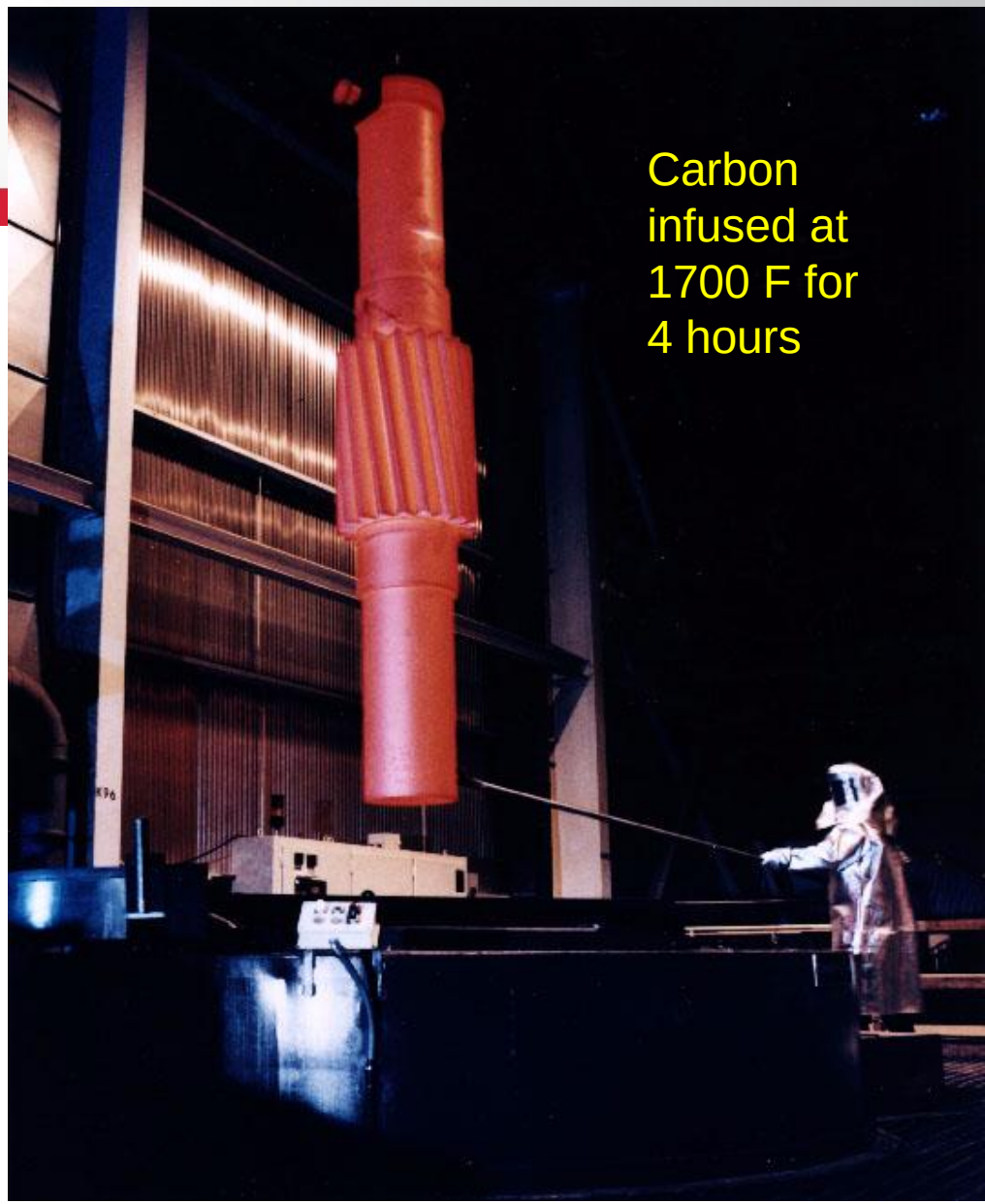
Higher Surface Hardness (58-62 Rc).

Smaller Speed Reducers for Same HP.

Lower Vibration Levels

Higher temperatures of Operation.

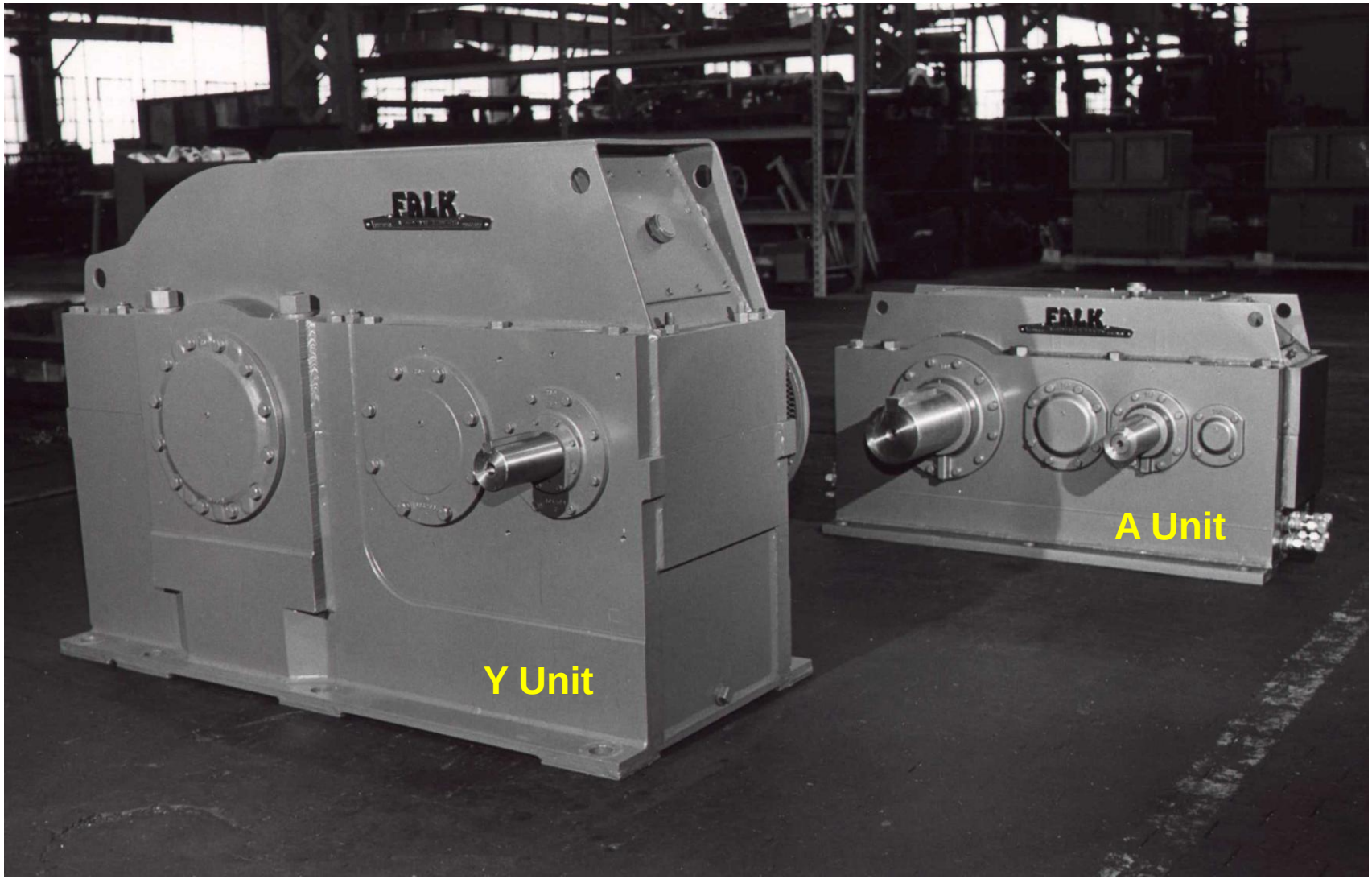
Higher Sensibility to Lubricant Condition.



Through Hardened Gear Reducer on Y Unit vs Surface Hardened Gear Reducer on A Unit

REXNORD

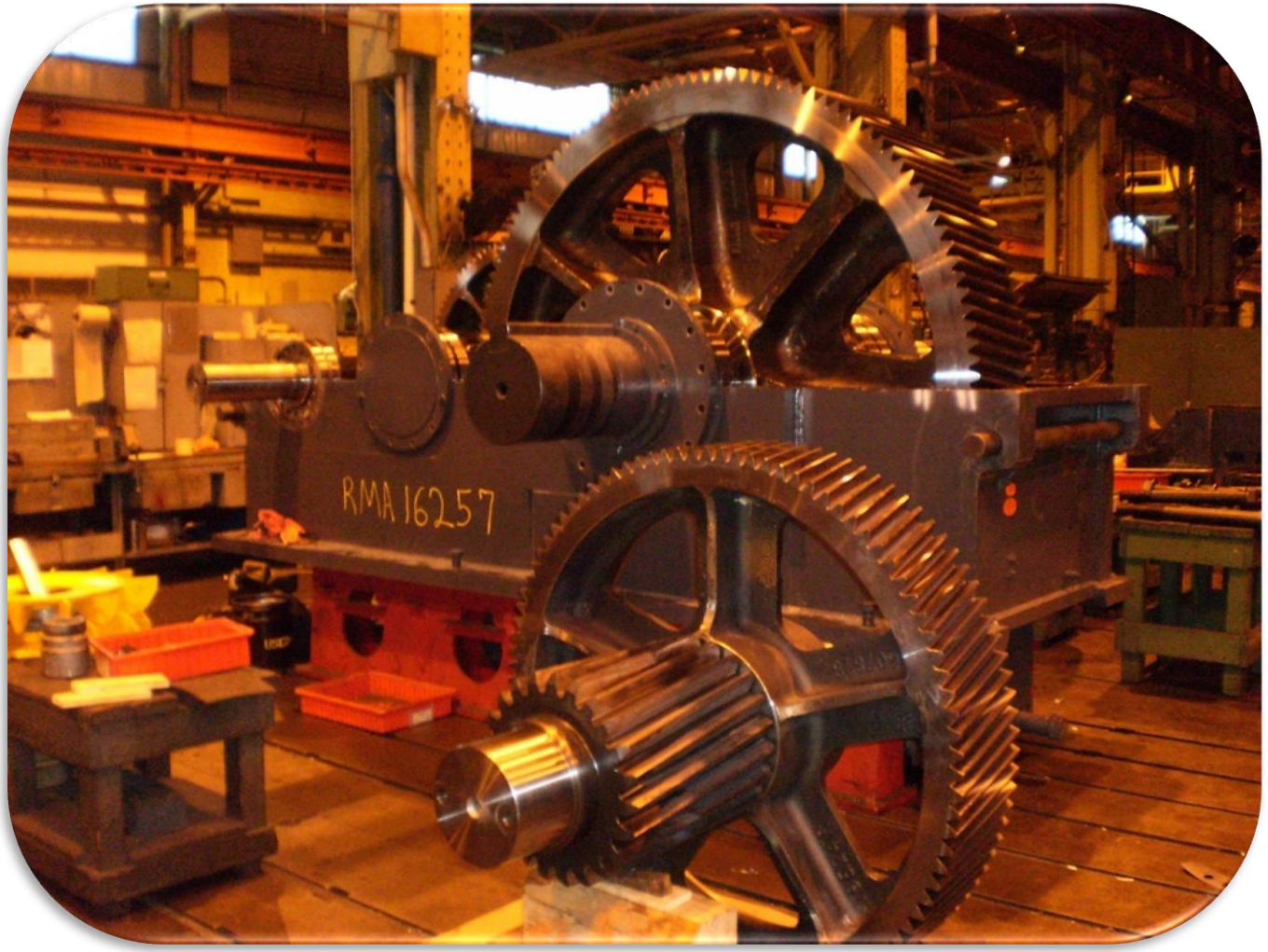
#AhmedEltayef



Y Unit Reducer at Renew

#AhmedEltayef

2195Y3 weighs 20,000 lbs and rates for 2.5 million in lbs



Service Factors

Nature of Application	Conveyor Loading	Duty Cycle: Less Than 10 Hours/Day	Duty Cycle: Greater Than 10 Hours/Day
Standard	Uniform	1.25	1.25
	Heavy Duty	1.25	1.50
	Severe	1.75	2.00
Critical	Uniform	1.50	1.50
	Heavy Duty	1.50	1.75
	Severe	2.00	2.25

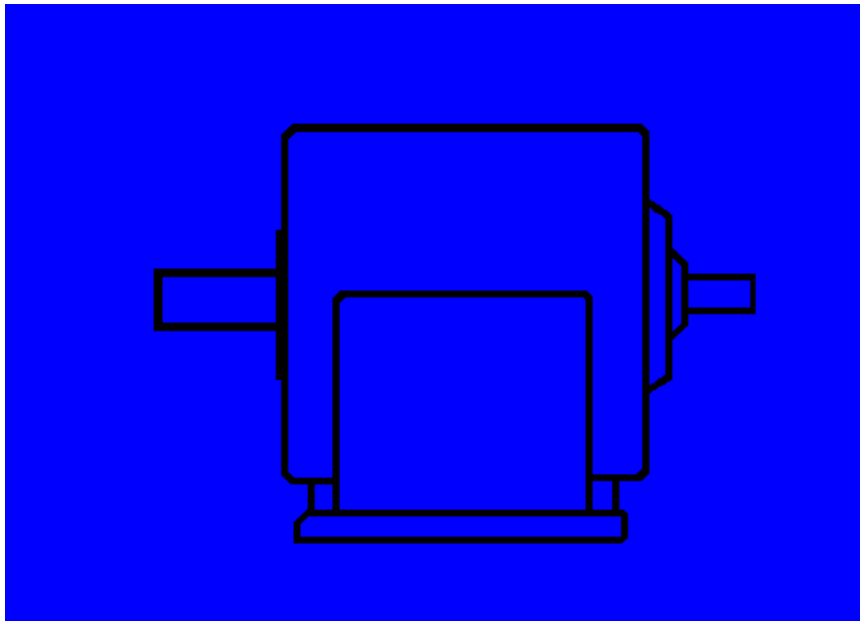
Selecting the correct service factor for the application is critical. If you don't get this right the reducer will fail prematurely.

Matching Reducer Rating to Motor HP

Mechanical Horsepower Requirement

ACTUAL HP x SERVICE FACTOR = MECHANICAL HP

Application requires 1.5 service factor

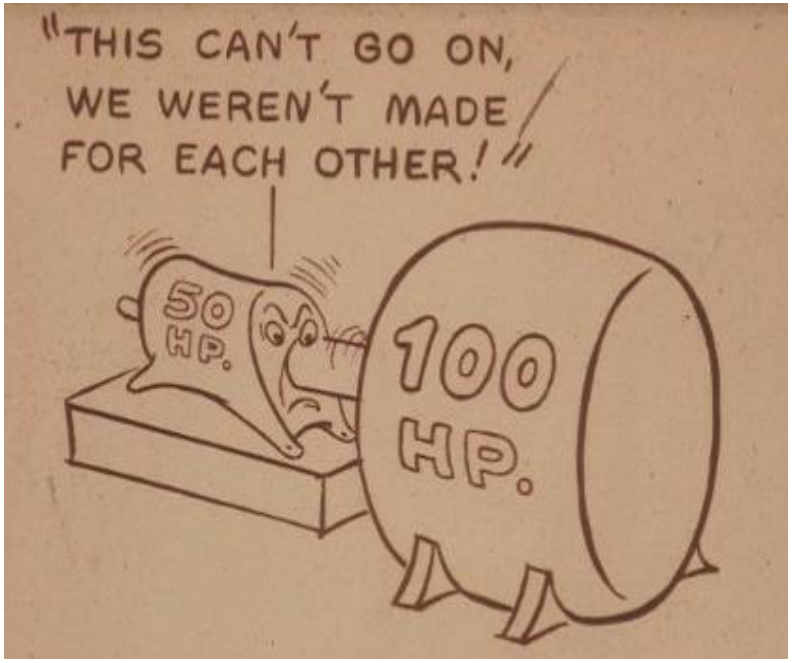


10 hp

1.5 SF x 10 HP = 15 MHP
Rated reducer required

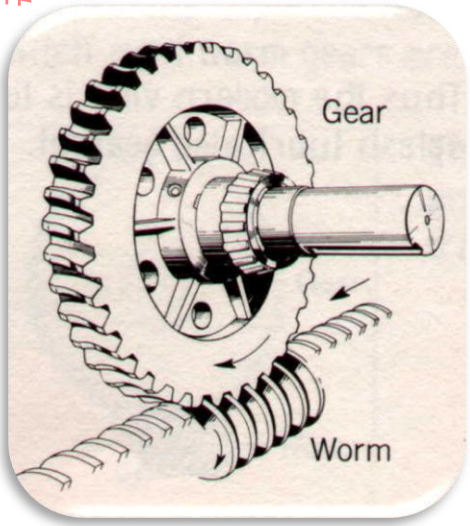
Pump Drive Running Hot – Motor Size Increased Above Design Limit

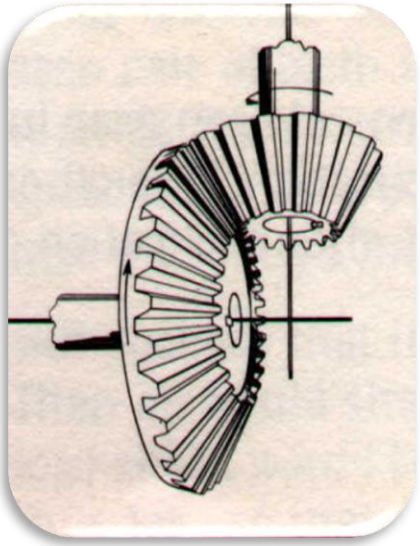
Air hose pointed at 2100FC high speed bearing for cooling. Motor was increased from 400 to 500 HP without telling Falk. Shaft Fan was not ordered by customer on replacement reducer.

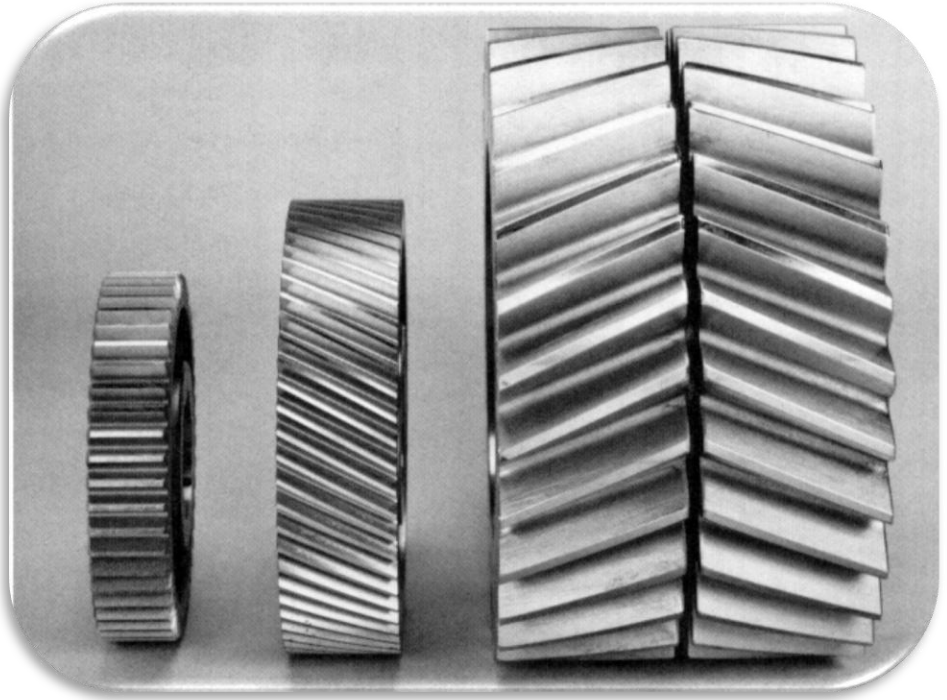


Types of Gears

- Spur Gears – Planetary Reducers
- Helical Gears – Parallel and Inline
- Double Helical / Herringbone Gears
- Bevel Gears – Right Angle
- Worm Gears – Right Angle





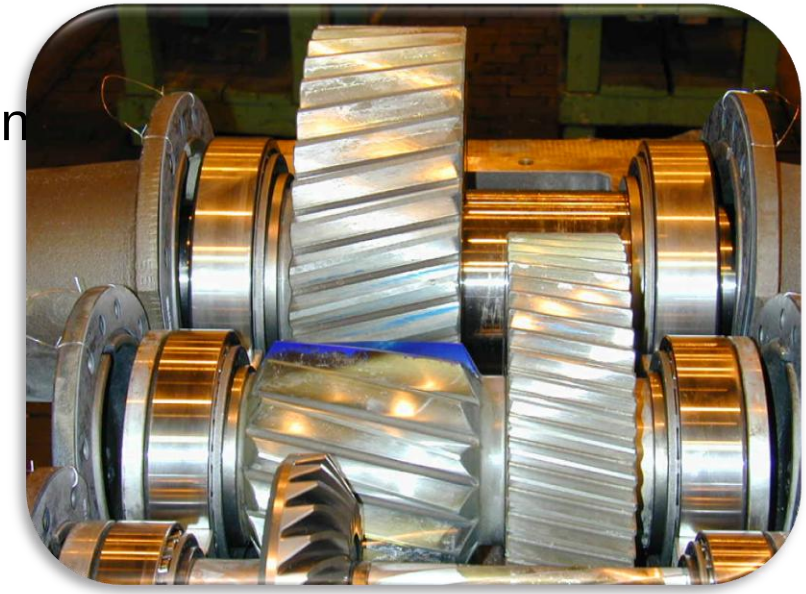


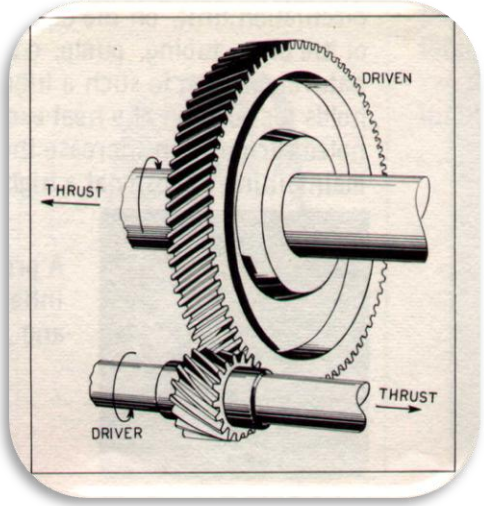
Spur Helical (Right Hand) Double Helical

Helical Gearing

REXNORD

- Uses:
  - Parallel and Inline Shaft configuration
  - Moderate to heavy loads
- Strengths:
  - Better Tooth-To-Tooth transfer of load than spur gearing. (smoother)
- Weaknesses:
  - Higher Cost than spur gearing
  - Creates axial load on housing and bearings

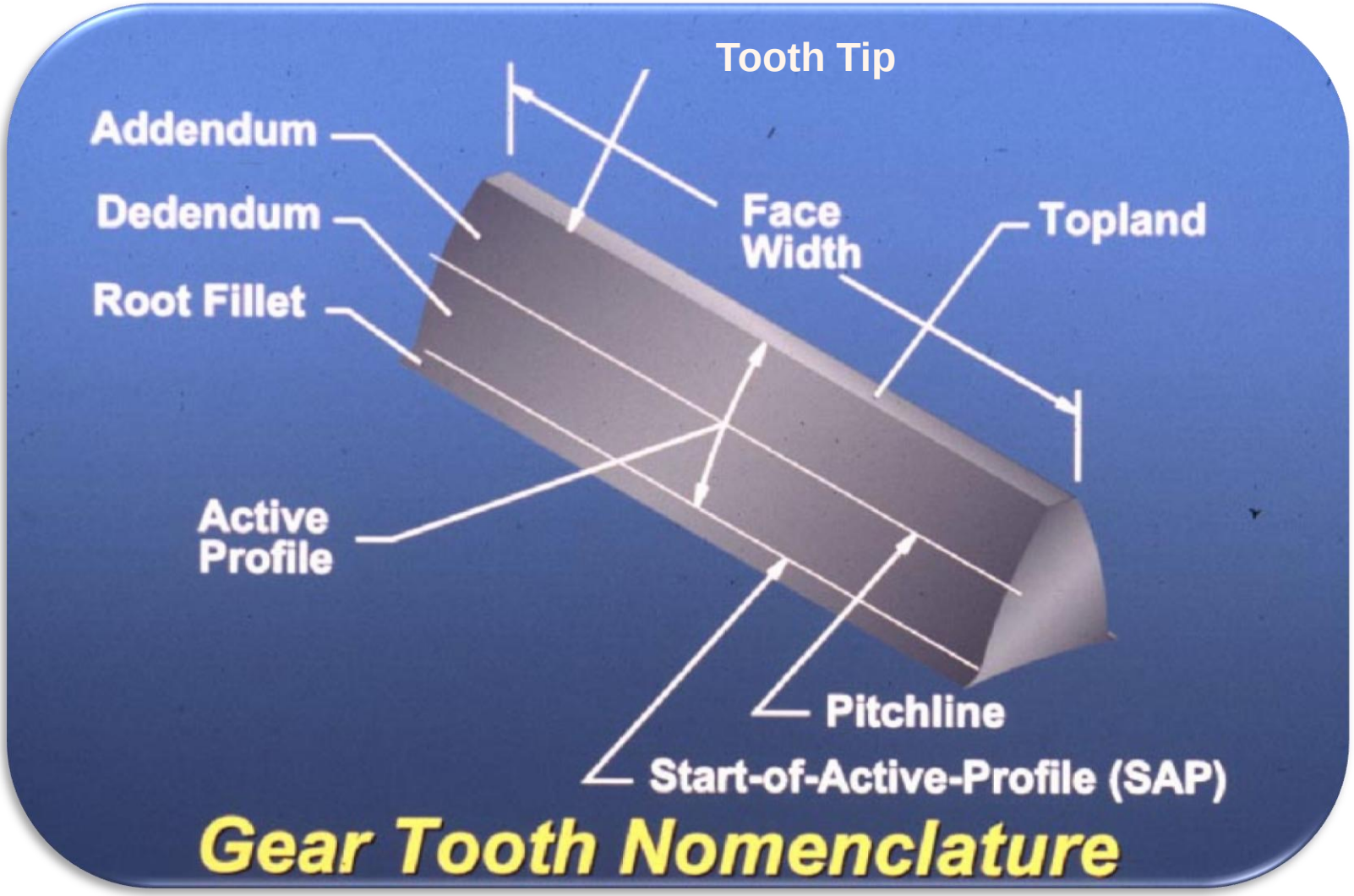




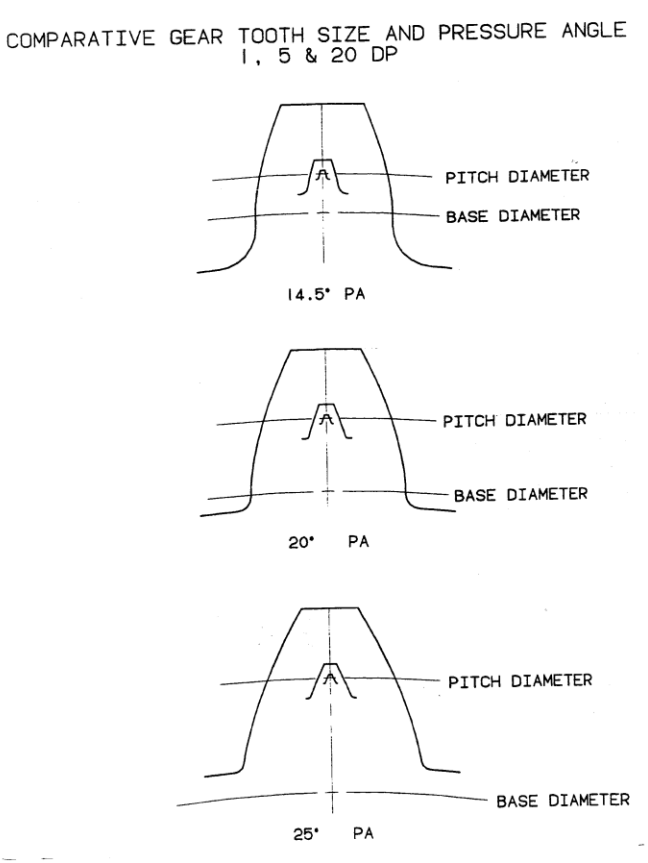
Gear Nomenclature

REXNORD

#AhmedEltayef



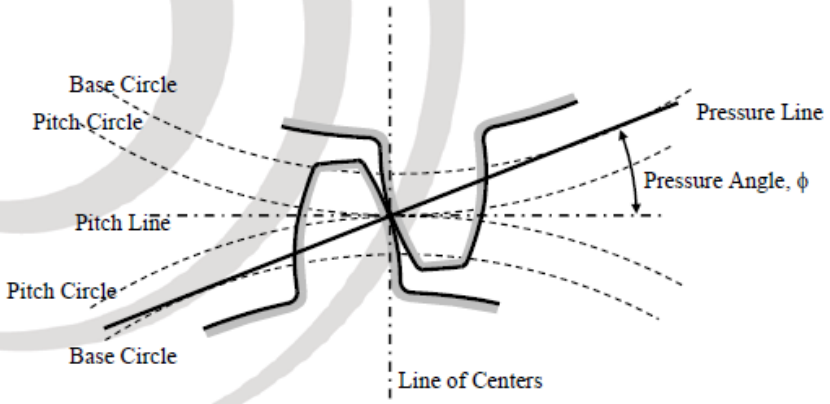
Pressure Angle



A 25 degree pressure angle gear tooth is stronger, however lower pressure angles produces less axial thrust.

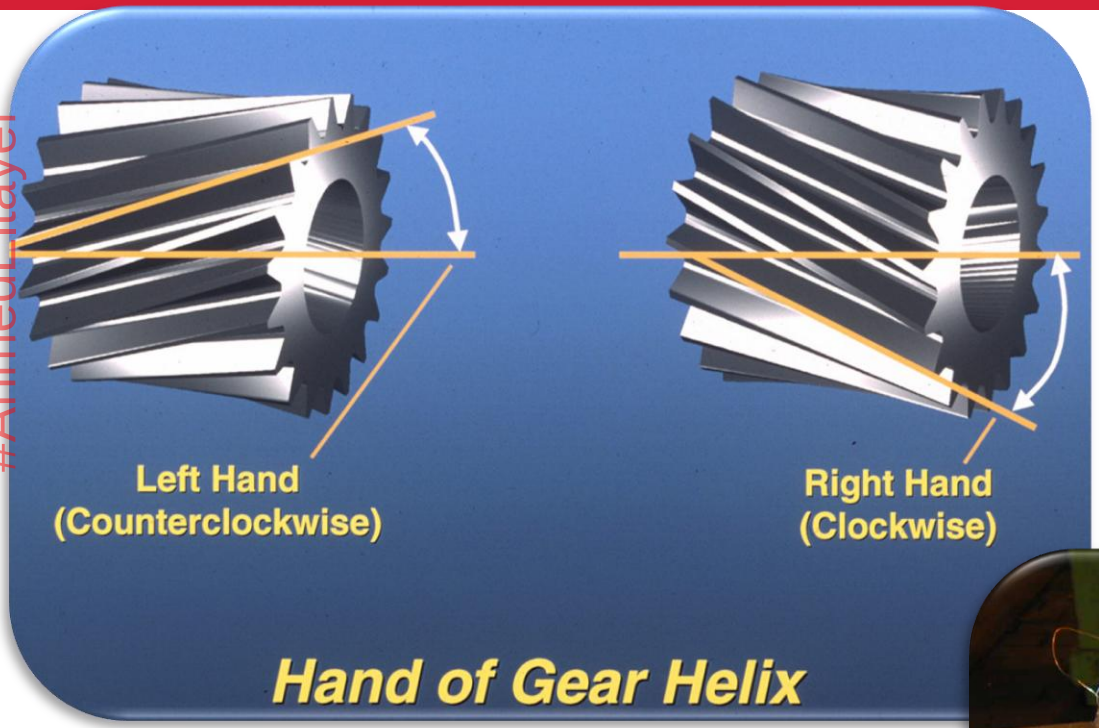
- Pressure Angle

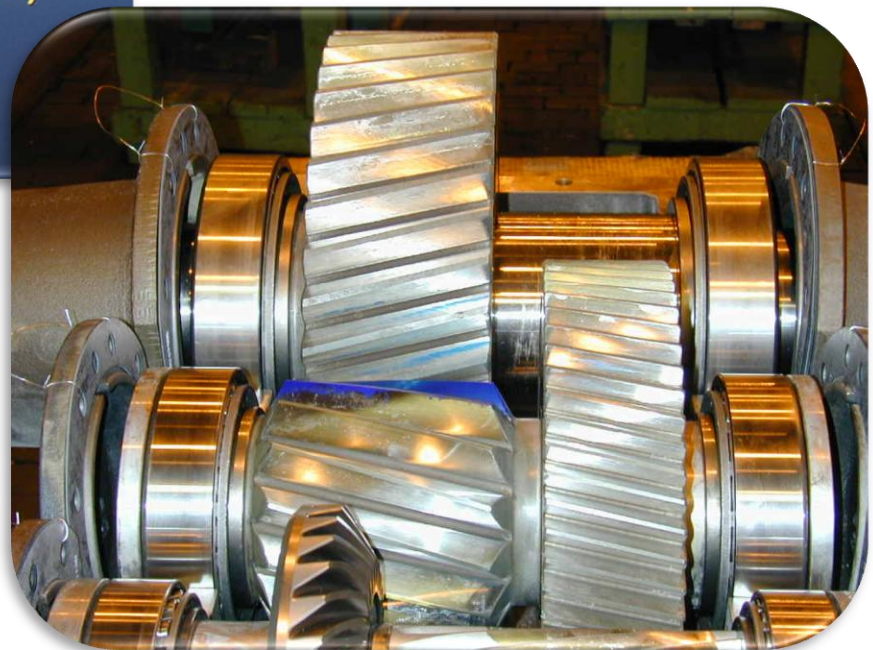
14½°, 20° & 25° are standard



Mating gears must have the same pressure angle and diametral pitch (relative size of tooth). Each manufacturer has their own proprietary design . Do not run different manufacturers gears against each other.

Hand of Helical Gear Teeth





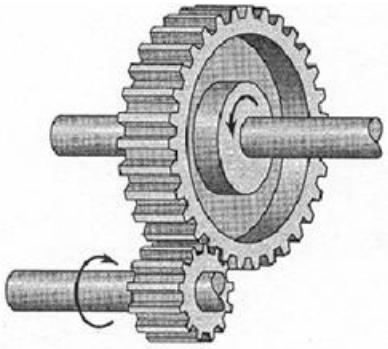
Helical gears are not machined as a matched set.

Spur Gearing / Planetary Gears

REXNORD

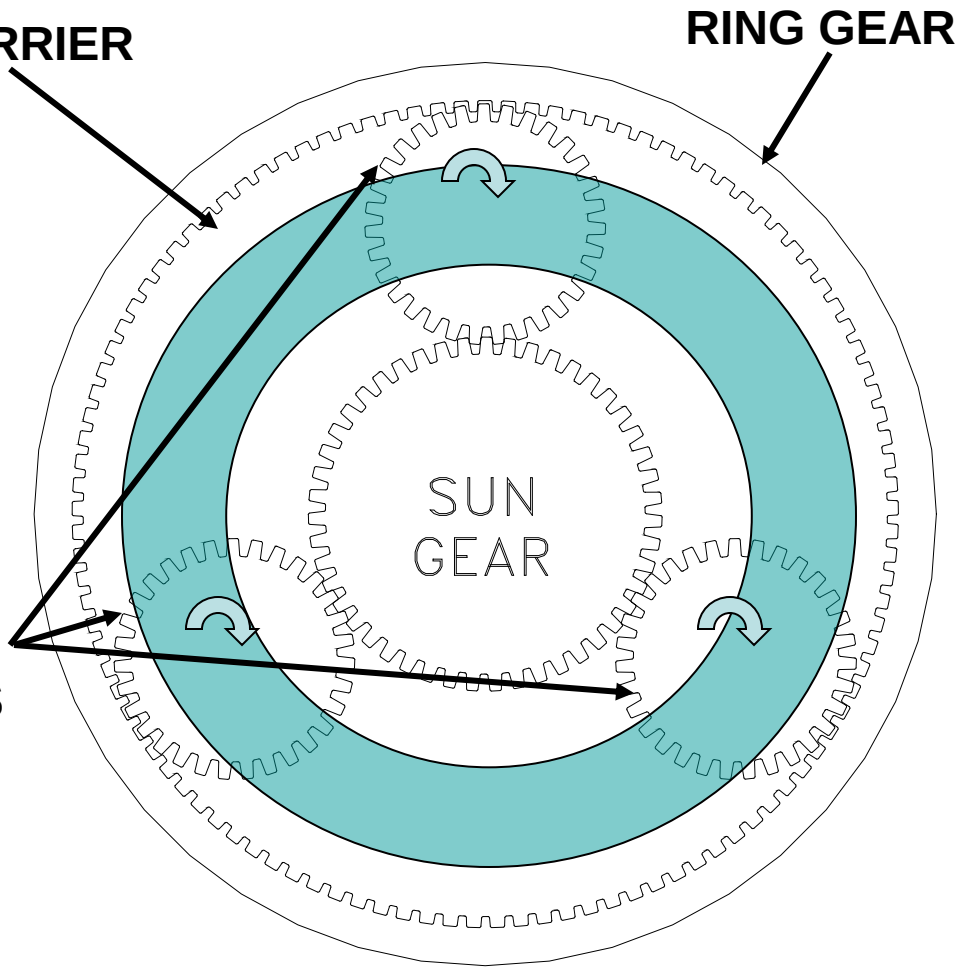
#AhmedEltayef

- Strengths:
  - Economical to produce
  - Compact Size for very high ratios
  - Three of four planets in contact with sun gear.
- Weaknesses:
  - Less strength than helical gearing
  - Less Tooth-To-Tooth accuracy than helical gearing. More noise generated.



Spur Gear

Planetary Gearing

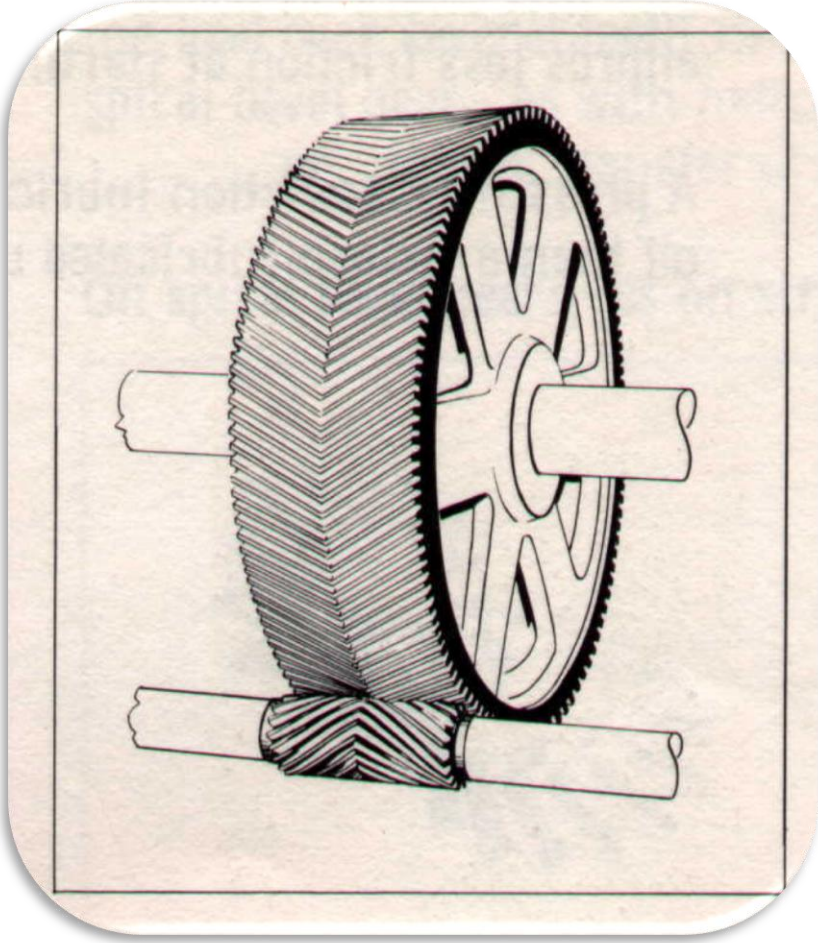


No Axial force is generated from spur gears. Bearings can handle greater overhung load. Spur gears have a zero helix angle.

Double Helical Gearing

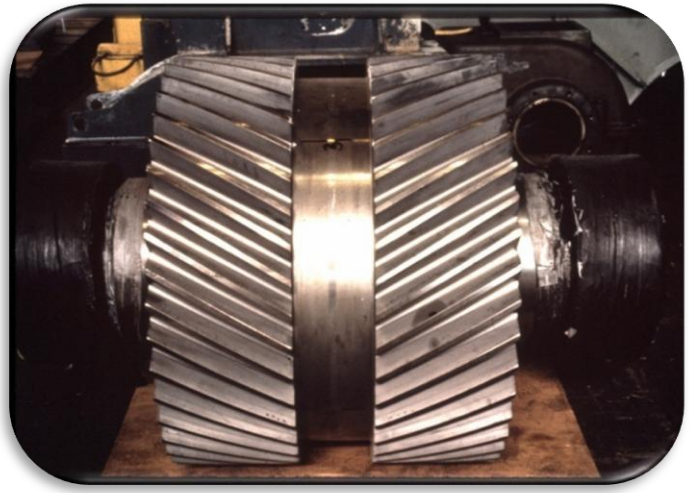
REXNORD

- Use:
  - Parallel Shaft
  - Moderate To Heavy Loads
  - Moderate To High Speeds
- Strength:
  - No Axial Load
- Weakness:
  - Higher Cost



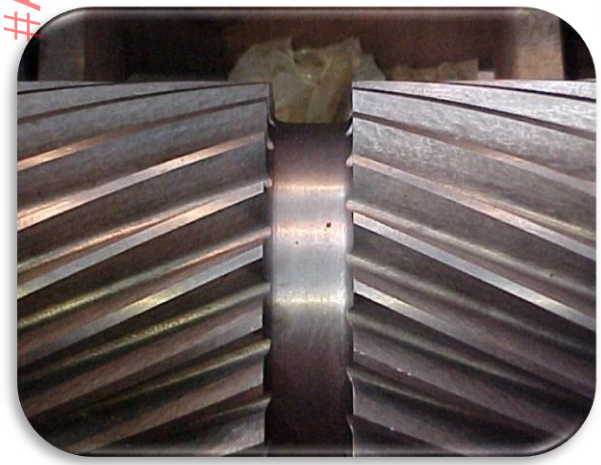
Double Helical Gears

Used by Falk



Double Helical

Not used by Falk

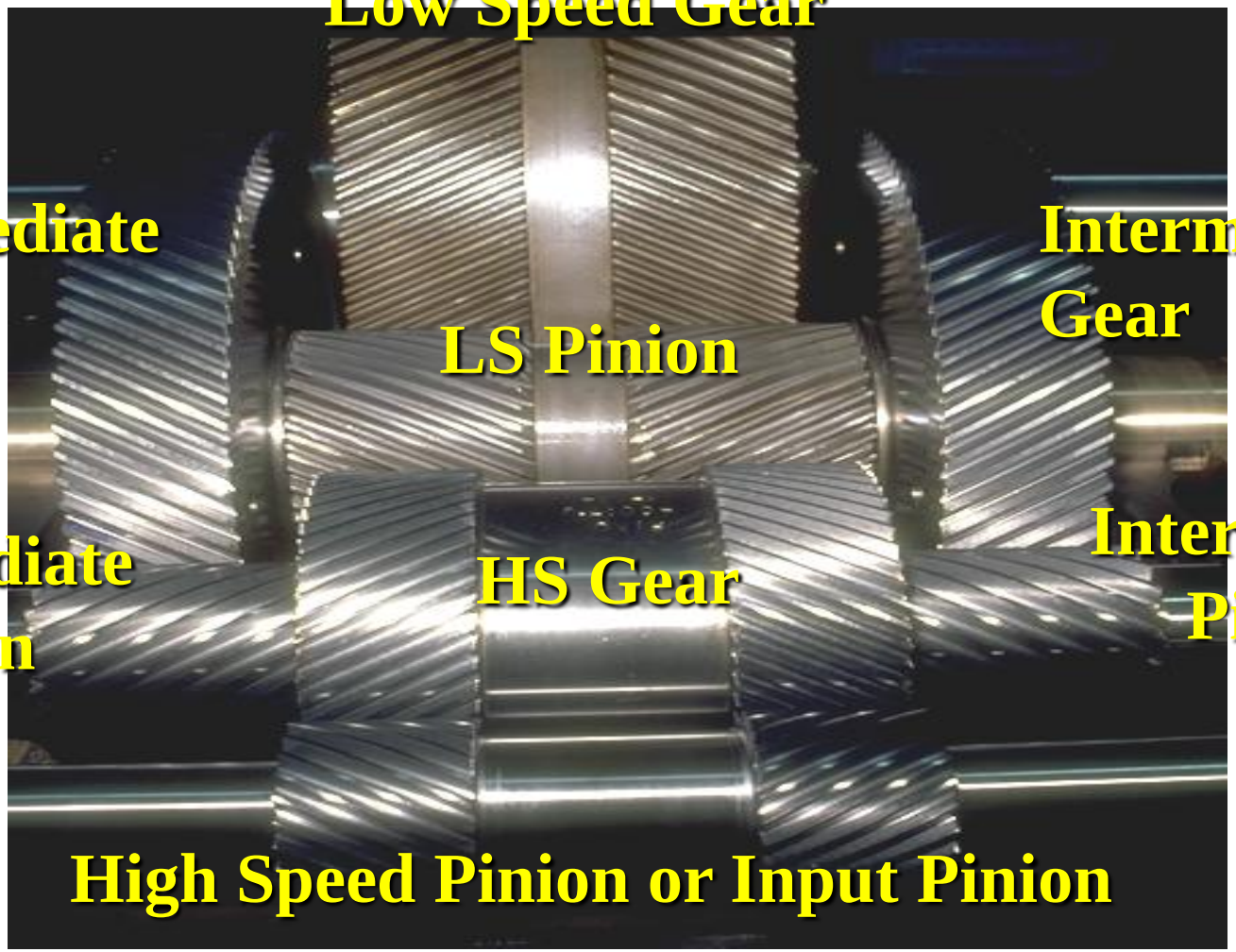


Staggered
Double Helical

Used by Falk

Herringbone

Gear Nomenclature - Triple Reduction

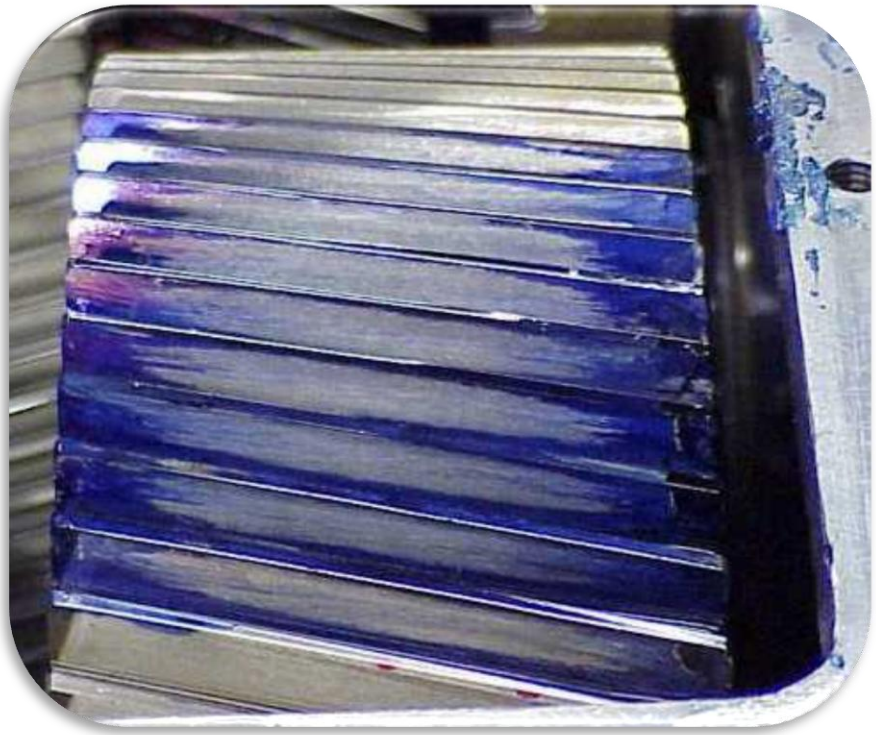


Design Features - Gearing

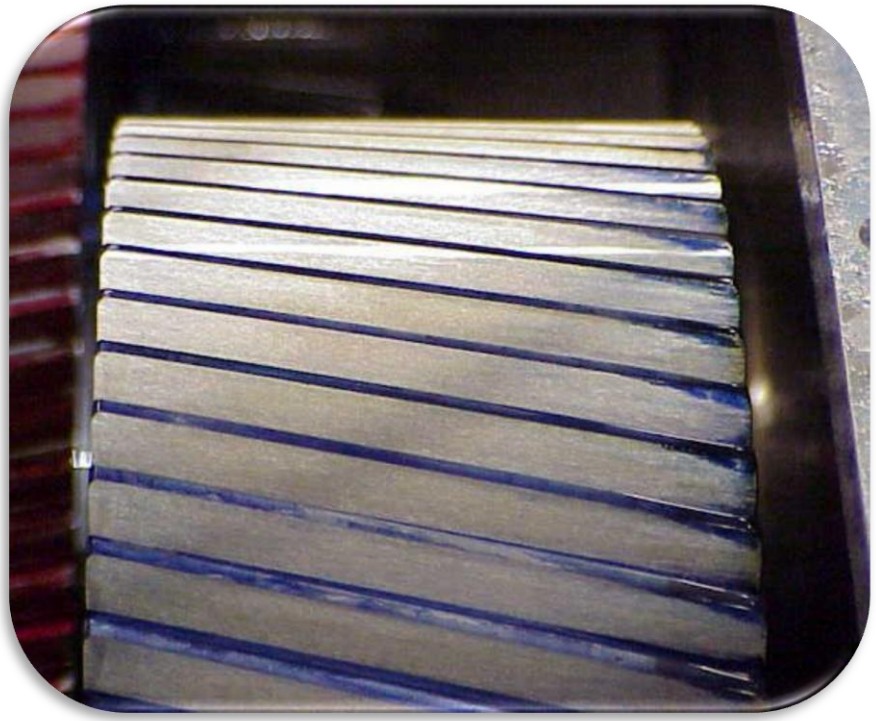
REXNORD

#AhmedEltayef

Gearing incorporates tooth modifications to maintain optimal tooth contact at higher loads, thus minimizing localized stress as well as gear noise and vibration.



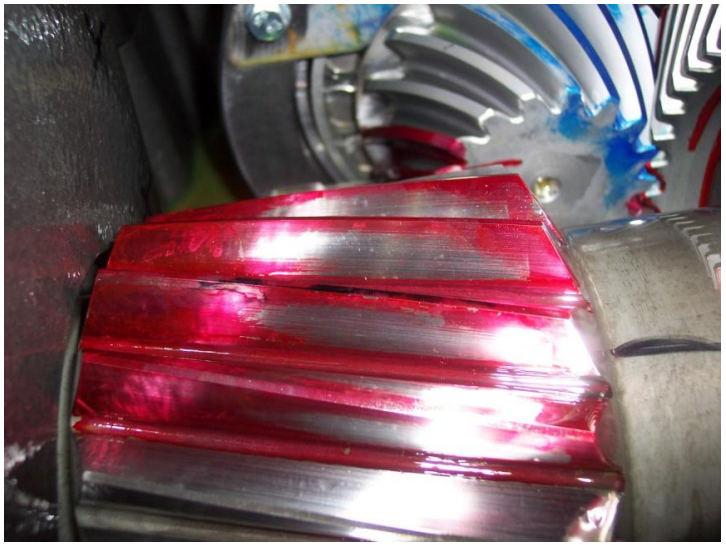
5% Load



80% Load

Falk Tooth Contact

- Carburized & Ground Gears – Up to AGMA Class 12
- AGMA Quality Number is for an unassembled Gear
- Designed to Engage Full Tooth Width Under Load



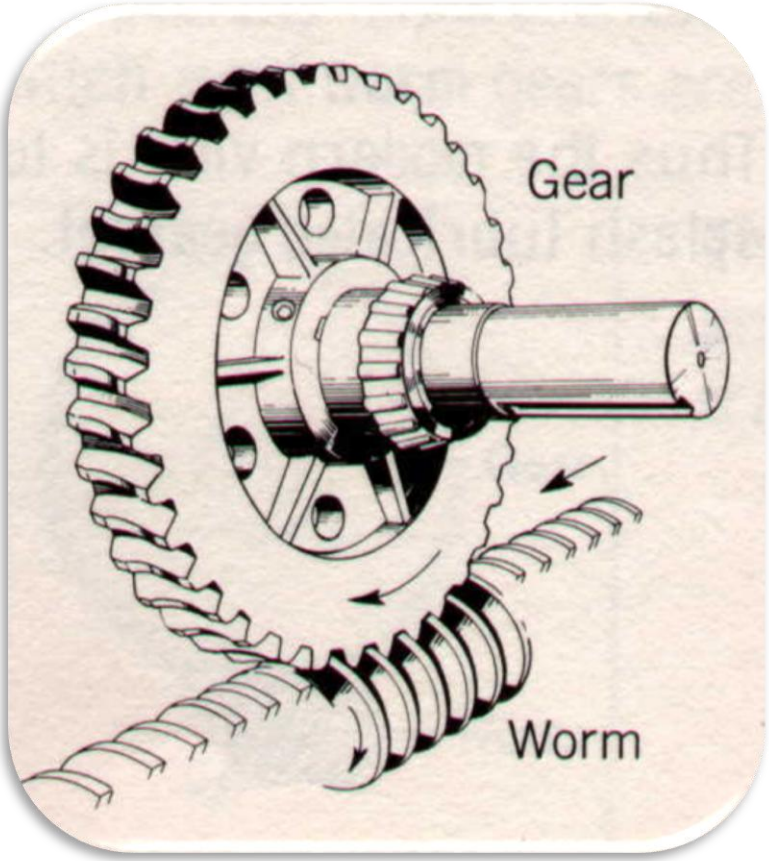
10% Load

80% Load

Worm Gearing

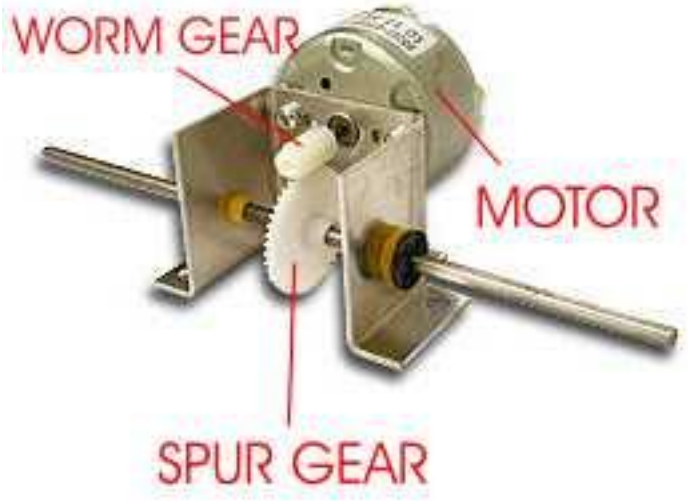
REXNORD

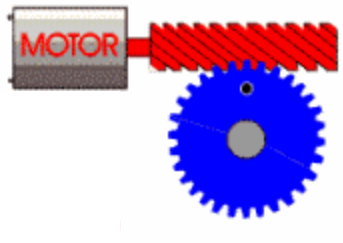
- Uses:
  - Low Torque Applications
  - Transfers power at right angle
- Advantages:
  - High Shock Load Capacity
  - High Ratios (70:1)
  - Quiet Operation
  - Potential Anti-Reversing
- Disadvantages:
  - Sliding Contact,
    Low Efficiency 60% eff.
  - High Thrust Load



Types of Gears

The arrangement of gears seen is called a *worm* and *wormwheel*. The worm, which in this example is brown in color, only has one tooth but it is like a screw thread. The wormwheel, colored yellow, is like a normal gear wheel or spur gear. The worm always drives the worm wheel round, it is never the opposite way round as the system tends to lock and jam.



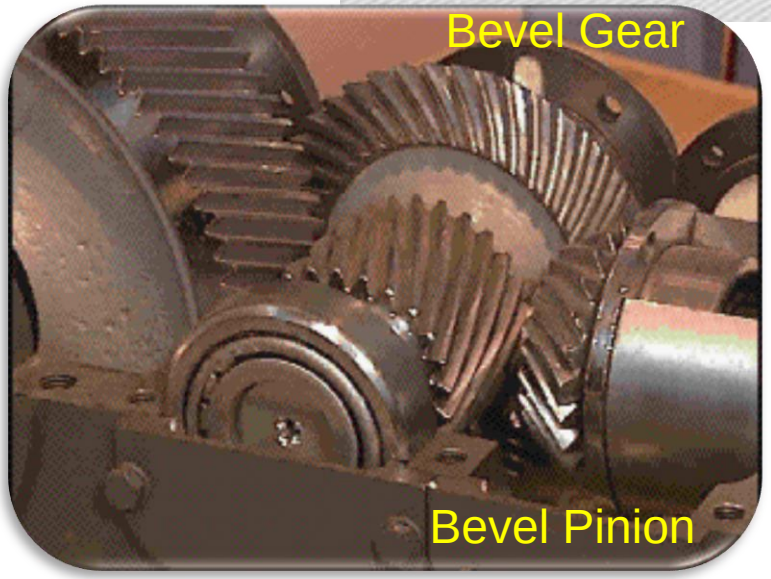


Spiral Bevel Gearing

- Uses: Used by Falk
  - Right Angle
  - Moderate & Heavy Loads
  - Moderate & High Speeds

- Advantages:
  - Better Tooth-To-Tooth transfer accuracy
  - High Load Capacity

- Disadvantages:
  - Higher Cost than helical gears
  - Much more complicated than helical gears



Lubrication and Cooling

WHAT IS THERMAL RATING?

- Actual HP a Reducer Will Transmit Continuously Without Overheating.
- No Service Factor Is Used Against Motor HP when checking THP Ratings. Must use thermal adjustment factors based on ambient temperatures, altitude, wind, etc.
- 50 HP Motor - Unit MUST Rate 50 HP Or More Thermally.
- Falk Limits Sump Temperatures To 200 Degrees F/93C; however targets Max. 170F.

ADJUSTED THERMAL RATING:

Use the following formula to determine application adjusted thermal rating:

$P_{TA} = P_T \times B_1 \times B_2 \times B_3 \times B_4 \times B_5$ where:

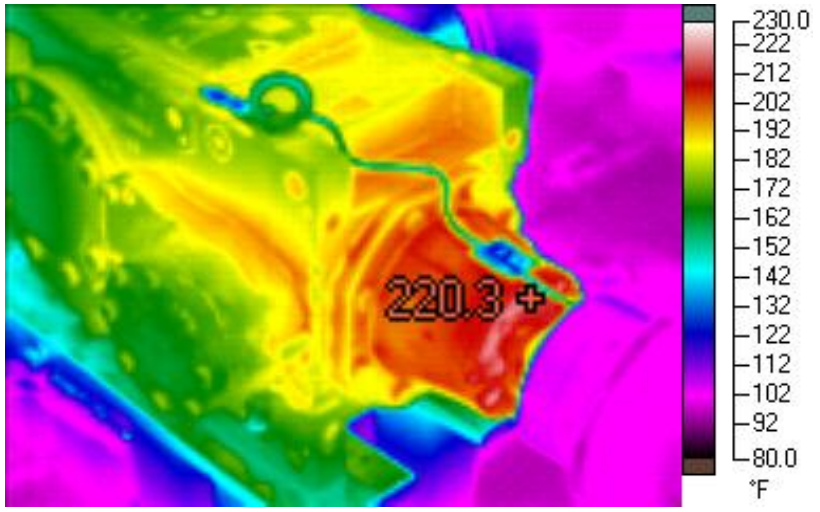
P_{TA} = Application Adjusted Thermal Rating
P_T = Basic Thermal Rating
B_1 = Ambient Temperature Factor (Table 1)
B_2 = Altitude Factor (Table 2)
B_3 = Ambient Air Velocity Factor (Table 3)
B_4 = Duty Cycle Factor (Table 4)
B5 = Orientation Factor (Table 5)

WHAT IS THERMAL RATING?

REXNORD

Falk V Class

Competitor Design



- Designed with thermal ratings based on sump temperature of 180°F (82°C) vs. the AGMA standard of 200°F (93°C) minimum. Adjustment factors.
- Cooler oil results in increased oil film thickness and extended operating life
- Lubricant minimizes heat, friction and wear

Bearing Failure – Thermal Breakdown of Lubricant

Black carbon like build up on the non-contacting surfaces indicate lube oil breakdown

Oxidized oil smells rancid

Drive Efficiencies

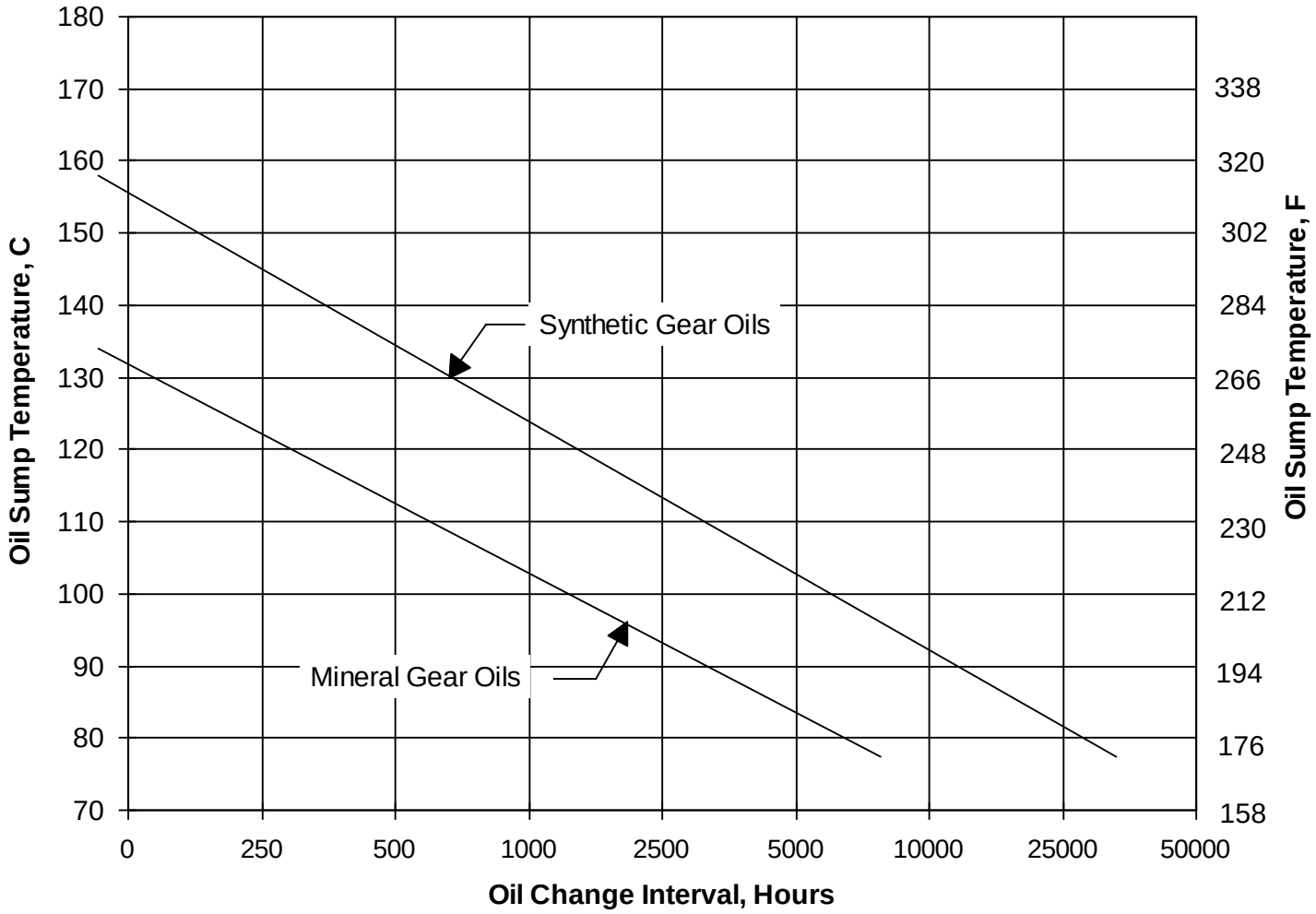
REXNORD

Inefficiency Cost =

% of Loss x HP x (0.746 Kw) x $kWh x hours

Speed Reduction Method	Approx. Efficiency
Synchronous Belt Drive	97%
V-Belt Drive	95%
Chain Drive	93%
Helical Double Reduction	98%
Bevel-Helical Double Reduction	97%
Planetary Double Reduction	95%
Cycloidal Single Reduction	95%
Worm Gear Single Reduction	60%

Oil Temperature vs Change Interval



Oil life is halved for every 18° F (10° C) rise in temperature.

Source: Stationary toothed gearing. Lubrication and maintenance. Mobil Oil AG Hamburg. 2nd edition.

Lubricant Maintenance Issues

REXNORD

#AhmedEltayef

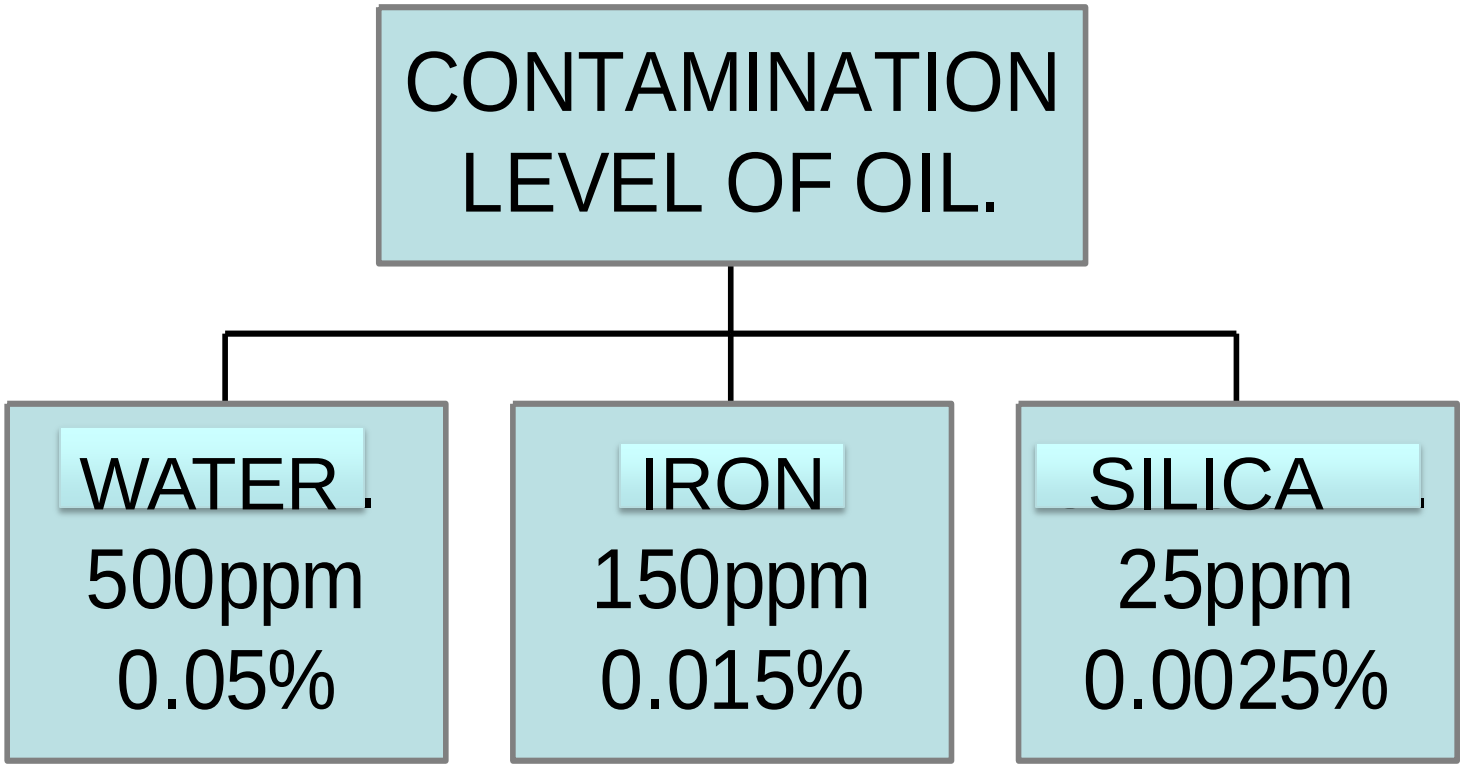
- Ensure Proper Grade – Viscosity and EP Requirement – Bearings versus Gears
- Look Inside for Visually Inspection
  - Check for metal contaminants (troughs & Dams)
  - Check for evidence of overheating (burnt aroma or sulfur smell)
  - Check for water contamination (milky color)
  - Check for oil oxidation (black sludge) – Oil Wears out over time
  - Check for foaming
- Check Air Filter and Oil Filter if a pressure lube system is being used
- Maintain Cooling Devices

Often times it is as simple as too much oil, to little oil or no oil! Proper lubrication is absolutely critical to long term reliability.

TABLE 2 — Viscosity Grade Recommendations for R & O or EP Lubricants

Output RPM	Normal Climates			
	15 °to 60 °F (-9 °to +16 °C)		50 °to 125 °F (10 °to 52 °C)	
	ISO-VG	AGMA	ISO-VG	AGMA
Output RPM Below 80	150	4	320	6
Output RPM 80 & Above	150	4	220	5

LUBRICANT QUALITY CONTROL

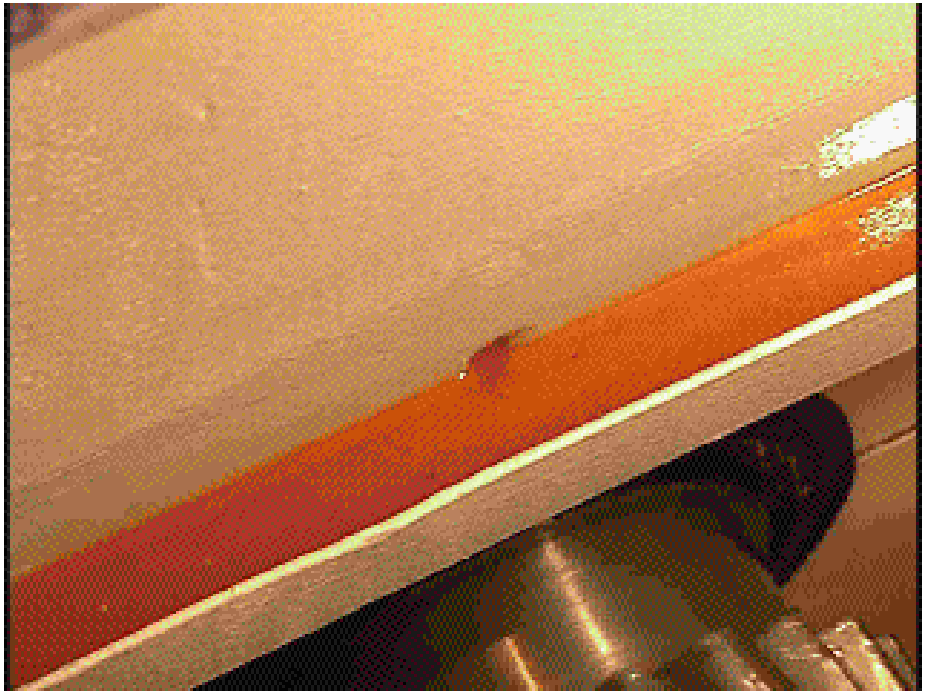


The viscosity should not change more than +/-15% of the original value.

HSS Bearing is most vulnerable

Splash Lubrication – Look for Contamination in Oil Troughs

Wiper Feeding Trough



Trough Feeding Bearing

Special provisions for low rpm and vertical applications

IronParticles at Magnetic Drain Plug

#AhmedEltayef

Need to investigate source of wear particles. Perform oil analysis .

Why Reducers Fail
Breather and Cooling Issues

Restricted
Breather

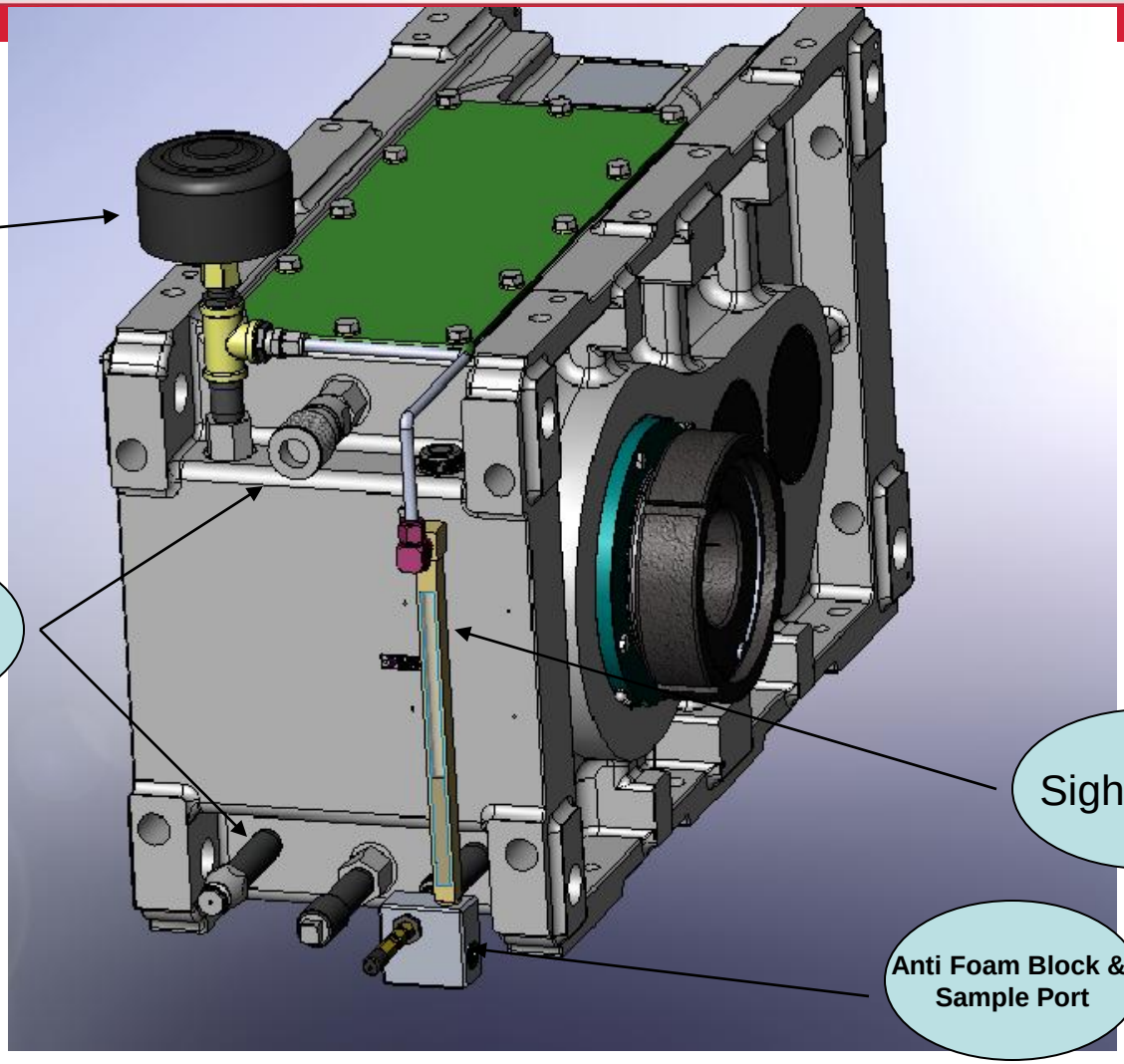
Cooling Tubes
Plugged

Wide Array of Lubricant Viscosities Used in Plants Today

ISO VISCOSITY GRADE		UTILITIES	FIBERS	FINISHED PRODUCTS
32	DTE 732	DTE 732		DTE 732
46	NUTO H 46 TERRESTIC 46	TERRESTIC 46	NUTO H 46	NUTO H 46
68	SHC 626 NUTO H 68 TERRESTIC 68	SHC 626 NUTO H 68 TERRESTIC 68	SHC 626 NUTO H 68	SHC 626 NUTO H 68 TERRESTIC 68
100	SHC 627 NUTO H 100 TERRESTIC 100	TERRESTIC 100	SHC 627 NUTO H 100 TERRESTIC 100	SHC 627 NUTO H 100
150	SHC 629 DTE PM 150	DTE PM 150	SHC 629 DTE PM 150	SHC 629
220	SHC 630 SPARTAN EP 220 SHC 220 GEAR TERRESTIC 220 DTE PM 220	SHC 630 SPARTAN EP 220 TERRESTIC 220 DTE PM 220	SHC 630 SPARTAN EP 220 SHC 220 GEAR TERRESTIC 220 DTE PM 220	SHC 630 SPARTAN EP 220 DTE PM 220
320	SHC 632 SPARTAN EP 320 SHC 320 GEAR MOBILGEAR 600 XP 320 TERRESTIC 320	SHC 632 MOBILGEAR 600 XP 320	SHC 632 SPARTAN EP 320 SHC 320 GEAR	SHC 632 SPARTAN EP 320 TERRESTIC 320
460	SHC 634 SPARTAN EP 460 SHC 460 GEAR	SHC 634 SPARTAN EP 460	SHC 634 SHC 460 GEAR	SHC 634 SPARTAN EP 460
680	SPARTAN EP 680 EXTRA HECLA SUPER CYLINDER OIL	SPARTAN EP 680		EXTRA HECLA SUPER CYLINDER OIL
1000	SHC 639			SHC 639

Multiple oils are often used within a plant. This can lead to the potential for the wrong oil to be used or cross contamination.

Reliability Package



Sight glass confirms correct oil level and condition of oil

Differential pressures cause air exchange through breather/filter. Humidity and dirt can be drawn in as contaminants. Old breather designs offer minimal protection.

Prevent Contaminants from Entering Reducer

F Unit removed from Service.

Where’s the dipstick?

Where is the breather?

2145Y1 Vacuum Pump Drive

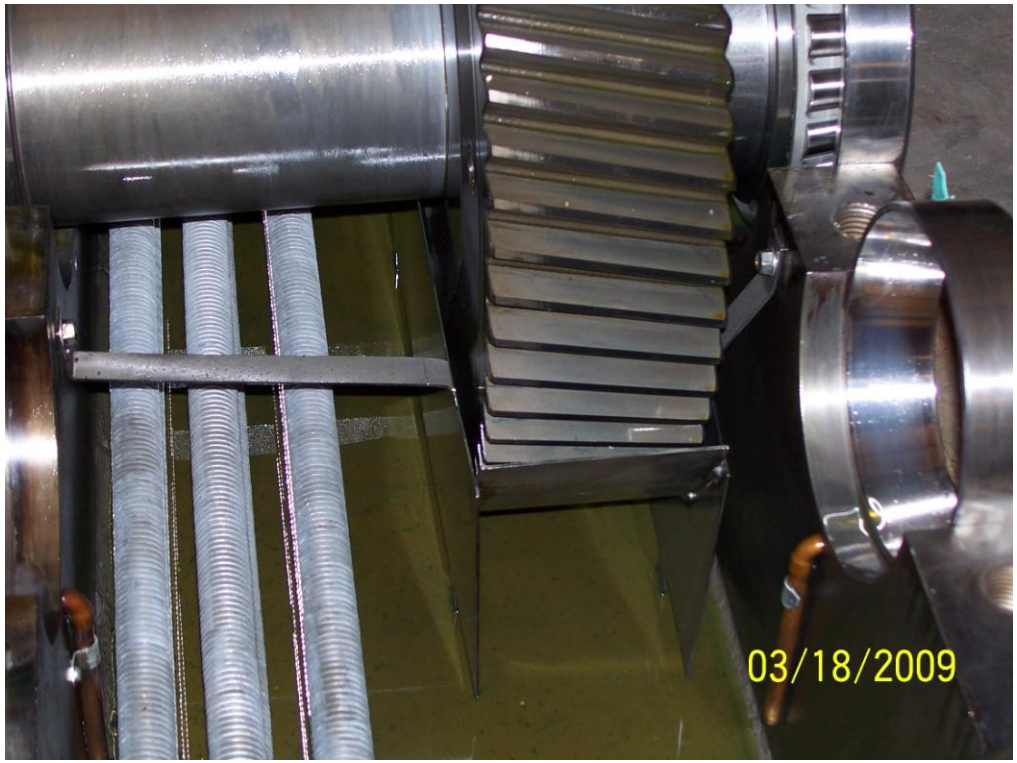
- Quoted (2) surplus Falk 2140Y1 reducers but lost order to competitor

- About two years later I get called in to a meeting with the Maintenance manager who says “I need your help, I can’t get these darn 2145Y1 reducers to last. They are running, hot, leaking and failing after approximately 1 year of service. Can you help me”.

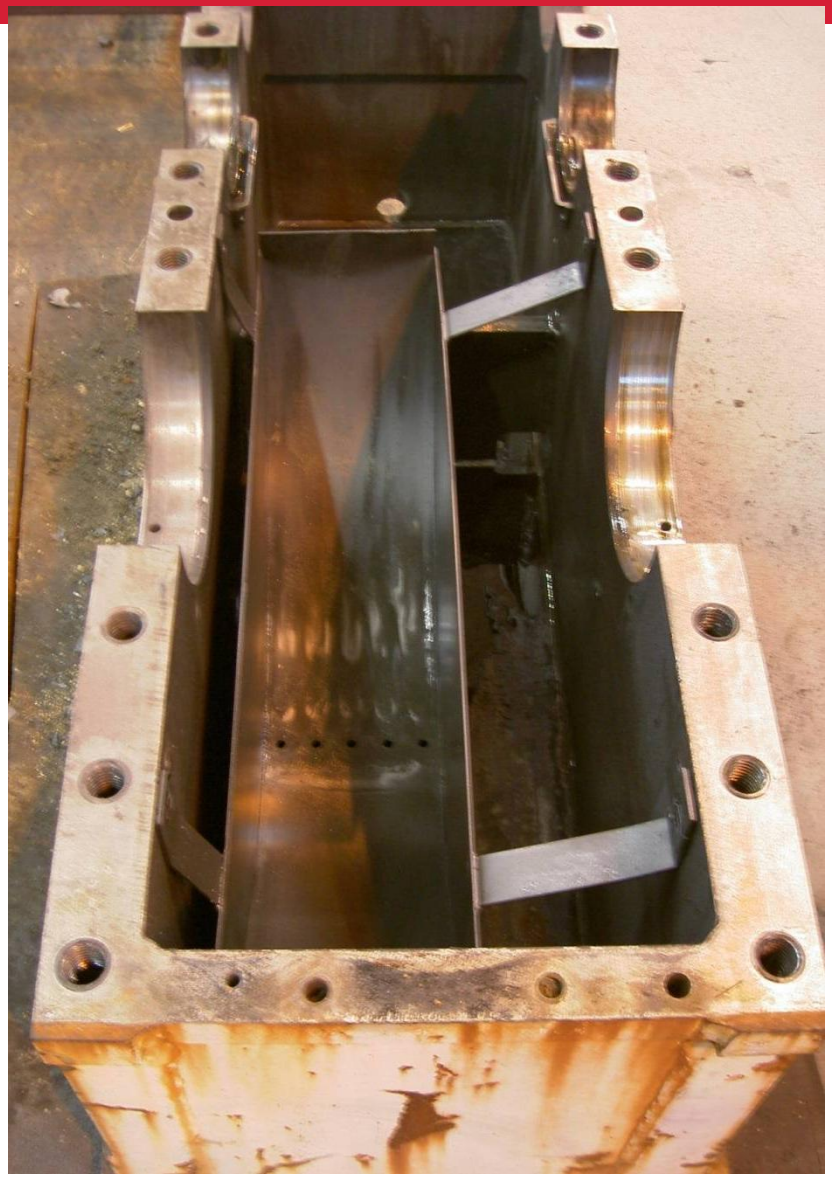
- We inspect the reducer and find out the following:

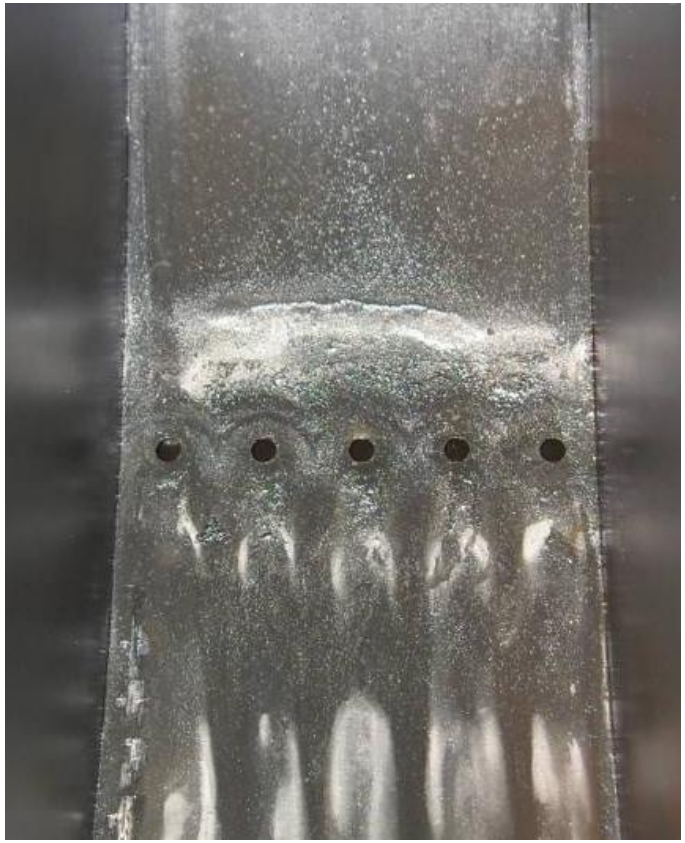
1. Wrong Oil Dipstick was installed
2. No oil pan was installed
3. Gear heat treatment incorrect
4. Drainback design was blocked
5. Vendor “XYZ” recommended adding an oil cooler to reduce the oil temperature.

Falk reducer may not be a Falk.



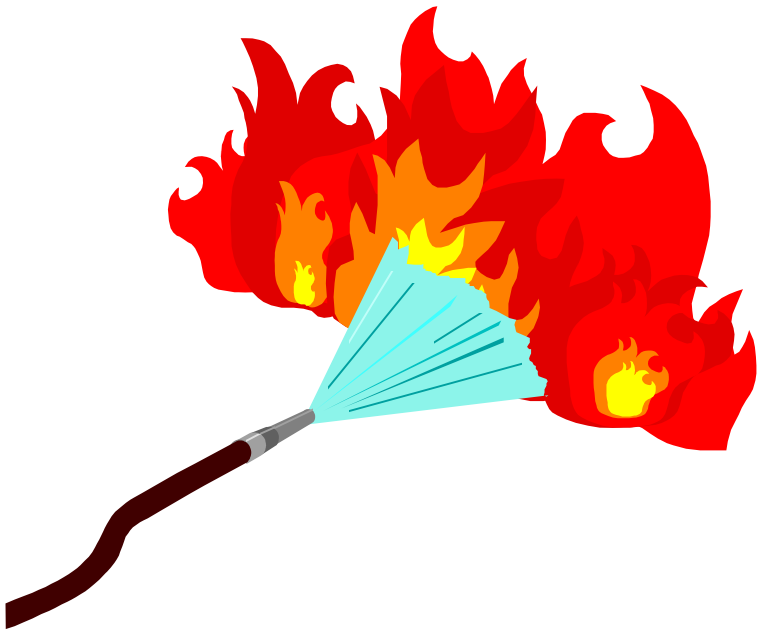
Fabricated Steel Housing with Exclusion Pan





Welded Steel Housing

How Hot is TOO HOT



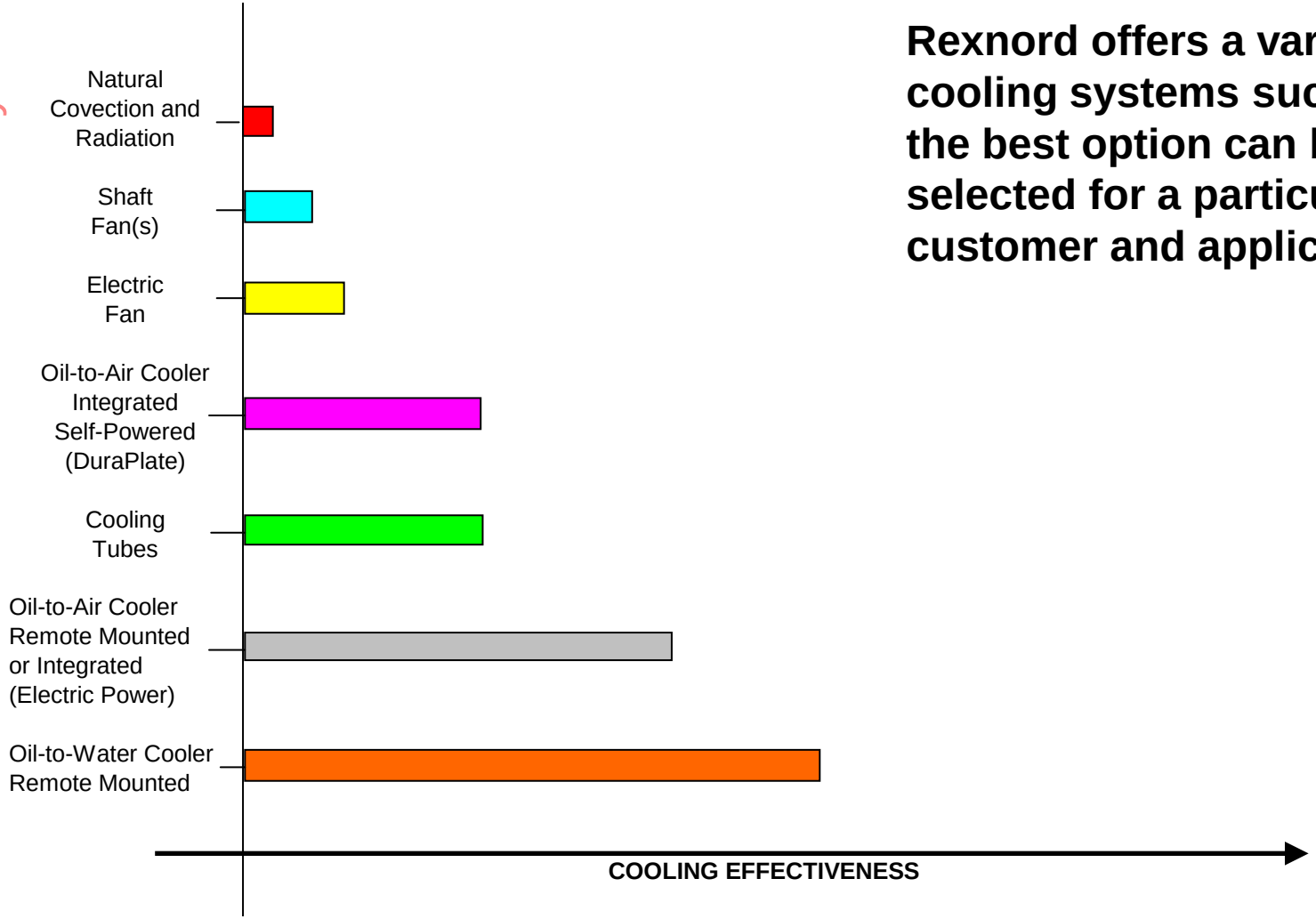
- Try to keep operating temperature below 160° F. Thermal limit is 200°F.
- What is the hottest spot on a gear reducer?
- What can be done to decrease operating temperatures?

Why Reducers Fail – Lubricant Breakdown

Sludge

This view shows a cup of lube taken from a drive returned for a warranty claim. At the time of this picture the cup sat on it's side for about ½ hour

What Are the Cooling Options ?

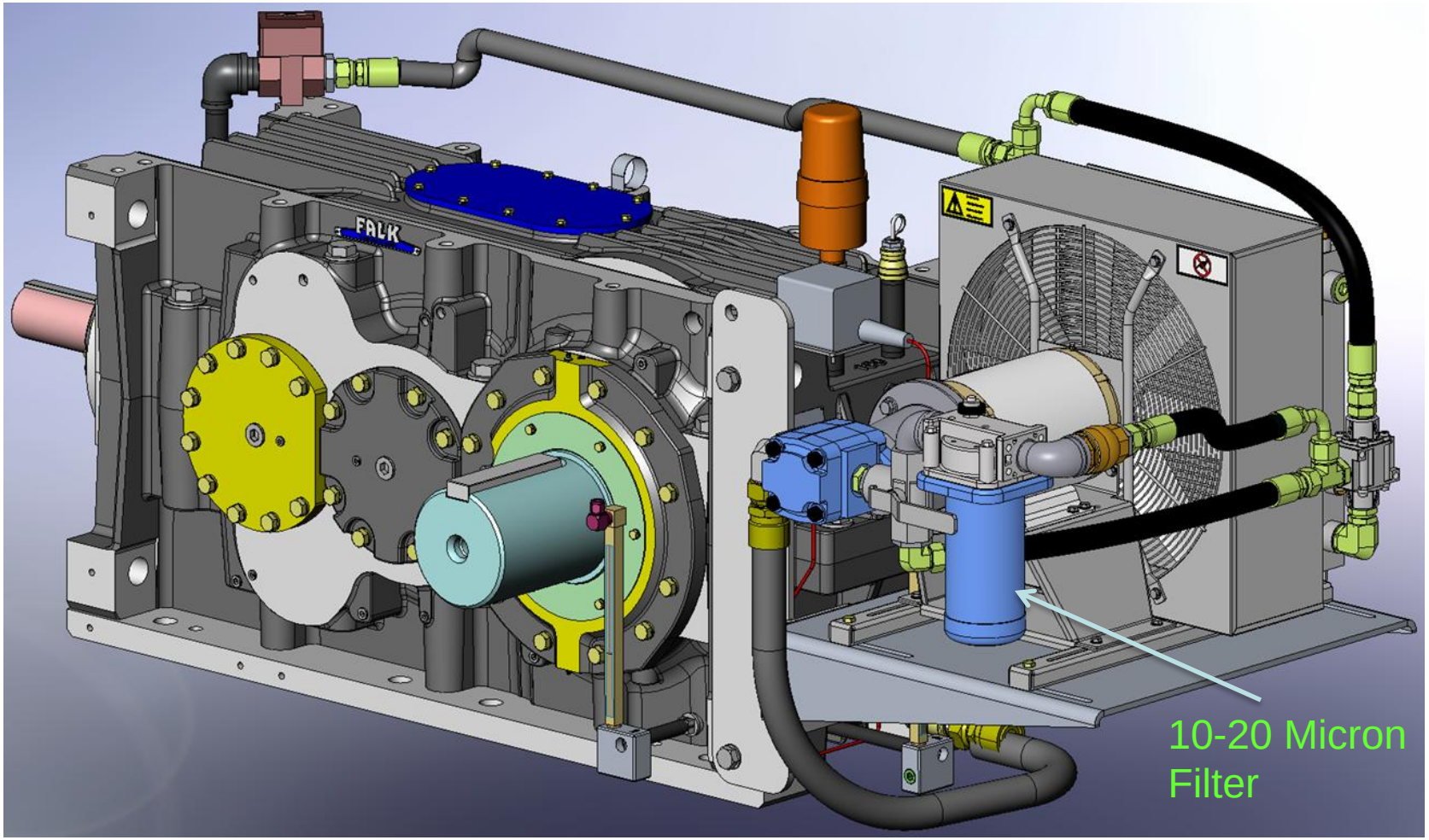


Rexnord offers a variety of cooling systems such that the best option can be selected for a particular customer and application

Air to Oil Cooler Package with Filter

REXNORD

#AhmedEltayef



External Oil-to-Air Cooler (Integrated/Electric Power)

Lube Pump Circulates Hot Oil Thru Radiator Where it is Cooled by Air Forced Thru Radiator by Fan

Interconnecting Hoses Are Provided

Fin and Tube Style Radiator

Thermostatic By-Pass Valve Routes Cold Oil Around Radiator

Double Ended Motor Drives Positive Displacement Pump on One End and Cooling Fan on the Other

600 Series Cooler on A1 Reducer

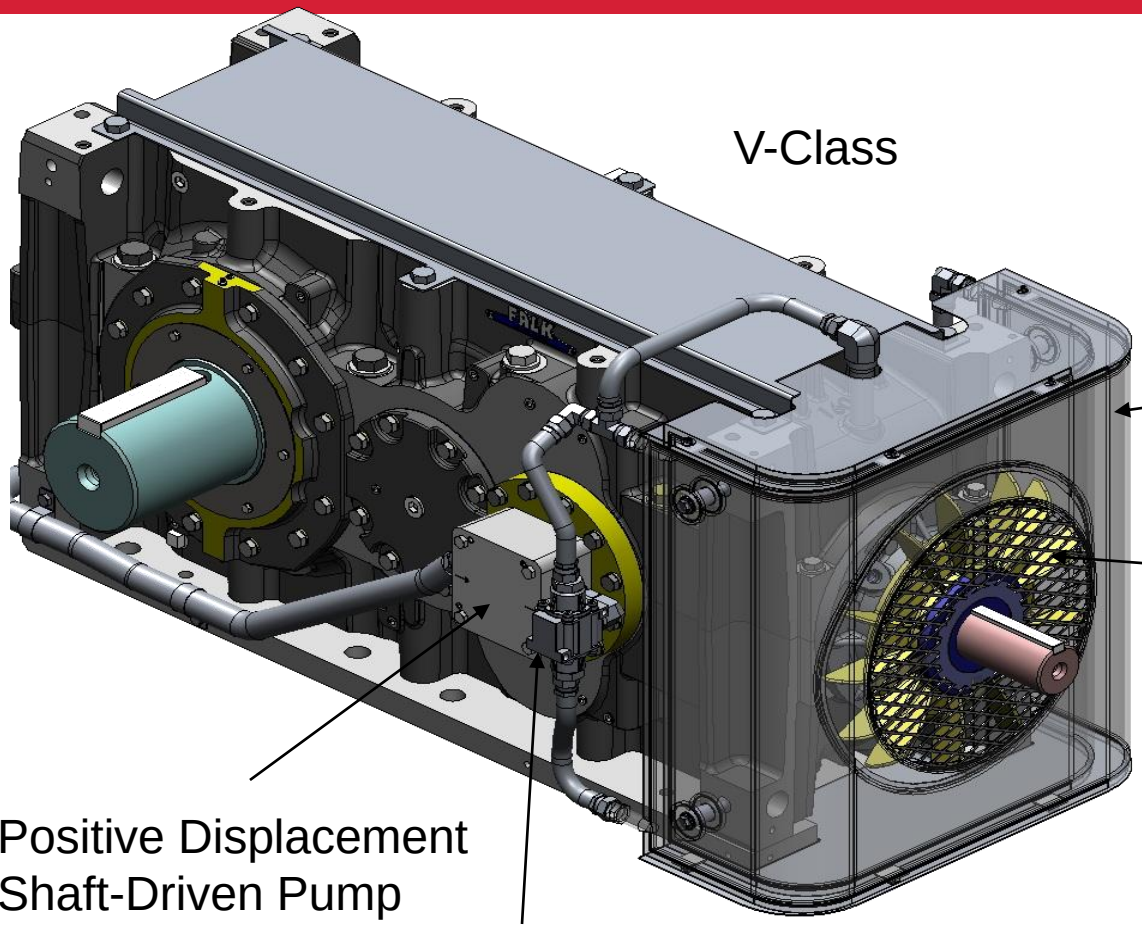
Mounting Plate is Bolted to Gear Drive Housing

610PA on 445A1-AS

Integrated Self Powered Air to Oil Cooler (DuraPlate)

REXNORD

#AhmedEltayef



V-Class

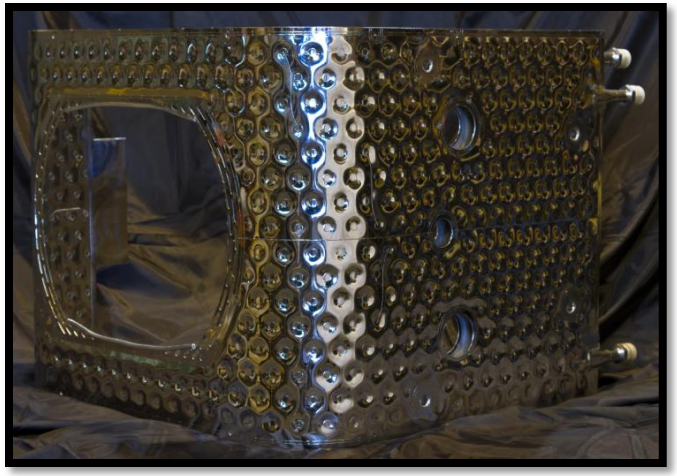
Lube Pump Circulates Hot Oil Thru Radiator Where it is Cooled by Air Forced Thru Radiator by Fan

Plate Style Radiator

Shaft Fan

Positive Displacement Shaft-Driven Pump

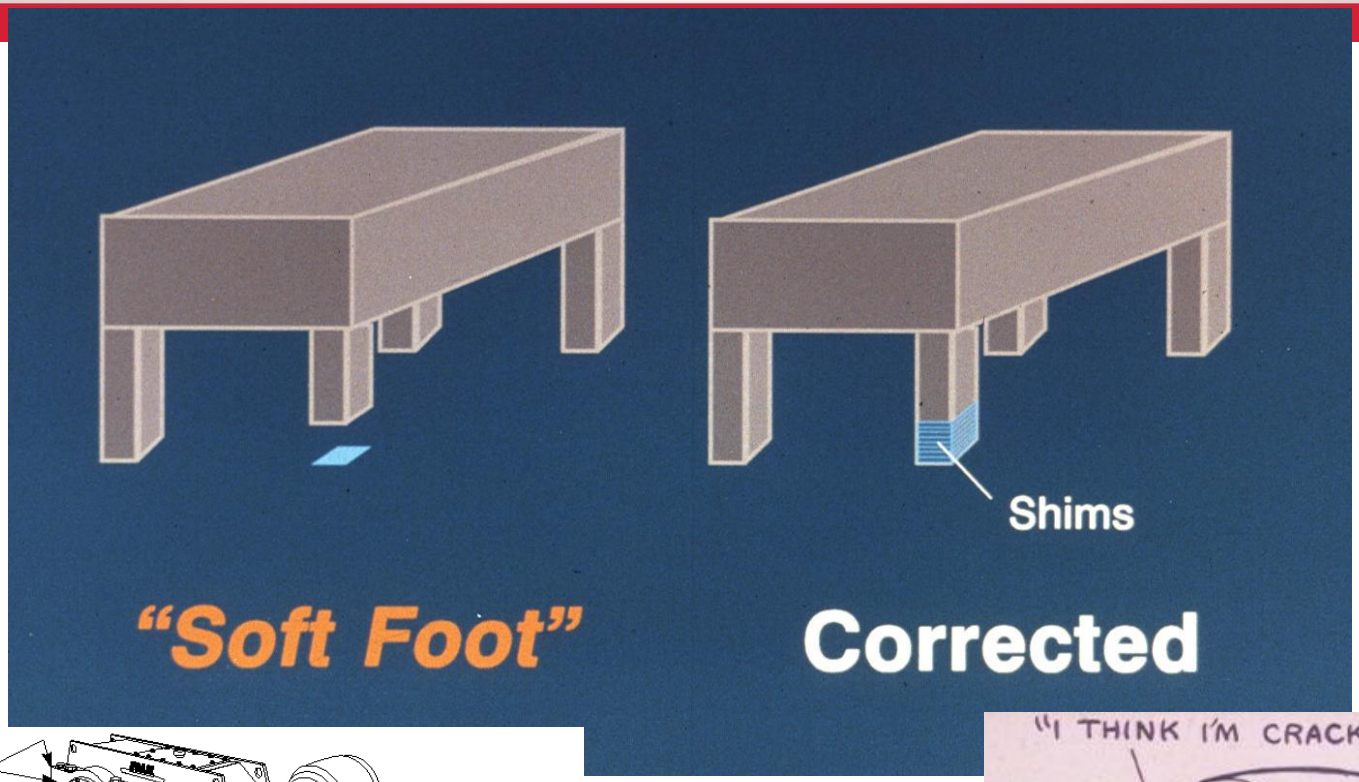
Thermostatic By-Pass Valve Routes Cold Oil Around Radiator

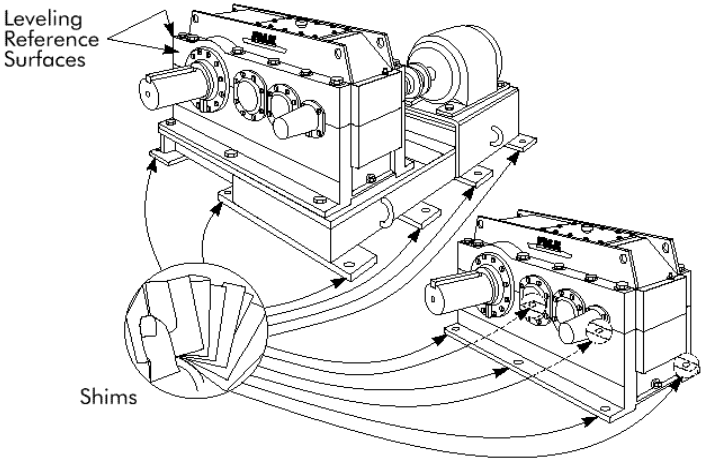


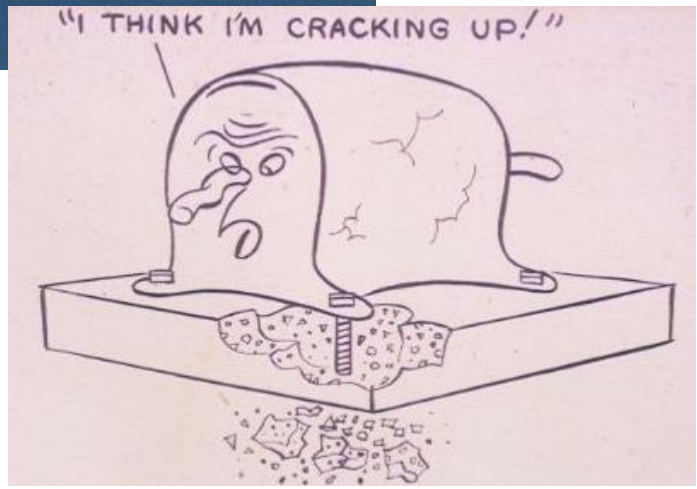
Falk Duraplate Cooling

Maintenance And Repair Practices

Why Reducers Fail - Soft Foot







Story About Soft Foot and Vibration – Shared by Rexnord Coupling Engineering

#AhmedEltayef

“Don Cutler visited a customer that was having serious vibration problems that had been going on for well over a year when he was asked to come in and evaluate. He met with the maintenance staff to discuss the problem with them and then went to work. As Don’s story goes he walked over with a ratchet and socket to check for Soft Foot, which is the first thing you should do prior to alignment of the equipment. As luck would have it, Don said he loosened the very first nut bolting the equipment to the base and immediately the vibration level dropped right off. He tightened it back down and the vibration level went right back up. He loosened it again and down went the vibration.

He turned to the people around him and said the problem is Soft Foot and all you need is to shim right here and all is good. The foreman was in disbelief and called the plant manager to come down to see what was going on. Don explained the problem to him as well and went on to explain how to fix it. The manager became angry telling Don they had been working to solve this for well over a year and there was no way someone could just walk in and correct everything in less than 5 minutes by loosening one nut. He told Don to collect his equipment and get out. He later called Don to apologize and thank him for a job well done. Don said the manager was just so frustrated and could not believe the correction was that simple that his emotions and temper got away from him when Don said it was soft foot.”

Customer was Running This Reducer!

#AhmedEltayef

Auxiliary Drive for a Lime Kiln

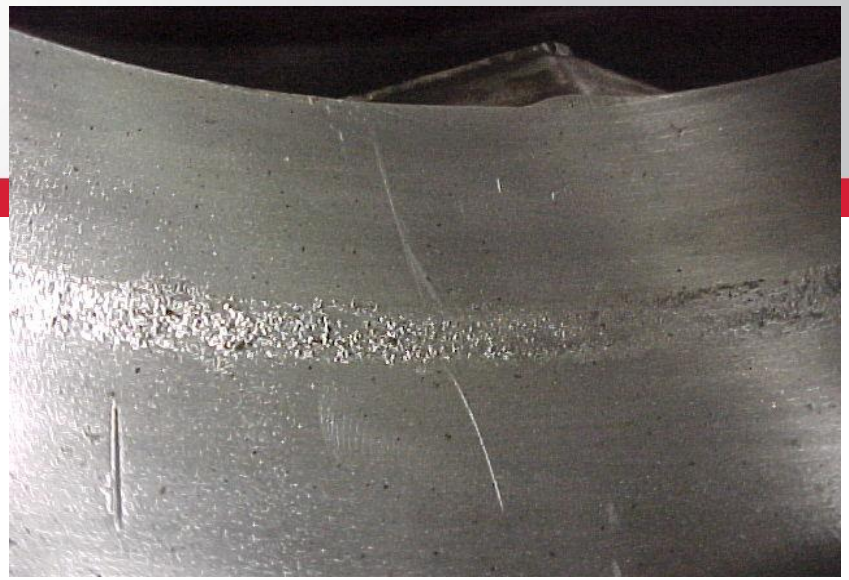
Request for Parts on a Falk Reducer Manufactured in November of 1940!

#AhmedEltayef

140YT Falk Reducer Returned to Falk after Several Repairs by Third Party Shop

0.040 housing Gap!

Gear hardness were out of specification. Be aware of what you are paying for and what you are getting.



Bearing bores Oversize and Pitted

Dowel holes are oversize and oblong allowing cover to deflect and twist excessively

Vibration Measurement

Guideline = 0.20 in/sec / 5.0 mm/sec filtered peak
(0.30 in/sec unfiltered)

#AhmedEltayef

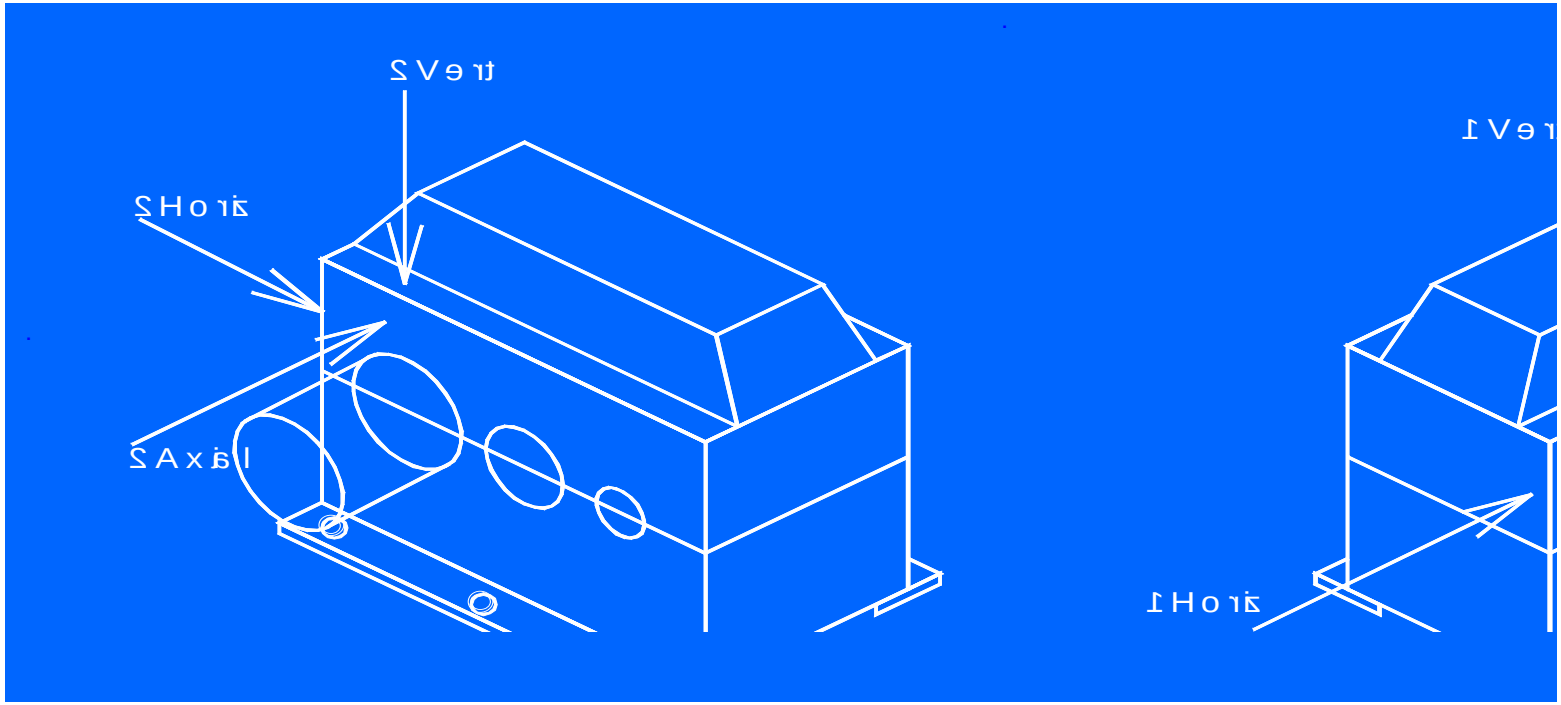
Remember this!

Below 0.2 in/sec -- O.K.
Above 0.2 in/sec -- check, find source

Don’t wait until the alarm trips. Catch trend early to be able to order parts if necessary and be able to schedule an outage in advance. Alarm point is an emergency point. Be aware of VFD’s and natural frequency issues.

Measurement Positions – Minimum

- Double Reduction Unit
  - All positions on housing, <u>not on seal cages or covers</u>



Vibration Analysis

VIBRATION ANALYSIS: **SATURN Triple**

REDUCER TYPE	SATURN S,D,T	GEAR CODE
RATIO	69.64	
INPUT SPEED (RPM)	1750.00	0444

REDUCTION LOCATION	NUMBER OF PLANETS	TOOTH COUNT			ACTUAL RATIO	INCLUDED RATIO
		SUN OR INPUT	PLANETS	RING		
FIRST REDUCTION	3.00	35.00	37.00	109.00	4.11	4.11
SECOND REDUCTION	3.00	35.00	37.00	109.00	4.11	16.93
THIRD REDUCTION	3.00	35.00	37.00	109.00	4.11	69.64
						69.64

FIRST REDUCTION GEAR FREQUENCIES*	
SUN/INPUT ONE PER REV	29.17
CARRIER ONE PER REV	7.09
GEAR MESH	772.71
PLANET GEAR DAMAGE	41.77
SUN/INPUT GEAR DAMAGE	66.23
RING GEAR DAMAGE	21.27

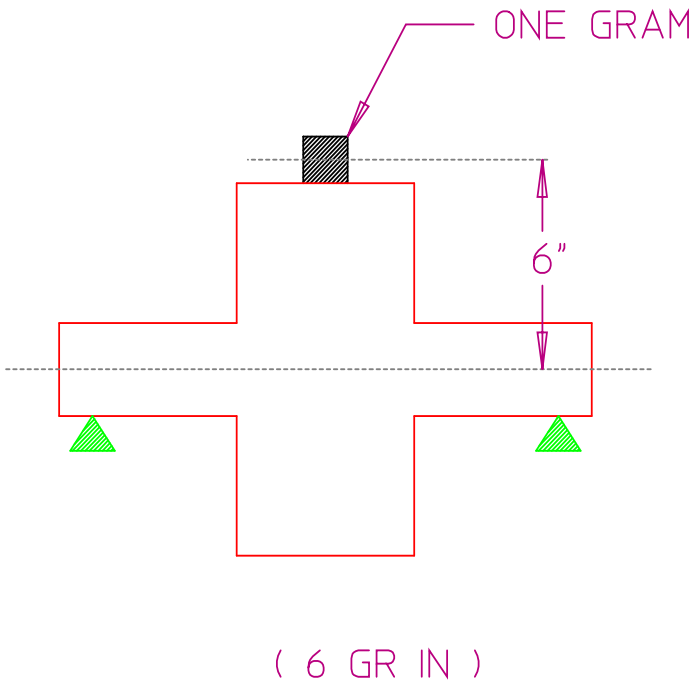
THIRD REDUCTION GEAR FREQUENCIES*	
SUN/INPUT ONE PER REV	1.72
CARRIER ONE PER REV	0.42
GEAR MESH	45.65
PLANET GEAR DAMAGE	2.47
SUN/INPUT GEAR DAMAGE	3.91
RING GEAR DAMAGE	1.26

SECOND REDUCTION GEAR FREQUENCIES*	
SUN/INPUT ONE PER REV	7.09
CARRIER ONE PER REV	1.72
GEAR MESH	187.81
PLANET GEAR DAMAGE	10.15
SUN/INPUT GEAR DAMAGE	16.10
RING GEAR DAMAGE	5.17

Unbalance Effect With Speed

REXNORD

Note: Be careful if VFD being used



SPEED (rpm)	FORCE (lbs)
1,000	.4
2,000	1.6
10,000	37
20,000	150

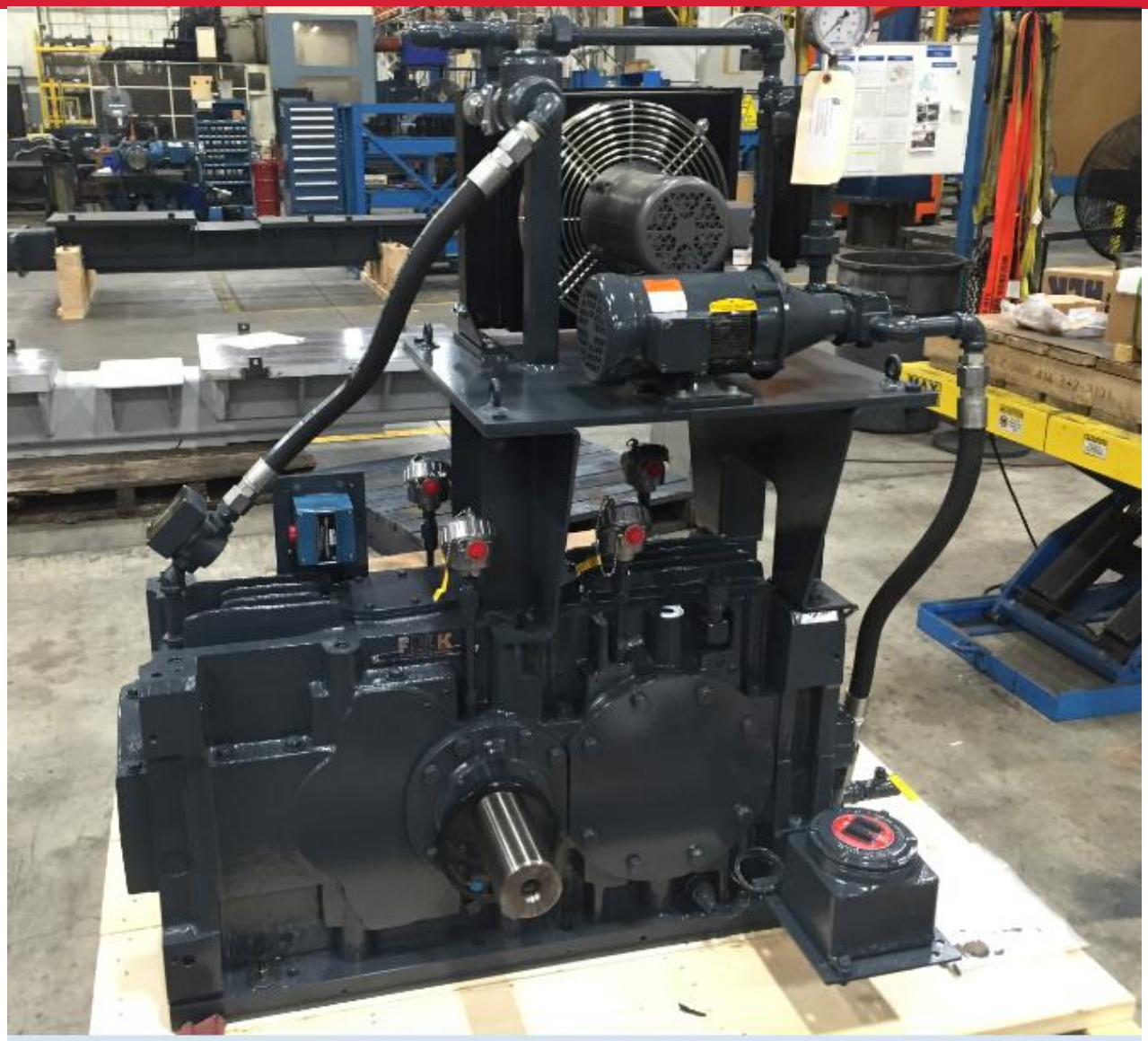
Unbalance Force = 0.000028416 x Weight x Radius x RPM^2

Instrumentation Packages are Far More Common Than in the Past.

Air to Oil Cooler Mounted to Top of V Class Reducer

REXNORD

#AhmedEltayef



Temperature and Vibration Monitoring

V class reducer installation at a papermill.
Vibration and Temperature monitoring in mills far more common than in the past.

Goulds Pump Vibration Indicator called Eye Alert. Built into pump design as a standard offering. Common even for basic ANSI pumps.

Failure Modes

Failure Modes

REXNORD

- Bearing Failures
- Gear Wear and Failures
- Lubrication Breakdown
- Shaft Failures
- Seal Failures

Lubrication or Load

Most Failures can be Traced back to Lube or Load as the Root cause.

- If the failure mode and root cause cannot be determined in the field then there is a process in place to return the reducer to the factory for a detailed inspection and a formal report.

- Sometimes the customer wants a factory report.

Formal Warranty Inspection and Report

#AhmedEltayef

Warranty Report: 8006691 - AAE0066300X1XA

FALK RENEW

Jeff Mann, Engineer II
Jeffrey.Mann@rexnord.com

Contents

REXNORD
PRECISION. POWER. PERFORMANCE.

METALLURGICAL ENGINEERING REPORT

c: T. Mazeika, R. Olson

Mat. Lab Number: A842B
Requested by: Dwight Sabee
Reported by: Jeff Firkell
Date: August 18, 2015

METALLURGICAL ANALYSIS OF ATLAS PLANET GEAR – RMA 18038B

Part Description
Name of part: Planet gear SRK
Drawing number: SRK300031

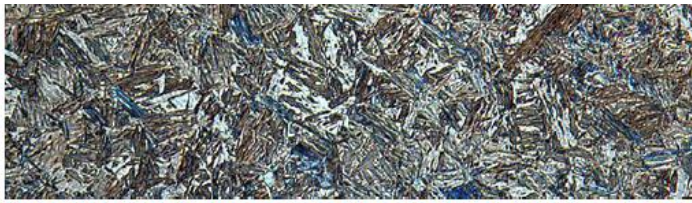
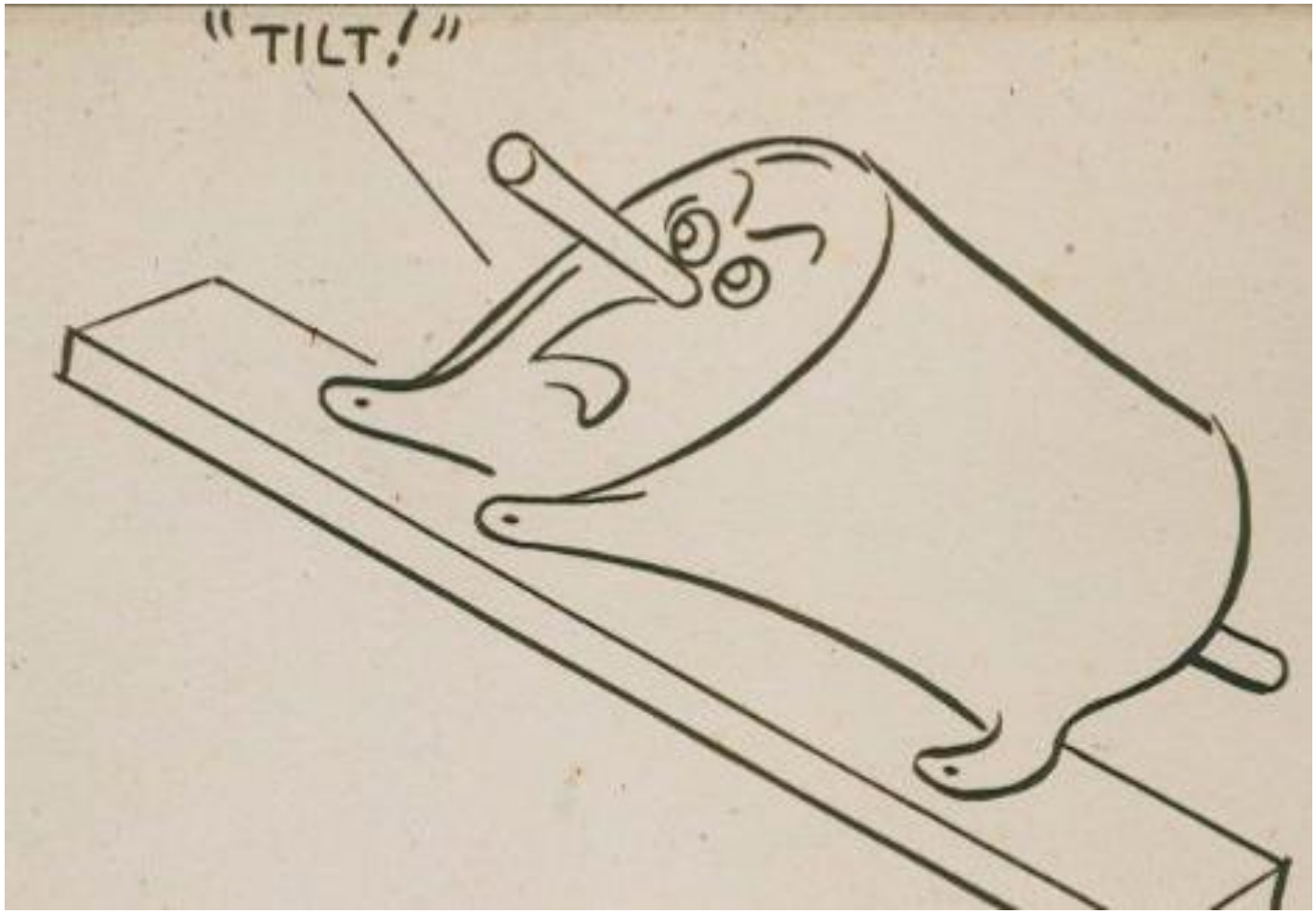


Figure 4 – Microstructure in the core of the material is primarily ter
etch, 500x.

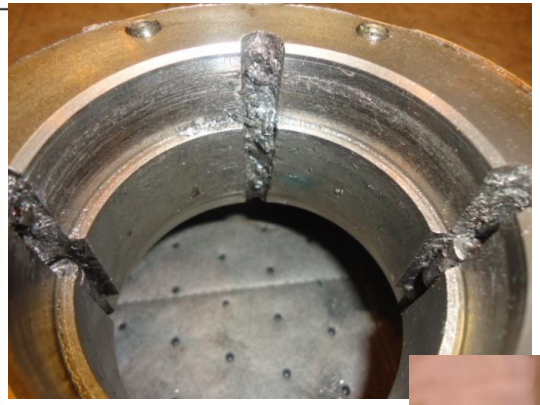
Why Reducers Fail – Excessive Mounting Angle



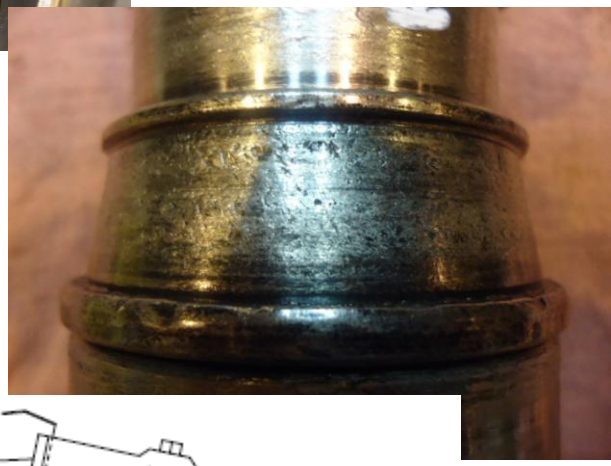
Installing Reducer On A Slope

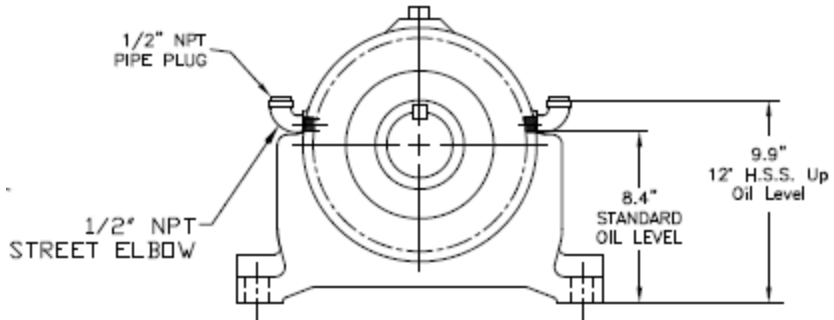
Maximum Mounting Angle Exceeded

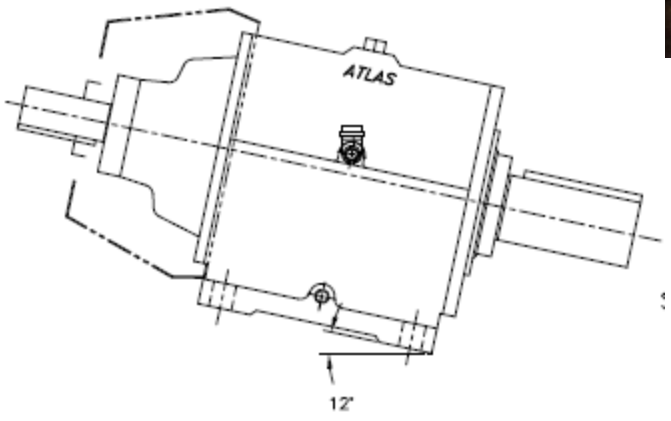
Fig 3. The high speed head components were disassembled, laid out and inspected. The bearing labeled B on the extended end of the shaft had failed. (043)



Identifying a bearing failure early on can prevent a much more expensive reducer failure



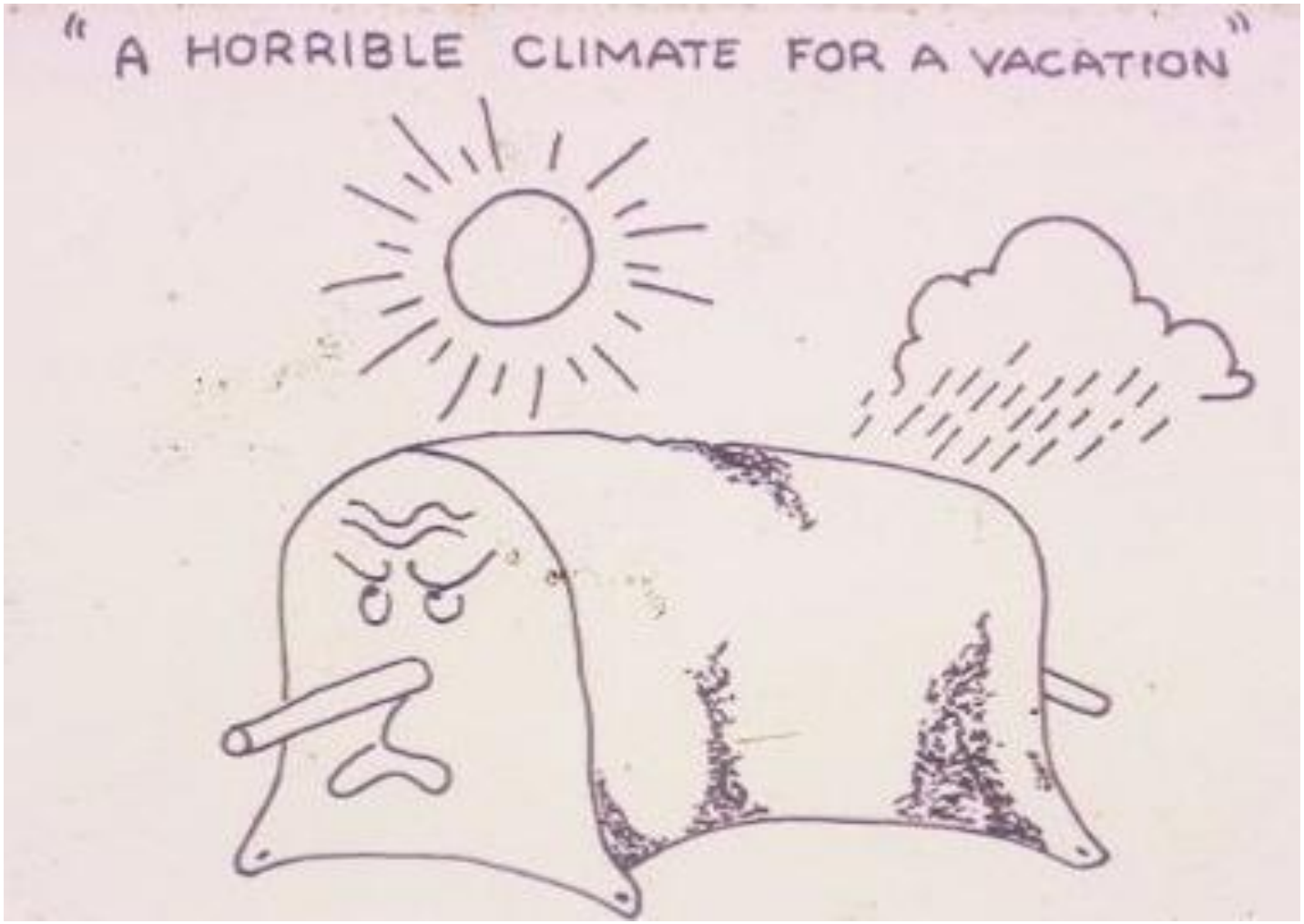




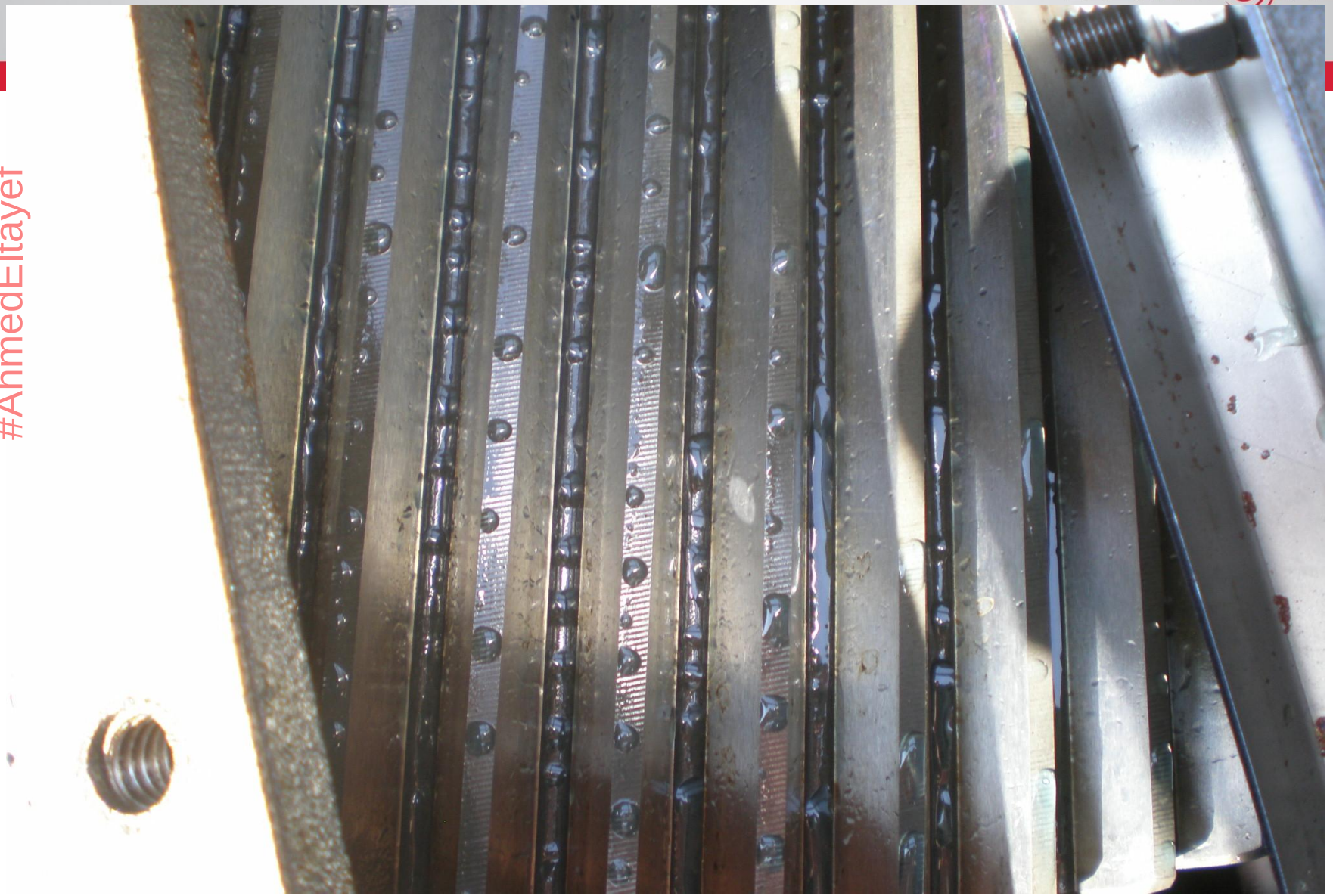
Why Reducers Fail – Improper Storage

REXNORD

#AhmedEltayef

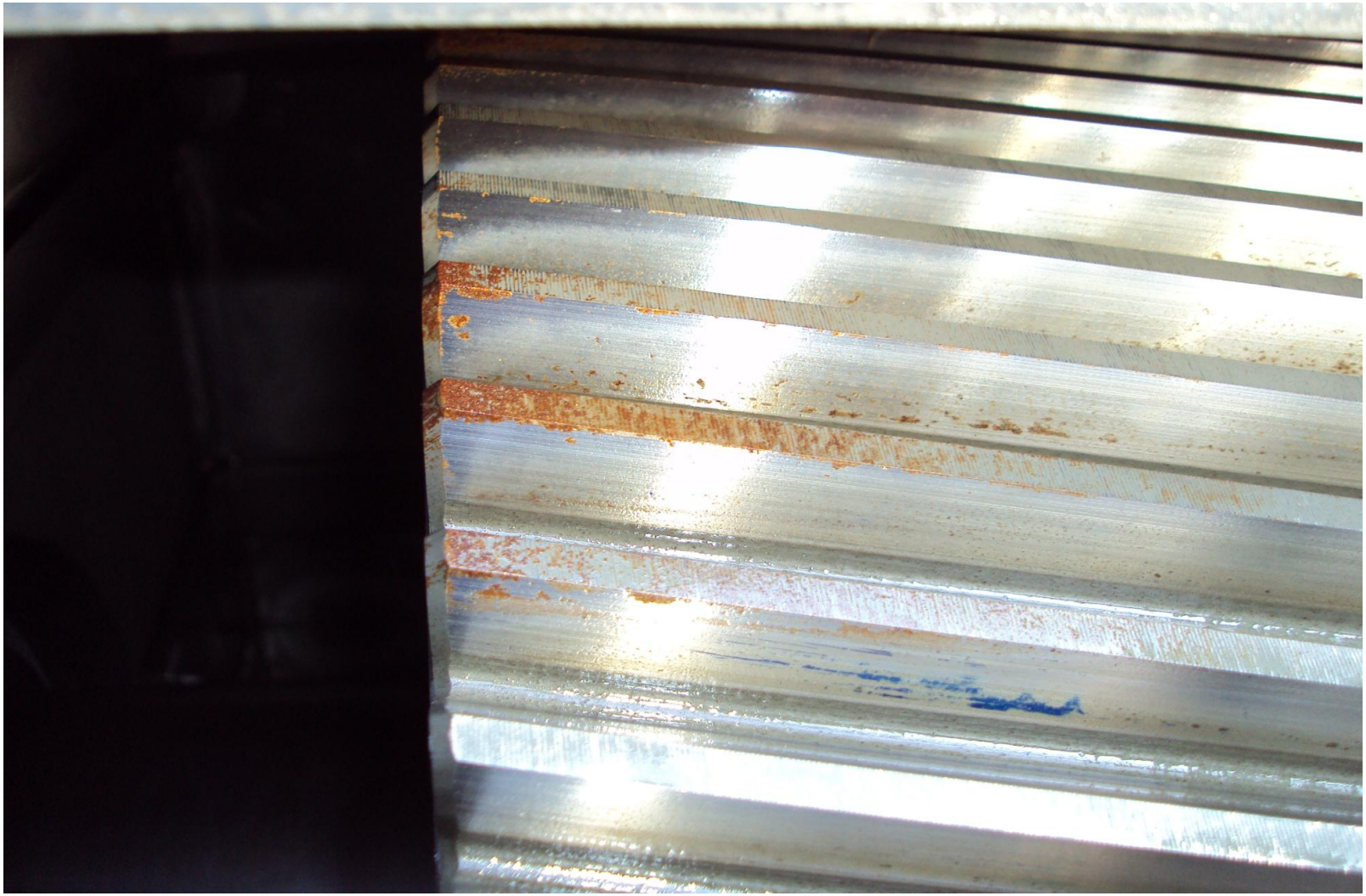


Condensation

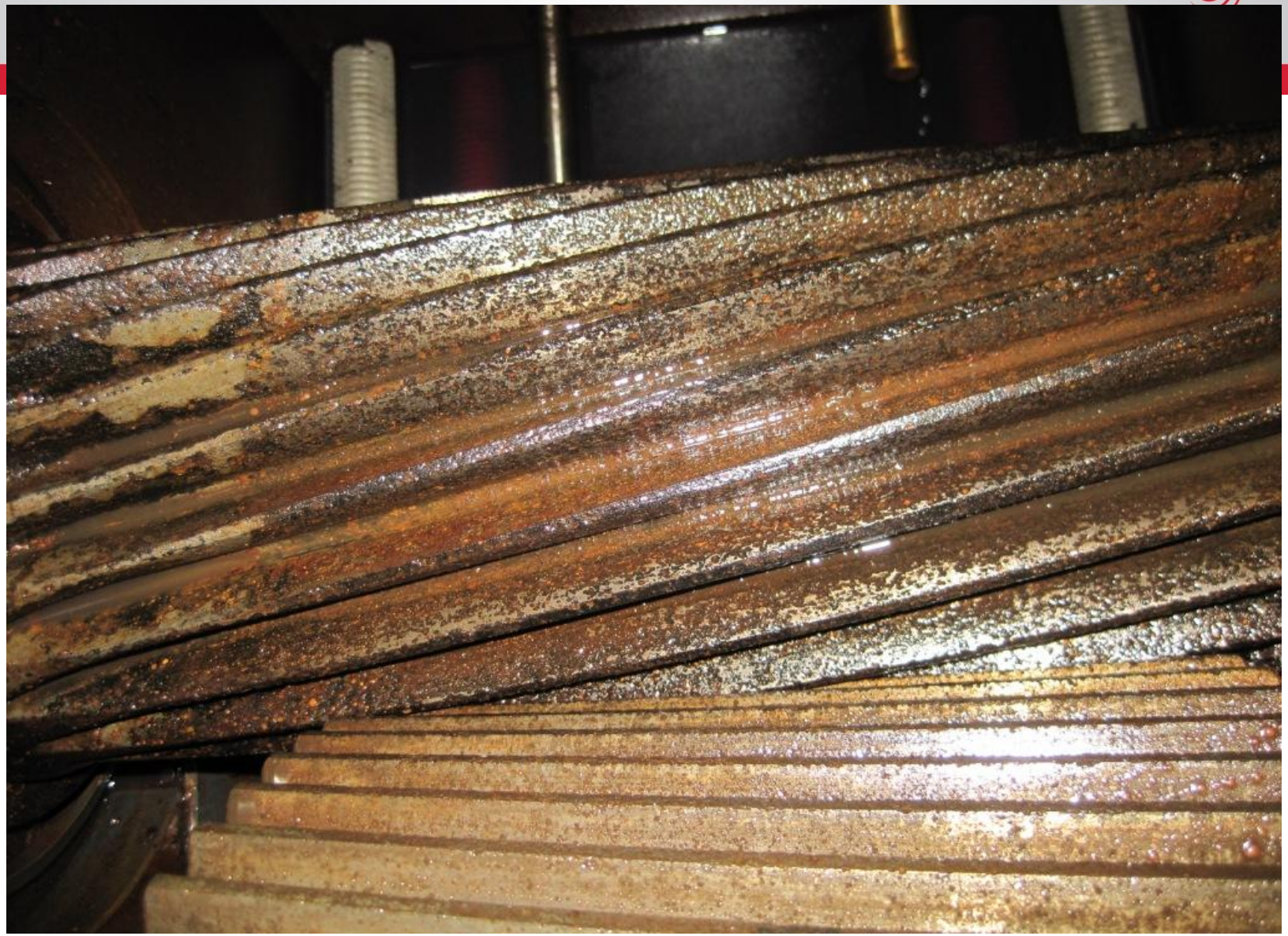


#AhmedEltayef

Surface Rust Starts to Form

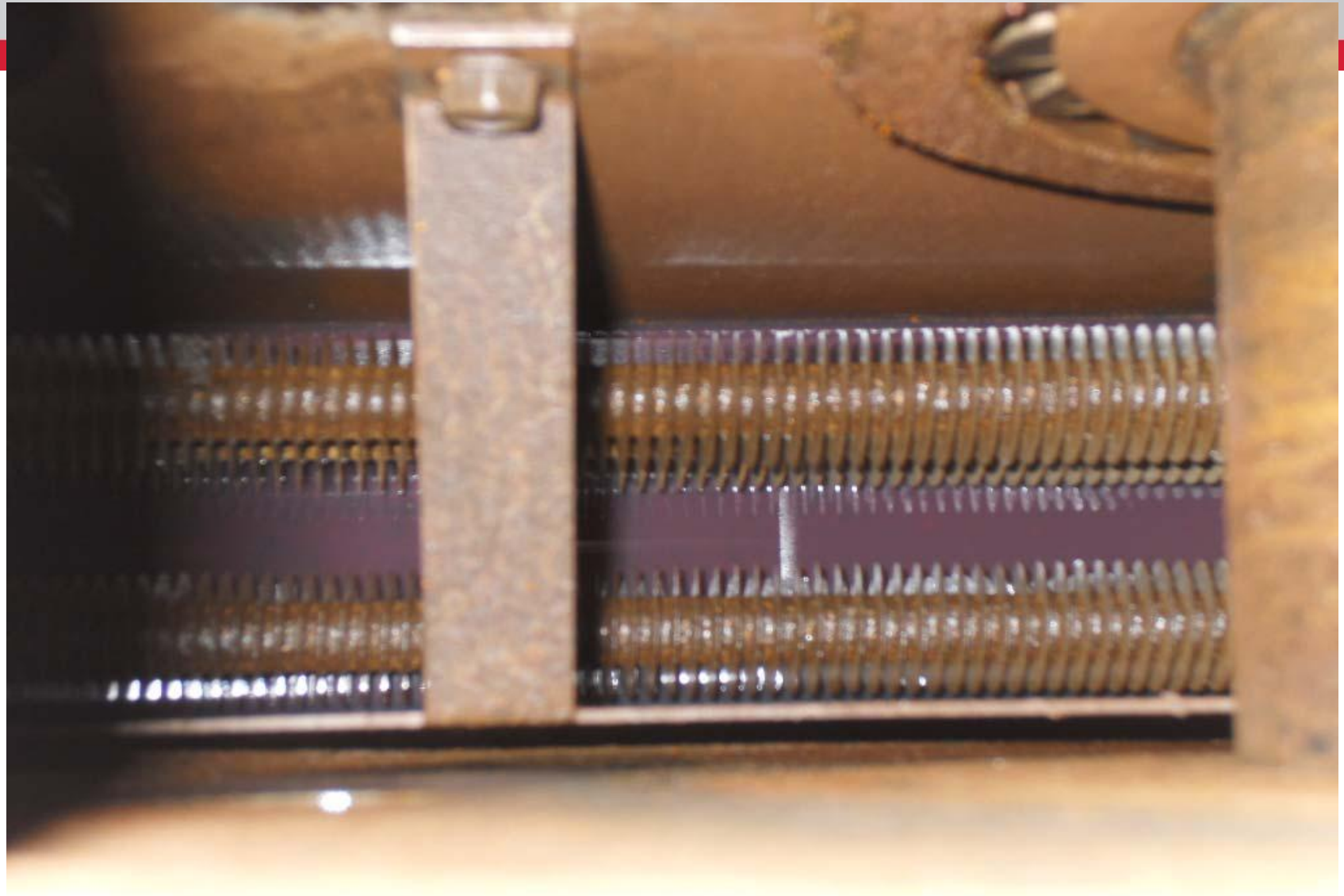


Severe Corrosion Can Result Over Time



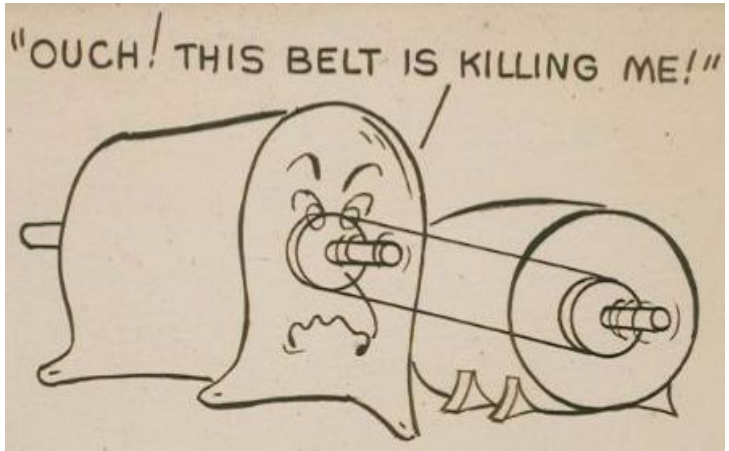
#AhmedEltayef

Rust Can Damage Gearing, Bearings and other Internal Surfaces



Why Reducers Fail - Overhung Load Damage to Bearing

Positioning of Sprockets or Pulleys to Far Out on Shaft



Direct connect designs preferred

Excessive Chain or Belt Tension

Heavy load zone spalling due likely to marginal lube and or excessive radial loads

Bearing Failure Type?

Lubrication failure due to incorrect bearing float setting.

Planetgear Installed at Sawmill

#AhmedEltayef

Investigating a Planetgear Failure at Sawmill

REXNORD

#AhmedEltayef

Sprocket is Contacting Bottom of Wood Stack. Heavy Contact Loads.

No Common Baseplate for Proper Chain Tension and Motor Alignment.

Gear (& Pinion) Tooth Rating

REXNORD

Gear Tooth Rating

Strength (**Bending Fatigue**)

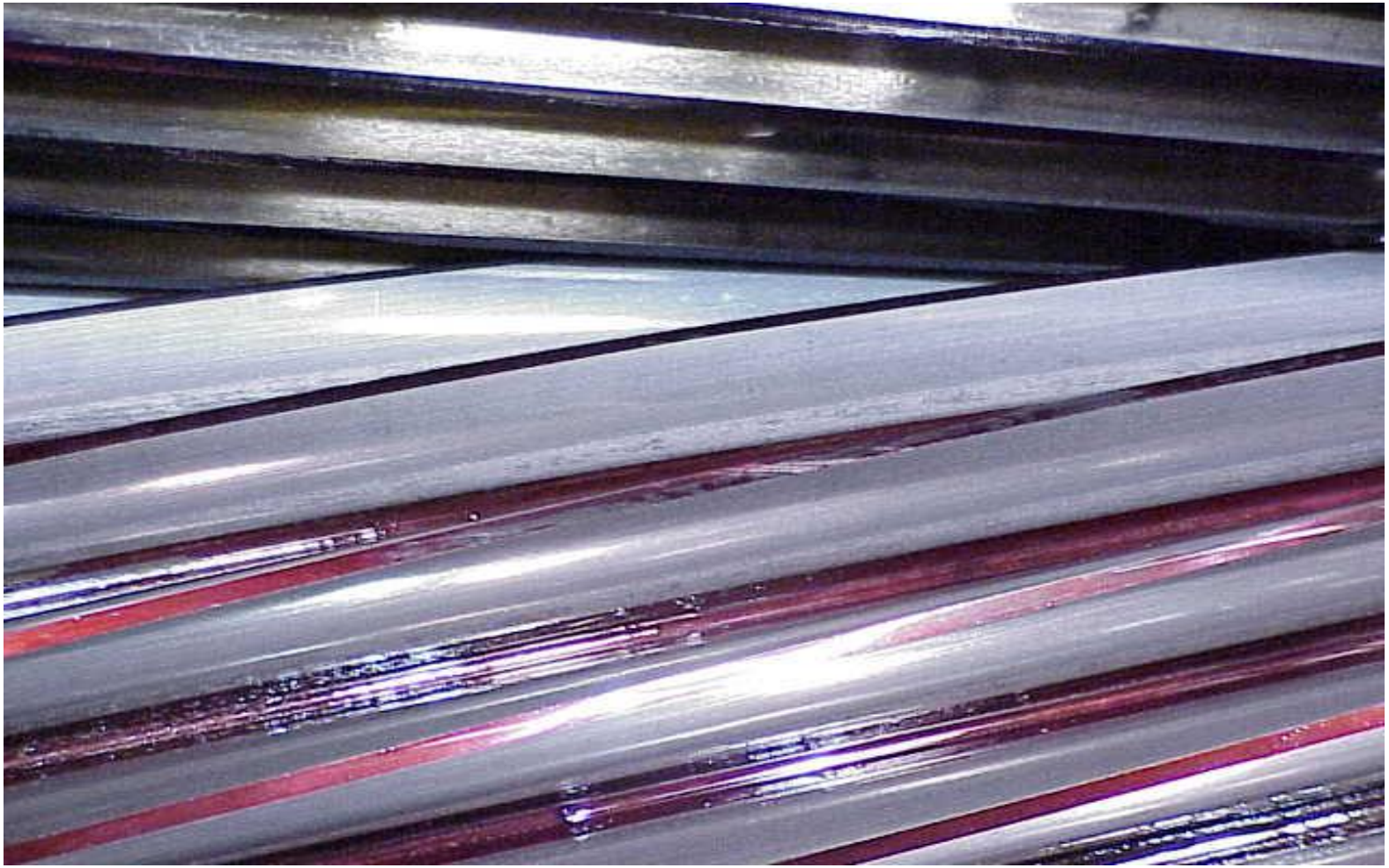
Load exceed strength Capacity. Whole tooth is at risk of fracture.

Durability (**Pitting Resistance**)

Surface fatigue leads to micro pitts and spalls

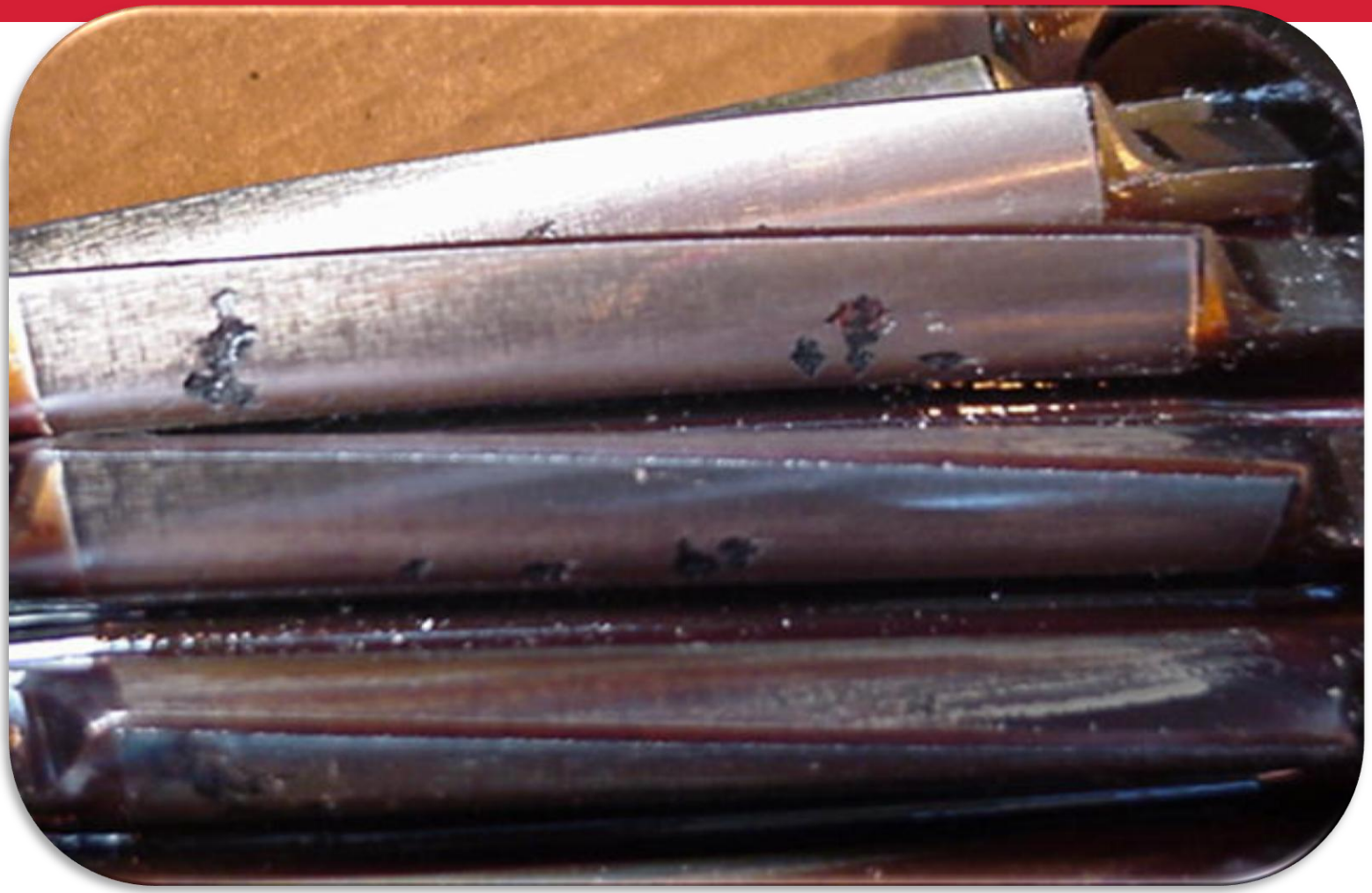
Micropitting, Frosting, Gray Staining – Contact Failure

Surface Fatigue (Carburized Gearing)



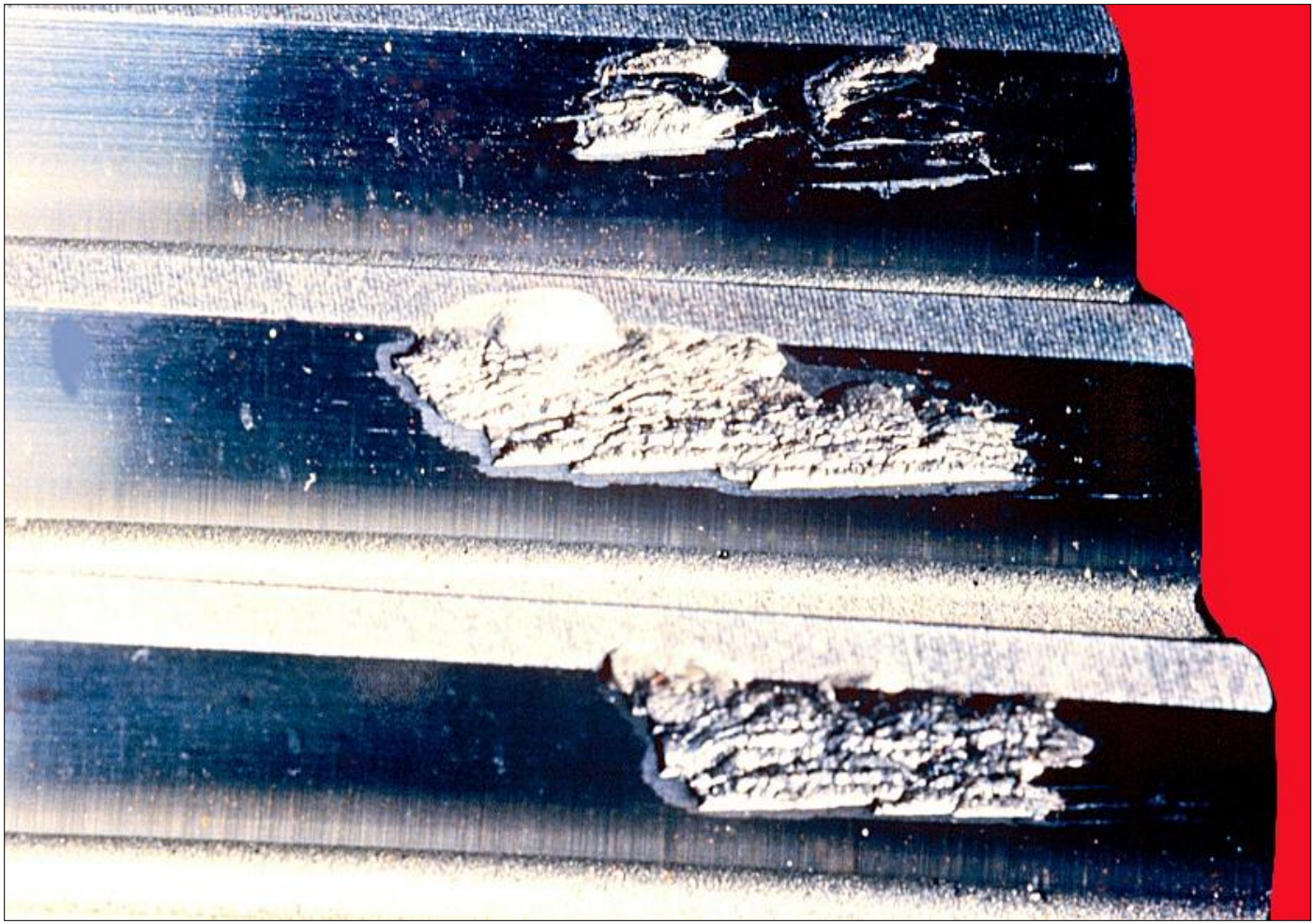
Micropitting is a Durability Failure. Surface of Gear Tooth is breaking down and pits have formed across the face of the tooth.

Why Reducers Fail - Gear Wear



Micropitting has progressed into spalling indicating marginal lube or high loads.

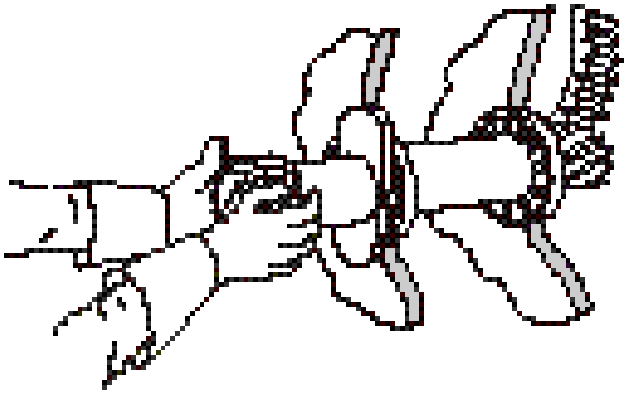
Surface Fatigue (Carburized Gearing)



Pitting Advances to Spalling and Eventually to Complete Case Separation

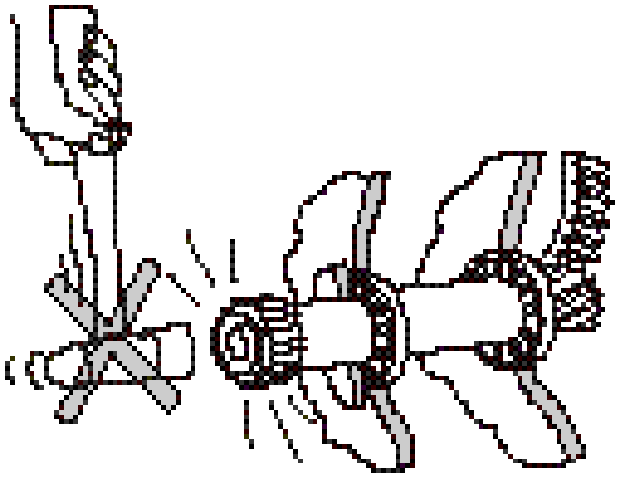
Failure Analysis Inspection

Why Reducers Fail – Incorrect Coupling Mounting Method



CORRECT METHOD

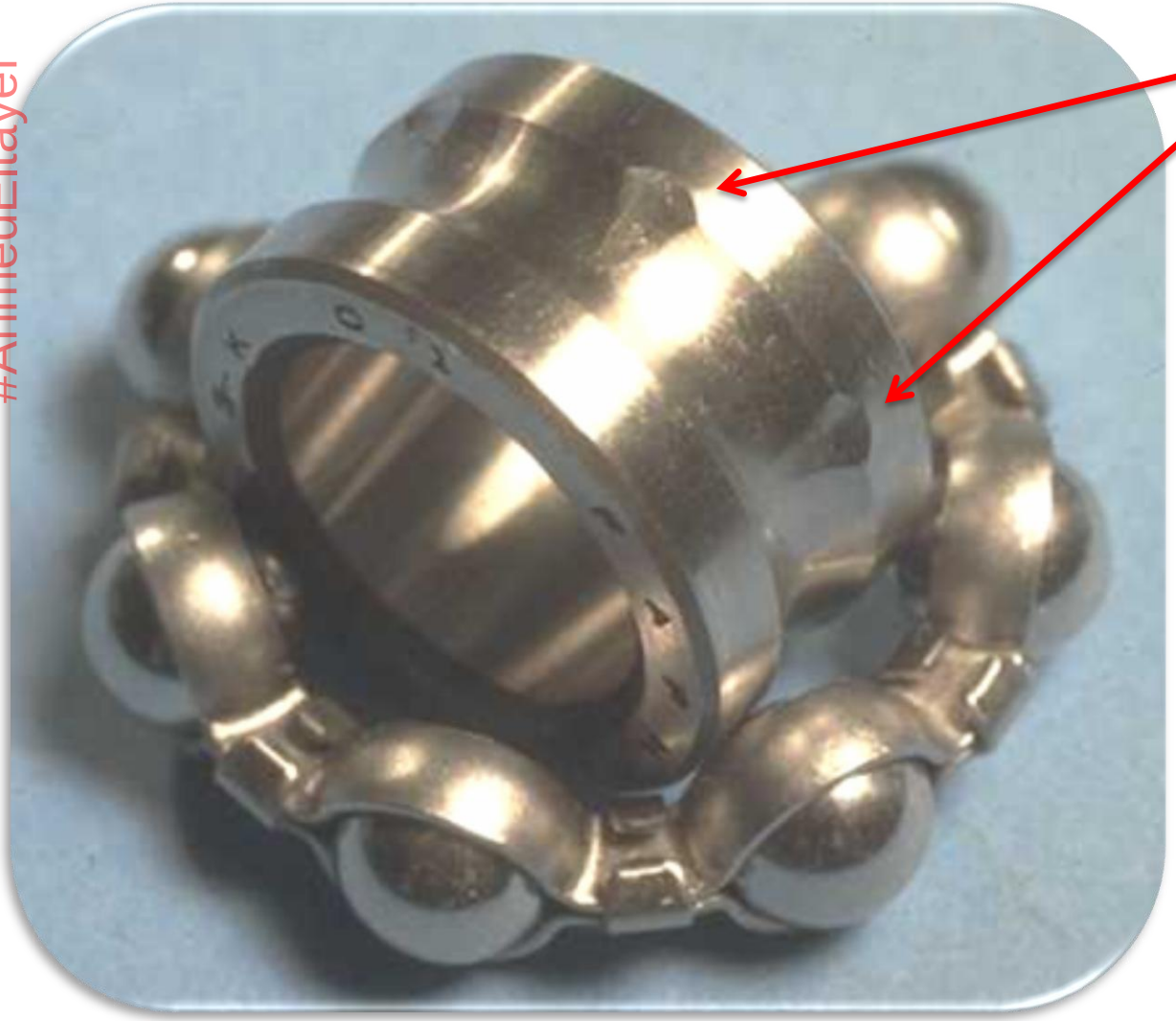
Heat interference fitted coupling hubs, pinions, sprockets or pulleys to a maximum of 275°F (135°C) and slide onto gear drive shaft.



INCORRECT METHOD

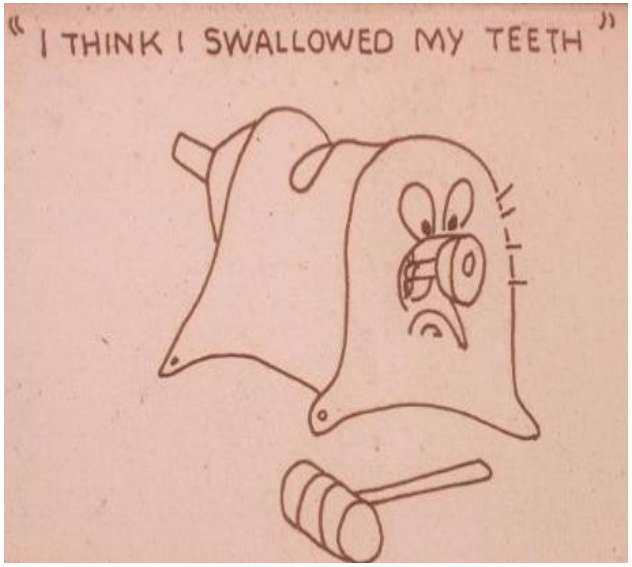
DO NOT drive coupling hub, pinion, sprocket or pulley onto the shaft. An endwise blow on the shaft/coupling may damage gears and bearings.

Bearing Failure



Brinelling

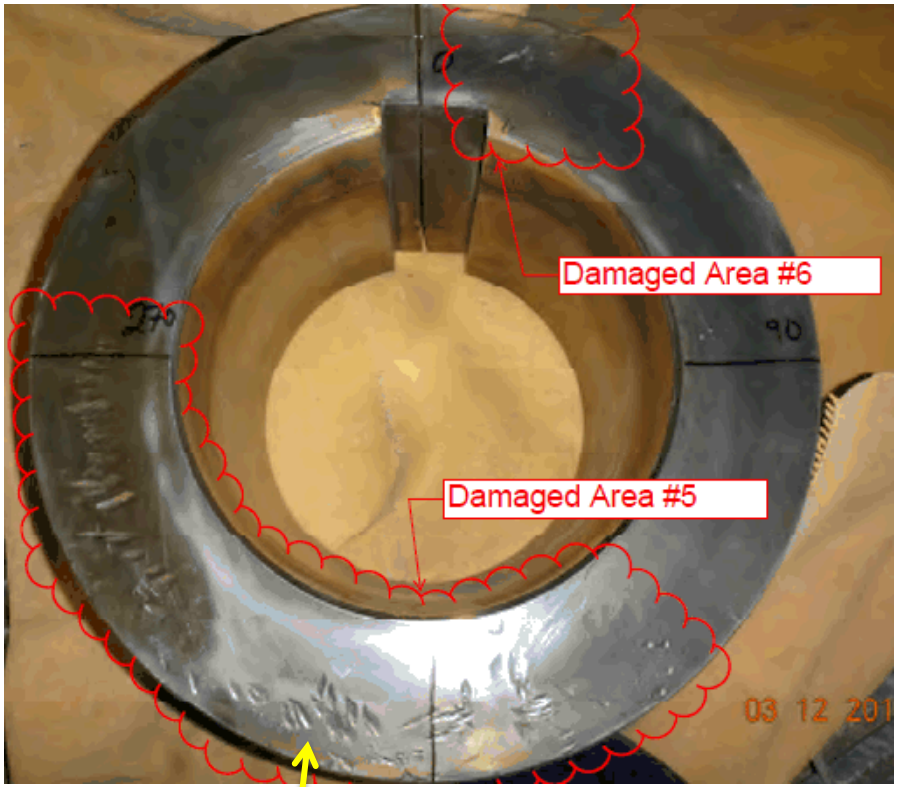
(Note Ball Space Dents in Race)



Motor Shaft Damage During Coupling Installation

4000HP Motor Shaft

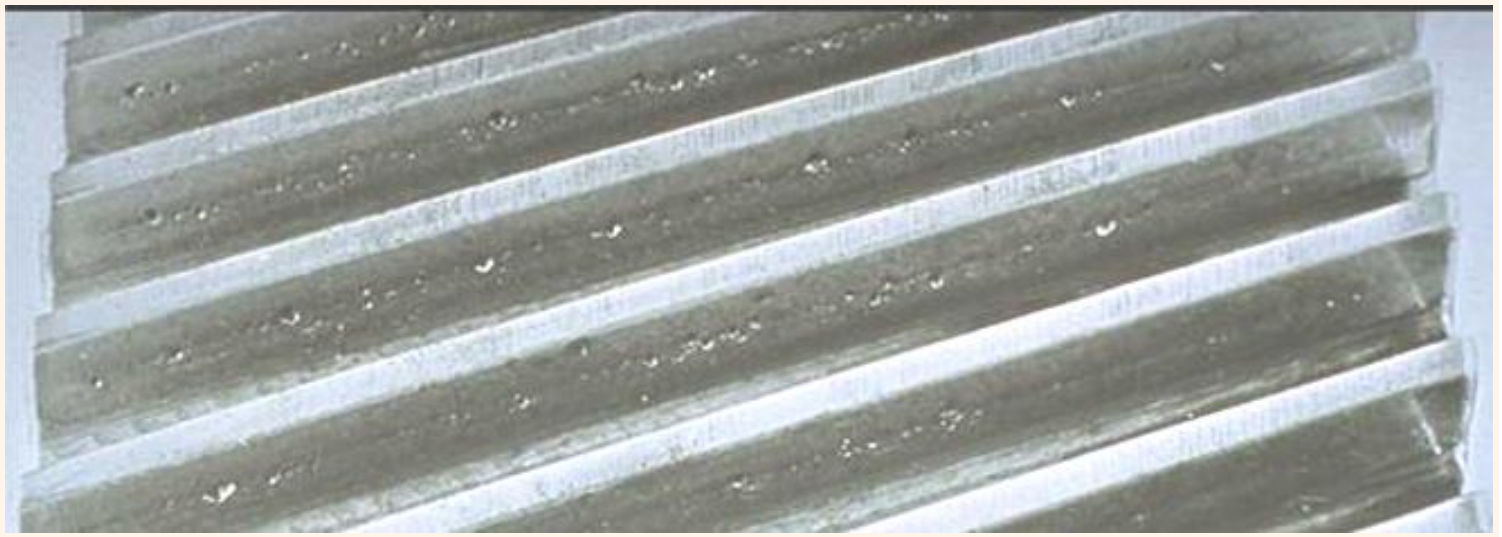
1070G Gear Coupling Hub

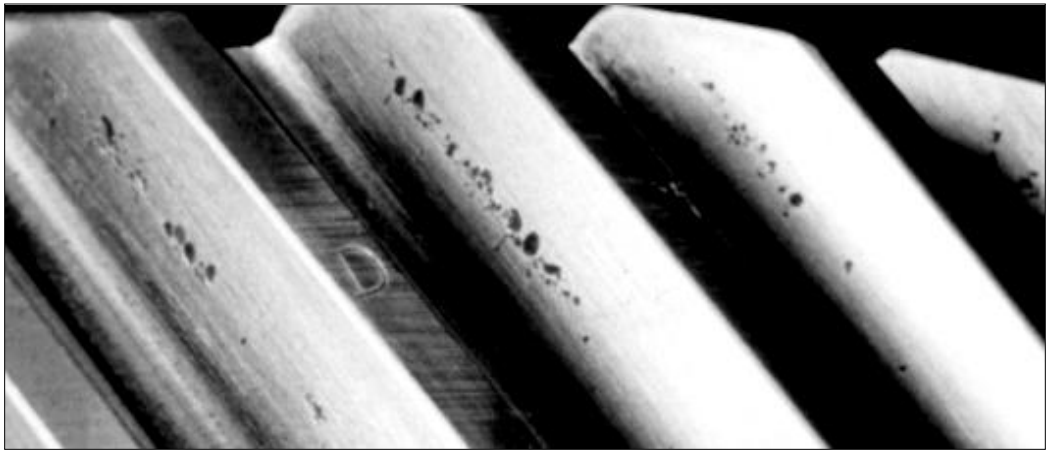


Hammer Time!

Initial or Corrective Pitting
Surface Fatigue (Through Hardened Gearing)

REXNORD

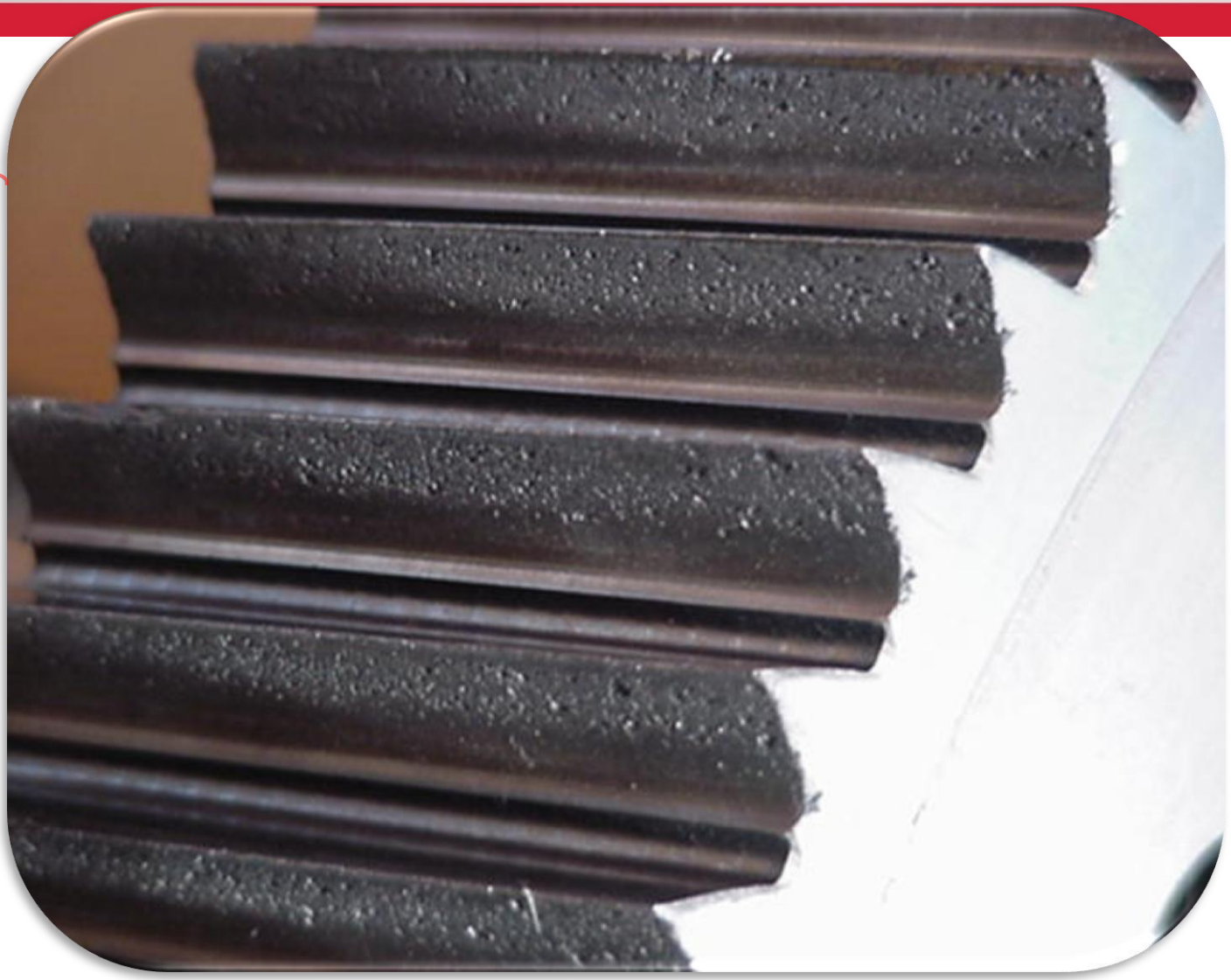




Destructive Pitting
Surface Fatigue (Through Hardened Gearing)

REXNORD

Gear Wear



Severe wear and pitting distress due to high loads or improper lube

Vacuum Pump Reducer

This reducer was removed from service with teeth running in this condition!

Tooth Root Fillet Fatigue Fracture Breakage

REXNORD

Bending Fatigue (Strength) Failure. Cracks generally develop and lead to complete tooth failure. Catastrophic tooth failure.

Dedendum Washout

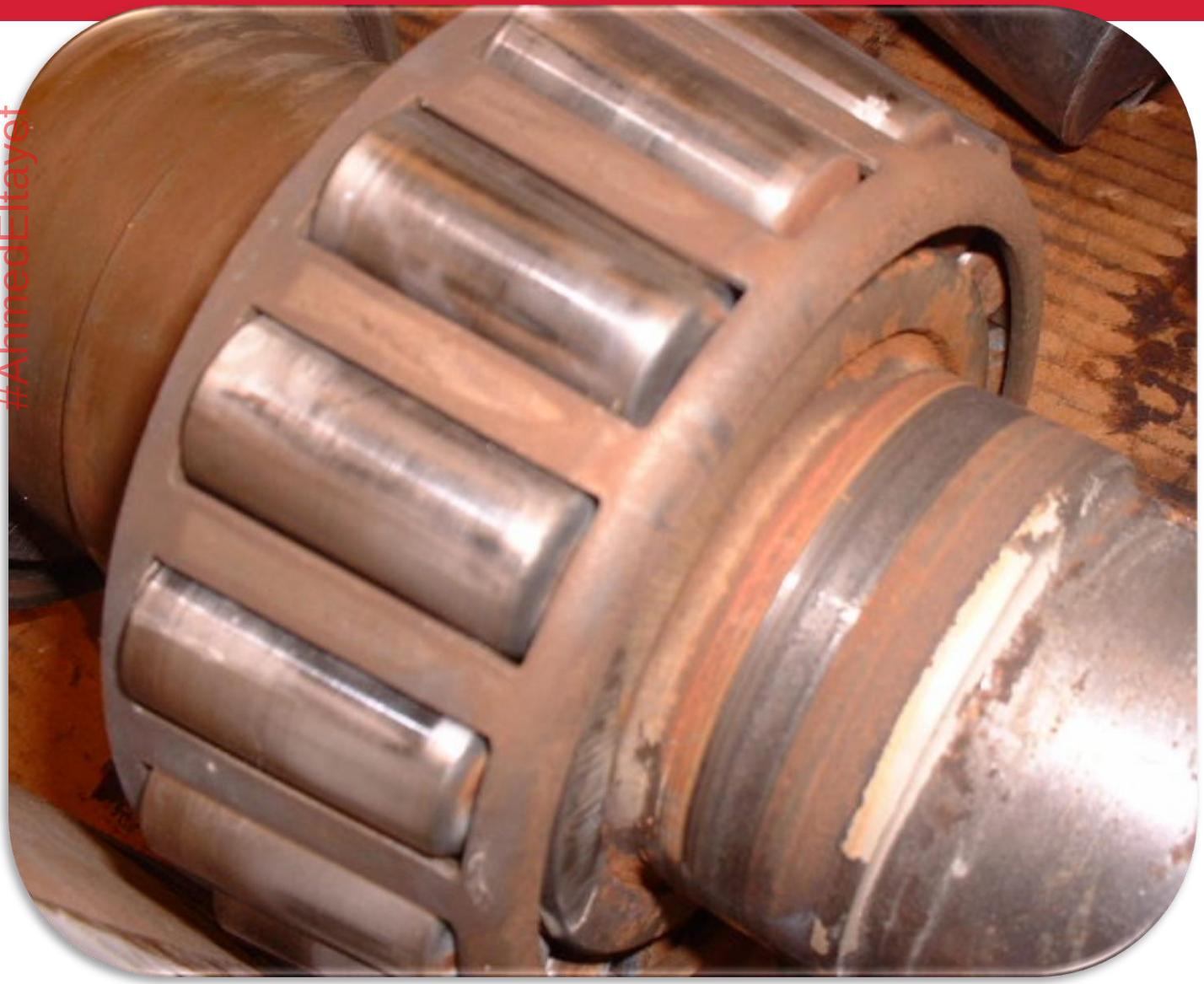
- Tooth fracture emanating from pits in the root of the tooth.

WWW – Lubrication Breakdown

#AhmedEltayef

The tar like coating on the pinion teeth and on the bearing rollers is due to lubrication breakdown

Bearing Failure Type?



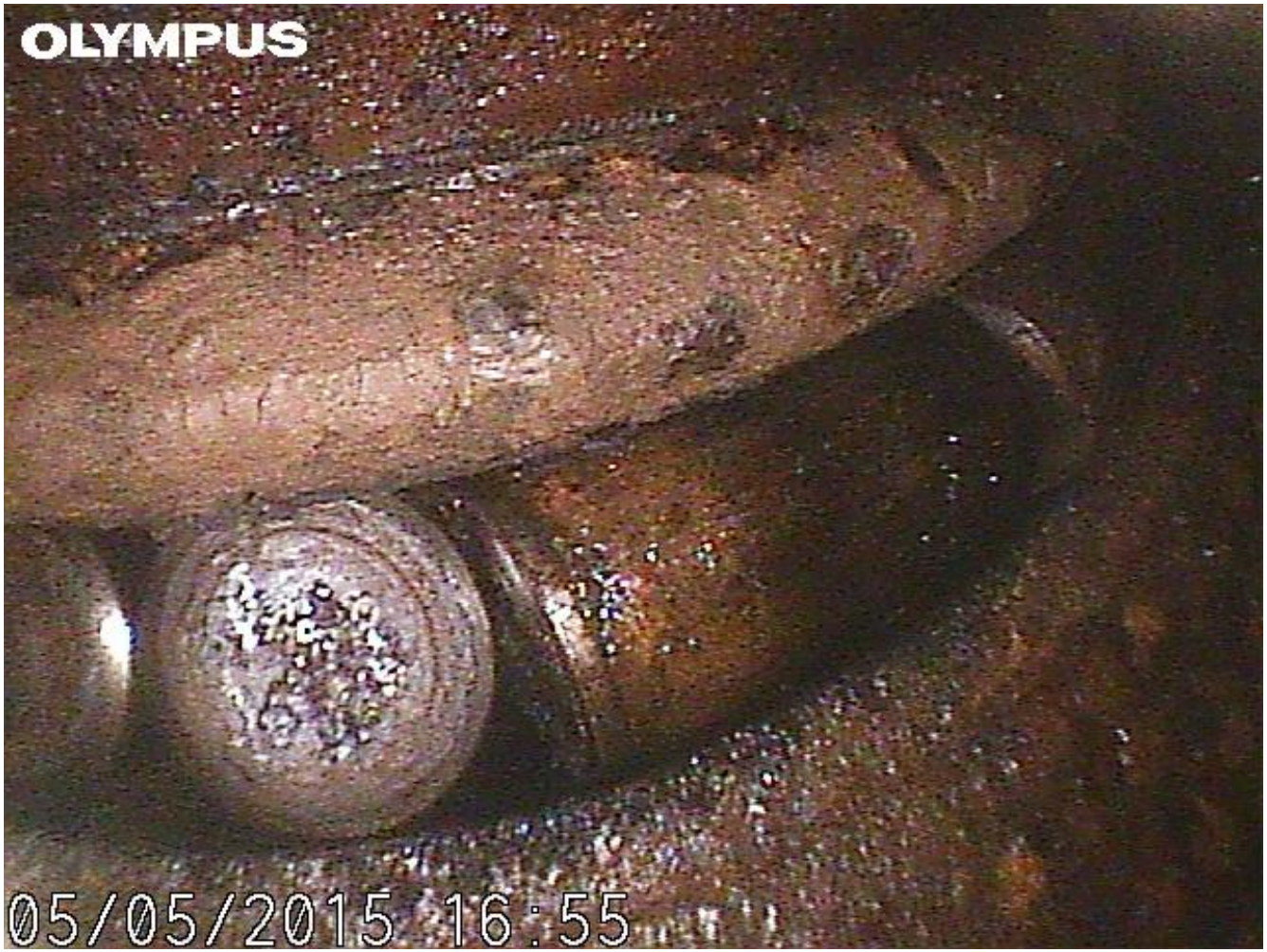
Roller lapping due to excessive moisture in the lube as evidenced by the rust

Bearing Failure Type?

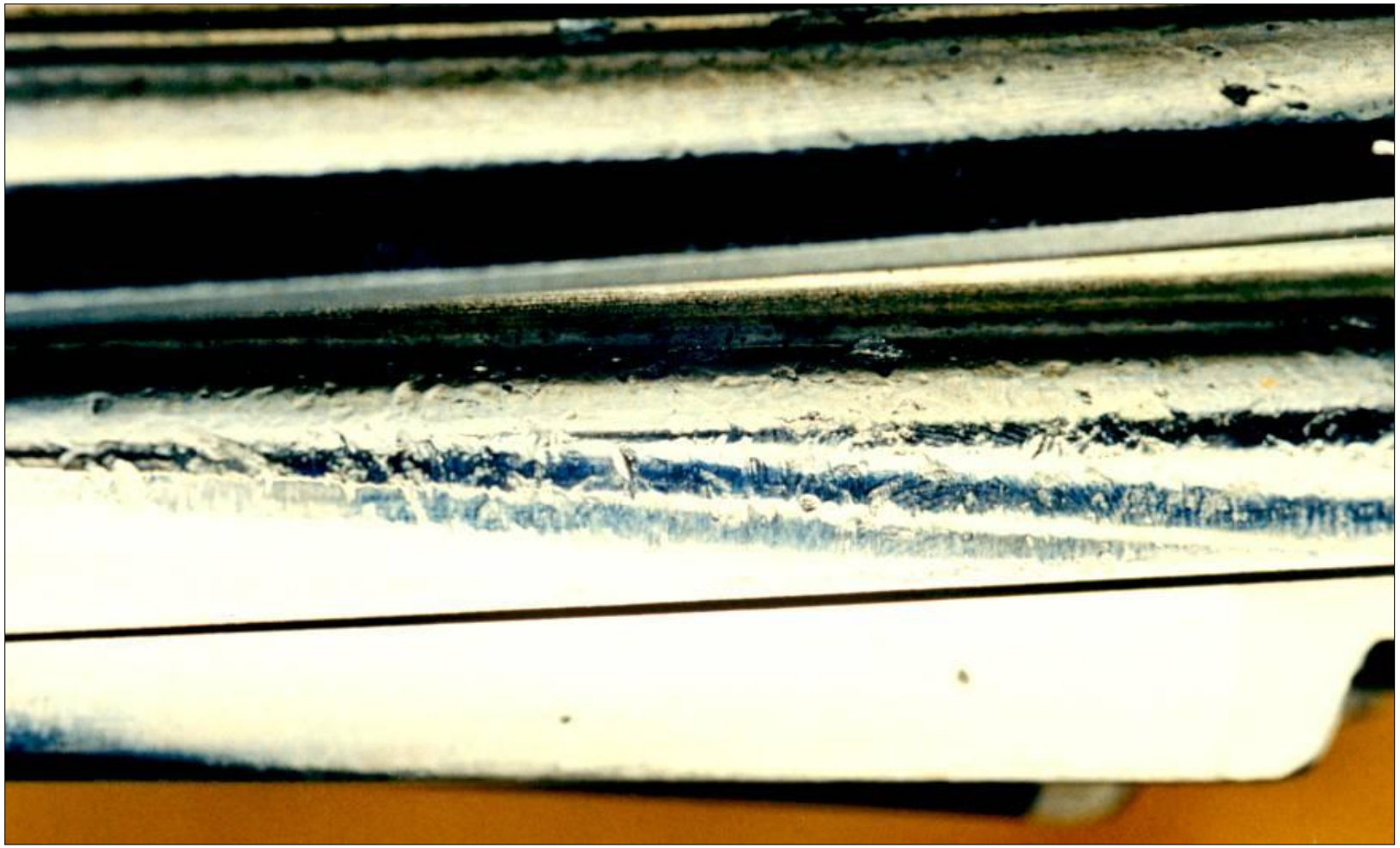
Severe spalling full roller length typical of marginal lube or high loads

Borescope Inspection

Bearing Inspection on YBX Reducer. Discovered bearing damage during field service inspection before a catastrophic failure occurred.

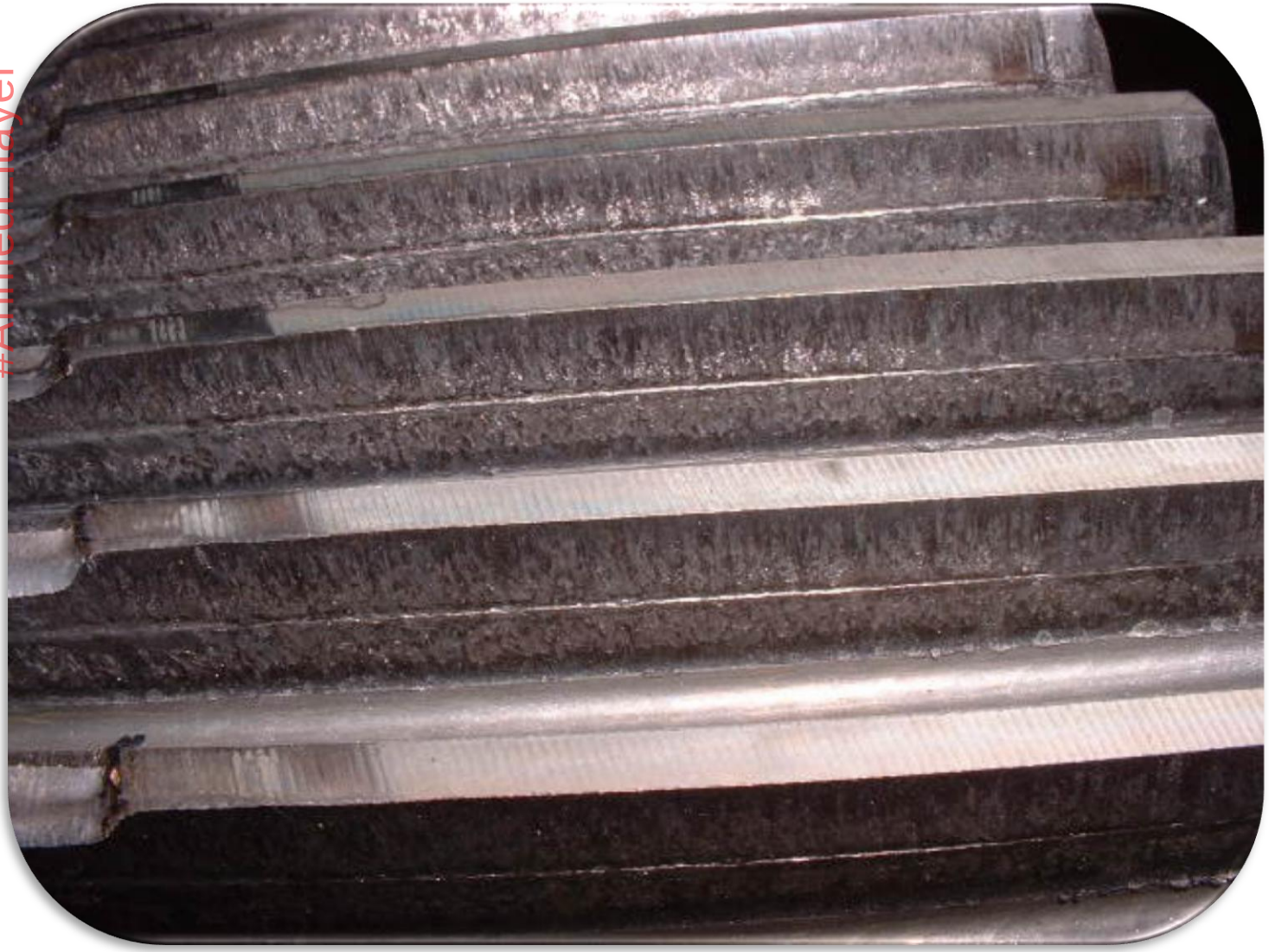


Debris Denting - Plastic Flow



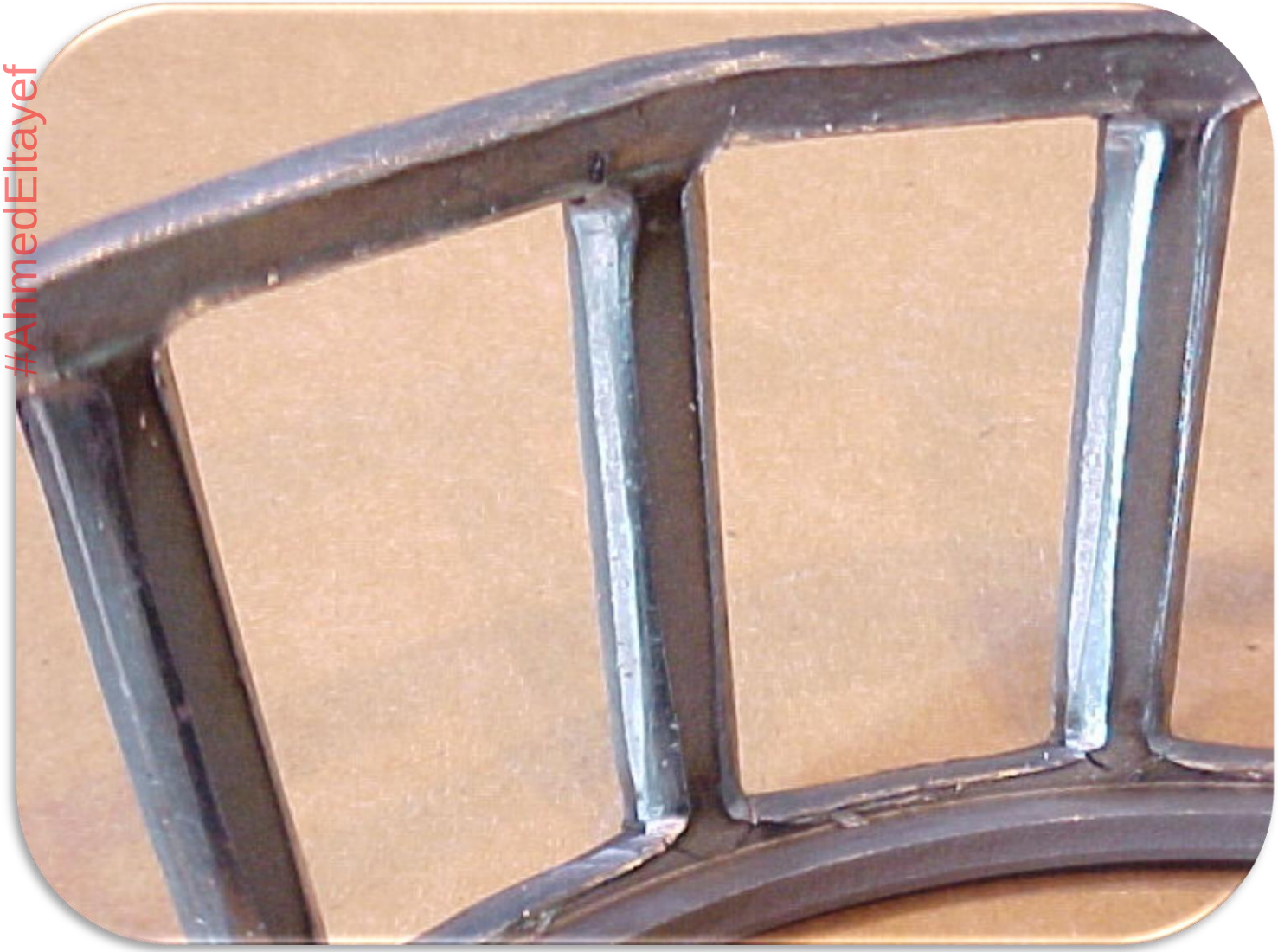
Debris denting is generally the result of contaminants in the lubricant.

Gear Wear



Severe distress above and below the pitch line is related to either marginal lube or high loads

WWW – Bearing Failure Type?



Severe wear on the bearing cage bars and pockets is due to excessive vibration

WWW – Shaft Failures

High cycle bending fatigue (smooth fracture perpendicular to the shaft axis) with a small final breakout

Questions