Application / Equipment
(Why We Need Lubricants and Why We Need to do Better)

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Introduction

Lubricants used for skids (pyramid building) and axle (chariot) greases have been shown to have been around for thousands of years.

Naturally as the equipment and needs are changing, so are the lubricants, the method of application and factors not directly relevant to the function. For the latter this can now include sustainability, byproducts formed during manufacturing, handling, service life, eco toxicity, biodegradability and disposal.

What Does It Do?

First the lubricant generally acts to physically separate the moving and static parts.

For example, to separate a shaft from the support structure.

This can be by forming a liquid film as in;

- hydrodynamic,
- elastohydrodynamic, and/or hydrostatic lubrication.

These are all or should be full films.

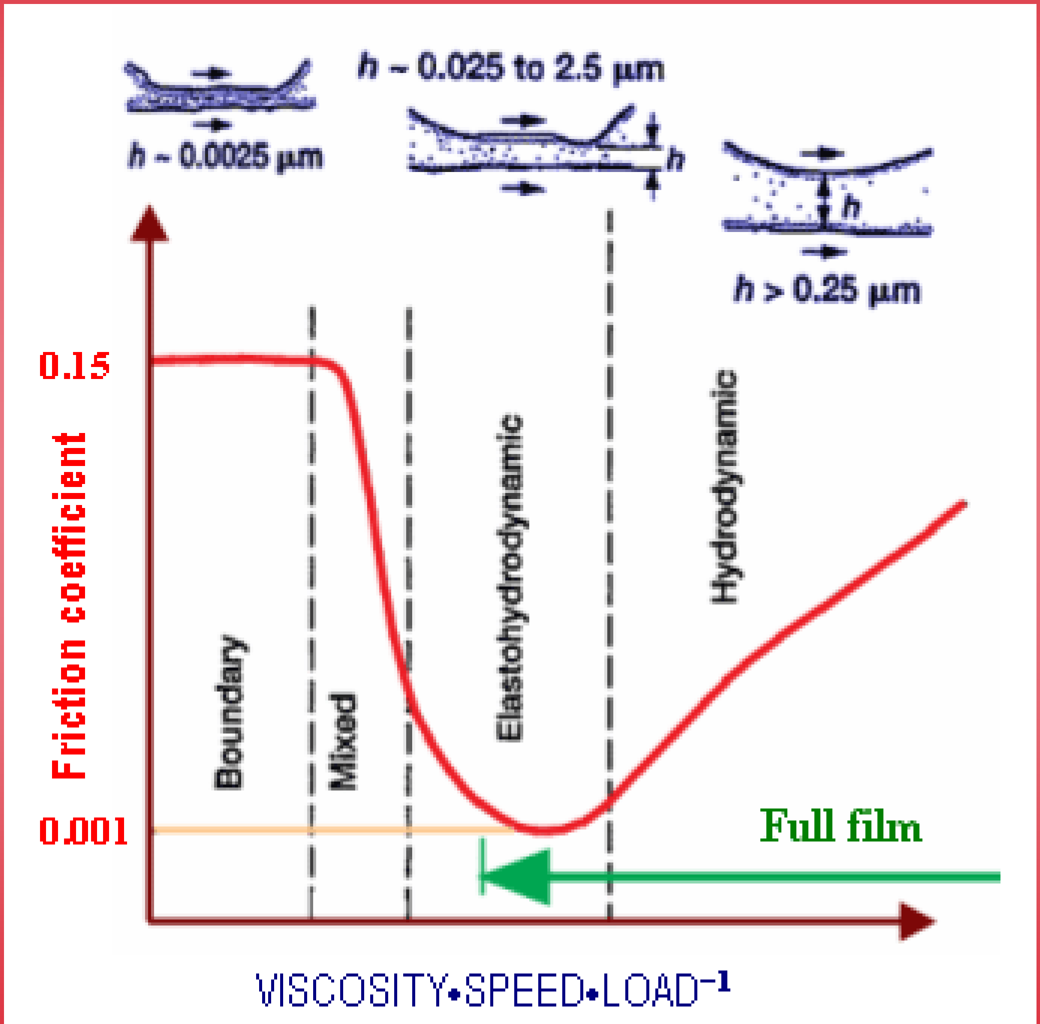
What Else Does It Do?

For bearings, gears and the like it can;

- Reduce (or increase) friction.
- Carry away heat.
- Reduce wear.
- Carry away wear debris.
- Prevent rust and corrosion.
- Seal out dirt, water or other contaminants.

In other applications, it can help seal gases in compressors, transmit power in hydraulics, dampen vibration or noise in shock absorbers, or act as a dielectric fluid in transformers.

Moving Surfaces - Stribeck Curve



Minimum Viscosities for Rolling Element Bearings*

Ball Bearings	13 cSt (70 SUS)
Cylindrical Roller Bearings	13 cSt (70 SUS)
Spherical Roller Bearings	20 cSt (100 SUS)
Spherical Roller Thrust	33 cSt (150 SUS)

****For cases where the bearing load is not known the oil should have at least these viscosities at the operating temperatures.***

Ref: SKF 'A Guide to Better Bearing Lubrication', 566 IIE, 73

Rolling Element Bearings Lives -1

$$L_{10h} = (C/P)^3$$

L_{10h} is the basic rating life in hours for 90% reliability

C is the bearing basic dynamic load rating

P is the load

An adjusted rating life takes into account the viscosity ratio of actual vs. required, type of bearing, type of loading and cleanliness of the oil.

Rolling Element Bearings Lives -2

An adjusted rating life takes into account the viscosity ratio of actual vs. required, type of bearing and type of loading.

$$L_{na} = a_1 \, a_2 \, a_3 (C/P)^P$$

L_{na} = *adjusted rating life in millions of revolutions*

a_1 = *life adjustment factor for reliability*

a_2 = *life adjustment factor for material*

a_3 = *life adjustment factor for operating conditions*

COMMON
ISO VISCOSITY GRADES

cSt @ 40°C	RANGE ±10%
32	28.8 - 35.2
46	41.4 - 50.6
68	61.2 - 74.8
100	90 - 110
150	135 - 165
220	198 - 242
320	288 - 352
460	414 - 506
680	612 - 748

In total 18 Viscosity Grades from 2 to 1500 each 59% greater.

Rolling Element Bearings Lives - Now

New life theory takes into account the viscosity ratio of actual vs. required, type of bearing, type of loading and cleanliness of the oil.

$$L_{naa} = a_1 \, a_{SKF} (C/P)^P$$

L_{naa} = *adjusted rating life in millions of revolutions*

a_1 = *life adjustment factor for reliability*

a_{SKF} = *life adjustment factor based on new life theory*

Adjustment Factor for Contamination

Very clean - Debris size the order of the film thickness	*1*
Clean – typical of bearings greased for life and sealed	*0.8*
Normal – typical of bearings greased for life and shielded	*0.5*
Contaminated – typical of bearings without integral seals, coarse filters and/or particle ingress from surroundings	*0.5 .. 0.1*
Heavily Contaminated	*0*

So What's The Problem?

The improper, incomplete or total lack of the application of proven tribological principles and devices is costing industry millions of lost dollars.

Perhaps even worse is that even companies with very tight dollar control may not have proper life cycle costing or even encourage employees to make tribological improvements.

Brown’s First Law Of Applied Tribology

(Power Generation)

If it's running,
It's wearing

If it's not running,
It's probably worn!

Corollary 1: if not the above then it may be on standby in case something else wears out.

Corollary 2: if the equipment is not economical to run, this is probably because of a loss of efficiency as a result of wear.

Rolling Element Bearings
(Ball And Roller Bearing
Or Anti Friction Bearings)

$2.3 billion worth of rolling-contact bearings will reportedly be consumed in the US during 1980 and only 10% of these will attain their full, useful, intended life span. This is $5.6 billion in 2007 terms and presents a 90-percent opportunity for improvement.

Rolling Element Bearings

Since more than half (57%) of these bearings are used industrially, the performance shortfall in the United Sates amounts to a $2.8 billion annual cost of bearings alone.

This does not take into account the loss of production, overall maintenance expense or damage to such peripheral equipment. These costs can be huge!

Ref: Hafner, E.R., ‘Proper Lubrication – The Key to Better Bearing Life’, Part I: Selecting the Correct Lubricant’, Mech. Eng., pp 32-37, October 1977

Rolling Element Bearings

Unfortunately the leading causes of failures are reported to be improper lubrication and improper mounting.

'These are preventable.'

Hafner, E.R., 'Proper Lubrication-The Key To Better Bearing Life, Part 1: Selecting The Correct Lubricant', Mech. Eng., pp 32-37, October 1977

Rolling Element Bearings

In real life it has been reported contaminants cause 50% of bearing failures.

Rolling Element Bearings

Remaining causes are;

Marginal lubrication	**30%**
Other	**17%**
Fatigue life	**3%**

It was reported that they typically fail at 20% of their catalogue life. Again this is a real waste.

Ref: NSK as reported in Machinery & Equipment MRO, p13 June 1999

Bearing Failures

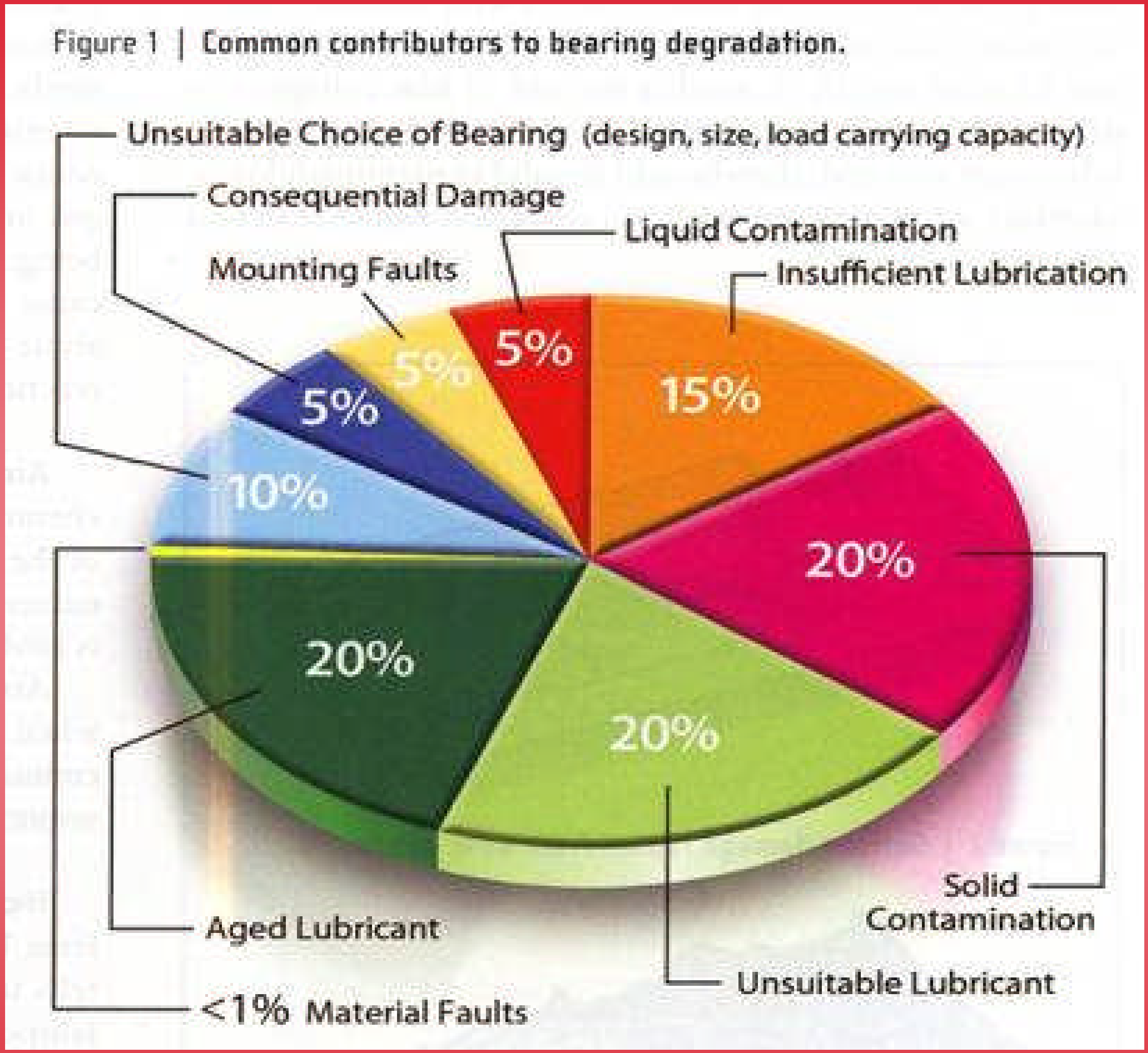
The majority of bearing failures are from lubrication and or the lubricant;

14% too much or too little lubricant
19% dirty lubricant
22% incorrect or aged lubricant

Total 55%

Most are likely preventable with a bit of effort and knowledge.

Ref: ‘Motor Bearings’, Global Cement Magazine October 2007



Ref: 'Lubricant management for non-circulating sumps', M. Johnson, TLT, August 2009 pp 16-23

Preventing Bearing Failures

Problem: Poor fitting, usually using brute force, accounts for 16% of premature bearing failures.

Solution: Provide the right training and tools.

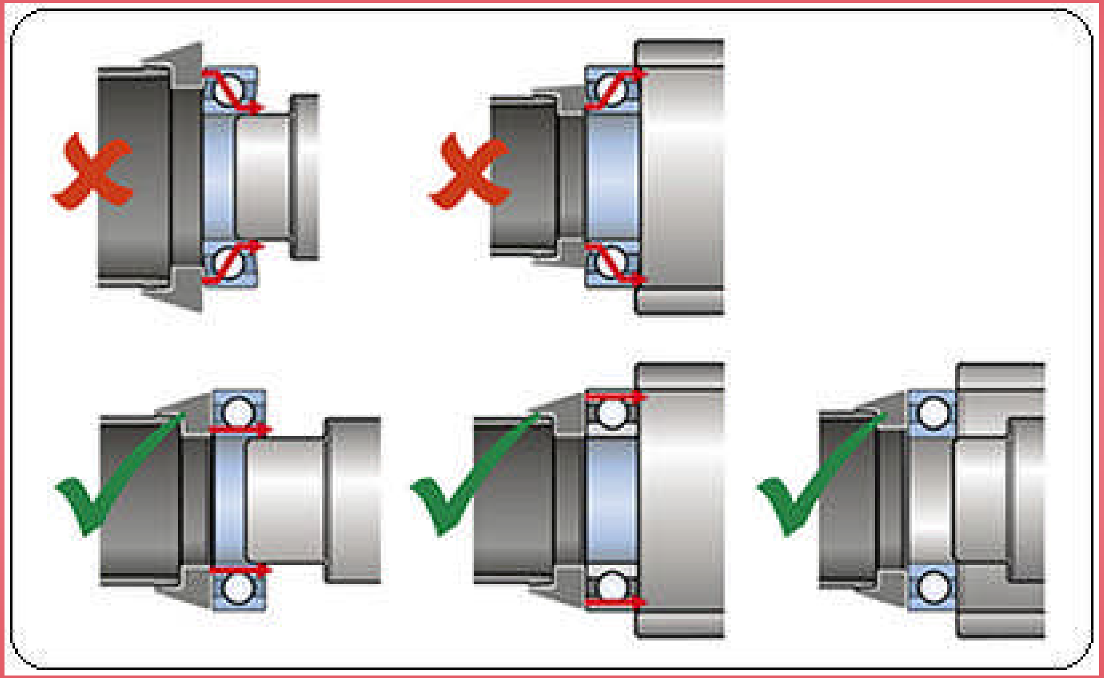
If you want it done right, you have to make it easy to do it right

Ref: www.mapro.skf.com/products/

Proper sized adapter ring, impacts sleeves and a soft tipped hammer

Ref: www.mapro.skf.com/products/

Mounting forces must not pass through the rolling elements



Ref: www.mapro.skf.com/products/

Lube Causes of High Bearing Temperatures

- Over-greasing the bearing, which forces the balls to push through excess grease as they rotate, leading to a sharp temperature rise
- Too little grease in the anti-friction bearing, or too little oil in the sleeve bearing
- Too low, or too high temperature, of the oil cooling water for the sleeve bearing
- Friction of the bearing sealing (bad shaft seals leading to loss of grease or oil)
- Using a low-temperature grease which does not provide adequate viscosity at normal operating temperatures
- Mixing incompatible greases, which can reduce the consistency of the grease and possibly the overall viscosity.

Ref: 'Motor Bearings', Global Cement Magazine October 2007

NLGI Grease Grades

GRADE	PENETRATION
000	445-475
00	400-430
0	355-385
1	310-340
2	265-295
3	220-250
4	175-205
5	130-160
6	85-115

Grease Quantities

For replenishment from the side of a bearing;

$$Gp = 0.005\ D\ B$$

For through the bearing outer or inner ring;

$$Gp = 0.002\ D\ B$$

Gp = grease quantity, g

D = bearing outside diameter, mm

B = bearing width (thrust bearings use height H), mm

Ref: SKF 2007

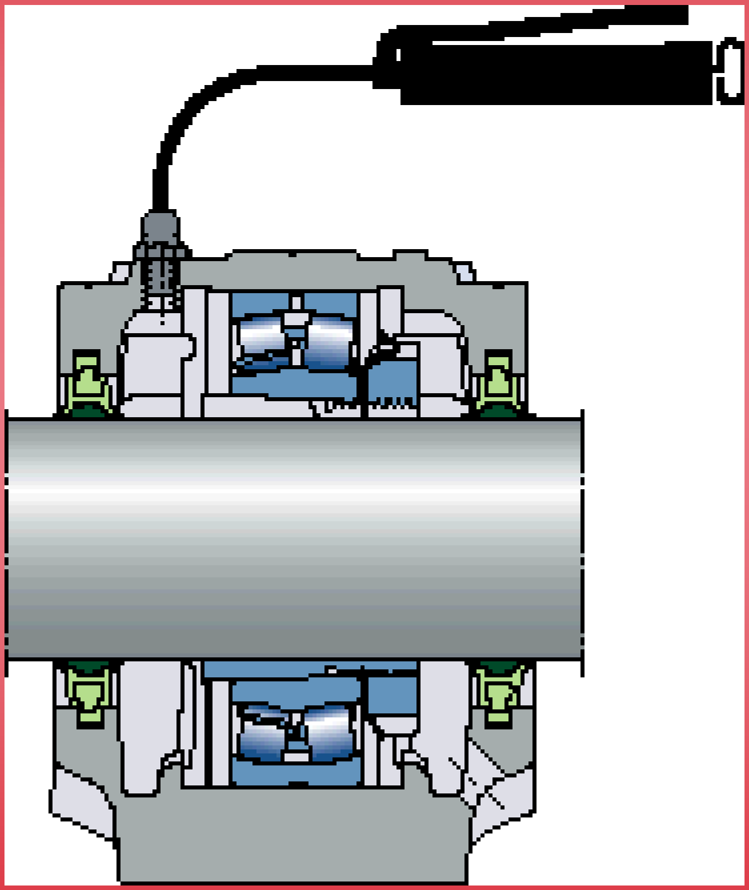
Example

6316 ball bearing; it should get about 0.005 X 170mm X 39mm

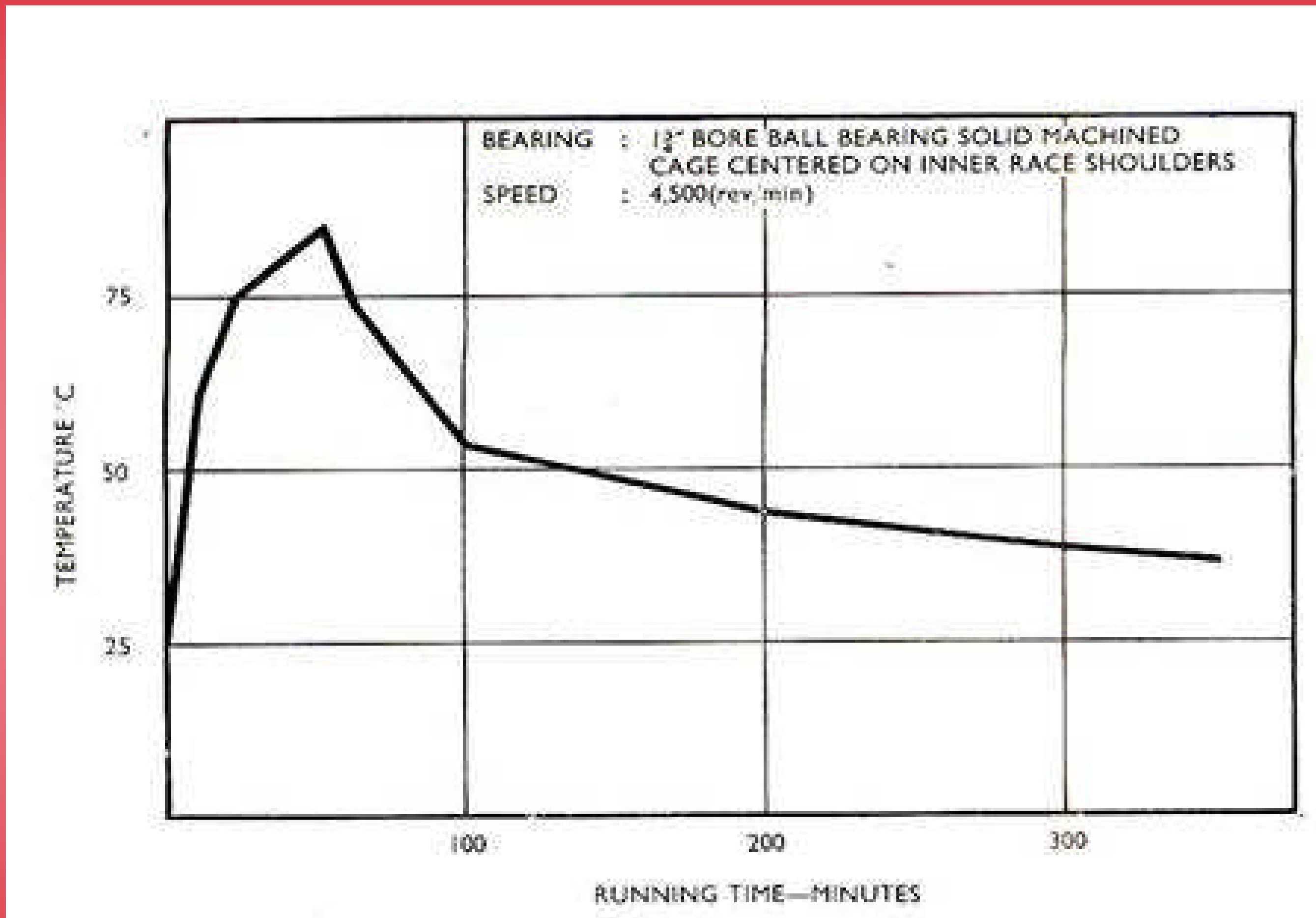
33g (1.2oz) of new grease.

With the 70MPa (10,000psi) high pressure grease guns often used, this can require 43 strokes.

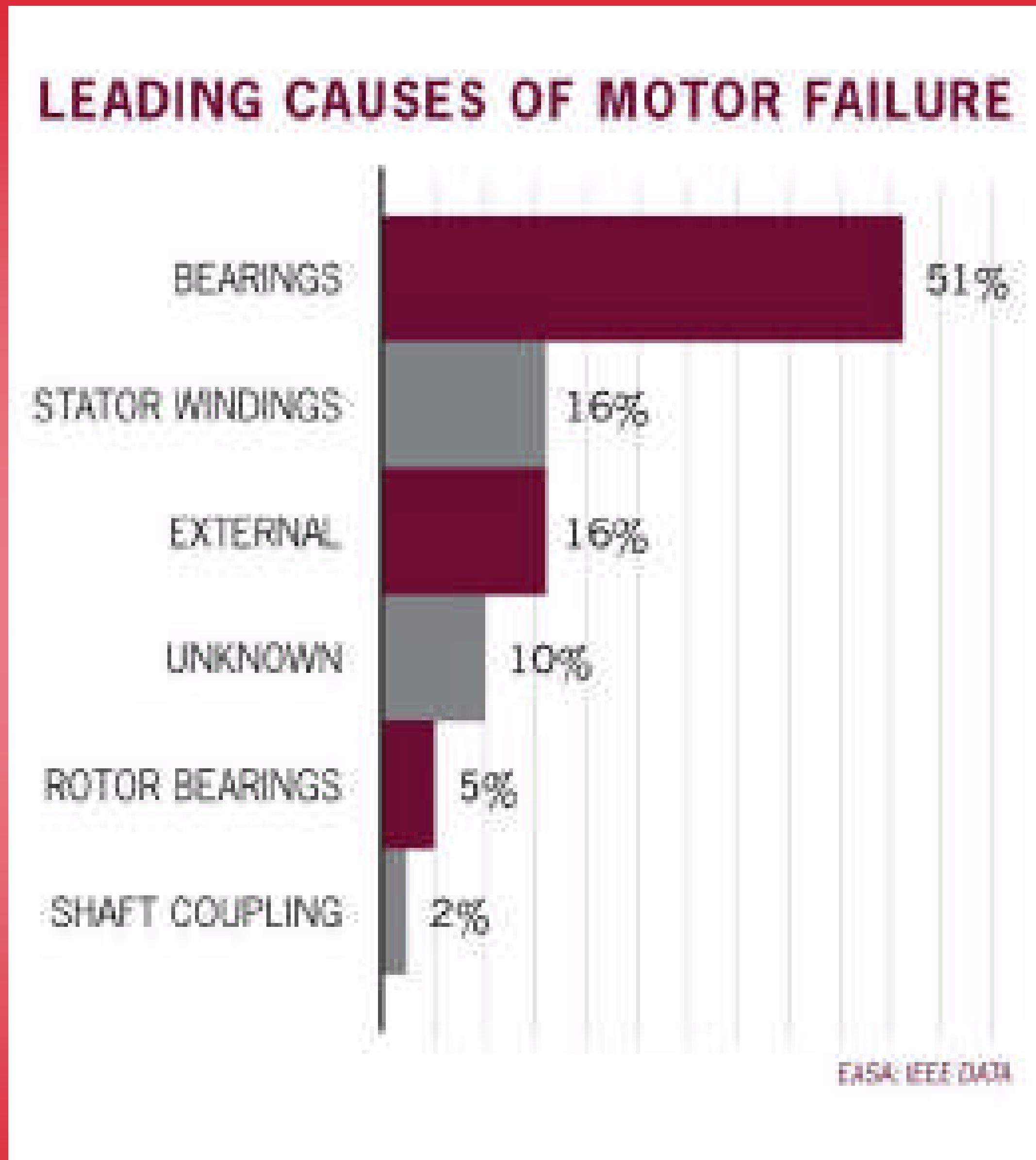
Greasing Bearings



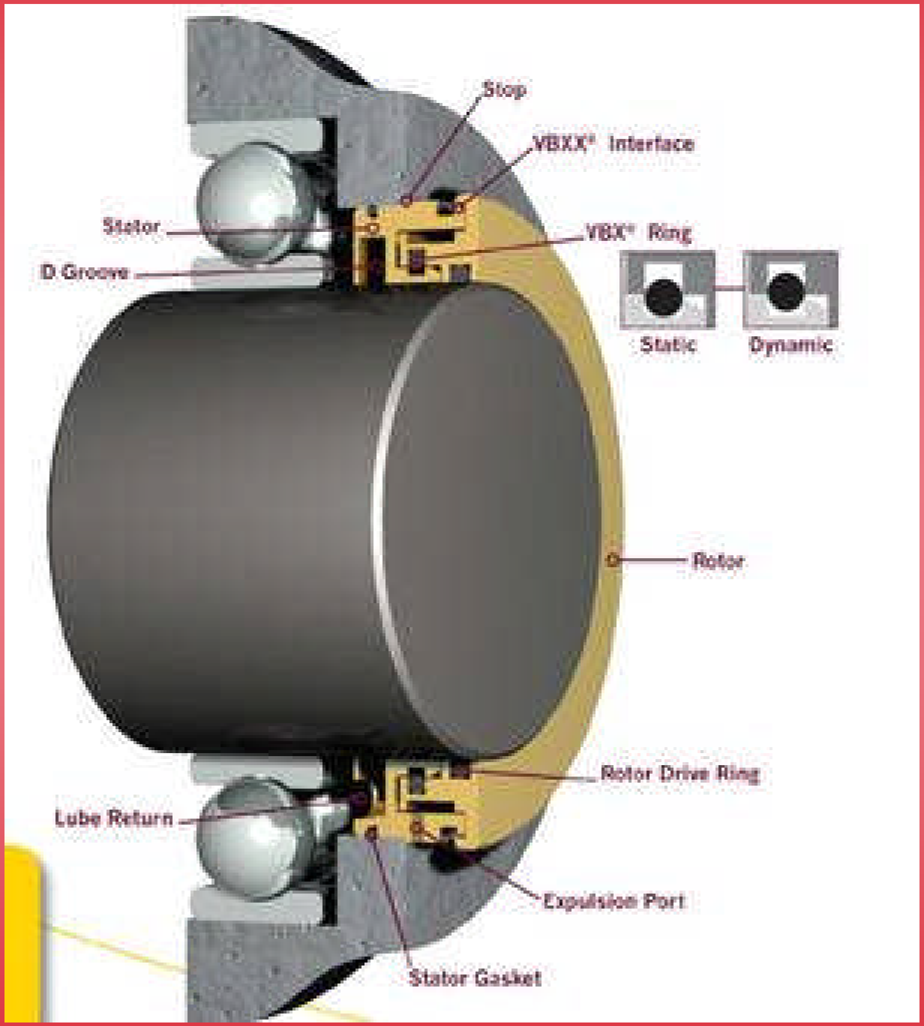
‘Normal’ Temperature Rise



Ref: Harries, A.F., ‘The Lubrication of Rolling Bearings’, p. 118, Shell Int’l Petroleum Co. Ltd., 1972


LEADING CAUSES OF MOTOR FAILURE
BEARINGS
51%
STATOR WINDINGS
16%
EXTERNAL
16%
UNKNOWN
10%
ROTOR BEARINGS
5%
SHAFT COUPLING
2%
EASA; IEEE DATA

Better Seals



Grease Gun Delivery

Grams	Ounces	Strokes
14	½	
28	1	36
43	1½	54
57	2	72
71	2½	90
85	3	108

Delivery used is 1 oz per 36 strokes. Standard 10,000 psi high pressure grease gun such as an Alemite 1056-S.

Grease Gun Delivery

Pressure (psi maximum)	strokes required to deliver 1 oz
10,000	21
4,500/3,000	33/16
10,000/6,000	21/16
10,000/6,000	12/16
2,000	7
10,000	36
1,800	7
10,000	20
5,000	10

When Is Enough?

Courtesy: EA Grease Caddy

Contamination

Contamination was shown to cause 70-85% of failures.

Wear problems with these contaminants were said to be solids, liquids or gases.

Cont'd

Contamination

These originate in the fresh lubricant, in new or repaired machines and in running equipment as either generated or ingested matter.

Unfortunately, many new pieces of equipment still do not have adequate filtration equipment and lack either procedures or provisions for flushing.

- Godfrey, D., ‘Clean, Dry, Oil Prolongs Life of Lubricated Machines’, Lubrication Engineering, **45**, 1, pp 4-8 1989

Motor Failures

Motor failures were found to be bearing related in 41% of the cases.

Causes included;

- **Design 39.1%**
- **Workmanship 26.8%**
- **Maloperation 20.4%, and**
- **Misapplication 13.7%.**

Ref: 'Improved Motors for Utility Applications, Volume 7: Bearings and Seals', EL-286, Electric Power Research Institute (EPRI), October 1986.

Steam Turbine Bearing Failures

Failures of steam turbine bearings and rotors cost the utility industry an estimated $150 million a year. A third of these failures involve contaminated lubricants or malfunctioning lubricant supply system components.

These systems can fail suddenly but while rare, they cause major damage to turbine bearings and rotors. This will result in an extended plant outage.

Ref: EPRI, Guidelines for Maintaining Steam Turbine Lubrication Systems, Report CS-4555, July 1, 1986

Pump Failures

Boiler feed pumps: 49% of the failures causing outages were because of tribological components.

These included seals, journal bearings, wear rings and thrust bearings. The bearing failure rate was 21.7%.

Ref: ‘Survey of Feed Pump Outages’, FP-754, Electric Power Research Institute (EPRI), April 1978.

Motor Failures Caused By Bearings

"The proprietary in-house statistics of a number of petrochemical plants in the United States indicate that approximately 60 percent of all motor difficulties originate with bearing troubles.

If a bearing defect is allowed to progress to the point of failure, far more costly motor rewinding and extensive downtime will often result.

Improvements in bearing life should not be difficult to justify, especially if it can be readily established that most incidents of bearing distress are caused by lubrication deficiencies."

Reference: Heinz Bloch, "Lubrication Strategies for Electric Motor Bearings", *Machinery Lubrication* Magazine, January 2004

Pump Failures

Unknown or Undetermined	**>10**
Bearing Design	**>80**
Incorrect type or application	**>50**
Lube system/System design	**>10**
Manufacturing (Q.A. Material)	**>3**

Ref: ‘Survey of Feed Pump Outages’, FP-754, Electric Power Research Institute (EPRI), April 1978.

Major Causes Of Premature Engine Bearing Failure

	%
Dirt	44.9
Misassembly	13.4
Misalignment	12.7
Insufficient Lubrication	10.8
Overloading	9.5
Corrosion	4.2
Other	4.5

Ref: Clevite AM-208-**8**

Boiler Fans

Bearings were the leading cause of fan failures.

Ref: 'Root-Cause Failure Analysis: Fossil-Fired Power Plant Draft Fans', CS-3199, Electric Power Research Institute (EPRI), July 1983

Motor Operated Valves (MOV)

Tribological related problems including lubrication and wear were including in the grouping that was the leading cause of failures.

Mechanical damage, lubrication, loose connection, dirty contacts, broken bolts and wear	**37.5%**
Improper torque/limit switch settings	**28.5%**
Burnout/high current/TOL device not shut off or trip, motor failed or grounded	**13.3%**
Torque/limit switch defective, replacement, preventive maintenance	**9.3%**
Miscellaneous	**9.0%**
Breaker trip, blown fuse, defective coil	**2.8%**

Ref: 'Recommended Maintenance Good Practices for Motor-Operated Valves', IEEE 89TH0248-5-PWR, Maintenance Good Practices for Nuclear Power Plant Electrical Equipment, pp 21-32, (1988)

Steam Turbine EHC Systems

Trouble free operation of steam turbine control systems is dependent on keeping the fluid in good condition, however, in many plants these systems have been a source of problems and the fluid has been a high maintenance item.

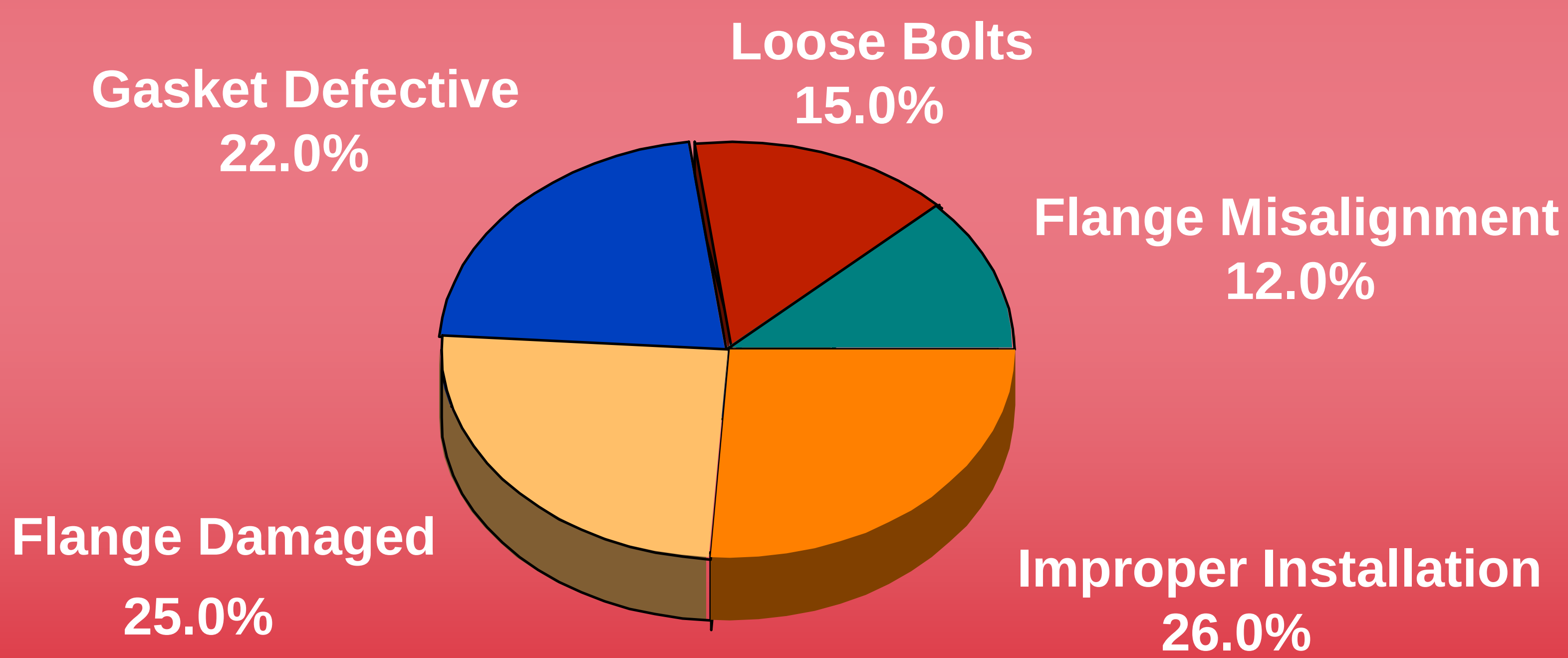
Most EHC system failures are related to problems with fluid cleanliness and chemistry.

The result is that over a five period it was found that for U.S. Nuclear power plants there were 248 EHC system failures. Of these 59% resulted in a reactor scram or manual shutdown and 24% led to a forced power reduction.

Ref: The Picture of Health, The Nuclear Professional, Fall 1992, pp 3-7.

Reasons For A Gasket Leak?

Based On A Study By The PVRC



Ref: W.L. Gore & Associates

Oil Leakage – Why Bother?

A one drop per second is equal to 420 gallons a year.

It has been estimated that over 100 million gallons of fluids could be saved every year in North America if external leakage from hydraulic machinery and other lubricated equipment was eliminated. In Canada alone, over 12 million gallons of oil is wasted due to leakage.

In economic terms the cost of this waste is staggering. Besides high oil consumption, the economic effects of hydraulic system leakage include inefficient machinery operation, environmental damage, safety and accident liability, premature machine component failure, poor manufacturing quality and increased capital costs.

Ref: 'Is Fluid Leakage Drowning Your Profits?', L. Leugner, Practicing Oil Analysis, 3/2000

Oil Leakage – Cost

- It was reported that Mobil Oil did a study in the U.S. that compared hydraulic reservoir oil capacity to actual oil consumption. This resulted Mobil's Hydraulic Fluid Index (HFI) which concluded that the HFI average is 4. This means that every year, the average plant uses four times more oil than it's machines actually hold!
- Assuming that one half of the 100 million gallons of lost lubricants previously described are hydraulic fluids. Assuming that the average cost of replacing these hydraulic fluids is $5.00 per gallon, the resulting direct cost in replacement lubricants alone is **$250 million!**

Ref: 'Is Fluid Leakage Drowning Your Profits?', L. Leugner, Practicing Oil Analysis, 3/2000

National Studies - Canada

There are a large number of studies that have been done in various countries that highlight in dollars the costs of poor tribological practises.

In Canada such a study (NRC/ACOT) found that in 1982 dollars the cost per year in just seven industrial sectors was over $5 billion! This is $10 billion in 2007 dollars!

Lubrication

Providing equipment components with the correct lubrication is often the simplest and most cost effective measure that can be taken to keep equipment operating at or close to their potential.

There is likely some lubrication already it requires little extra effort to do it right.

In addition, real fixes are usually not expensive.

Ten Benefits Of Effective Lubrication

- ✓ Reduced downtime
- ✓ Increased machine availability
- ✓ Extended lubricant changeout intervals
- ✓ Reduced energy consumption
- ✓ Reduced "fire fighting" maintenance
- ✓ Increased planned maintenance
- ✓ Reduced machine and product contamination
- ✓ Cleaner environment
- ✓ Extended machine life
- ✓ Increased company profitability

Ref: K.J. Brown

Test Sample Sizes

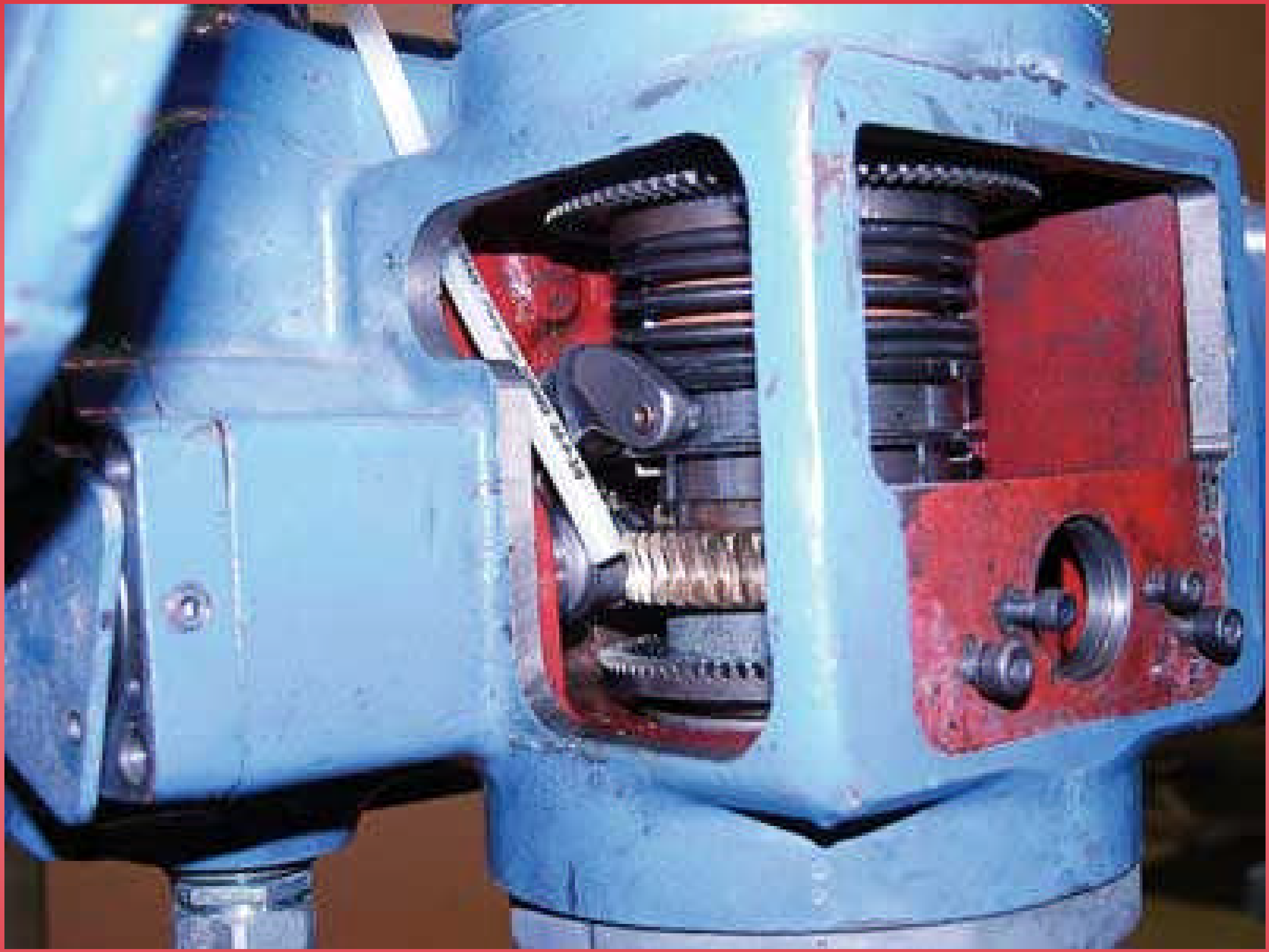
Appearance	small
FTIR	trace
Ruler	0.2 ml
HPDSC	1 or 2g
Tactile stiffness	small
Blotter test	small
Rheometry	small
Dropping point	5g
Base number	20g
Evaporation loss	25ml
Oil separation	100g
Penetration: ¼&½ scale	100g
Four ball wear	200g
Deleterious particles	200ml
Penetration: full scale	1lb
Pin-on–disc (pod)	1oz

Table d'équivalences entre les échelles de couleurs Pétroles Esso Canada

Esso Petroleum Canada Color Scale Comparison Chart

Saybolt	*+30*	*+20*	*+10*	*0*	*-10*	*-23*
Tag Robinson					*22*	*18*
A.S.T.M.					*0.5*	*1.0*

Saybolt	*-28*					
Tag Robinson	*13*	*10.5*	*9.5*	*4.5*	*2.5*	*1.0*
A.S.T.M.	*1.5*	*2.5*	*3.5*	*5.5*	*6.5*	*8.0*



Showing Grease Sampling With A Tube

‘New’ Tests

R/S Rheometer

‘New’ Tests

Ruler Test Equipment

‘New’ Tests

Spectroil Q100 Oil Analysis Spectrometer

Standard includes 22 elements.

Wear Metals: Al, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Mo, Ni, Ag, Sn, Ti, V & Zn

Contaminants: B, Ca, K, Si & Na

Additives: Ba, B, Ca, Cr, Cu, Mg, Mo, P, Si & Z

Additional 13 can be added: Sb, Bi, As, In, Co, Zr, W, Sr, Li, Ce, Nb & Rh

Blotter

Fresh And Three Aged Samples – Color Change
(Left For 5 Hours At Room Temperature)

Reducing Motor Bearing Failures

Shell Canada found that at one of their refineries, 91% of the problems with motors were the bearings.

They were able to achieve a 90% reduction in such failures, mainly by better control of lubrication.

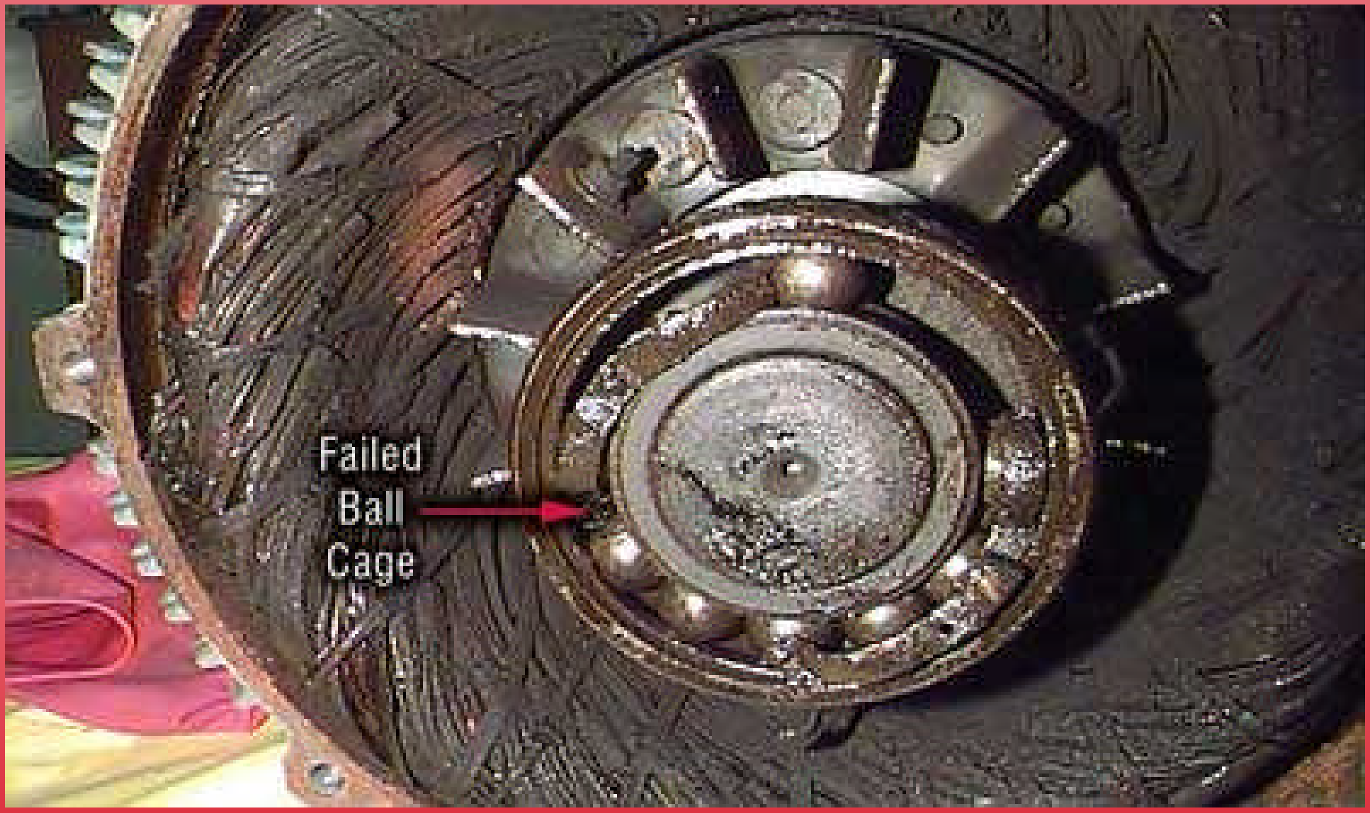
Greasing Motors - Nukes

Over greasing rolling element bearings in motors has been an industry problem for several years.

More motors have bearing failures due to over greasing than from under greasing.

The nuclear regulatory commission (NRC) provided Information Notice 88-012, issued in July 1988.

Over Greasing



The method delivered mixed performance results motivating some organizations to develop additional improvements.

One such improvement, produced the Electric Power Research Institute (EPRI) Electric Motor Predictive and Preventive Maintenance Guide, NP-7502.

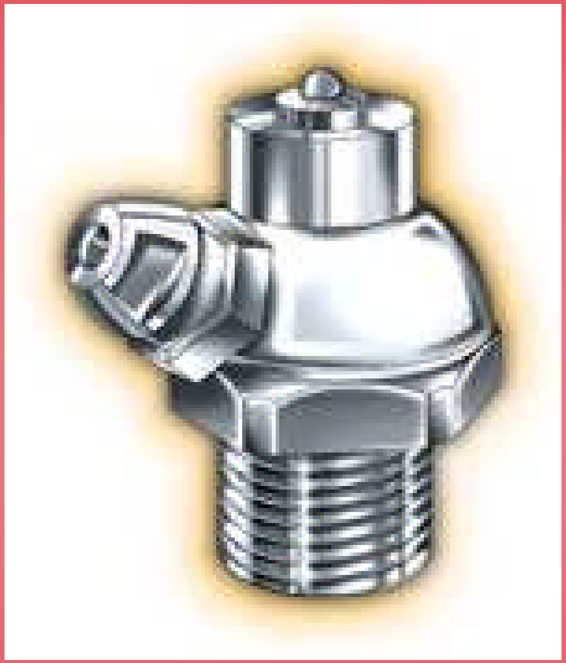
This provides guidance on how to regrease motors, when to add grease and how much grease to add.

TVA Relubrication Methods

The normal sequence to regrease a motor is as follows:

- If possible, the bearing should be at a stable, normal operating temperature, making the grease less viscous.
- Remove the drain plug and any hardened grease.
- Clean the grease (Zerk) fitting before attaching the grease gun.
- Use the regreasing guidance provided by EPRI NP-7502 for the grease fill quantity and regreasing frequency.
- After regreasing is complete, leave the drain plug out and operate the motor under normal bearing operating temperatures for at least one hour. This allows the grease to thermally expand and vent out the port, relieving any excess pressure in the cavity.
- After thermal expansion is complete, clean the excess grease and reinstall the drain plug.

Preventing Over Pressurization



Provides for pressure-specific shut-off (for example, 20 psi). At the given shut-off pressure, the grease flow will stop.

$0.35 each

Improved Efficiency

Using a synthetic PAO based gear oil a coal fired plant with worm gears in their pulverizers were able to achieve 8-10% energy savings. This was based on the reduced motor power consumption.

The energy savings alone paid for the higher cost of the synthetic oil in just four months. Plus, there can be added benefits of longer oil lives, lower operating temperatures and reduced gear wear.

Benefits of Synthetic Lubes

A brewery with several large motors totaling 347.5 HP, with an average efficiency of 85%, an average load factor of 75% and one shift operating using synthetic lubricants would see a 10% reduction in energy losses.

This works out to electric power savings of $1,050 per year. Synthetics carry a price premium however they can last much longer which offset the increased costs. Assuming a cost of $800, the simple payback is 9 months.

Ref: Energy Efficiency Opportunities in the Canadian Brewing Industry, Second Edition, 2010, Brewers Association of Canada

Steam Turbine Bearing Solution

A station with eight 500mw turbines was experiencing LP bearing wipes when on turning gear or half speed whirl when at speed. A bearing failure would usually mean an outage of several days if there was not other damage.

The solution was to modify the top half of existing lemon bore (elliptical) bearings to incorporate a pressure dam. The bearing was modelled using computer programs.

Estimated cost savings was $4.4 million then and over $7 million in 2007 dollars.

Ref: Brown, K.J., 'Turbine Generator Bearing Retrofit', National Research Council Associate Committee on Tribology, Proc. Of the 4th ACOT Research Seminar, Tribology Research for Canadian Industry, May 27-29, 1987.

The "Right" Stuff

Achieving any real benefit requires true consideration of the Right Stuff which are the five R's of lubrication.

- ✔ right lubricant
- ✔ right amount
- ✔ right place
- ✔ right time
- ✔ right way

Plus

Some form of feedback or monitoring so that you can determine if it worked.

Adding True Value

Many people can sell a lubricant that will likely work, but the added value is to provide the most suitable lubricant for the application.

This will provide be the most cost effective when all factors are properly considered.

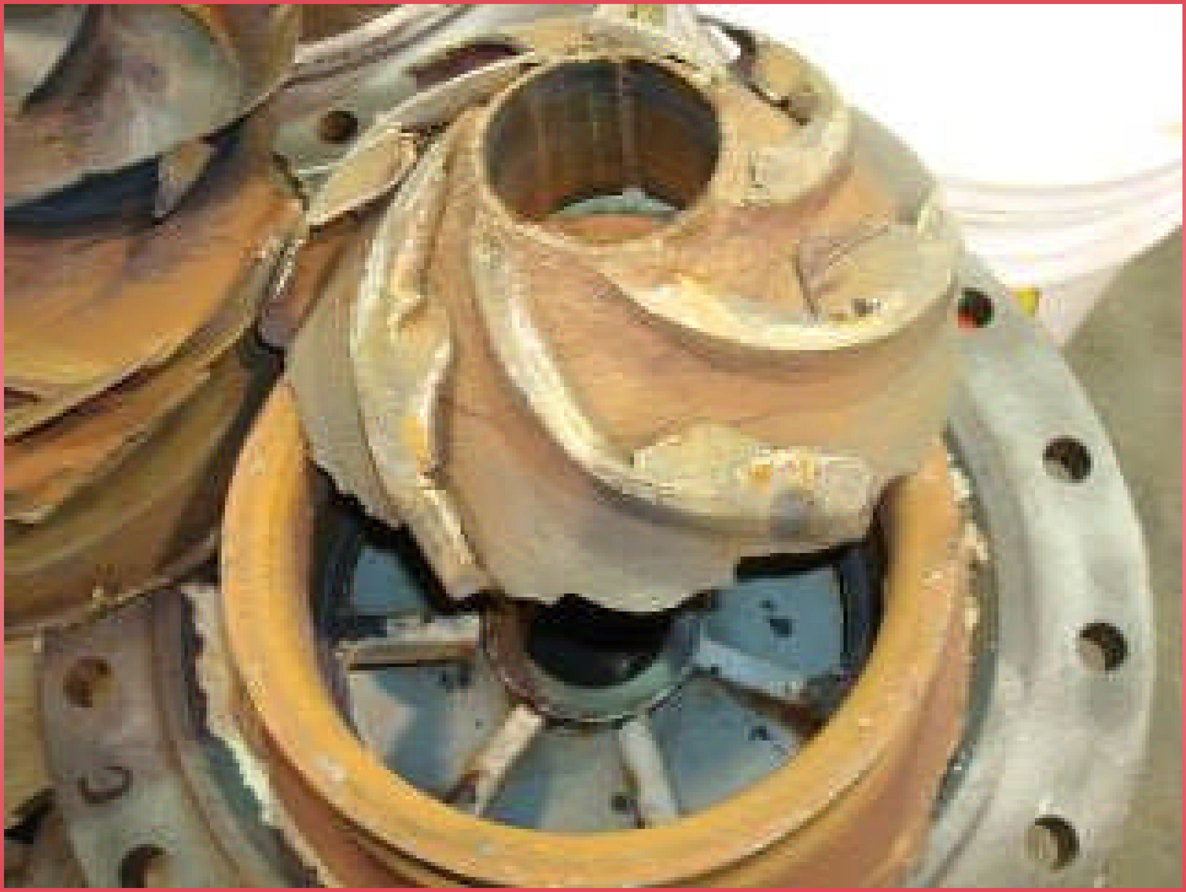
Are we getting better?

Still recalls.
Still failures.
Less training and fewer skilled crafts.
More outsourcing.
More ‘penny’ control.
Plus, counterfeit parts.

Wind Turbines – expensive candles

Needs re knowing forces, lube requirements, maintenance and condition monitoring

Port Hope – water pumps



What happened, why and what warning signs were missed?

Systemic Obstacles to Improvements

Supply only considers the purchase price.

Maintenance has to carry the added cost of any better lubricants.

Operations just wants to run and not do repairs or monitoring or to 'risk' something different (new to them).

No champions.

Management ignorant of the problems inherent in all of the above.

Summary

1. Friction, wear and failures of tribological components are costing industry billions of dollars.

2. Much of this can be easily prevented by just making use of existing technology, but

3. **Change** requires knowing what is being used, what is required, what is available and how to apply it properly.

4. To be effective requires both cost accounting and **management** systems that encourage improvement and methods to monitor costs.

TAKING ACTION

Who makes lubricant and tribological **decisions** at your facility?

What **training** do they have?

What **performance** measures are in place?

Is there room for **improvement**?

Thank you