We Need to do Better – Tribology for Everyone

Ryerson
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Ken is a P.Eng. with a BASc and MASc in Mechanical Engineering from the University of Waterloo. He is an active member of STLE (has his CLS) and ASTM D2. From 1976-1993 he was with Ontario Hydro's (now OPG) Power Equipment Department of D&D working on bearings, lubes, seals and EHC fluids for new and existing fossil and nuclear power stations. With OH he helped save millions of dollars with better bearing designs, lubricants and seals.

After OH he helped develop a 'green' grease for hydroelectric turbine wicket gates and a much improved grease for nuclear motor operated valves. His current clients include operators, associations and suppliers to power stations. For STLE Ken has been on the Board of Directions, the first Canadian Fellow, Chair of the Toronto Section, and recognized with both the P.M. Ku and Vic Joll awards.

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!

Tribology

This is from the Greek word tribos. **Tribology is the science and engineering of interacting surfaces in relative motion.**

It includes the study and application of the principles of friction, lubrication and wear.

This includes lubricants, but also seals, bearings, wear, metal working, condition monitoring and numerous related fields. Plus, ceramics, biomaterials, plastics and friction materials.

History

With the 1966 UK Jost report, the Good Ship Tribology set sail. Did it sink in Canada? Studies have shown that about **2% of a nation's GDP is spend on friction and wear.**

In Canada, we had the 1986 NRC report that over that **$5 billion is lost annually.** This had 10 recommendations that including more research but also better training and education as well as improving both information sources and co-ordination.

Why should you care?

60 to 80% of bearing failures are lubrication-related.

This will affect your job and you!

Ref: UE Ultrasonics 2021

Why did they fail?

1. Wrong one
2. Bad design
3. Poorly stored or installed
4. Overloaded
5. Underloaded
6. Wrong lubricant
7. Too much lubricant
8. Too little lubricant
9. Contamination
   - Dirt
   - Water
   - Gases

Which ones are your responsibility?

All of them!

A good design should consider all the envelope including the physical application, ergonomics, operations, maintainability, service life, condition monitoring as well as taking into account life cycle costs, at least as much as you can given client restraints.

Which ones will you learn about at University?

Maybe
enough to
get a start, but then
expect to do some continuing
education all of your working life!

How are we doing?

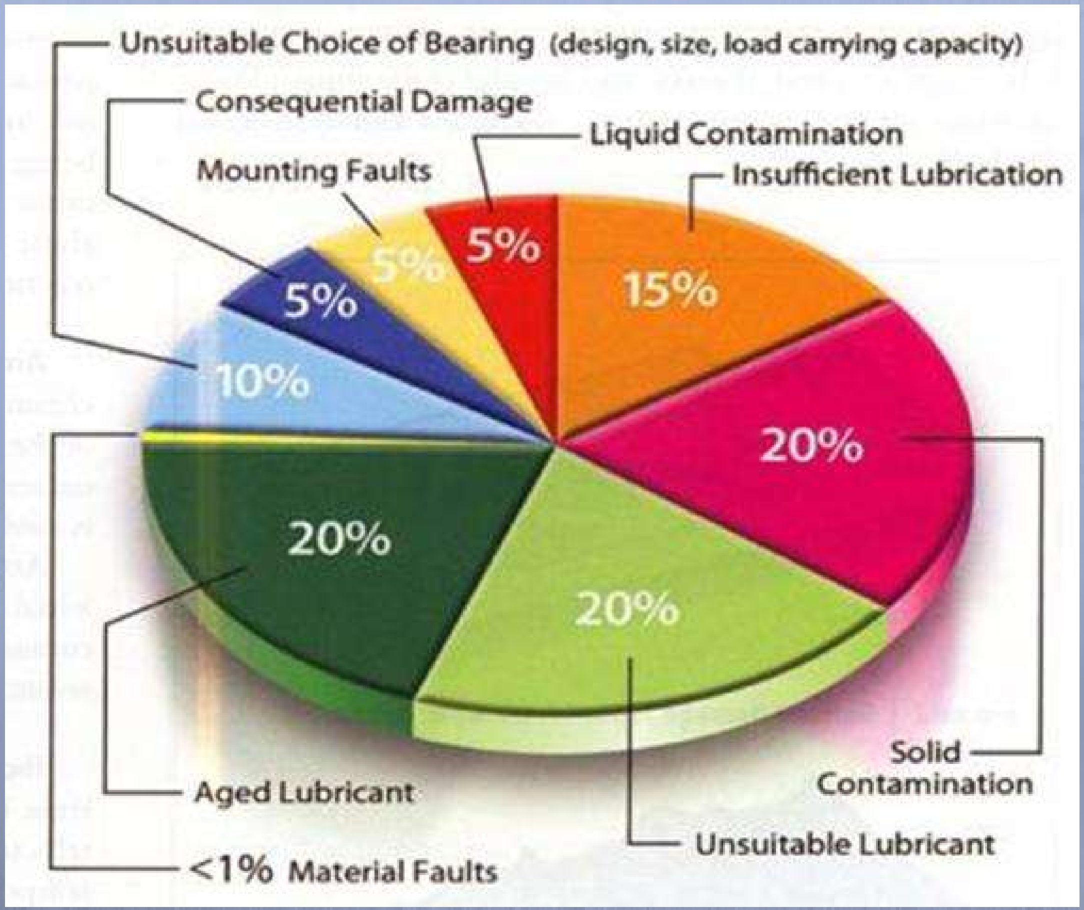
Motor Failures

Bearing troubles account for 50 to 65 percent of all electric motor failures, and **poor lubrication practices** account for most of these bearing troubles.

Proper maintenance procedures, planning and the use of the correct lubricant can increase productivity by reducing these bearing troubles and motor failures.

Ref: http://www.machinerylubrication.com/Read/1125/electric-motor-lubrication

How Are We Doing?
Pump Failures



90% of these failures are preventable!

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

How Are We Doing?
Rolling Element Bearings

Note: Only 3% reach their design life!

According to SKF (bearing manufacturer) contaminants cause 50% of bearing failures.

Do We Design Correctly?
Ball Bearing Fatigue Lives - Now

New life theory (ISO 281:2007) takes into account the viscosity ratio of actual vs. required, type of bearing, type of loading and **cleanliness** of the oil.

$L_{naa} = a_1 \, a_{ISO}(C/P)^3$

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

a_1 = life adjustment for reliability (i.e.. 10% failure)

a_{ISO} = life adjustment factor based on new life theory

C = Basic load rating

P = Equivalent dynamic bearing load

Rolling Element Bearings Lives - Now

Life Modification Factor a_{ISO}

Among other things considers the influence of:

- ***Fatigue limit of the bearing material by the fatigue load limit C.***
- ***Grade of contaminations by the factor e_c.***
- ***Lubrication conditions by the viscosity ratio κ.***

Note: *ISO 281:2007 does not cover the influence of wear, corrosion and electrical erosion on bearing life.*

Note: Using lube as supplied can reduce life by 50%!

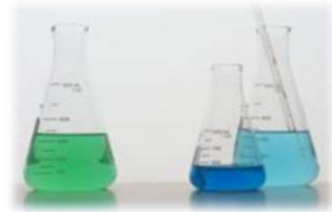
Ref: www.cwbearing.com

War - It costs us all

Car front wheel bearing – 2007 Sienna 280,000 km.
$800

LUBRICATING OILS

Crude Oil



Synthetic Base Stocks

Formulated Lubricant

Natural Gas

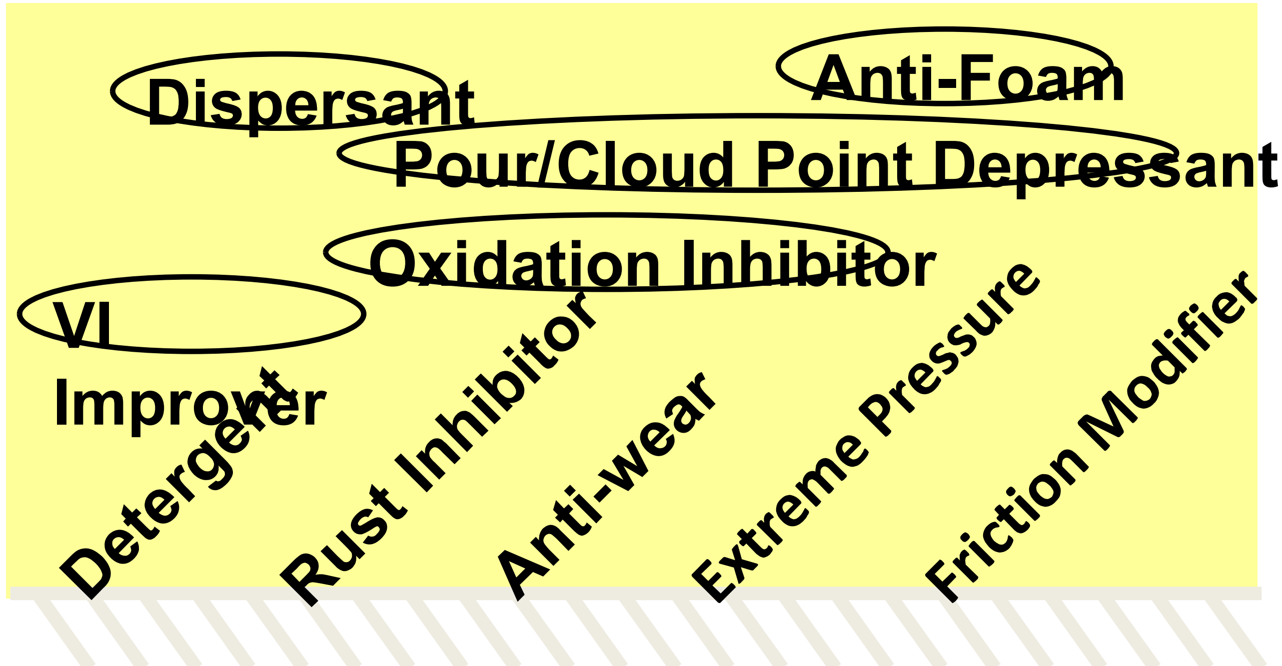
Mineral Base Stock

Additives

FUNCTIONS OF A LUBRICANT

- Reduce Friction
- Minimize Wear (Keep Moving Surfaces Apart)
- Cool Parts (Carry Away Heat)
- Prevent Corrosion
- Disperse Combustion Products (e.g. Soot)
- Act as a Sealant
- Transmit Power

ADDITIVES AT WORK



Formulated for specific applications. Do not mix.

Some additives work in the oil, some work on the metal surface –
A VERY DELICATE BALANCE

PETRO-CANADA LUBRICANTS

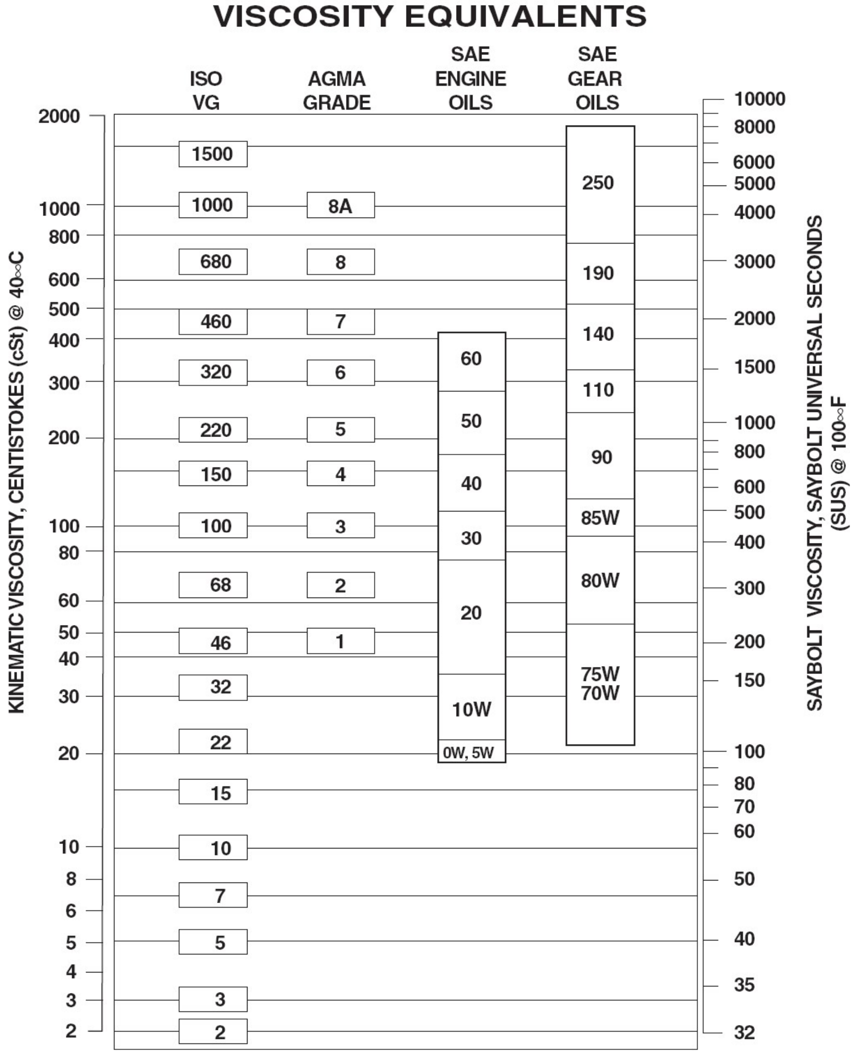
ISO-VISCOSITY SYSTEM
FOR INDUSTRIAL FLUID LUBRICANTS [ASTM D 2422-97 (2007)]

ISO Viscosity Grade	Mid Point cSt @ 40°C	Kinematic Viscosity @40°C Limits			
		Minimum		Maximum	
		cSt	SUS	cSt	SUS
2	2.2	1.98	32.0	2.42	34.0
3	3.2	2.88	35.5	3.52	37.5
5	4.6	4.14	39.5	5.06	42.5
7	6.8	6.12	46.0	7.48	50.5
10	10	9.00	55.5	11.0	62.5
15	15	13.5	71.5	16.5	83.5
22	22	19.8	97.0	24.2	116
32	32	28.8	136	35.2	165
46	46	41.4	193	50.6	235
68	68	61.2	284	74.8	347
100	100	90.0	417	110	510
150	150	135	625	165	764
220	220	198	917	242	1121
320	320	288	1334	352	1631
460	460	414	1918	506	2344
680	680	612	2835	748	3465
1000	1000	900	4169	1100	5095
1500	1500	1350	6253	1650	7643
2200	2200	1980	9171	2420	11209
3200	3200	2880	13340	3520	16305

Note: Grades increase by ~50%

Ref: 2013 PC Lube Handbook

VISCOSITY COMPARISON CHART



NOTE:

- Read across horizontally
- Assumes 96 VI single grade oils
- Equivalence is in terms of viscosity at 40°C only
- Viscosity limits are approximate: for precise data, consult ISO, AGMA and SAE specifications
- ‘W’ grades are represented only in terms of approximate 40°C viscosity
- For low temperature limits, consult SAE specifications

Viscosities of Common Fluids

	Centipoise (cP)	Centistokes (cSt)
Water	1.0	1.002
SAE 10 oil	70	80
Olive oil	100	110
SAE 30 oil	300	350
Glycerin	500	400
SAE 50 oil	800	910
Honey	2,000	1,430

International Lubricants Standardization and Approval Committee (ILSAC)

American Petroleum Institute (API)

Later can go earlier, earlier can not go later!

New ILSAC GF-6 and API SP

ILSAC GF-6

GF-6 will replace the GF-5 category and is divided into two separate sub-categories:

> **GF-6A**: Fully backward-compatible for older vehicles that previously used GF-5 oils.
>
> **GF-6B**: Covers the new, lower-viscosity oil grade OW-16 and will NOT be backward-compatible in most cases (unless specified by the OEM).

API SP is fully backward-compatible with previous API service categories, including API SN PLUS, SN, SM, SL or SJ.

https://kendallmotoroil

Why the Change?

- **Environmental**

OEMs have turned to several methods to help reduce greenhouse gas emissions and increase fuel economy. The major strategies include the development of new, lighter weight and higher performance engine technologies as well as the push for updated motor oils.

- **Turbocharged Gasoline Direct Injection (TGDI) Engines**

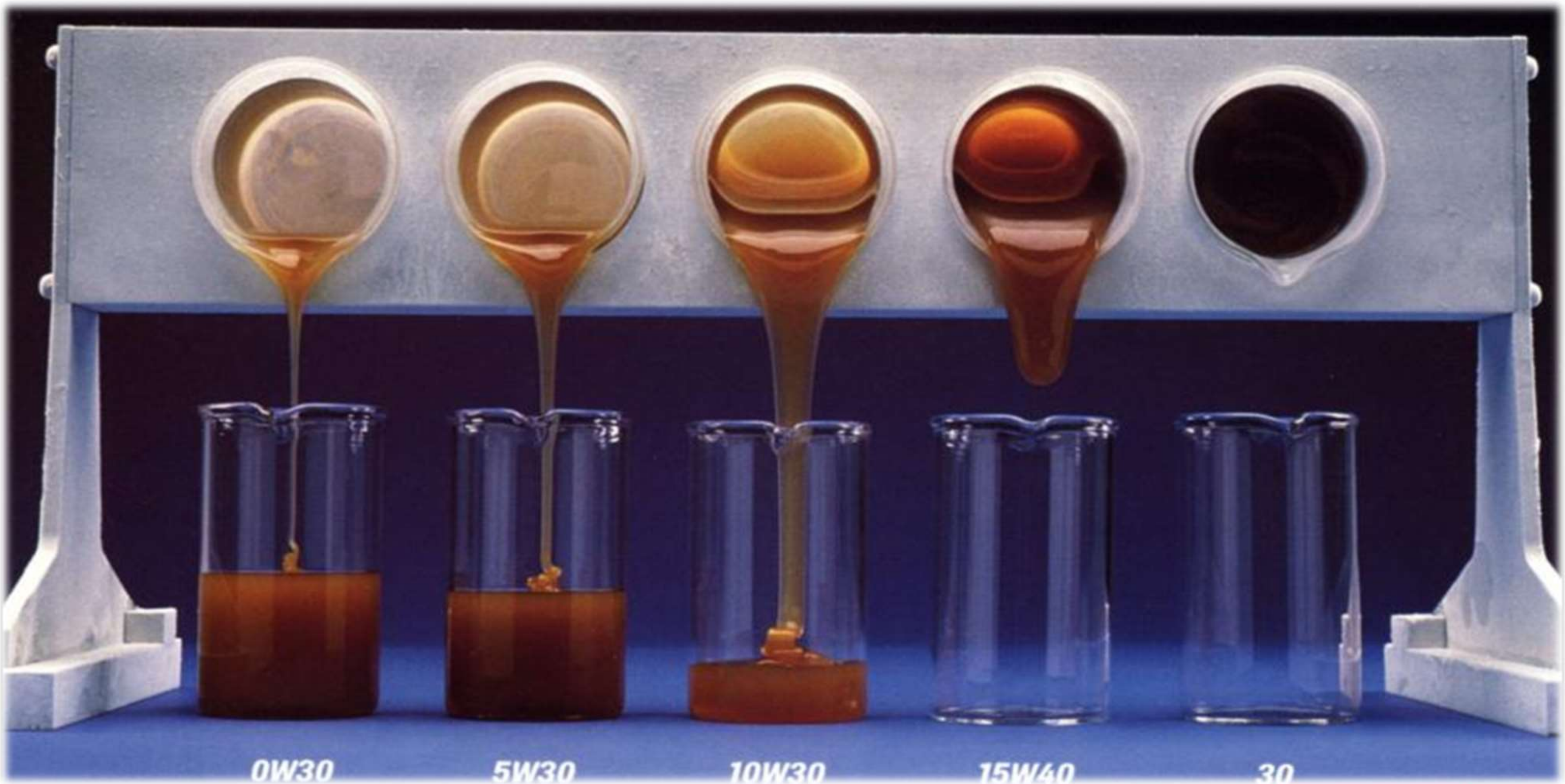
Combining turbochargers with GDI presents a unique set of problems, including an abnormal combustion phenomenon known as **low speed pre-ignition (LSPI)**. LSPI is an uncontrolled combustion event that takes place prior to spark ignition, often resulting in knock, and has been known to cause catastrophic engine damage.

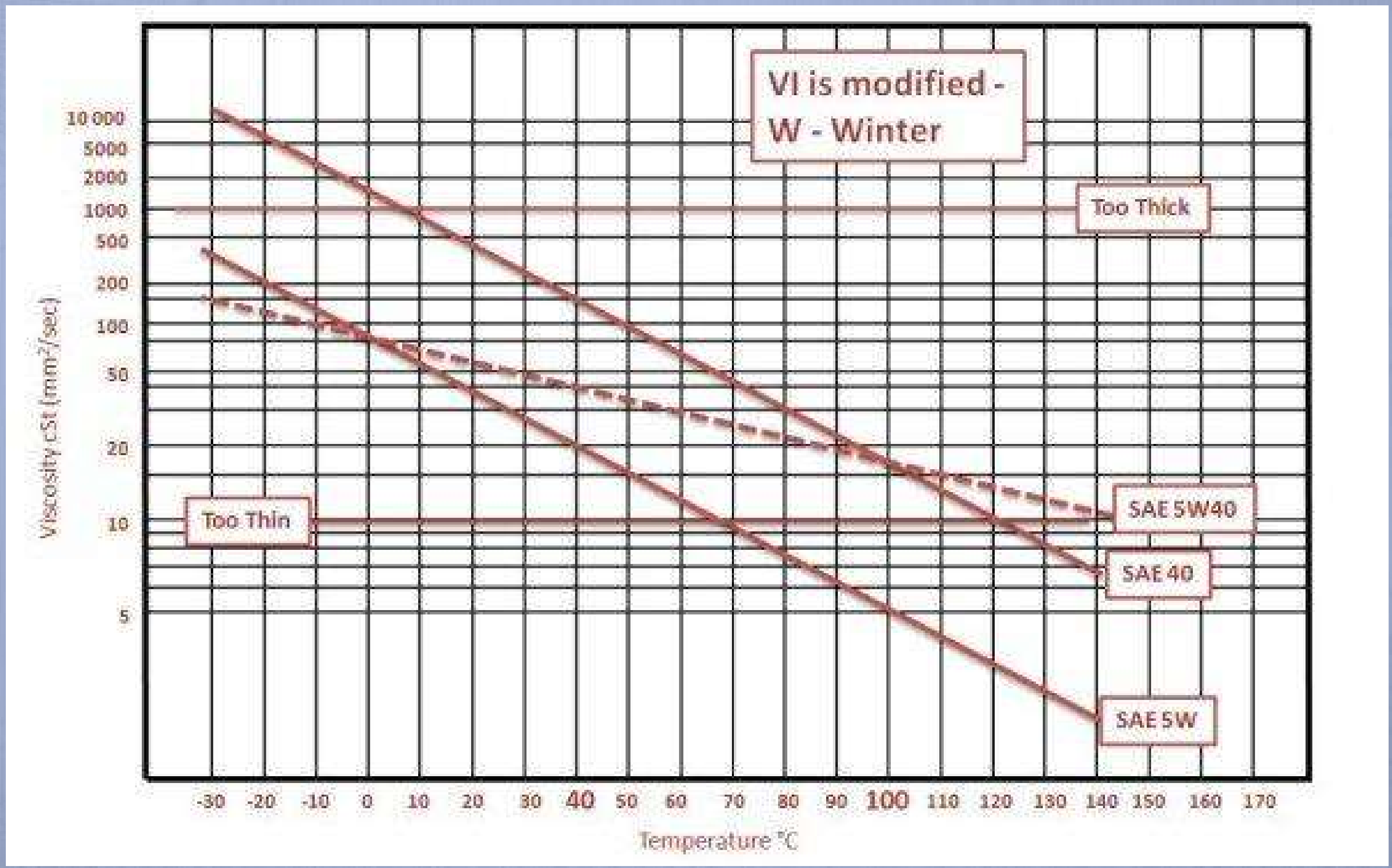
- **Start-Stop Engine Technology**

These engines stop when a vehicle becomes stationary at a stoplight or in heavy traffic, and then start back up again as soon as you hit the gas pedal. This feature helps reduce emissions and improve fuel economy.

VISCOSITY

Viscosity is a measurement of the oil's internal resistance to motion.





Both too cold and too hot can be bad!

Grease Stiffness Grades

NLGI 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

Note: The grade has nothing to do with quality.

Grease Thickener Characteristics

GREASE PROPERTIES

The following chart is designed to help you select a type of grease that will satisfy the intended application.

	REGULAR GREASES				COMPLEX			SYNTHETIC	CLAY
Properties	Calcium	Lithium	Sodium	Aluminum	Calcium	Barium	Lithium	Polyurea	Bentone
Dropping Point °C	80-100	175-205	170-200	260+	260+	200+	260+	250+	None
*Max Temp °C	65	125	125	150	150	150	160	150	150
High Temp Use	V. Poor	Good	Good	Exc	Exc	Good	Exc	Exc	Exc
Low Temp Mobility	Fair	Good	Poor	Good	Fair	Poor	Good	Good	Good
Mech. Stability	Fair	Good	Fair	Exc	Good	Fair	Exc	Good	Fair
Water Resist.	Exc	Good	Poor	Exc	Exc	Exc	Exc	Exc	Fair
Oxidation Stability	Poor	Good	Good	Exc	Exc	Poor	Good	Exc	Good
Texture	Smooth	Smooth	Fibrous or Smooth	Smooth	Smooth	Fibrous	Smooth	Smooth	Smooth

*These temperatures refer to continuous operation. They may be exceeded temporarily in the case of complex greases, and where rigorous lubrication practice is followed.

Note: There is no universal grease. All thickener systems have pros and cons.

Ref: PetroCanada 2013 Lubricants Handbook

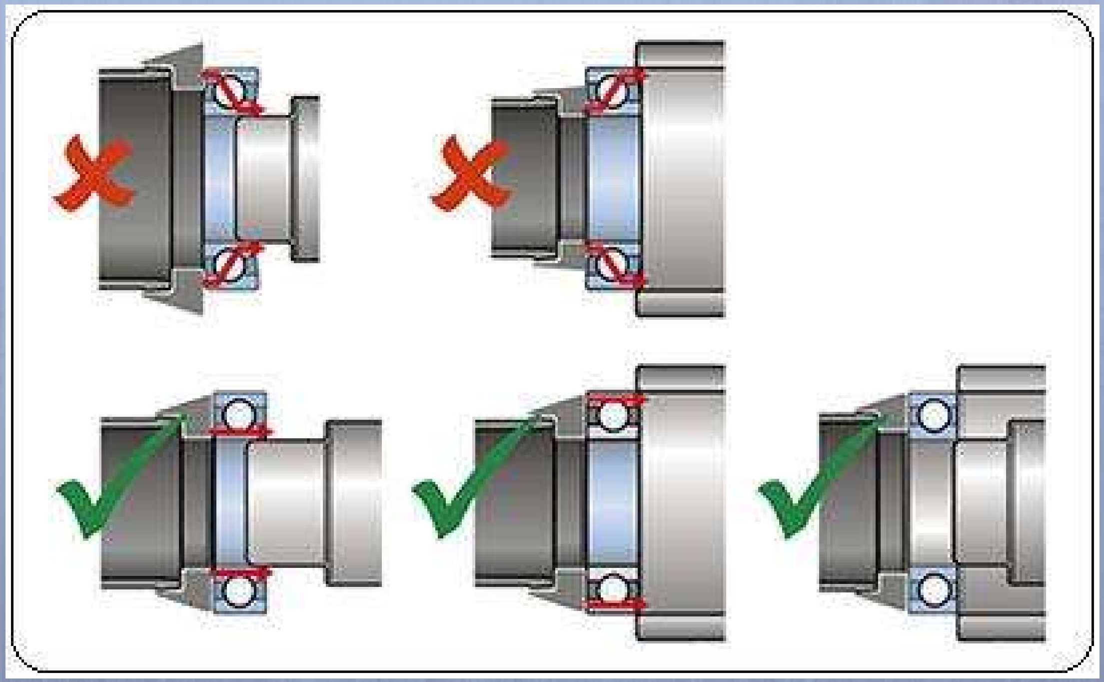
Installation – Do They Have the Right Tools?

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

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

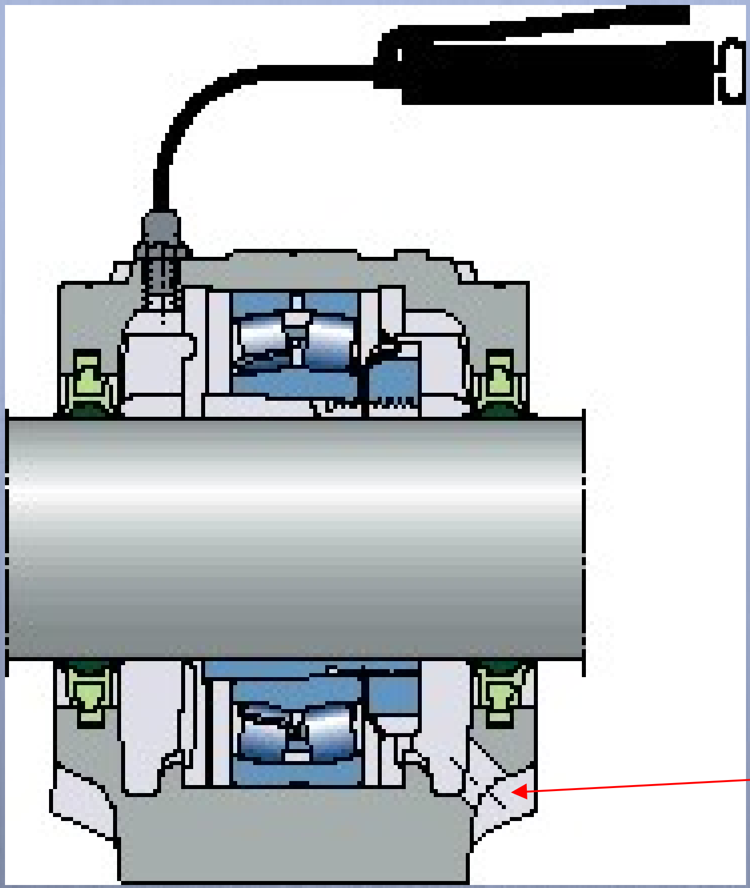
Proactive – Do They Have the Right Training?

Mounting forces must not pass through the rolling elements



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

Do We Know How to Do it?
Greasing Bearings



Note: There are many many variations. Few have easy places for the spent grease to exit. Know how to do it in each case.

Volumetric Grease Relief Port

Calculating Grease Quantity, Frequency

Units of Measurement

(•) Imperial ( ) Metric

Sizing Source: Bearing Size

Bearing Type: Ball

Width: mm 39

Outer Diameter: mm 170

Shaft Diameter: mm 80

Shaft RPM: 1800

Operating Temperature: 125°F (51.7°C) - 150°F (65.6°C)

Particle Contamination: Light, non-Abrasive

Moisture: < 80% Humidity

Vibration: < 0.2 ips

Position: Vertical

Ref: Machinery Lubrication

Other Factors

$$T = K \times \left[\left(\frac{14{,}000{,}000}{n \times (d^{0.5})}\right) - 4 \times d\right]$$

Where:

T = Time until next relubrication (hours)

K = Product of all correction factors
Ft x Fc x Fm x Fv x Fp x Fd
(see table)

n = Speed (RPM)

d = Bore diameter (mm)

Note:
ips = inches / second
0.2 inches / second = 5 mm / sec.

Grease Interval Correction Factors

Condition	Average Operating Range	Correction Factor
Temperature Ft	Housing below 150°F 150 to 175°F 175 to 200°F Above 200°F	1.0 0.5 0.2 0.1
Contamination Fc	Light, non-abrasive dust Heavy, nonabrasive dust Light, abrasive dust Heavy, abrasive dust	1.0 0.7 0.4 0.2
Moisture Fm	Humidity mostly below 80% Humidity between 80 and 90% Occasional condensation Occasional water on housing	1.0 0.7 0.4 0.1
Vibration Fv	Less than 0.2 ips velocity, peak 0.2 to 0.4 ips Above 0.4 (see note)	1.0 0.6 0.3
Position Fp	Horizontal bore centerline 45 degree bore centerline Vertical centerline	1.0 0.5 0.3
Bearing Design Fd	Ball bearings Cylindrical and needle roller bearings Tapered and spherical roller bearings	10 5.0 1.0

Ref: Noria 'Calculating Grease Quantity, Frequency'

Grease Quantities – as a 'best guesstimate'

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

Note: Also check the manual and take into account any lessons learnt.

Ref: SKF 2007

Regreasing Amount Example

6316 ball bearing; ID 80, OD 170 mm Width 39 mm

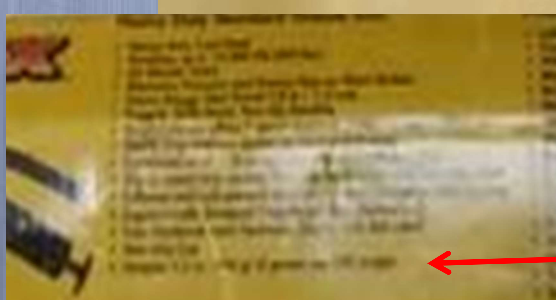
It should get about 0.005 X 170 mm X 39 mm

= 33 g (1.2oz) of new grease.

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

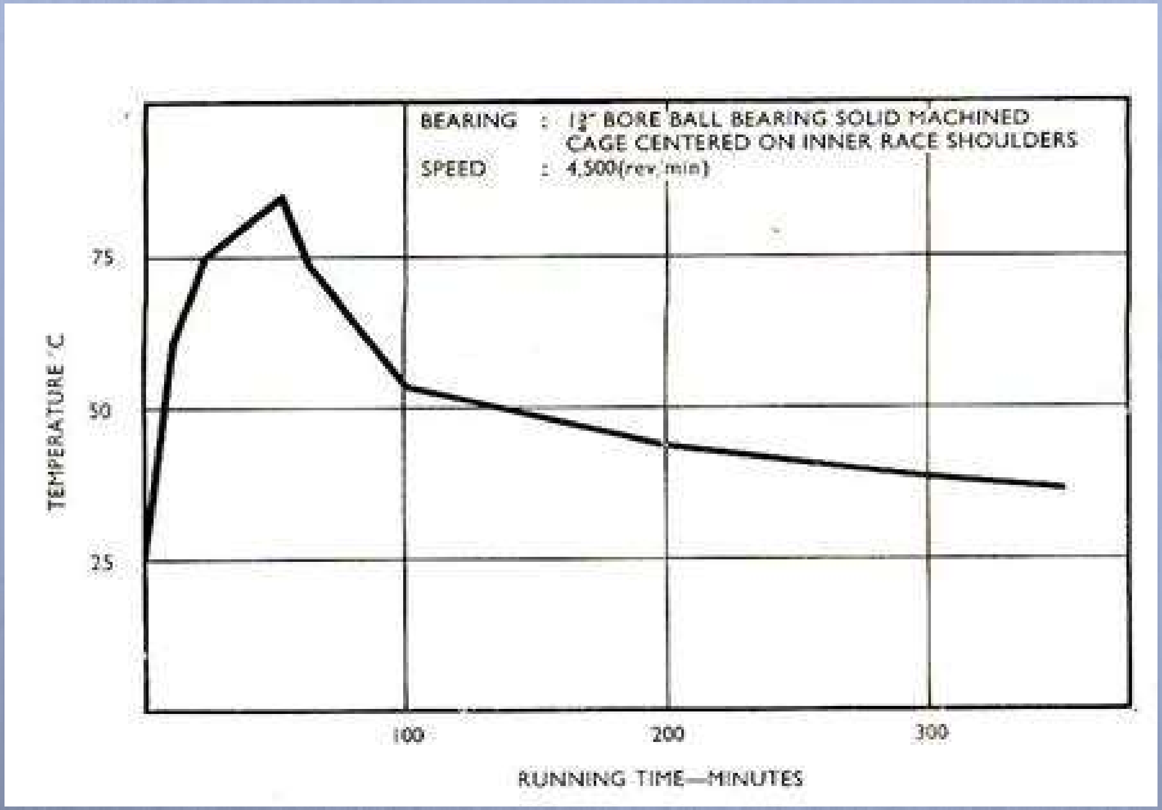
Note: Verify delivery rate of the grease gun being used. Pump into a paper cup or onto a paper towel. Density of grease is about the same as water. In this case 33 g ~ 33 ml or 1/8 cup

Grease Gun Delivery – what is it?



Outputs 5.2 oz (150g) of grease per 100 strokes

‘Normal’ Temperature Rise



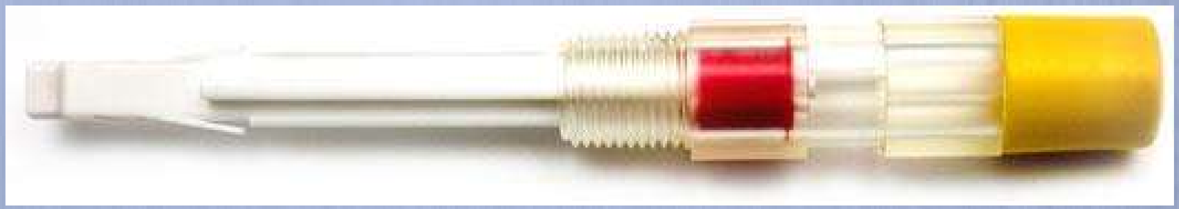
Note:
Lubricators need to communicate with operators. Do not raise temperature limits or use less than required grease amounts.

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

When Is Enough or Not Enough?

Courtesy: EA Grease Caddy

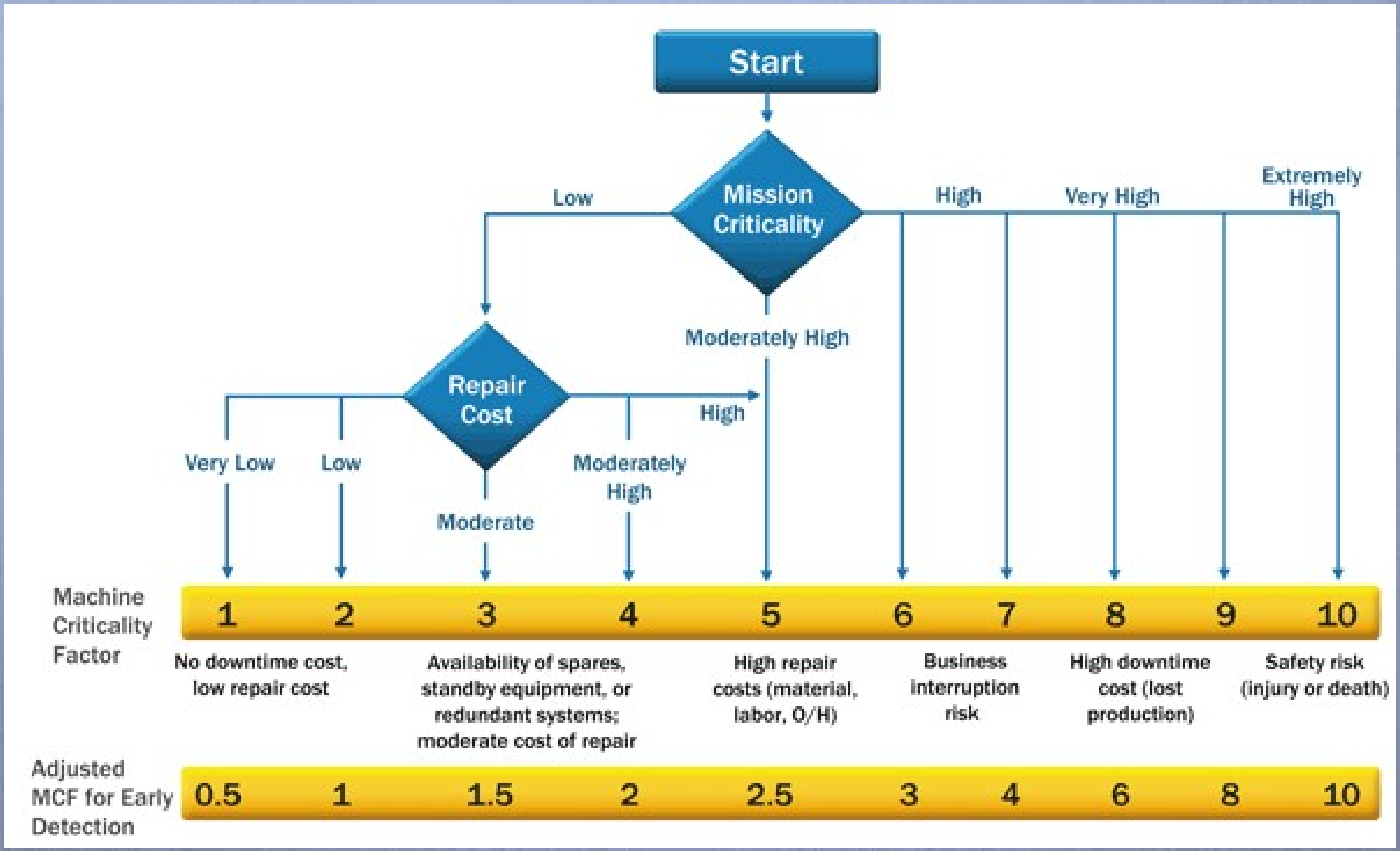
How Do You confirm When?



Now getting a grease sample is just as easy as an oil sample. Just screw in place of the grease plug.

MRG Grease Thief

Machine Criticality



What to Test and When - Oils

This is best based on your specific equipment, lubes, skill sets and criticality but there are still good guidelines readily available.

Example: ASTM D6224 Standard Practice for In-Service Monitoring of Lubricating Oil for Auxiliary Power Plant Equipment

For gear/circulating oils, hydraulic oils, diesel engine oils, turbine type oils, air compressor oils, EHC (PO_4 esters) EHC Mineral Oils.

ISO Cleanliness Codes

ISO 4406 is only the method of reporting the counts not the procedure.

>4, >6, >14 microns

Counts can also be reported for other sizes.

With servo valves target 17/15/12 or lower.

ISO 4406:1999 Scale Number Table		
Number of particles per millilitre		Scale number
More than	Up to and including	
2 500 000		> 28
1 300 000	2 500 000	28
640 000	1 300 000	27
320 000	640 000	26
160 000	320 000	25
80 000	160 000	24
40 000	80 000	23
20 000	40 000	22
10 000	20 000	21
5 000	10 000	20
2 500	5 000	19
1 300	2 500	18
640	1 300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1
0	0.01	0

Recommended ISO Cleanliness Codes
>4 / >6 / >14 microns

BEARINGS

Ball Bearing Systems	**15/13/11**
Roller Bearing Systems	**16/14/12**
Journal Bearings (high speed)	**17/15/13 >400 RPM**
Journal Bearings (low speed)	**18/16/14 <400 RPM**
General Industrial Gearboxes	**17/15/13**

Ref: Eaton Vickers – The Systemic Approach to Contamination Control

Fluid Additions – Condition Monitoring?

Right way?

Ref: Des-Case

$$\text{BETA RATIO} = \frac{\text{NO. OF PARTICLES AT INLET}}{\text{NO. OF PARTICLES AT OUTLET}}$$

IN	BETA RATIO	OUT
10,000	10	1,000
	50	200
	75	133
	200	50
	500	20
	1000	10

Just one factor!

Visual – Pressure Indicators – some are not so good

How Are We Doing?

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

86% could be preventable!

Ref: Clevite AM-208-8

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.

Can you afford not to do it?

Make it easier to do it right

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

$0.35 each

Coloured grease fitting caps

$0.20 each

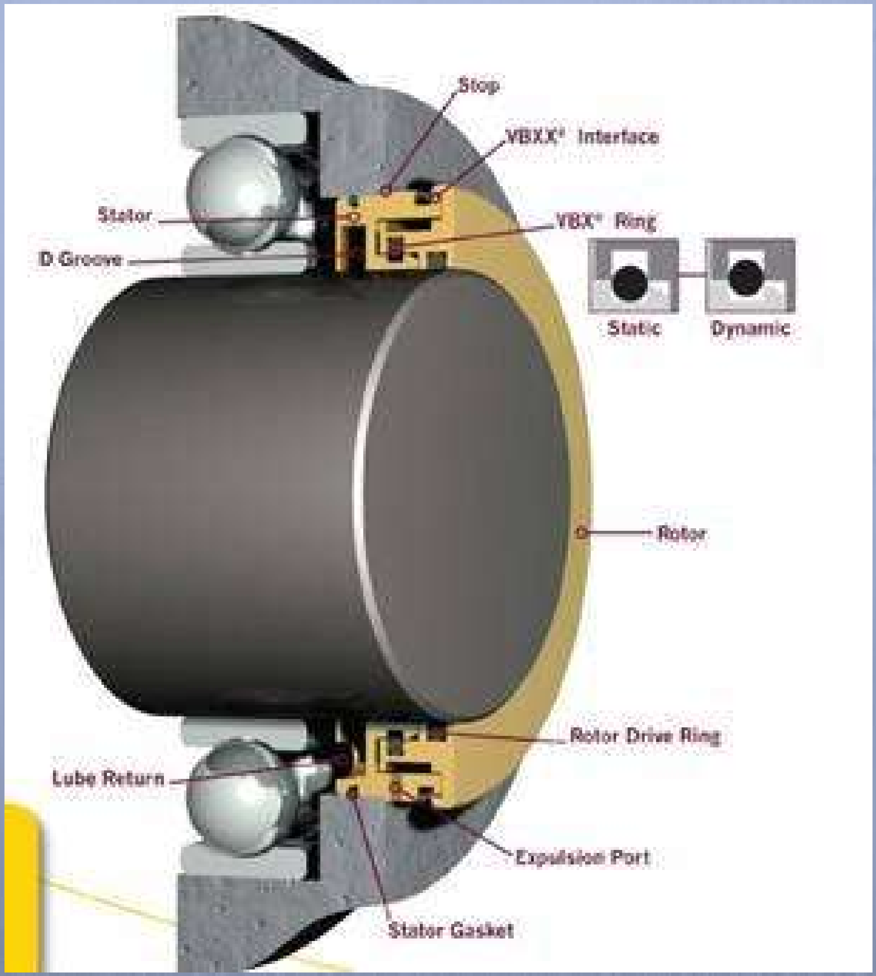
How Are We Doing?
Hydraulic Systems

More than **3/4** of all problems can be traced back to **contaminated oil**. Monitoring **oil cleanliness** is therefore the most important factor in preventing system failures.

Monitoring hardware only detects around 20% of all unplanned downtimes.

Ref: Rexroth Oil Contamination Booklet RE 08016 2011

Better Seals – What is being used?



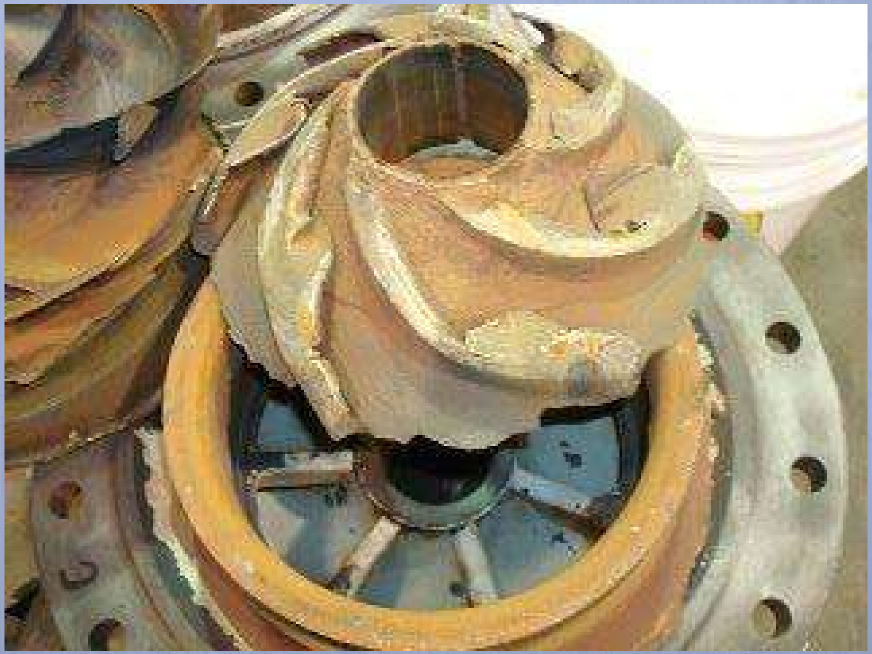
Note: No rubbing contacts to wear out or increase temperatures.

Plus retains lube and excludes water and dirt.

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?

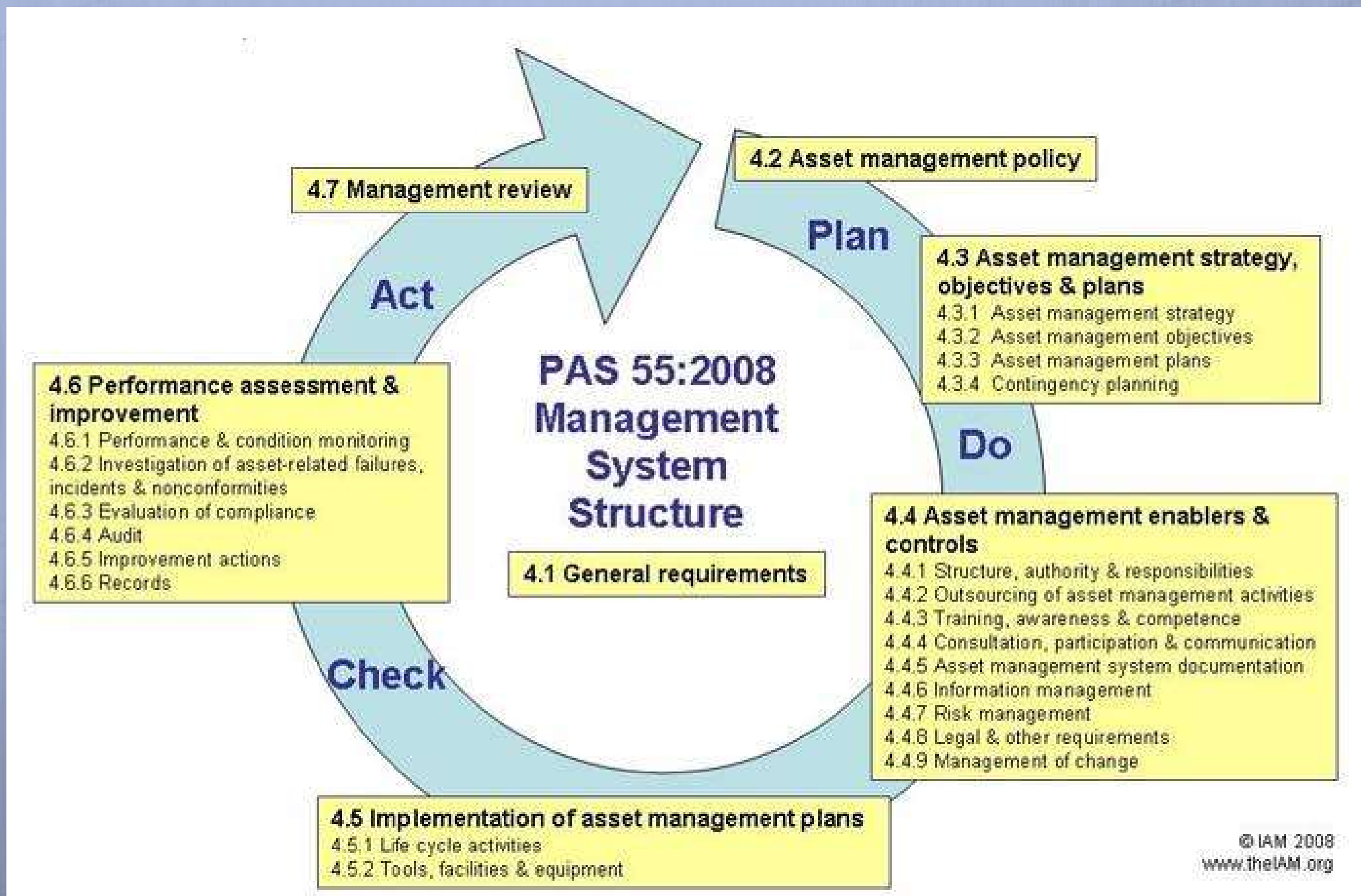
Wheel issue caused 2014 Brockville CN Rail train derailment, report finds

TSB blamed a combination of factors: the speed of the train, the type of car where the wheel issue manifested itself a 24-metre-long "centrebeam bulkhead flat car" and the worn condition of the side bearings.

Proactive – How Do You Compare?

Ref: IAEA-TECDOC-1551 Implementation Strategies and Tools for Condition Based Maintenance at Nuclear Power Stations

PAS55
(Publically Available Specification)
ISO55000



ISO 55000 Asset Management

ISO 55000:2014 Asset management - Overview, principles and terminology

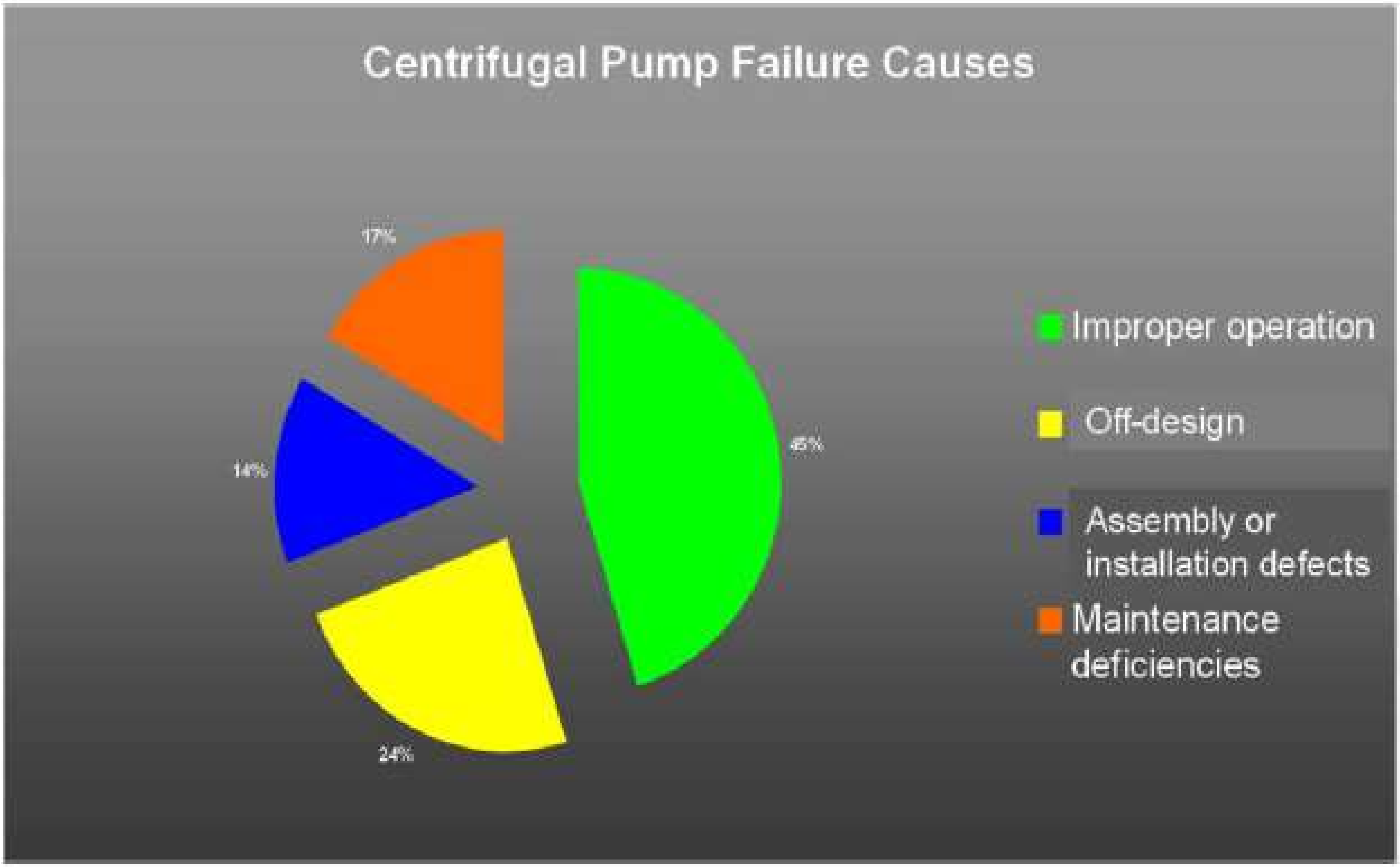
- Provides an overview of asset management, its principles and terminology, and the expected benefits from adopting asset management.
- Can be applied to all types of assets and by all types and sizes of organizations.

- **ISO 55001:2014 - Asset Management, management systems requirements**

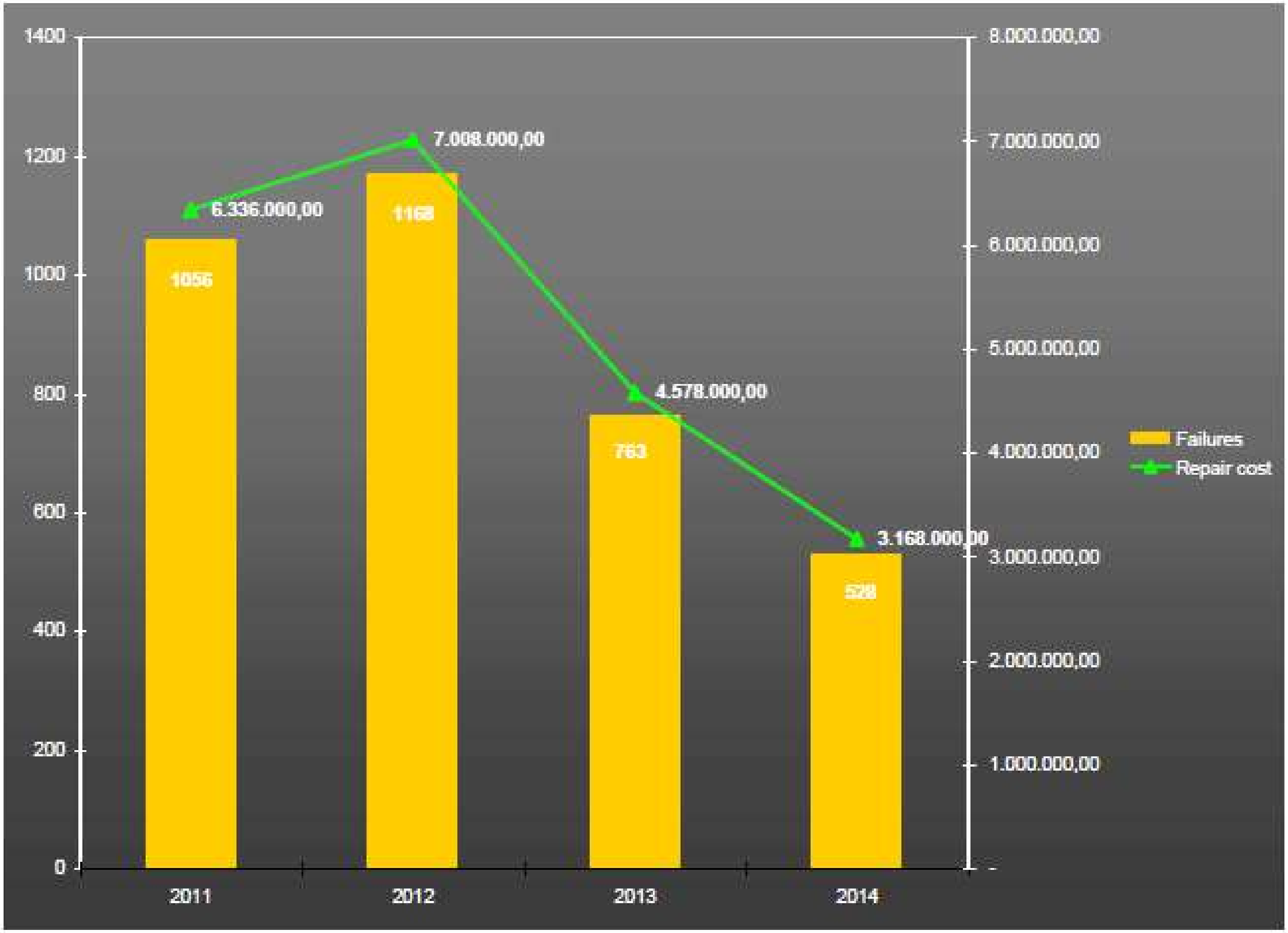
- **ISO 55002:2014 - Asset Management, management systems guidelines for the application of ISO 55001**

It contains explanatory text necessary to clarify the requirements specified in ISO 55001 and provides examples to support implementation

The Real World



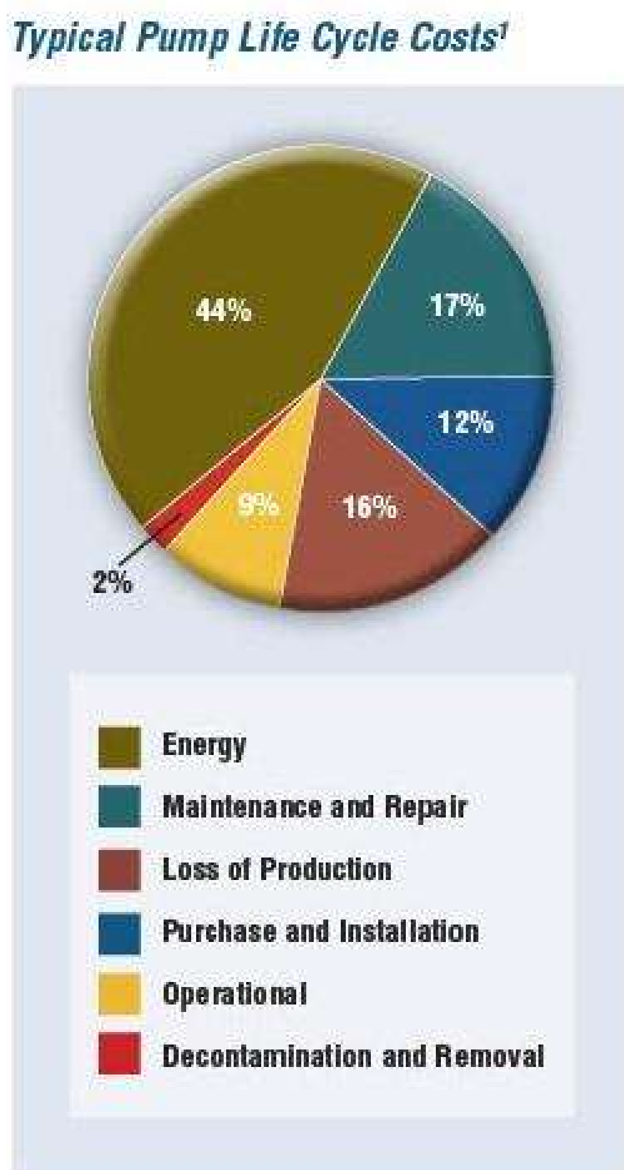
Centrifugal Pumps Failures and Repair Costs for 2011-2014



Many equipment factors can impact on the success or failure of a business

Major ones to design better relate to efficiencies and reliability.

Reference: Flowserve



[1] While exact values may differ, these percentages are consistent with those published by leading pump manufacturers and end users, as well as industry associations and government agencies worldwide.

My Summary

1. Most bearings do not reach their design life.

2. The leading cause of hydraulic system failures is contamination.

3. The leading cause of electric motor failures are the bearings.

4. Many failures can be easily prevented.

Failure Analysis

- This an opportunity to make improvements.
- For all failed, worn and/or replaced parts, examine them to determine why and if improvements would be beneficial.
- Do not let them clean parts without collecting samples and/or taking photos.
- Do not assume, verify.
- Get any needed help.

Want to save money – help equipment run longer.

Life Extension Table - Cleanliness Level, ISO Codes

	21/19/16	20/18/15	19/17/14	18/16/13	17/15/1	16/14/11	15/13/10	14/12/9	13/11/8	12/10/7
24/22/19	2 1.6 1.8 1.3	3 2 2.3 1.7	4 2.5 3 2	6 3 3.5 2.5	7 3.5 4.5 3	8 4 5.5 3.5	>10 5 7 4	>10 6 8 5	>10 7 10 5.5	>10 >10 >10 8.5
23/21/18	1.5 1.5 1.5 1.3	2 1.7 1.8 1.4	3 2 2.2 1.6	4 2.5 3 2	5 3 3.5 2.5	7 3.5 4.5 3	8 4 5 3.5	>10 5 7 4	>10 7 9 5.5	>10 10 10 8
22/20/17	1.3 1.2 1.2 1.05	1.6 1.5 1.5 1.3	2 1.7 1.8 1.4	3 2 2.3 1.7	4 2.5 3 2	5 3 3.5 2.5	7 4 5 3	9 5 6 4	>10 7 8 5.5	>10 9 10 7
21/19/16		1.3 1.2 1.2 1.1	1.6 1.5 1.5 1.3	2 1.7 1.8 1.5	3 2 2.2 1.7	4 2.5 3 2	5 3 3.5 2.5	7 4 5 3.5	9 6 7 4.5	>10 8 9 6
20/18/15			1.3 1.2 1.2 1.1	1.6 1.5 1.5 1.3	2 1.7 1.8 1.5	3 2 2.3 1.7	4 2.5 3 2	5 3 3.5 2.5	7 4.6 5.5 3.7	>10 6 8 5
19/17/14				1.3 1.2 1.2 1.1	1.6 1.5 1.5 1.3	2 1.7 1.8 1.5	3 2 2.3 1.7	4 2.5 3 2	6 3 4 2.5	8 5 6 3.5
18/16/13					1.3 1.2 1.2 1.1	1.6 1.5 1.5 1.3	2 1.7 1.8 1.5	3 2 2.3 1.8	4 3.5 3.7 3	6 4 4.5 3.5
17/15/12						1.3 1.2 1.2 1.1	1.6 1.5 1.5 1.4	2 1.7 1.8 1.5	3 2 2.3 1.8	4 2.5 3 2.2
16/14/11							1.3 1.3 1.3 1.2	1.6 1.6 1.6 1.4	2 1.8 1.9 1.5	3 2 2.3 1.8
15/13/10								1.4 1.2 1.2 1.1	1.8 1.5 1.6 1.3	2.5 1.8 2 1.6

Hydraulics and Diesel Engines	Rolling Element Bearings
Journal Bearings and Turbo Machinery	Gearboxes and others

Figure 28: Life Extension Table, cleanliness level - See the example on page 25 *Source: Noria Corp.*

ACOT 1986 Recommendations

1. Strengthening of Industrial R&D in Tribology
2. Joint Government-Industry Support of “Mission-Orientated R&D Programme in Tribology
3. Strengthening of Consulting Service in Tribology
4. Human Resource Development
5. Strengthening Contract R&D in Tribology in Universities
6. Strengthening Research In Tribology in Universities
7. Strengthening of Information Services in Tribology
8. Strengthening of In-house Programmes in Tribology in the National Research Council Canada
9. Co-ordination of Tribology R&D Programmes
10. Promotion and Review

Did not happed in Canada!

Not too late, yet!

1. More tribological awareness is needed.

2. Financing skills including Return on Investment (ROI) and Life Cycle Costing (LCC) should be taught to engineers.

3. Root cause analysis should be part of all design courses.

4. Asset Management is key and must know ISO 55000.

5. Applied knowledge and solution finding often begin after graduation so encourage interactions and learning.

What Else?

Embrace or at least take advantage of any the many '**green**' attributes;

Sustainable	Lasts Longer
Less toxic	No seasonal changes
Less required	Less make-up
Lower friction	Less wear
Less energy	Less heat
Safer	Lower disposal costs

Lower life cycle costs!

What's Required

1. Better training for engineers, trades, managers and accountants.

2. Commitment to ongoing training and certification.

3. Recognizing that change, as improvements, is both beneficial and necessary.

4. We can easily do better.

It can take time.

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Thank you

Questions?

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