Lubrication System Design an
Run-In Practices

Robert Armbruster, GE Transportation

Wind Turbine Condition Monitoring Worksh
8-9 Oct 2009

GE Transportation

DriveTrain Description

Industry Trends

Lubrication System Design

Manufacturing

Validation Testing

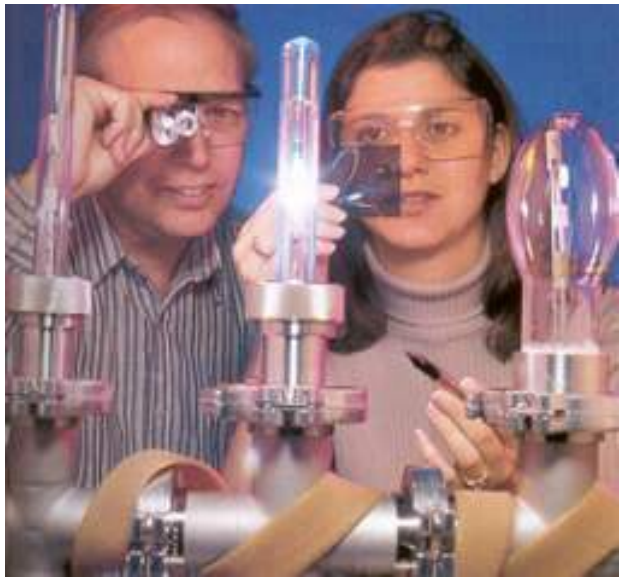
GE … a tradition of innovation

Founded in 1878 as the Edison Electric Co.

130 years of successful operation

320,000 employees worldwide

Strong technology focus … Research centers in Germany, India, China and the U.S.



Four segments …aligned for growth

Energy Infrastructure

- Energy
- Oil & Gas
- Water

Technology Infrastructure

- Aviation
- Enterprise Solutions
- Healthcare
- **Transportation**

Capital

- Aviation Financial Services
- Commercial Finance
- Energy Financial Services
- GE Money
- Treasury

NBC Universal

- Cable
- Film
- International
- Network
- Sports & Olympics

Transportation

2008 Revenue of $5.2 B

Locomotives

Signaling & Comm

Financial Solutions

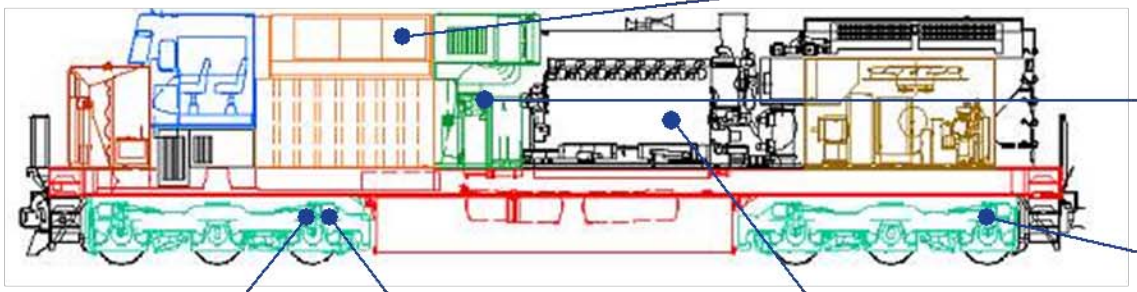
Traffic Mgmt Systems

Parts & Service

Propulsion & Specialty Services

P&SS …a derivatives business

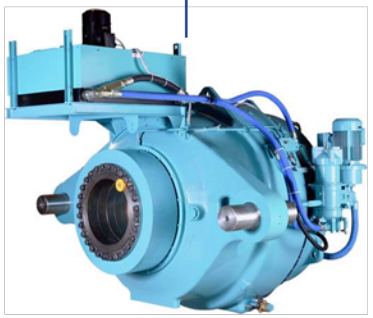
15,000 Engines Operational in 20 countries



Mining / OHV

Drive Systems
for Mining Trucks

18000 drives shipped



Transit

Propulsion for
Transit Cars

Drill

DC/AC Motors
for Drill Rigs

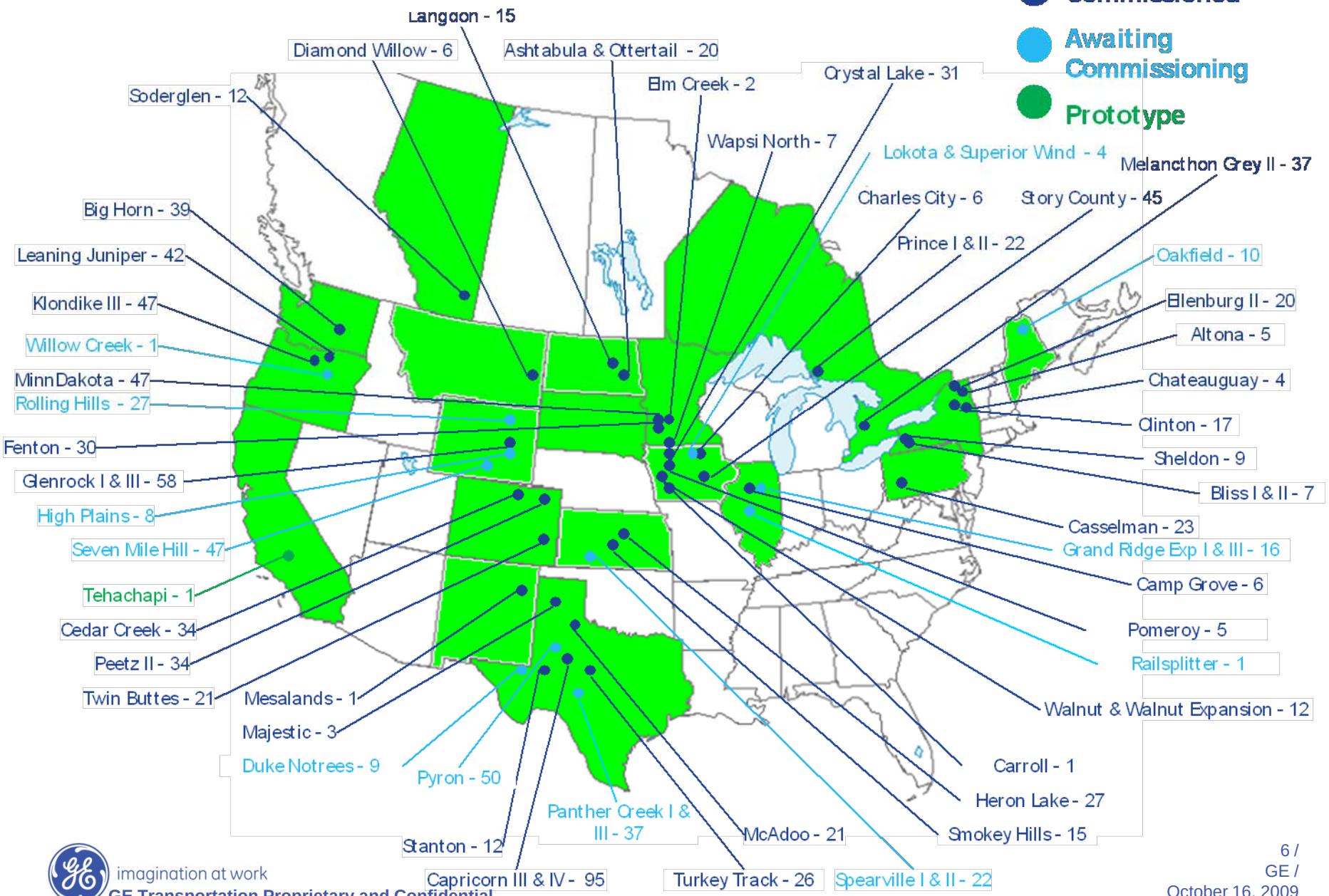
Marine & Stationary

Engines for Boats
& Power Generators

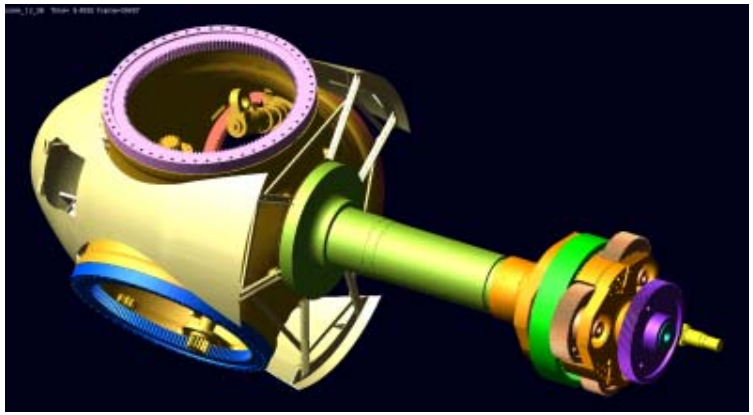
Drivetrain Technologies

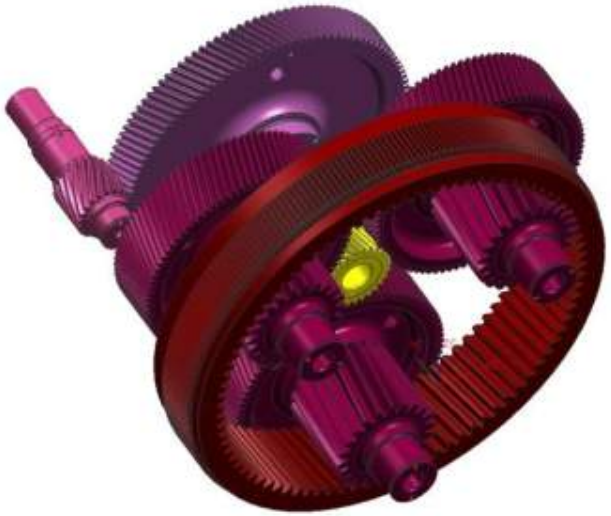
Wind Turbine
Gearboxes

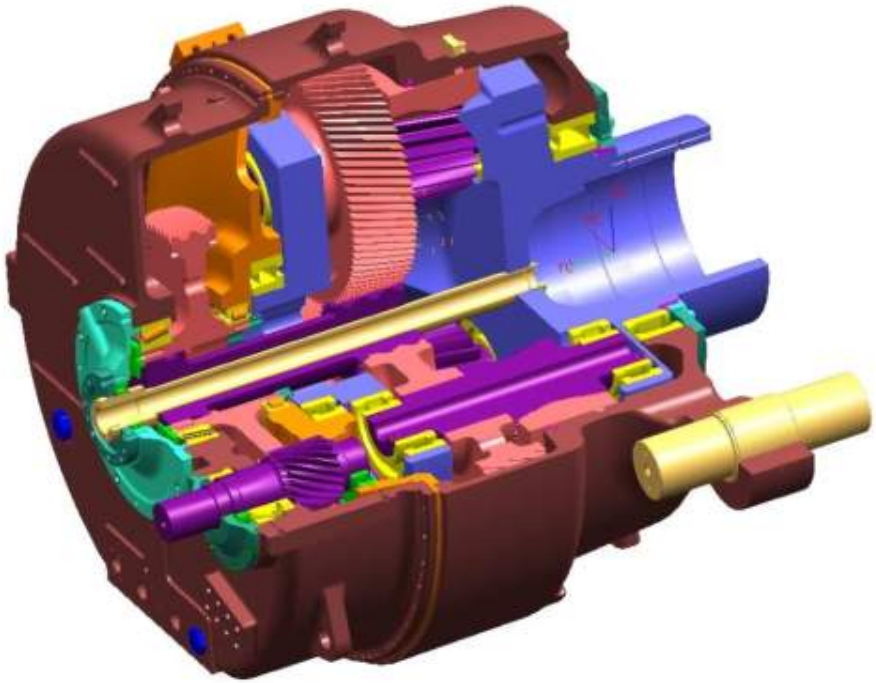
Installed base – **1500 gearboxes** (1.5MW)



7GA87E – 1.5MW 1:78 ratio Compound Planetary

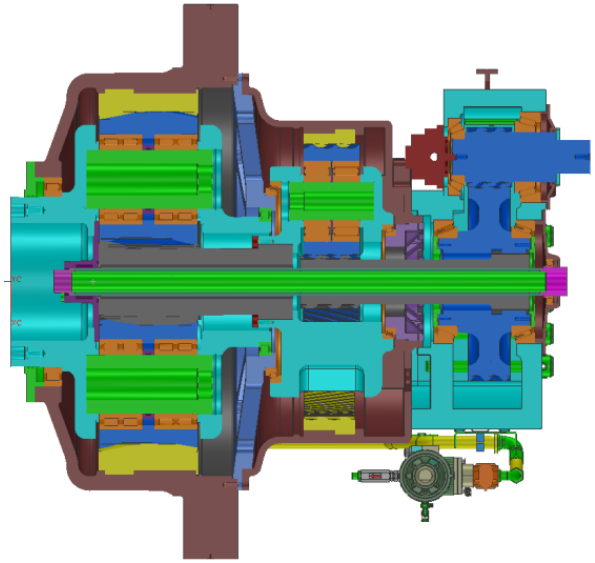




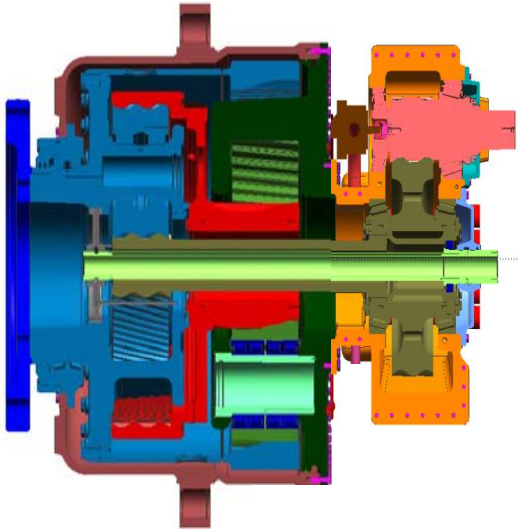


- 3 stage CP design with helical gearing
- Straddle mounted planet bearings
- Flexible, splined ring gear
- No reversed bending loads on planet teeth
- One high speed stage
- Oldest fleet at 41 months

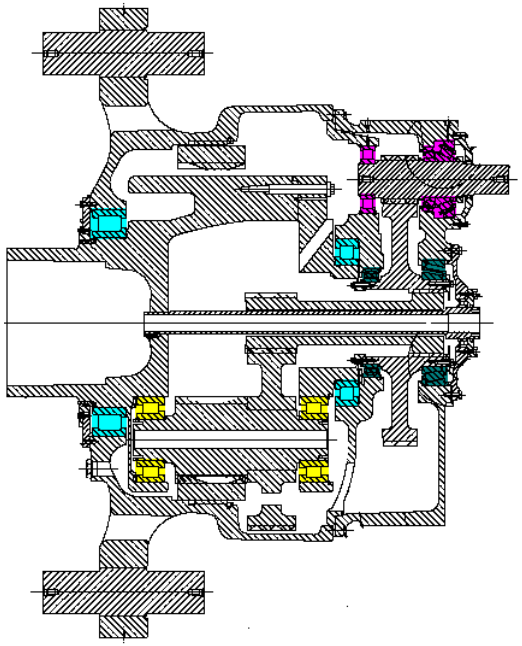
Current GET Gearboxes



2 Simple Planetaries + Parallel Shaft
2.3 – 2.9 MW @ 14 – 16 RPM Input Speed
1500 – 1920 kNm Input Torque
78:1 – 136:1
Approximate Weight: 46,500 Lbs
Horizontal Output Shaft @ 550mm CD
2550mm Overall Length



Differential Planetary + Parallel Shaft
2.0 – 2.7 MW @ 14.4 – 18 RPM
1400 – 1900 kNm Input Torque
60:1 – 97:1 Ratio Possibilities
Approximate Weight: 39,000 Lbs
Horizontal and vertical output shaft locations @ 550mm CD
2350 / 2150mm Overall Length



Compound Planetary + Parallel Shaft
1.4 – 1.8 MW @ 16 – 20 RPM
700 – 970 kNm Input Torque
59:1 – 86:1 Ratio Possibilities
Approx Weight: 33,000 Lbs
Horizontal Output Shaft @ 550mm CD
.Working on Vertical Output Shaft for 2009.
2200mm Overall Length

Gearbox System Requirements

- Speed & Torque Conversion
- 20 Year Life
- Efficiency
- Operating Environment

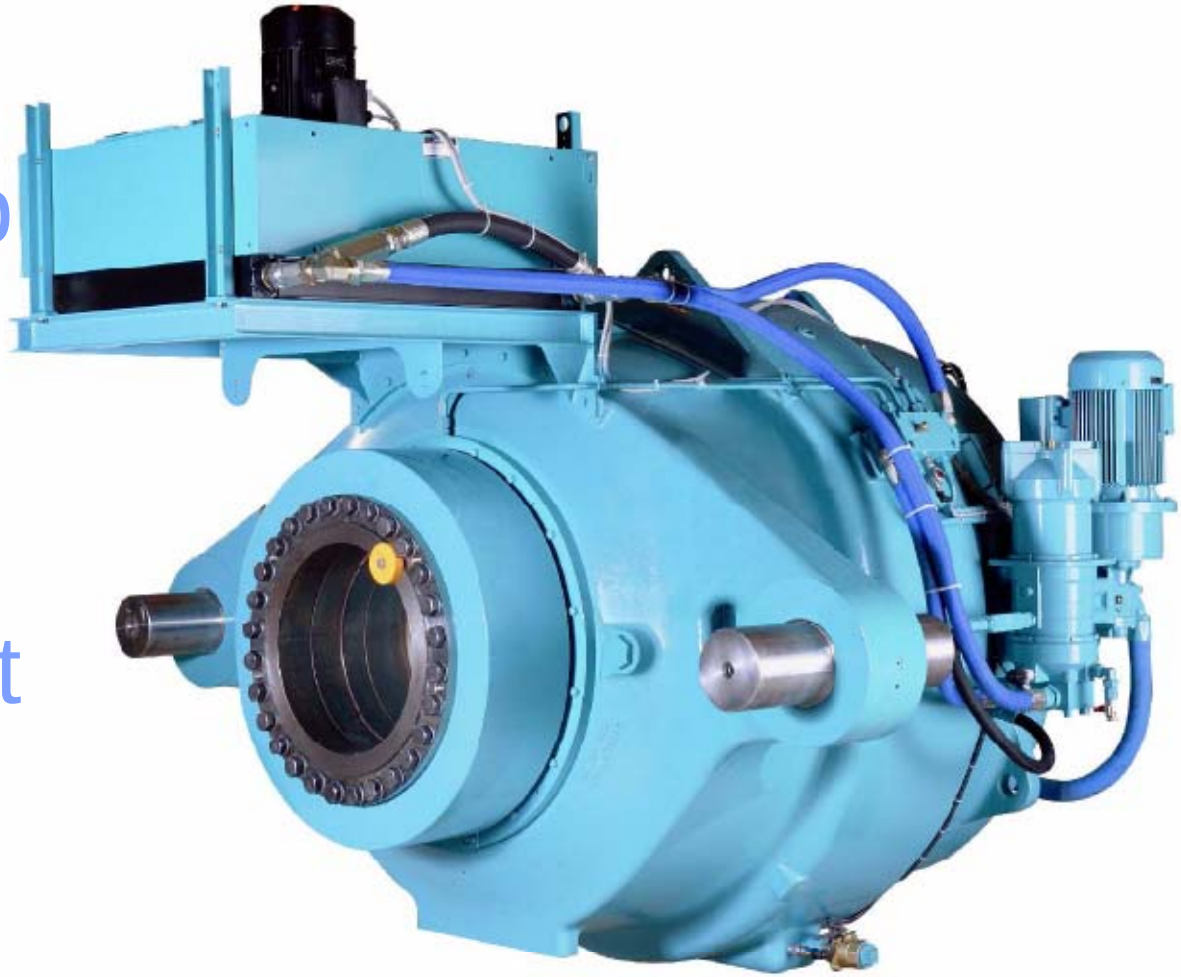
Work → Friction → Heat

Friction → Wear

Need for Lubrication

Lubrication System Requirements

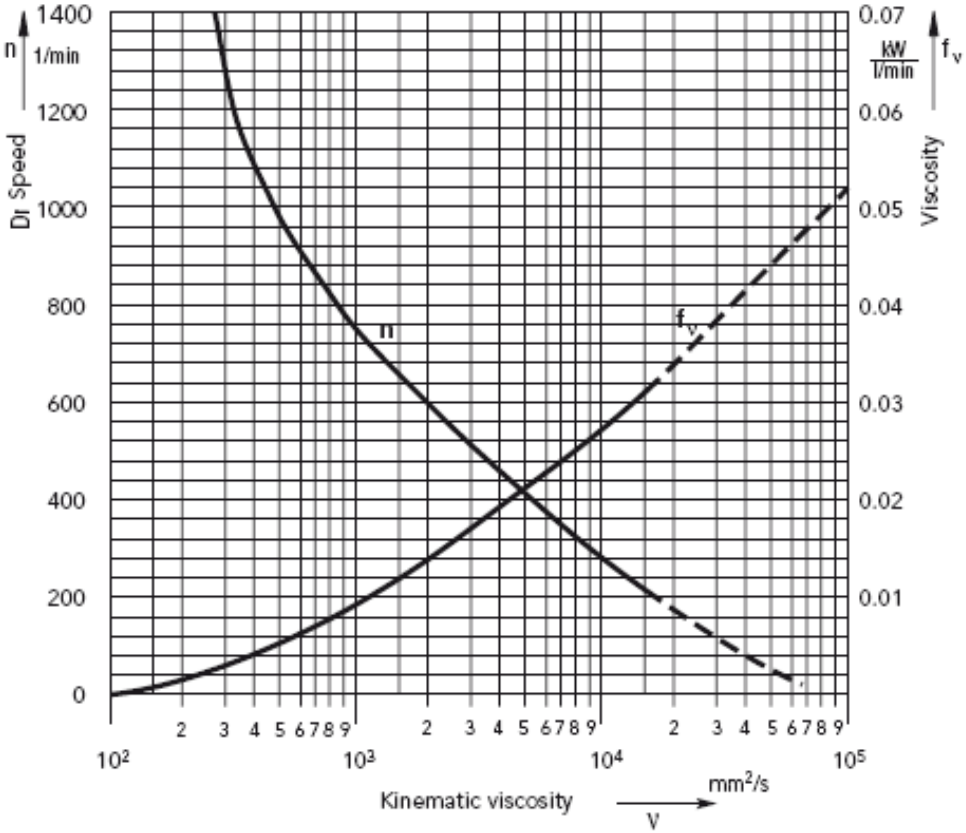
- Flow Rates
- Viscosity / Temp
- Cleanliness
- Efficiency
- Operating Environment



Flow Rates

Q = f(load, speed, gear geometry, oil viscosity)

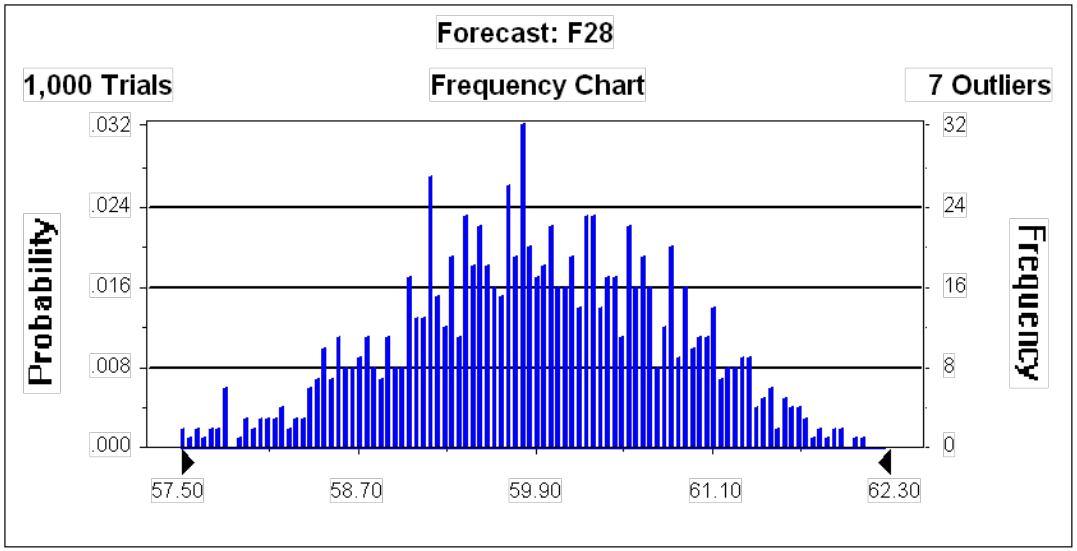
Flow requirements specified at each delivery point.
Determine worst case operating condition to size pump(s).
Don't assume Full Load is worst case!



Check Critical Conditions: Idle, Partial Power, Full Power, & Derated Power

Pump Sizing

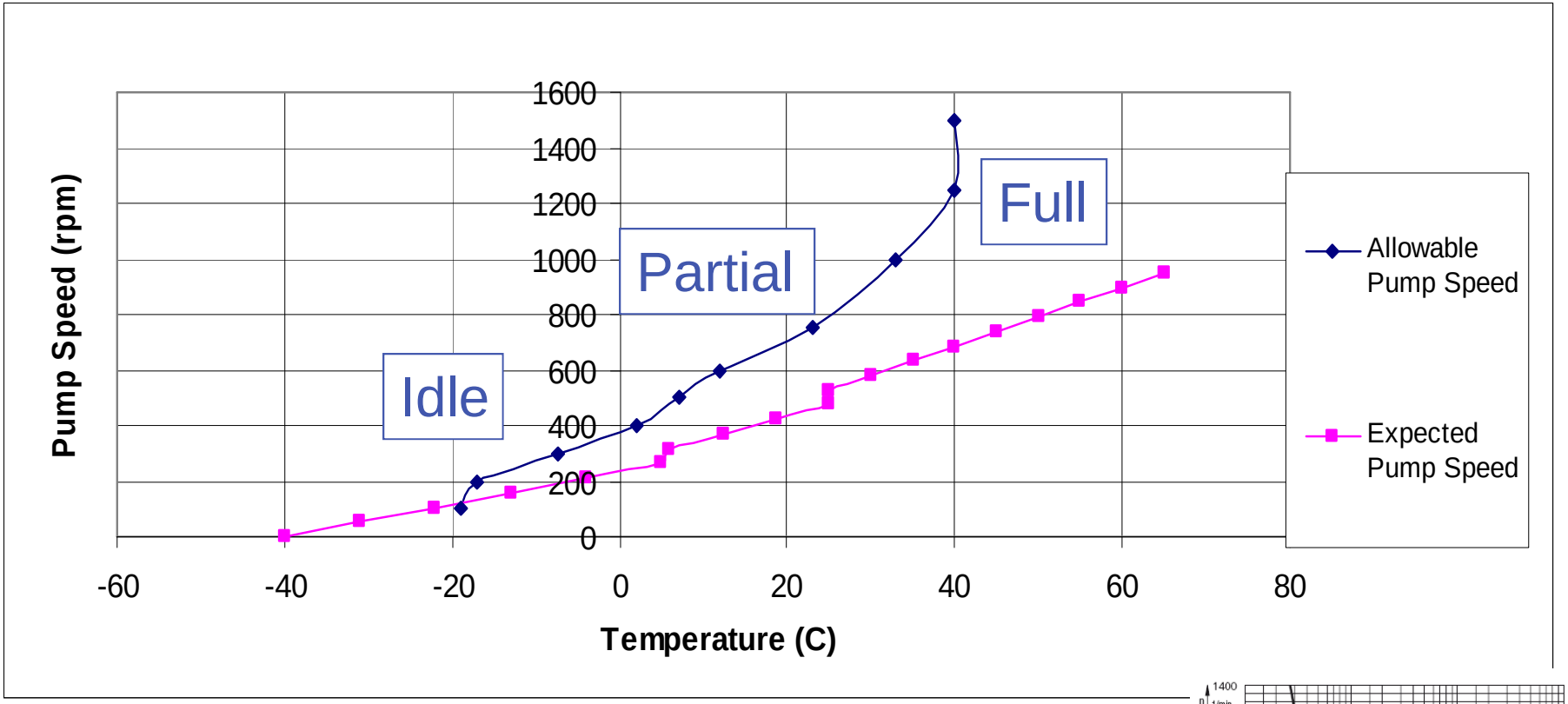
- Flow testing shows actual flow to have a std. dev ~ 5%.
- Pump size is based on six sigma software determining total flow



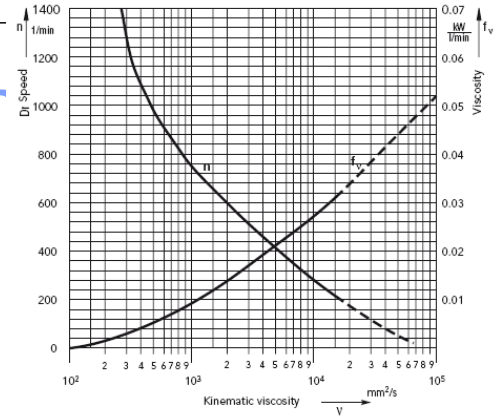
Size pump for 6 Sigma Total Flow

6σ

Expected vs. Allowable Pump Speed



Temp / Visc Consideration



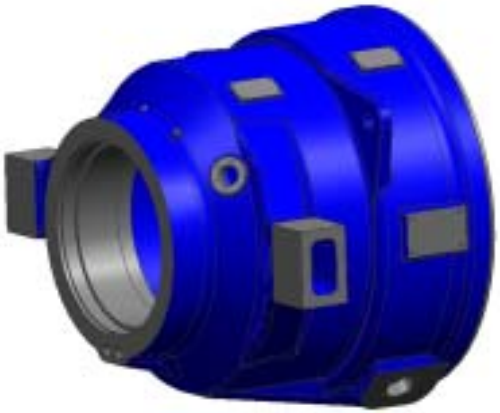
Pipe and Drain Nozzle Sizing

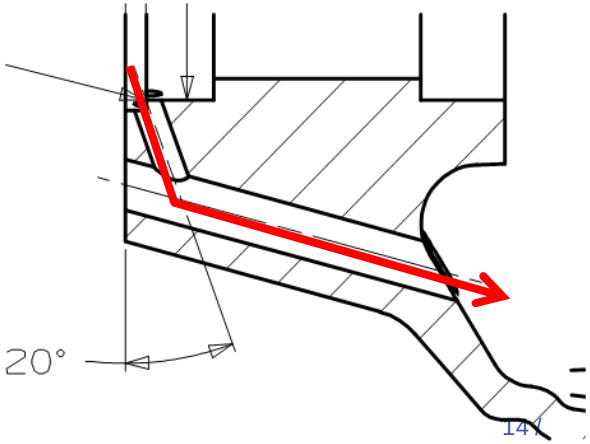
*Pipe Sizing (*Applied Flow Technology Modeling)*:*

- Pressure Drop
- Temp/Viscosity
- Flow Rates

Drain Sizing:

- Worst Case (High Flow, low Visc & Low Flow, High Visc)
- Pressure Drop
- Temp/Viscosity
- Flow Rates

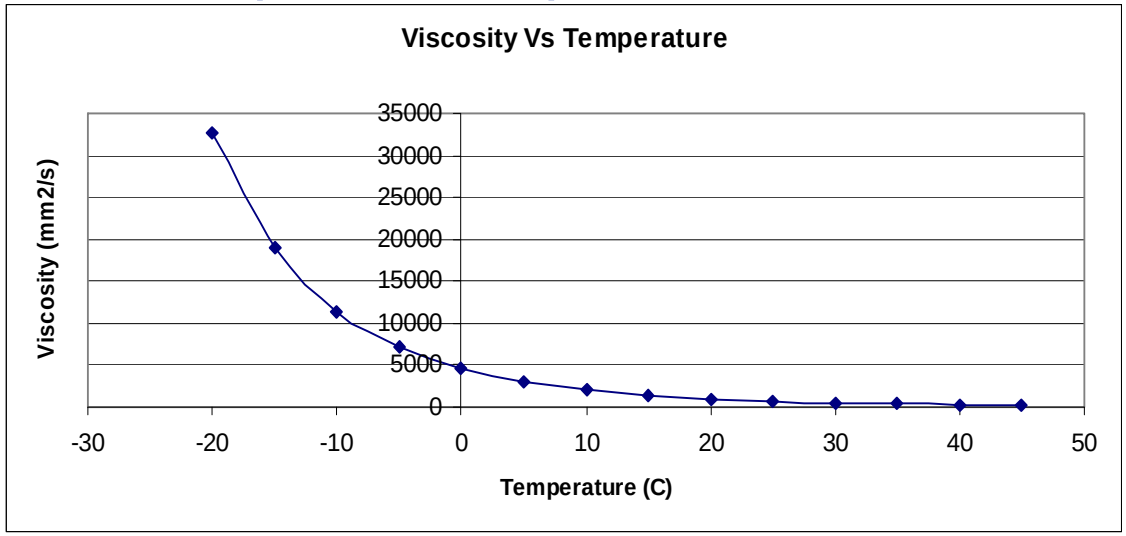




Viscosity / Temperature

Viscosity ∝ 1/T

Visc Properties Dependent on Oil Choice



High viscosity contributes to high churning losses, high pressure drop, and **insufficient flow**

Preferred oil viscosity is dependent on the environmental Temperature range of the application.

Low viscosity causes low film thickness, which **increases wear**.

Heat Exchanger Sizing

Determined By:

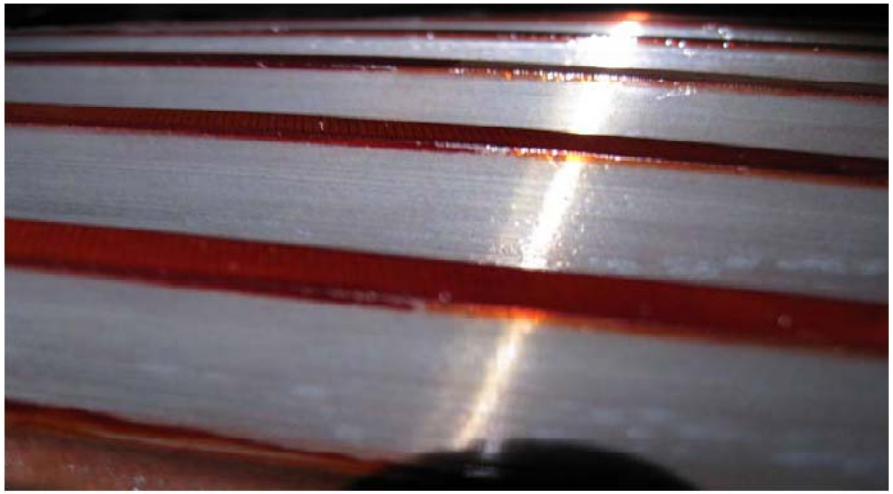
- Environmental Conditions - ambient temp and barometric pressure
- Sump Temperature Limits
- Size of Gearbox (MW)
- Efficiency
- Heat Exchanger Fouling

$$C[kw/K] = \frac{\left(\dfrac{losses}{fouling \cdot altitude\ \ factor}\right)}{T_{oil} - T_{amb}}$$

Cleanliness

Gear sets that run with low lambda ratios are particularly susceptible to debris damage.

Result of heavy loads and low speeds



- Debris can be :
  - Introduced during manufacturing & maintenance
  - Ingested through breathers and seals
  - Internally generated

Cleanliness

ISO 4406 Standard: 18/14/11

1300-2500 particles > 4 T
80-160 particles > 6 T
10-20 particles > 14 T
Per Milliliter

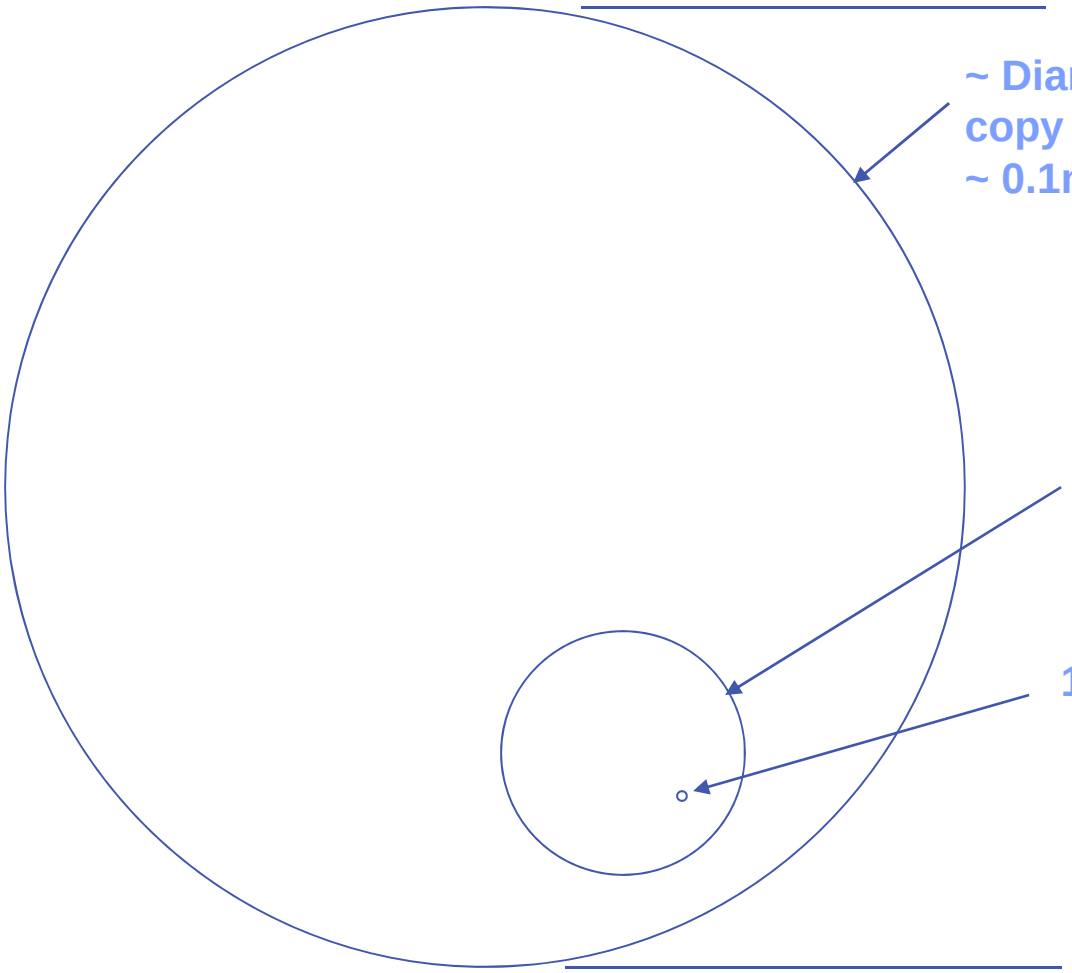
Number of Particles Per Milliliter

ISO 4406 Range Number	Greater Than	Less Than
24	80,000	160,000
23	40,000	80,000
22	20,000	40,000
21	10,000	20,000
20	5,000	10,000
19	2,500	5,000
18	1,300	2,500
17	640	1,300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.3	2.5
7	0.64	1.3
6	0.32	0.64
5	0.16	0.32
4	0.08	0.16
3	0.04	0.08
2	0.02	0.04
1	0.01	0.02

Requirements defined by

- Gear mesh film thickness
- Bearing film thickness
- Required life of the gear set
- Cost and difficulty of gear set replacement
- Defined maintenance cycle

Relative Sizes & Conversion of mils & microns



~ Diameter of human hair, thickness of copy paper
~ 0.1mm = 100 microns = .004 inch

1 mil = .001 inch = 25.4 microns

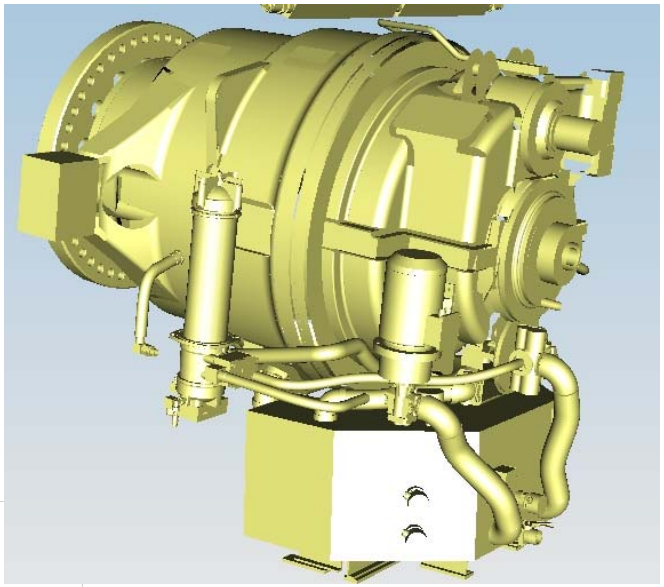
1 micron = 1 Tm = 1e-6 meters = .001 mm

Film thickness on low speed wind bearings ~ 0.15 micro

Efficiency

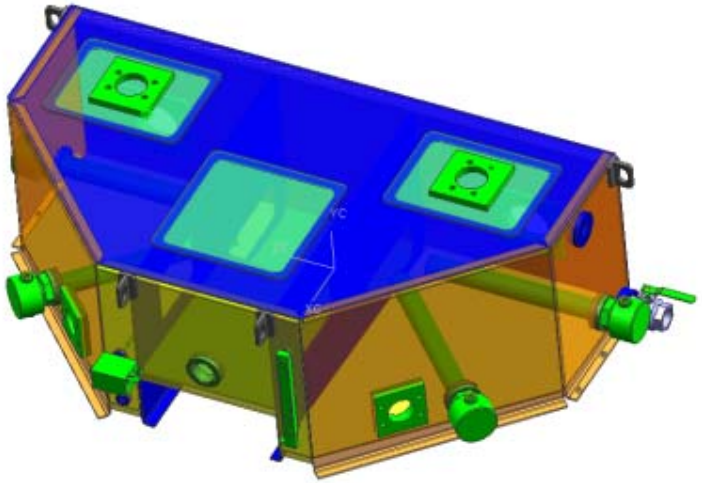
Wet Sump

Dry (External) Sump



Dry (Integrated) Sump

Sump Sizing



Methods for the sump volume calculations

1. Sump Volume = Volume in system + wetted gearbox + minimum required to keep heaters submerged

2. AGMA 6006 definition for minimum oil

   V min (liters) = P(kW)x0.15+20

3. GE definition for minimum oil = P (kW) x16/100x1.1

Operating Environment

-30C to +45 C

Extreme Conditions

Survivability Requirement at -40°C
Cold Start Requirement at -30°C

- Heaters in Sump
- External heater blanket applied to pump and suction line
- Heaters on motor coils on pump and fan.

$$Warm\ up\ time = \frac{mCp\left(T_{amb} - StartTemp\right)}{Heater\ Power}$$

Major Components of Lube System

Dissipating Heat

Oil Flow → Pumps & Lines

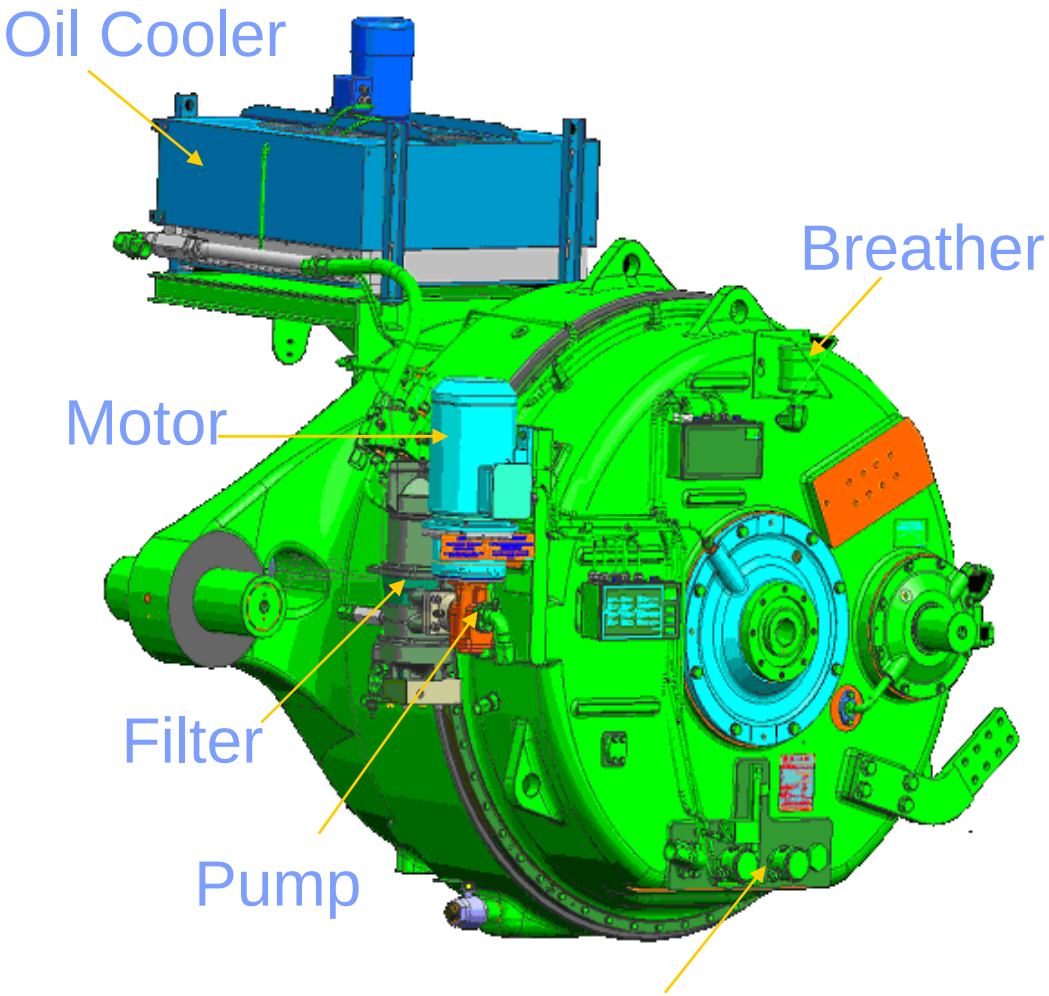
Preventing Wear

Clean Oil → Filter

Proper Visc → Heaters & Oil Cooler

Operating Env

Exp / Contr from Temp Changes → Breather



Systems Level Testing

Cold Chamber

Lube System Flow Rate

Tilt Stand Test

Run-In Test

Bucket Testing

Simulated gearbox structure imitates the geometry of the nozzle and pump position

Measure the oil flow rate of nozzles at various oil temperatures to validate flow design

Cleanliness Validation

Cleanliness Validation

ISO Code 4406: 18/14/11

- 1300-2500 Particle Count > 4T
- 80 – 160 Particle Count > 6T
- 10 – 20 Particle Count > 14T / mL

Flushing Procedure:

- Filtered, Heated and Circulated from gearbox to off board filter station until ISO 4406: 18/14/11 is achieved or at least 1 hr

- Gearbox rotated slowly while oil is circulated to the off board filter station to ensure all gears are wetted for cleaning until ISO 4406: 18/14/11 is achieved or at least 1 hour.

Cleanliness Validation

Cleanliness Validation

ISO Code 4406: 18/14/11

- 1300-2500 Particle Count > 4T
- 80 – 160 Particle Count > 6T
- 10 – 20 Particle Count > 14T / mL

Gearbox Production Test:

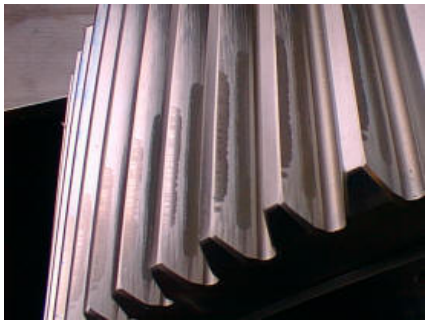
- Filtered with ON board filter and pump until ISO 4406: 18/14/11 is achieved.
- Gearbox loaded 100%
- Debris generated – possible damage

http://www.gastops.com/MetalSCAN.html#4

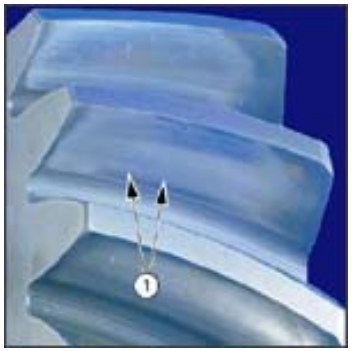
Run-In

Gear & Bearing Failure Modes

Scuffing



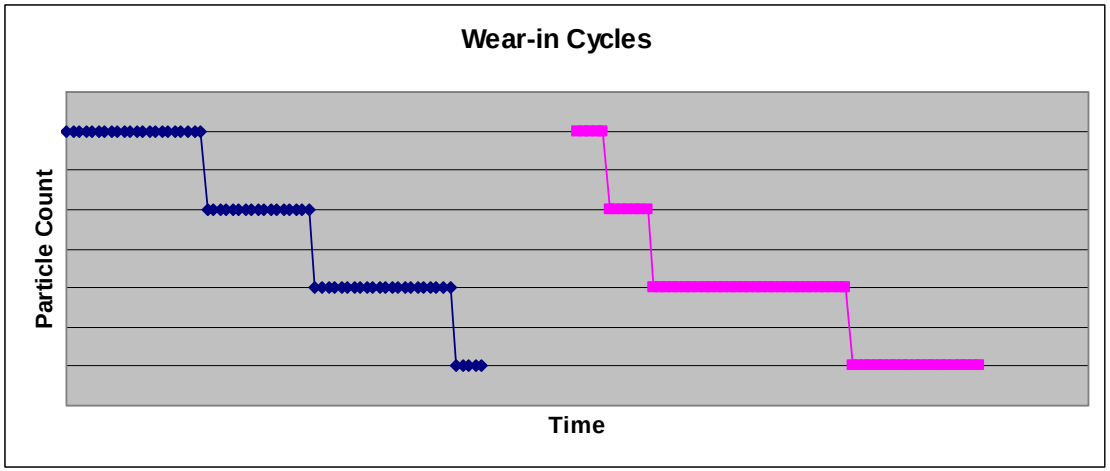
Micropitting (may lead to macropitting)



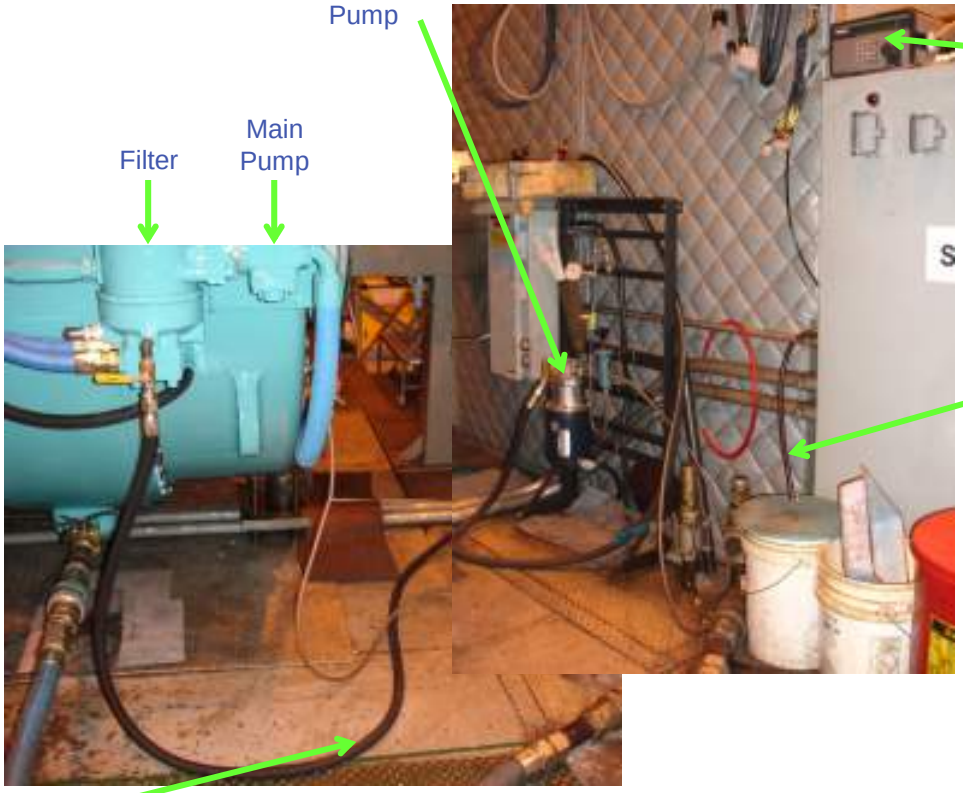
Risk Reduction Method

Run-in the gearbox, starting at low power level and increment, running for specified time

- Improve surface finish
- Improves Σ ratio



Run-In Test Set Up



Pre-filtered oil taken from gearbox and sent to particle counter.

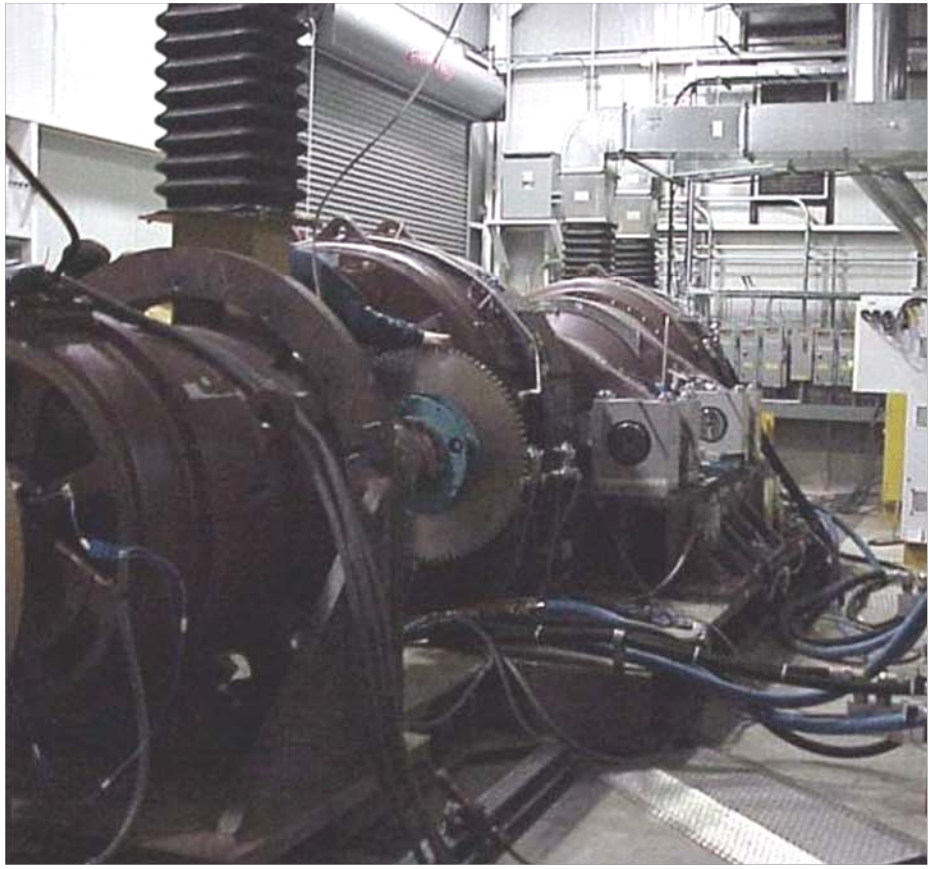
** Oil from the particle counter was not returned to the gearbox in order to prevent introducing more particles to the system.

Tilt Stand and CWE Testing

- Lubrication test to ensure bearings and gear teeth are properly lubricated
- Monitoring wave behavior of oil level in sight glass
- Functionality test of the oil level switch
- Oil tightness test to ensure lubrication system is free of oil leaks

Performed while the input side of the gearbox is inclined at an angle of 4° above horizontal

HALT "graduation" test



Simulates 20 yr life on gearing

- Loads increased to decrease total test time
- 3x and 2x overloads
- Run on dedicated engineering test stand

Monitoring

- Bearing and oil temperatures
- Oil pressures
- Stresses in critical components
- Power, torque, and speed
- Gear wear patterns
- Particle count

Capability

- 2.5 MW @1440 rpm continuous

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DriveTrain Description

Industry Trends

Lubrication System Design

Manufacturing

Validation