Machine Condition Monitoring

and

Fault Diagnostics

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Course Overview

- Introduction to Machine Condition Monitoring and Condition Based Maintenance
- Basics of Mechanical Vibrations
- Vibration Transducers
- Vibration Signal Measurement and Display
- Machine Vibration Standards and Acceptance Limits (Condition Monitoring)
- Vibration Signal Frequency Analysis (FFT)

Course Overview

- Machinery Vibration Testing and Trouble Shooting
- Fault Diagnostics Based on Forcing Functions
- Fault Diagnostics Based on Specific Machine Components
- Fault Diagnostics Based on Specific Machine Types
- Automatic Diagnostic Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods

Current Topic

- Machinery Vibration Testing and Trouble Shooting
- Fault Diagnostics Based on Forcing Functions
- Fault Diagnostics Based on Specific Machine Components
- Fault Diagnostics Based on Specific Machine Types
- Automatic Diagnostic Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods

Wear Particle Analysis

Contamination

Particle Contamination

- Damage depends on particle size, shape, hardness and chemistry
- Particles enter from vents and breathers, ineffective or damaged seals, new oil, filters that are full, damaged or deffective

Contamination

Particle Contamination – Effect on Oil

- Alter oxidation rate
- Strip oil of additives
- Increase oil viscosity (many small particles in suspension)

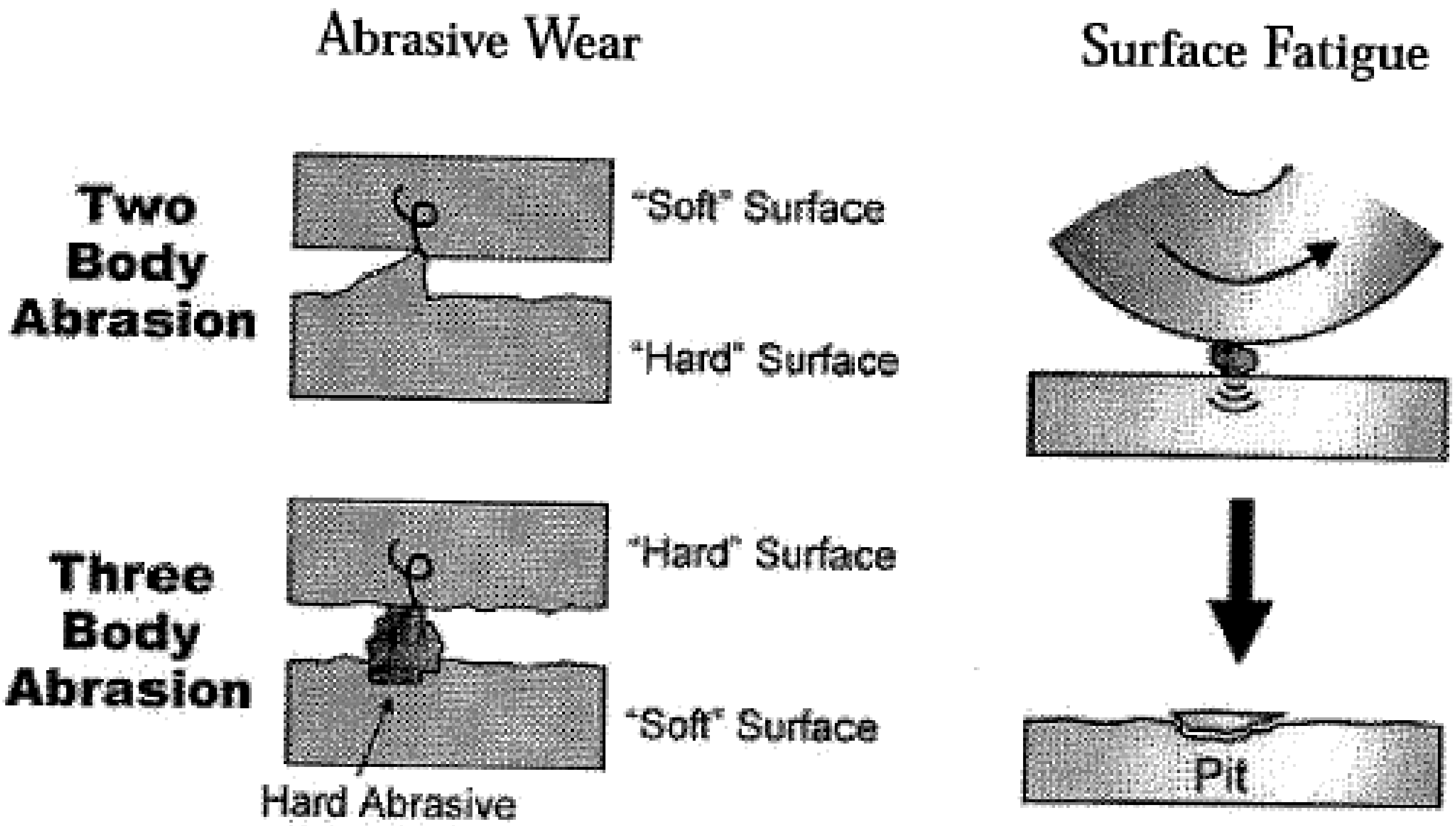
Contamination

Particle Contamination – Effect on Machine

- Increase wear rates
- Reduce oil film thickness
- Damage or cut away component material
- Increase local loads between mating surfaces
- Cause erosive wear (at high velocity)

Contamination

Particle Contamination – Effect on Machine



Contamination Control

Controlling Particle Contamination - Filters

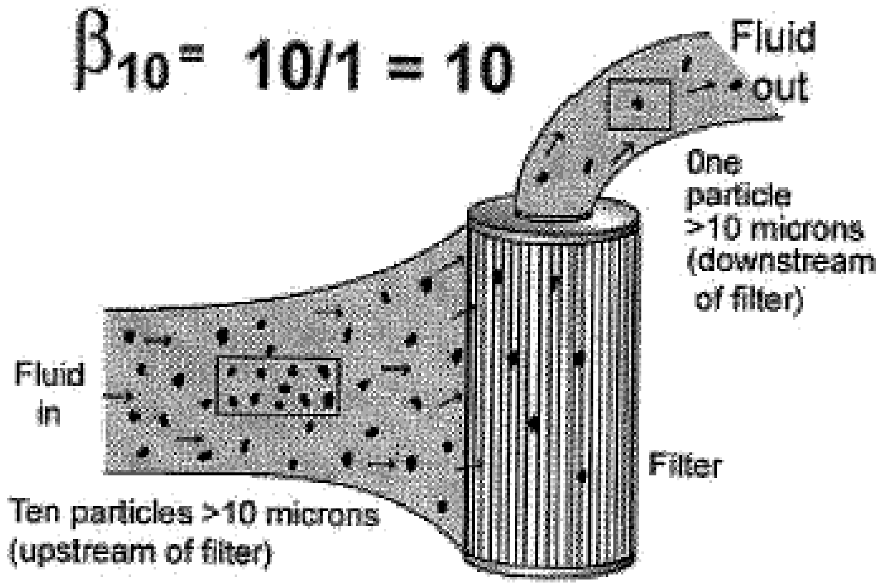
- Filter stability over time (temperature, pressure fluctuations, vibrations)
- Filter capacity (amount of contaminant filter can remove)
- Filter efficiency

Contamination Control

Controlling Particle Contamination - Filters

$$\beta_x = \frac{\text{No. of particles greater than X microns upstream}}{\text{No. of particles greater than X microns downstream}}$$

$$\beta_{10} = 10/1 = 10$$



$$\%\ \text{Efficiency} = \frac{\beta - 1}{\beta} \times 100$$

Contamination Control

Particle Separation Methods

- Cellulose fiber media filters – good for larger particles
- Micro-fiberglass media filters – superior to cellulose fiber filters
- Centrifugal separators
- Electro-static separators

Wear Particle Analysis

Wear Particle Analysis

- good for direct detection, diagnosis, prognosis
- ease of access
- skill requirements high
- care in sampling
- on-line possible

Origins of Particles

Environmental

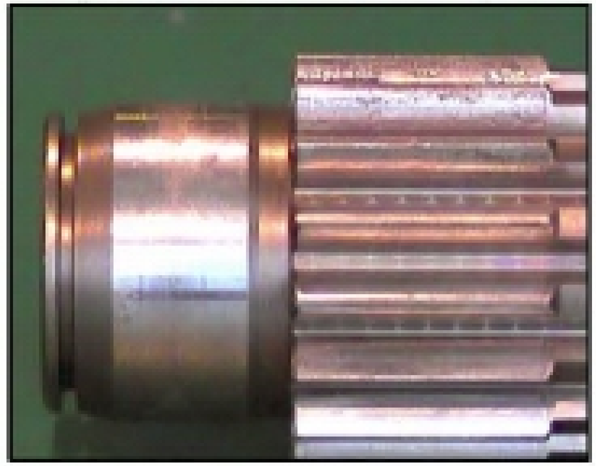
- dust contamination
- moisture contamination
- fumes
- careless maintenance
- improper repairs
- malicious acts
- biological contamination

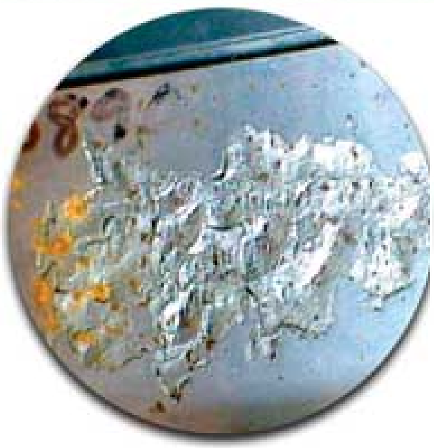
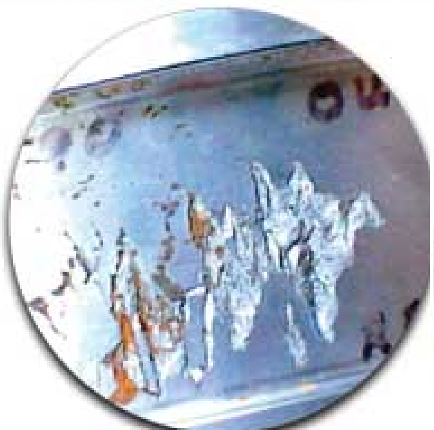
Origin of Particles

Generated Particles

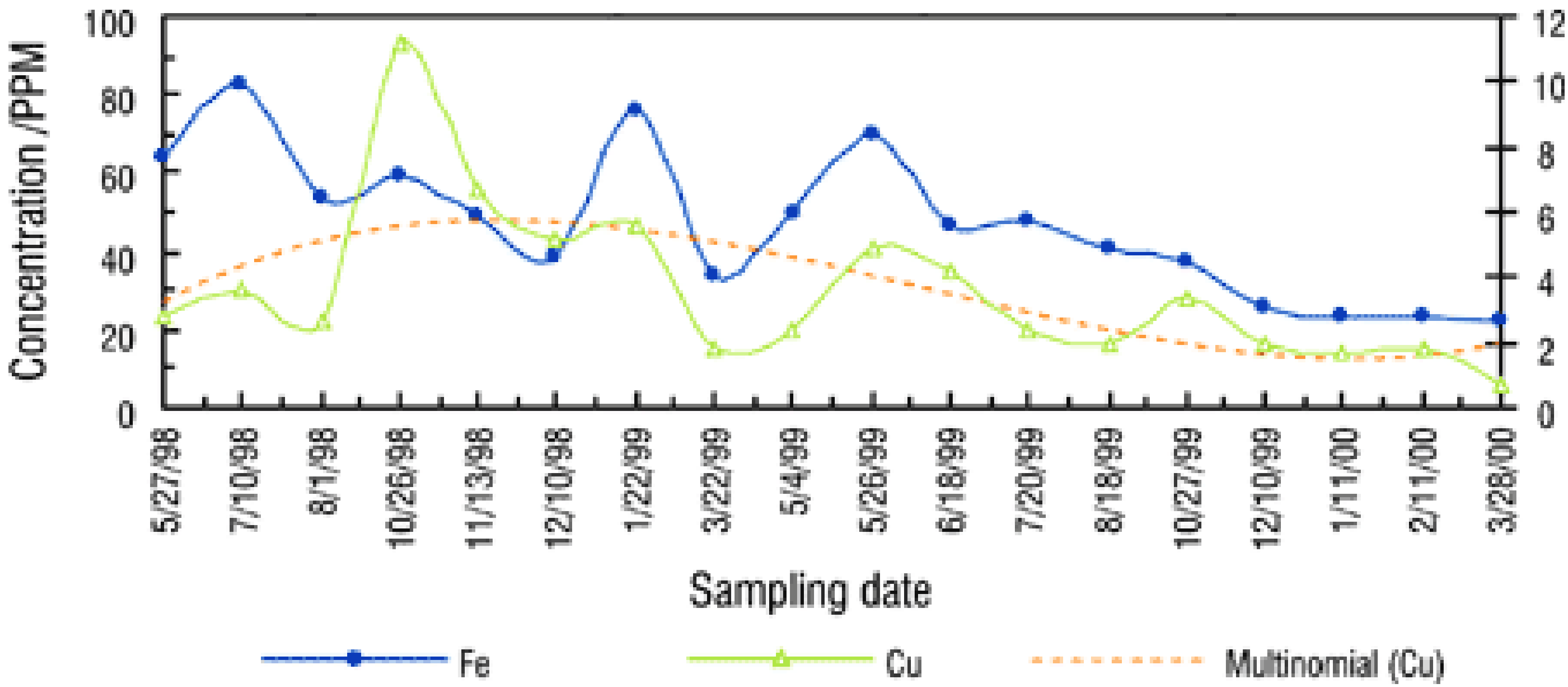
- standard wear modes
- mechanical interference
- material incompatibility
- surface fatigue

Origin of wear particles

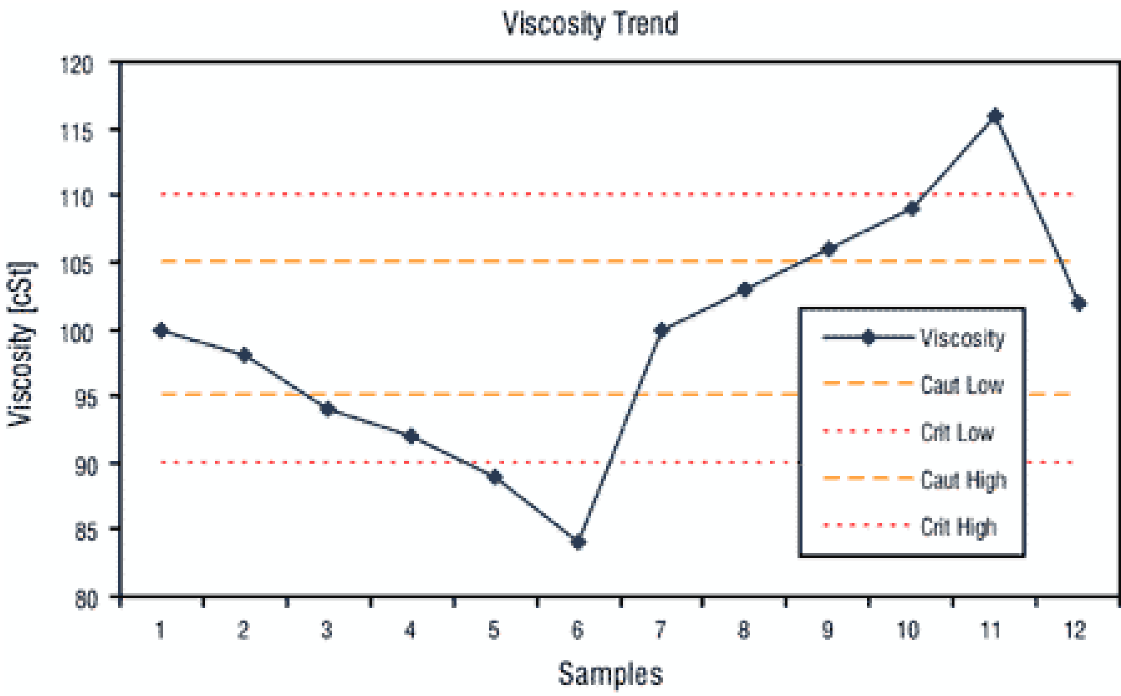



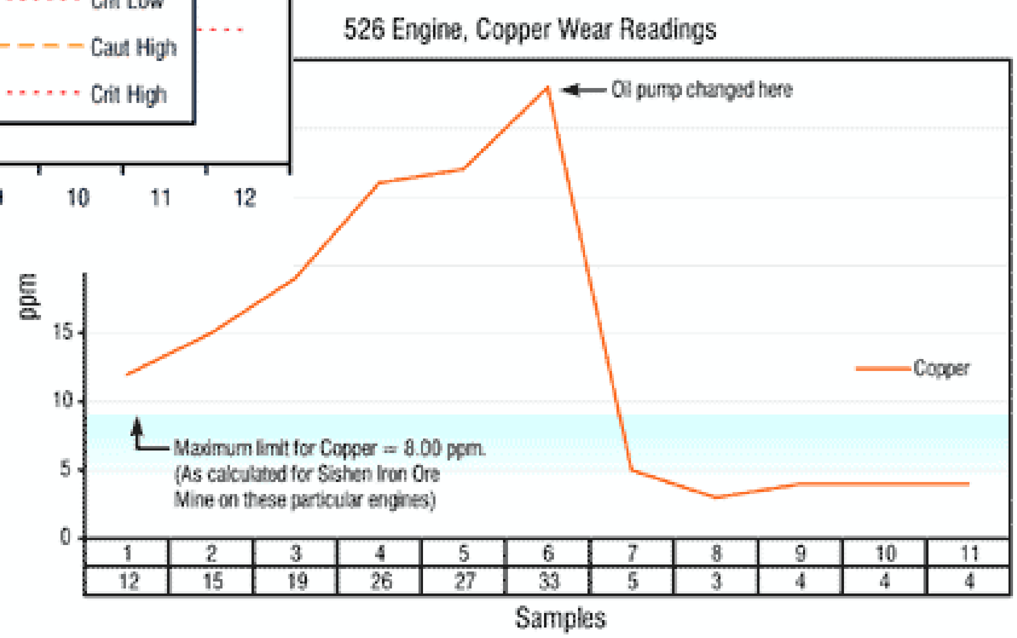
Trending



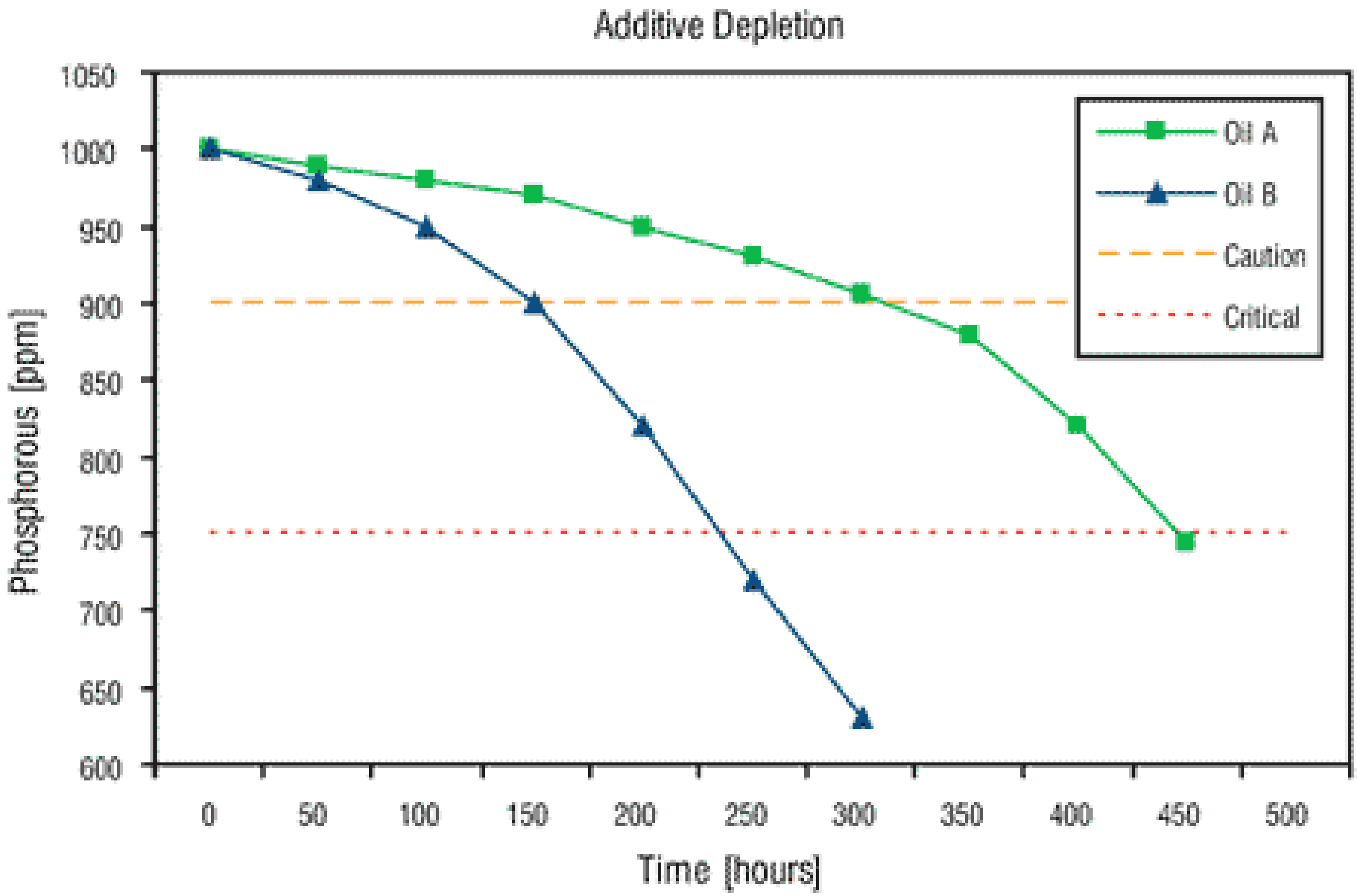
Concentration /PPM
100
80
60
40
20
0
12
10
8
6
4
2
0
5/27/98
7/10/98
8/1/98
10/26/98
11/13/98
12/10/98
1/22/99
3/22/99
5/4/99
5/26/99
6/18/99
7/20/99
8/18/99
10/27/99
12/10/99
1/11/00
2/11/00
3/28/00
Sampling date
Fe
Cu
Multinomial (Cu)

Trending using Wear Particles

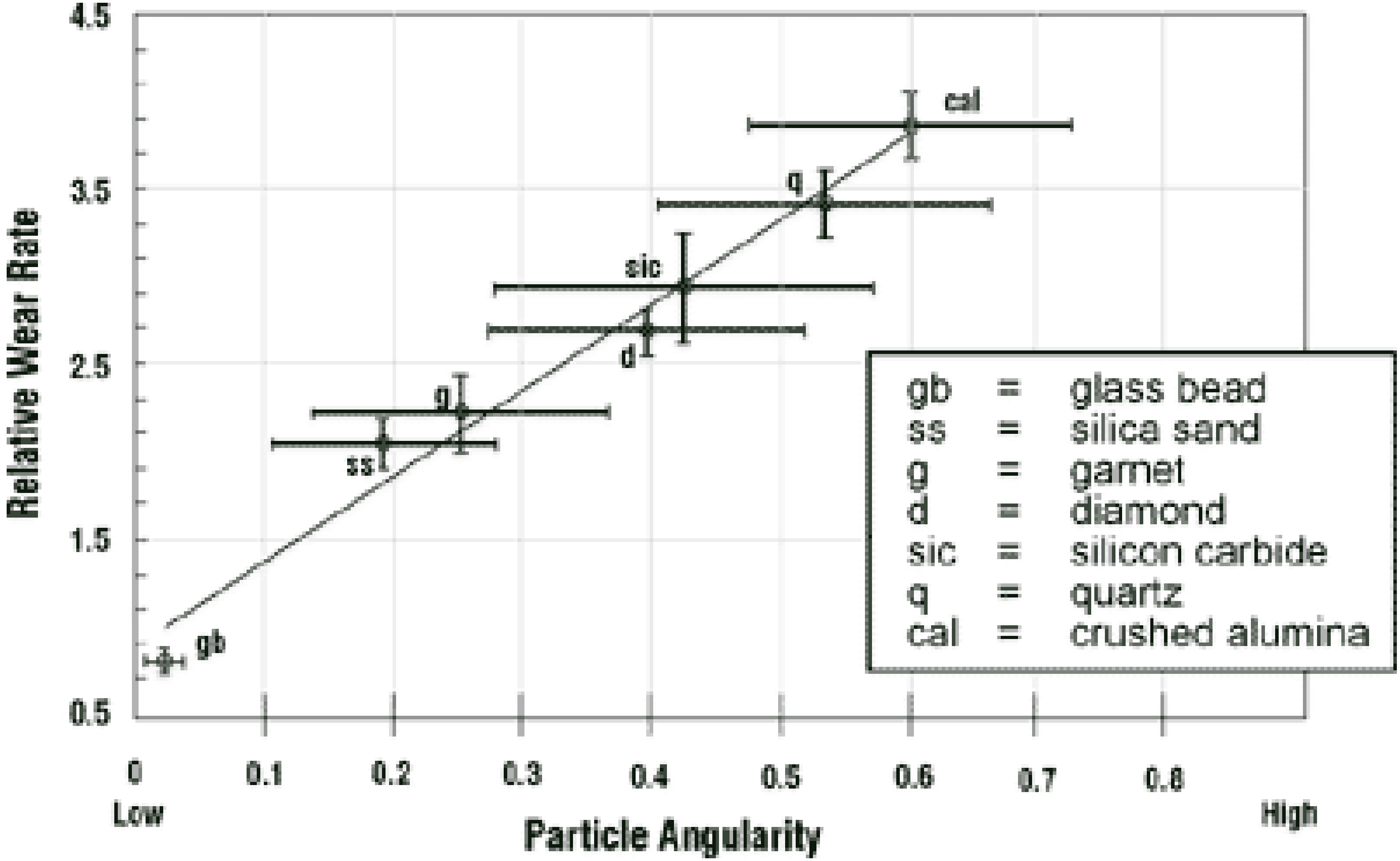




Trending using Wear Particles



Wear Rate vs. Particle Angularity

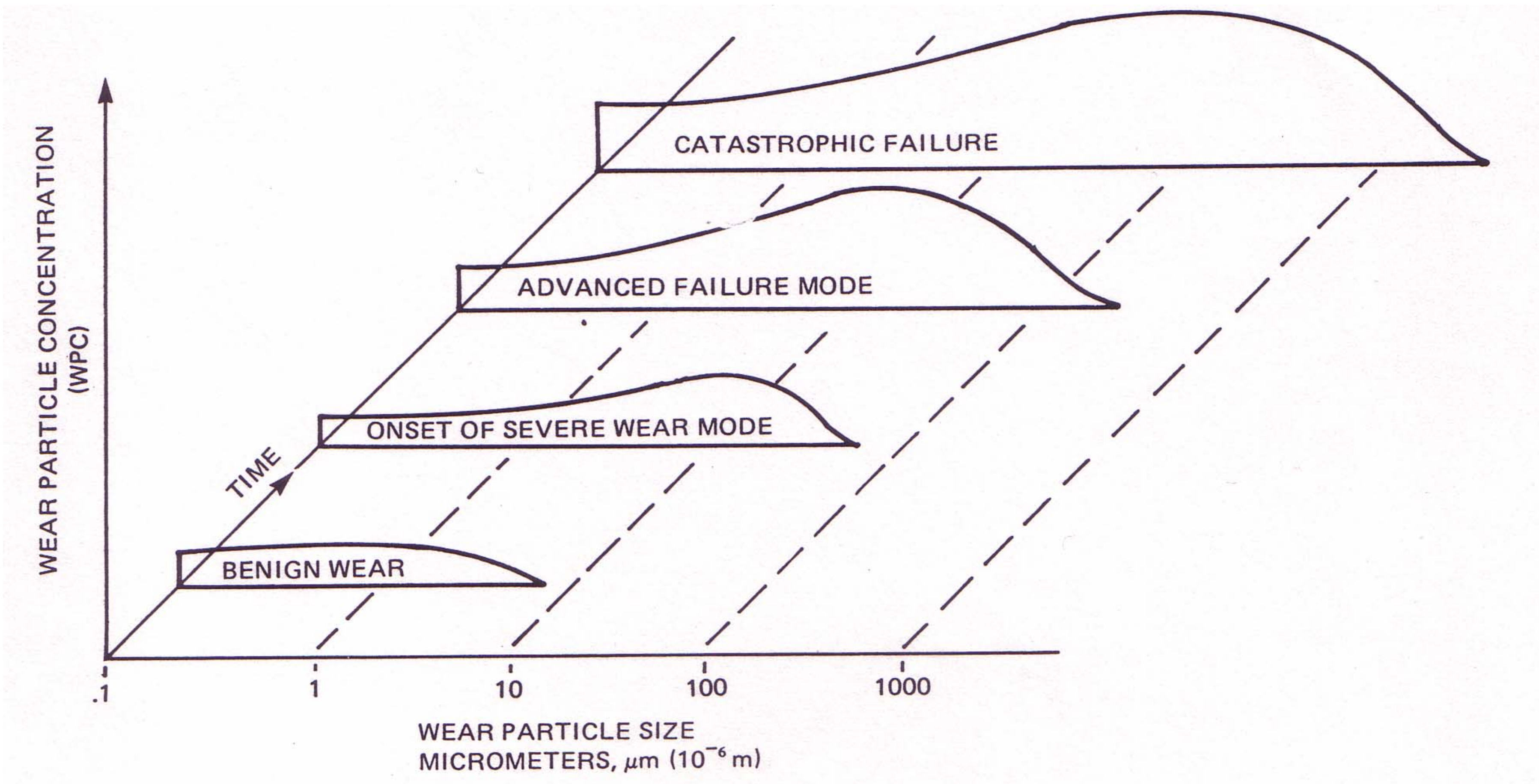


Wear and Contamination Particles

ISO 4406 (1999) oil cleanliness coding

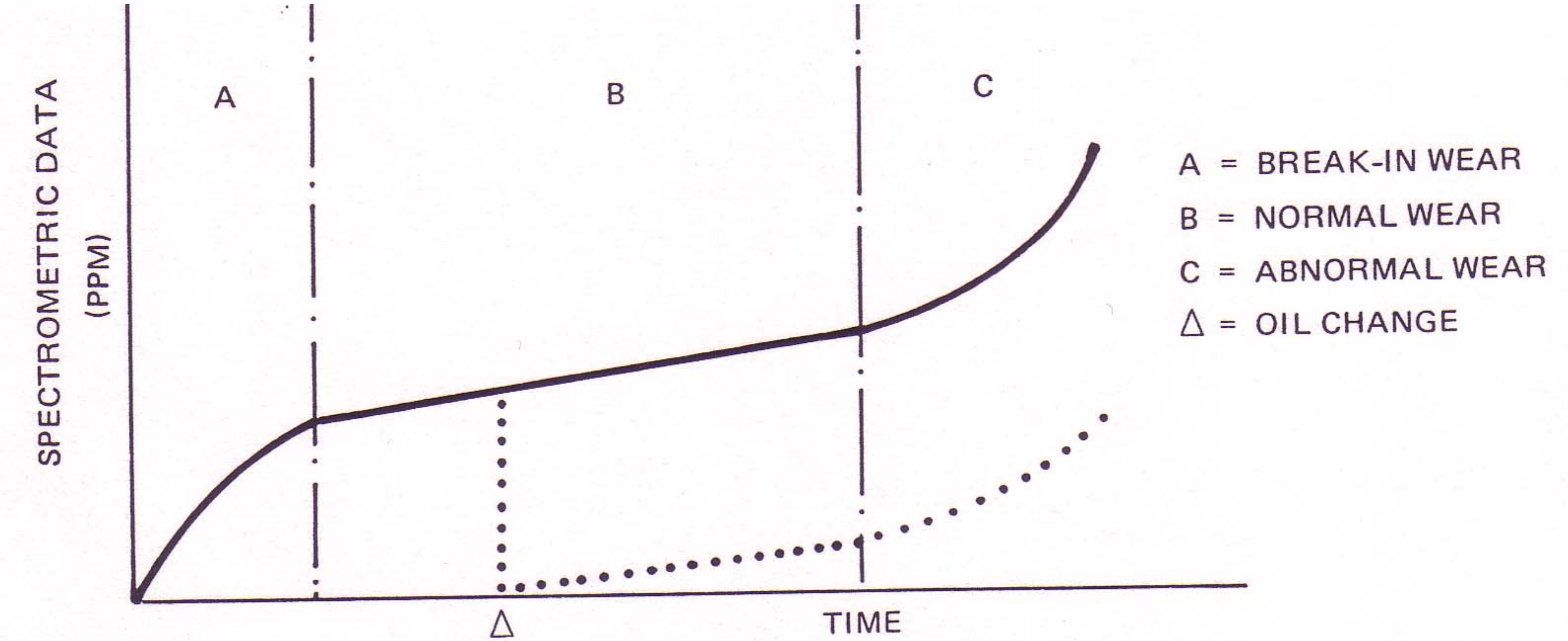
Particles per ml		
> than	*< than*	*Number*
80 000	160 000	24
40 000	80 000	23
20 000	40 000	22
10 000	20 000	21
5000	10 000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1

Wear and Contamination Particles



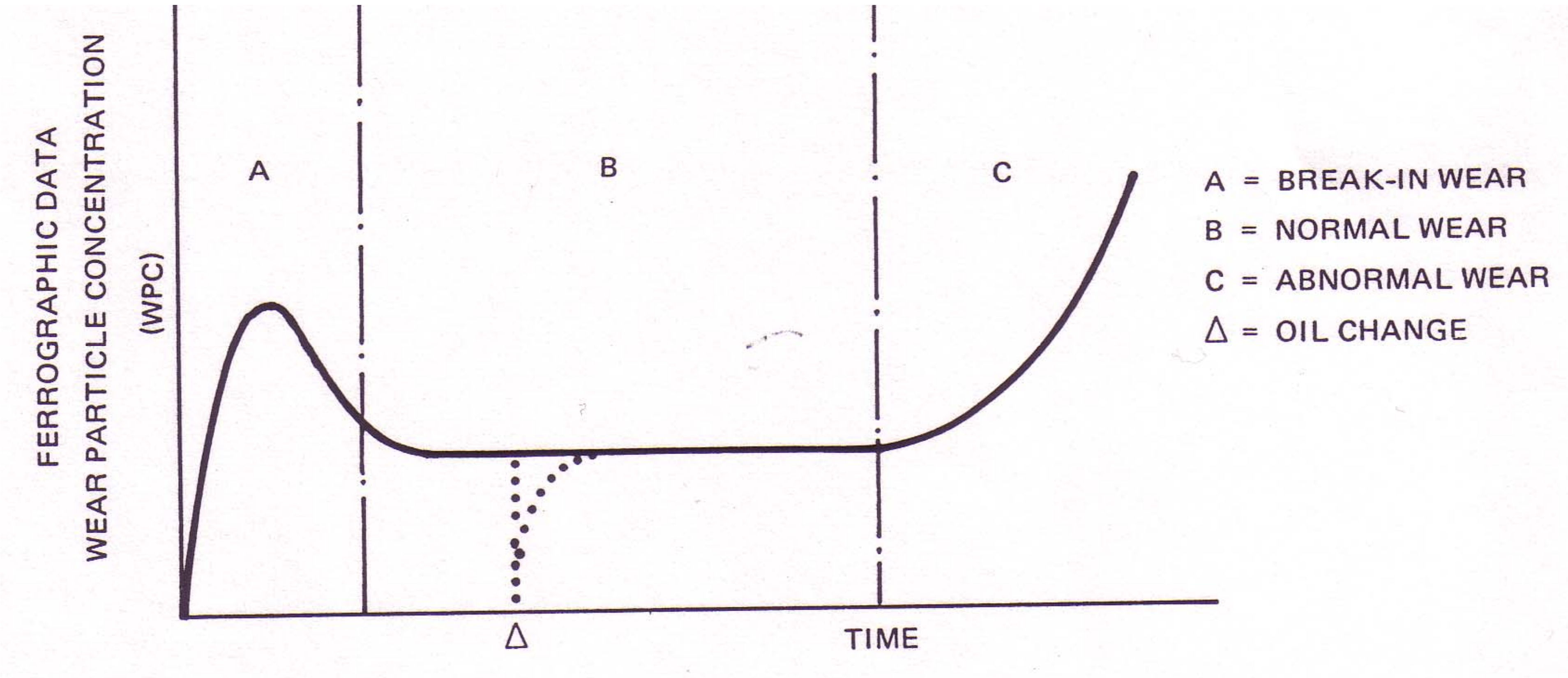
Typical progression of wear particle generation

Wear and Contamination Particles



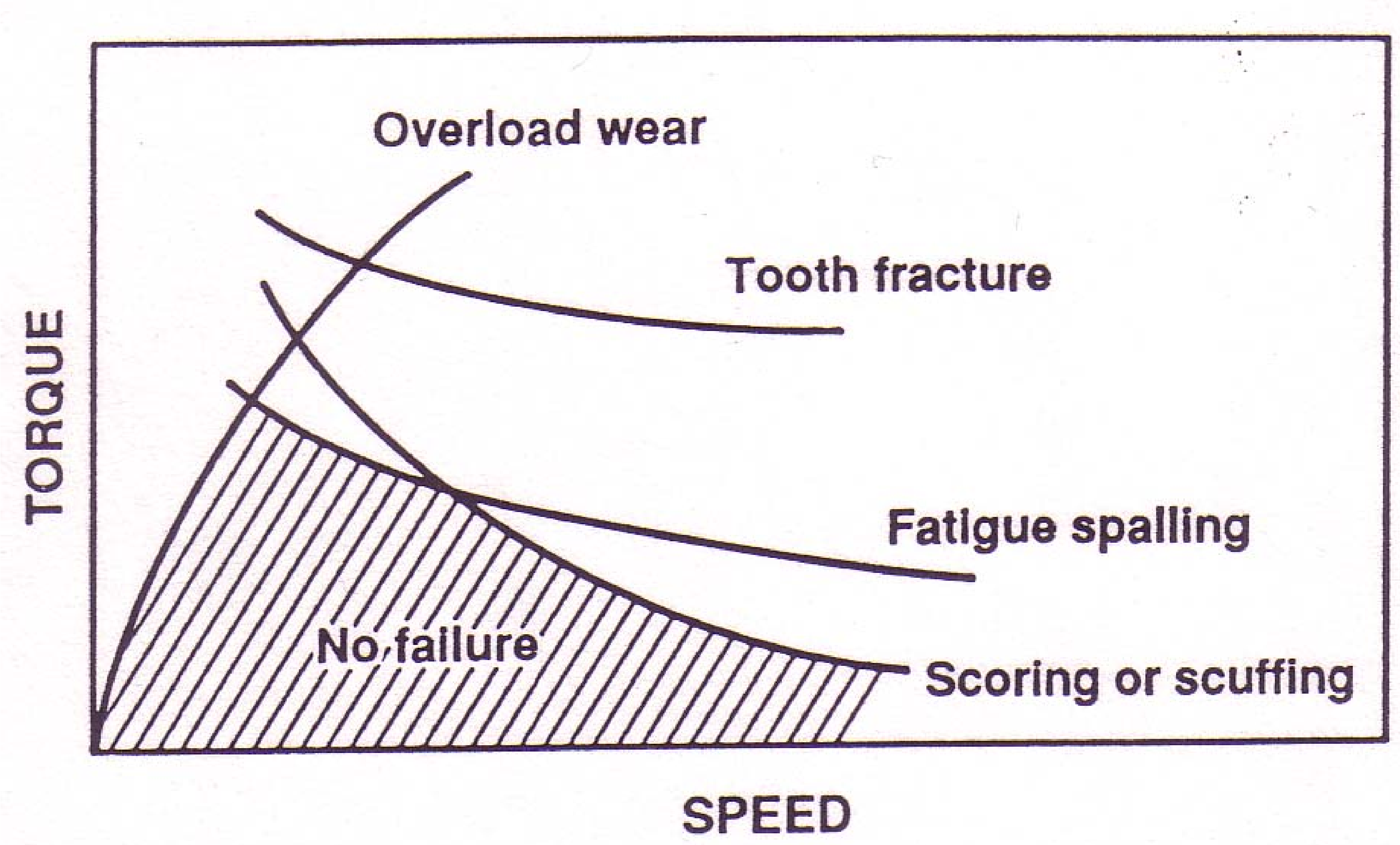
Typical wear particle generation profile for **small** particles

Wear and Contamination Particles



Typical wear particle generation profile for **large** particles

Wear Particle Generation



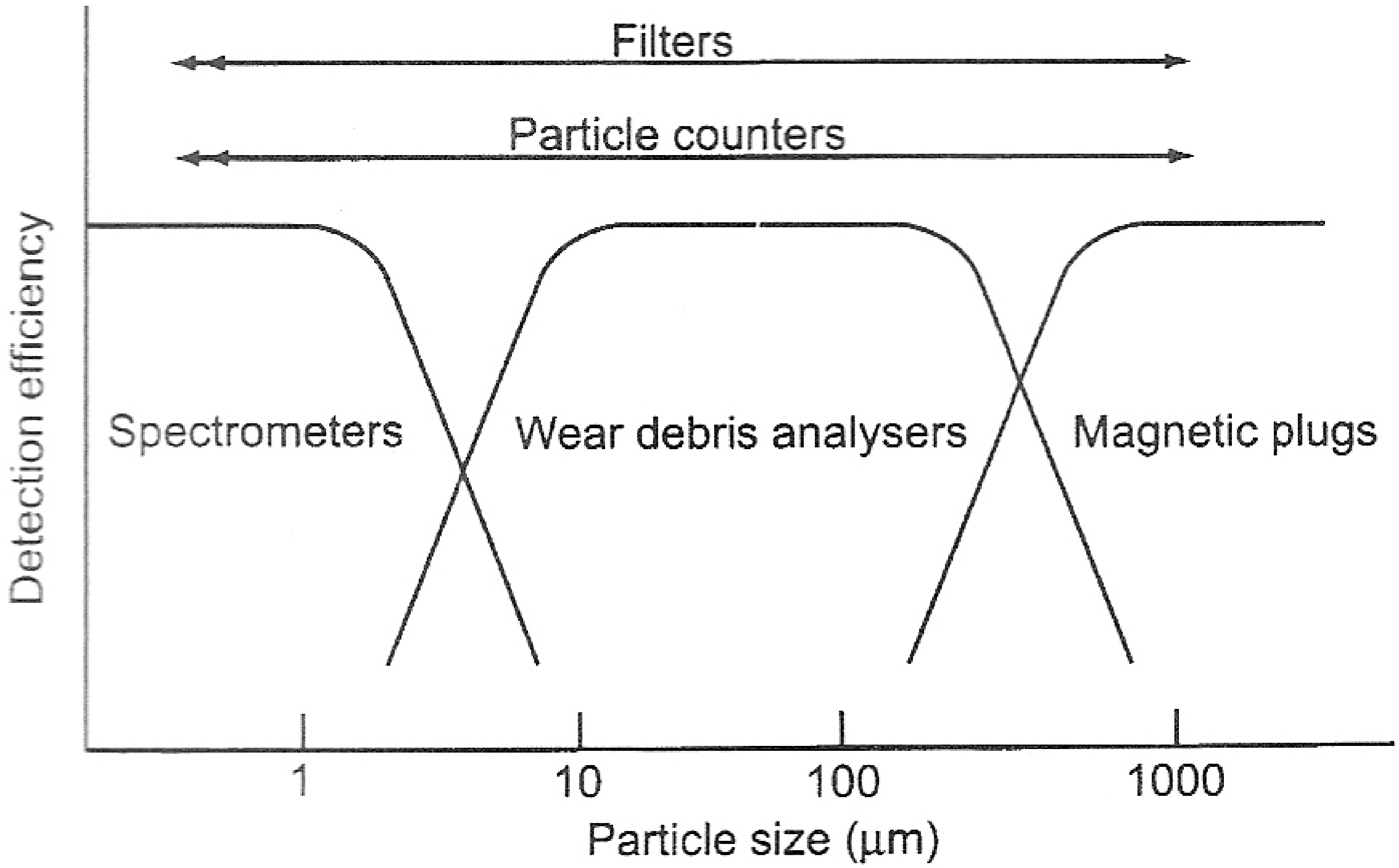
Gear system operating regimes as a function of speed and load

Oil / Wear Particle Analysis

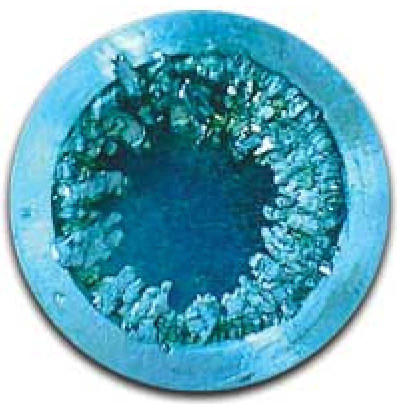
Techniques

- Magnetic plugs - Ferrous only wear particles
- Filters - wear particles and contaminants
- Nephelometer - all particles and mixed fluids
- Lab tests - oil quality, wear and contamination particles and fluids
- Can also be applied to grease

Oil / Wear Particle Analysis

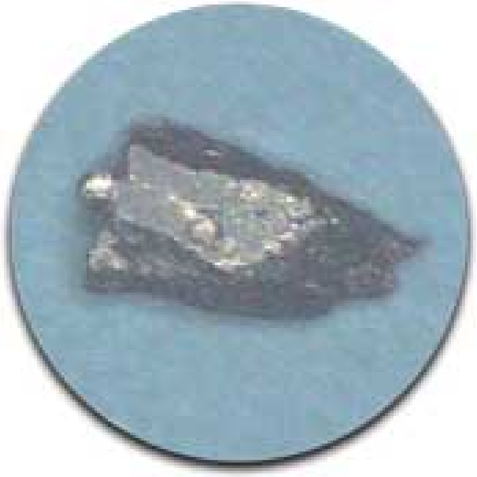


Magnetic Plugs



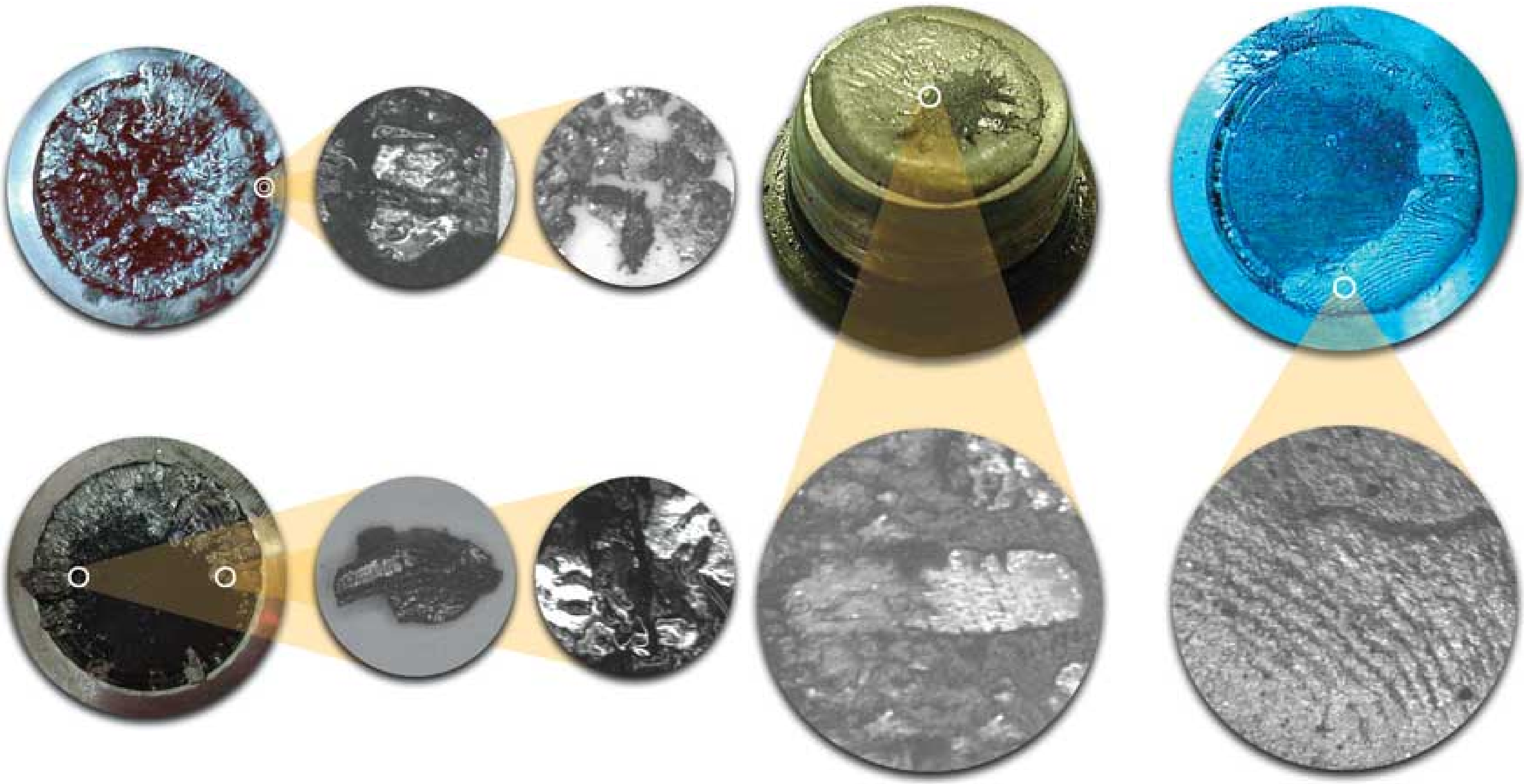
Magnetic Plugs

Chunks



Magnetic Plugs

Chunks, Flakes and Fines



Particle Counting

light / laser blockage

all particles

gives size distributions

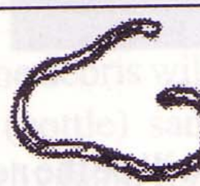
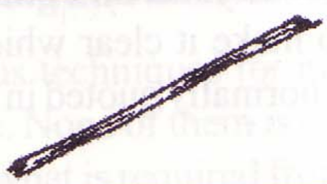
Visual Methods

Analytical Ferrography

- magnetic separation
- ferrous only

Rotary Particle Depositor

- magnetic separation
- ferrous only

Particle shape	*Typical names*	*Some possible origins*
	Spheres	Metal fatigue Welding 'sparks Glass peening beads
	Pebbles and smooth ovoids	Quarry dust Atmospheric dust
	Chunks and Slabs	Metal fatigue Bearing pitting Rock debris
	Platelets and Flakes	Running-in metal wear Paint or rust Copper in grease
	Curls, Spirals and Slivers	Machining debris produced at high temperature
	Rolls	Probably similar to platelets but in a rolled form
	Strands and Fibres	Polymers Cotton and wood fibres Occasionally metal

Analytical Ferrography

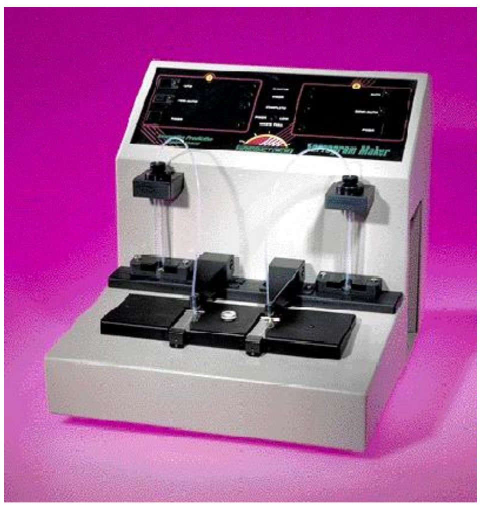
Wear debris image capture system
1) optical microscope with CCD digital camera 2) additional color monitor 3) computer 4) display 5) color printer

- First ferrograph in 1971
- Consisted of a pump, magnet, and a slide

Method	Size range	Quantity	Size Distribution	Morphology	Composition
Spectrometric	<10	✓			
Particle Counting	1 -150	✓	✓		
Magnetic Plug	100 -1000	✓	✓	✓	✓
Ferrograph	1 -100	✓	✓	✓	✓

Analytical Ferrography

Analytical Ferrography can show amounts and sizes of case hardened steel, low alloy steel, and medium alloy steel abnormal gear and bearing wear particles up to 120 microns in size



Ferrogram Maker

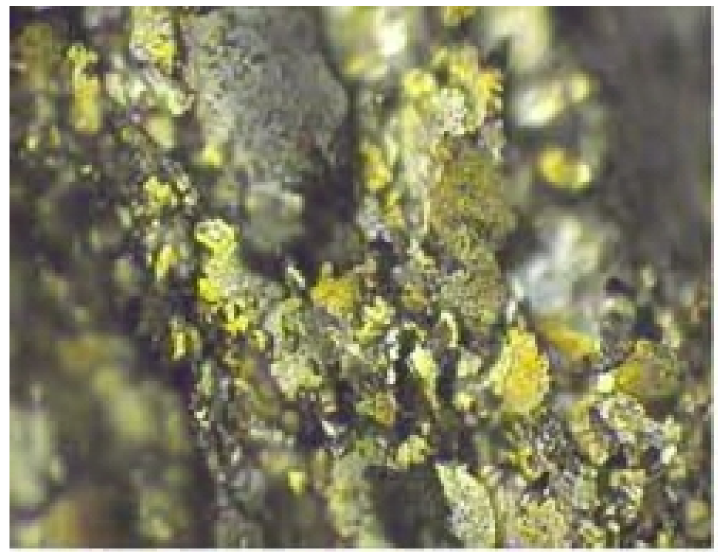


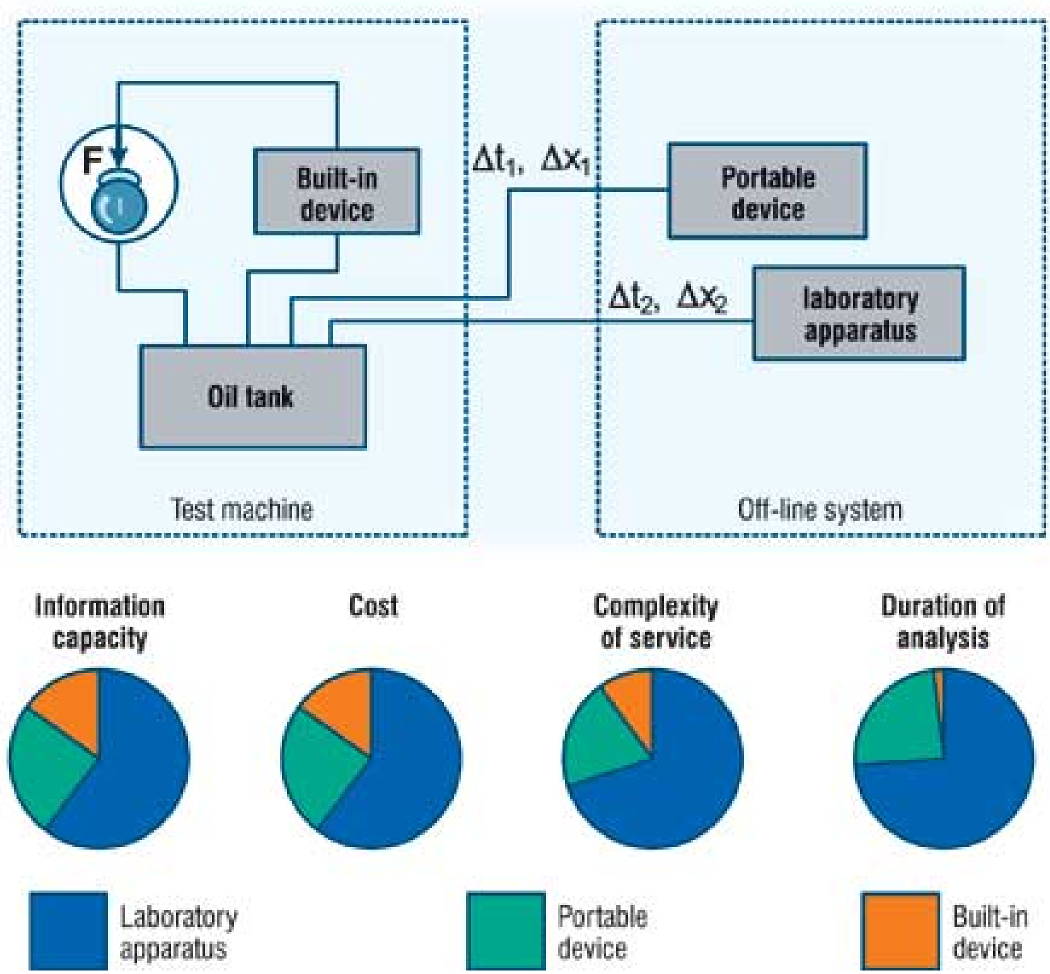
Figure 15: case hardened steel gear and bearing wear particles (120μm max.) 200X

Analytical Ferrography

Wear debris classification:

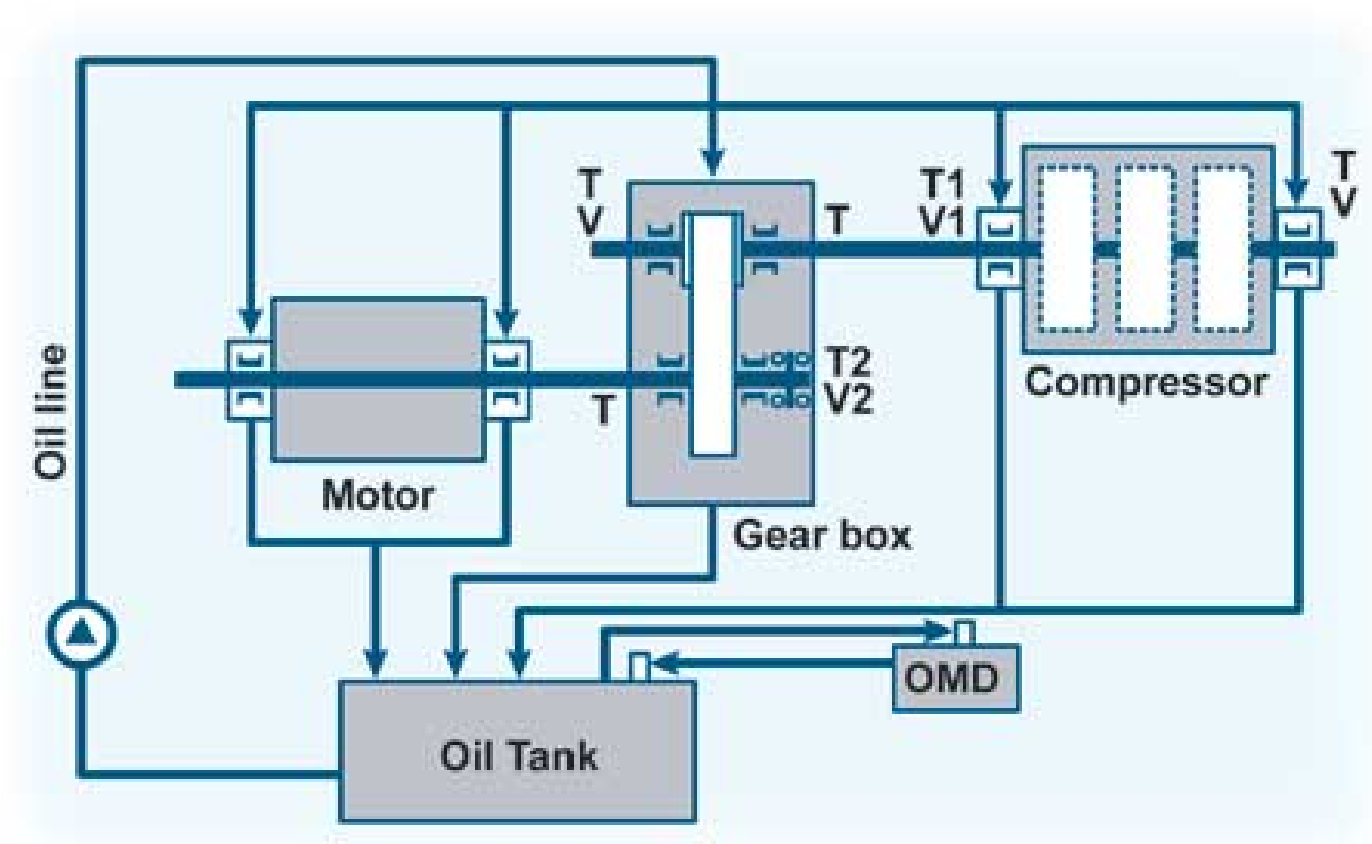
SP – spherical particle;
CT – cutting;
LM – laminar;
FC – fatigue chunk;
SS – severe sliding;
RO – red oxide;
DO – dark oxide;
UN – unrecognized;
ST – steel;
CA – copper alloys

Analytical Ferrography



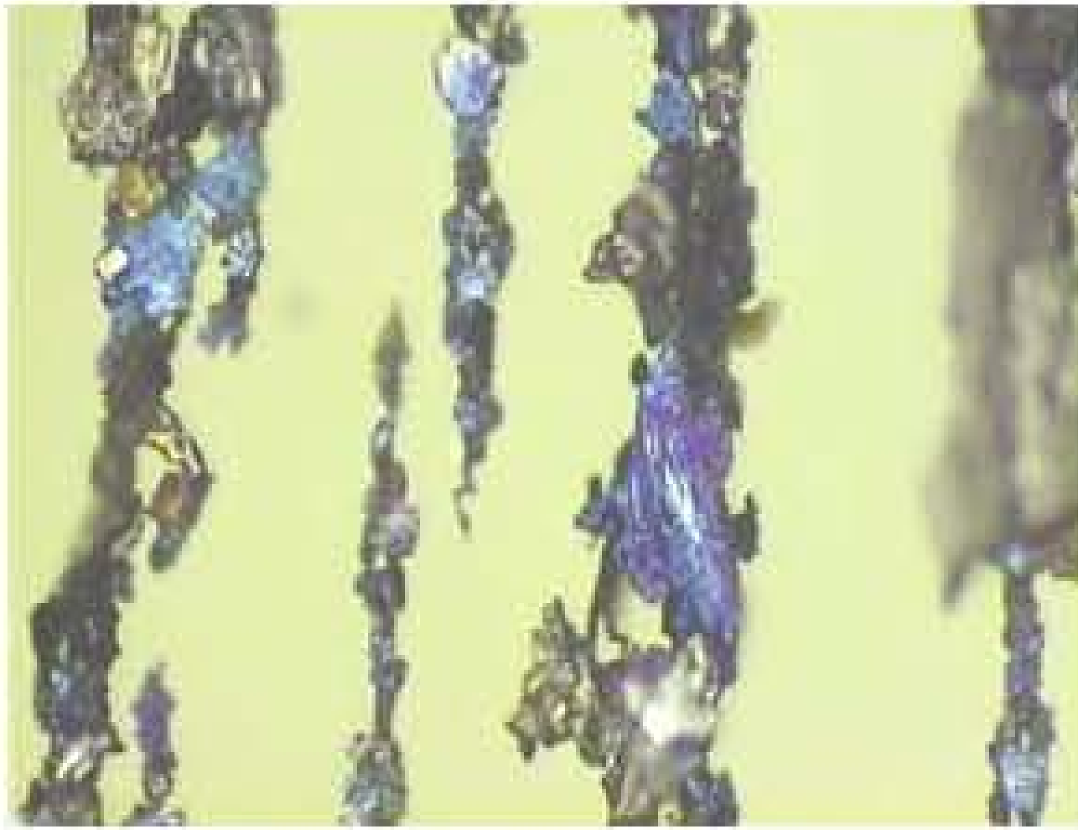
Condition-monitoring systems based on wear debris analysis

Analytical Ferrography

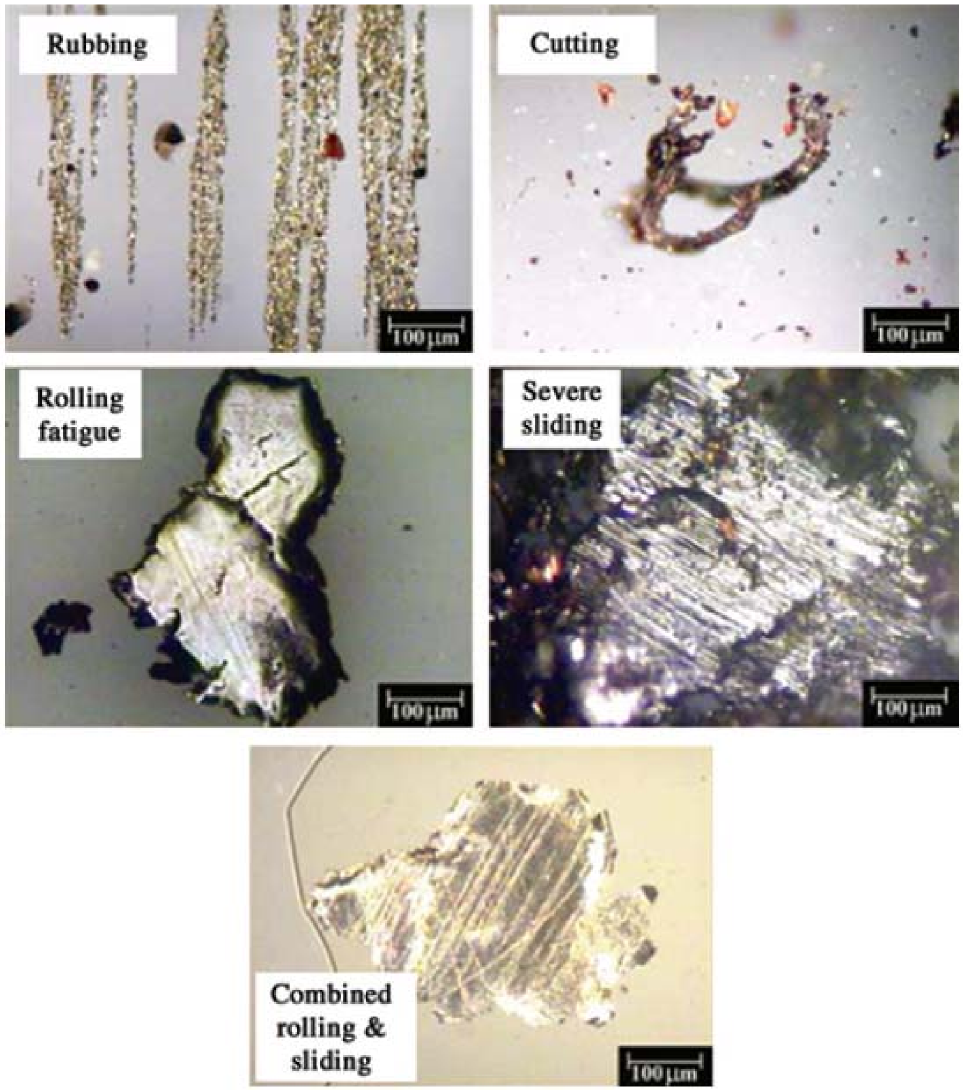


Example: Air-compressor system.
V, T – vibration and temperature sensors
OMD – optical-magnetic detector

Analytical Ferrography



Low and high alloy steel gear and bearing wear particles
(120 μm max.) 200X



Wear Particles (Raadnui, 2005; Khan and Starr, 2006)

Filter Debris Analysis

- filter separation
- > filter pore size

Filtergrams

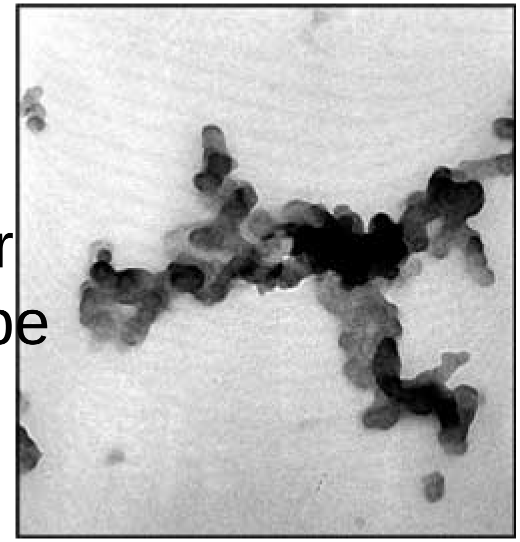
- filter separation and clarification
- > filter pore size

Scanning Electron Microscope

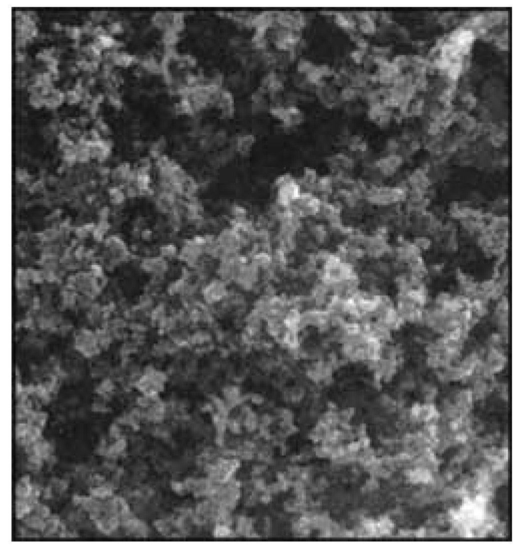
- all particles
- expensive

Scanning Electron Microscopes

Soot analysed under traditional microscope



Soot analysed under SEM



Spectrametric Oil Analysis

Elemental analysis can detect up to 24 elements, measuring less than 5 μm, that can be present in used oil due to wear, contamination or additives.

Wear Particle Types

Wear Particle Types

Rubbing Wear

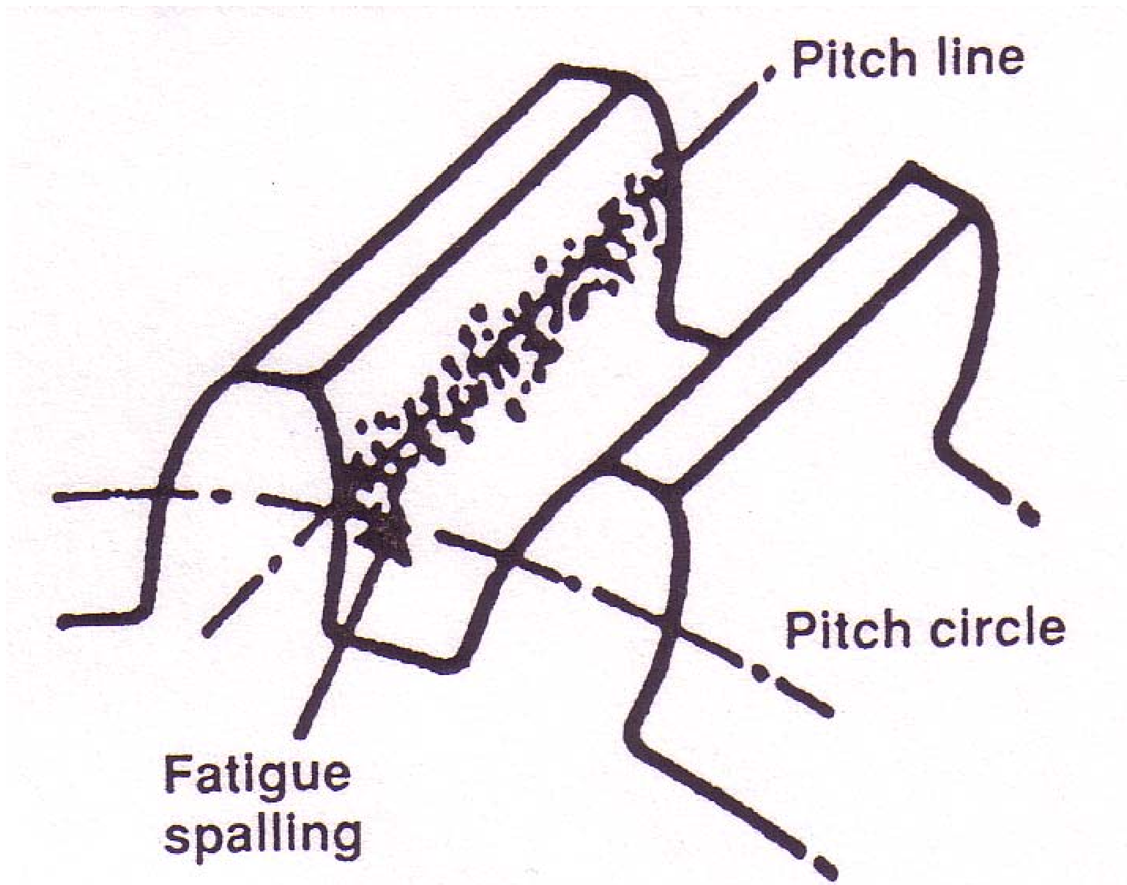
- normal wear
- small flakes of metal
- less than 10 μm in size
- occur throughout the life of machine.

Wear Particle Types

Fatigue chunks

- sub-surface stressing in gears or shafts
- large chunks of metal (up to 5000 μm)
- occur during periods of machine stress
- rolling element bearing chunks are usually rolled flat or broken into smaller sizes (see laminar wear)

Wear Particle Generation



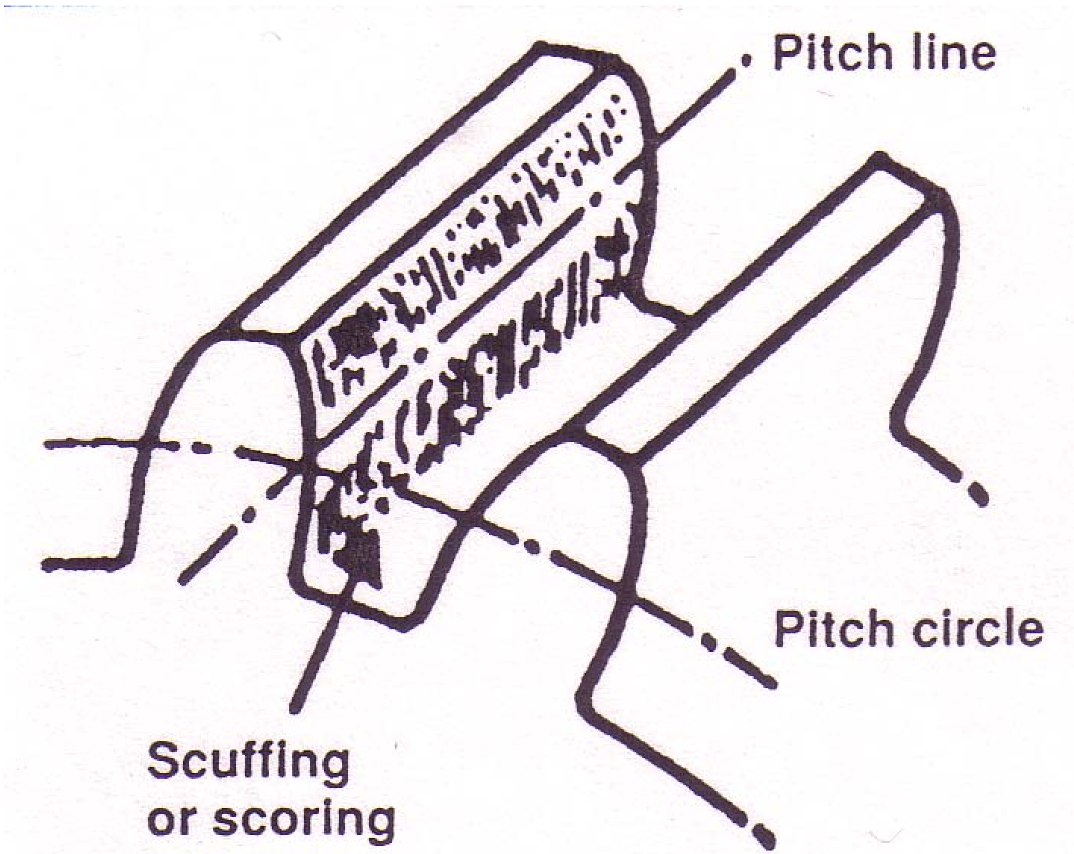
Rolling wear

Wear Particle Types

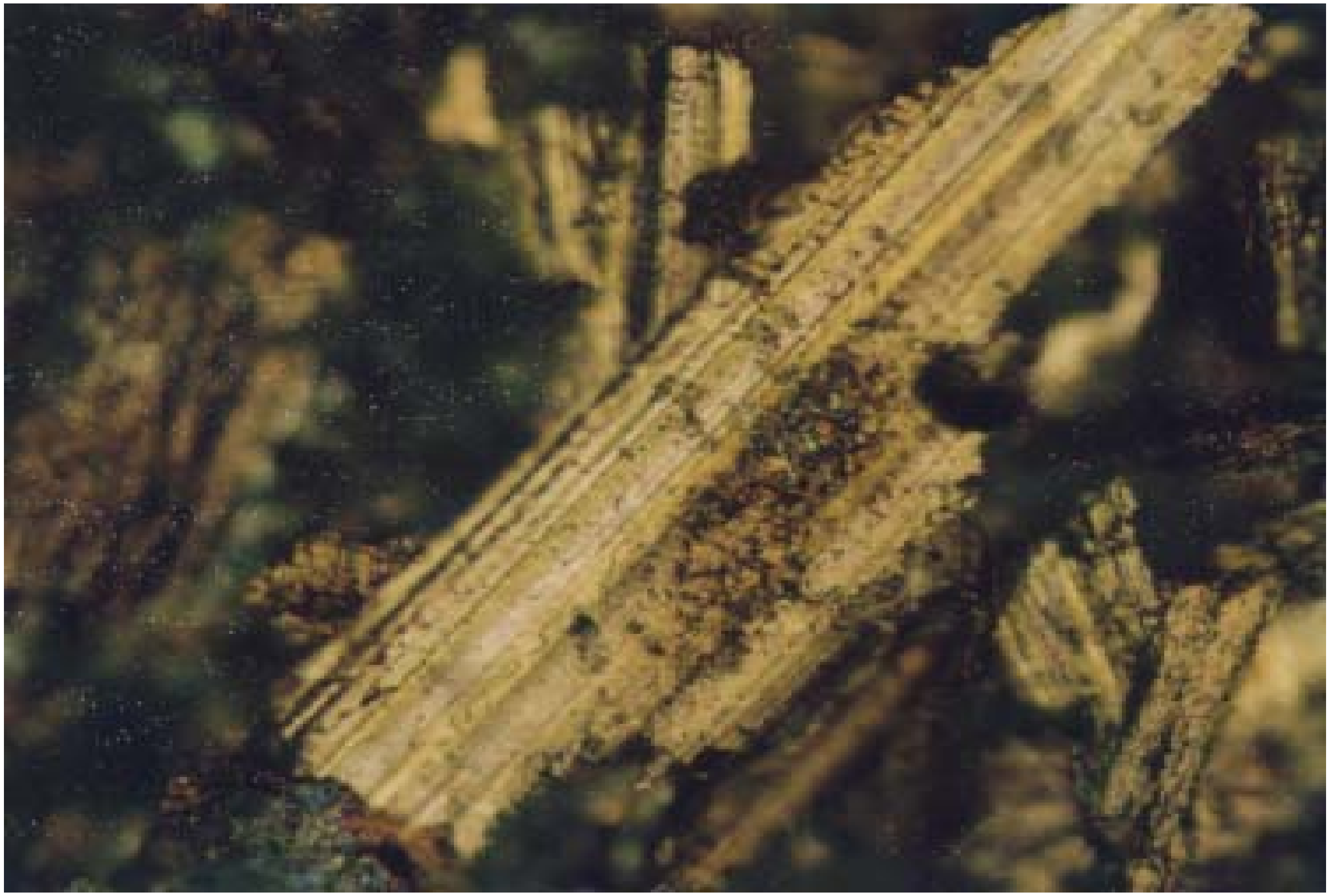
Sliding wear

- scuffing wear
- metal-to-metal contact - no lubricant film
- gear teeth, pistons, hydraulics, loose bearings
- parallel striations on surface
- lubricant loss, overloading, wrong oil
- 5μm to 5000 μm (15 - 50 μm usual)

Wear Particle Generation



Sliding wear

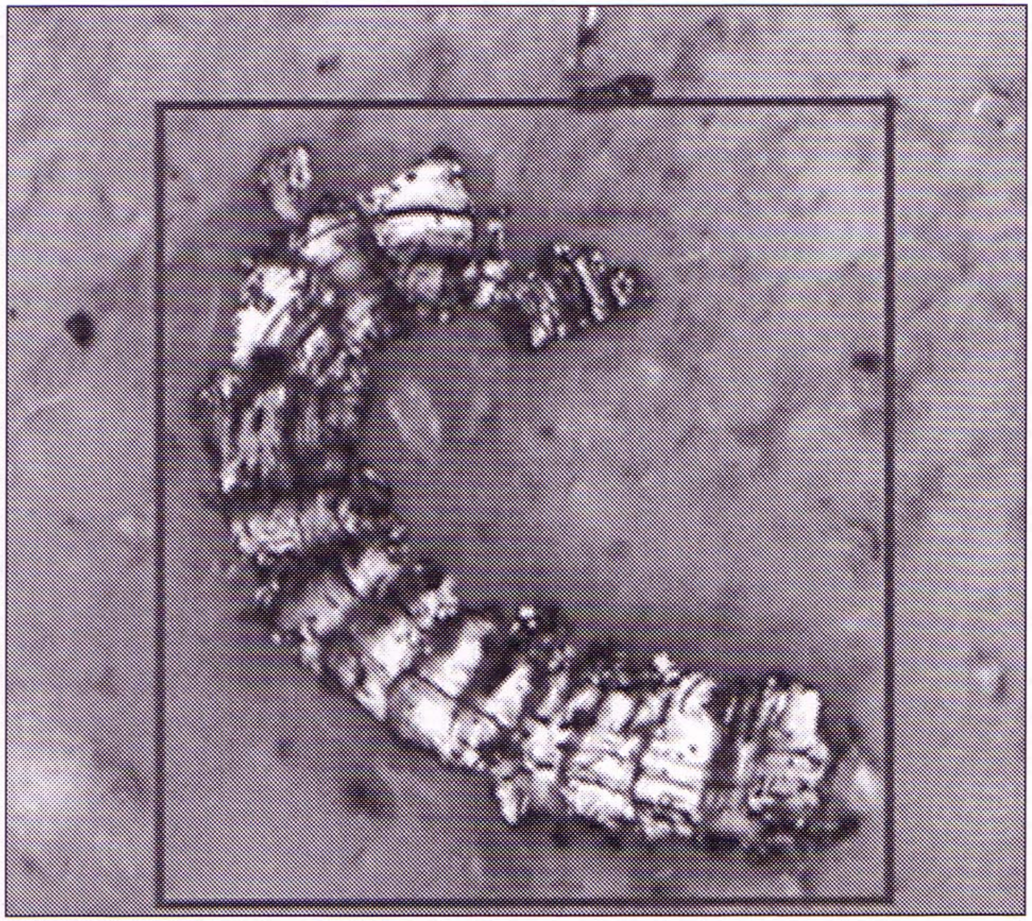


Severe Sliding Wear

Wear Particle Types

Cutting wear

- abrasive contact between two surfaces
- 2 body wear (metal/metal) softer metal is cut
- 3 body wear (metal/contaminant/metal) harder metal is cut
- curls of metal like lathe swarf
- 5 μm to 5000 μm (10-85 μm usual)
- bad machining, contaminants, misalignment

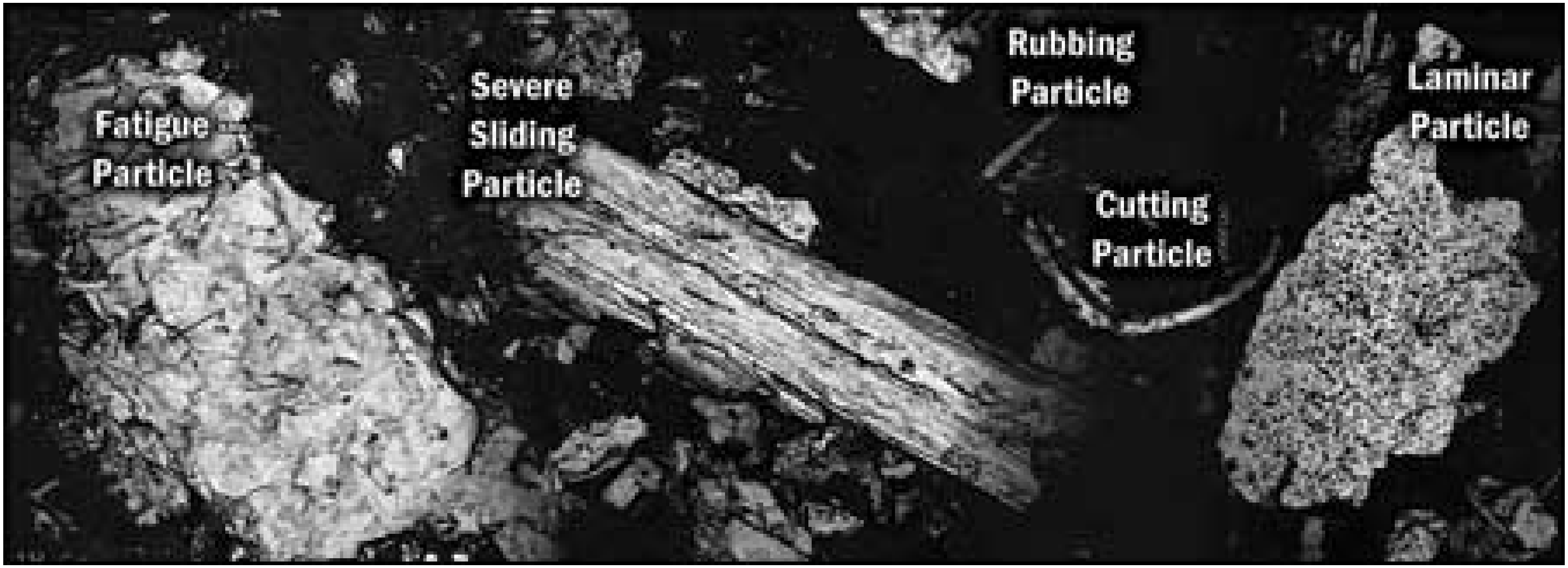


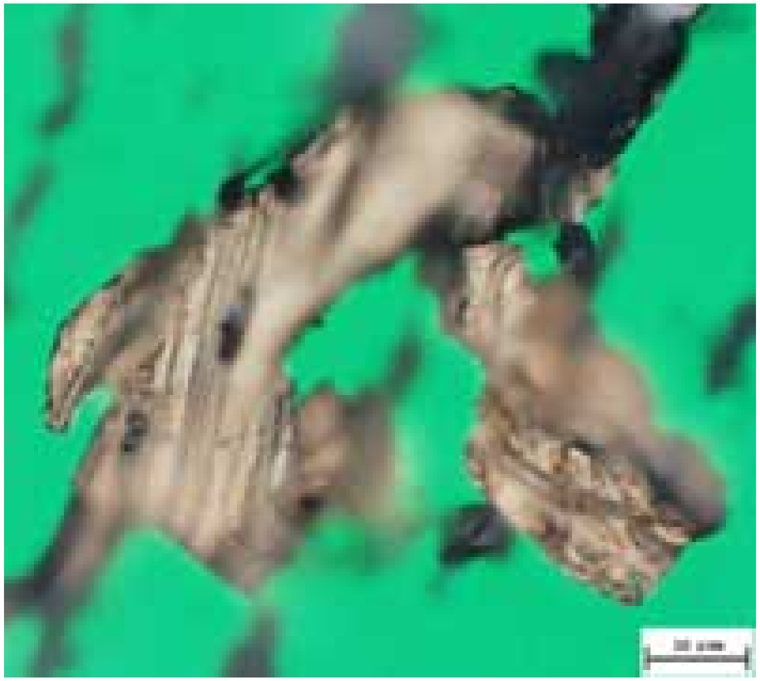
Three body cutting wear (x400 magnification)

Wear Particle Types

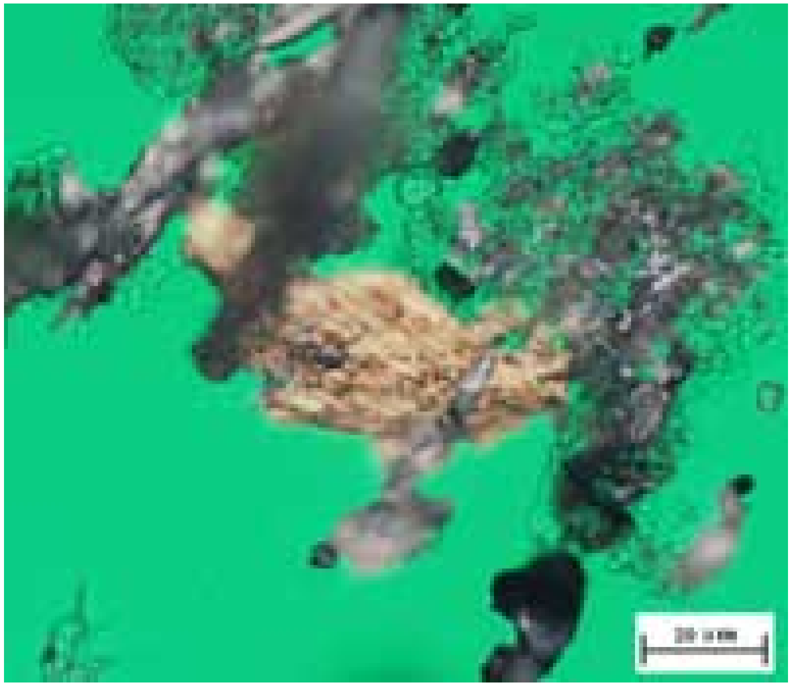
Laminar wear

- sub-surface stressing in rolling element bearings
- reworked wear particles
- flat, thin flakes of metal
- 5 μm to 200 μm (15 - 65 μm usual)
- bearing spalling, poor filtration


Fatigue Particle
Severe Sliding Particle
Rubbing Particle
Cutting Particle
Laminar Particle



Copper alloy particle
before run-in

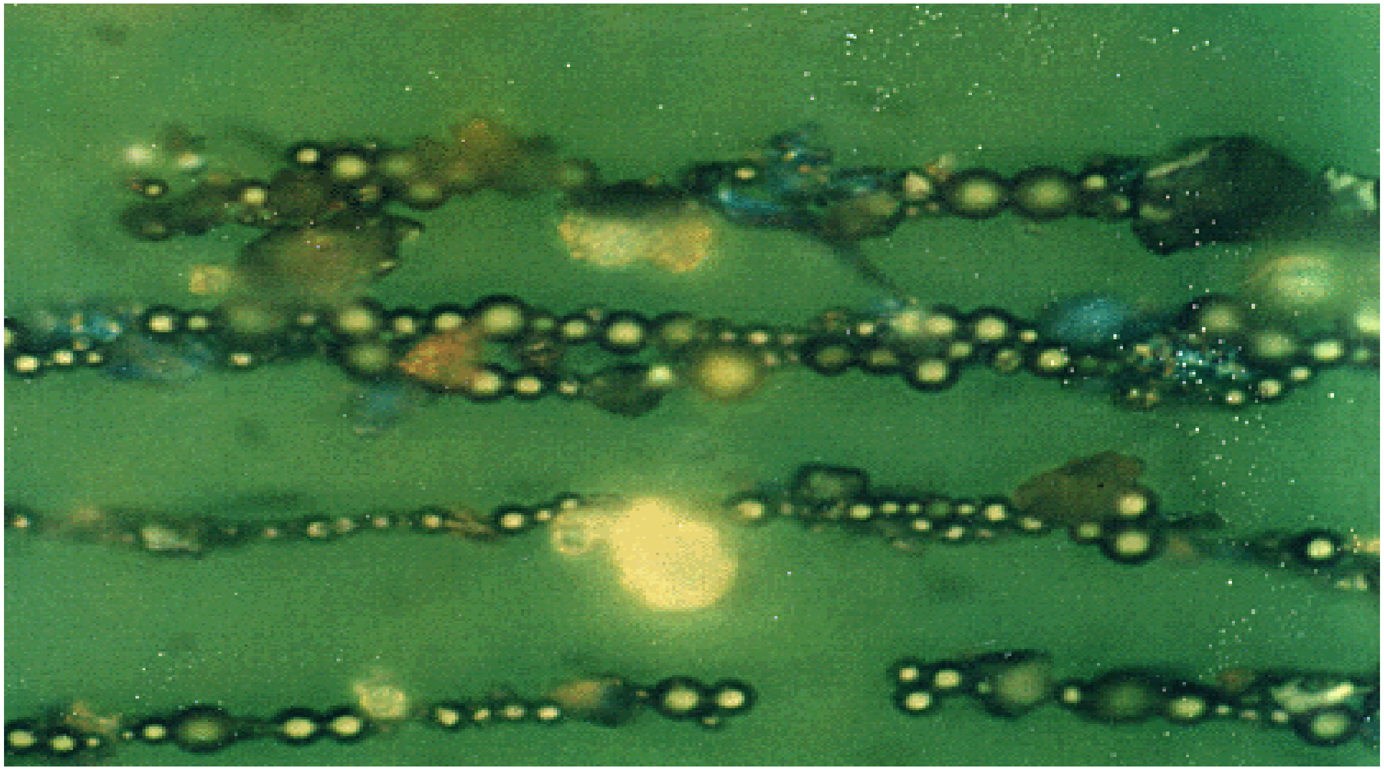


Copper alloy particle
after run-in

Wear Particle Types

Spheres

- friction reworking of other wear particles
- small ball-bearing like spheres
- 5 μm to 30 μm (5 - 15 μm usual)
- only during periods of extreme friction



Spheres (500x optical)

Wear Particle Types

Oxides

- heating of wear particles
- any shape, 5 μm - 5000 μm (15 - 50 μm)
- during periods of high temperature, wrong oil, overloading, no oil

The End