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Gear box fault detection

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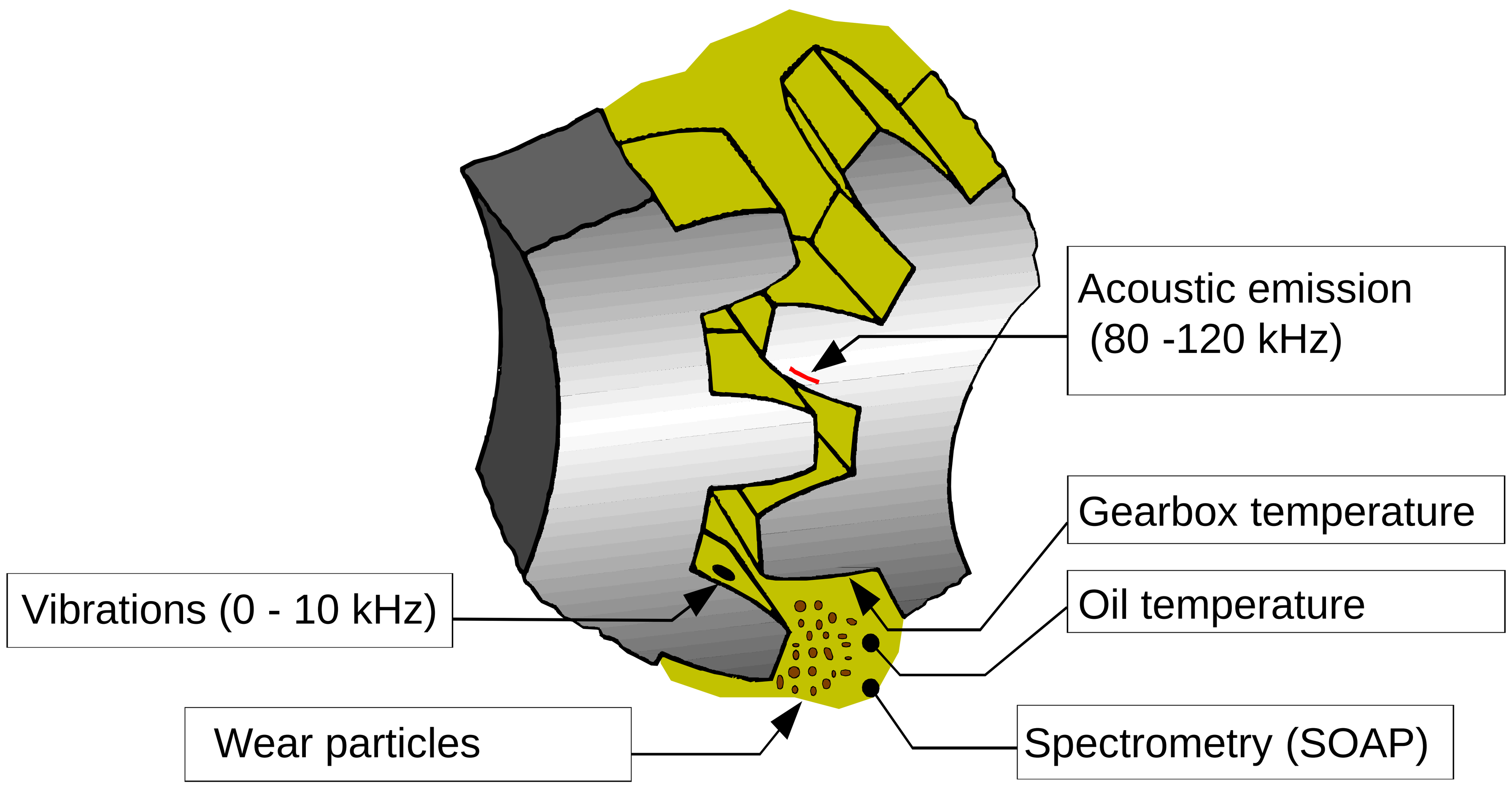
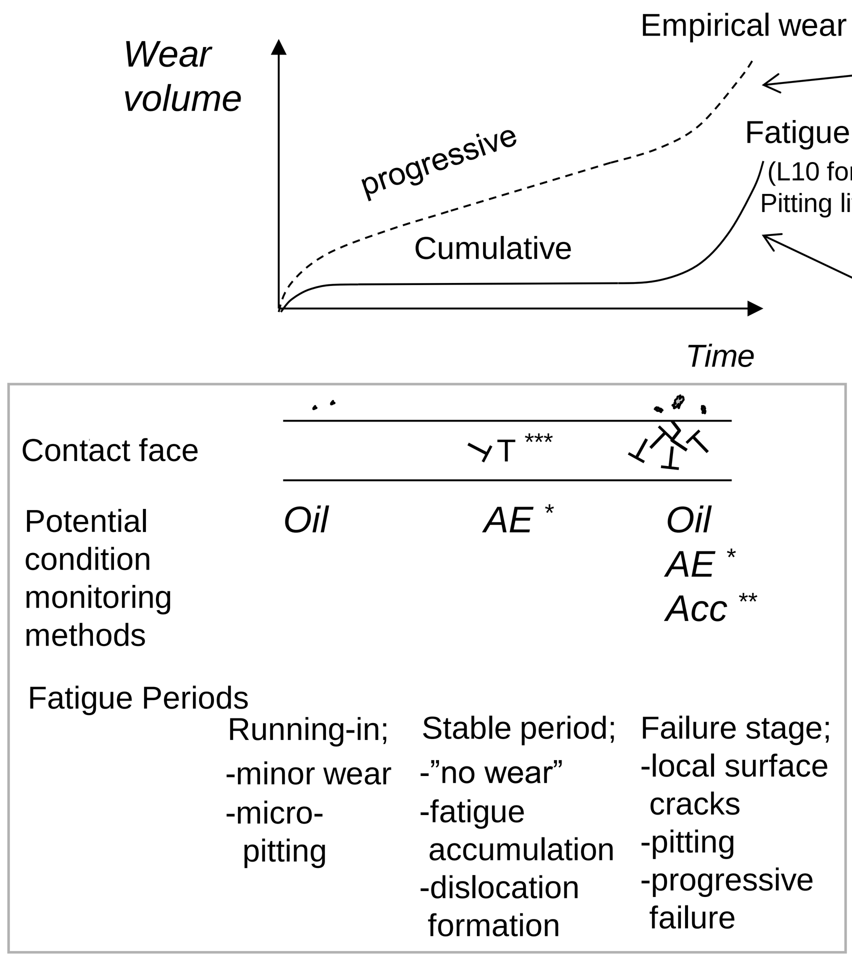
Condition monitoring measurements for rolling bearings and gears



Failure modes – overview

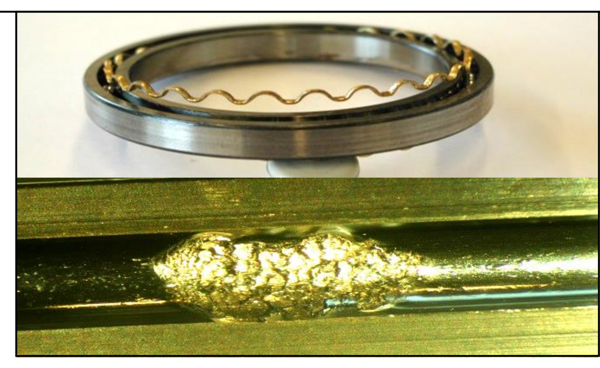
Failure due to fatigue or wear



* Acoustic emission
** Vibration acceleration
*** Dislocation

Causes for increasing wear rate
- Loading in the wrong range
- Overloading
- EP additive adhesion to wear particles
- Oil ageing
- Drift of viscosity range

Causes for acceleration of fatigue
- Load increase
- RPM increase
- Decrease in viscosity
- Contaminations (wear particles, dirt, oxide particles, water, etc.) increase



Rolling contact fatigue failure in ball bearing

Gearbox analysis in Tolkku

Statistical feature for fault detection

The most common statistical features used for general gearboxes are peak, R.M.S, crest factor and kurtosis. With the provided vibration signal, sampling frequency and input shaft speed, the following functions for statistical features are made in Tolkku:

Feature Name	Definition
Energy ratio	$Energy\ ratio = \frac{std(d)}{std(r)}$
FM0	$FM0 = \frac{p2p}{Amp(GMF_1) + Amp(2GMF_1) + Amp(GMF_2) + Amp(2GMF_2)}$
FM4	$FM4 = Kurt(d)$
M6A	$M6A = \frac{\sum_{i=1}^{N}(d_i - \bar{d})^6}{\left(\sum_{i=1}^{N}(d_i - \bar{d})^2\right)^3}$
M8A	$M8A = \frac{\sum_{i=1}^{N}(d_i - \bar{d})^8}{\left(\sum_{i=1}^{N}(d_i - \bar{d})^2\right)^4}$
NA4	$NA4 = Kurt(r)$
NB4	$NB4 = Kurt(r')$ where $r' = abs(hilbert(r))$
FM4*	$FM4^* = \frac{\sum_{i=1}^{N}(d_i - \bar{d})^4}{\left(\frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{k=1}^{N}(d_{jk} - \bar{d}_j)^2\right)^2}$
M6A*	$M6A^* = \frac{\sum_{i=1}^{N}(d_i - \bar{d})^6}{\left(\frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{k=1}^{N}(d_{jk} - \bar{d}_j)^2\right)^3}$
M8A*	$M8A^* = \frac{\sum_{i=1}^{N}(d_i - \bar{d})^8}{\left(\frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{k=1}^{N}(d_{jk} - \bar{d}_j)^2\right)^4}$
NA4*	$NA4^* = \frac{\sum_{i=1}^{N}(r_i - \bar{r})^4}{\left(\frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{k=1}^{N}(r_{jk} - \bar{r}_j)^2\right)^2}$
NB4*	$NB4^* = \frac{\sum_{i=1}^{N}(r_i' - \bar{r'})^4}{\left(\frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{k=1}^{N}(r'_{jk} - \bar{r'}_j)^2\right)^2}$

- FM0 is a robust indicator of faults involving gear meshing.
- FM4 is defined to be the kurtosis of the difference signal over each time. FM4 is supposed to work well for detection of initial faults
- M6. The underlying theory of M6 is the same as that of FM4. It is expected that M6 will be more sensitive to peaks in the difference signal.
- NA4 can not only detect the onset of damage, as FM4 does, but also continue to react to the damage as it spreads and increases in magnitude.
- The NA4* indicator is robust for indicating not only initiating damage but also progressing damage.
- NB4 is defined on the run ensemble of the envelope of the obtained bandpass filtered signal. The theory behind NB4 is that the damage on gear teeth will cause transient load fluctuation that is different from that caused by healthy teeth, and that this can be seen in the envelope of the signal.
- NB4* aims to improve the performance of NB4 in tracking damage progression.

Frequency domain analysis

Analysis techniques	Diagnostic approaches	
Fourier analysis	FFT spectrum Welch spectrum	Amplitude spectrum Power spectrum Power density spectrum
Cepstrum analysis	Cepstra	
Time-frequency domain analysis	Short time Fourier transform	Spectrogram
	Wigner Ville distribution	Spectrum of Wigner Ville distribution
Envelop analysis	Statistical features or spectrum of envelop signals	
Hilbert Huang transform or called Empirical mode decomposition	Spectrum of each IMF. Trends of Instantaneous frequency, Instantaneous energy, Mean marginal spectrum, Degree of non-stationary for fault progression	

Case: Konecranes gearboxes

- Two similar fixed shaft gearboxes were tested
- Vibration acceleration sensors x 12 pcs
- Different loading and driving conditions

(Source:Konecranes - Vibration Measurements).