Detection and Quantification of Impeller Wear in Tailing Pumps and Detection of faults in Rotating Equipment using Time Frequency Averaging across all Scales

Enayet B. Halim, Sirish L. Shah and M.A.A. Shoukat Choudhury

Department of Chemical and Materials Engineering
University of Alberta

Outline

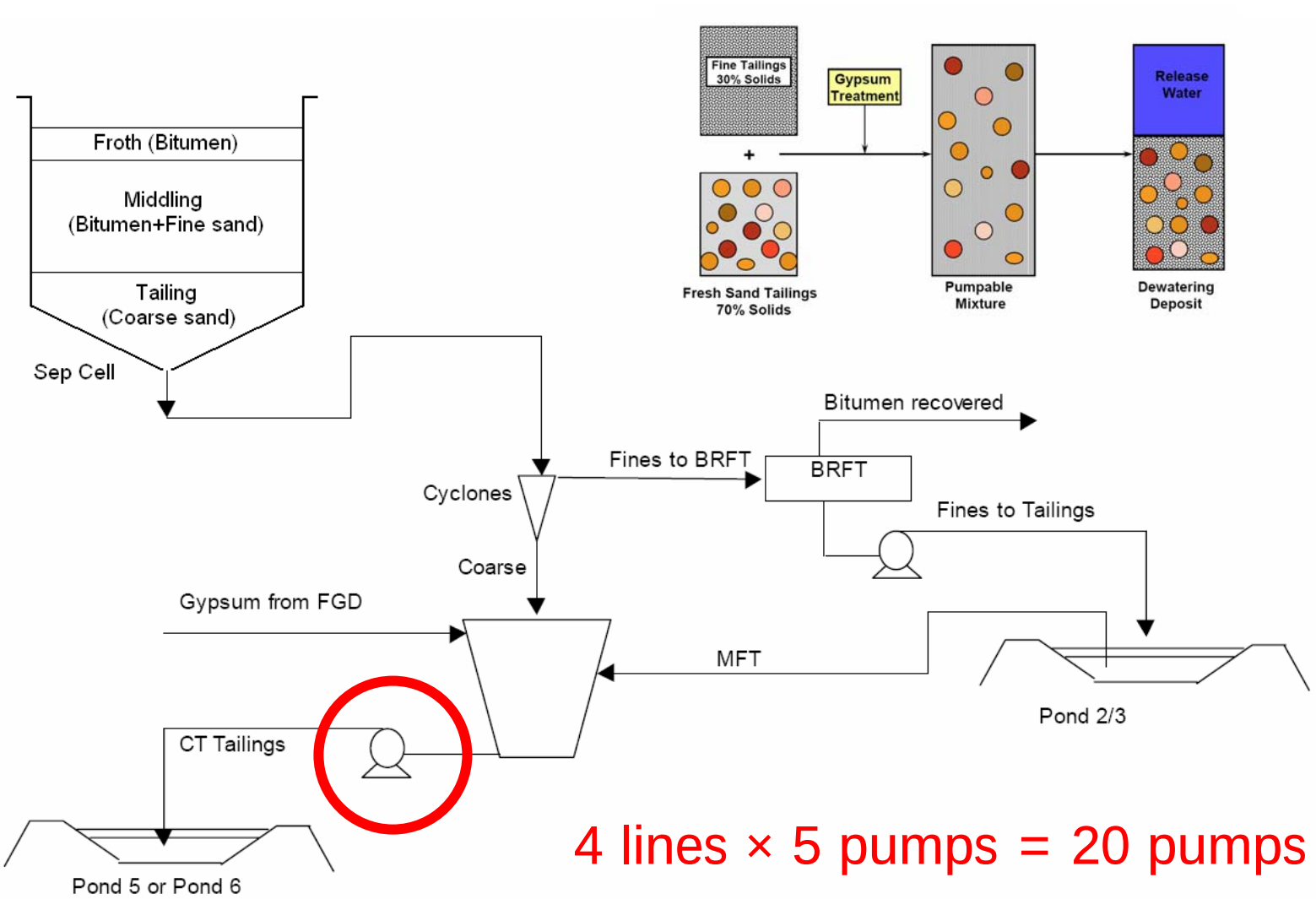
- Detection and quantification of impeller wear in tailing pumps at SUNCOR.
  - Defining the problem
  - Existing Technique
  - Bicoherence Analysis
  - Application of Bicoherence on SUNCOR data
  - Latest SUNCOR data and Results

- Detection of faults in Rotating Equipment using Time Frequency Averaging across all Scales
  - Gearbox, Fault and Vibration
  - Cyclostationarity and Continuous Wavelet Transform
  - Time Domain Averaging Across all Scales
  - Pilot Plant Case Study

Detection and Quantification of Impeller wear in Final Tailing Pumps

Defining the Problem

Consolidated Tailings (CT)



4 lines × 5 pumps = 20 pumps

Pump Impeller

Pump impeller pictures from Suncor show impeller wear in 13 weeks time. Objective of this study is to increase the maintenance period by condition based monitoring.

Existing Technique

Data Collection

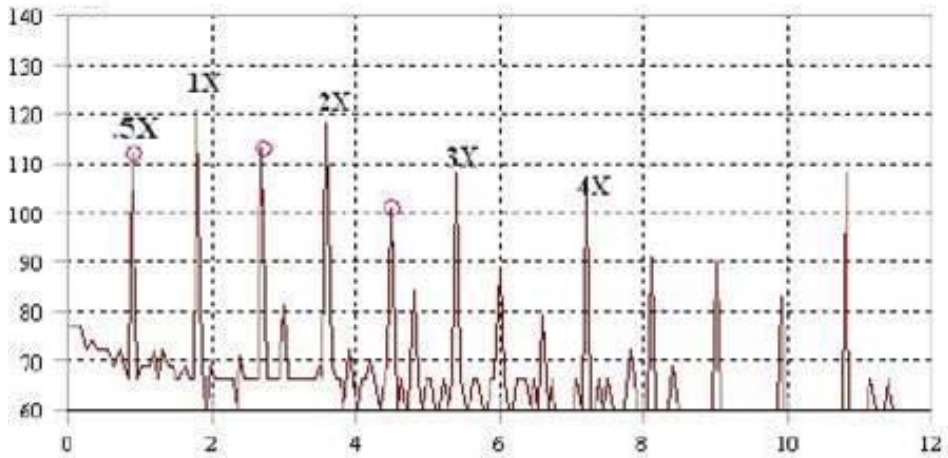
1. Data is collected using a handheld vibration meter.
2. For the first 3 pumps, data is collected at motor, gearbox, and pump. For the last 2 pumps fluid-drive coupling is added.
3. For each device, data is collected at 3 positions.
    - Horizontal
    - Vertical
    - Axial
4. Sampling frequency of data ranges from 1000-1800 Hz.
5. Data collection time is ~3 seconds.
6. Data collection frequency is once a month.

Data Analysis

1. Classical Fourier Transform is used as the tool of analysis.
2. Software used : AMS Suite (Machinery Health Manager) by Computational Systems Inc. (CSI)
3. For every device, the model number is fed to the software, which then collects the device parameters from the server and calculates the vibration parameters for that specific device.
4. Vibration data is analyzed in velocity or acceleration.
5. Alarm limits are set based on the overall RMS (root mean square) amplitude value of the vibration data set.

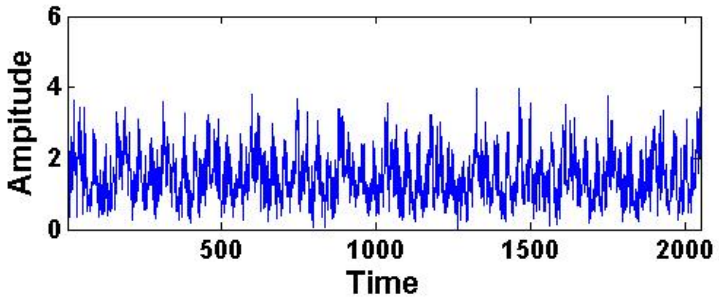
Vibration from Gearbox

- Once the RMS overall value is exceeded, detailed analysis is performed based on Fourier Transform Analysis.
- RMS overall value can give erroneous result.
- Classical Fourier Transform Analysis depends mostly on the analyzer.

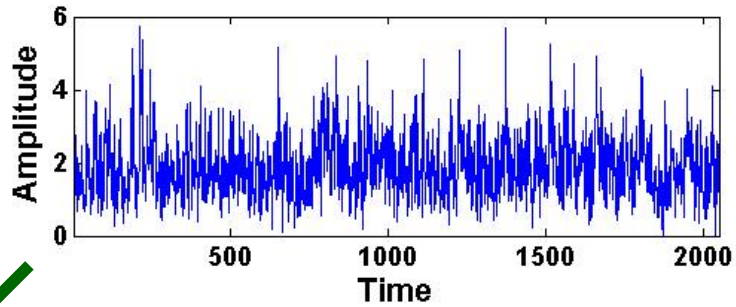


Time Trend Plots

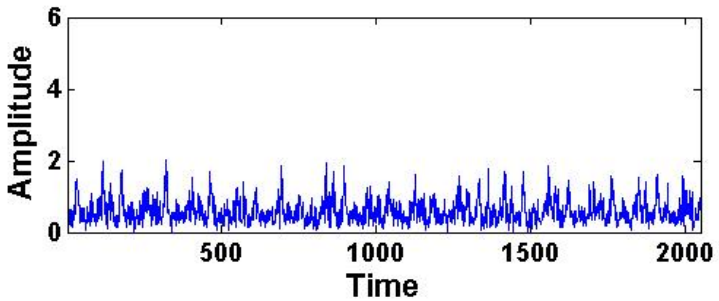
July 2006



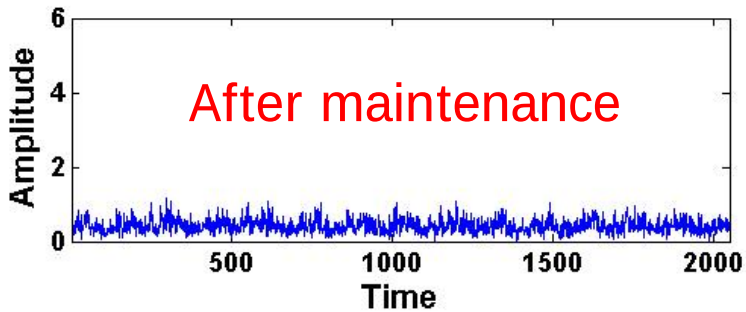
August 2006



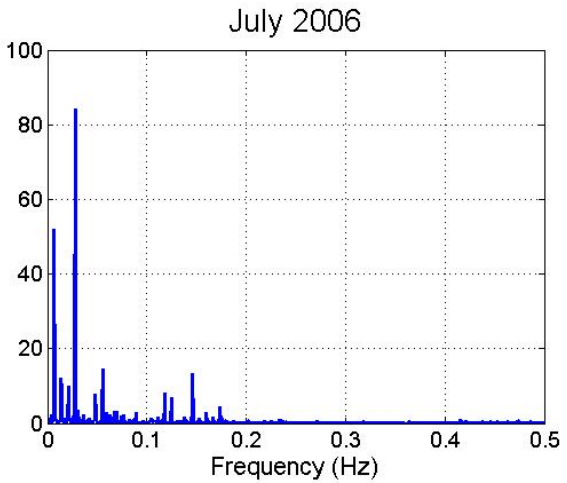
September 2006

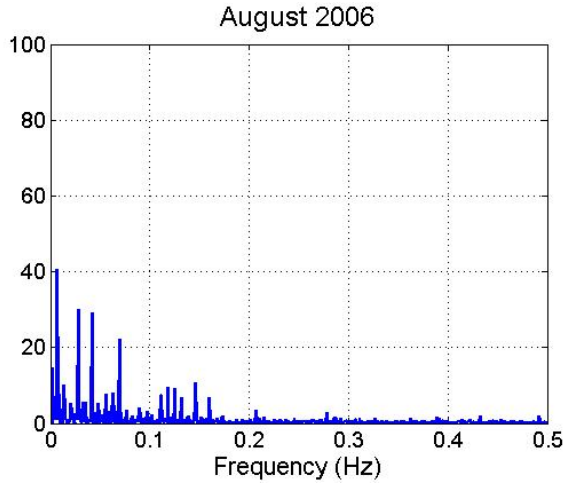


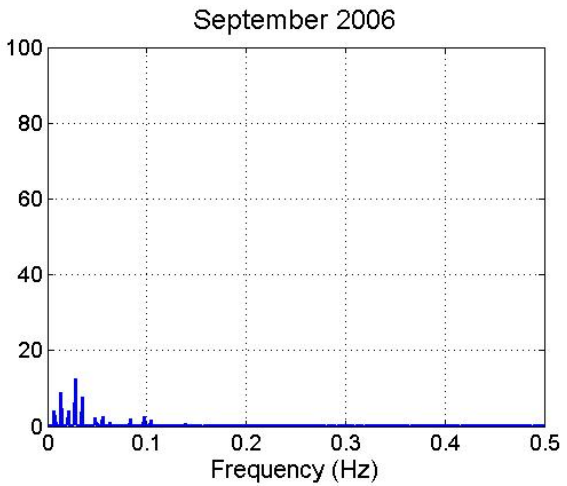
October 2006

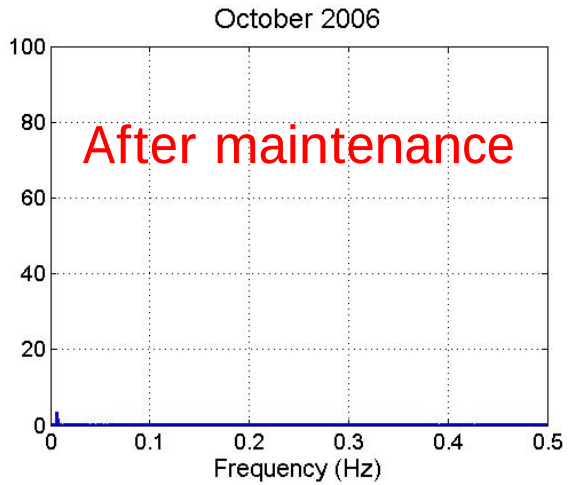


Power Spectra









Bicoherence Analysis

Higher Order Statistics (HOS)

Power Spectrum (or Fourier Analysis) is not sufficient to detect impeller wear in pumps.

Faults in rotating machineries leave their signature on the vibration signal sensors and generally manifest themselves as a non-linear transformation in the vibration signal.

The First and Second Order Statistics (e.g. mean, variance, autocorrelation, power spectrum) are only sufficient to describe linear processes.

For non-linear processes, Higher Order Statistics is required. Higher Order Statistics (HOS) is used to detect and quantify non-linearity in the time-series.

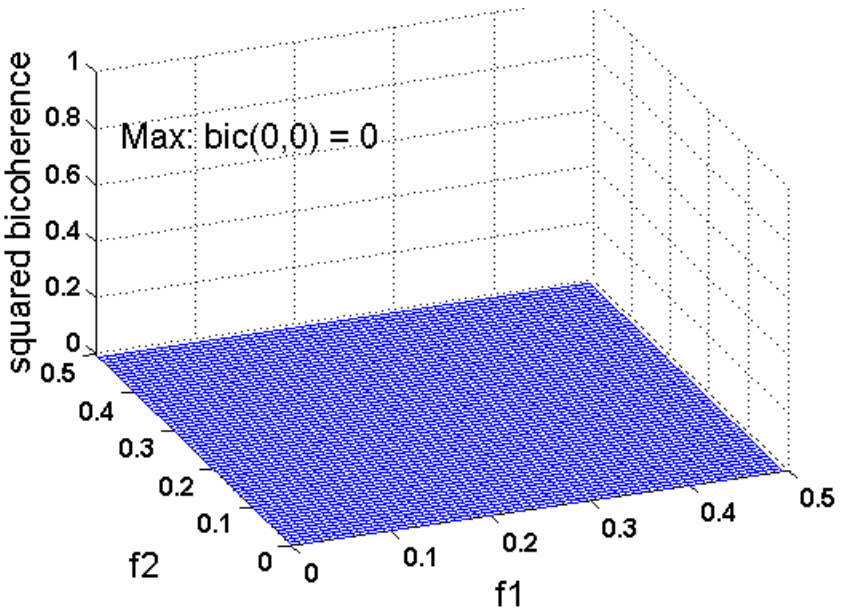
Illustrative Example of Bicoherence

$$x'(k) = sin(2\pi f_1 k + \phi_1) + sin(2\pi f_2 k + \phi_2)$$

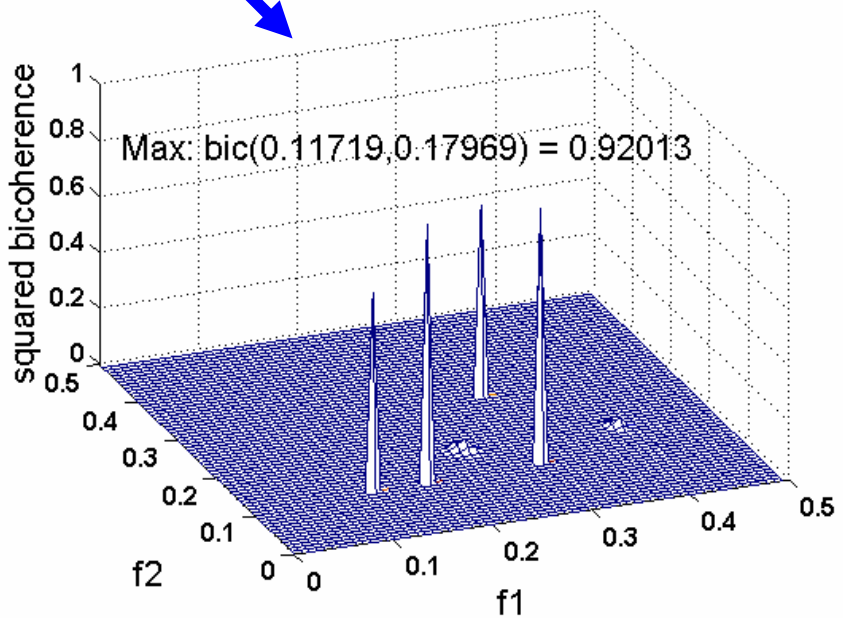
$$x(k) = x'(k) + d(k)$$

$$y(k) = x'(k) + 0.1x'(k)^2 + d(k)$$

f_1=0.12, f_2=0.30, d(k) is white noise with variance 0.04



(a) linear signal x

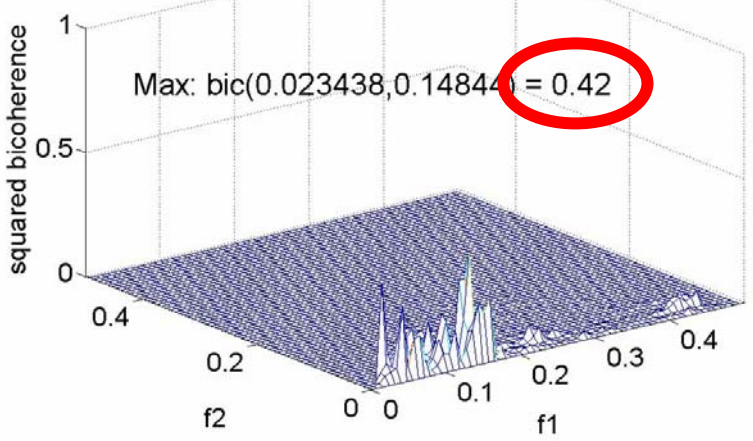


(b) non-linear signal y

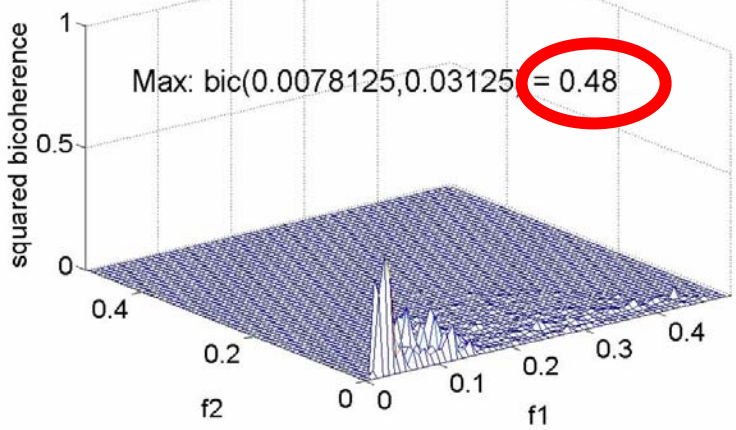
Application of Bicoherence Analysis on SUNCOR data

Bicoherence on Impeller Wear Data

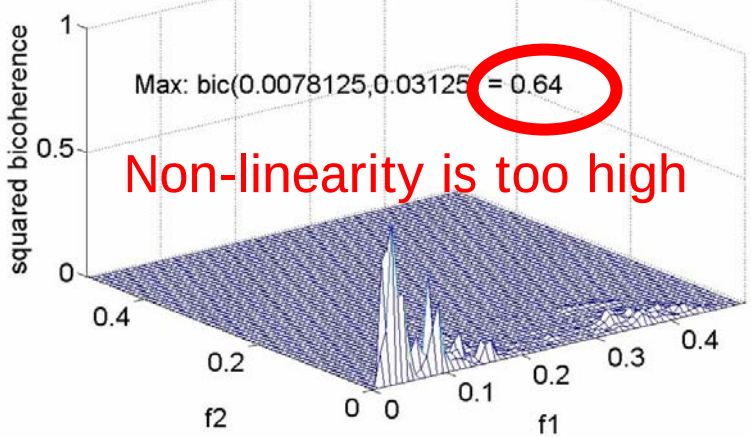
July 2006



August 2006

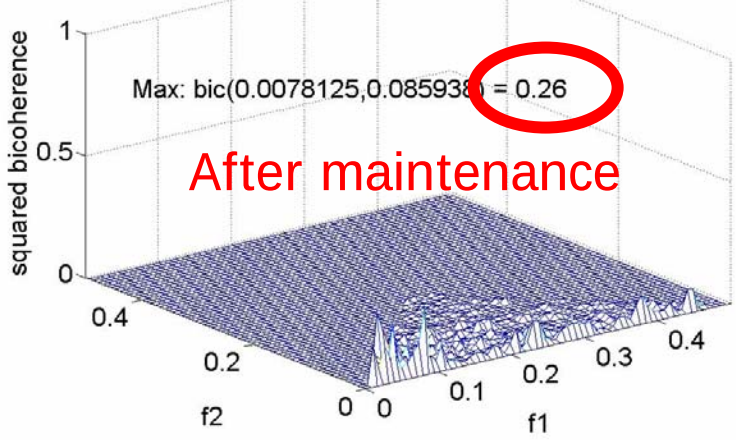


September 2006



Non-linearity is too high

October 2006



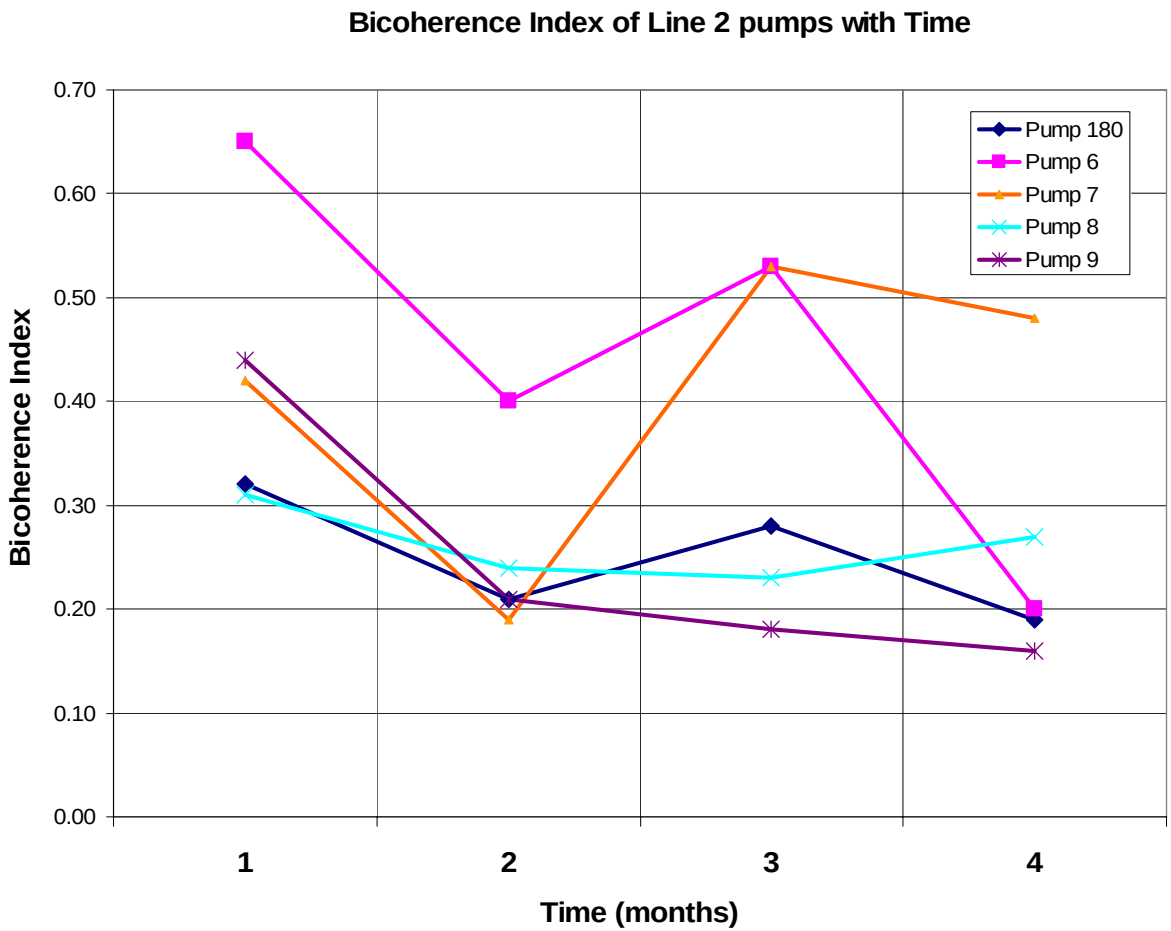
After maintenance

Latest SUNCOR Data and Results

Data and Analysis

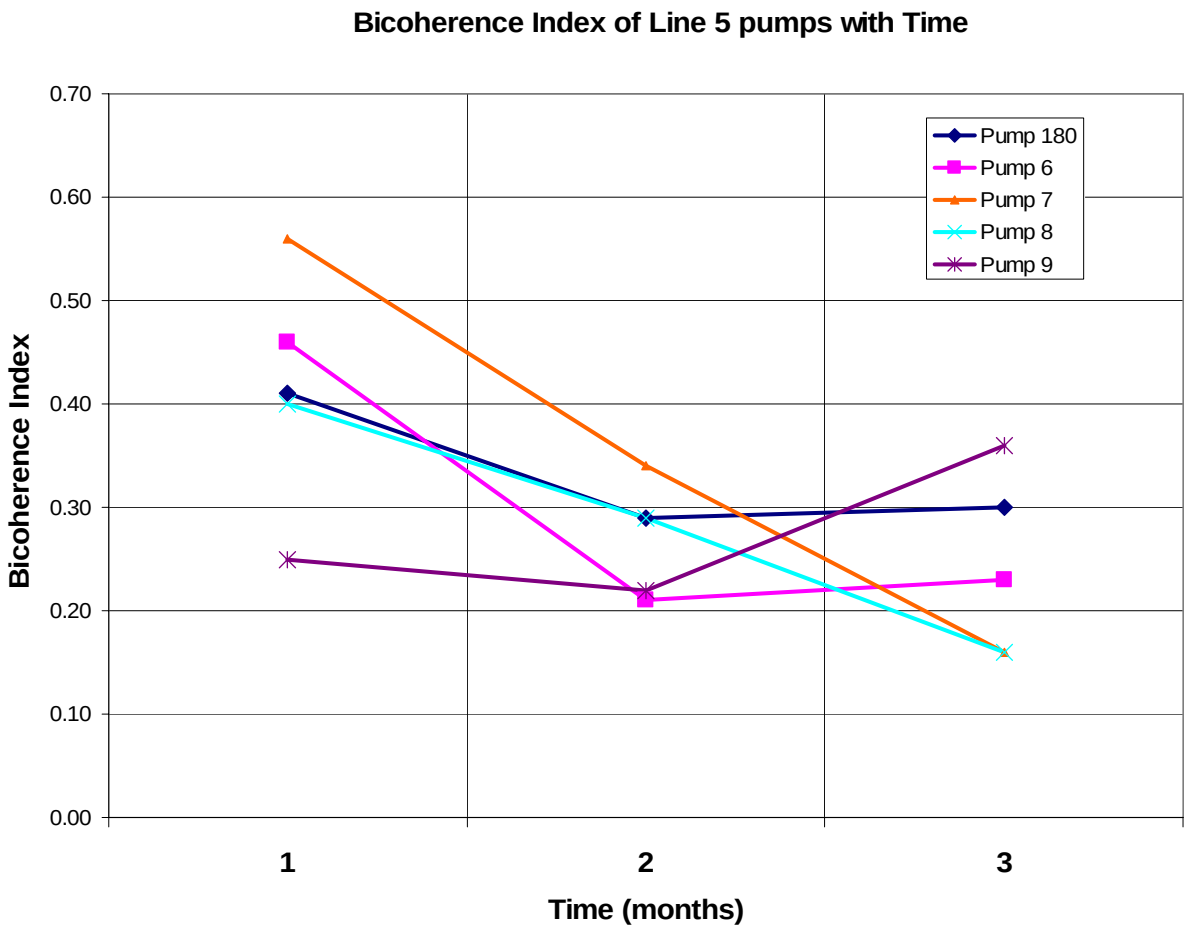
Data has been given for a time period of 1 year for 20 pumps.

Following plot shows analysis of data from November 2006 to January 2007.



Data and Analysis

Following plot shows analysis of data from Sept 2006 to Nov 2006. Maintenance was performed in October 2006 which shows up in the chart.



Result

Line 1 : Maintenance performed between February 2007 and March 2007.

Line 2 : Maintenance performed between November 2006 and December 2006.
Process changed between December 2006 and January 2007.

Line 3 : Process changed between March 2007 and April 2007.

Line 5 : Maintenance performed between September 2006 and October 2006.
Process changed between December 2006 and January 2007.

Concluding Remarks

1. Initially Bicoherence Analysis was carried out on Inboard Horizontal Data of one single pump in Line 5 for 4 months. Bicoherence Index gave consistent results and perfectly indicated the health (wear) of the impeller.

2. Bicoherence Analysis has been carried out on Outboard Horizontal Data of 20 pumps in 4 lines for 1 year. Bicoherence index clearly indicates the period of maintenance and process changes. Result verification is underway.

3. Threshold limits of the indices to generate alarms have to be individually set for each pump.

Detection of faults in Rotating Equipment using Time Frequency Averaging across all Scales

Gearbox, Fault and Vibration

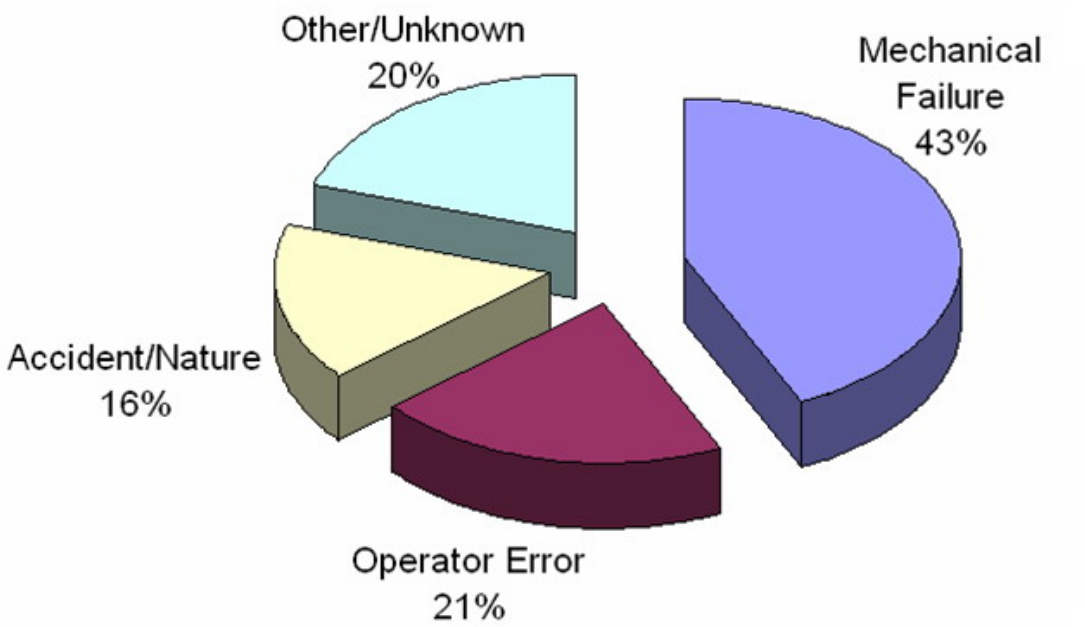
Motivation

Unplanned production shutdowns are the largest cost in the process industries, costing $1million or more per day.

Mechanical failure contributes to 43% of plant shutdown.

Suncor alone spends $40 million on preventive maintenance each year.

Mechanical failure is the largest contributor to plant shutdown



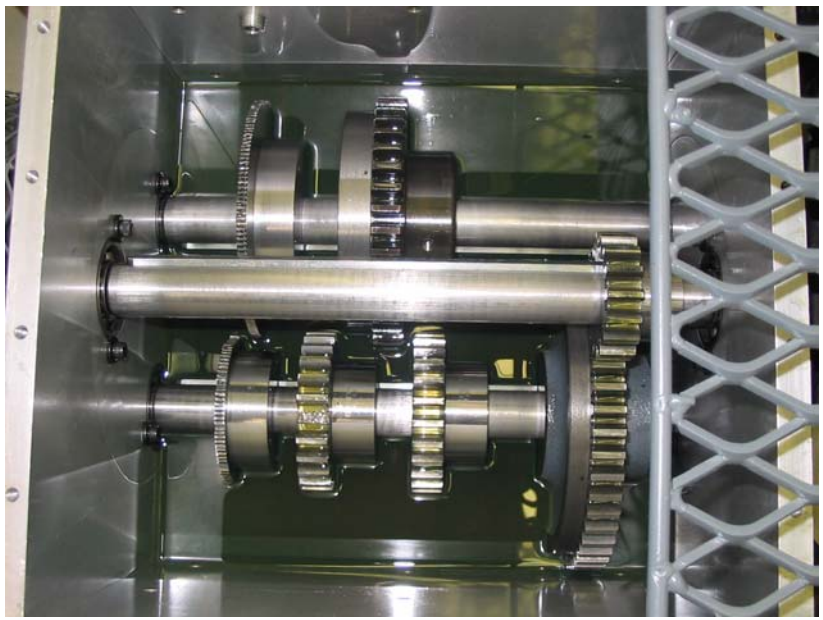
Source : IEE Computing and Control Engineering, June-July 2005

Condition Based Maintenance (CBM) for predictive fault detection and diagnosis is 'IN'. Fail and Fix is 'OUT'.

Gear and Gearbox

A Gearbox is considered as a typical example of rotating machineries.

Gear : A gear is a toothed wheel designed to transmit torque to another gear or toothed component.

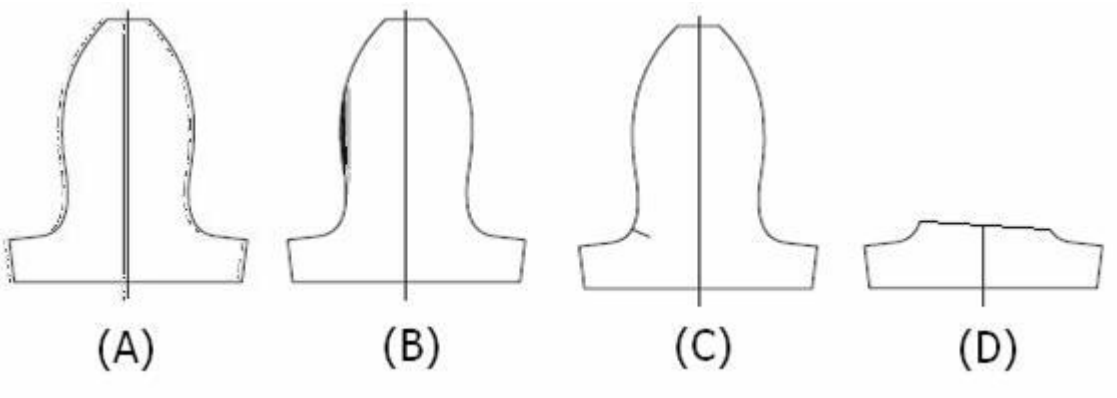


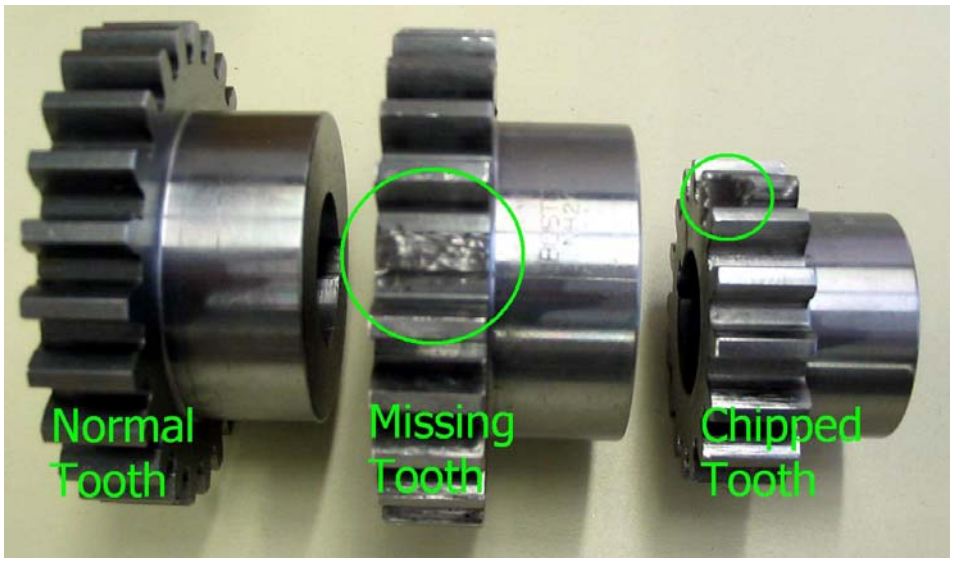
Gearbox : A gearbox is an assembly of gears in a shell (metal casing) allowing the rotational speed of an input shaft to be changed to a different speed to an output shaft.

Gear Faults

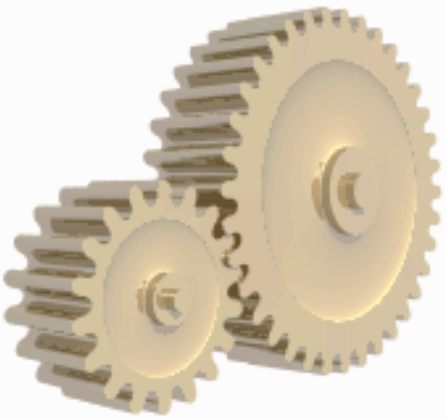
Gear Tooth Faults can be classified into 4 major classes:

A. Worn Tooth
B. Chipped Tooth
C. Cracked Tooth
D. Missing Tooth



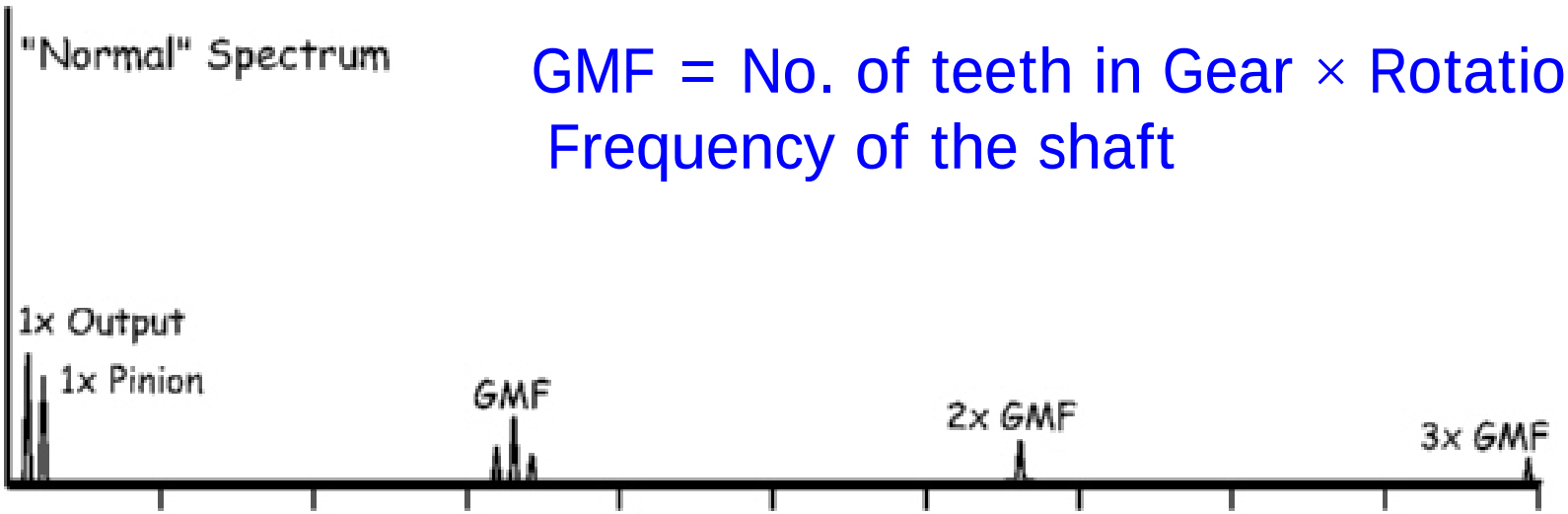


Vibration from Gearbox



The power spectrum of the vibration signal indicates:

- Rotational frequency of the input shaft
- Rotational frequency of the output shaft
- Gear-mesh frequency GMF and its integer multiples

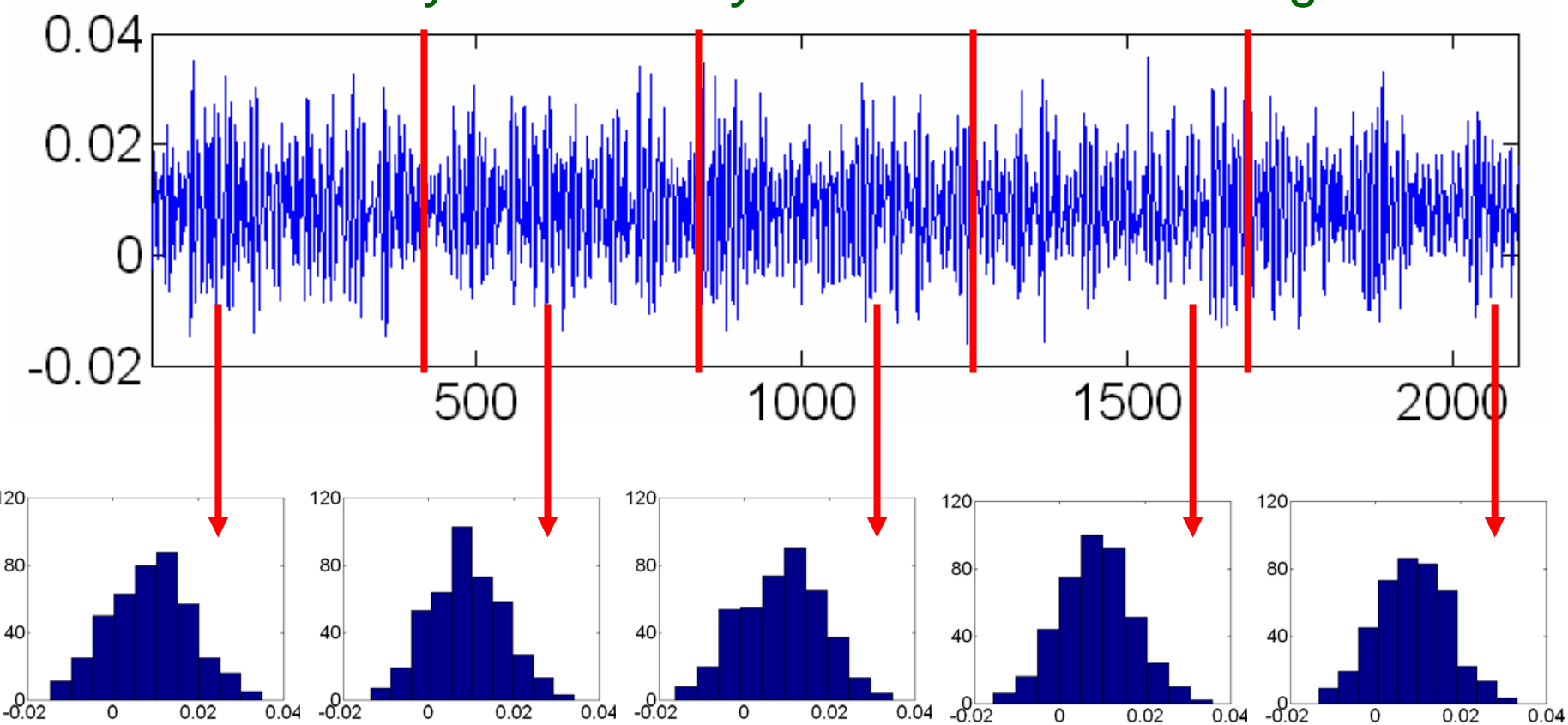


GMF = No. of teeth in Gear × Rotation Frequency of the shaft

Cyclostationarity and Continuous Wavelet Transform

Cyclostationarity (example)

Real cyclostationary vibration data from rig.



Signal from a rotating machinery is usually weak or wide sense cyclostationary.

Time Domain Average

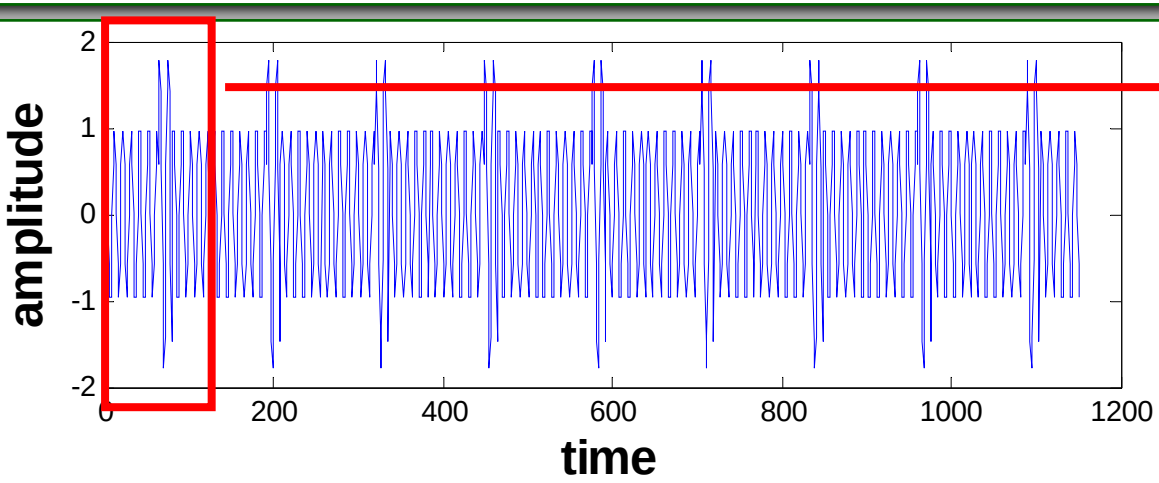
Time Domain Average is a single period representation of the vibration signal generated by synchronously arranging each period of the signal and averaging them over a large number of rotation of the machine.

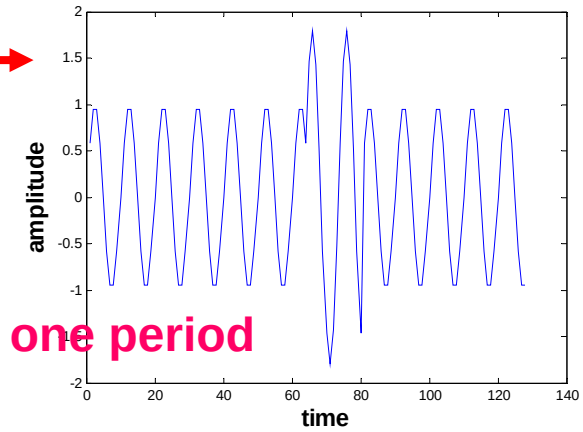
If the vibration signal x(t) has N rotations with a rotation period of T then the Time Domain Average m(t) is:

$$m(t) = \frac{1}{(N-1)} \sum_{l=0}^{N-1} x(t + lT)$$

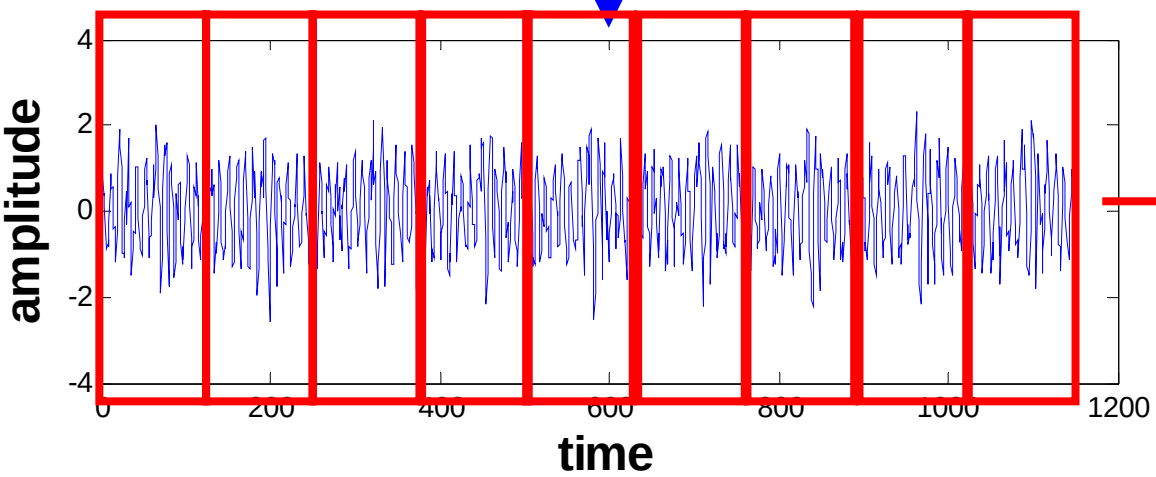
For a gearbox signal, the time synchronous average of a signal represents the vibration produced by the meshing of teeth over one complete revolution of the gear in time domain.

Time Domain Average Example

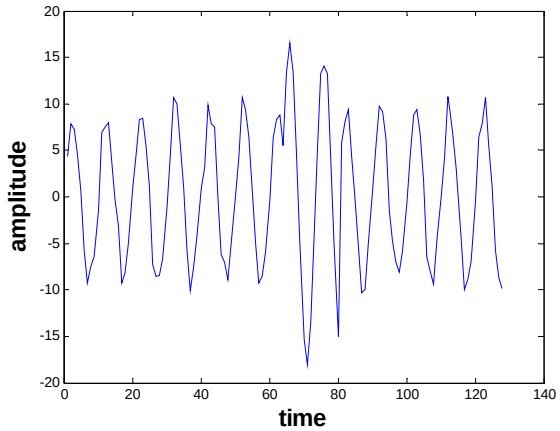




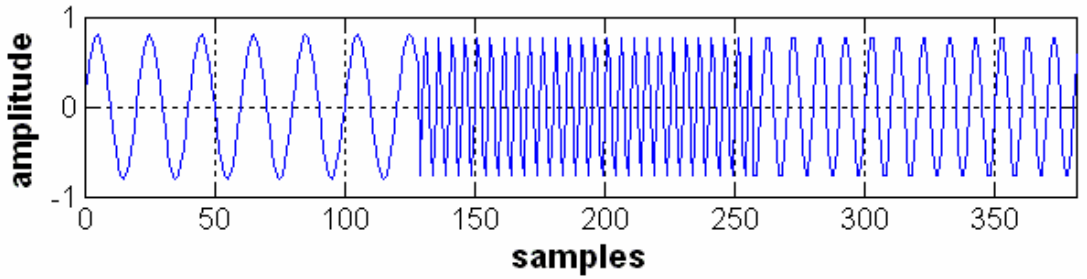
SNR=5

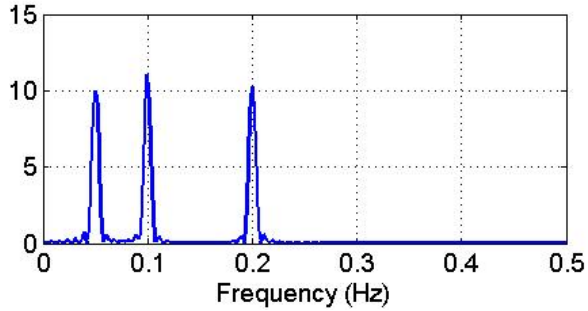


Time Domain Average

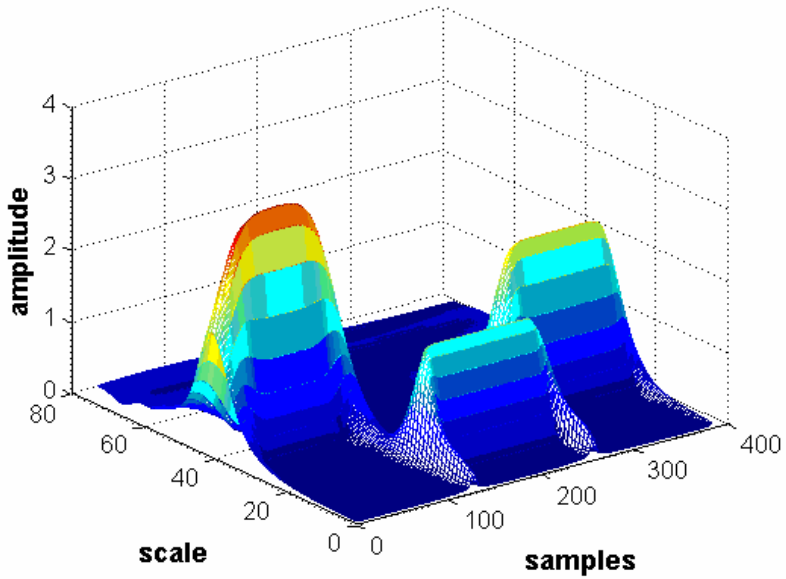


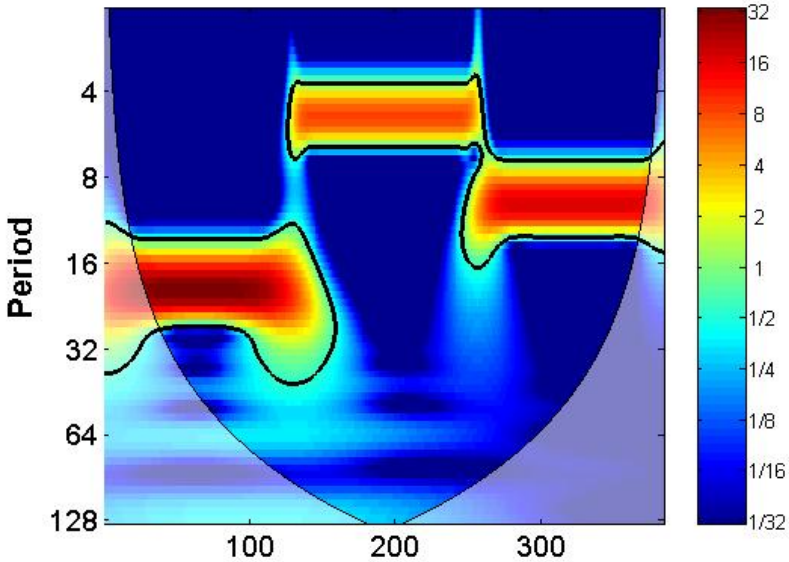
Continuous Wavelet Example





Signal made of three frequencies (0.05, 0.2 and 0.1 Hz) each present in 128 consecutive samples.





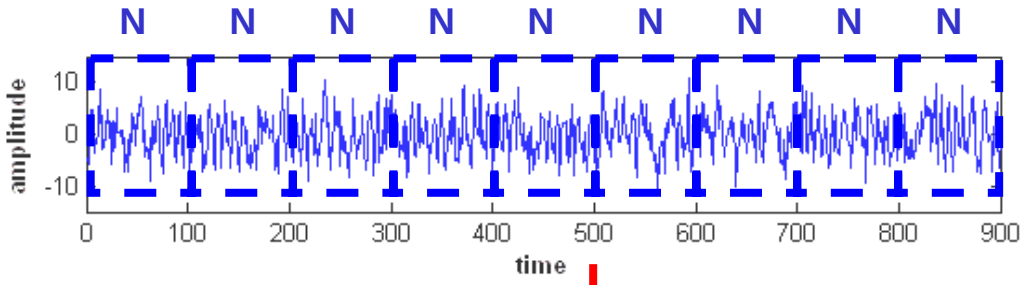
Time Domain Averaging across all Scales (TDAS)

Gearbox Data Characteristics

1. Gearbox data is periodic and the periodicity is related to the rotation frequency of the shaft. (Time Domain Average)
2. Vibration data is very noisy. (Time Domain Average)
3. Gear faults can be detected more effectively by observing the Gear Meshing Frequency GMF. (Wavelet Analysis)
4. Both distributed and local faults need to be detected by observing and characterizing the local features of the signal at different scales. (Wavelet Analysis)

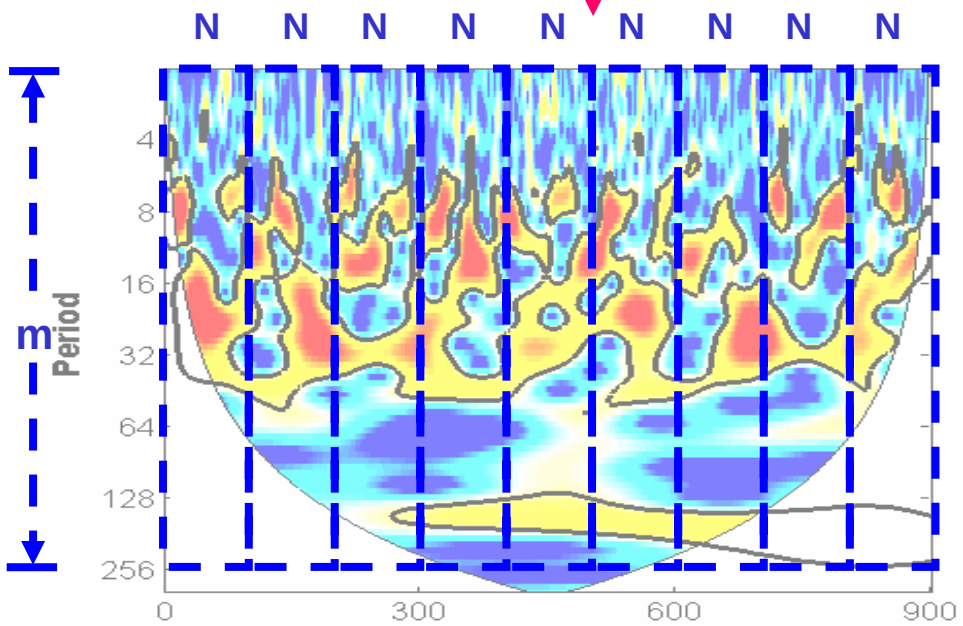
- This Proposal : Combine both Wavelet analysis and Time Domain Averaging Technique

Methodology



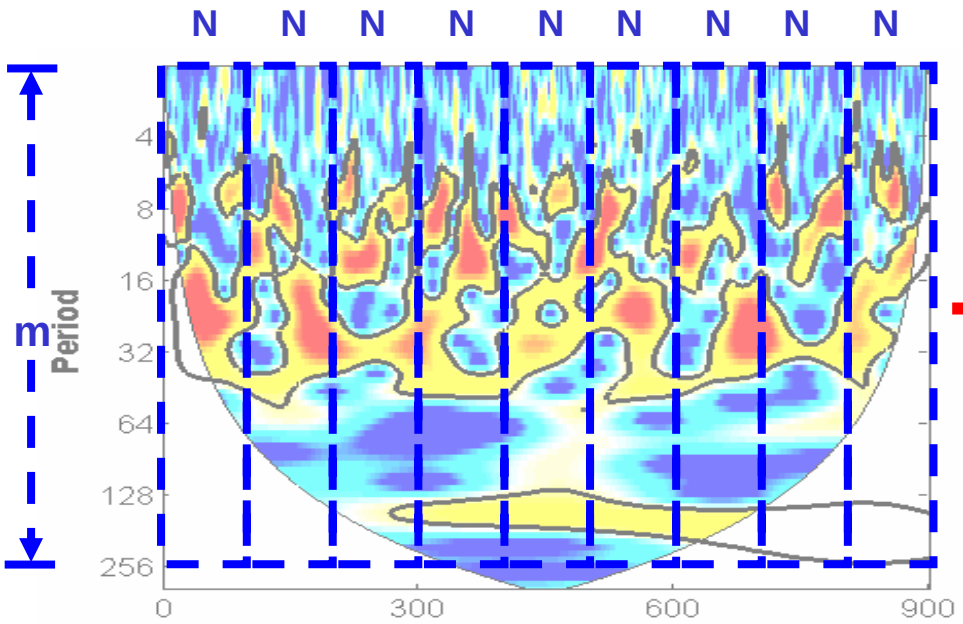
Periodic Time series x(t)
Row vector with n samples and period N

Performing Wavelet Transformation and taking the absolute value

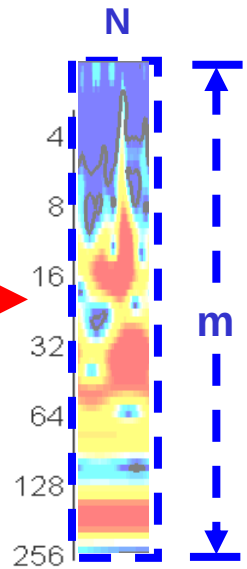


Wavelet Coefficient W(s)
Matrix with n samples and m scales

Methodology (cont.)



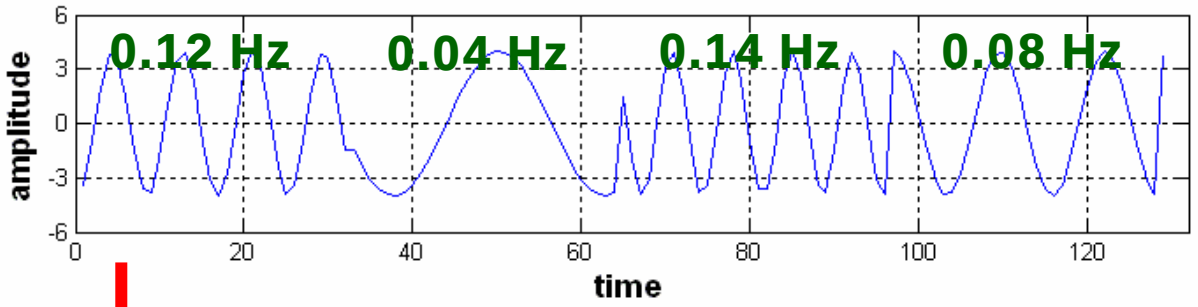
Folding or averaging each time series of all scale over N samples



Wavelet Coefficient W(s)
Matrix with n samples and m scales

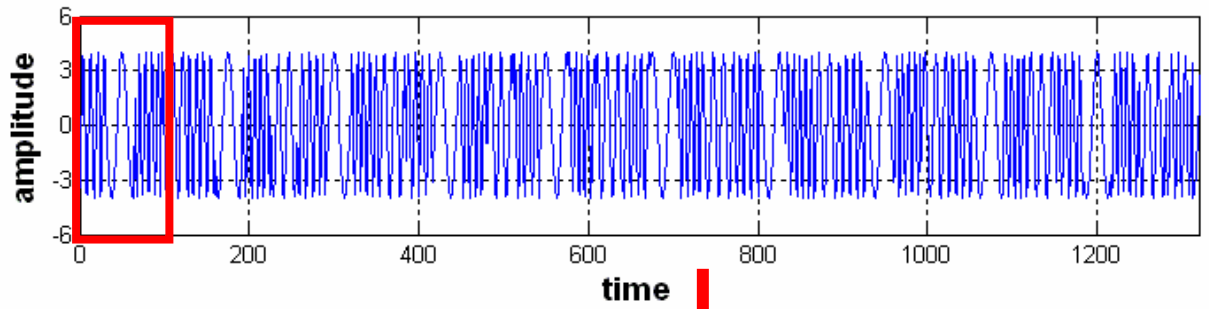
TDAS Segment V(s)
Matrix with N samples and m scales

Example – Signal Generation

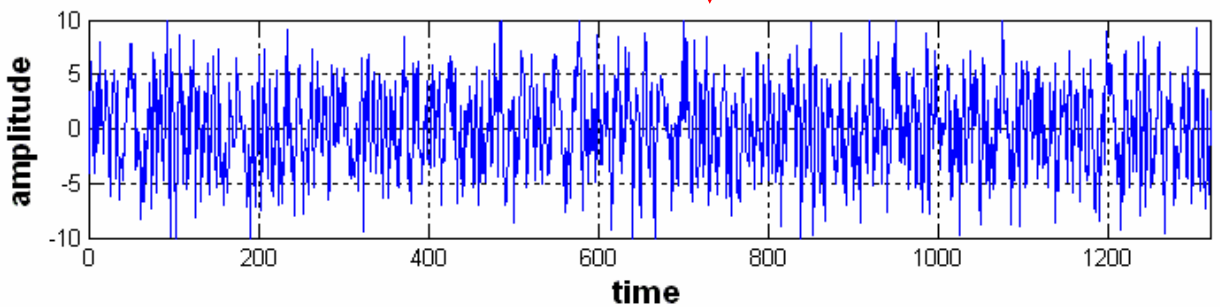


4 frequencies of 32 samples each

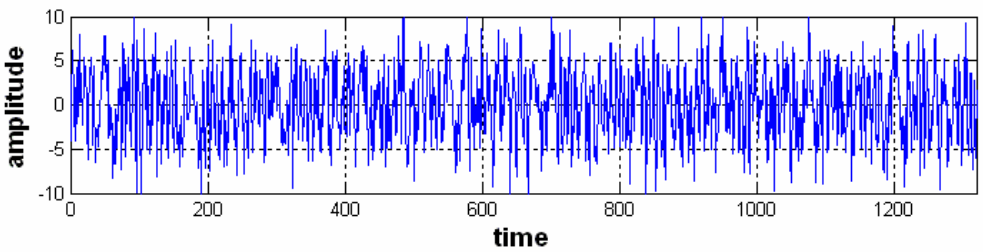
1 period of 128 samples

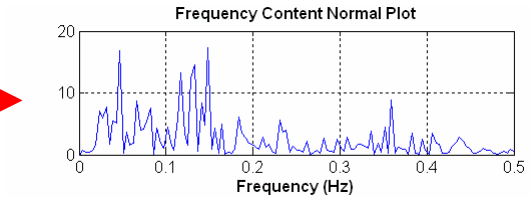


adding noise SNR=1



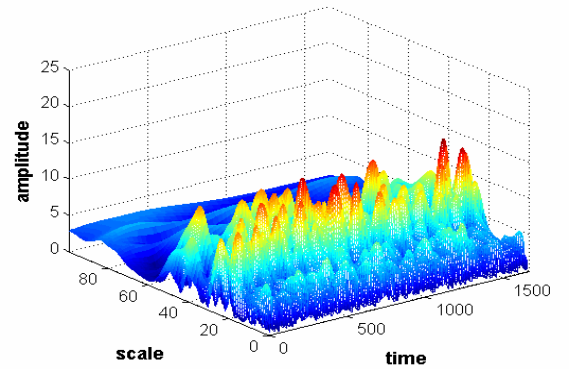
Example – Wavelet and TDAS



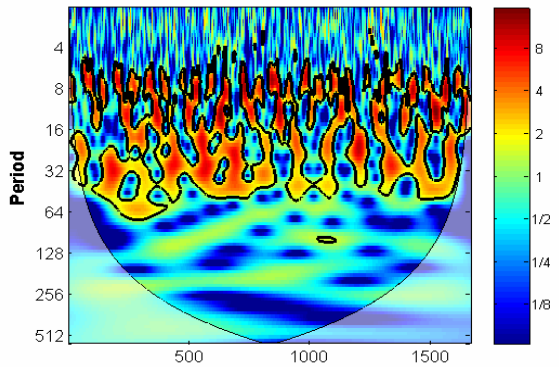


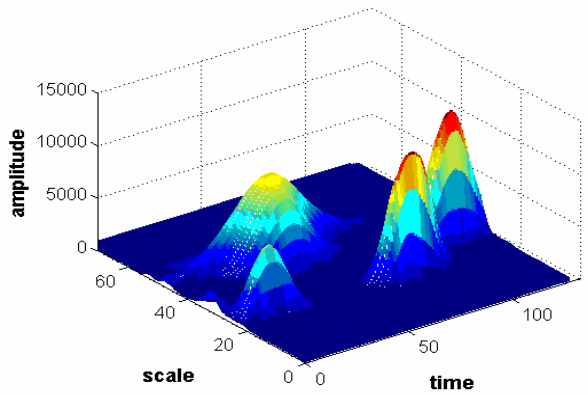
Power Spectrum

Time Trend Plot

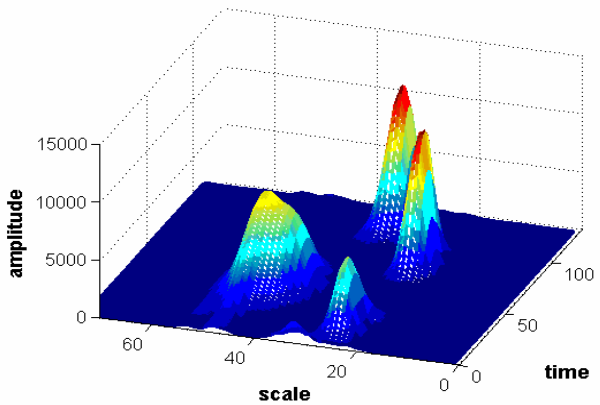


Wavelet Plot



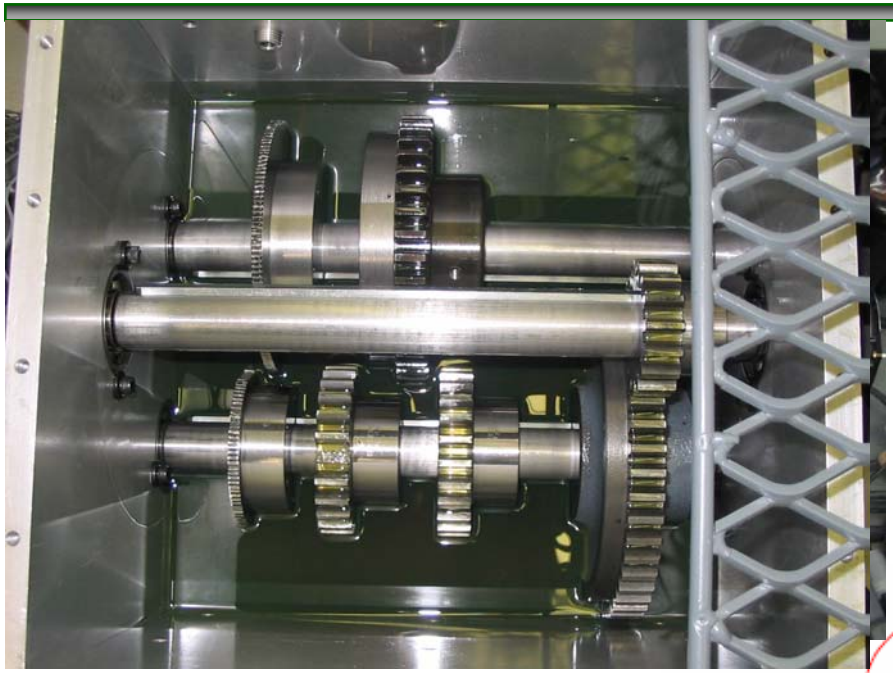


TDAS Plot



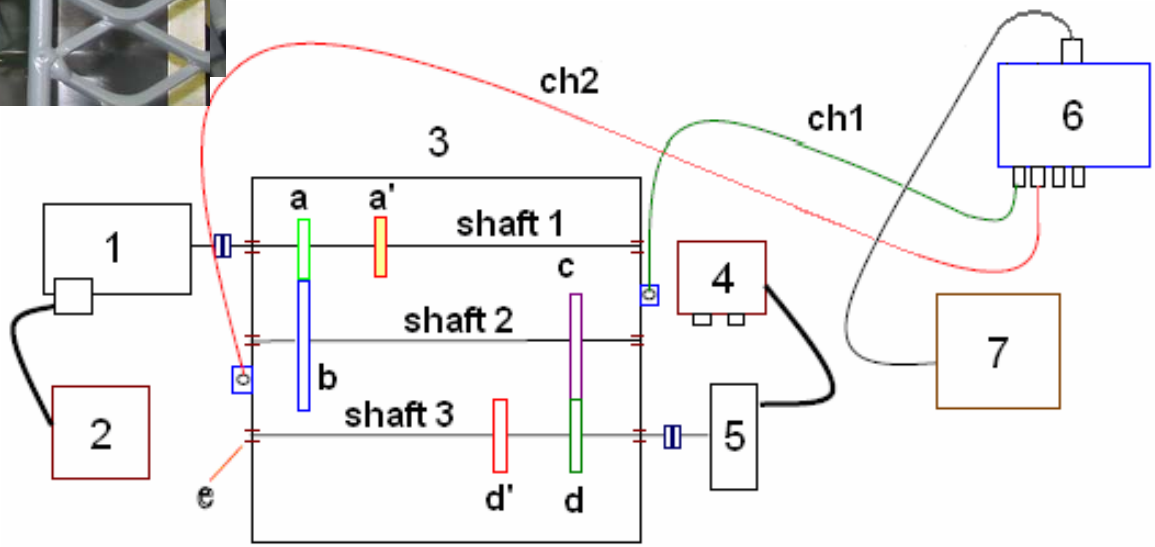
Pilot Plant Case Study

Pilot Plant Case Study



Rig to generate data for pilot plant case study, located in the Reliability Lab of Mechanical Engineering Department at University of Alberta.

1-Motor,
2-Speed Controller,
3-Gearbox,
4-Brake Controller,
5-Brake,
6-Vibration Analyzer,
7-Computer



Data Set

Data was generated for the following 4 conditions:

1. Gear with all normal teeth

2. One Chipped Tooth in one gear

3. One Missing Tooth in one gear

4. One Chipped Tooth in one gear and one Missing Tooth in another gear

The gearbox had 3 shafts rotating at 10 Hz, 3.3 Hz and 5 Hz approximately.

Calculating the period

The 2 shafts holding the faulty gears were rotating at:

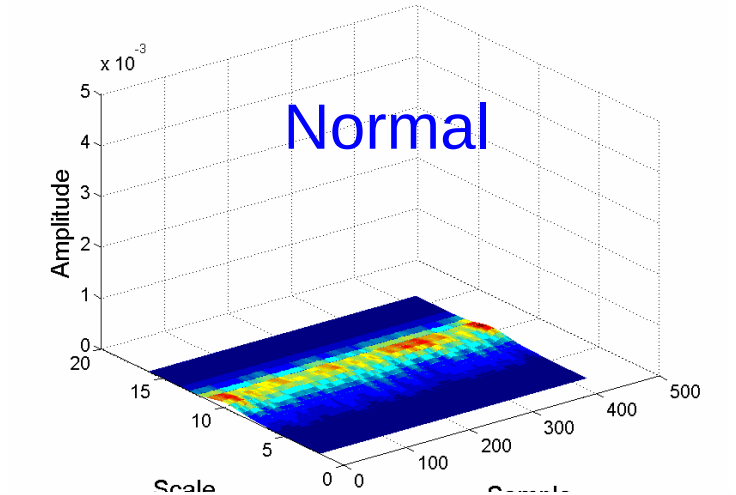
1. Gear with Chipped Tooth : Period of 0.1 sec (10 Hz)
2. Gear with Missing Tooth : Period of 0.2 sec (5 Hz)

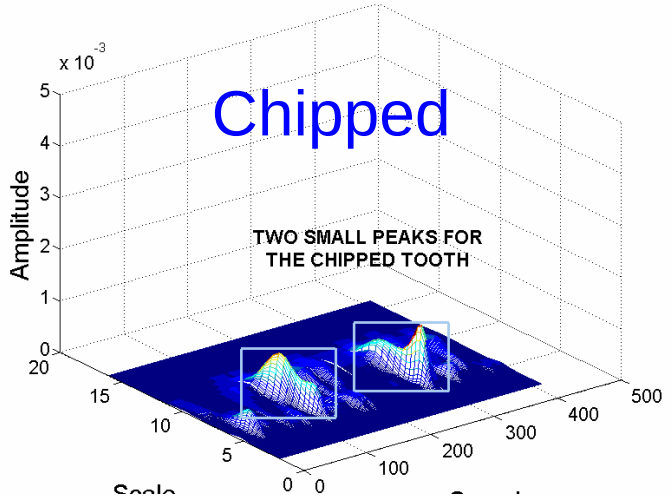
The LCM (Least Common Multiple) of the periods of the rotating shafts is 0.2 sec, and this is taken as the period to calculate the Time Domain Average across all Scales (TDAS).

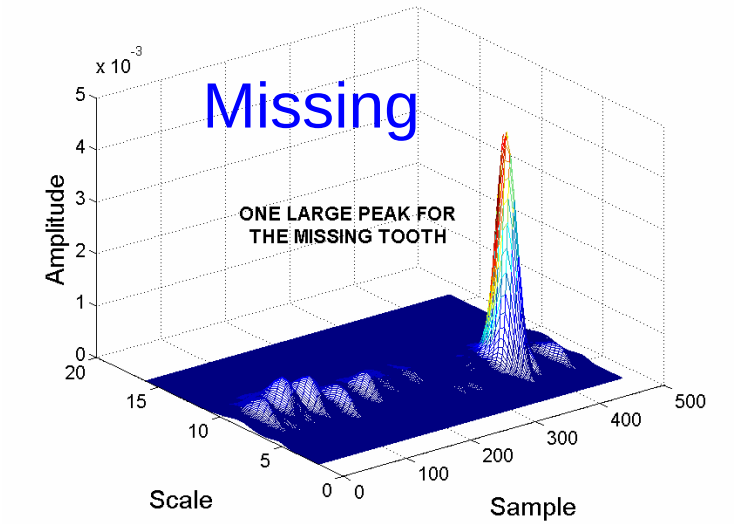
In a TDAS period the shafts holding the faulty gears rotate:

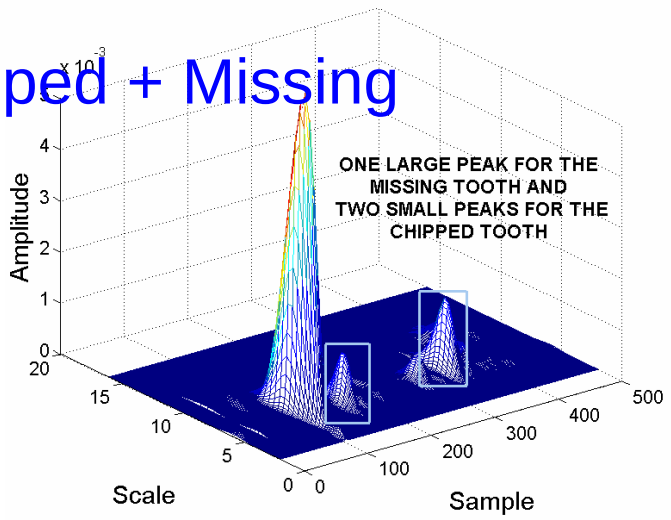
1. Gear with Chipped Tooth : 2 times (0.2/0.1)
2. Gear with Missing Tooth : 1 time (0.2/0.2)

Application on Real Data









Acknowledgements

1. Ramesh Kadali and Trevor Hrycay

2. John Hersey

3. Riaan Van Schalkwyk and Jim Geddes

4. NSERC – Suncor – Matrikon - iCore

QUESTIONS ?