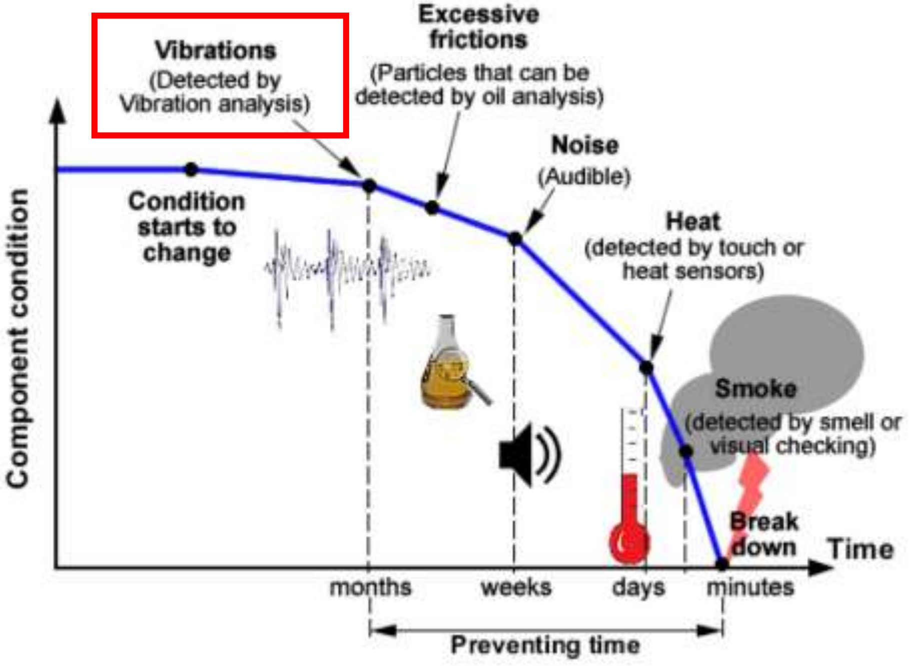
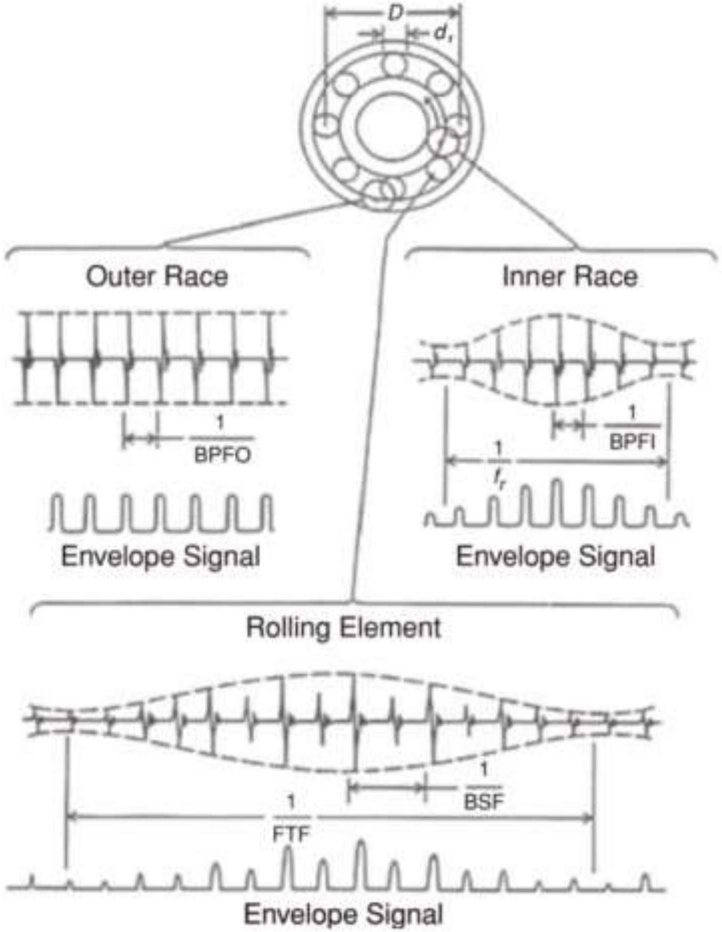
Optimal Feature Performance Analysis in IESFOgram for Bearing Diagnostics

A. Mauricio[1, 2], S. Schmidt[3], K. Gryllias[1,2]

[1]Department of Mechanical Engineering, KU Leuven
[2]DMMS-M: Dynamics of Mechanical and Mechatronic Systems, Flanders Make
[3]Centre for Asset Integrity Management, Department of Mechanical and Aeronautical Engineering, University of Pretoria, Pretoria, South Africa

Condition monitoring





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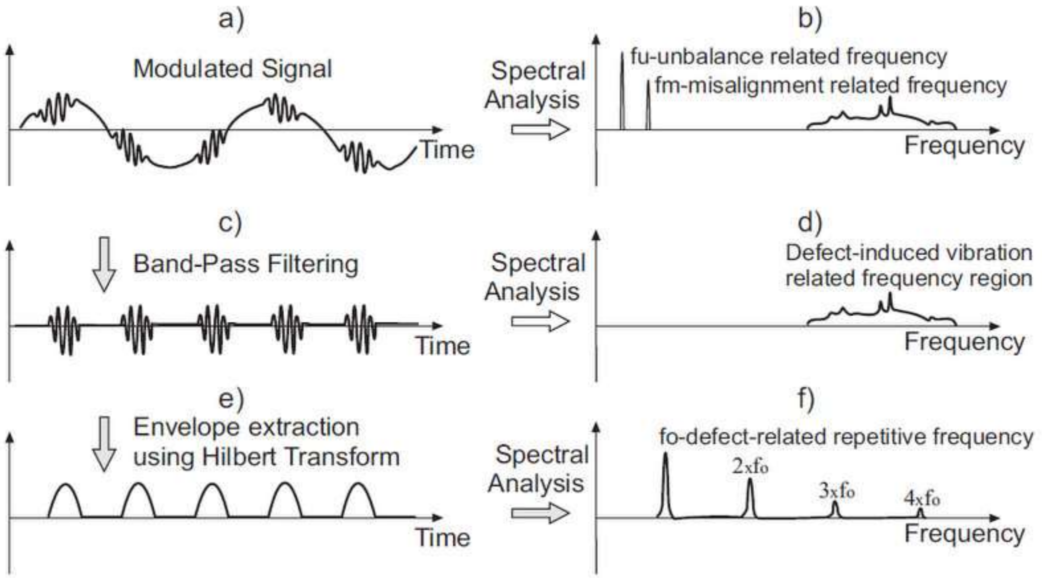
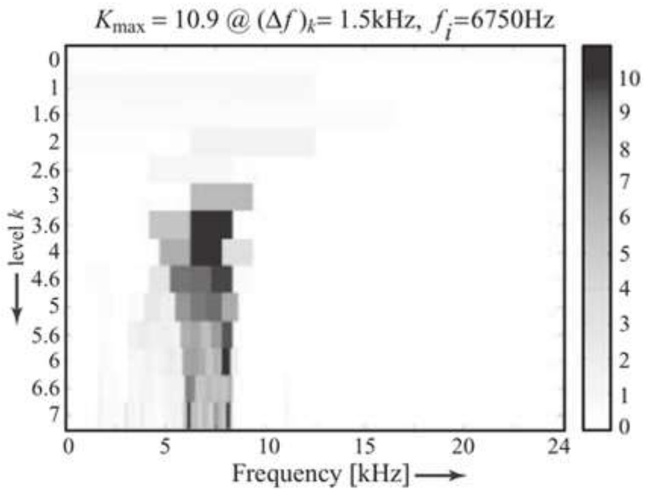
Bearing damage detection

Filtered SES



Fast Kurtogram



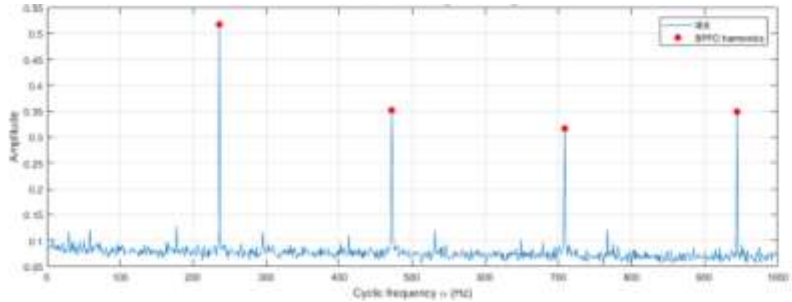
Blind Features:
Fast Kurtogram
Autogram
Protrugram
Infogram
…

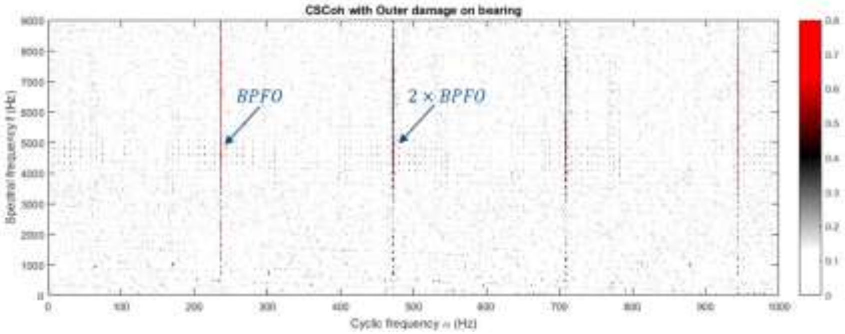
Frequency Targeted:
Cyclogram
ICS2gram
IFBIgram

Blind and Targeted features on the Cyclic Spectral Coherence

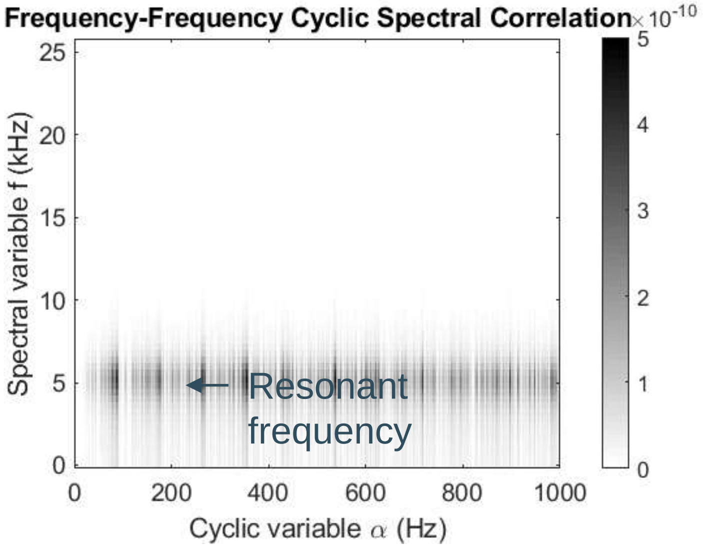
Steady and varying speed for diagnostics

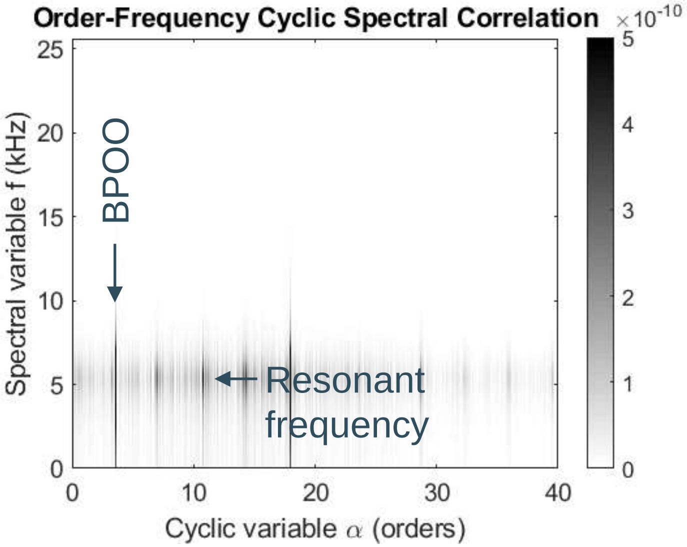
Steady speed





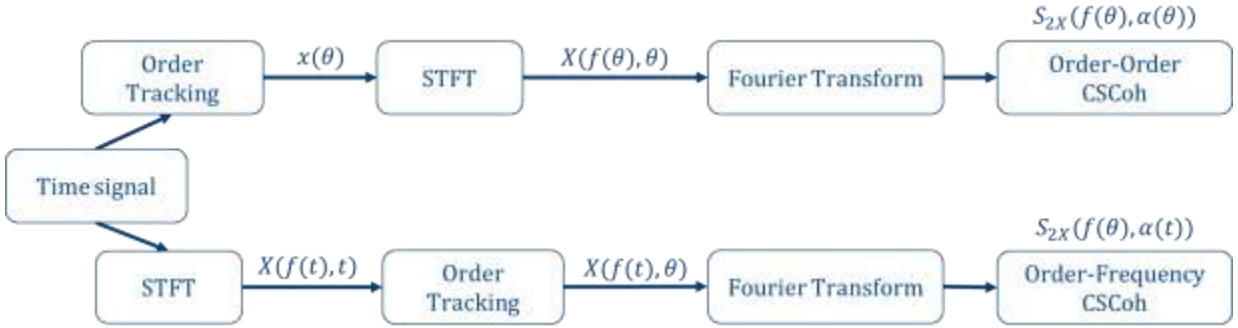
Varying speed



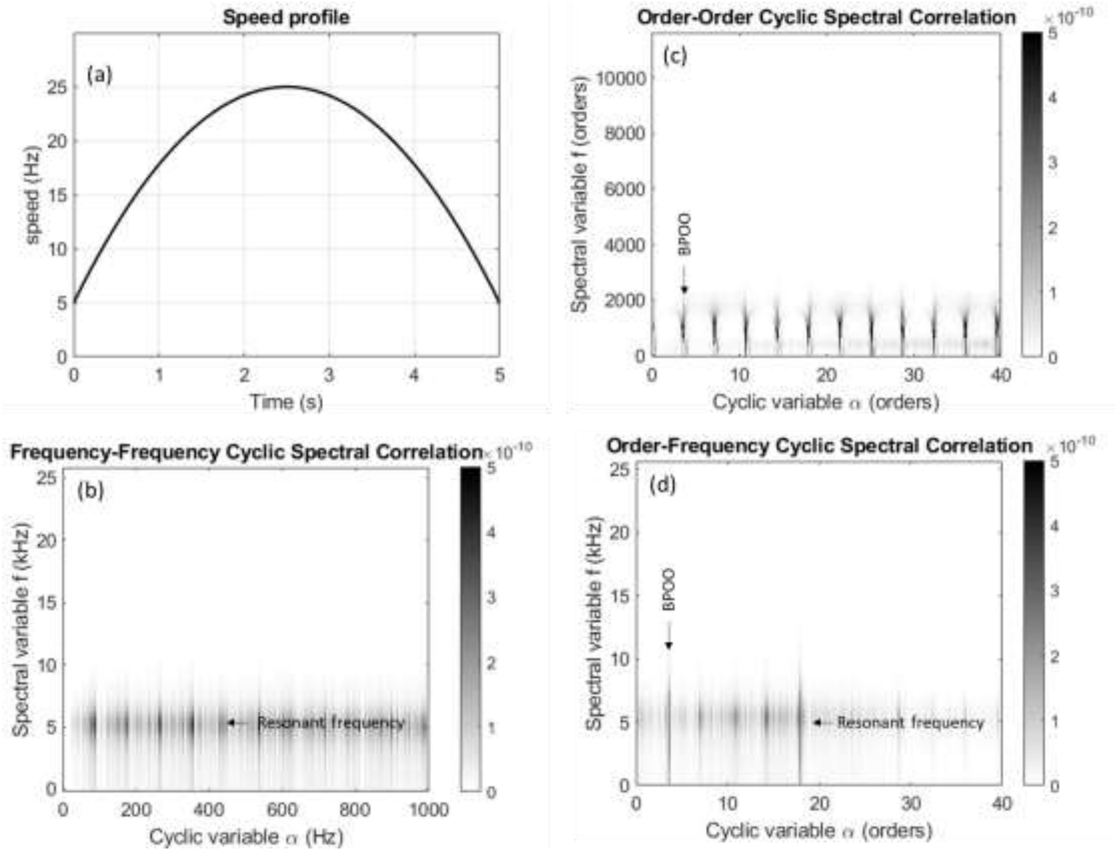


Steady and varying speed for diagnostics

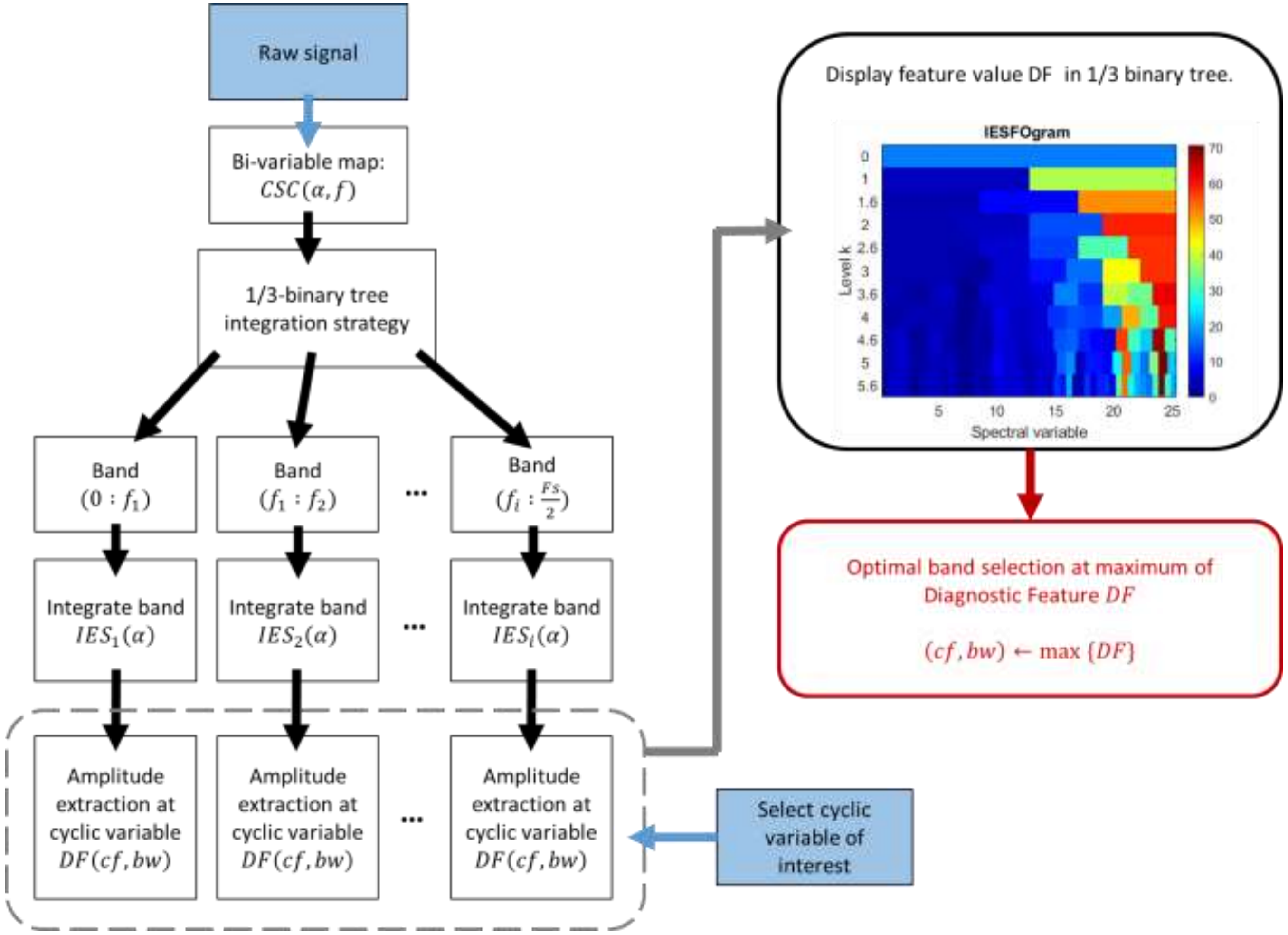
Retains angle-related carrier frequencies.



Retains time-related carrier frequencies.



Methodology



Blind features:

Spectral Kurtosis,
Spectral Negentropy
Gini Index
Spectral Flatness

$$K = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^4}{(\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2)^2} - 3$$

$$Neg = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{x_i^2}{\frac{1}{N}\sum_{i=1}^{N} x_i} ln \frac{x_i^2}{\frac{1}{N}\sum_{i=1}^{N} x_i}\right)$$

$$G = 1 - 2\frac{1}{N}\sum_{i=1}^{N}\frac{x_{(i)}}{||x||}\left(\frac{N - i + \frac{1}{2}}{N}\right)$$

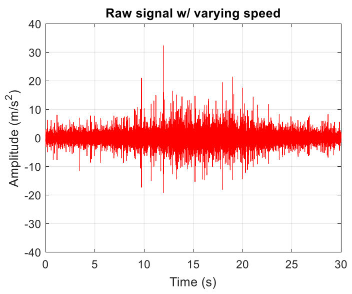
$$SF = \frac{exp(1/N\sum_{i=1}^{N-1} lnX(i))}{1/N\sum_{i=1}^{N-1} X(i)}$$

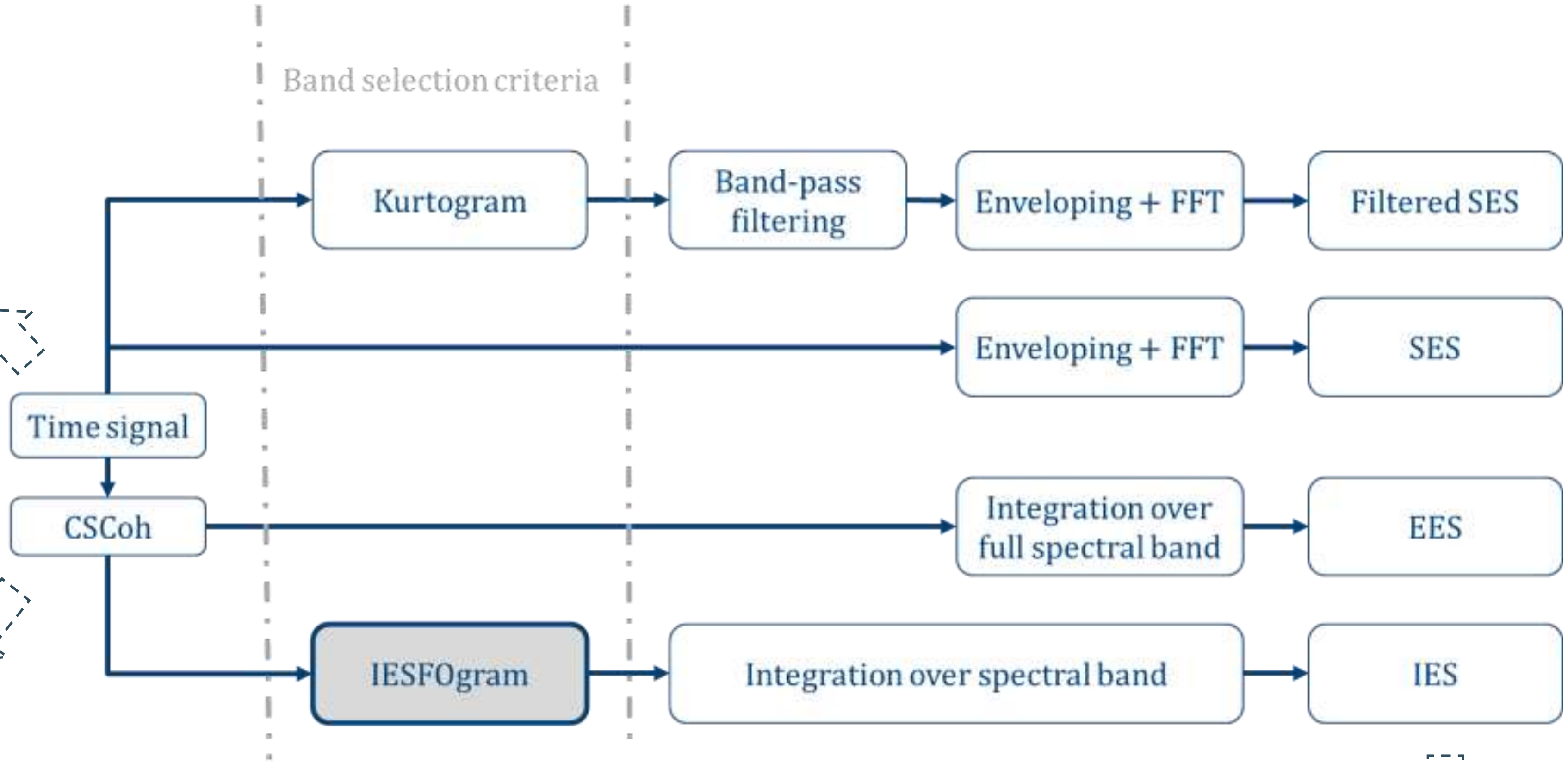
Bearing Frequency-Targeted features:

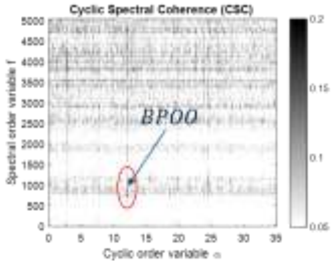
α_{fault} = BPFI, BPFO, BSF or FTF

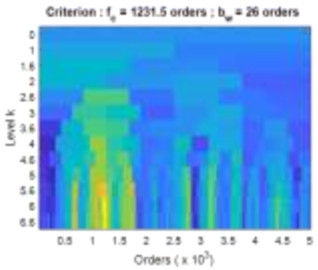
$$DF(cf, bw) = \sum_{k=1}^{N}\frac{IES_{cf,bw}(k \times \alpha_{fault})}{\frac{1}{2f_b}\left[\int_{kf_{fault}-f_b}^{kf_{fault}+f_b} IES_{cf,bw}(\alpha)d\alpha - IES_{cf,bw}(k \times \alpha_{fault})\right]}$$

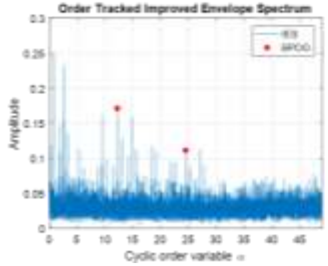
Methodology











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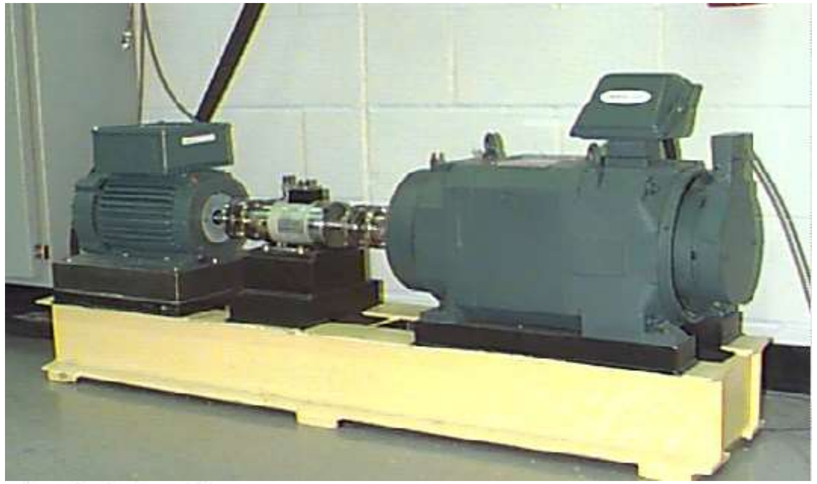
Experimental Setup

Case Western Reserve University (open dataset)



The test stand consists of a 2 hp motor (left), a torque transducer/encoder (center), a dynamometer (right), and control electronics (not shown). The test bearings support the motor shaft. Single point faults were introduced to the test bearings using electro-discharge machining with fault diameters of 7 mils, 14 mils, 21 mils (1 mil=0.001 inches)

Bearing Information

Drive end bearing: 6205-2RS JEM SKF, deep groove ball bearing

Size: (inches)

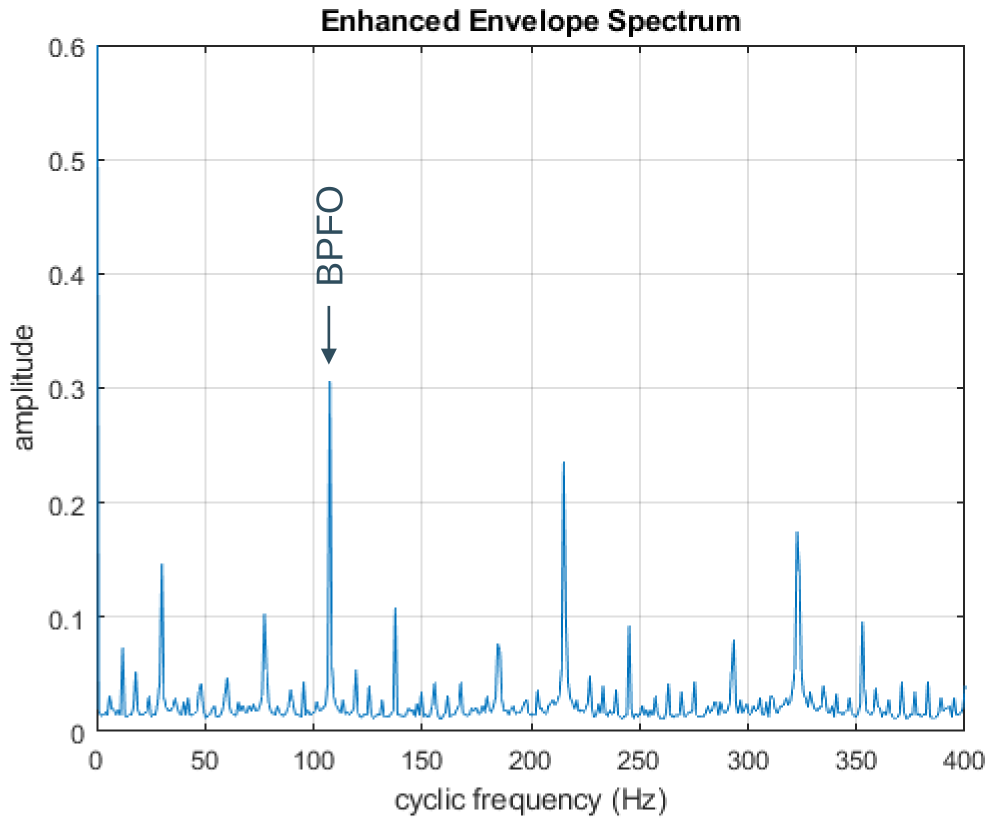
Inside Diameter	Outside Diameter	Thickness	Ball Diameter	Pitch Diameter
0.9843	2.0472	0.5906	0.3126	1.537

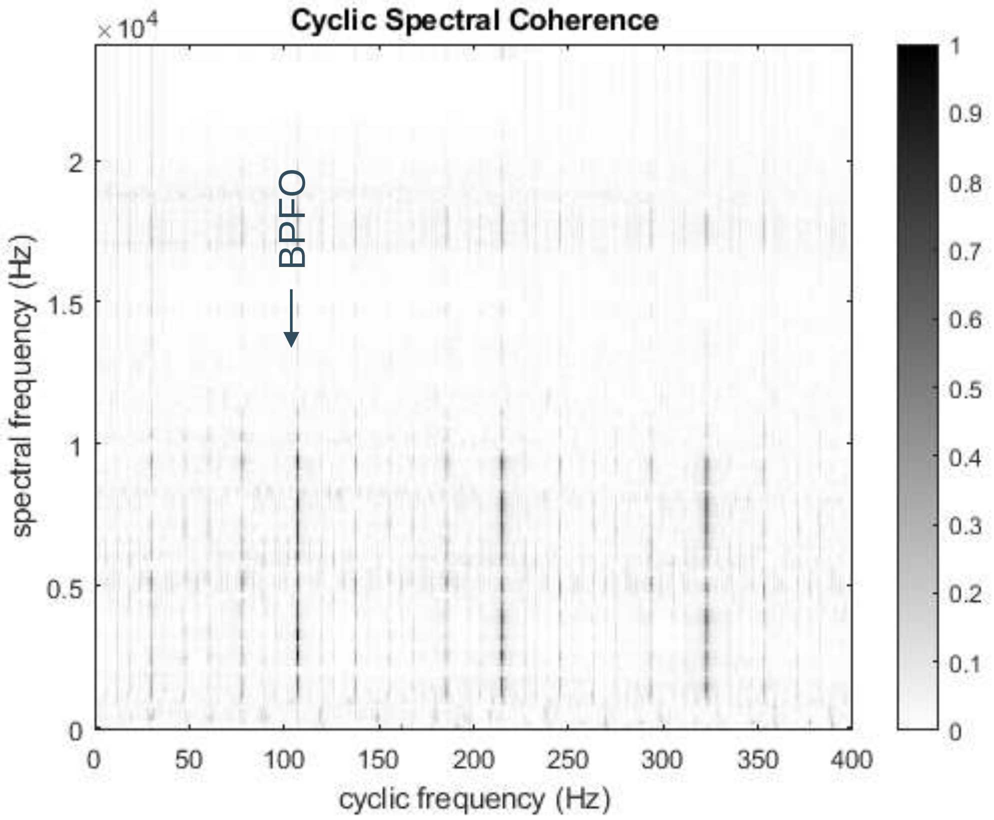
Defect frequencies: (multiple of running speed **in Hz**)

Inner Ring	Outer Ring	Cage Train	Rolling Element
5.4152	3.5848	0.39828	4.7135

Fan end bearing: 6203-2RS JEM SKF, deep groove ball bearing

Outer race damage (7'')

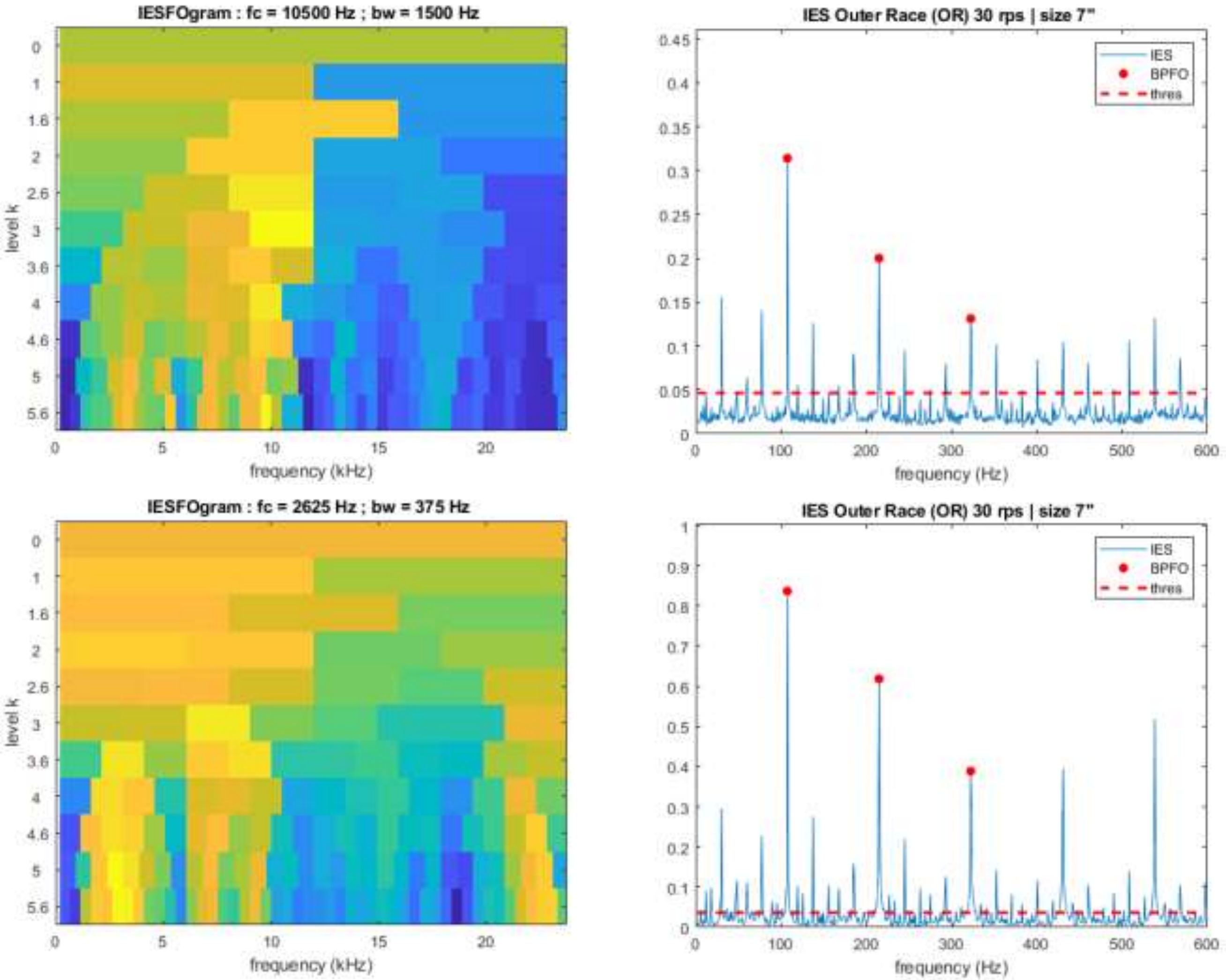




Targeted at BPFO and Gini Index (Blind)

From all features, the targeted feature at the damage related frequency (BPFO) shows a selection of a rich band carrier resulting in clear diagnosis.

The Gini Index also shows good performance on selecting a rich band throughout the dataset.

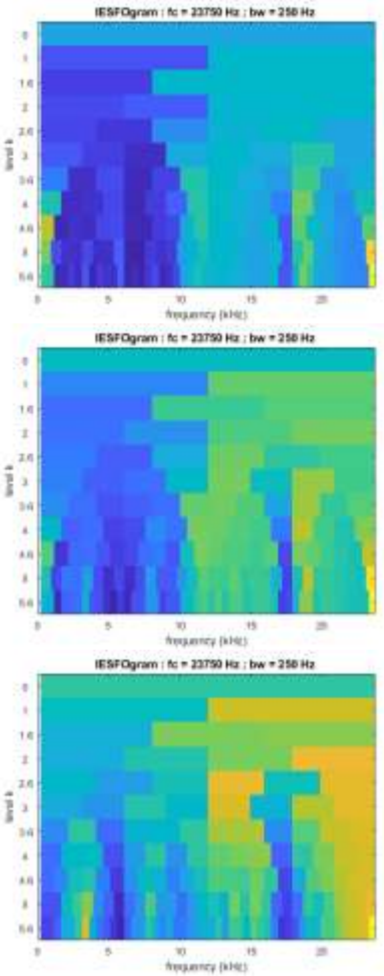


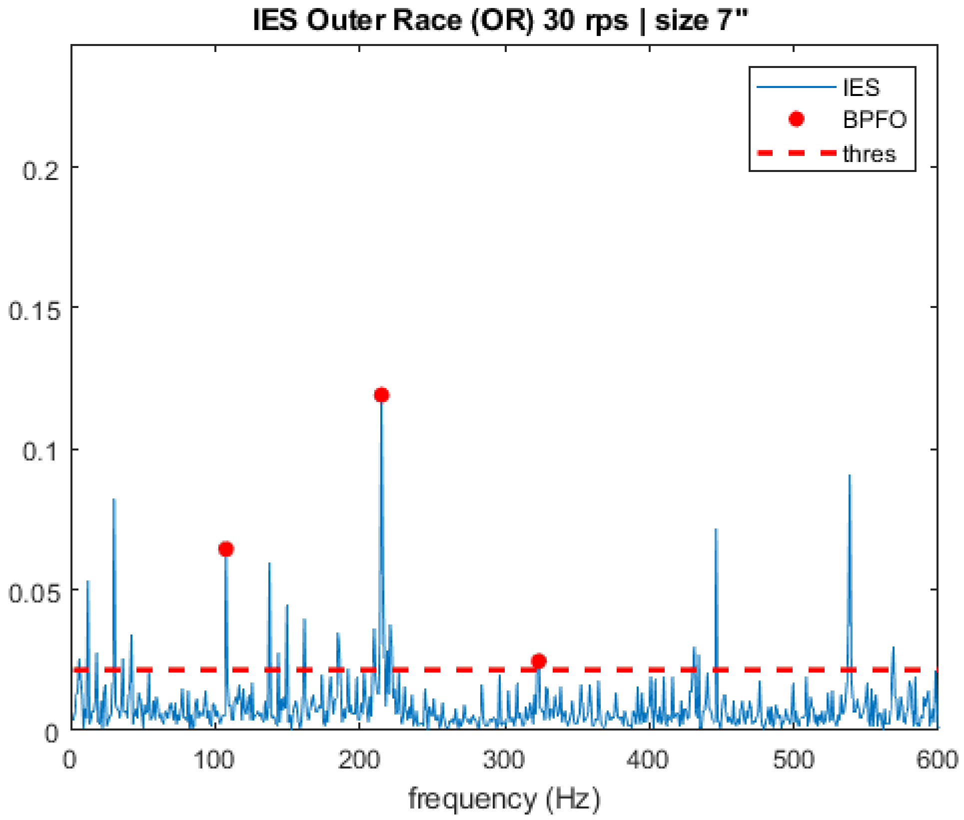
Remaining blind features

Other blind features select (converge) to small band at the Nyquist.

Envelope spectra at Nyquist is seen often to be sparse.

Kurtosis
Spectral Negentropy
Spectral Flatness





DMMS-M Drivetrain setup

Self-aligning bearing SKF 2206

Damage with width approx. 5.5mm
Made with dremel

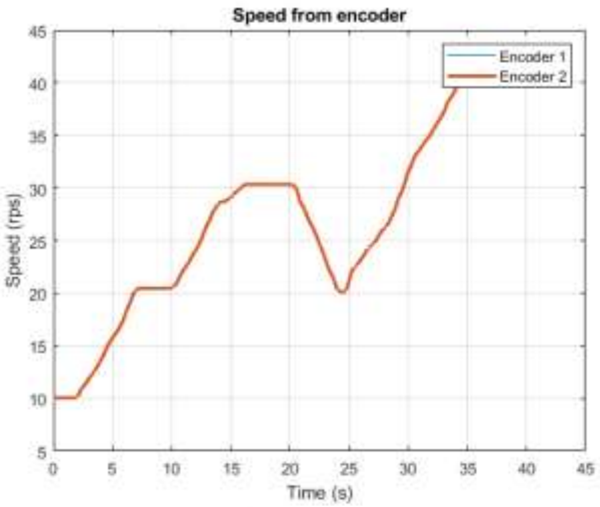
Characteristic damage frequency:

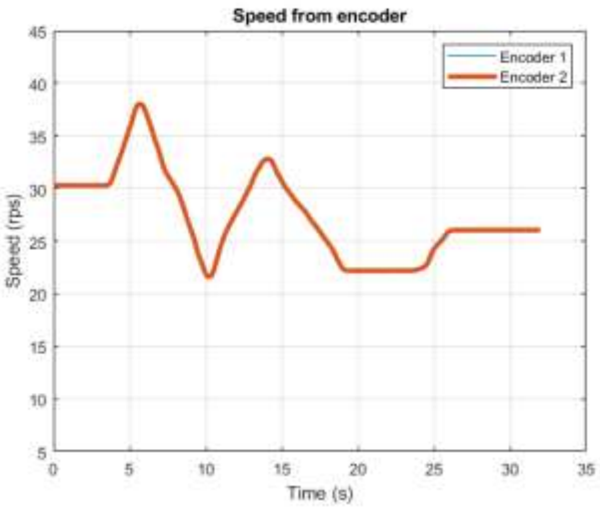
Ball Pass Frequency of Outer race

$$BPFO = fshaft * BPOO$$
$$BPOO = 4.724$$

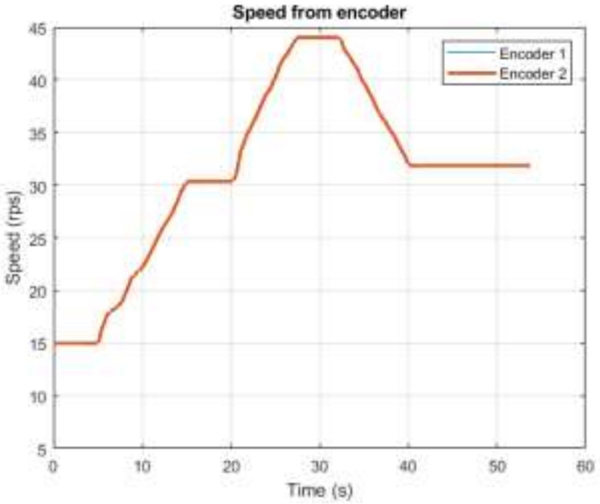
One disc mounted at the middle distance between the bearings (bearing-150mm-disc-150mm-bearing).
One 3D accelerometer PCB 256A15 mounted on the housing (X-radial horizontal, Y-radial vertical, Z - axial)
One microphone PCB 378B20 distanced 300mm from housing

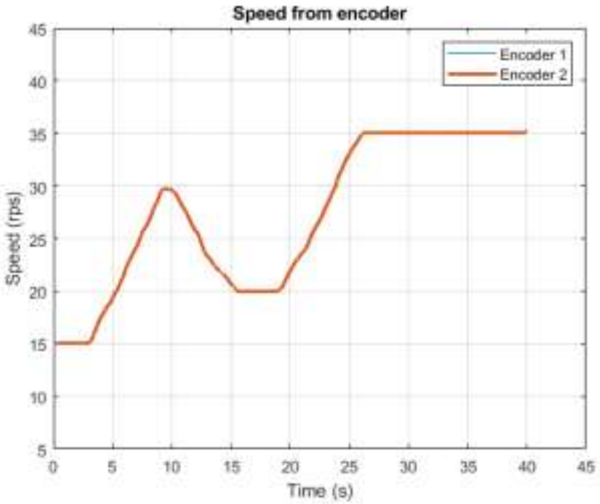
Varying speed measured





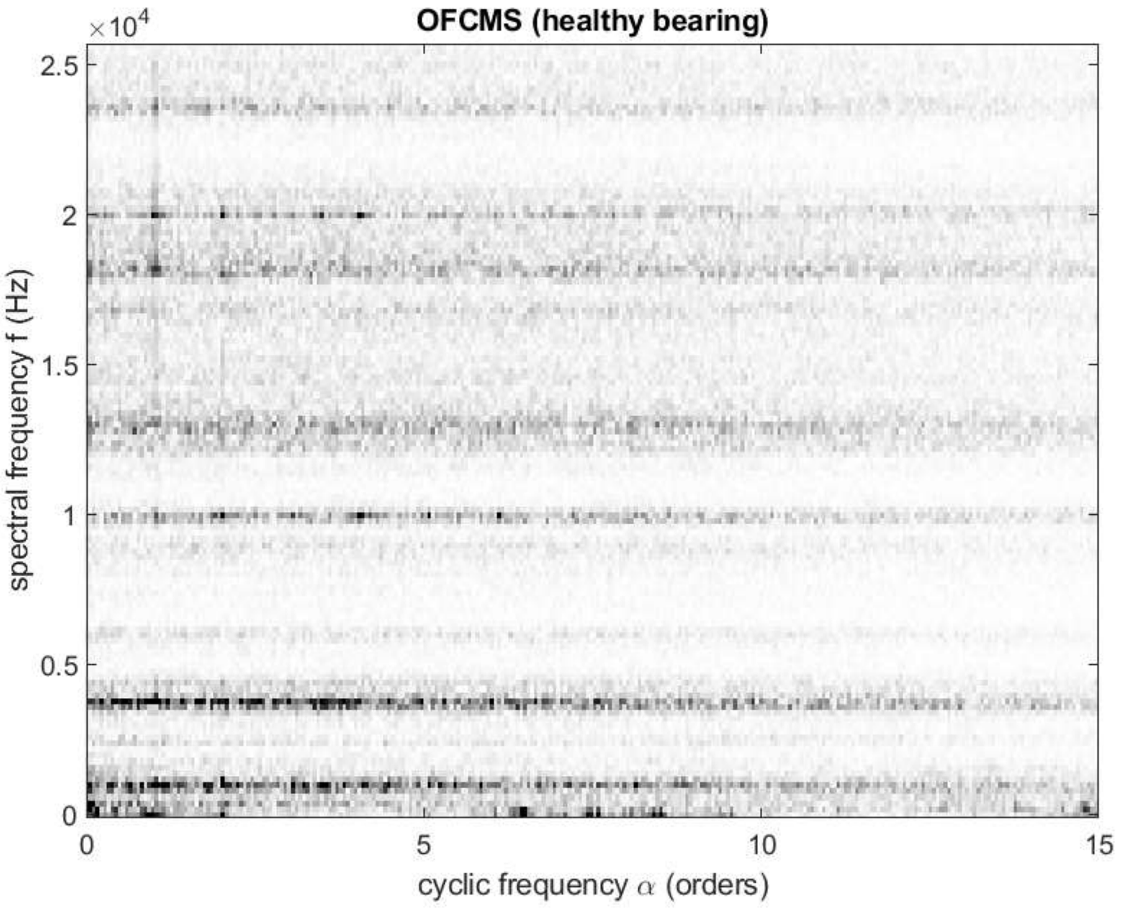
Damaged signals

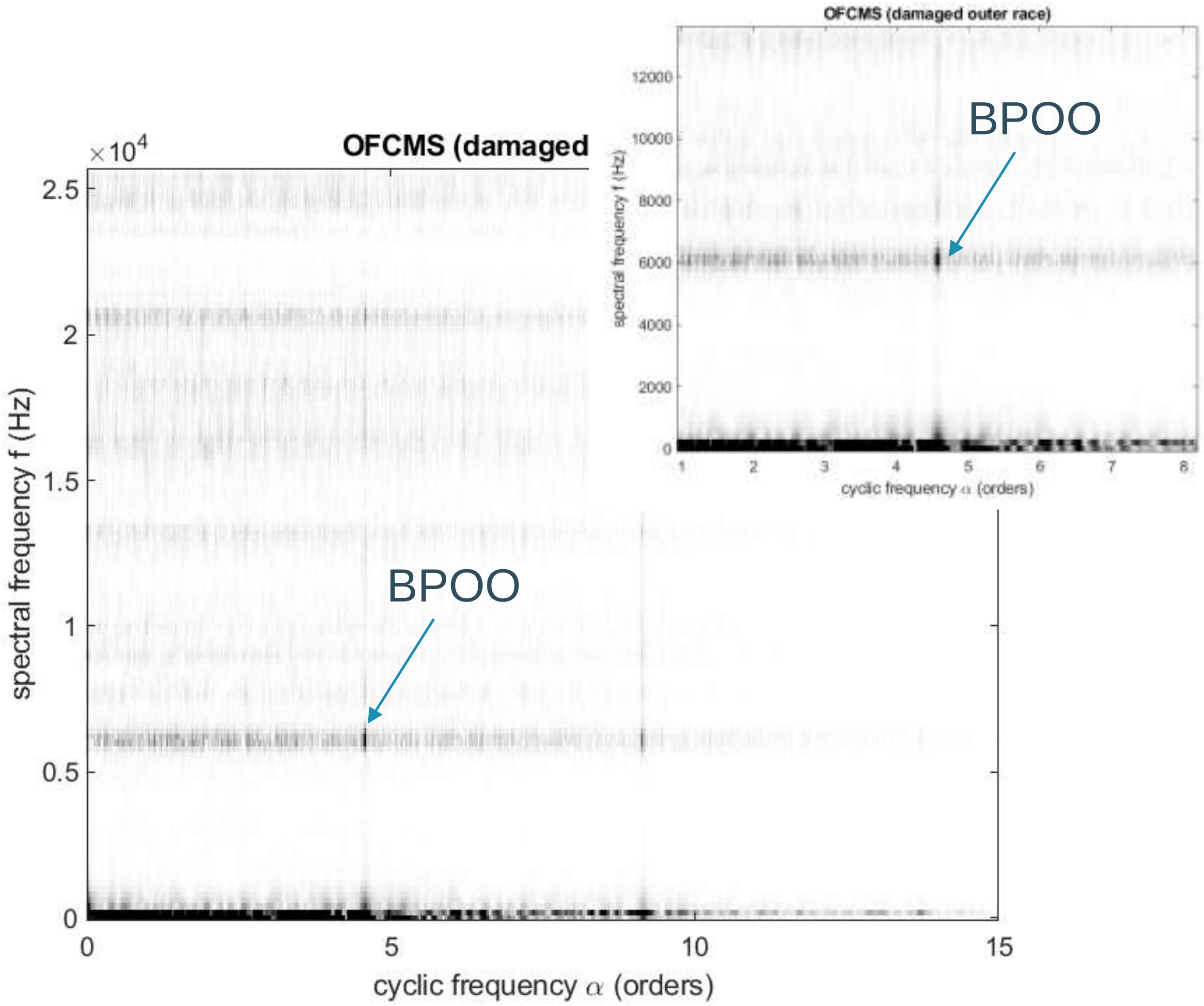




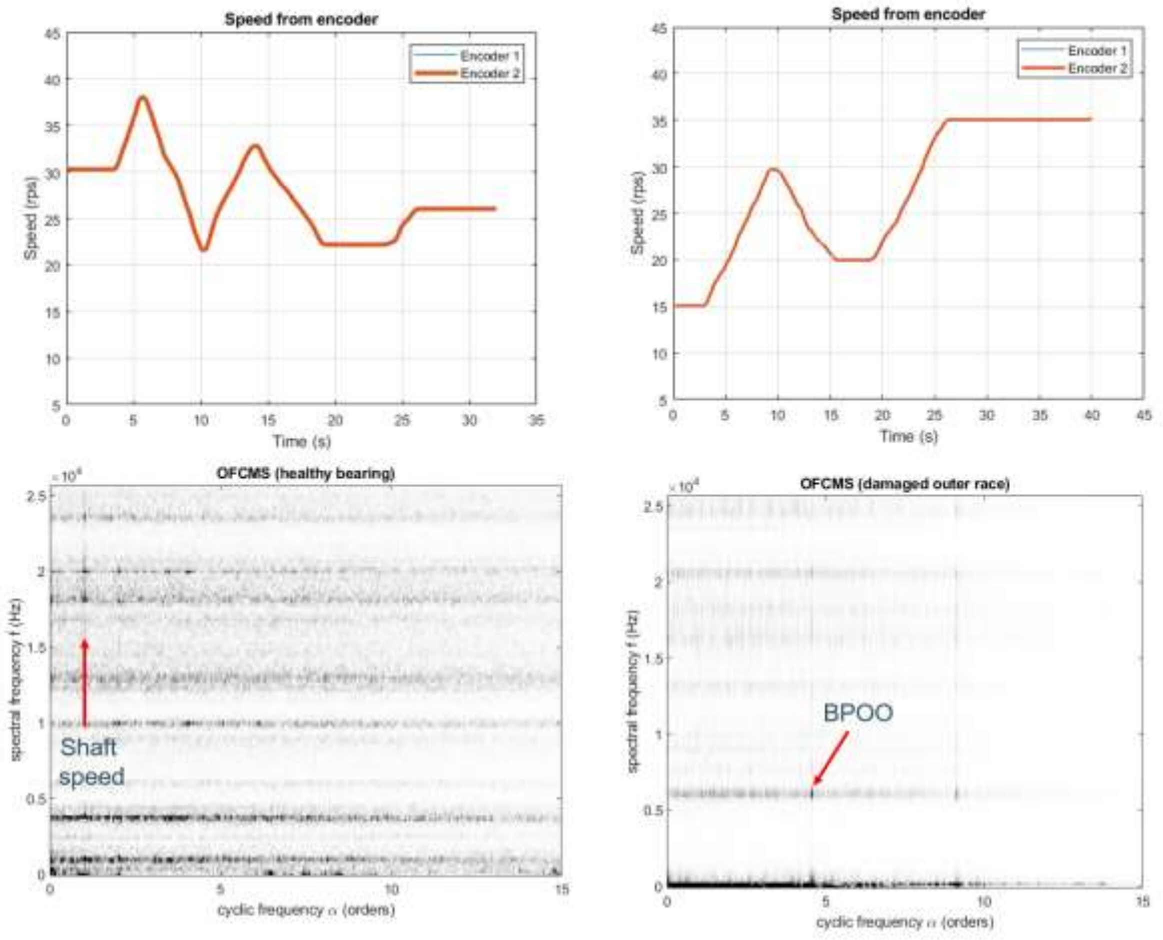
Healthy signals

Order Frequency Spectral Correlation



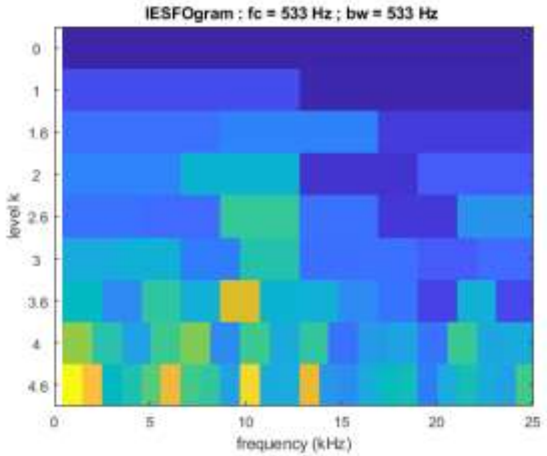


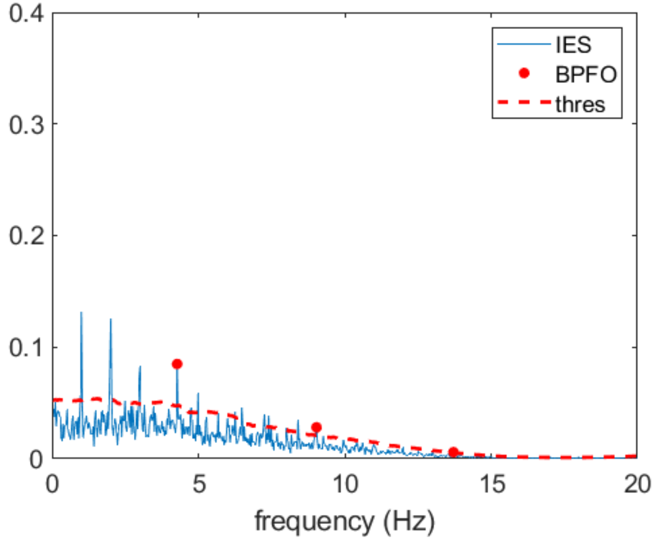
Overall view on speed and OFCMS for healthy and damaged



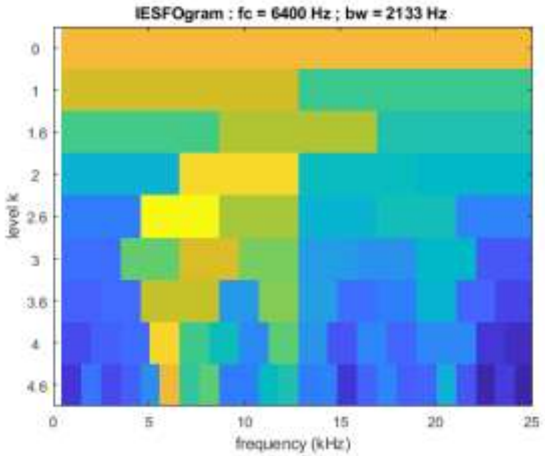
IESFOgram targeted at BPFO

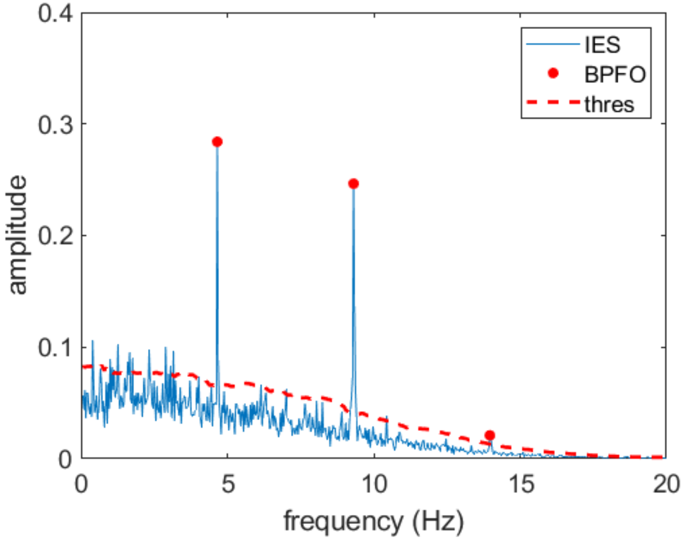
Healthy



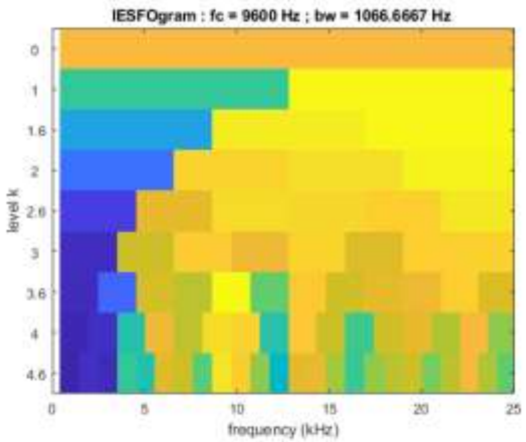


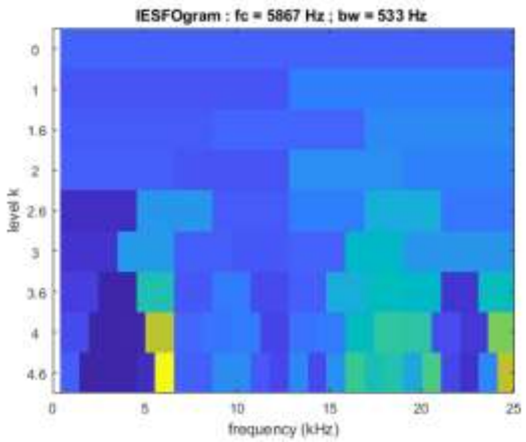
Damaged



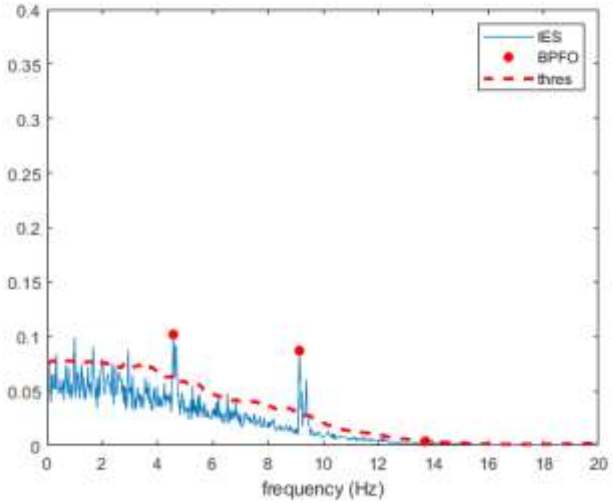


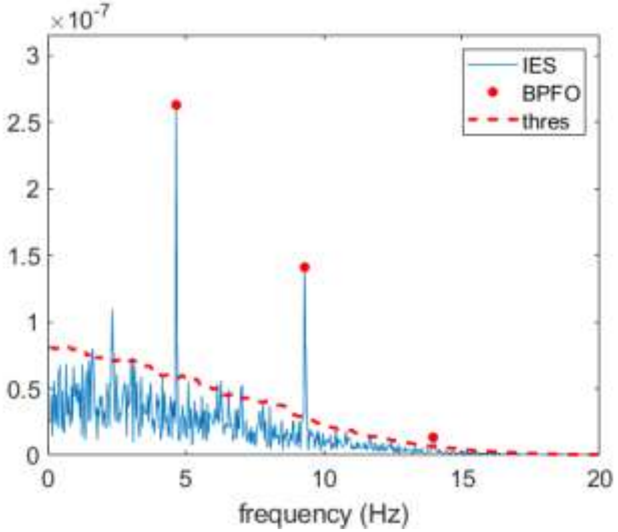
Blind IESFOgram on damaged case





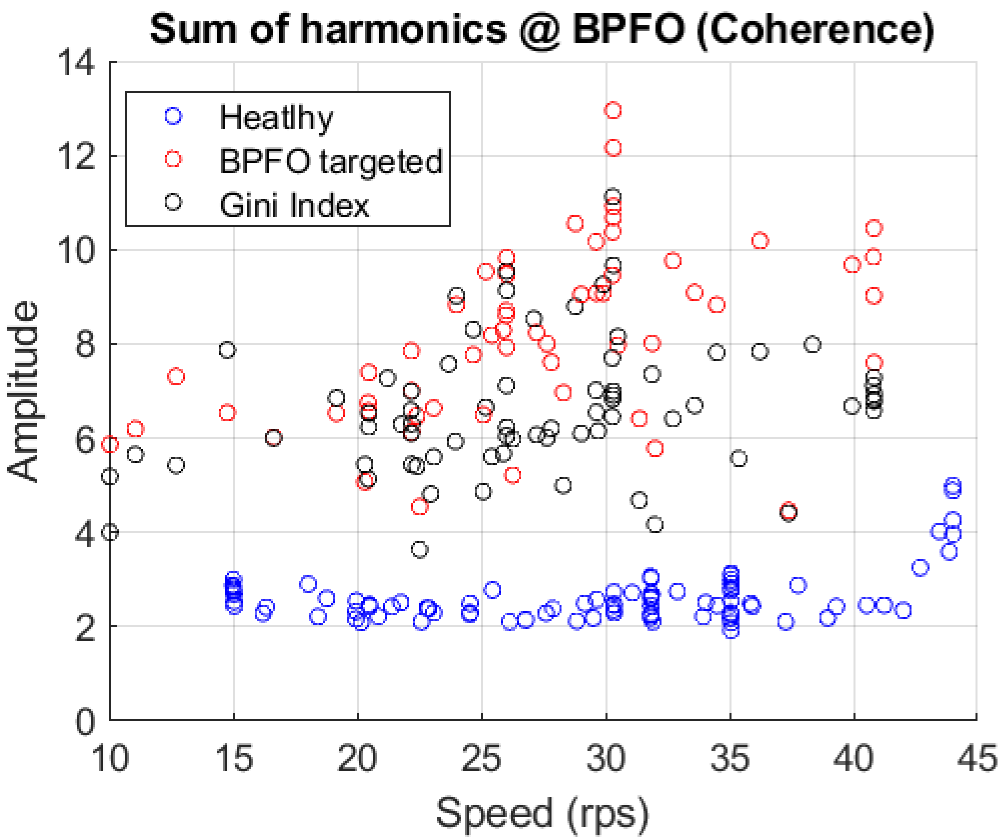
Kurtosis

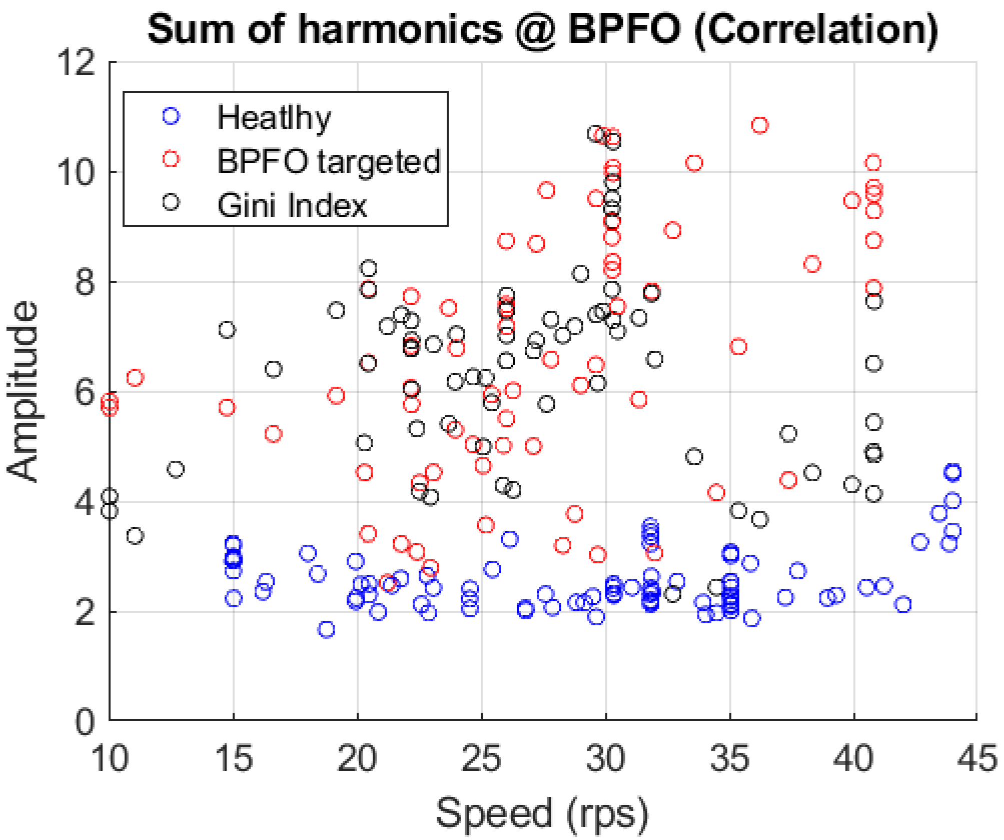




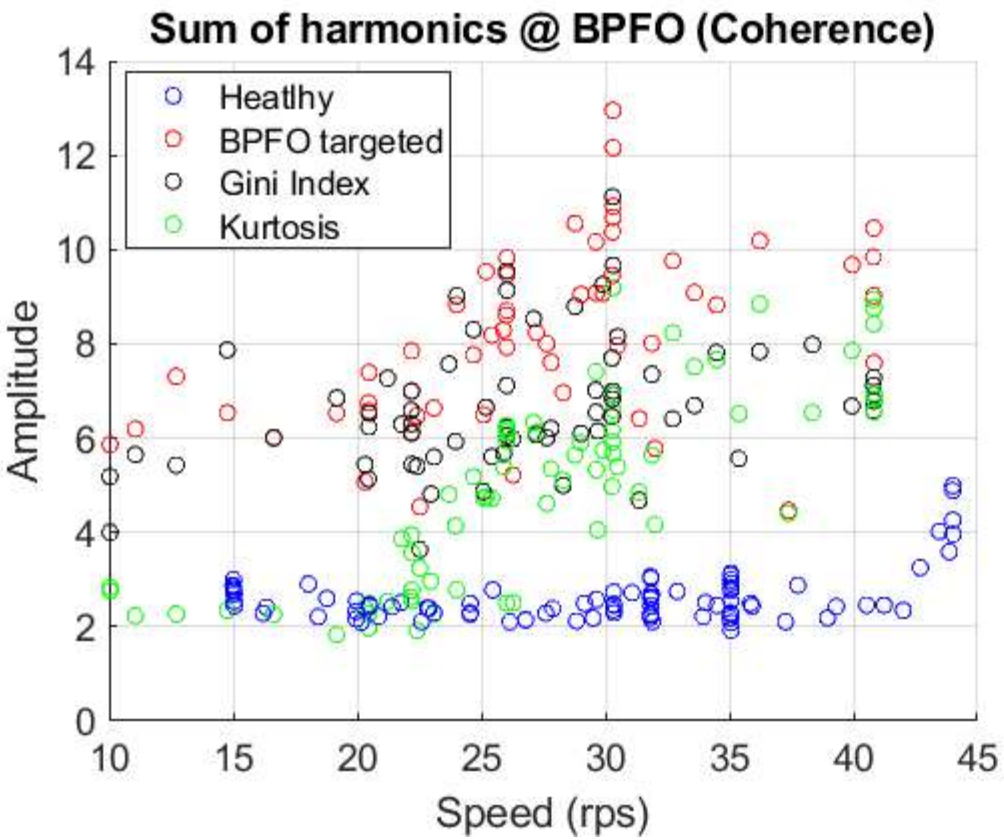
Gini Index

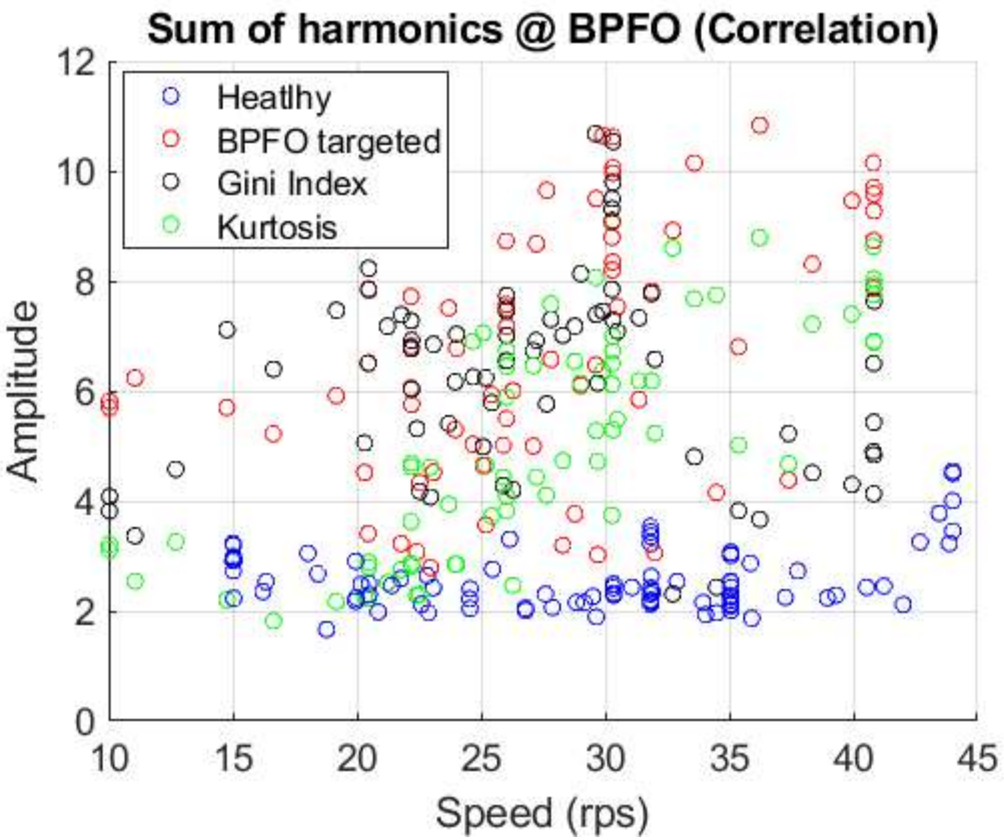
Sum of harmonics at the BPFO (Normalized)



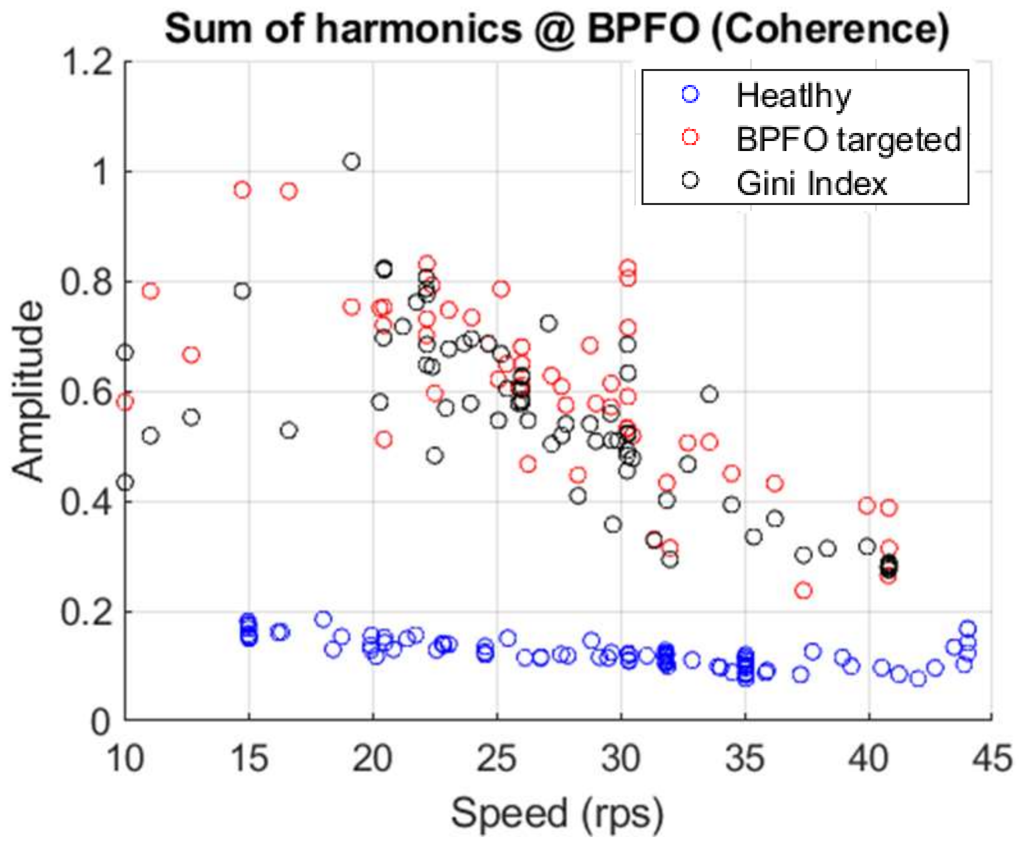


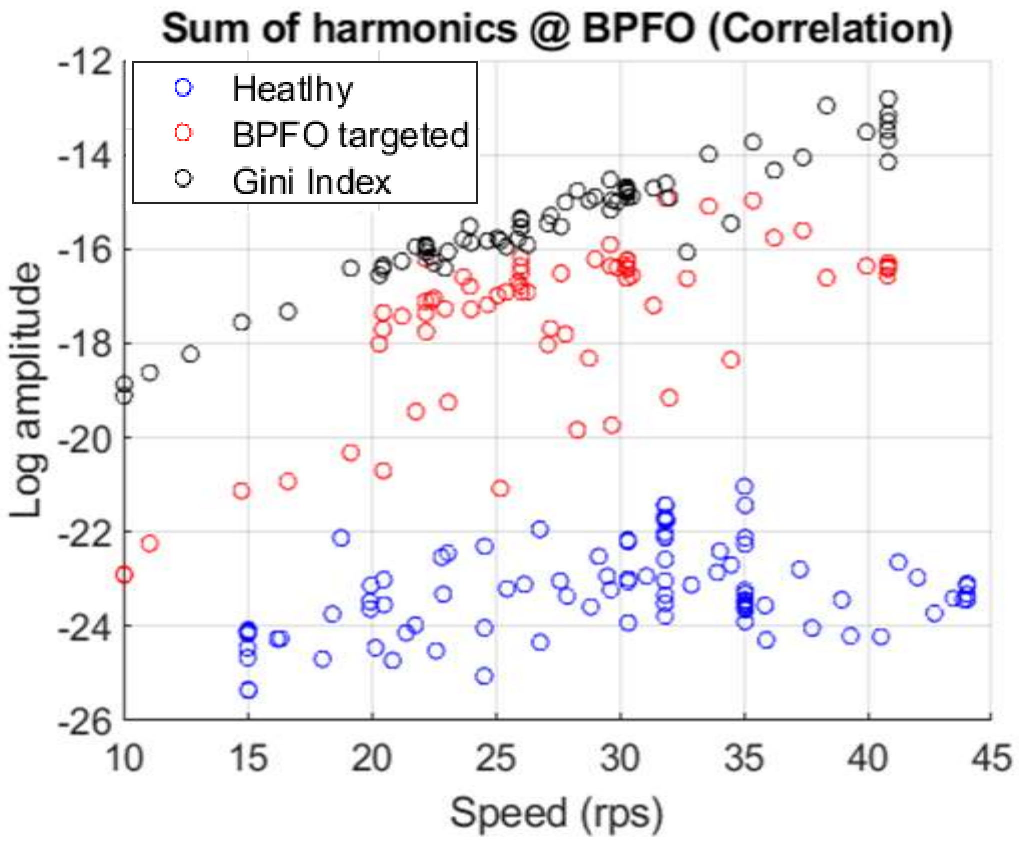
Sum of harmonics at the BPFO (Normalized)





Sum of harmonics at the BPFO (Absolute)





Conclusions

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- A comparison of the performance of frequency-targeted features vs. blind feature for band selection has been performed.
- The features were extracted from the Cyclic Spectral Coherence in either Frequency-Frequency or Order-Frequency domain (IESFOgram)
- Vibration signals under steady and varying speed conditions were used to validate and research the features robustness.
- Frequency-Targeted feature provides the best performance, albeit kinematic knowledge of the rotating structure is necessary.
- Gini Index as a feature for band selection showed good performance for steady operating conditions and varying speed conditions at the DMMS-M drivetrain
- Other blind features did not show good diagnostic capabilities for the studied cases.

Acknowledgement

The Research Foundation - Flanders (FWO) is gratefully acknowledged for its support through the ROBUSTIFY research grant No. S006119N.

KU Leuven Noise & Vibration

kuleuven.mod

KU Leuven
noise & vibration research group

@KULnoisevib

KU Leuven
noise & vibration research group

alex.ricardomauricio@kuleuven.be

www.mech.kuleuven.be/mod

Thank you for your attention

Alexandre Mauricio

Department of Mechanical Engineering, Noise & Vibration Research Group, Belgium
Dynamics of Mechanical and Mechatronics Systems, Flanders Make, Belgium
alex.ricardomauricio@kuleuven.be