Induction Generator Condition Monitoring Based in Stator Current Analysis

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Definitions

- Condition monitoring

  Collection and Interpretation of data suitable for a quantitative assessment of equipment and component condition for the purpose of instituting and conducting condition-based, predictive maintenance programs.

- Current signature analysis

  Is a non-invasive technique used to determine the operating condition of AC rotating machinery. CSA techniques can be used in conjunction with vibration and thermal analysis to confirm key machinery diagnostic decisions. CSA operates on the principle that induction machine circuits can, in essence, be viewed as a transducer and harmonic fluxes are produced in the air gap. These fluxes induce current components in the stator winding that produce current components at predictable frequencies.

- Closed frequency expressions

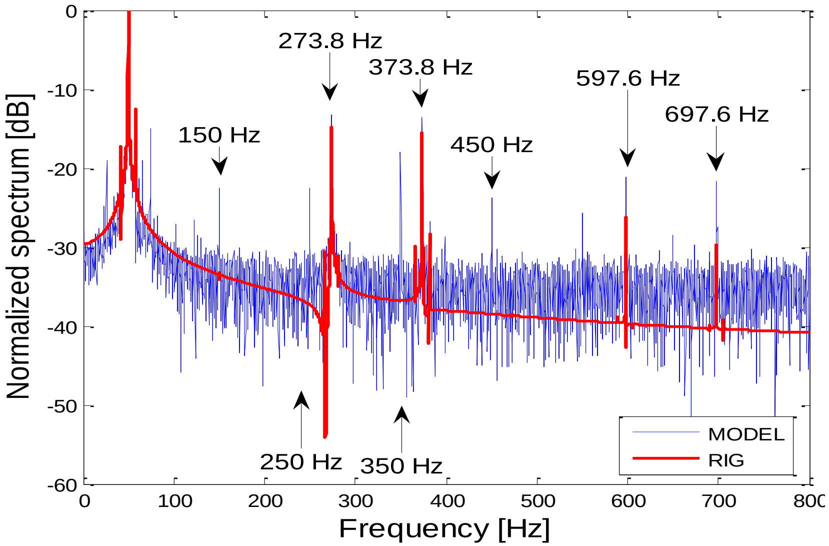
  Analytical expressions that relate the frequencies in the current spectrum with the operational condition of the machine.

General rules for DFIG steady state stator current harmonic frequencies for various balanced/unbalanced operating conditions

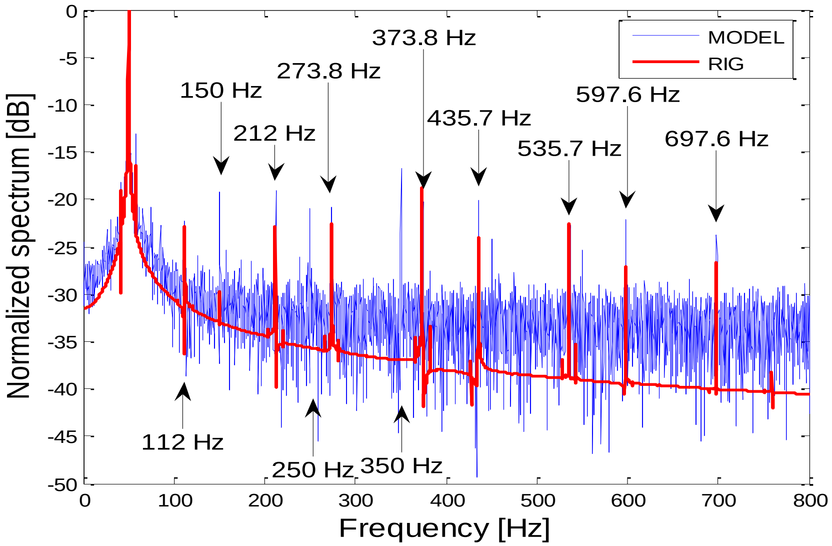
WINDINGS		SUPPLY		INDUCED DFIG STATOR CURRENT FREQUENCIES
STATOR	ROTOR	STATOR	ROTOR	
BALANCED	BALANCED	BALANCED	BALANCED	$f_{ind}^{k} = \left\|6k(1-s) \pm 1\right\| f$
BALANCED	BALANCED	BALANCED	UNBALANCED	$f_{ind}^{k} = \left\|6k(1-s) \pm 1\right\| f$ $f_{ind}^{k} = \left\|6k(1-s) \pm (1-2s)\right\| f$
BALANCED	UNBALANCED	BALANCED	BALANCED	$f_{ind}^{k} = \left\|\frac{2k}{p}(1-s) \pm \left[s + \frac{1-s}{p}\right]\right\| f$
BALANCED	BALANCED	UNBALANCED	BALANCED	$f_{ind}^{k} = \left\|6k(1-s) \pm 1\right\| f$
UNBALANCED	BALANCED	BALANCED	BALANCED	$f_{ind}^{k} = \left\|\frac{2k}{p}(1-s) \pm 1\right\| f$

$$k=0,1,2,3\ldots$$

Steady-state analysis: Frequency content of predicted and measured stator line current for healthy DFIG and a stator winding open-circuit fault

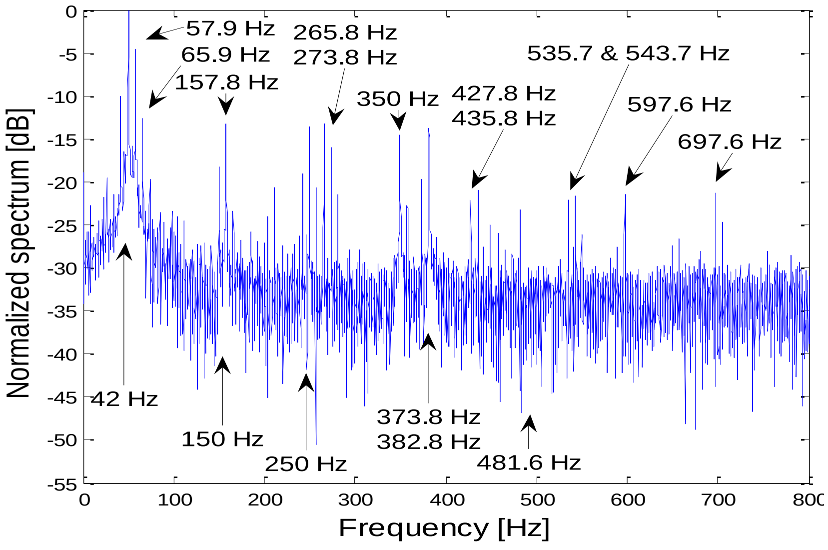


a) Healthy DFIG

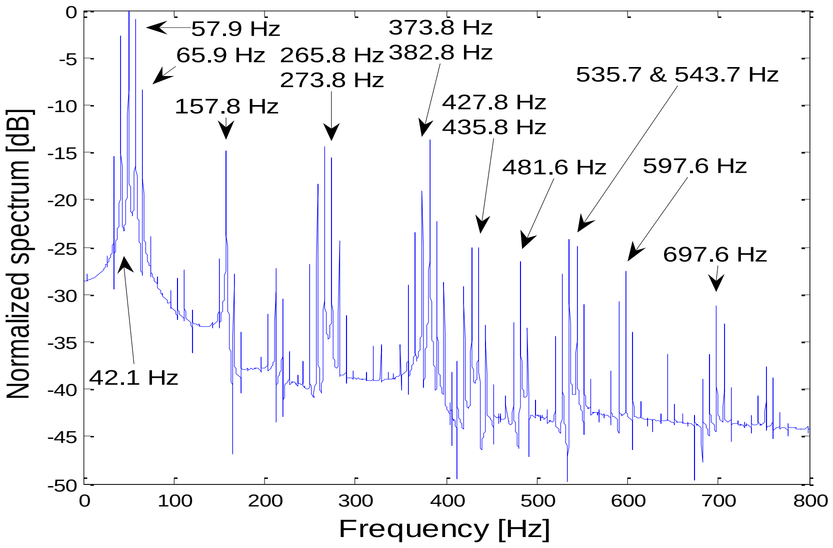


b) Stator winding fault

Steady state analysis: Predicted and measured DFIG stator line current spectra DFIG operating on-line with winding fault



a) Experimental current spectrum



b) Predicted current spectrum

DFIG operation with rotor winding fault

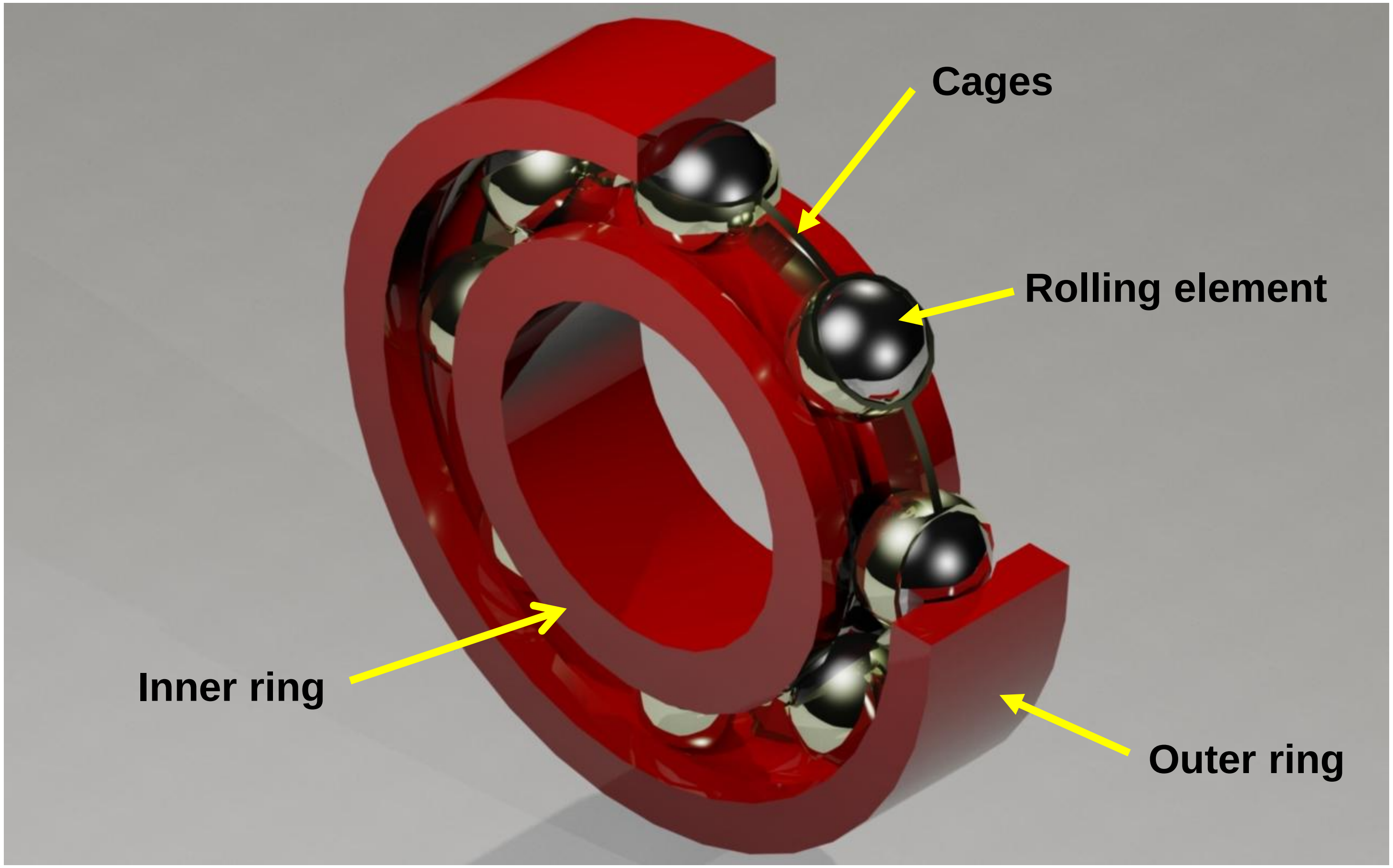
Bearing faults

- Account for 40 % of machine failures
- Vibration analysis is the preferred method for mechanical faults detection
- A fault induces the appearance of a characteristic frequency in the vibration spectrum

Why to use CSA ?

- Current transducer are cheaper than vibration transducer
- Uses existent infrastructure, stator current is usually measured
- Less susceptible to external vibration
- Reliability improvement in fault detection by using redundant detection mechanisms

Rolling bearing parts



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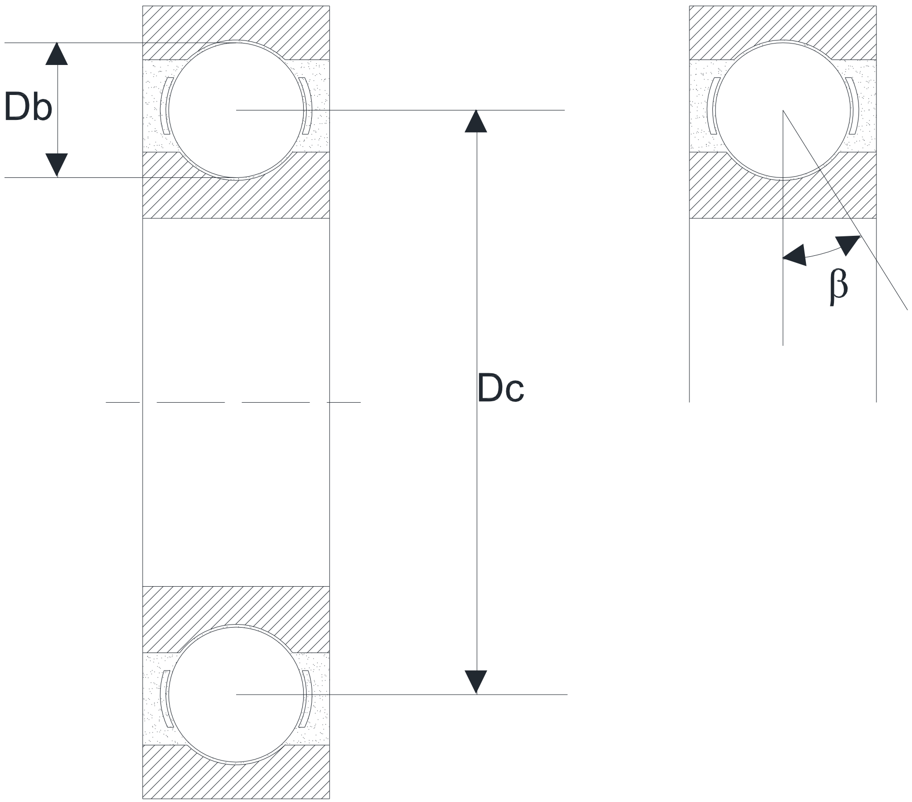
Rolling bearing geometry



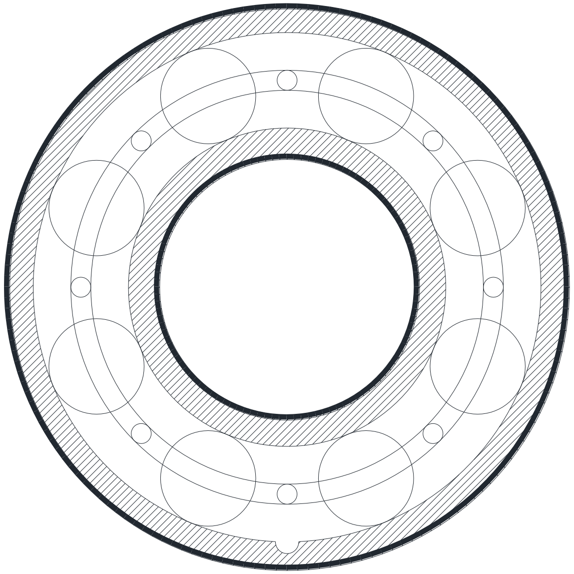
D_b ball diameter

D_c ball pitch diameter

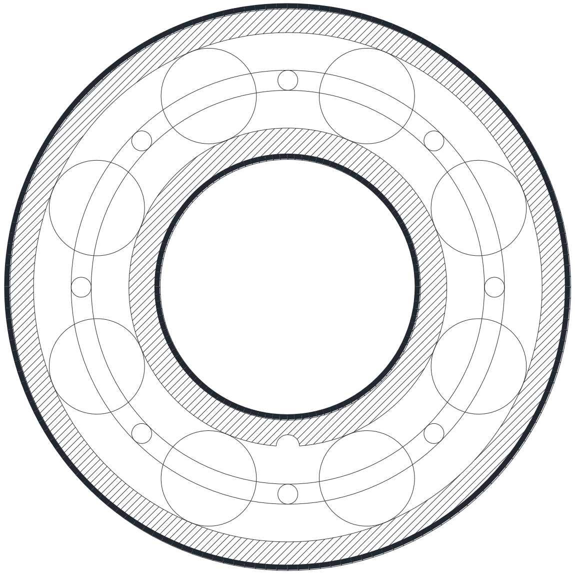
β contact angle

SKF XL
Designed and developed especially for large wind turbine generators.

Rolling bearing race frequencies



Outer race

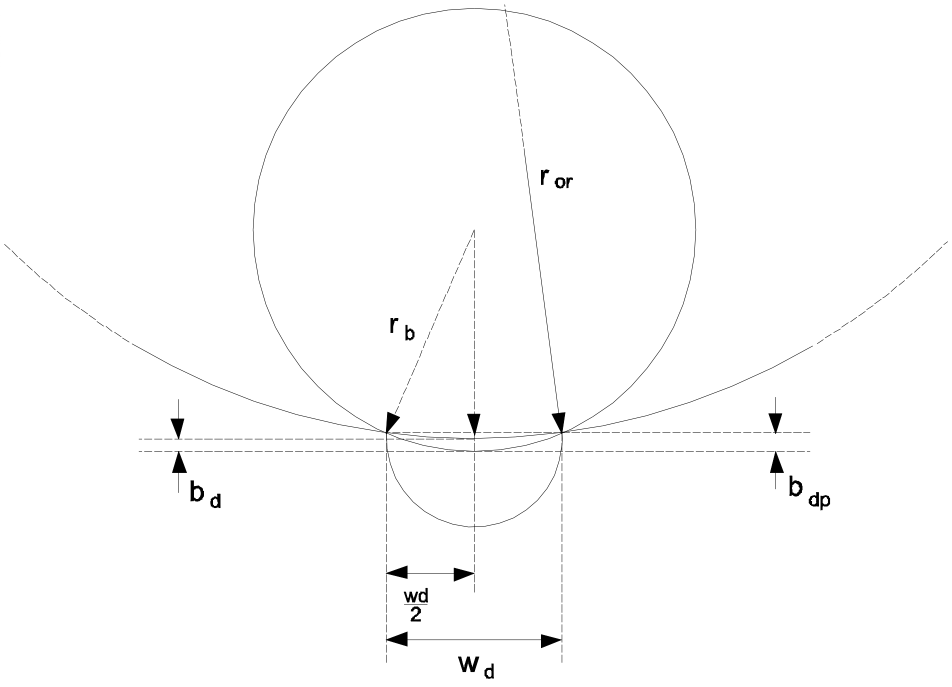


Inner race

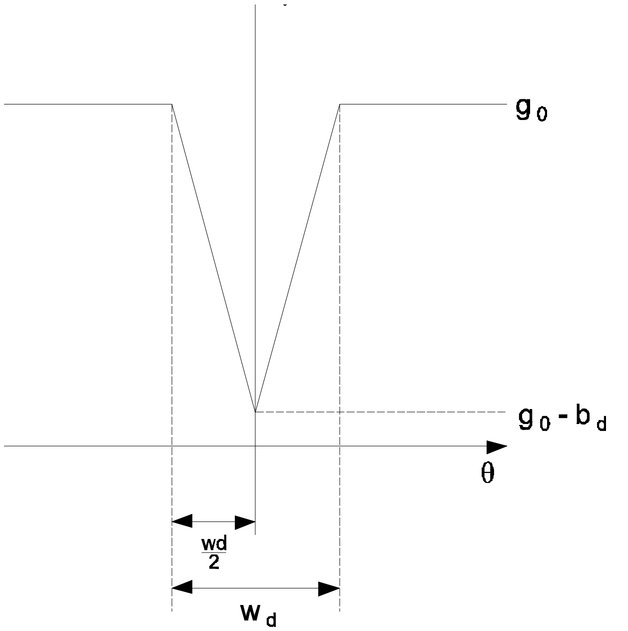
$$f_{co} = \frac{N_b}{2}\left(1 - \frac{D_b}{D_c}\cos\beta\right)$$

$$f_{ci} = \frac{N_b}{2}\left(1 + \frac{D_b}{D_c}\cos\beta\right)$$

Air-gap variation

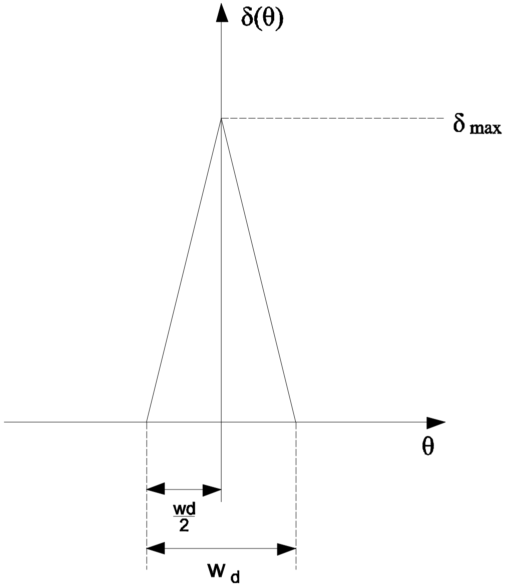


Ball drop

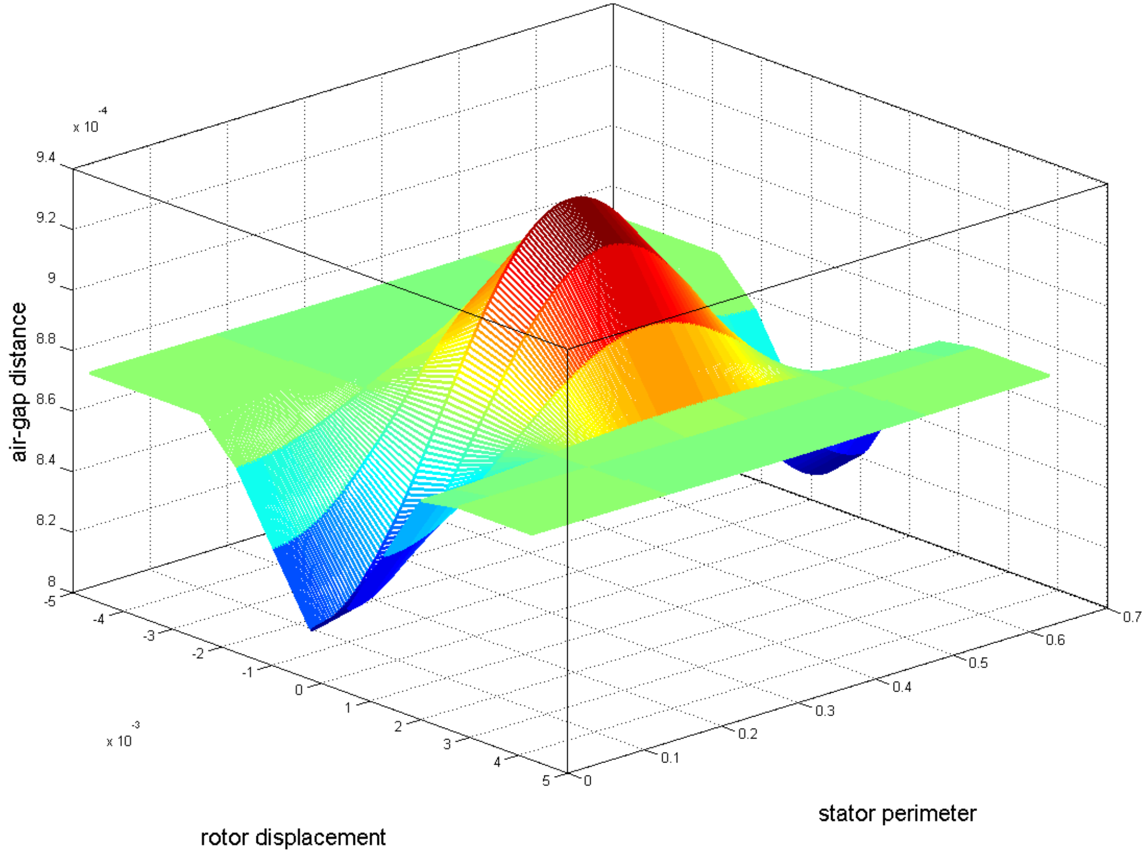


Air-gap variation

Eccentricity variation



$$g(\alpha,\theta)=g_0-g_0\delta(\theta)\cos(\alpha-\theta)$$



Ball bearing faults types

Flaking

False brinelling

Crack

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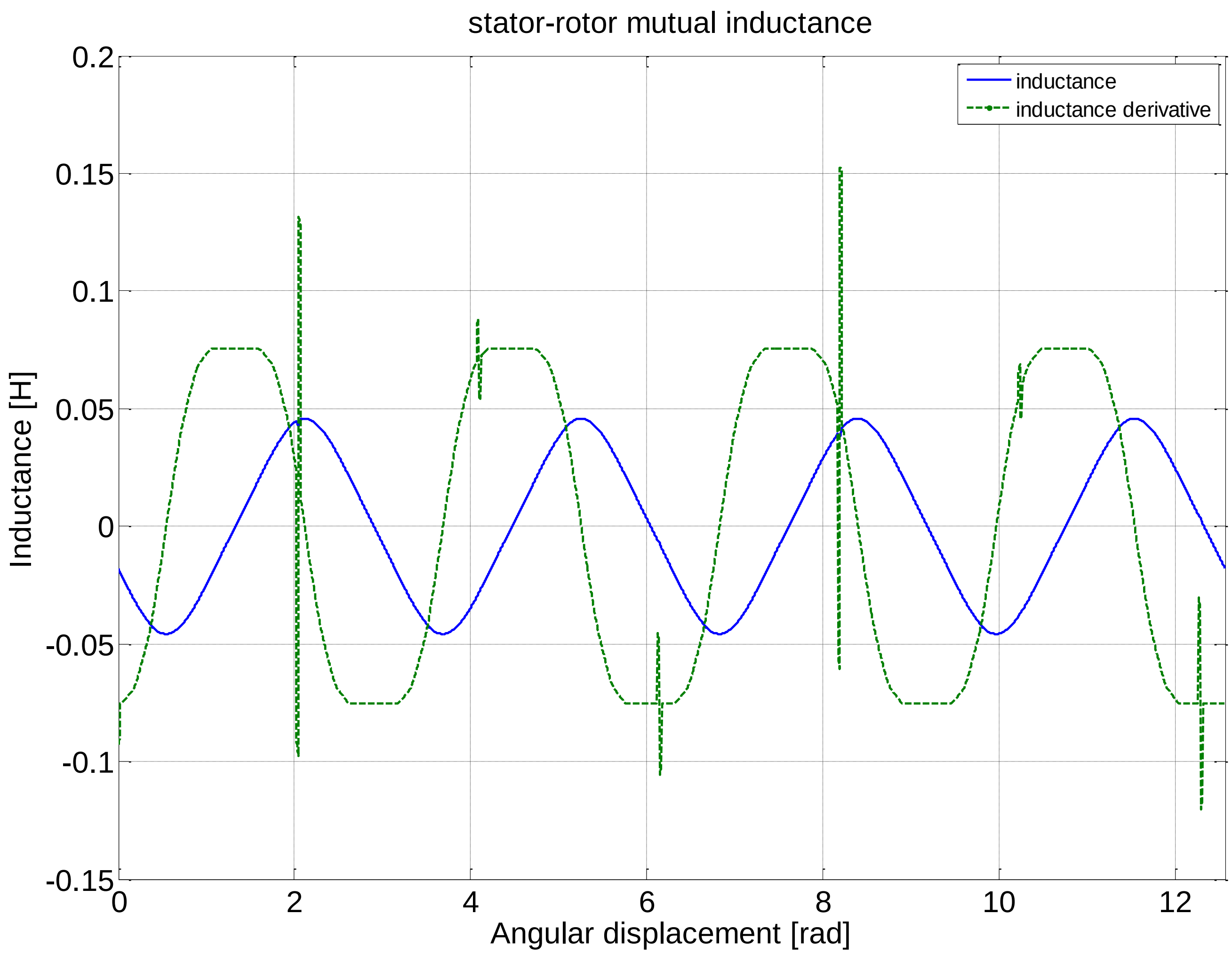
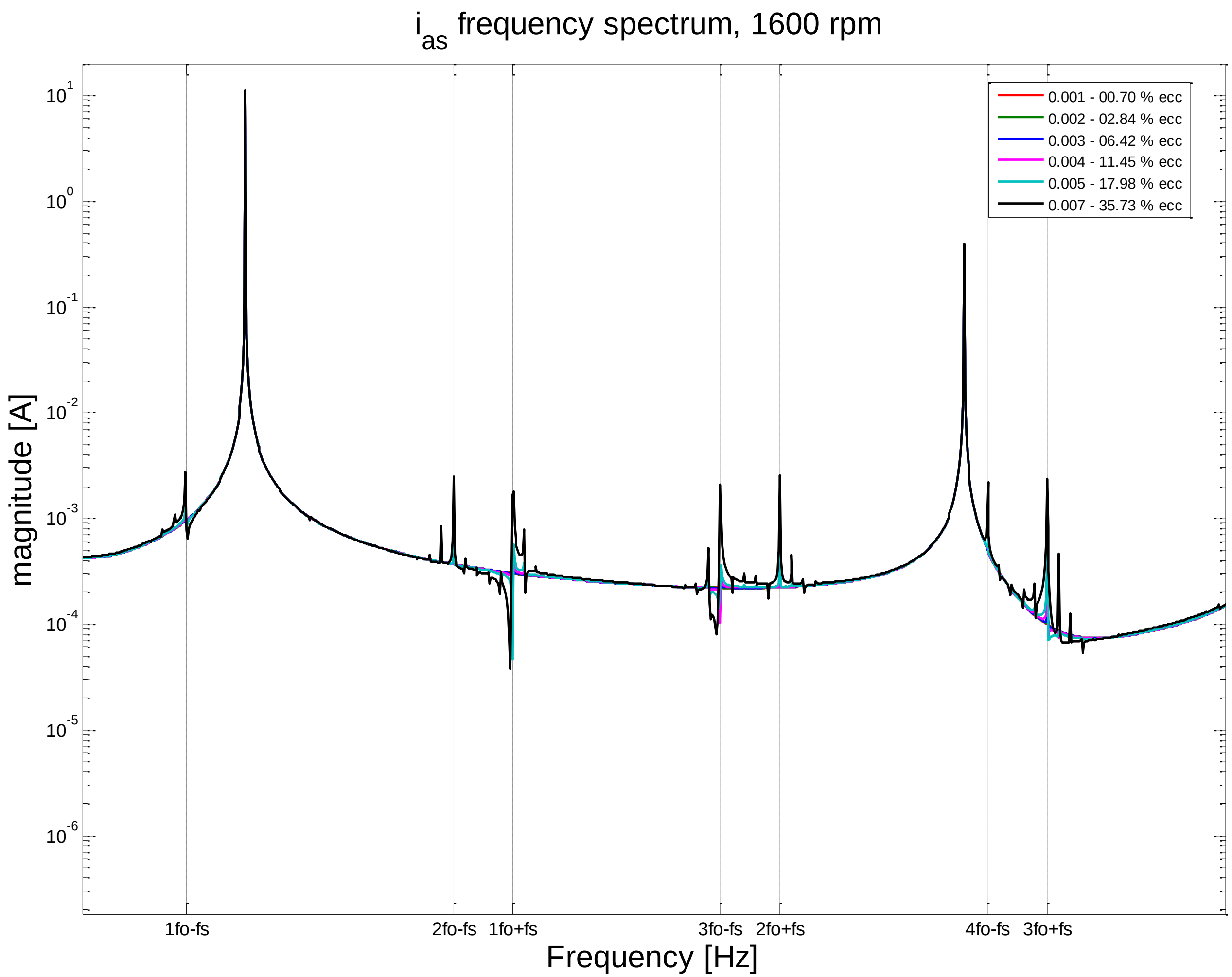
Machine model

- Based on coupled-circuit approach.
- A circuit is defined as ‘any series connection of coils’.
- Complex conductor distribution is used to describe the spatial distribution of the windings
- Coupling inductances are calculated between circuits.
- Periodic eccentricity variation product of the bearing fault is considered
- Small air-gap variations are assumed
- Axial asymmetry is accounted for by halving the total eccentricity
- Analytical expression for machine inductances are obtained

Non-periodic machine inductances



Simulation results



Bearing fault harmonics

- Outer race fault frequencies, $f_o = f_r f_{co}$

$$f_{or} = \left| fs \pm k f_o \right|$$

- Inner race fault frequencies, $f_i = f_r f_{ci}$

$$f_{ir} = \left| fs \pm k f_i \right|$$

- Increase with severity of the fault
- Are very small

Experimental rig

- 30 kW, 240 V wound rotor induction machine, 0.6 mm air-gap
- Short circuited rotor windings
- Parallel and series stator connection were considered
- Constant speed, driven by a DC motor
- Sub-synchronous and super-synchronous regimes were investigated
- The ball bearing in the load side of the machine was replaced between measurements
- SKF 6313-2Z/C3 ball bearings
- 8 balls, D_c = 10.22 cm D_b =2.381cm
- Contact angle, $\beta = 0$
- f_{co} = 3.0679, f_{ci}=4.9321

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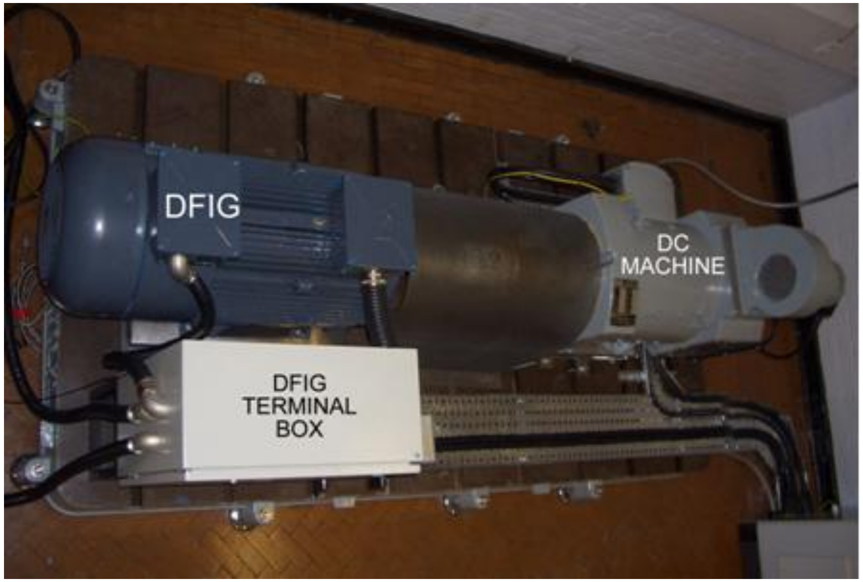
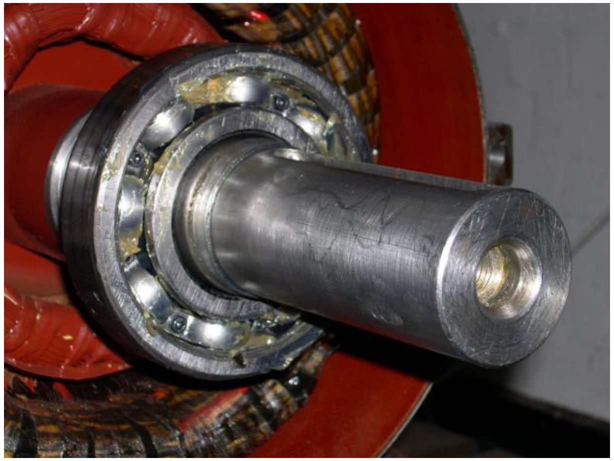
Test Rig Description



Laboratory test bed (viewed from above)

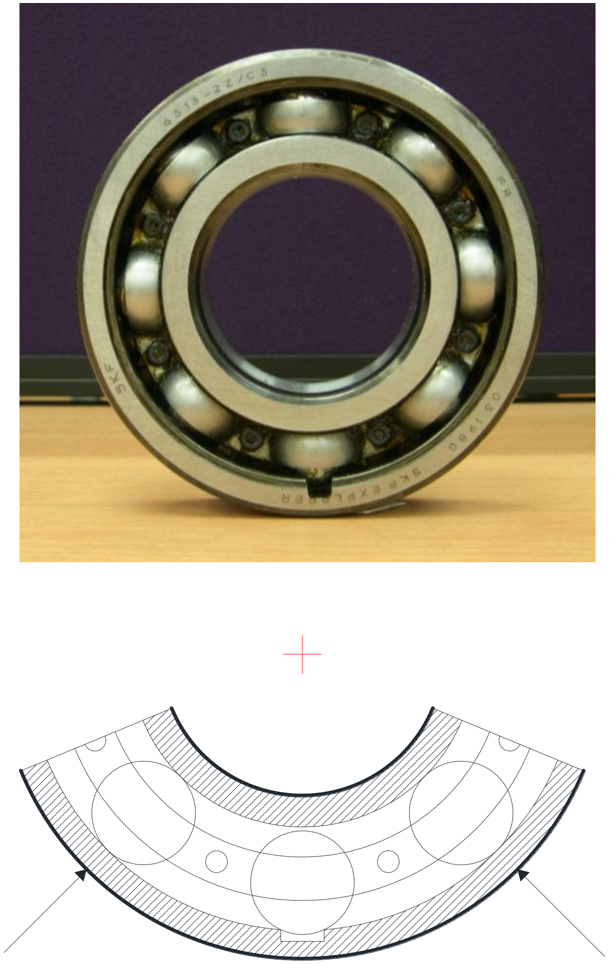


Load side bearing

Terminal box

Experimental bearing fault simulation

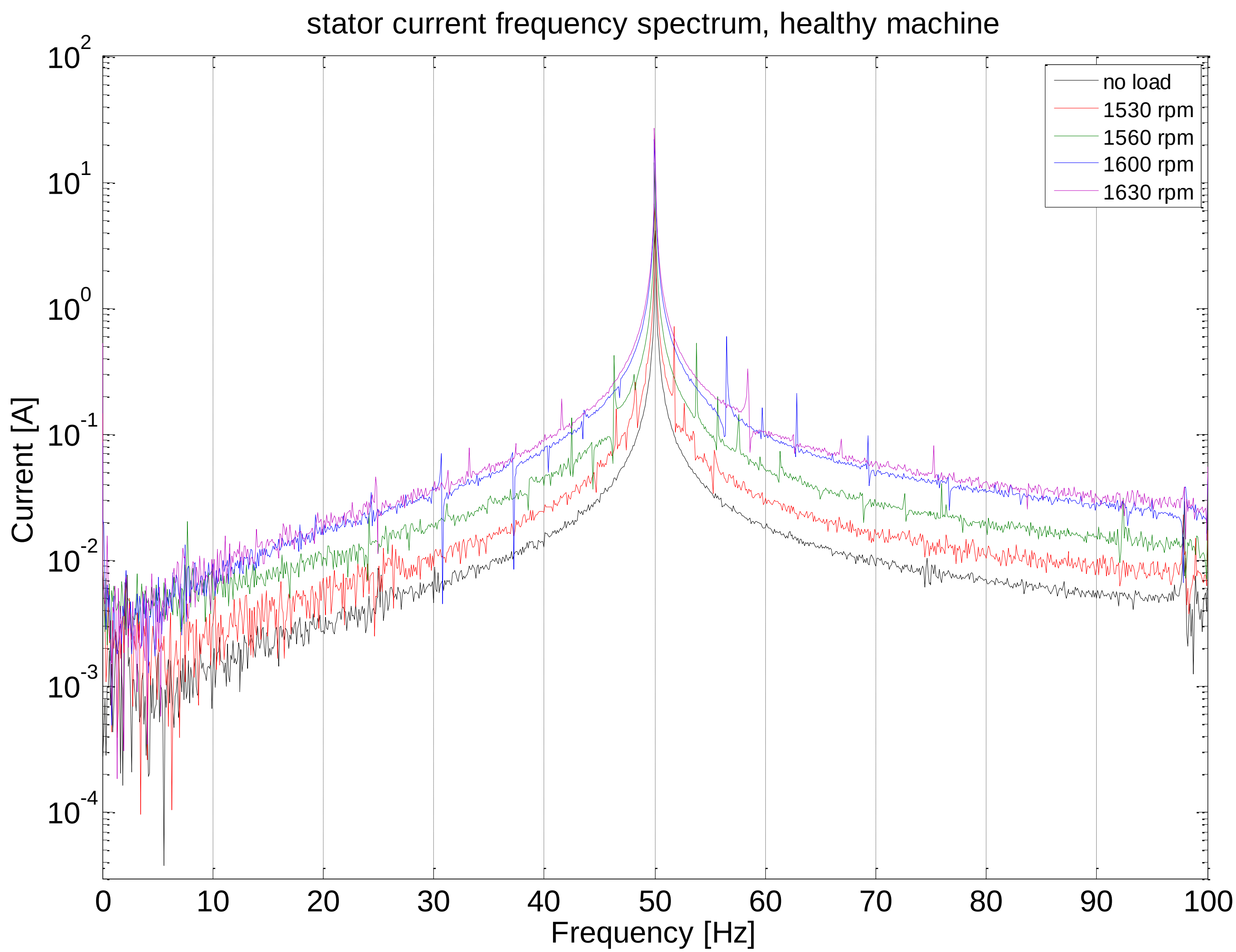
Outer race hole



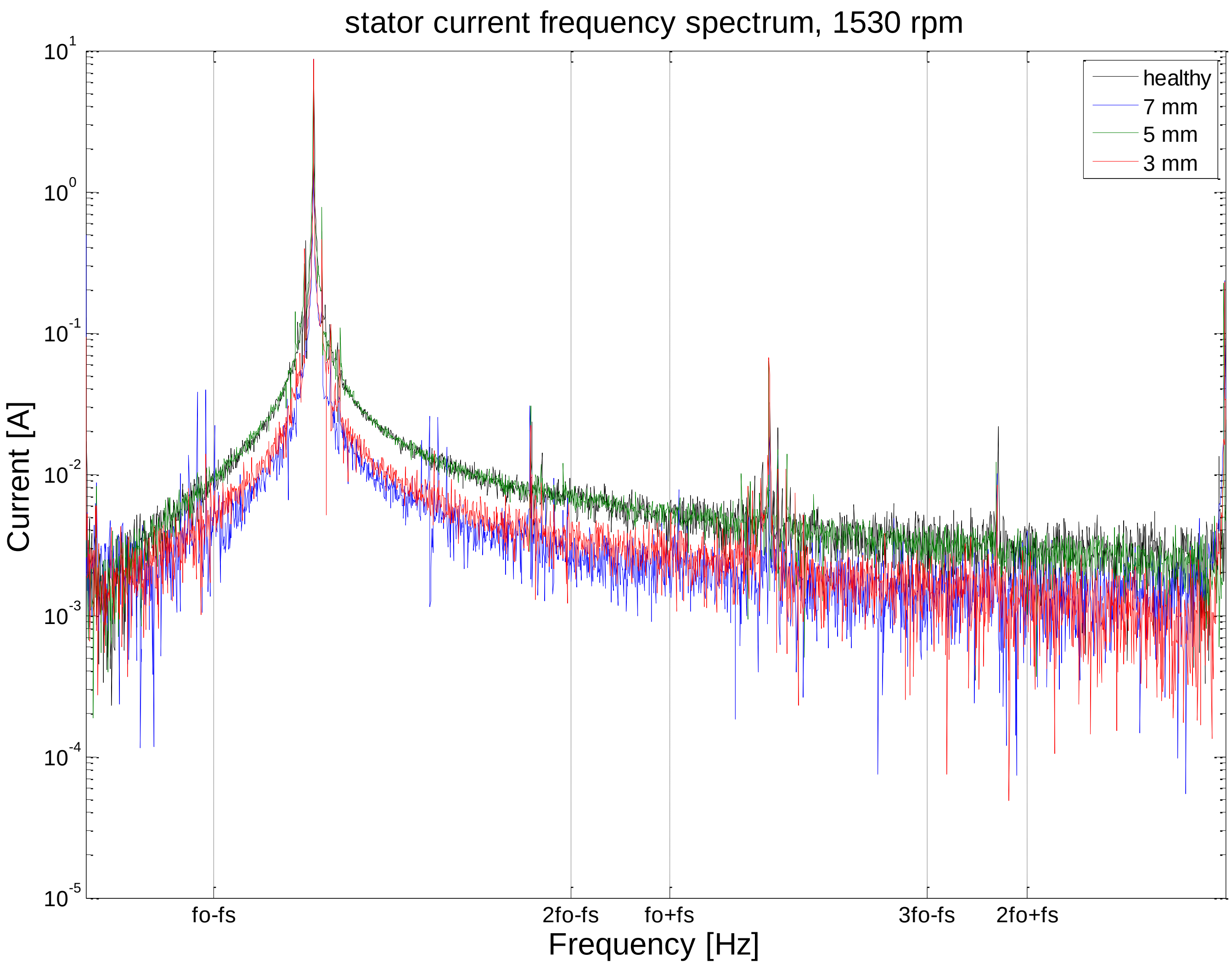
Outer race groove

Experiment 626

Experimental results



Experimental results



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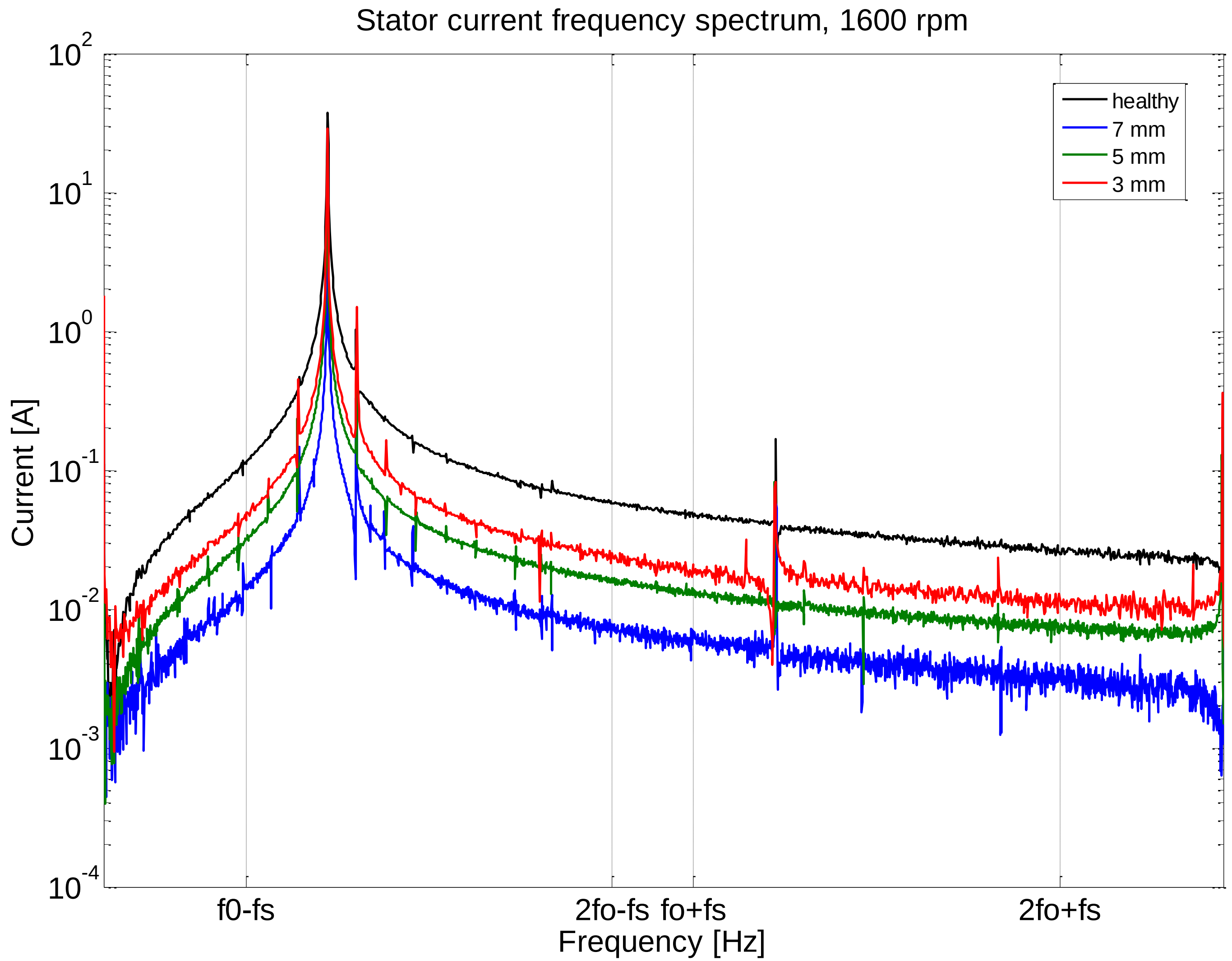

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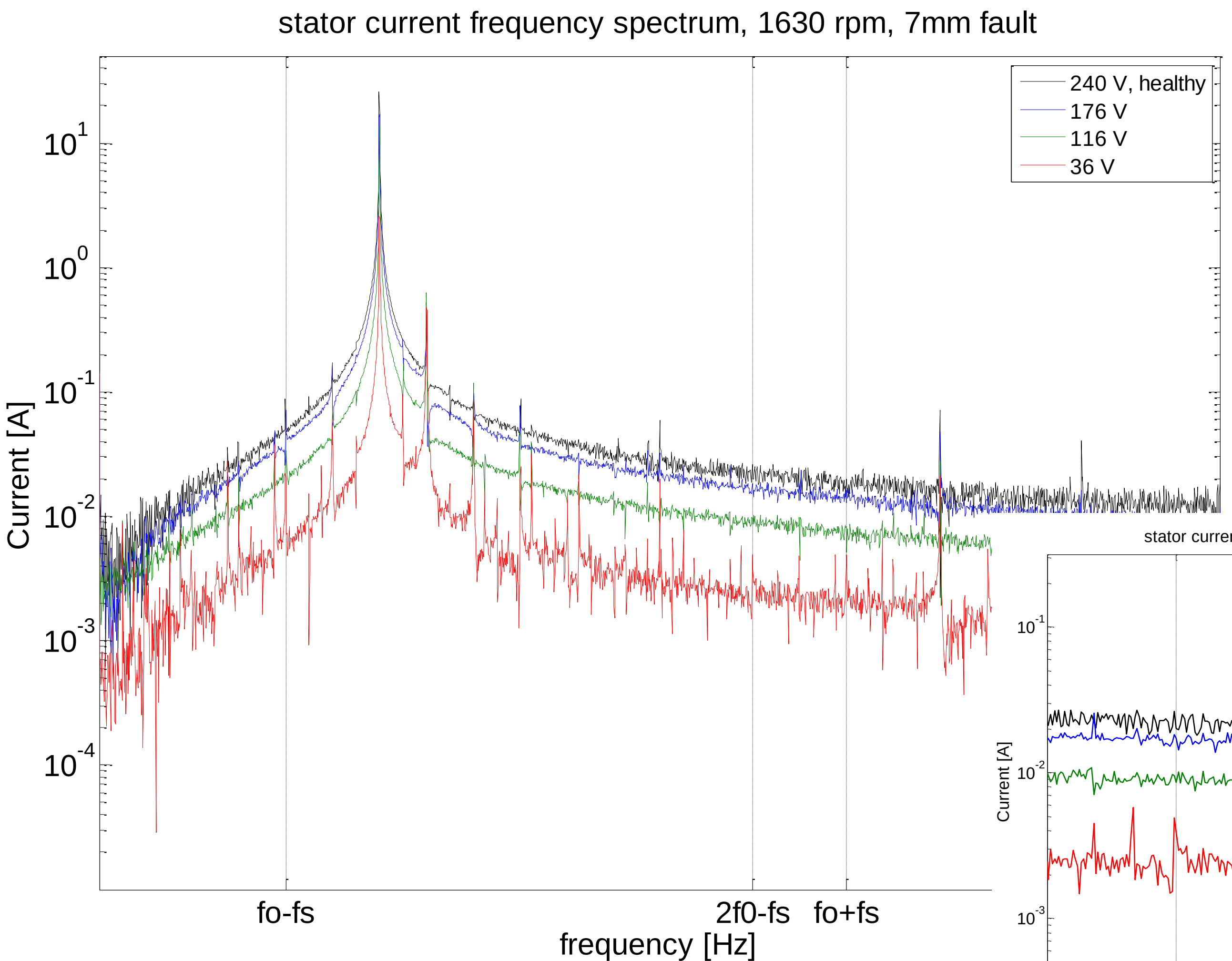
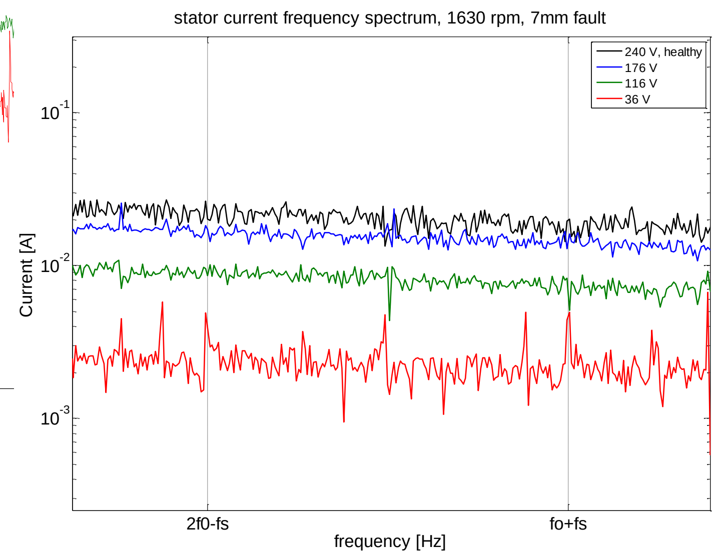
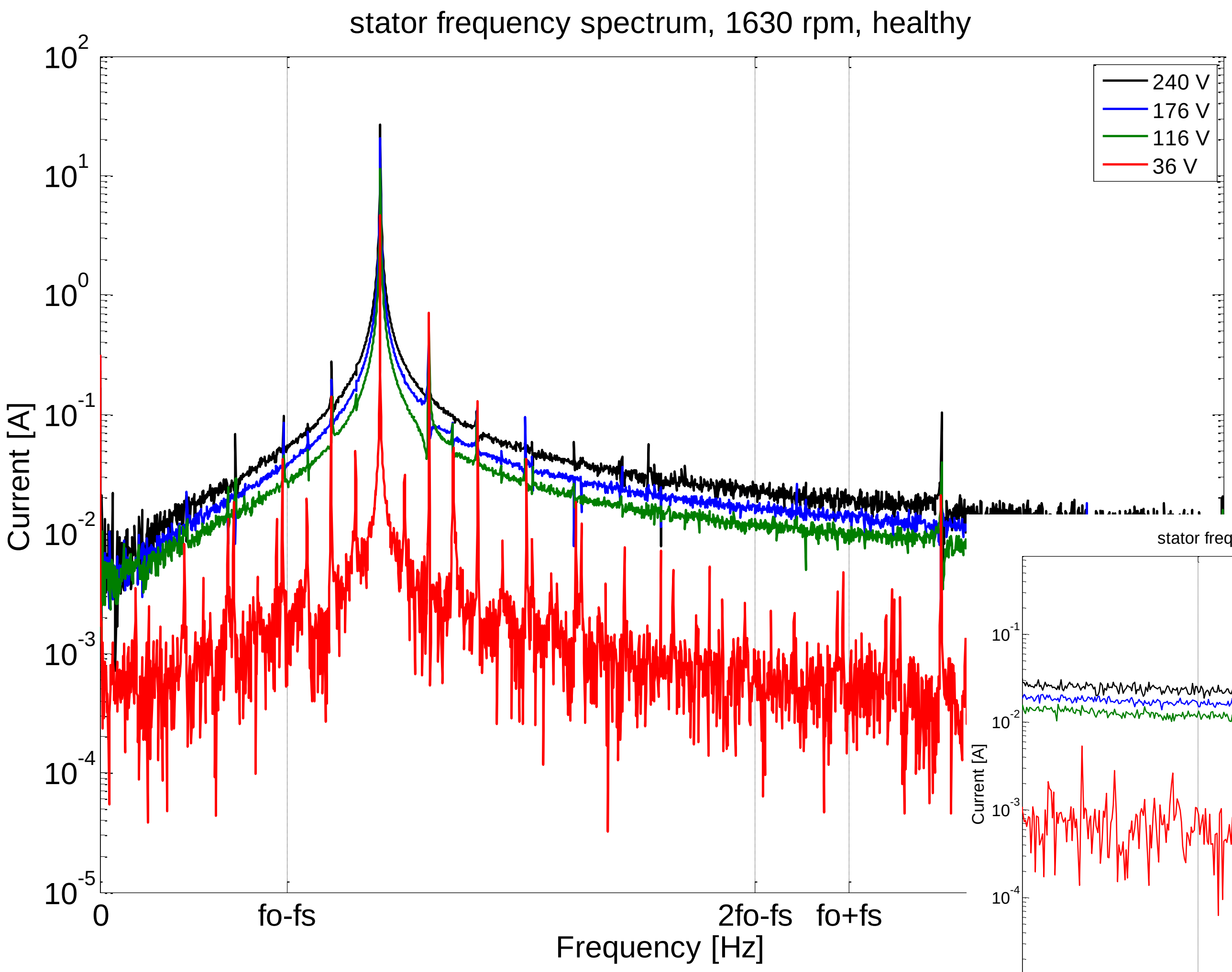




Experimental results



Conclusions

- Characteristic frequencies appear in the stator current spectrum as a consequence of a bearing fault
- Very small in magnitude, difficult to detect
- Below noise level in many cases
- Large faults may be detectable
- Additional signal processing techniques are required
- Not to substitute vibration analysis (complement)

Thank You