Theme 3 Operation, Maintenance & Decommissioning

Manchester Research Update

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SUPERGEN Wind General Assembly 2017

16th November 2017

The University of Manchester

MANCHESTER 1824

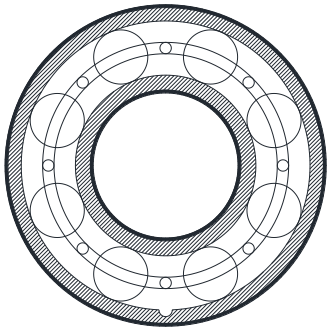
SUPERGEN WIND

Research so far: summary

Focused on CM/diagnostic techniques for drive train components:

- Fault model development for drive train / generator CM - mechanical (bearing/misalignment) and electrical (winding/unbalance) faults
- Improved diagnostics - signature definition, multi-signature correlation
- Low cost intelligent drive train CM – controller embedded diagnostics
- Real-time signature extraction – time/frequency signal analysis
- In situ sensing for improved CM – component embedded monitoring

Models for drive train mechanical and electrical faults



Bearing outer race fault

Fault effect modelling

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

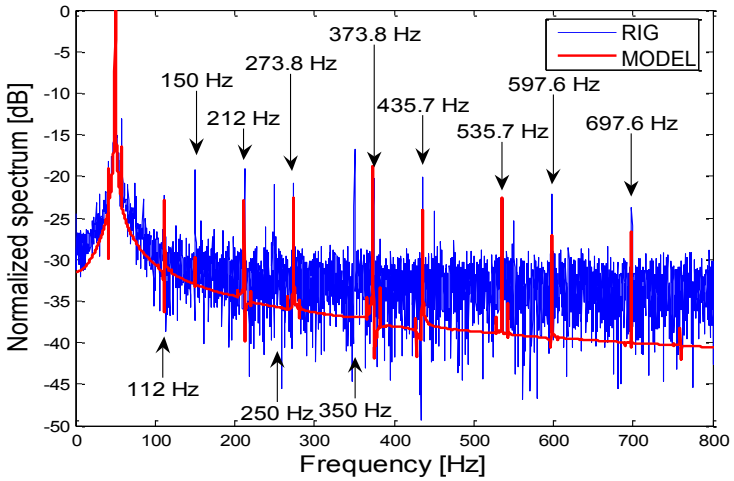
Advanced generator fault models

$$[V] = [R][I] + \frac{d[\psi]}{dt}$$

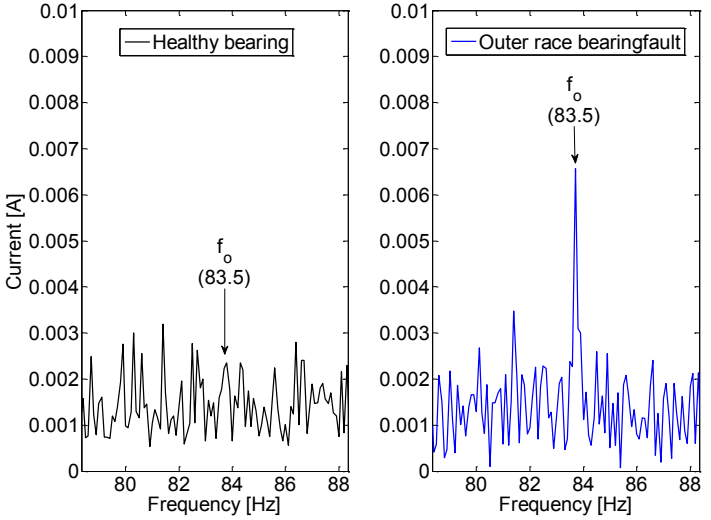
$$L_{A,B} = \frac{\mu_0 w \pi d^3}{2g} \sum_{v=-\infty}^{v=+\infty} k_{sk}^{v} \frac{\overline{C_A^k}\,\overline{C_B^k}}{v^2} e^{-j\left(\frac{2v\beta(t)}{d}\right)}$$

$$T_e = \frac{1}{2}[I]^T \frac{d[L]}{d\theta_{mech}}[I]$$

Test validation

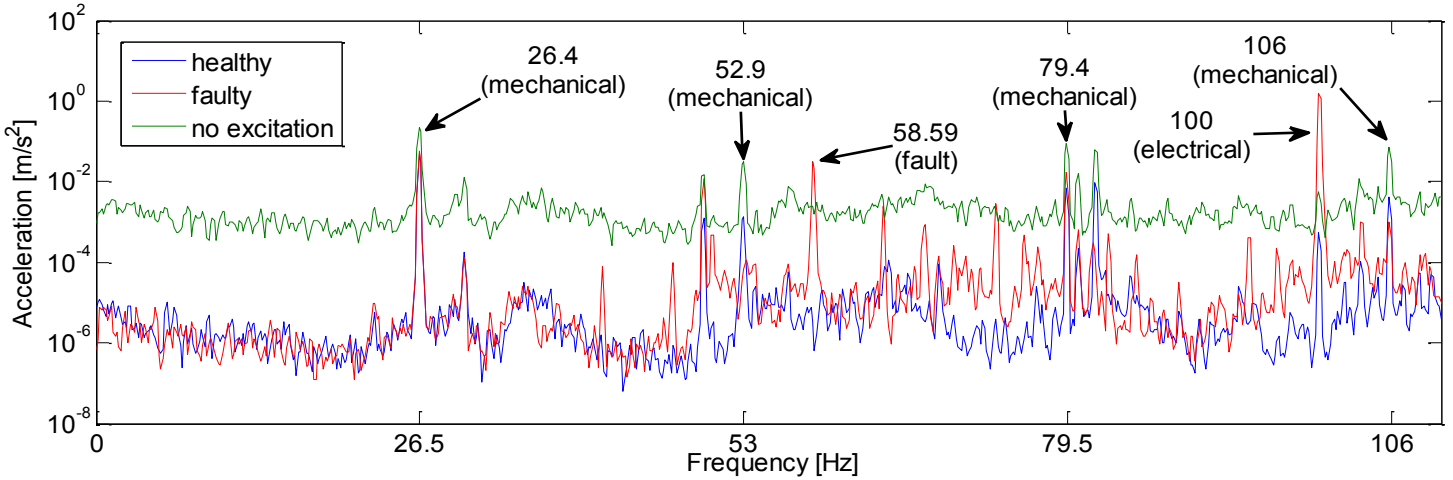


DFIG short circuit signature analysis



DFIG bearing fault analysis

Improved diagnostics: vibration signal use for electrical fault diagnostic



Measured test generator vibration spectrum

- Conventional drivetrain diagnostic platforms largely vibration based and mechanical fault oriented
- There is a need to better understand the potential of vibration monitoring for electrical fault diagnostics
- Findings show that improved understanding of electric fault signature in vibration signal is possible

Generator vibration frequencies

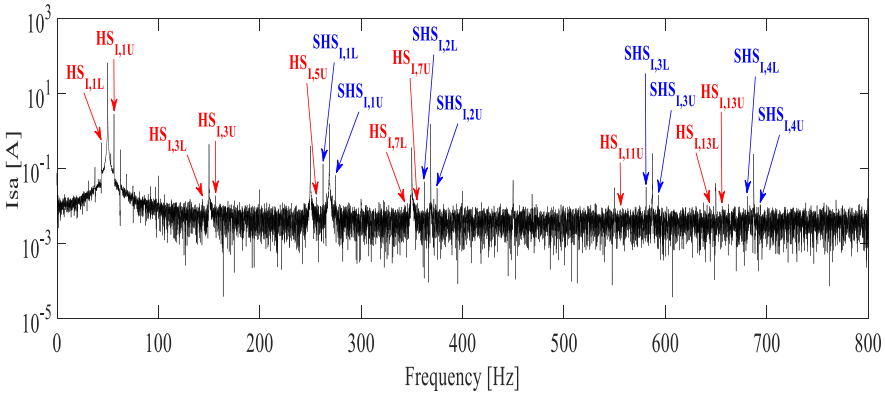
Winding	Supply	Freq.
Balanced	Unbalanced	$\lvert 6k(1-s)\rvert f_s$ $\lvert 2 \pm 6k(1-s)\rvert f_s$
Unbalanced	Unbalanced	$\left\lvert \frac{k}{p}(1-s)\right\rvert f_s$ $\left\lvert 2 \pm \frac{k}{p}(1-s)\right\rvert f_s$

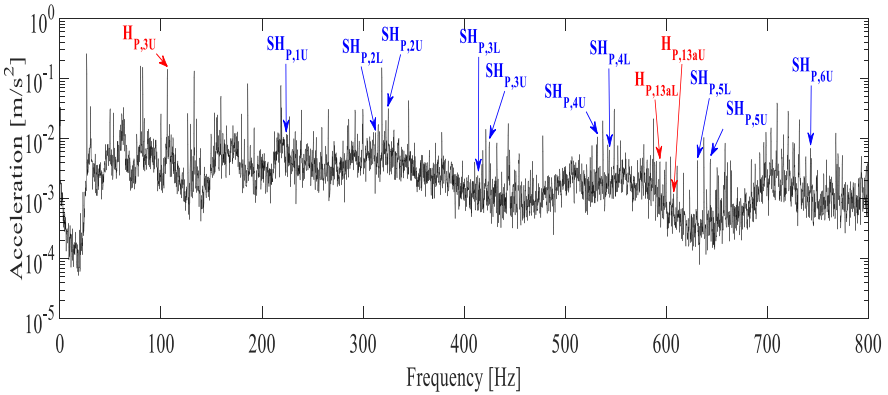
Improved reliability fault recognition – signature fusion

Can we amalgamate diagnostic information from multiple CM signals to enhance the resolution/reliability of fault recognition ?

Machine Signal	Expression	
	Balanced Rotor (CF)	Unbalanced Rotor (CF ± *2nsf*)
Stator Current	$\|i \pm 6k(1-s)\|f$	$\|(i \pm 2ns) \pm 6k(1-s)\|f$
Stator Active Power	$\|[l \pm i] \pm 6k(1-s)\|f$	$\|([l \pm i] \pm 2ns) \pm 6k(1-s)\|f$
Electromagnetic Torque	$\|[l \pm i] \pm 6k(1-s)\|f$	$\|([l \pm i] \pm 2ns) \pm 6k(1-s)\|f$
Rotational Speed	$\|[l \pm i] \pm 6k(1-s)\|f$	$\|([l \pm i] \pm 2ns) \pm 6k(1-s)\|f$

Diagnostic signatures in DFIG signals

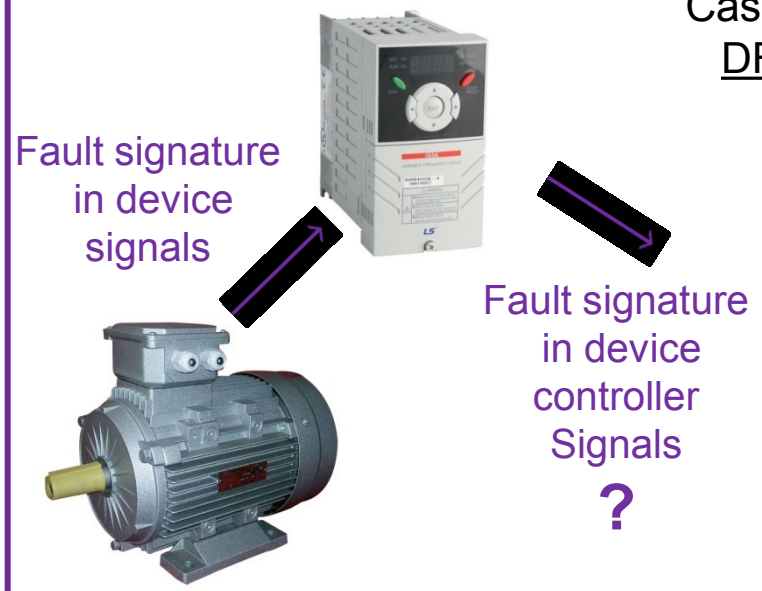




- A case study undertaken with Durham University on correlating the rotor unbalance signature in current, power, estimated electromagnetic torque, speed, mechanical torque and frame vibration signals
- It is shown that by combining specific diagnostic information from multiple signals the reliability of fault recognition can be significantly enhanced

Low cost intelligent drive train CM – controller embedded diagnostics

- Electric drive controller embedded CM algorithms
  - How do mechanical/electrical fault signatures propagate through electric drive signals and can they be detected in these?
  - Can we utilise the existing control logic for improved low cost CM?



Case study:

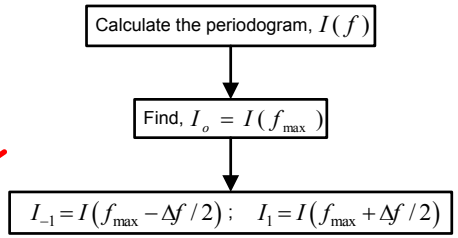
<u>DFIG controller signal embedded signature mapping</u>

- Advanced DFIG drive harmonic model developed
- Advanced test rig providing access to commercial controller loop signals developed
- Analytical definition of controller embedded diagnostic signatures
- Experimental/model study/validation

Research on real time signature extraction techniques

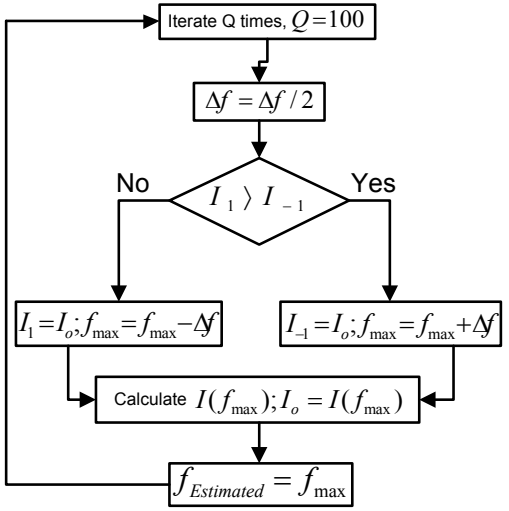
- Real-time tracking/interpretation of electrical / mechanical spectral signature – rapid real-time spectral processing and recognition
- Researched the use of hybrid iterative search enhanced FFT algorithms for spectral component real-time tracking – Dichotomous Search Algorithm
- Implemented on commercial FPGA platforms and validated in real-time experiments
- Shown to deliver high resolution and rate real-time signature tracking suited to the continual nature of drive train CM signals avoiding the frequency domain interpretation issues typical of non stationary methods.

Dichotomous search algorithm based signature tracking



STEP 1: First, a low resolution DFT periodogram is calculate and the frequency maximising it, f_{max}, identified.

STEP 2: A search procedure is then undertaken that adjusts the f_{max} estimation towards adjacent DFT coefficients in a series of iterative steps to obtain final high resolution frequency estimate

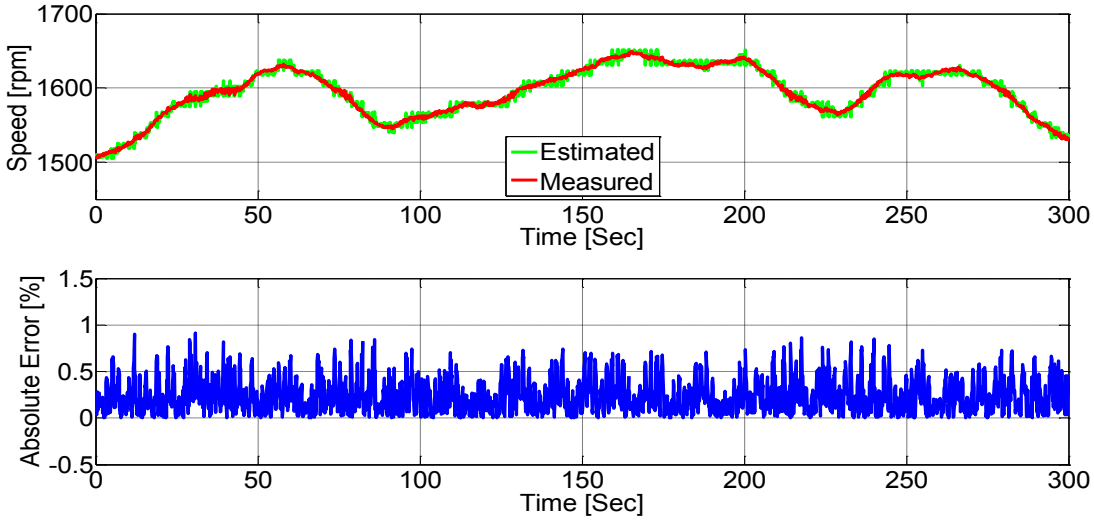


Research on real time signature extraction techniques

Case study:

Real time current signal signature time/frequency analysis for rotor velocity estimation in extended slip WT drives

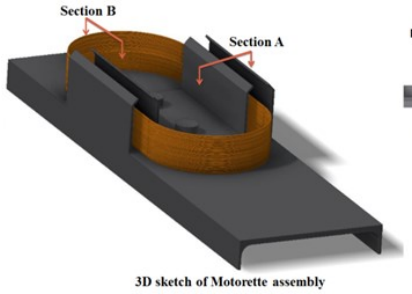
- Signature tracking algorithm applied for speed dependent current spectral component real time tracking – implemented on a cRIO platform
- A 7.5 kW test extended slip WT generator test system developed
- Test generator driven in 10% slip region using a scaled realistic WT profile representative of WT speed dynamics
- Results demonstrate good potential for accurate real-time signature tracking

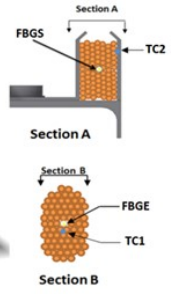


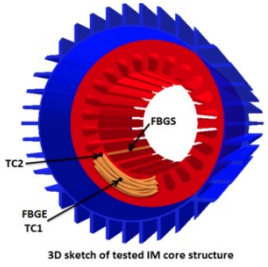
Real-time test results, signature tracked at 12 estimates per second, wind turbine driven profile

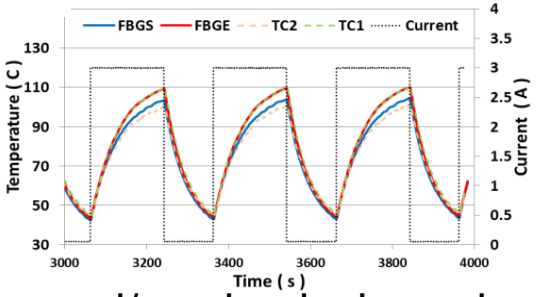
In-situ sensing for high fidelity thermal/mechanical signature monitoring in drive train components

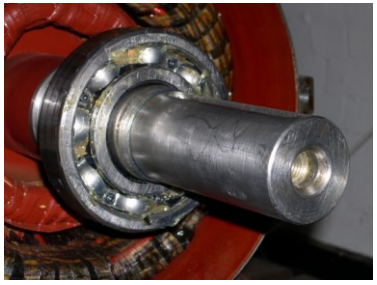
- Existing CM platforms constrained in sensing access to critical, device embedded, drivetrain component failure points
- This largely reduces diagnostic/prognostic capability and awareness of components' operational integrity
- Sensing in the vicinity of failure points would provide diagnostic/prognostic advantages
- Novel sensing techniques that can enable the extraction of improved fidelity information on drive train components' integrity needed to enable future reliability targets
- FBG technology/infrastructure already exist on WT platforms – considerable potential to enable drive train component in-situ monitoring but requires significant research











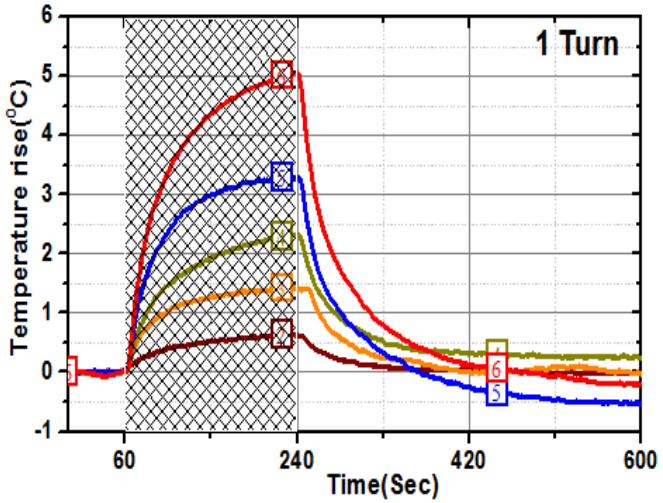
Prototyping embedded thermal/mechanical sensing on motorette and bearing systems

In-situ sensing for high fidelity thermal/mechanical signature monitoring in drive train components

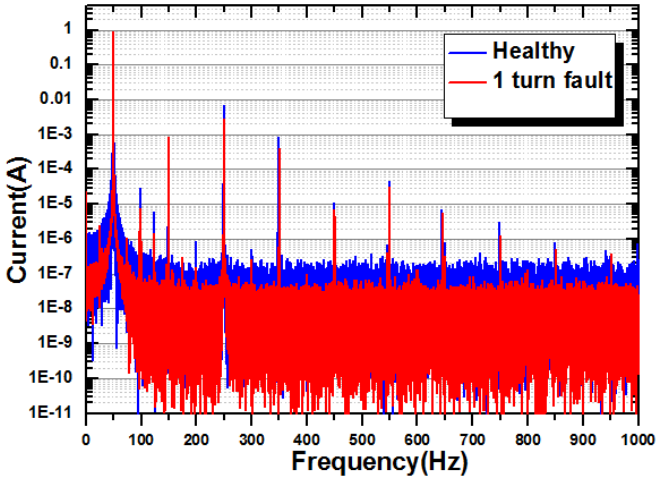
Case study – initial results:

Generator winding fault detection using FBG thermal in-situ sensing

- Techniques developed for in-situ thermal network deployment in generator windings
- A test system developed to enable testing under realistic fault conditions – equipped with a commercial WT drive train CM platform, fully rated IM drive
- Results demonstrate diagnostic capability that can not be obtained using commercial CM platforms for WT drivetrains



In-situ thermal rise measurement for a short circuit fault



Current signature analysis on commercial CM platform