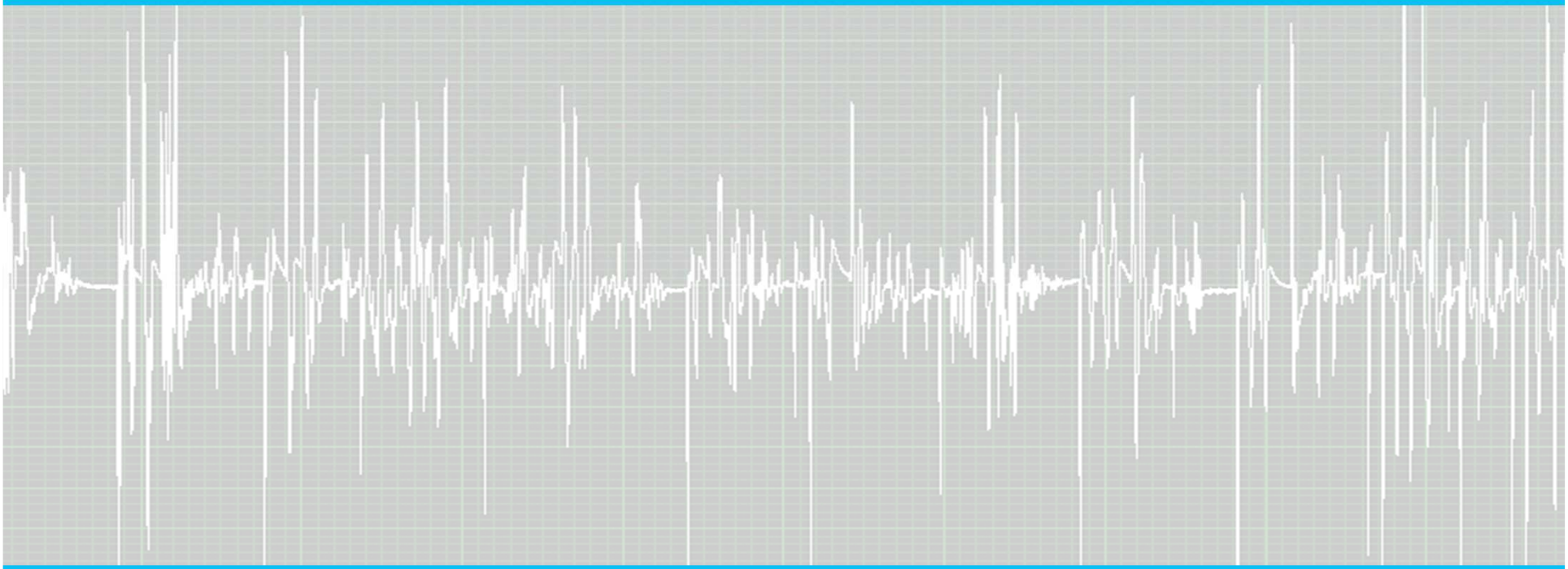
Results from EASA project 2012.OP.13 - VHM



Dr Matthew Greaves

Cranfield University

8th Rotorcraft Symposium

www.cranfield.ac.uk

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About Cranfield

We are an exclusively postgraduate university that is a global leader for education and transformational research in technology and management.

Cranfield Safety and Accident Investigation Centre

- Trained over 1000 accident investigators, delegates from organisations including:
  - AAIB, NTSB, BEA, BFU, ATSB, AIBN, TAIC…
  - AgustaWestland, Airbus, Boeing…
  - Bond, Bristow, CHC, Shell, PHI…
- Queen's award for "*world-leading work in aviation safety through research and training in air accident investigation*"
- Safety research including MGB lubrication, operational safety and maintenance error.

Contents

- Motivation
- Project overview and approach
- Accident review
- Technology review
- Lab-based testing
- Wireless
- Full-size testing
- Preliminary results

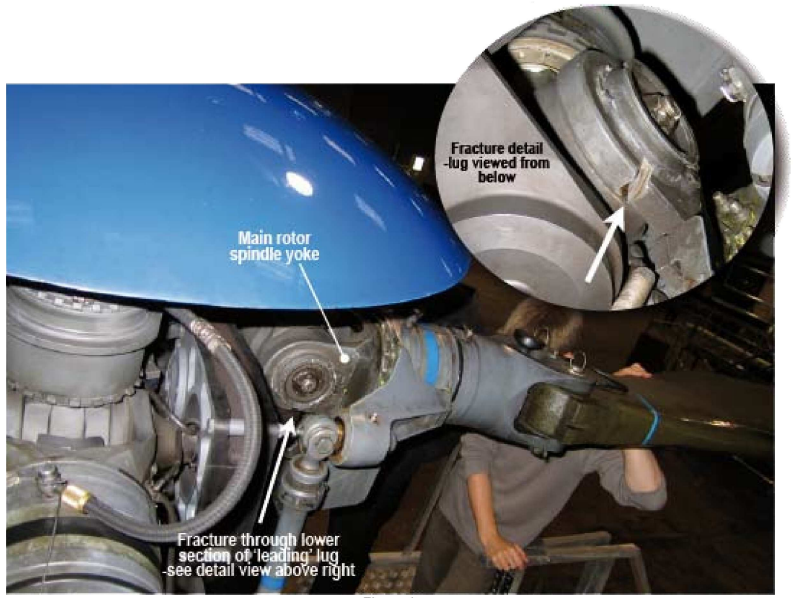
Motivation (1)

- G-PUMI
- AS 332L Super Puma
- 13 October 2006

- "*…one main rotor blade spindle had fractured, through the lower section of its attachment yoke on the leading side of the spindle…*"

- *UNKG-2010-027: It is recommended that the European Aviation Safety Agency, with the assistance of the Civil Aviation Authority, conduct a review of options for extending the scope of Health and Usage monitoring Systems (HUMS) detection into the rotating systems of helicopters.*

- Dan Wells, AgustaWestland 29C

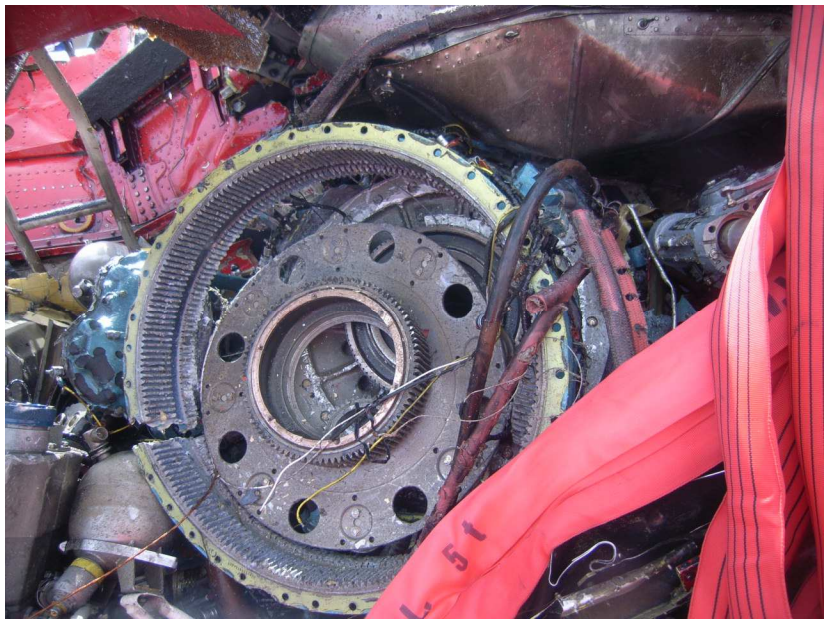


Motivation (2)

- G-REDL
- AS 332L2 Super Puma
- 1 April 2009

- "*The catastrophic failure of the Main Rotor Gearbox was a result of a fatigue fracture of a second stage planet gear in the epicyclic module*."

- *UNKG-2011-041: It is recommended that the European Aviation Safety Agency research methods for improving the detection of component degradation in helicopter epicyclic planet gear bearings.*



Project approach

- EASA tender issue
- Aim to look ahead to the next generation of HUMS sensors
- Improve signal-to-noise ratio by working inside the gearbox
- A view to real-time HUMS

Accident review

- 12 reports selected from 413 candidates

- G-REDW/CHCN
- G-BJVX
- G-CHCF
- 9M-SSC
- C-FHHD
- C-GZCH
- G-ASNL
- G-JSAR
- G-REDL
- G-BBHM
- G-PUMI
- LN-OPG

- Fault-tree analysis
- EHEST database
- No clear trends, so focussed on the most serious, G-REDL

Environment

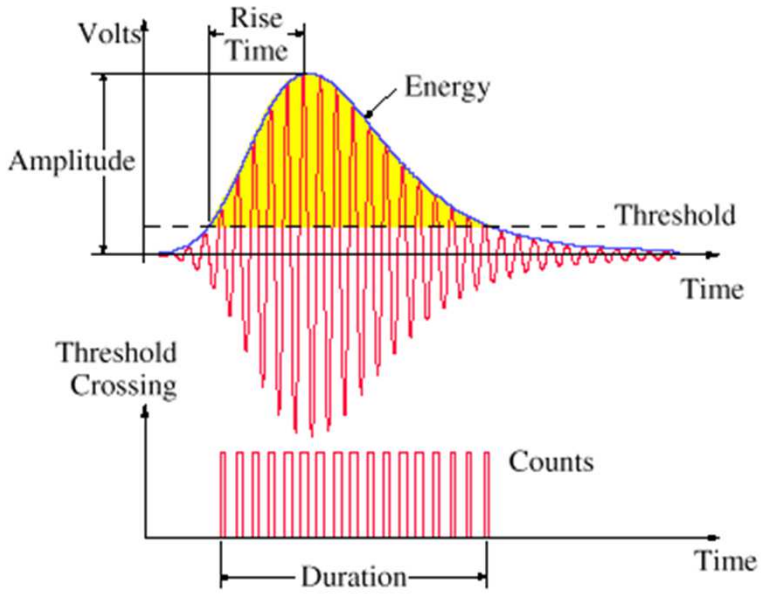
- MGB epicyclic stage is not a hospitable place!:
  - Rotation
  - Oil
  - Faraday cage
  - Large rotating metallic components
  - Temperature
  - Vibration levels
  - Power transfer
  - Space
  - Risk of damage

Technology review

- Survey of existing and potential sensing technologies
- Looked across other relevant industries including motorsport, wind turbines, rail and marine
- Started with a very wide range of potential technologies including: visual, torque rate sensing, fibre-optic etc.
- Down-selected to:
- vibration; strain; temperature; acoustic emission (AE); and audible acoustics as potential sensing technologies.

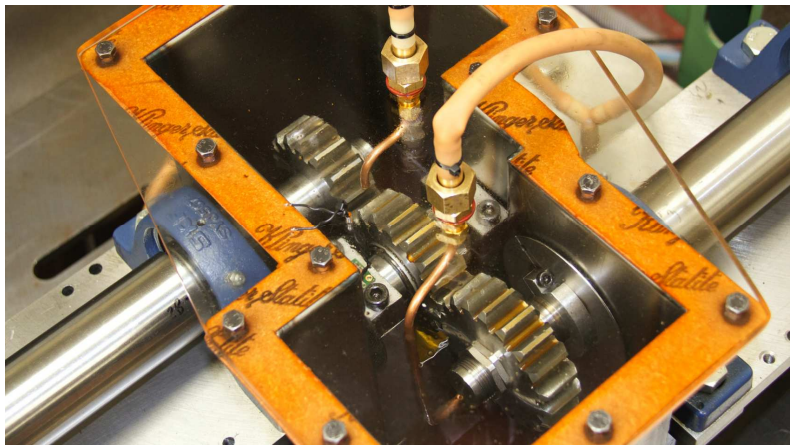
Acoustic emission (AE)

- Neither acoustic nor emitted!
- High frequency (~100 kHz to ~1 MHz)
- Surface stress waves
- Different analysis approach required – counts, time analysis, rms, rise time, kurtosis etc.



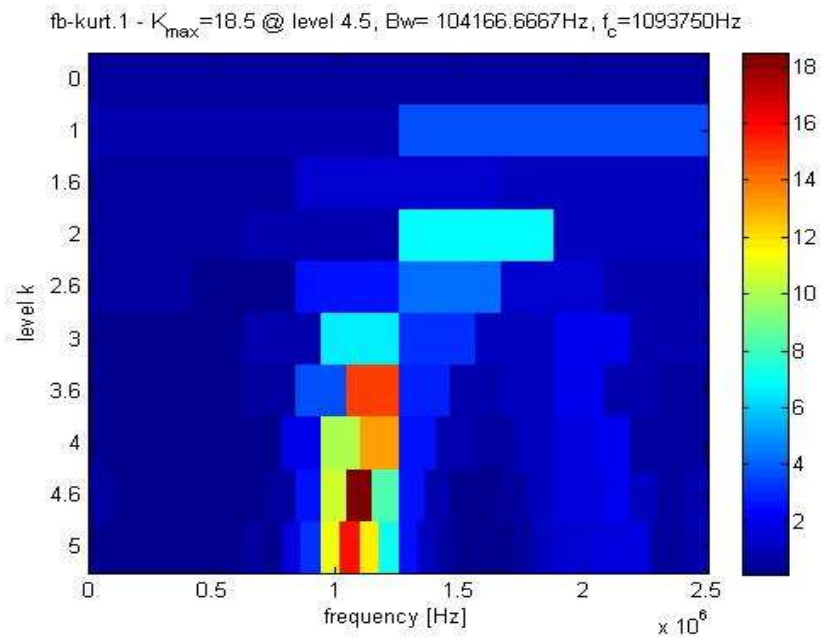
Lab-scale testing

- Comparison of acceleration and AE
- 3 gear rig setup: Input – idler – output in oil bath giving ‘single planet epicyclic’
- Double roller bearing in idler
- Different fault levels seeded

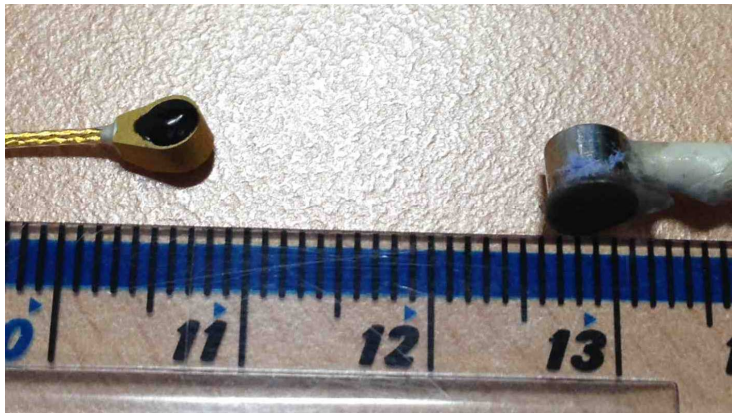


Analysis

- Rudimentary indicators not useful
- Separation of signal into deterministic and non-deterministic
- Spectral Kurtosis used to extract the envelope parameters
- AE outperformed vibration in detecting the damage

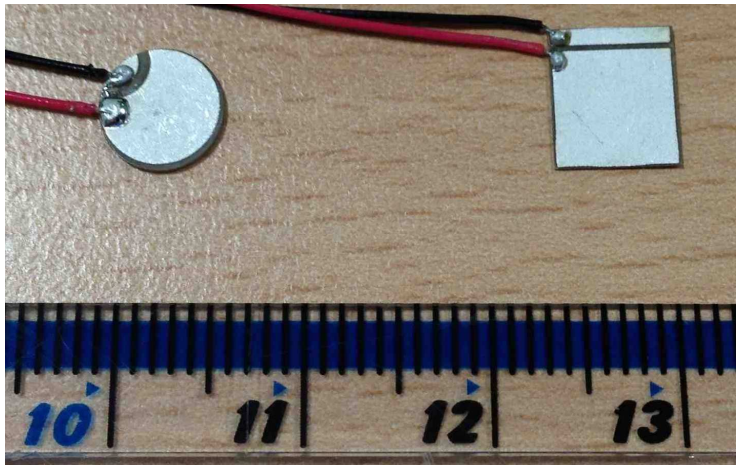


Sensor choice

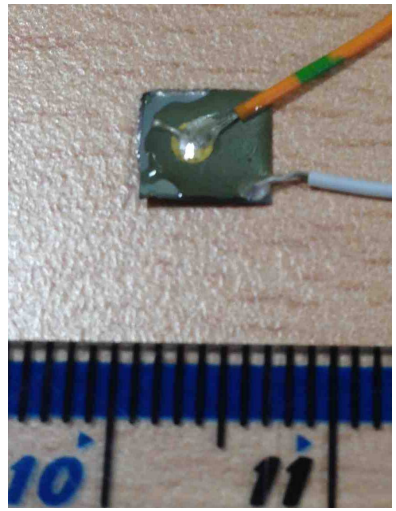


- COTS

- PWAS



- ‘Nano’



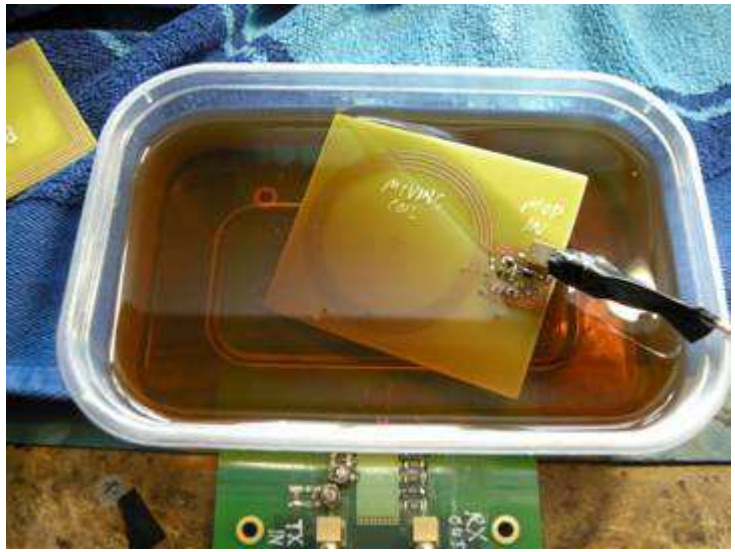
Wireless transmission

- Faraday cage will defeat any propagating EM wave
- Data rates for AE are immense
- High freq transmission may give rise to modes
- Power requirements are an issue

	WiFi	Bluetooth	ZigBee
Standard	IEEE 802.11	IEEE 802.15	IEEE 802.15
Max range	50-100m	10-100m	10-100m
Frequency	2.4 and 2.5 GHz	2.4 GHz	868 MHz Europe 900 - 928 MHz US 2.4 GHz World
Power consumption	High	Medium	Low
Max network speed	>11 Mbps	700 kbps – 1 Mbps	20 kbps - 250 kbps
Network join time		3 s	30 ms

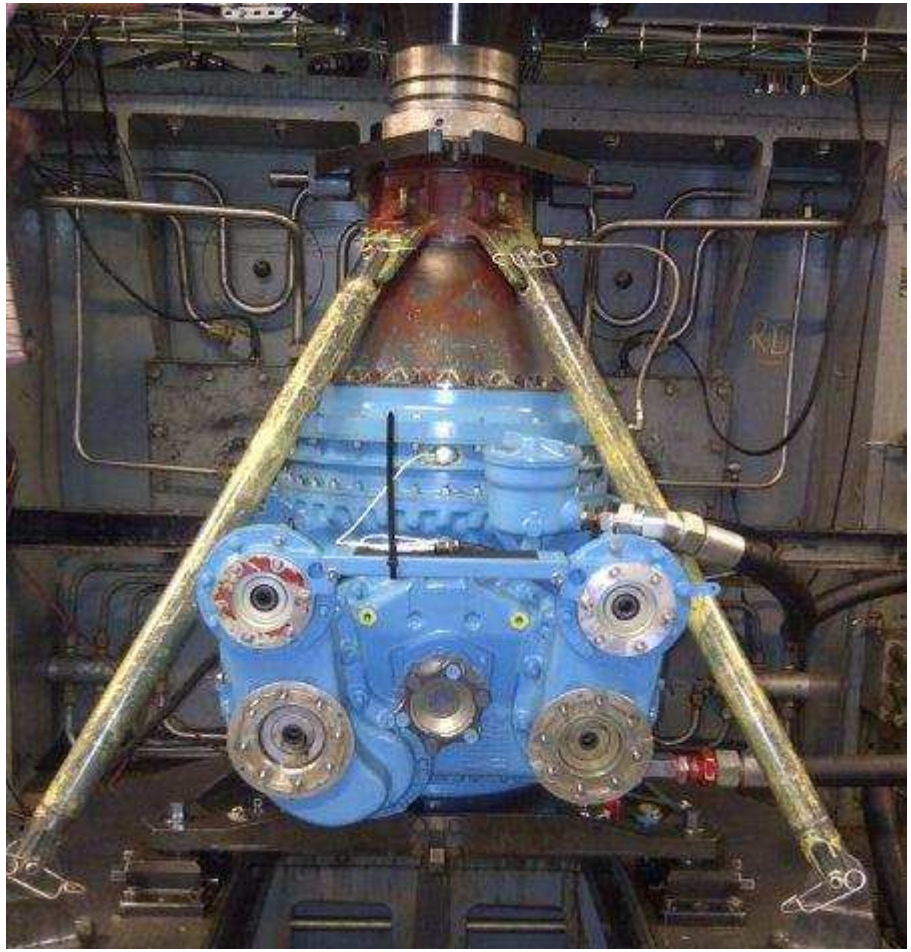
Wireless transmission

- Homodyne system using modulated backscatter
- 13.56 MHz band
- Use of near-field magnetic coupling
- Two parallel coaxial coils
- Analogue modulation of the carrier allows very broadband transmsission
- Also allows scavenging of power for signal conditioning

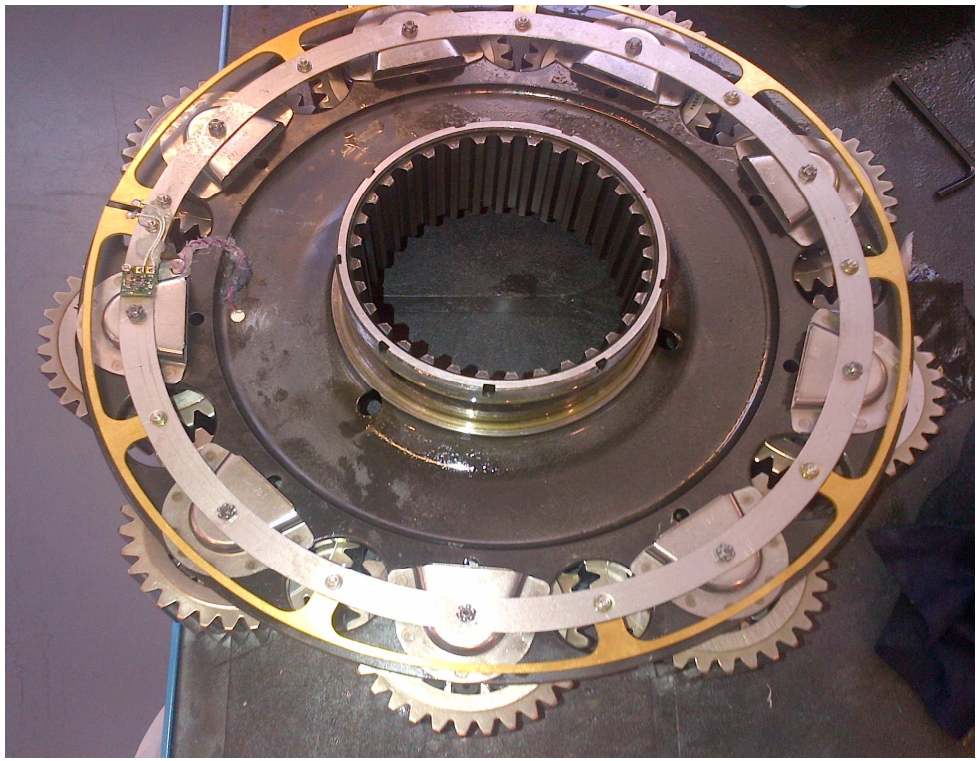


Full-scale testing

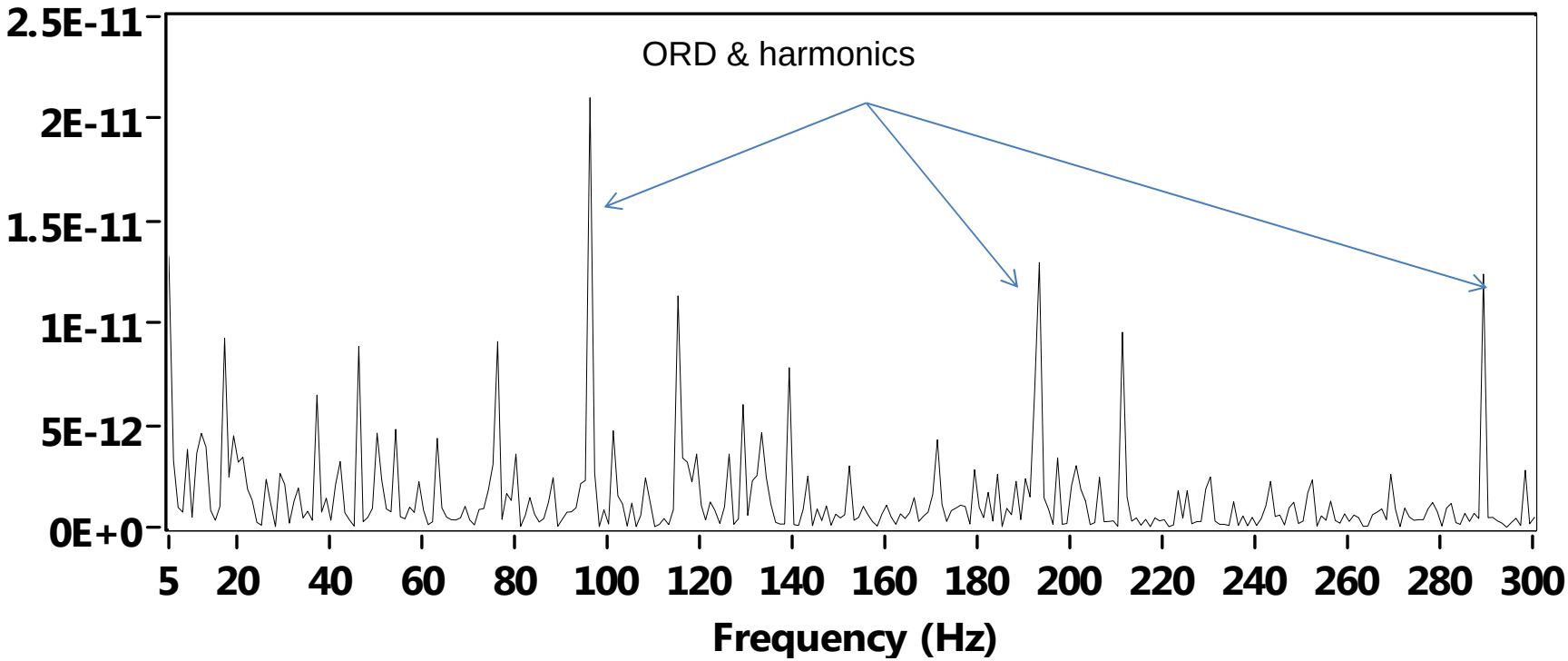
- System fitted to SA330 Puma gearbox
- 3 planet damage conditions:
  - good, slight, major
- Varying power:
  - Cruise – 110% max T/O
- High temperature
- ~10 hours running



Full-scale testing



Full-scale testing



Concluding remarks

- Successful demonstration of an internal sensor
- Wireless transfer of a meaningful AE signal from inside a MGB
- Power transfer for signal conditioning
- Report and further results of analysis in the near future
- Potential for high signal-to-noise ratio measurements, with improved diagnostics / prognostics