Internal vibration monitoring of a Planetary Gearbox

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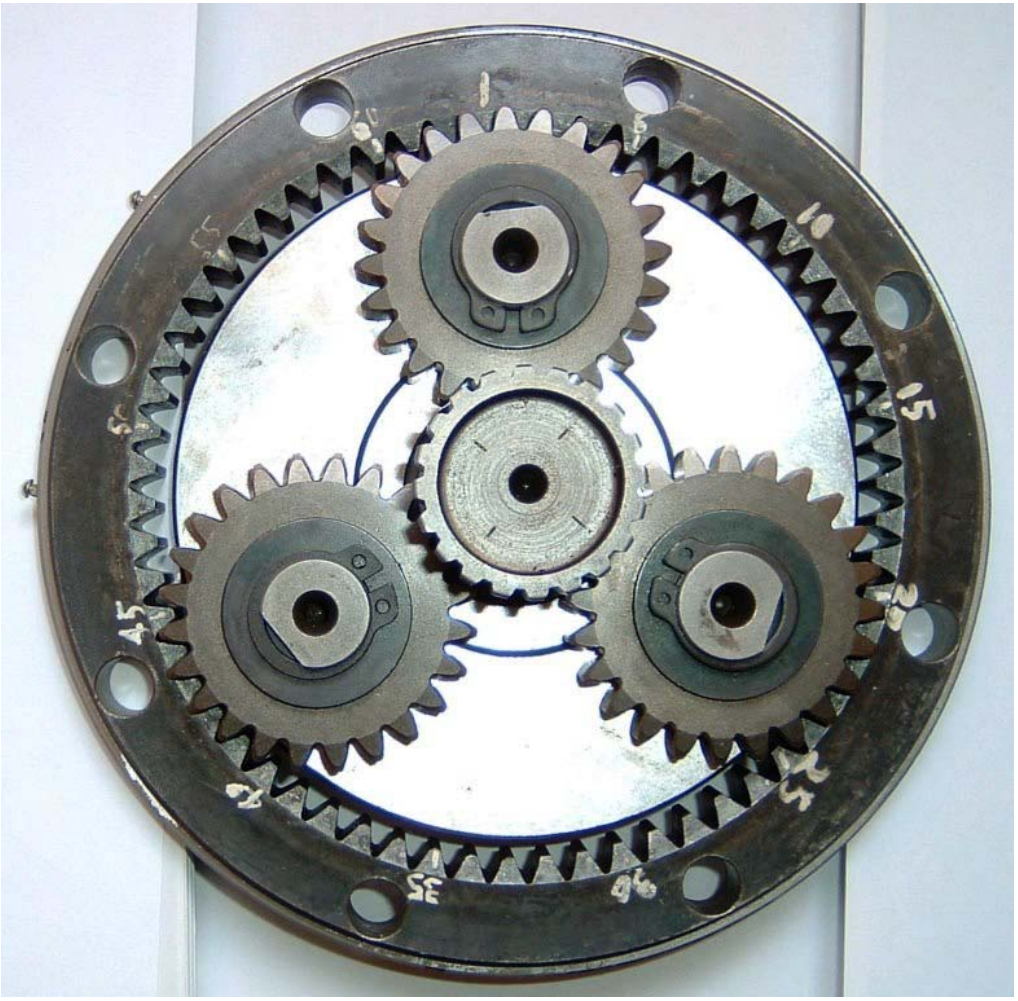
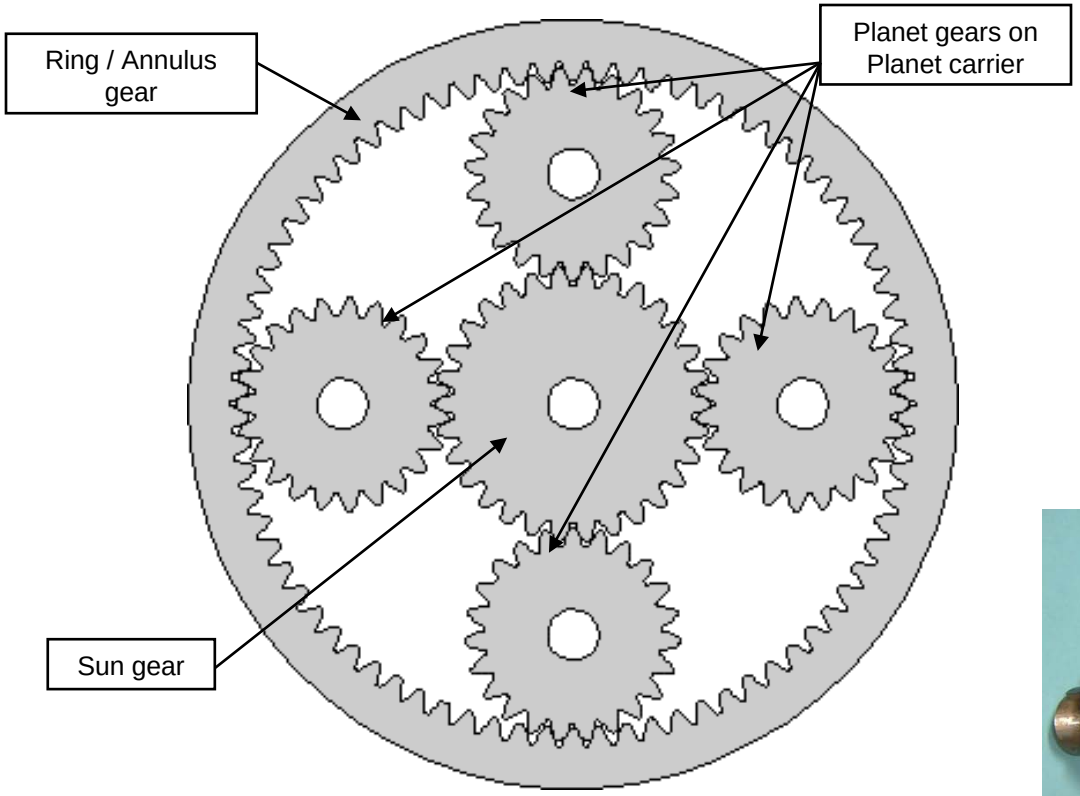
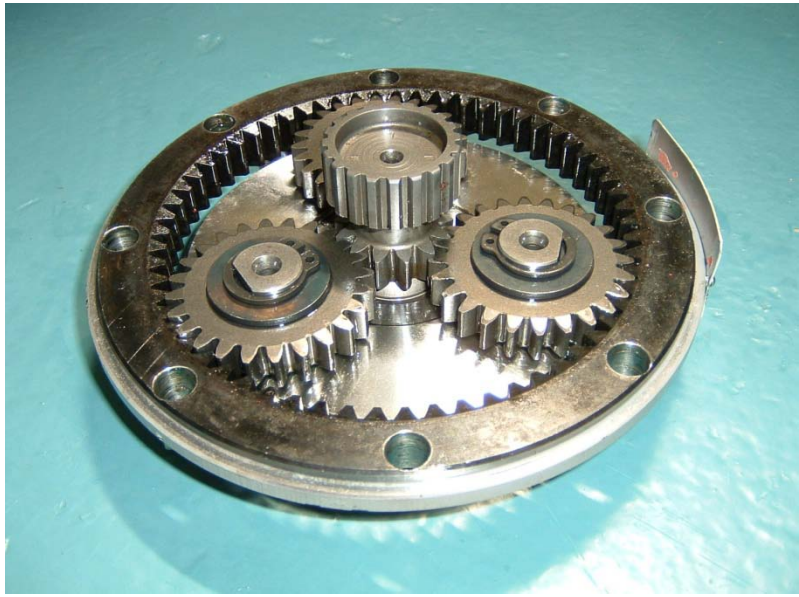


What is a Planetary or Epicyclic Gearbox?





How does it work?

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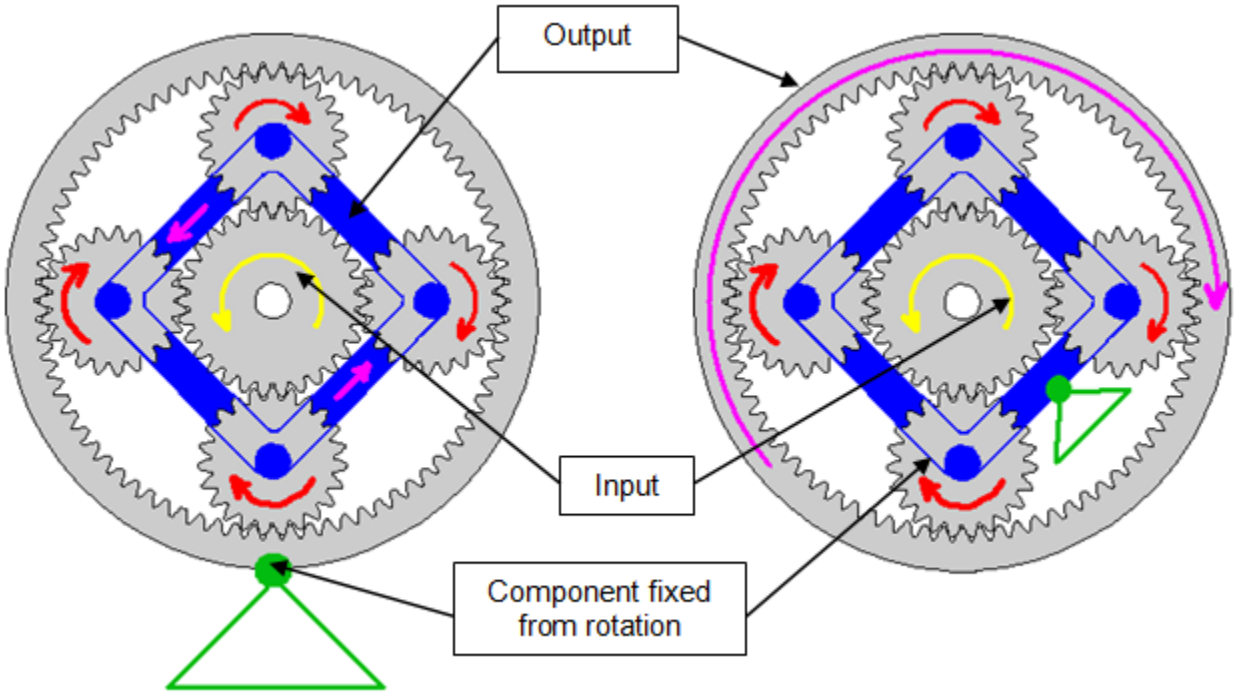


Various operational modes

- Usually: Sun gear input, ring gear stationary and planet carrier output

Where are epicyclic gearboxes used?

- Most aircraft gearboxes
- Automatic transmissions
- Earthmoving equipment
- Agricultural equipment

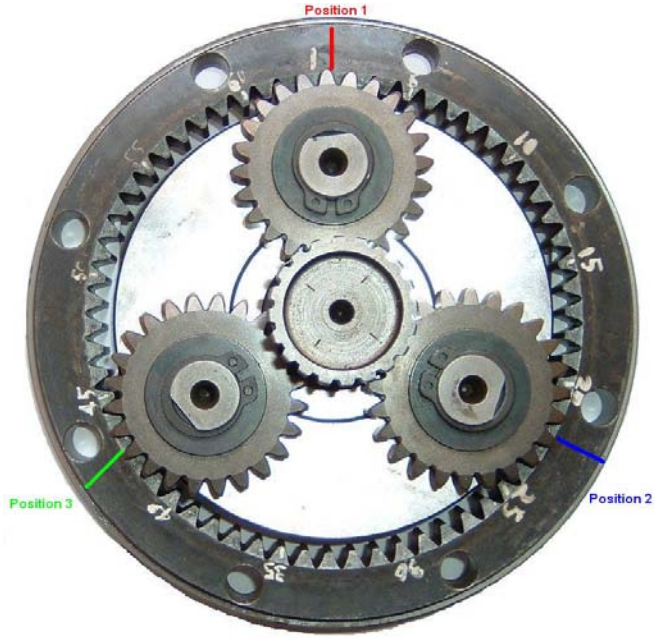
Why are they used?

- Input and Output shafts on same axis
- Large speed reduction / torque increase
- Extremely reliable
- Low vibrations
- Compact

Vibration monitoring of epicyclic gearboxes

Why not use standard techniques?

- Standard techniques assume that transfer path from teeth in mesh to transducer remains constant.
- Multiple meshing of identical gears causes faults to be masked or hidden
- Suppression of normal frequencies gear mesh frequencies can occur

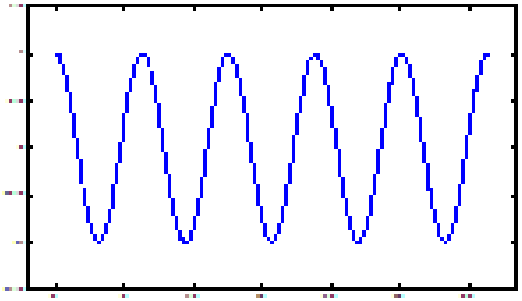


Current epicyclic gearbox monitoring techniques

- General monitoring using existing techniques
  - No diagnostic capability – you don't know what is damaged
  - Detection often only occurs when damage is severe
- Adapted time synchronous averaging technique
  - Developed by Howard, Forrester and Blunt (1990 to present)
  - Refined over time
- Various condition indicators
- Wigner-Ville Distribution
- Harmonic Index
- Intra-Revolutionary Energy Variance
- Limited success with all these methods excepts TSA!

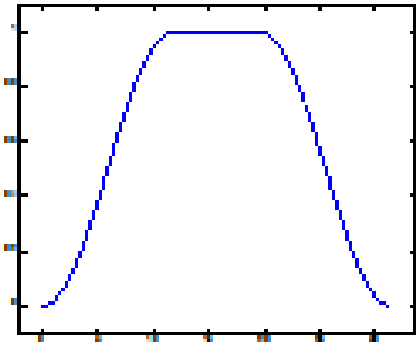
EpiTSA (Epicyclic Time Synchronous Averaging)

SIGNAL FROM ACCELEROMETER

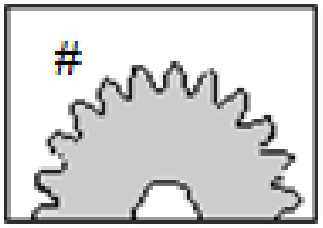


- At each mesh point

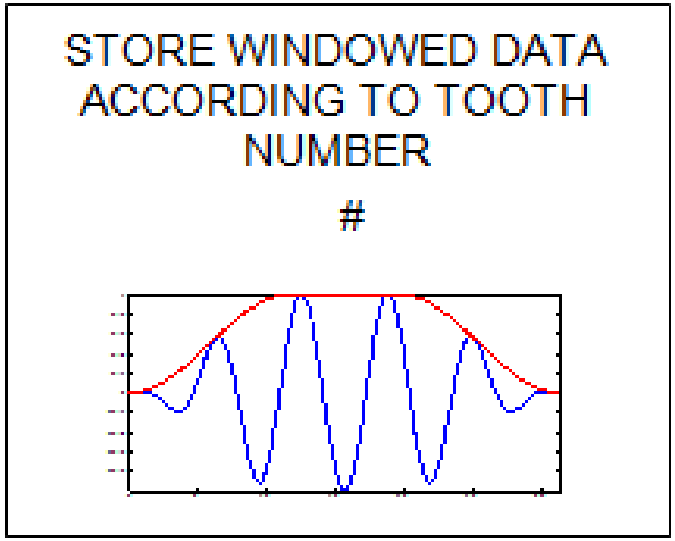
APPLY WINDOW FUNCTION



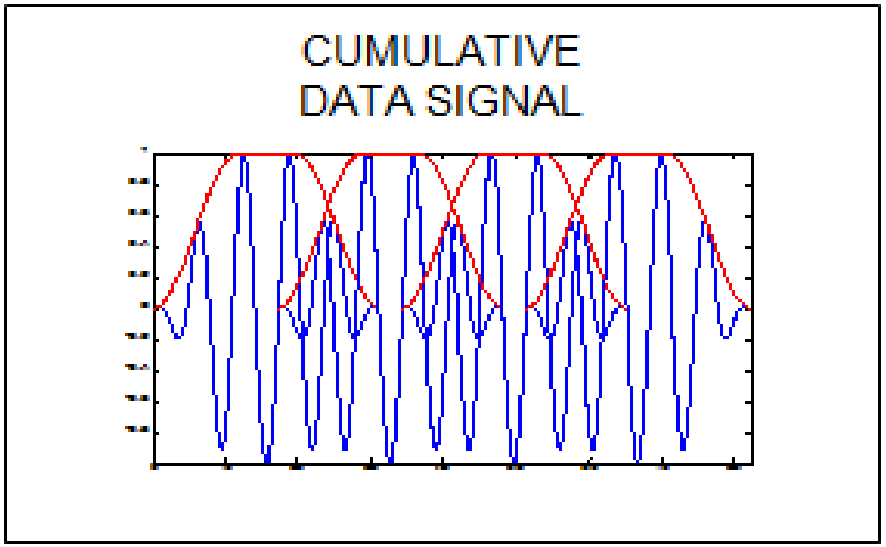
DETERMINE TOOTH IN MESH



EpiTSA (Epicyclic Time Synchronous Averaging)



- Repeat once for each tooth



- Repeat once for each average required

Disadvantages of EpiTSA

- Technique is difficult to implement
- Many variables that affect accuracy
- Requires customization to the specific gearbox
- Requires complex post processing

This leads to the question – is there any way that on could remove the relative motion between the accelerometer and the point of gear mesh?

- Planet gears are mounted on a planet carrier.
- There is no relative motion between the planet carrier and point of gear mesh

Theoretical concept

If a accelerometer is mounted on the planet carrier, planet gear vibration could be measured directly as there is no relative motion between the transducer and the planet gear.

How to prove the theory?

- Implement the EpiTSA method
- Obtain a baseline using EpiTSA
- Modify an epicyclic gearbox for internal monitoring
- Measure data internally
- Compare with EpiTSA data
- Do this for different levels of damage

Epicyclic gearbox for research

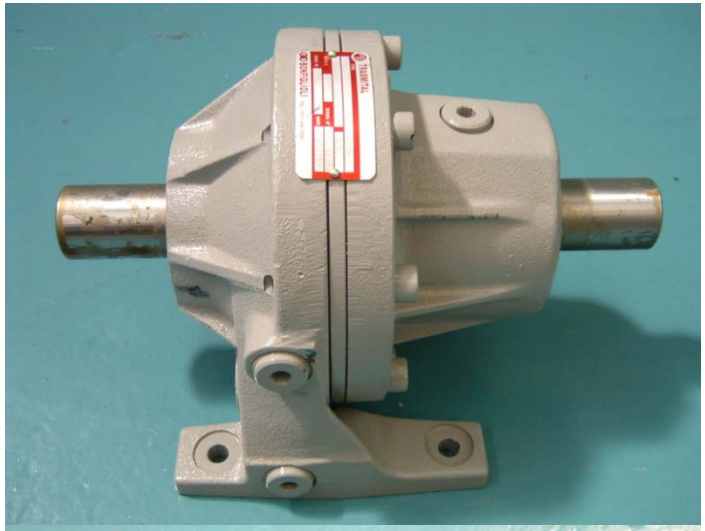
Initial test done on Oryx main gearbox

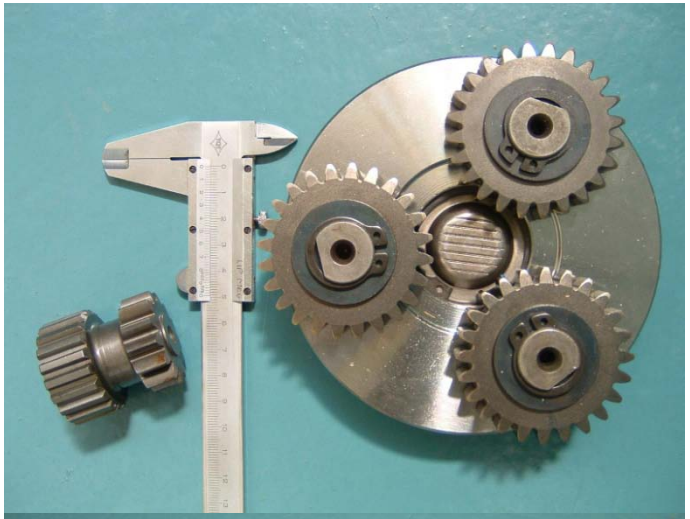
- Too expensive to run
- No modifications were allowed
- Very noisy signal
- Could only test at single speed

Epicyclic gearbox test bench

Epicyclic test bench at University of Pretoria

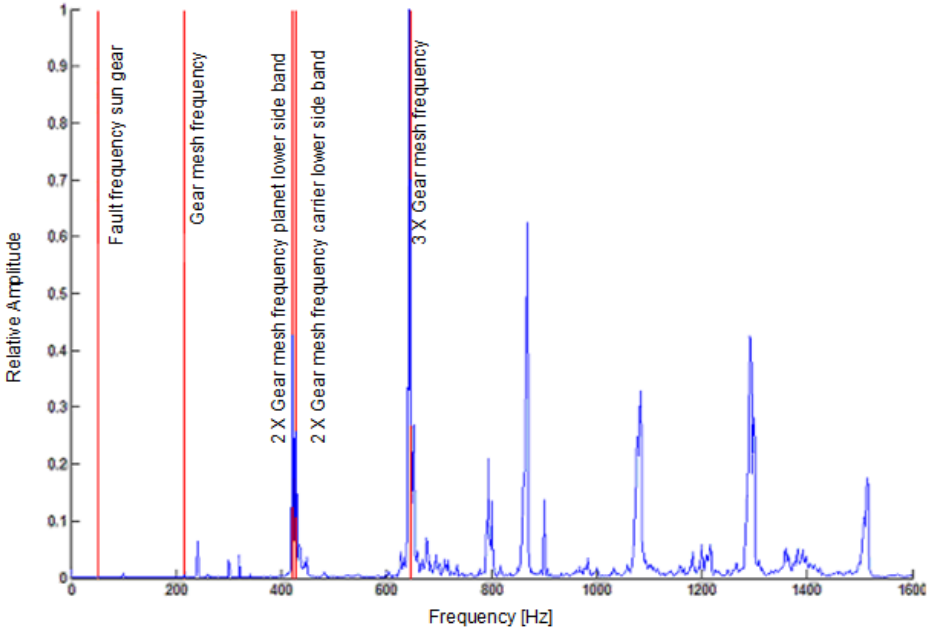
- Bonfigliogli 300-L1-5.77-PC-V01B-E epicyclic gearbox





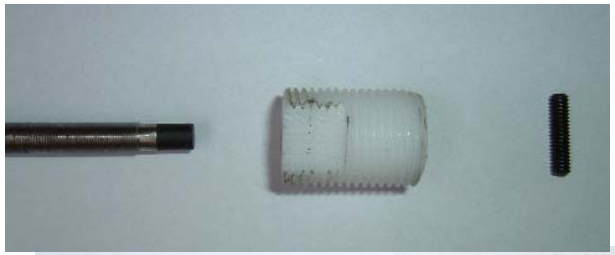
Epicyclic test bench at University of Pretoria

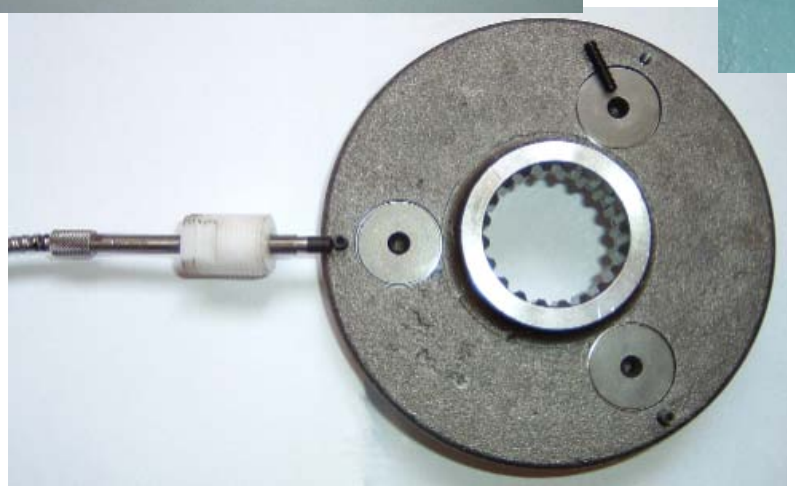
- Bonfigliogli 300-L1-5.77-PC-V01B-E epicyclic gearbox
  - Ring gear - 62 Teeth
  - 3 x Planet gear - 24 Teeth
  - Sun gear - 13 Teeth
- GMF suppression occurs
- PSD dominated by 3 X Gear mesh frequency
- Any ring gear tooth will only see odd or even planet gear teeth



Implementation of EpiTSA

- Gearbox modifications
  - Two accelerometers stud mounted to ring gear
  - Different length pins and a magnetic pickup used to determine centre of gear
  - Damage induced on a planet gear tooth

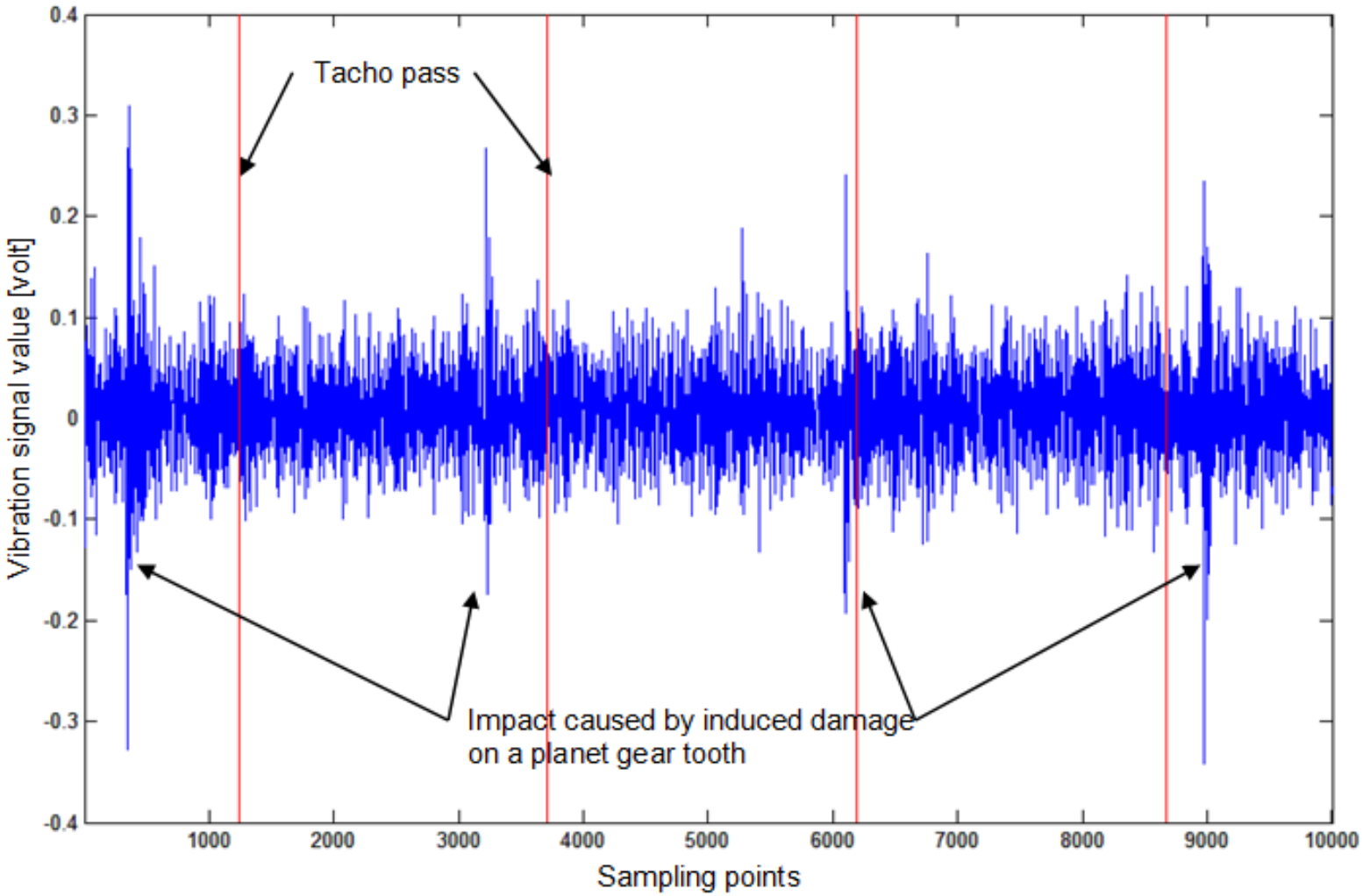




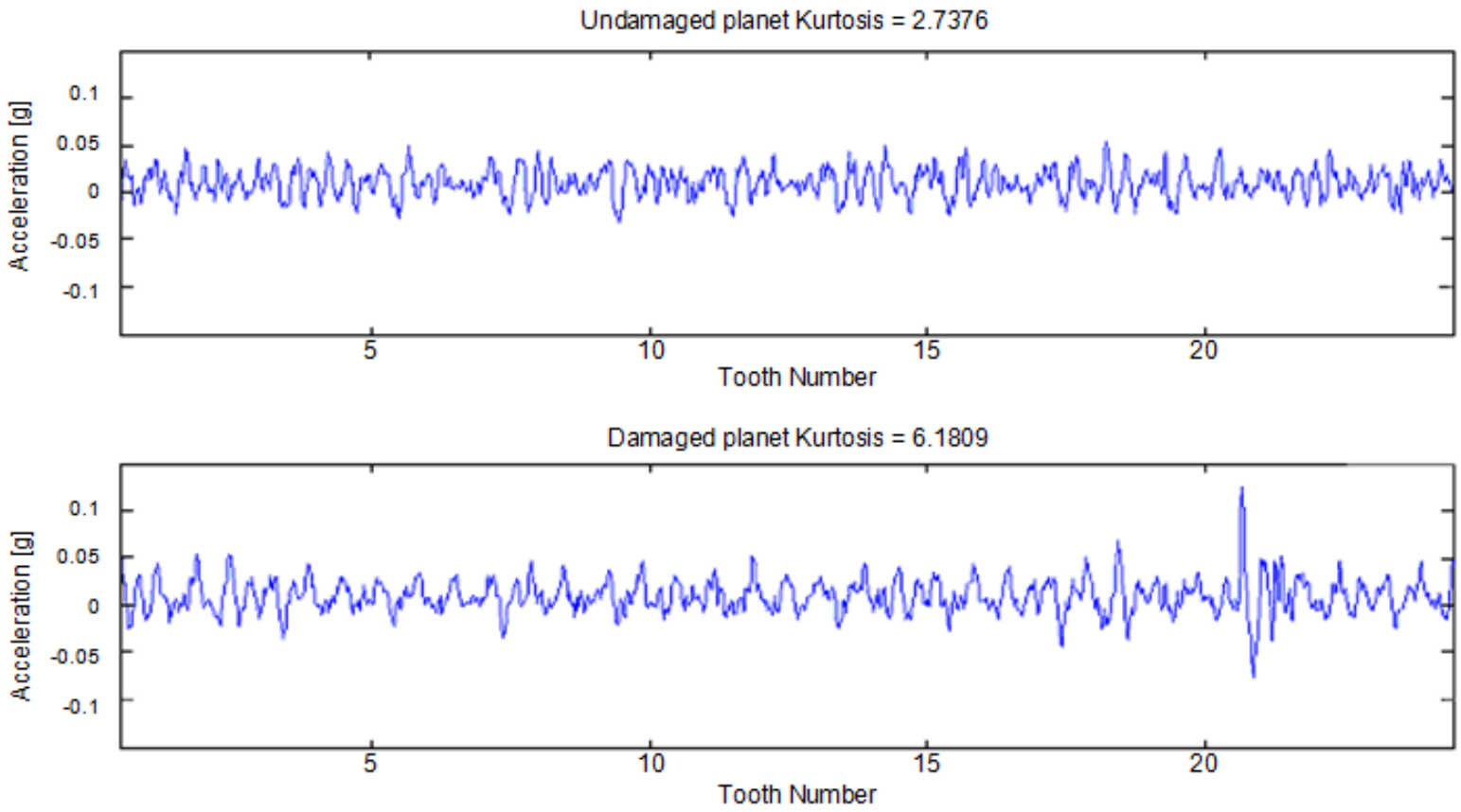
Implementation of EpiTSA

- Software Implementation
  - Particle swarm optimization algorithm used to optimize window size and taper
  - Algorithm implemented in Matlab code
    - Dual accelerometer input
    - Tacho signal marking planet pass
    - Gear tooth mesh calculator
    - Makes use of tacho signal to determine planet gear and mesh point
- Successfully able to identify damage

Raw externally measured data



Result from EpiTSA

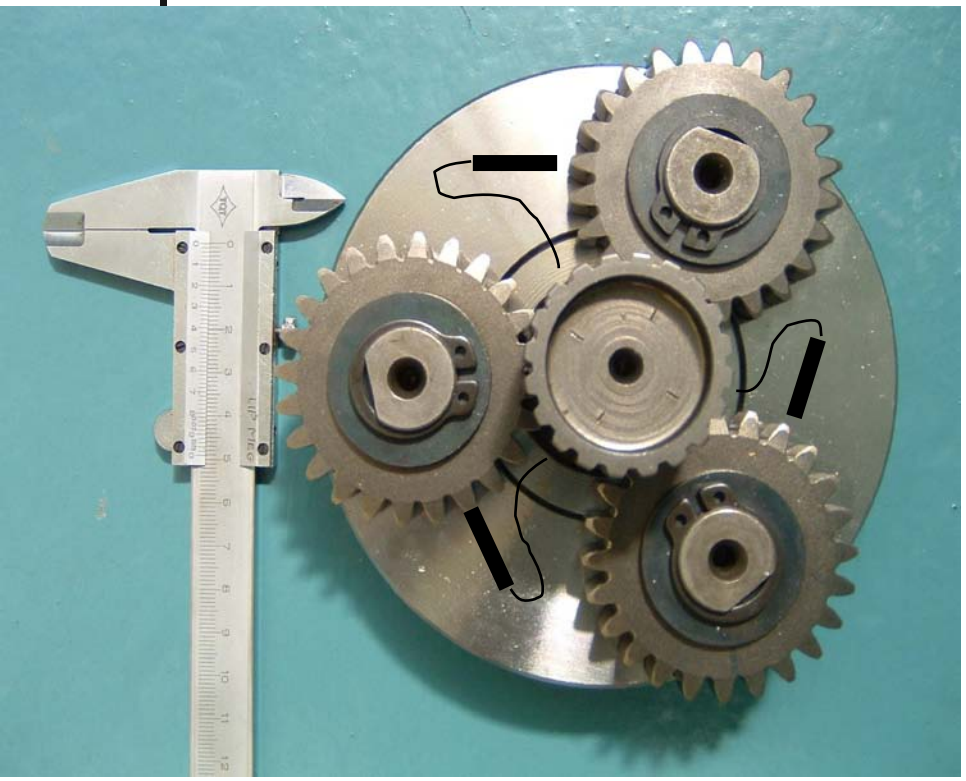


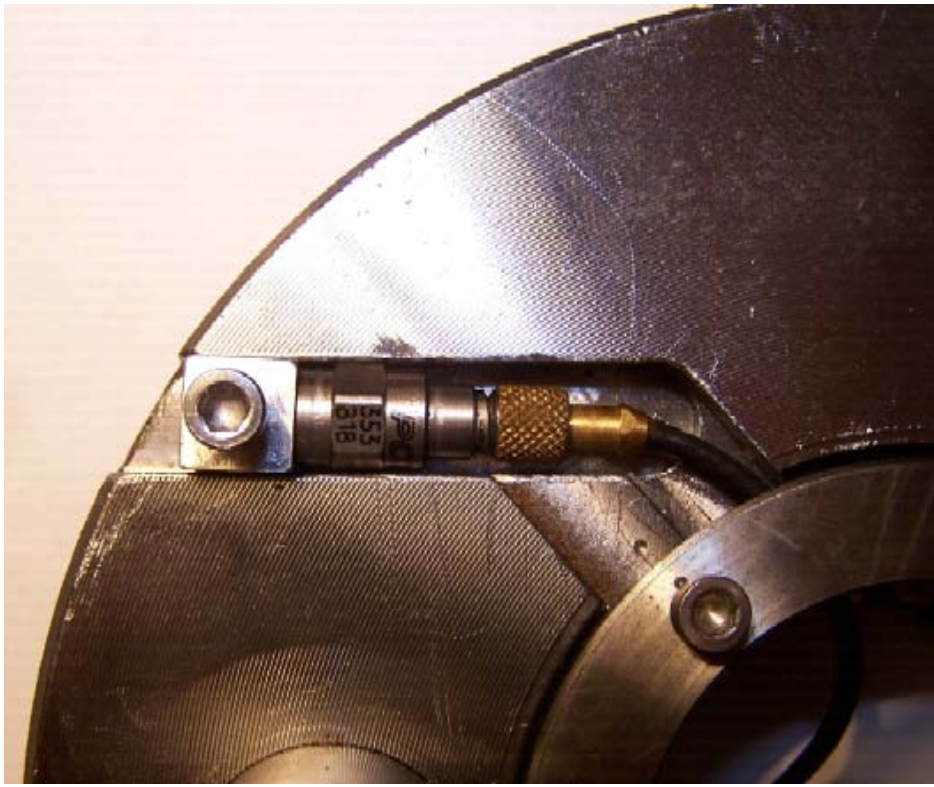
Proposed method for internal monitoring

- Data measured from the planet carrier should be directly comparable to data extracted by EpiTSA method

- Mount an accelerometer internally on the planet carrier
- Transmit the measured signal to the outside of the gearbox
- Compare the internally measured signal to the EPITSA signal

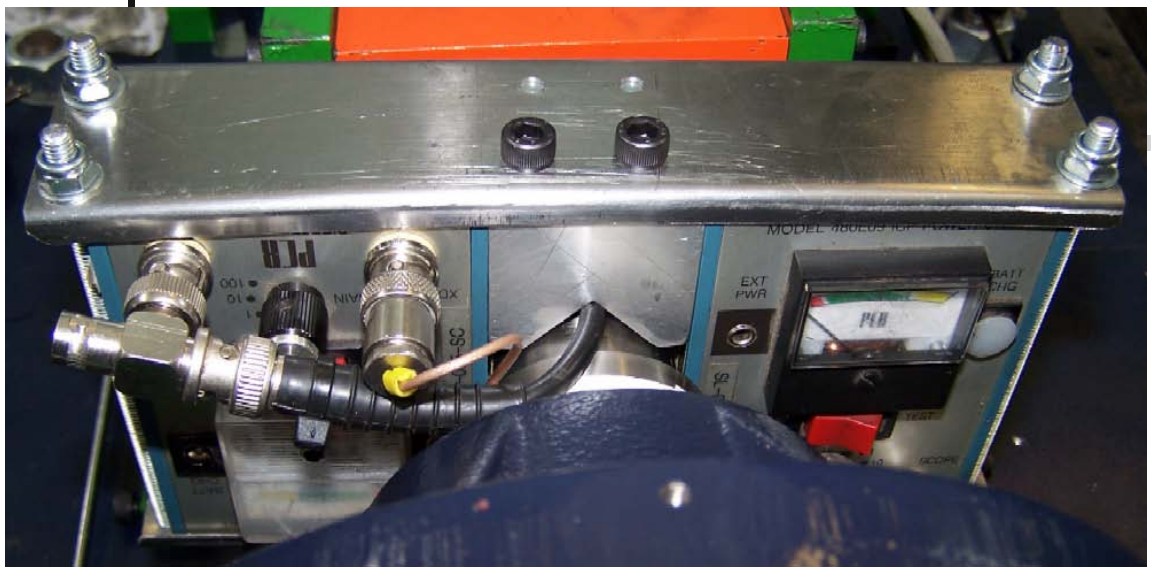
Implementation of internal measurement





- PCB accelerometer mounted on planet carrier

Implementation of internal measurement

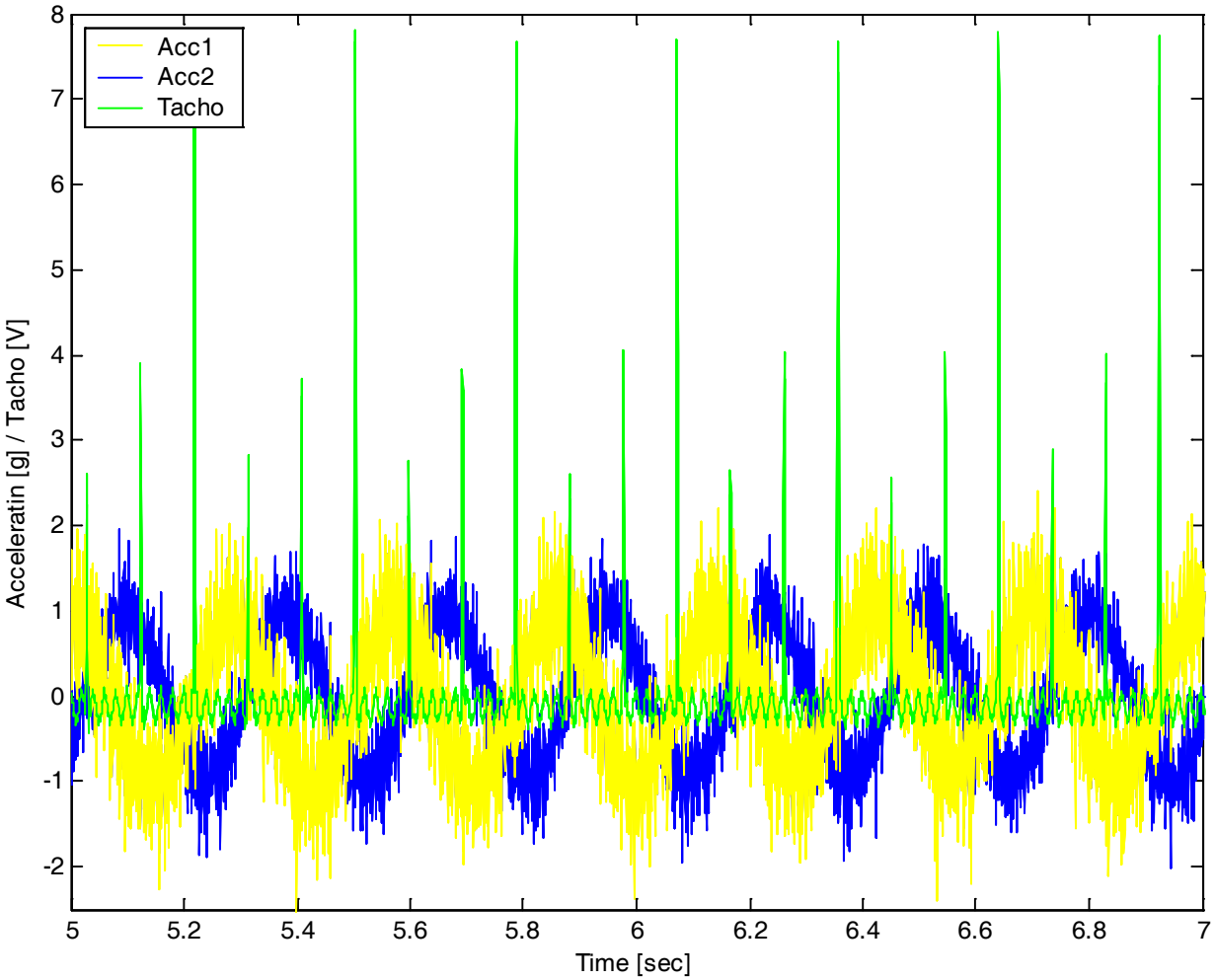


- PCB battery powered power supply boxes
- Slip ring mounting
- High quality gold plated slip rings

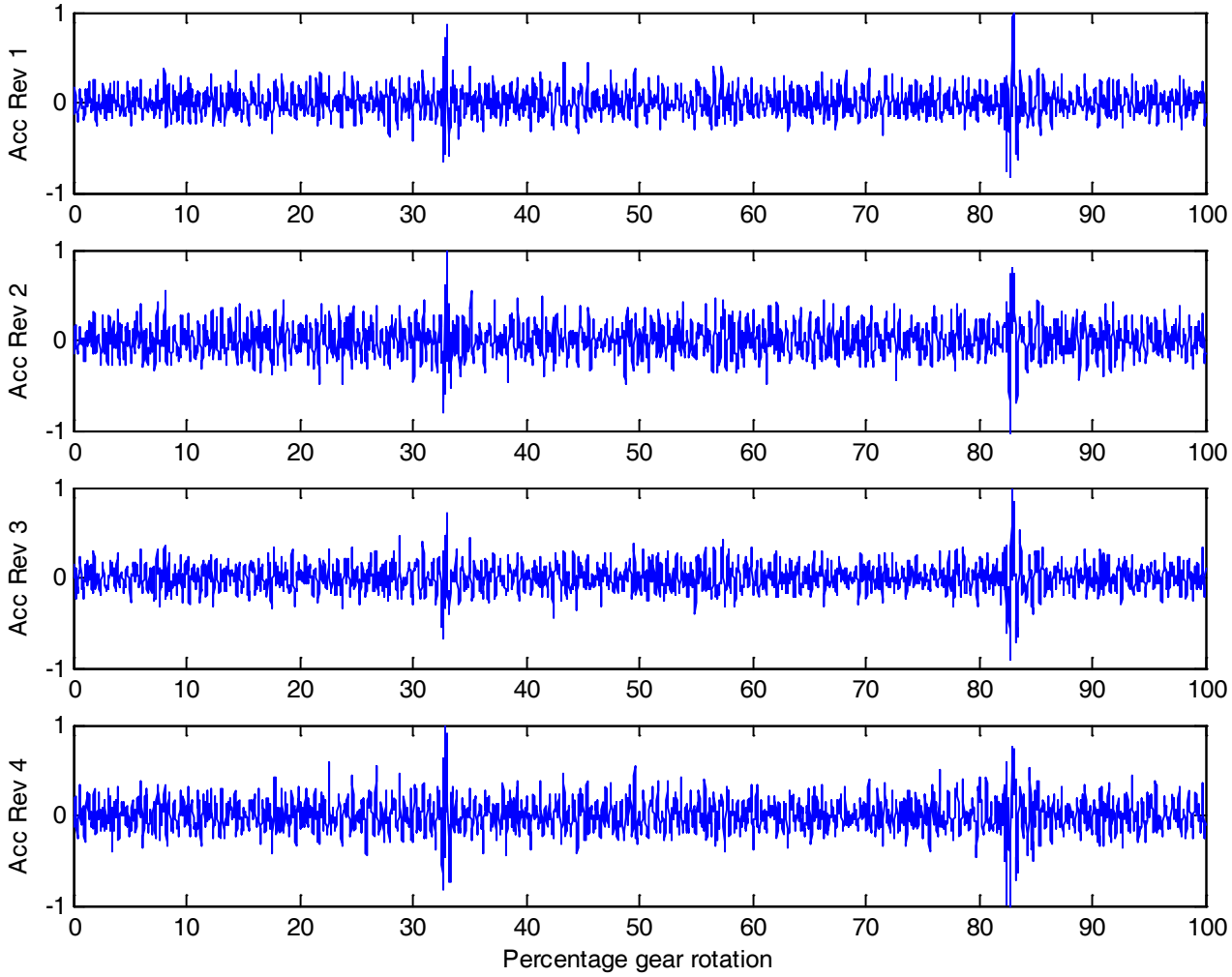
Internally measured data

- Data measured at four different levels of damage
  - (UD) Undamaged
  - (SD) Slight damage
  - (MD) Moderate damage
  - (ED) Extreme damage
- Rotation through gravitational field is evident
- Butterworth filter used to remove gravitational effect

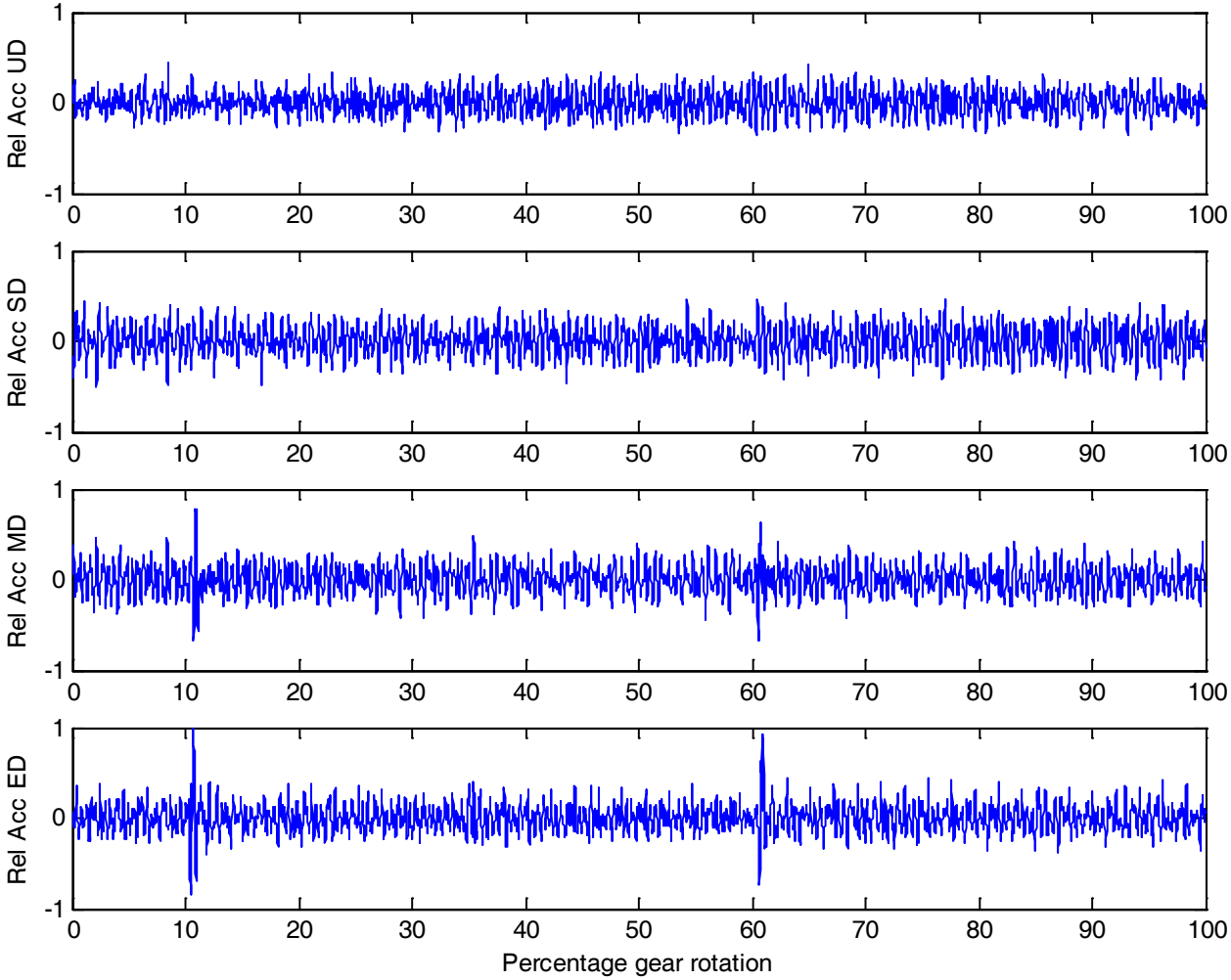
Raw internally measured signal



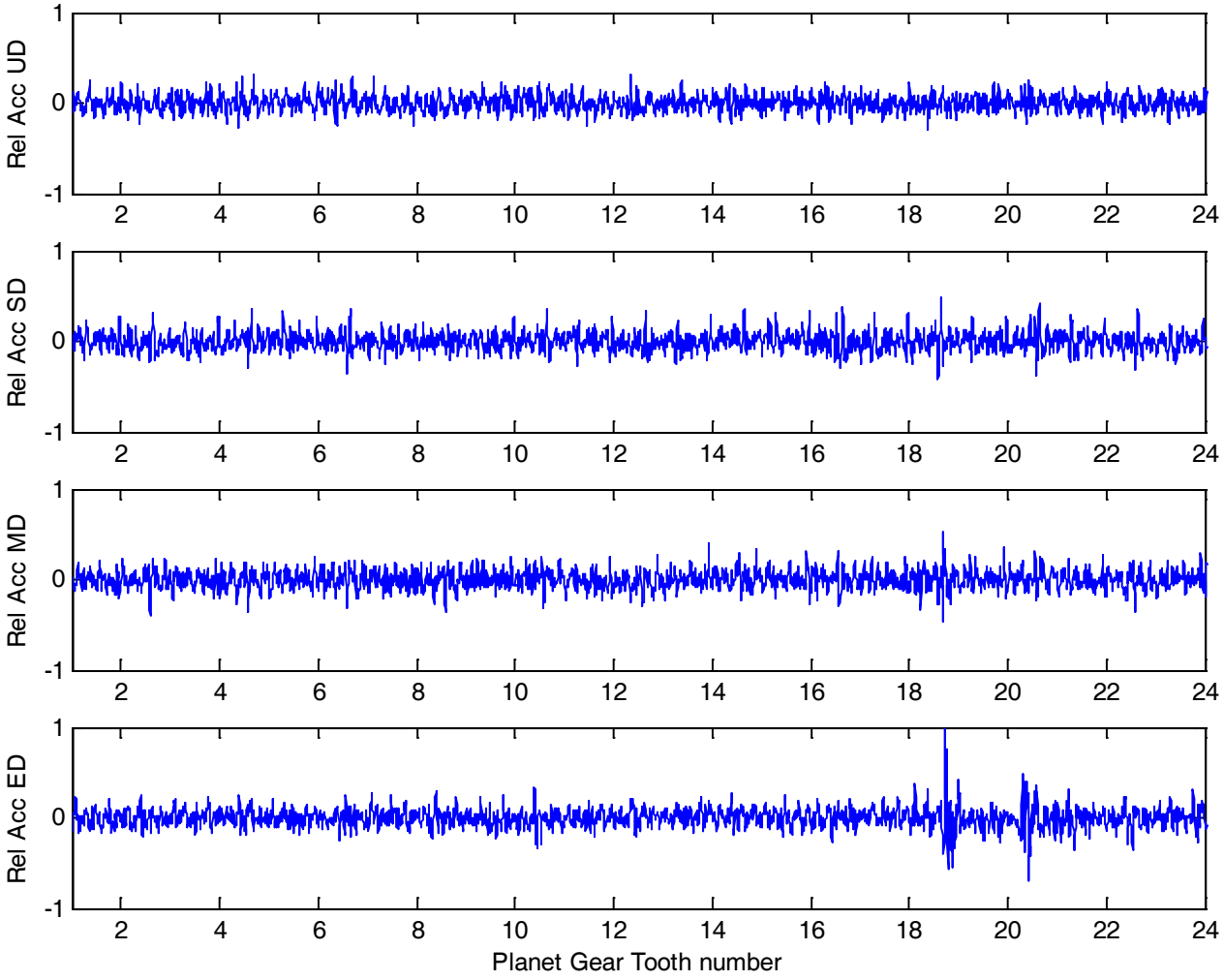
Internally measured data for Moderate Damage



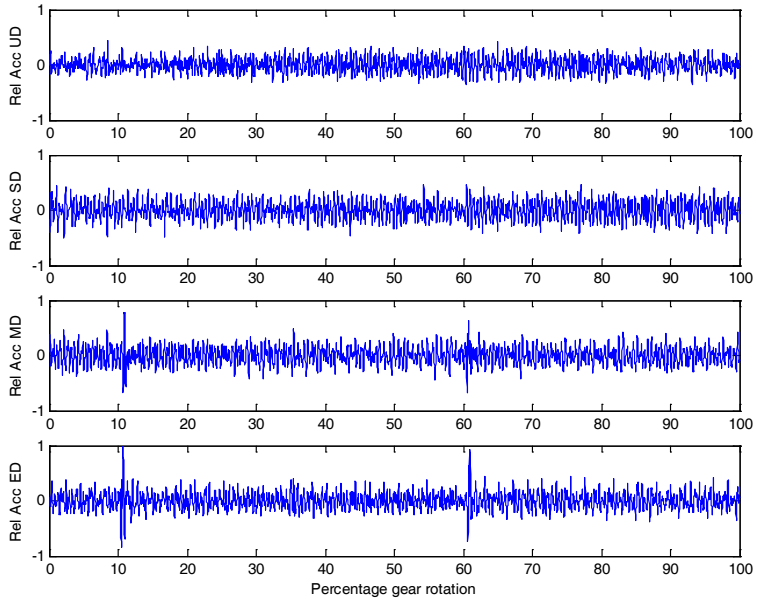
Internally measured data for increasing damage

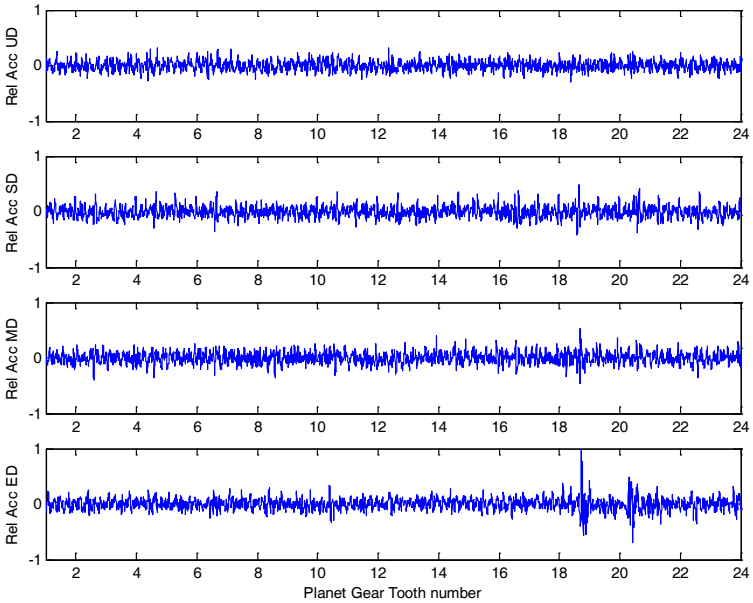


EPITSA data for increasing damage



Internally measured vs EPITSA

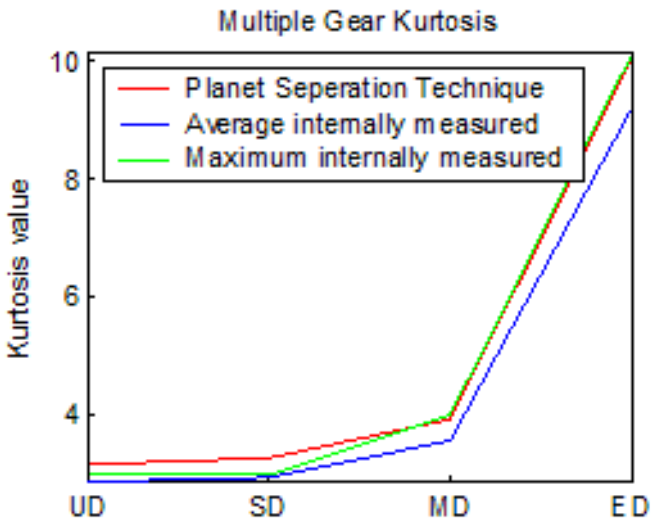


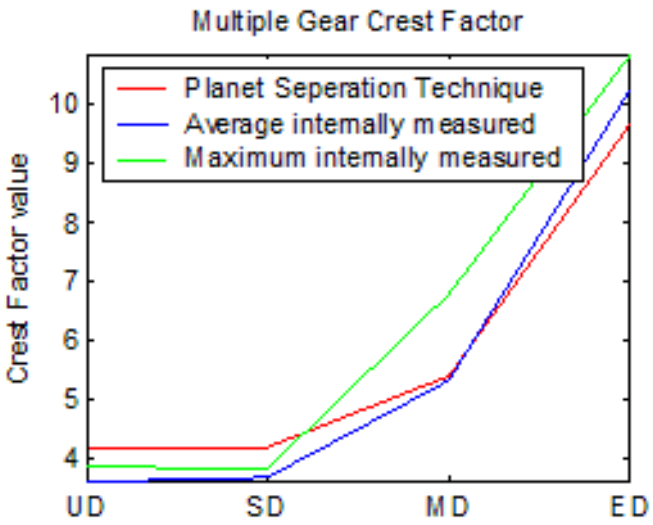


Internally measured

EPITSA

Condition Indicators – Kurtosis & Crest Factor





Condition indicators show internally measured equally effective in determining increasing damage

Findings

- Once the gearbox is modified, it is easy to measure and interpret internally measured vibration data
- Planet gear damage is easy to detect and identify even at low levels of damage

- Drawbacks of the internal measurement technique:
  - Planet carrier requires modification
  - Output shaft requires considerable modification
  - Signal must be amplified before being transmitted through the slip rings
  - Slower rotational speed due to slip rings

Conclusion and Contribution

- Internal vibration monitoring of an epicyclic gearbox is possible
- Internally measured data is comparable to existing techniques
- Internal measurement places restrictions on the operation of the gearbox
- Improvements in sensor technology could solve some of these restrictions

QUESTIONS