Diagnostics Research

Army Research Laboratory
Vehicle Technology Directorate (VTD)
NASA Glenn Research Center (GRC)

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Mechanical Components Branch

December 6, 2004

VTD/ARL NASA GRC Diagnostics Research

Objective: Develop advanced health management technologies to reliably and accurately detect and quantify damage of critical mechanical components in aerospace drive systems.

Approach:

- Develop analytic tools to simulate damage
- Validate the tools by experimental testing (Components through full-scale transmissions)
- Cooperate & coordinate with Government agencies, Industry and Academia

VTD/ARL NASA GRC Diagnostics Research

Research Assets

- Three highly qualified researchers (2 Ph.D., 1 MS)
- Gear and bearing component fatigue test facilities
- Full scale transmission test facilities
- Access to data from OH-58 flight tests at NASA Ames

VTD/ARL NASA GRC Diagnostics Research

Research Focus Areas

- Development of data fusion technologies for gears and bearings
- Gear crack detection and propagation research
- Development of robust planetary diagnostics tools
- Development of fault detection systems for hybrid bearings

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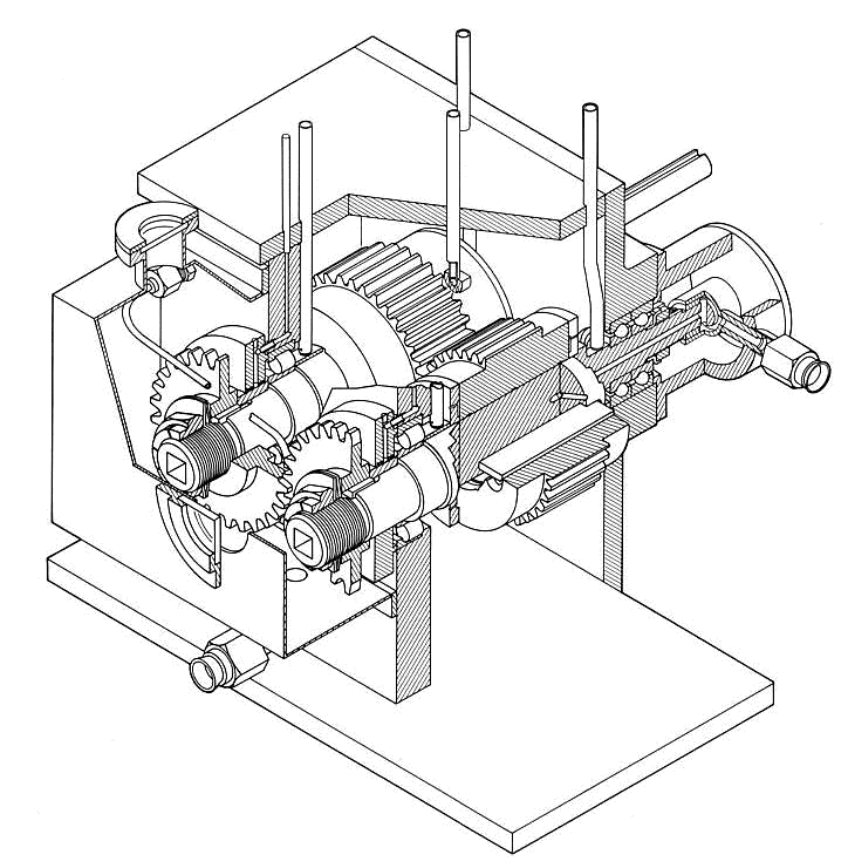
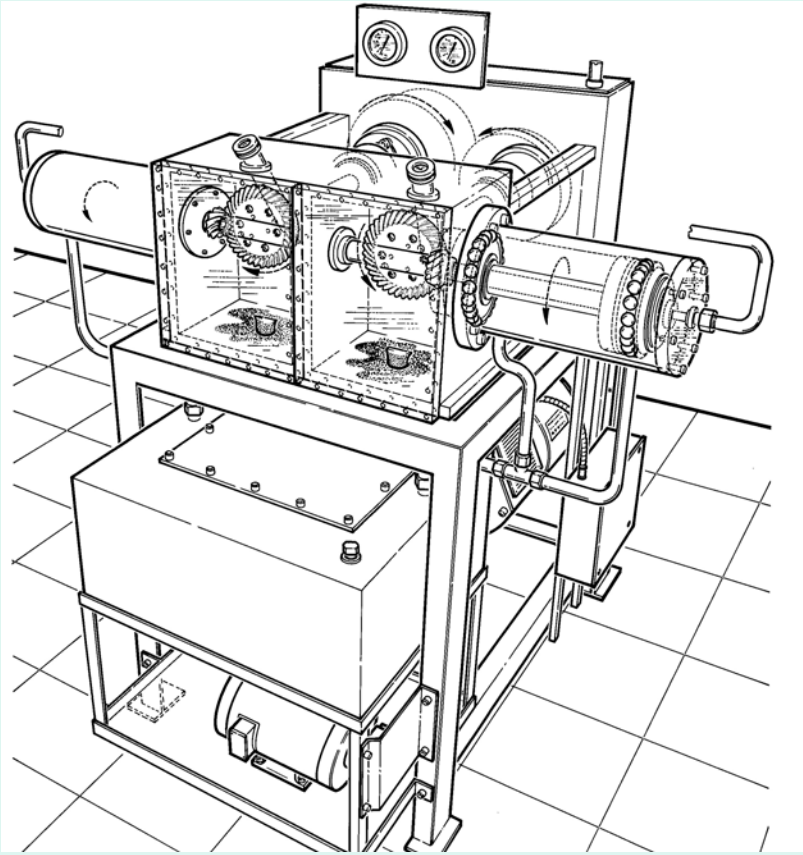
Component Test Facilities at NASA GRC



Spur Gear Fatigue Rig



Spiral Bevel / Face Gear Fatigue Rig

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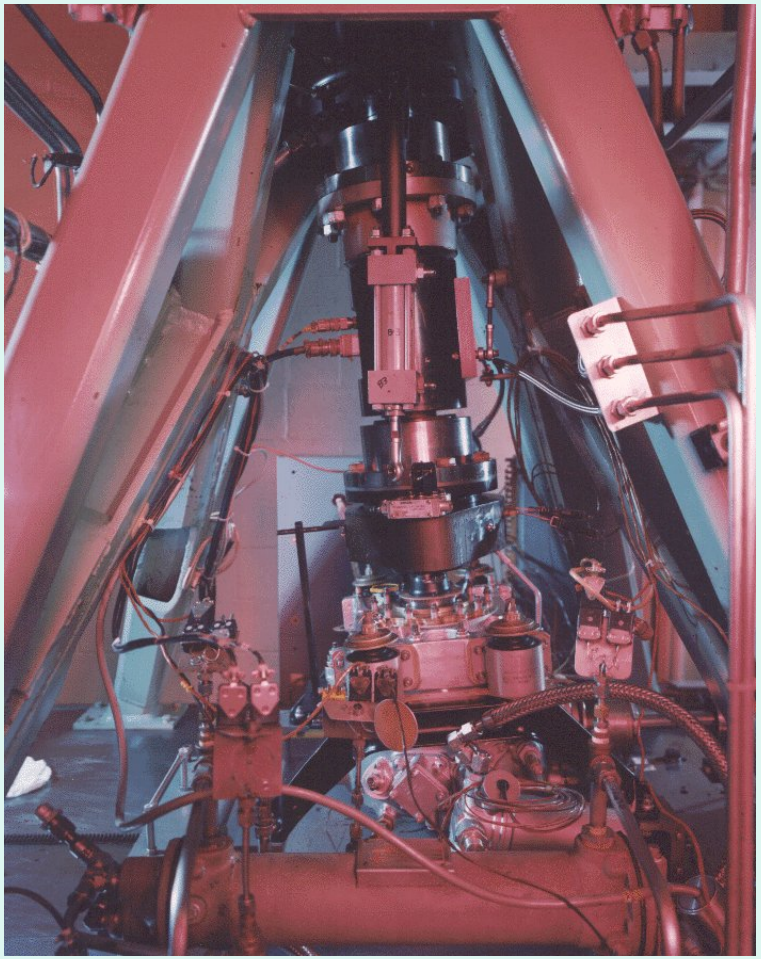
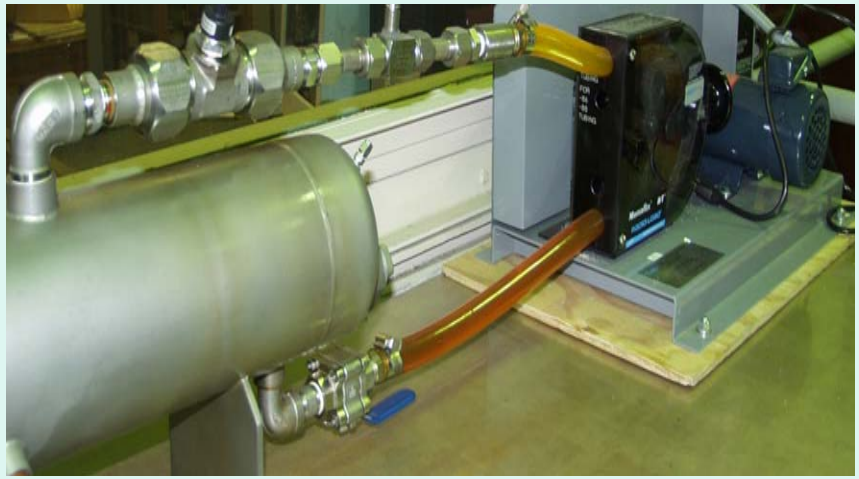
Test Facilities at NASA GRC

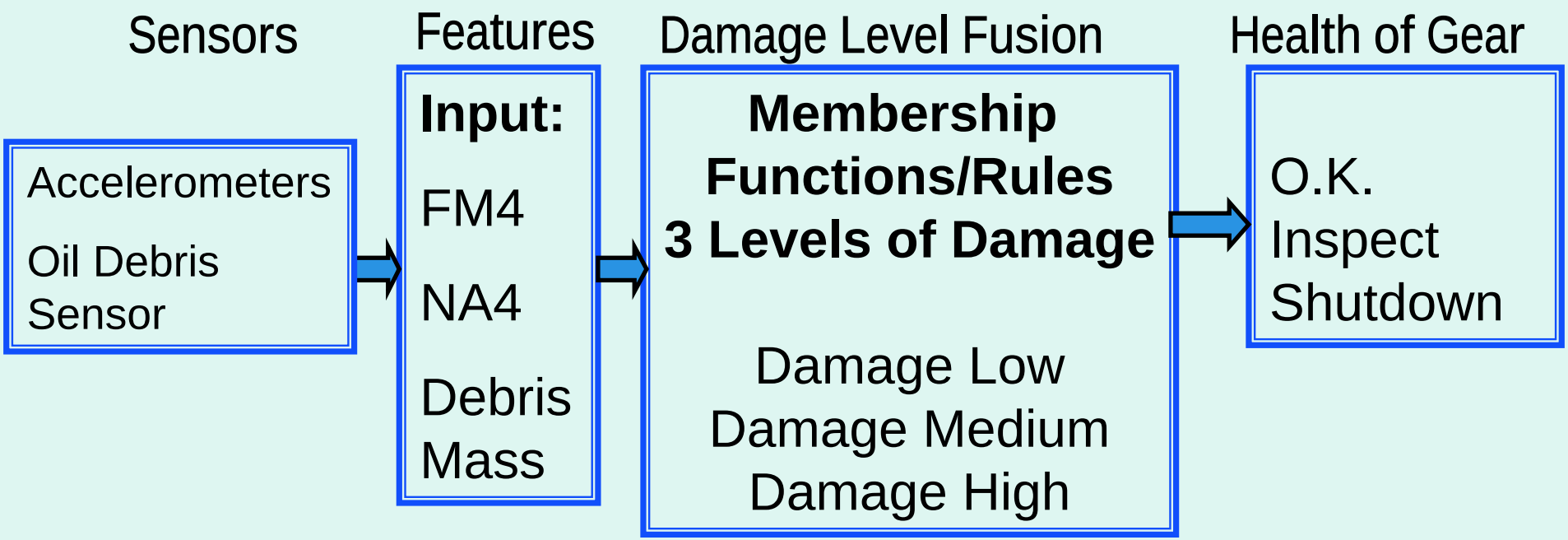


500 hp Helicopter Transmission Facility



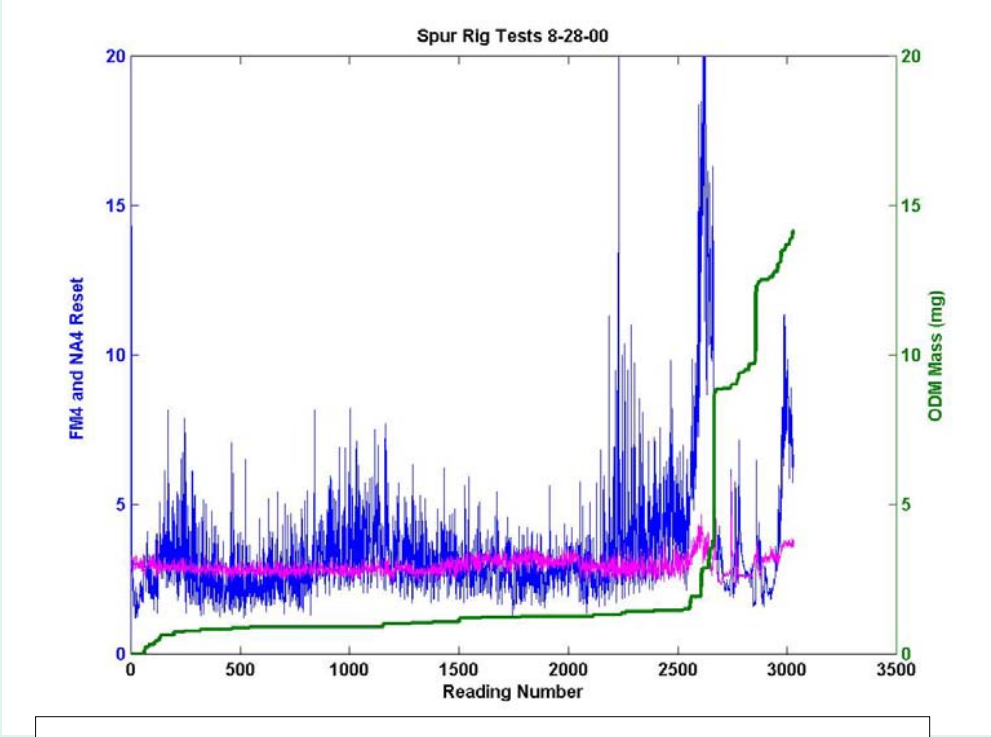
Oil Debris Sensor Flow Test Rig

Data Fusion Analysis

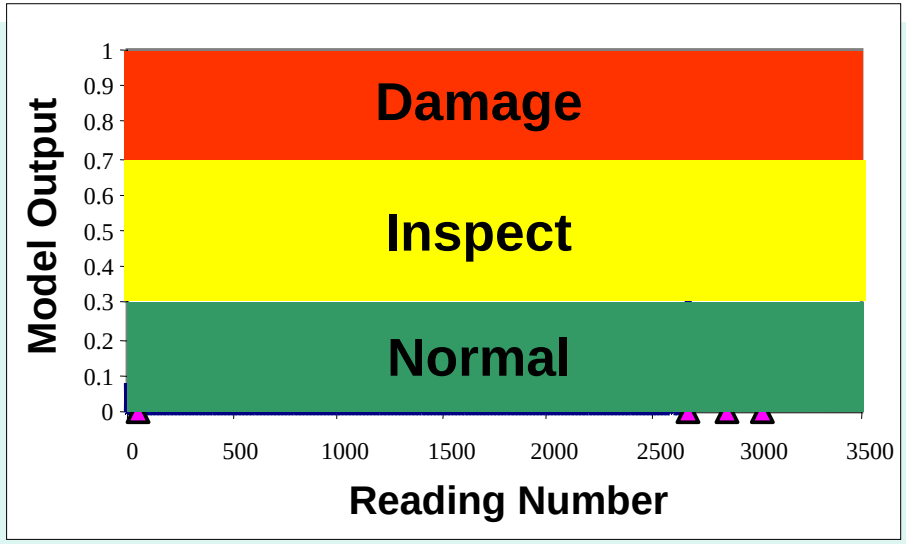


- Fused oil debris and vibration diagnostic features
- Fuzzy logic identifies gear damage level
- Sensor fusion at the decision level

Data Fusion Applied to Spur Gear Fatigue Testing

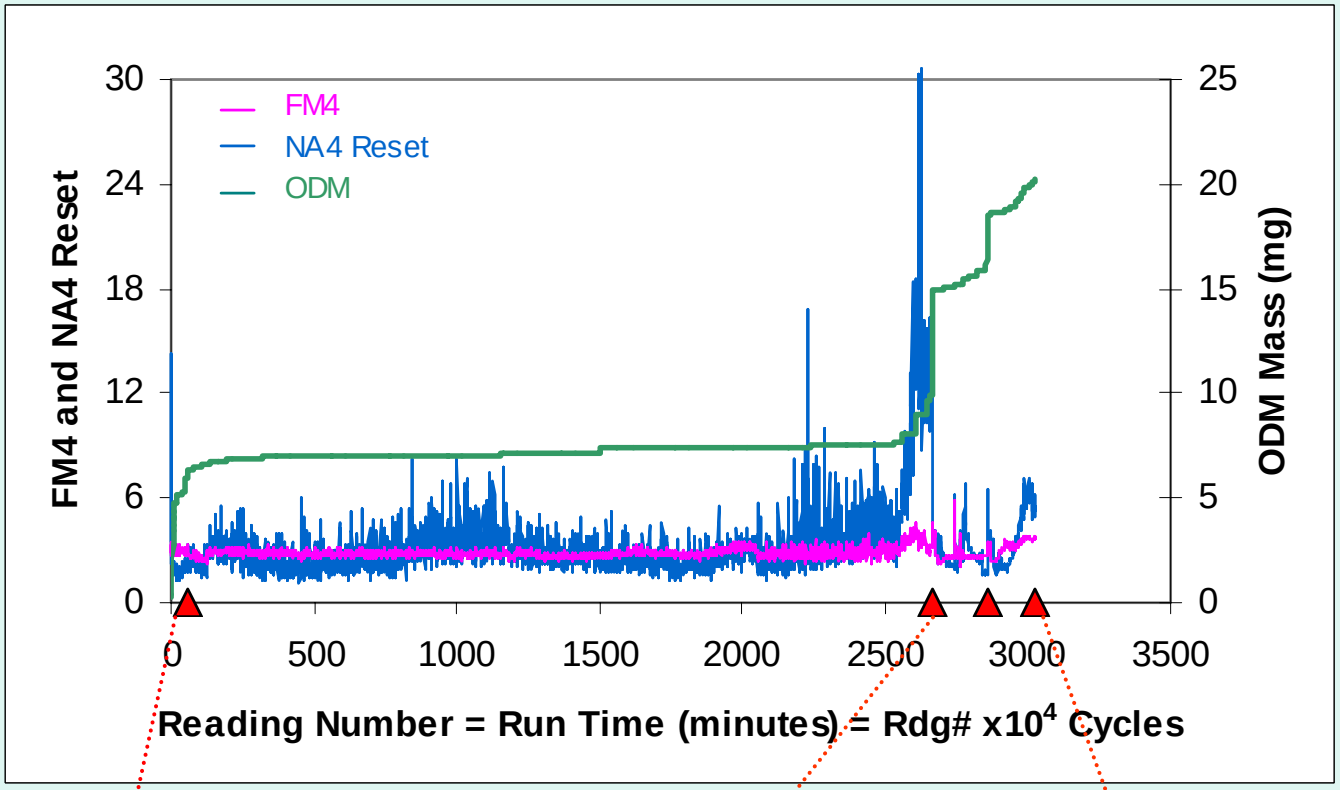


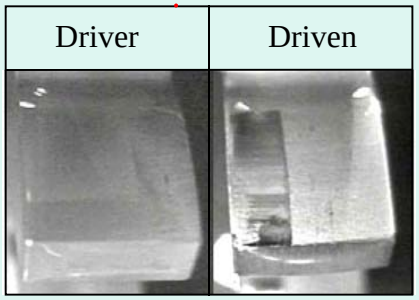
FM4,NA4 and Oil Debris

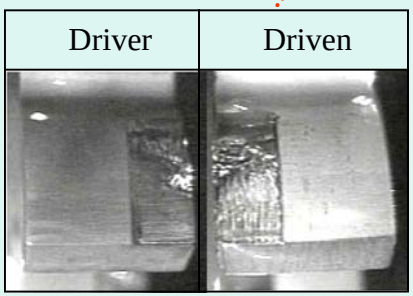


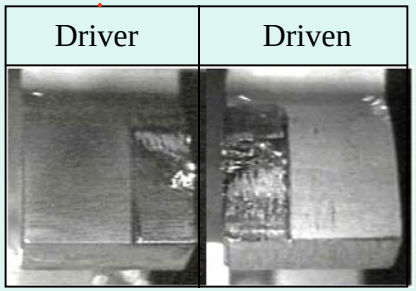
Output of Fuzzy Logic Model

Spur Gear Surface Fatigue Testing Diagnostics Data









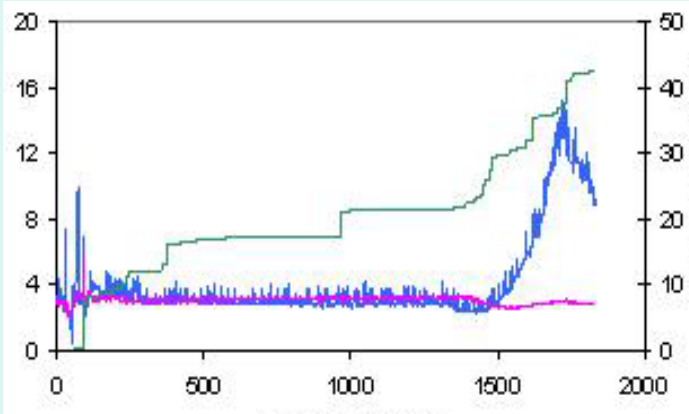
Data Fusion Applied to Spiral Bevel Gear Testing

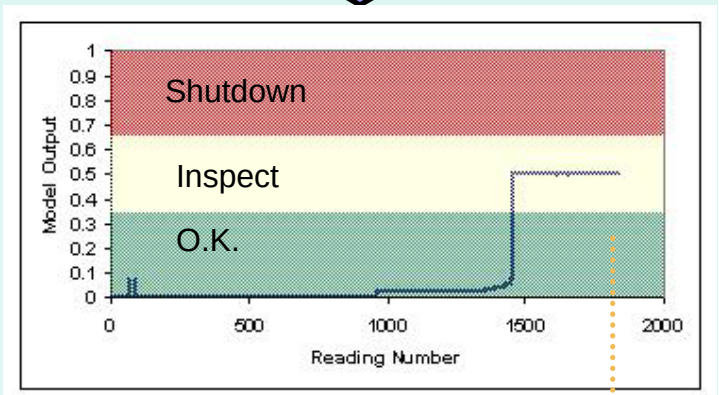
Objective: Developed a damage detection system for spiral bevel gears using oil debris and vibration data fusion/fuzzy logic analysis validated on a spur gear system.

Approach: Oil debris membership function rescaled to correlate debris with gear tooth surface contact area.

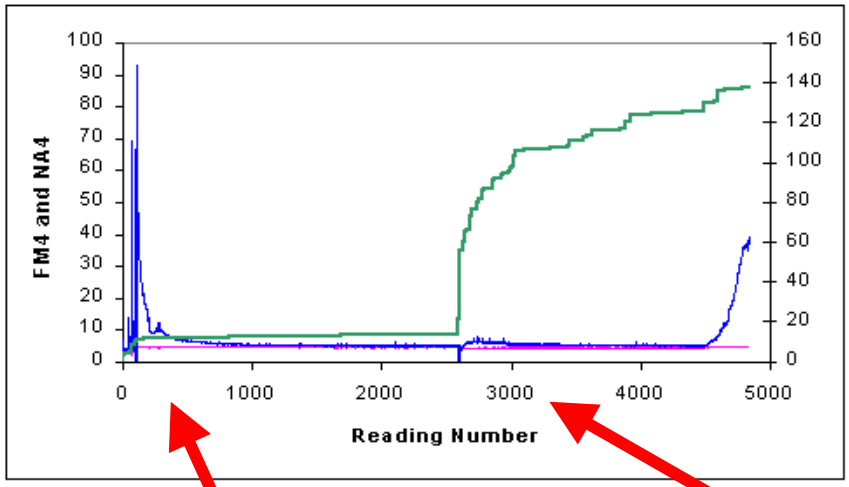
Results:

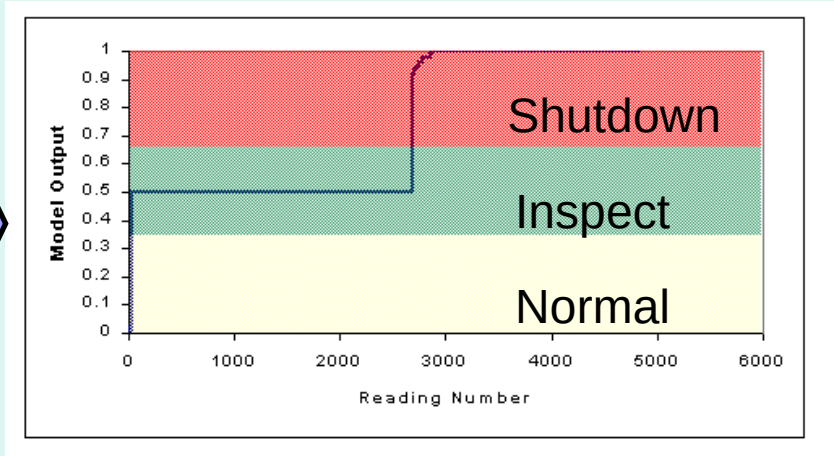
- Location of damage indicated by NA4 feature.
- Demonstrated data fusion analysis can be applied to other geared systems.
- Fusing vibration and oil debris improves damage detection and decision making capabilities.

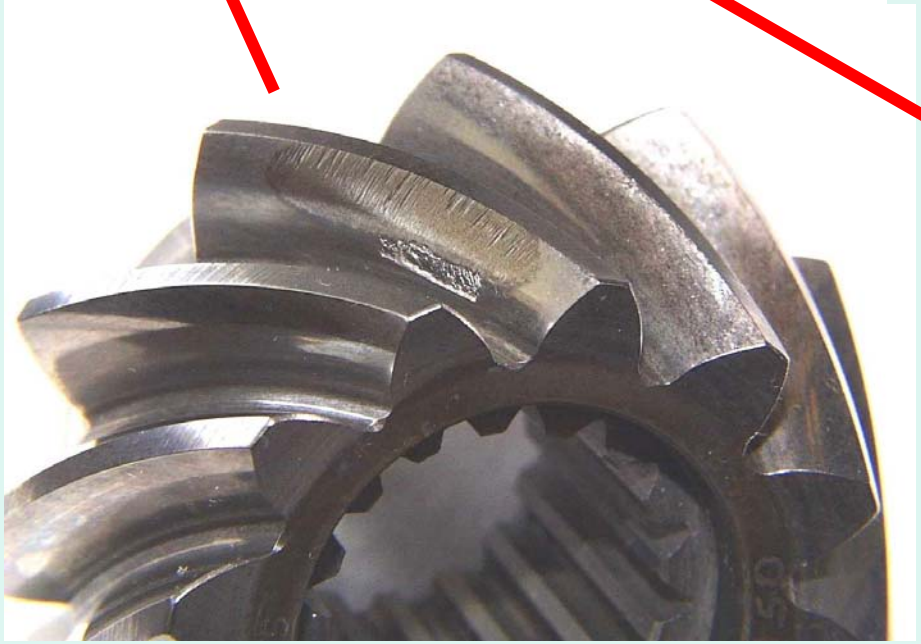




Data Fusion and Bearing Diagnostics







OH-58C Gear Fault Detection Project

Objectives:

- Evaluate performance of gear diagnostic methods in detecting gear tooth fatigue cracks.
- Determine effects of operating torque loads on fault detection capability and crack propagation times.

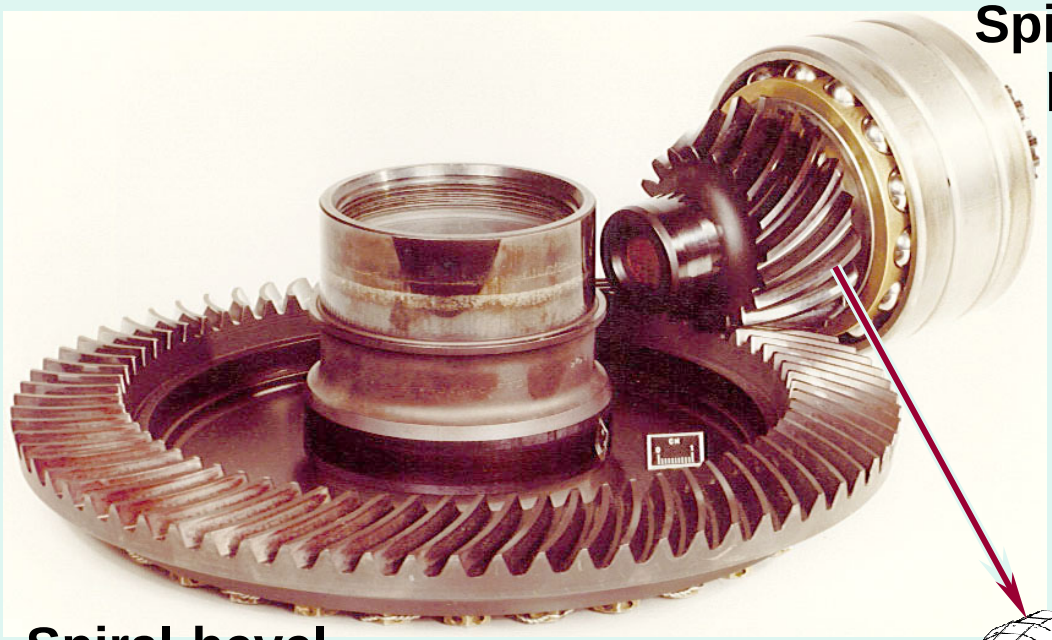
Approach:

- In-house crack tests of OH-58C spiral-bevel pinion in NASA GRC's 500HP Helicopter Transmission Test Facility.

Plans / Current Testing:

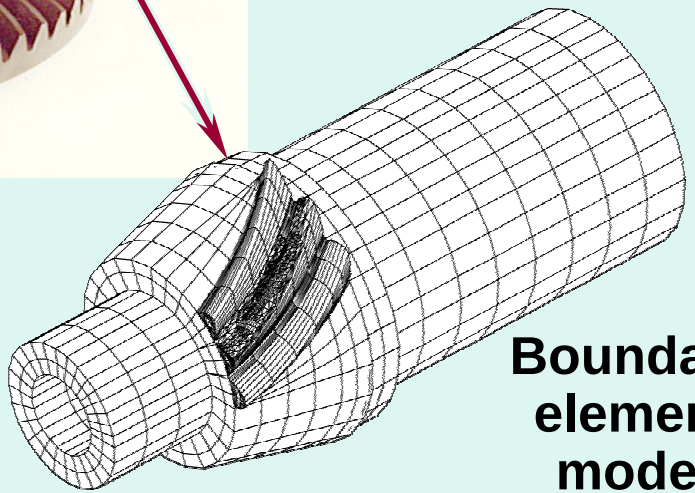
- Validate fault detection techniques
- Establish time to failure
- Data for rig / flight tests comparison

OH-58 Spiral-Bevel Mesh



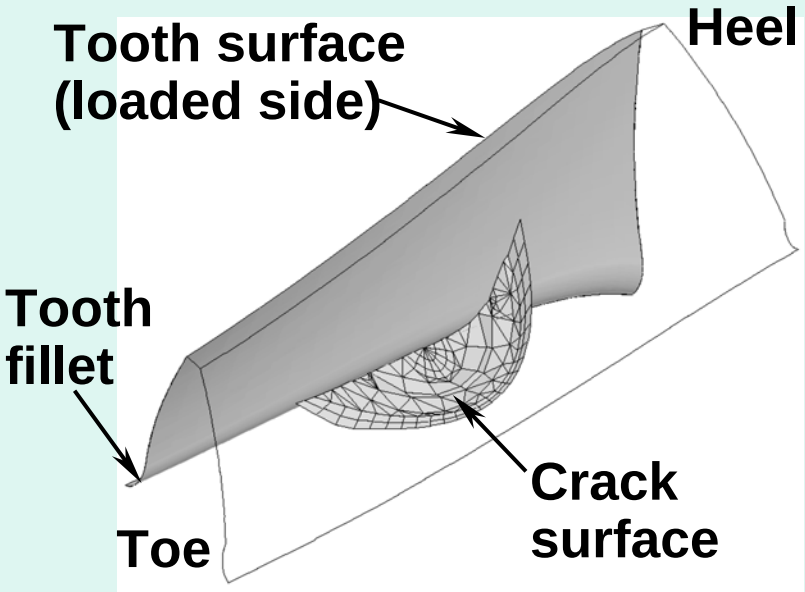
Spiral-bevel pinion

Spiral-bevel gear

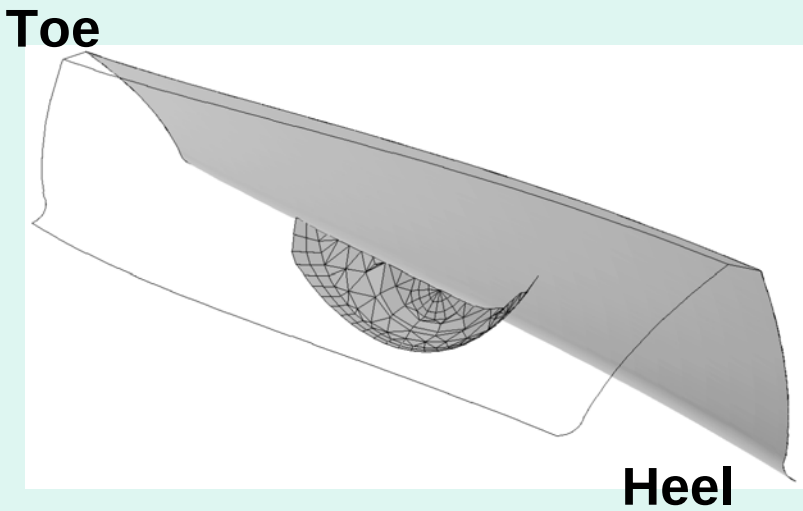


Boundary element model

OH-58 Spiral-Bevel Pinion Tooth Crack Propagation Simulation



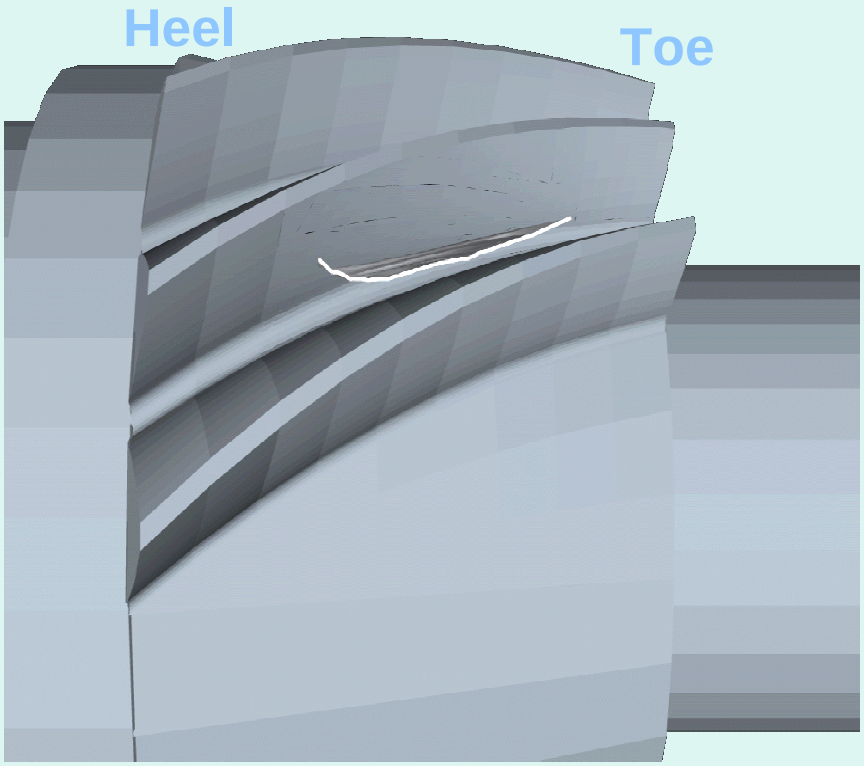
TOE-SIDE VIEW



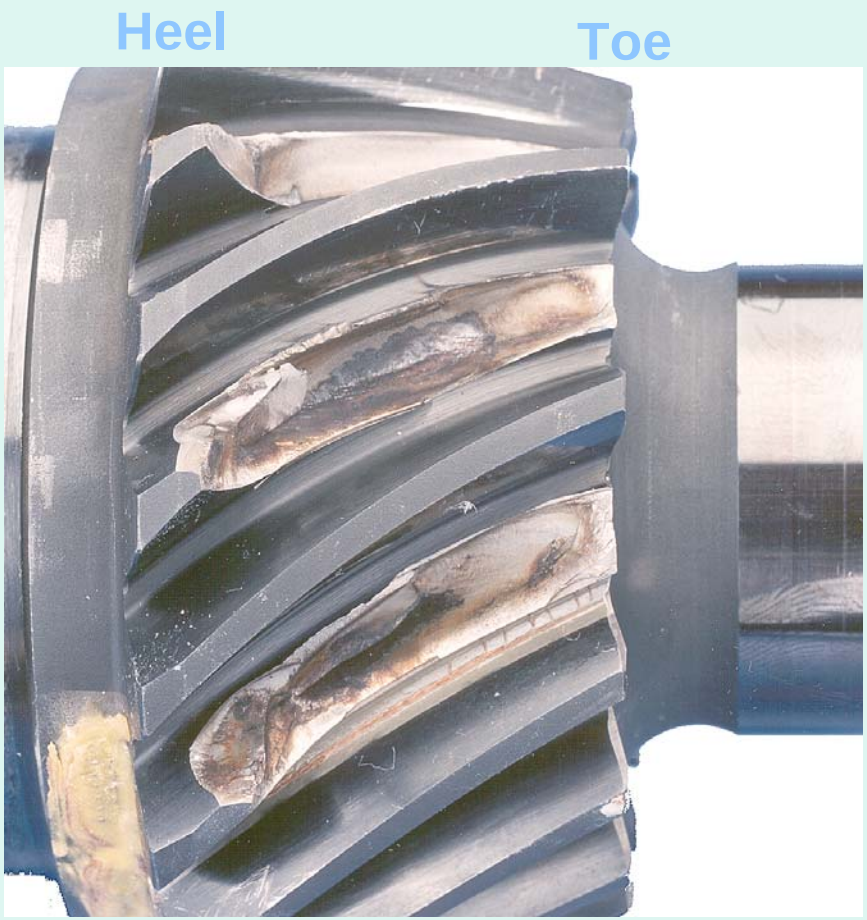
HEEL-SIDE VIEW

Comparison Between BEM Analysis and Full-Scale Gear Tests

SIMULATION



EXPERIMENTS



Robust Diagnosis of Planetary Gear Train Faults

Objective: Develop robust fault detection methods for planetary gear systems.

Approach:

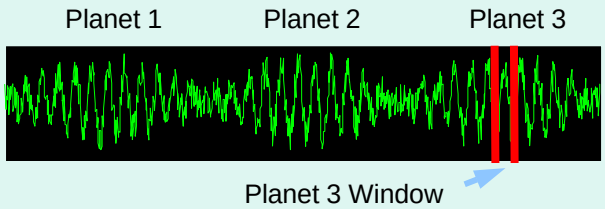
- NASA Safety Program funded grant with the Univ. of Maryland, Dr. Darryll Pines, Principal Investigator,

Plans / Results:

- Method for separating vibration signatures of individual sun, planet, and ring gears was developed.
- Time-averaged and time-frequency diagnostic methods for planetary system fault detection was developed.
- Validation tests and fault simulation studies to be completed.

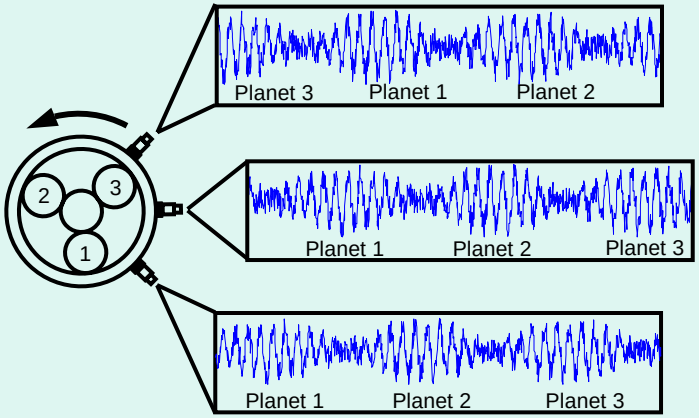
Vibration Separation Methodology

Basic Algorithm

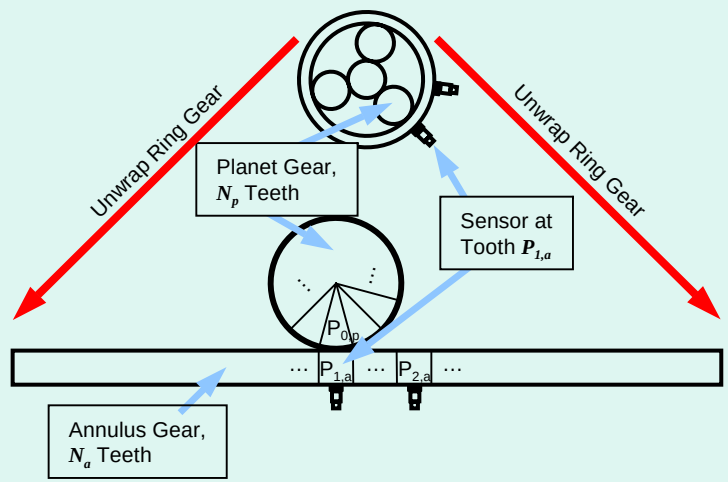


- Capture a window of data (width equals a few tooth meshes) when a given planet is at the sensor.
- Capture a window for each planet tooth and each sun tooth, then assemble these windows into a single synthesized vibration signal for each planet gear and the sun gear.

Extension to Multiple Sensors

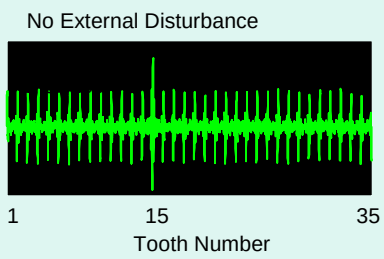


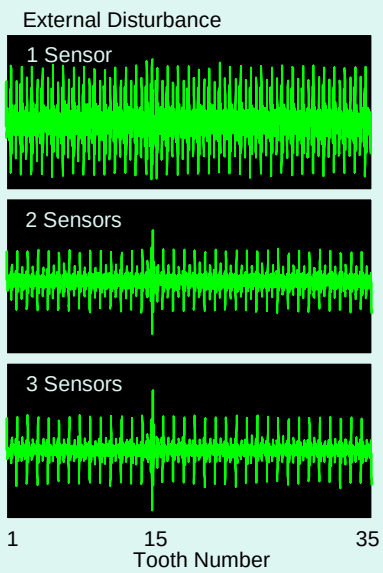
$$X_r(t) = \frac{1}{M_e M_v J} \sum_{n=0}^{M_e N_{n_{\mathrm{Reset},r}} - 1} \sum_{j=1}^{J} \left[H_0 x(t) u(t) v\left(t - (nT_c + T_m S_{j-1})\right) \right]_j * r(t)$$



Analytical Example

- Averaged planet vibration signals.

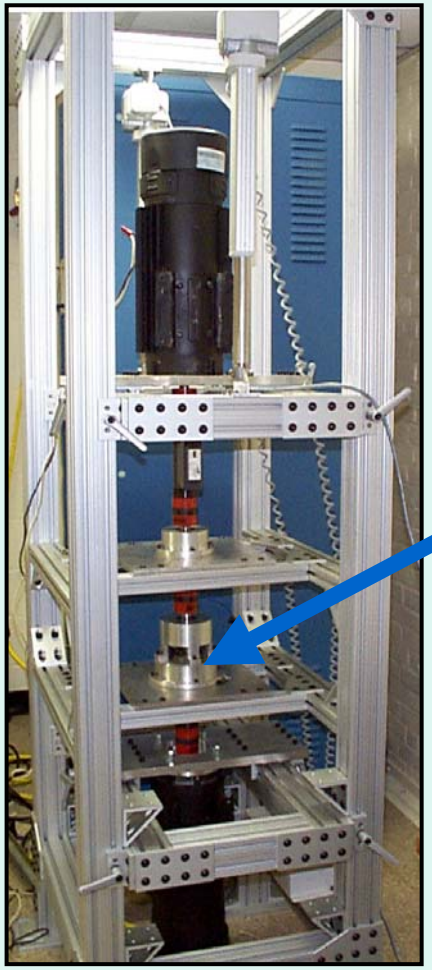




- Significant performance improvement with increased number of sensors.

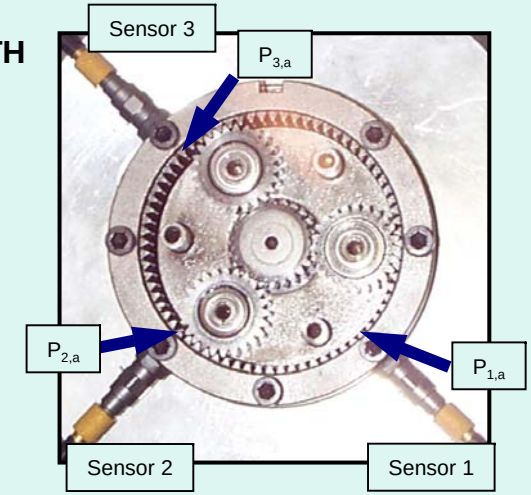
Experimental Results: Vibration Separation

University of Maryland Test Rig



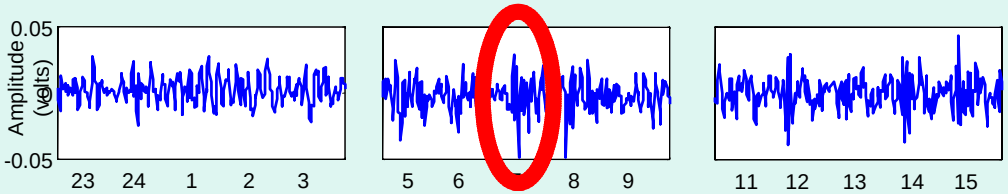
NOT HUNTING TOOTH

- Gearbox characteristics:
  - Sun Teeth = 24
  - Planet Teeth = 24
  - Ring Teeth = 72
  - Reduction Ratio = 4:1
  - $n_{Reset,p} = 1$

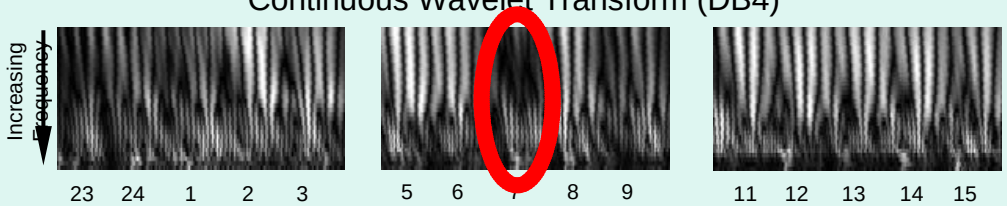


Excessive Spalling Damage: Planet Gear 1: Tooth 7

Averaged Planet Gear Vibration Signal



Continuous Wavelet Transform (DB4)



Tooth Number

Scale of colors from MIN to MAX

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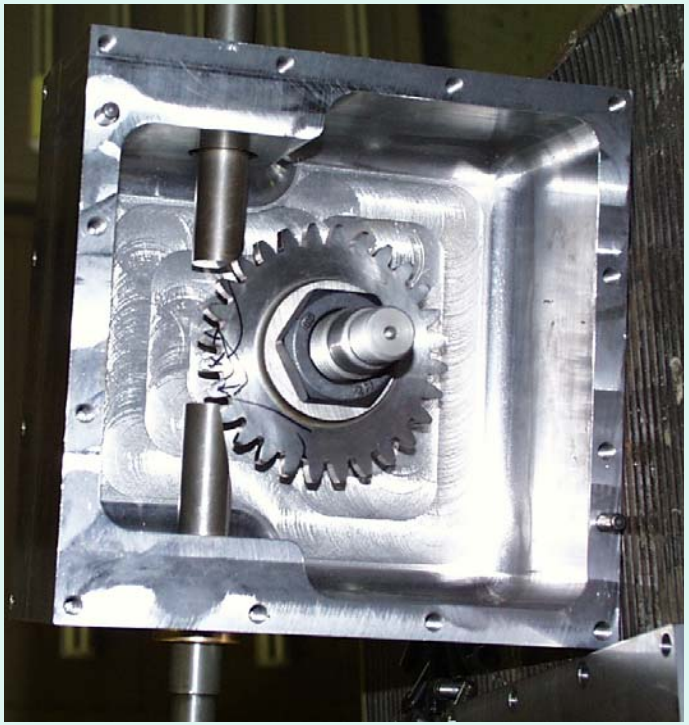
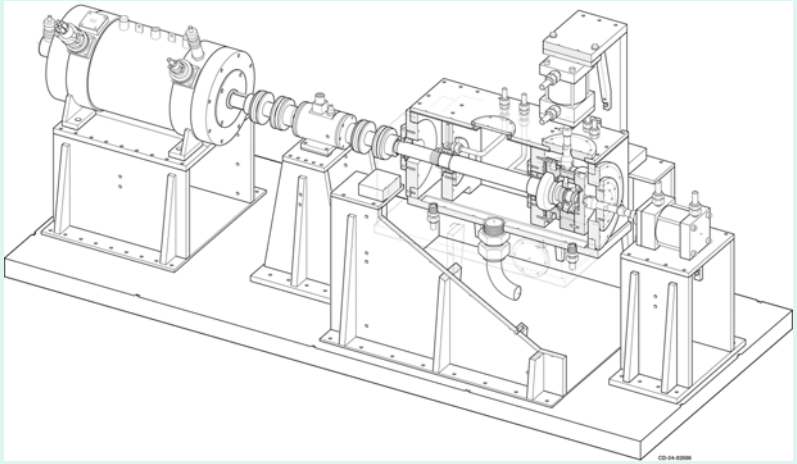
Future Test Facilities (FY05) at NASA GRC



Single Gear Tooth Bending Test Rig



Hybrid Bearing Prognostics Test Rig

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Future Plans:

- Extend data fusion test work – sensor systems on other test facilities within NASA GRC, and at contractor facilities
- Seeded fault testing of planetary gear trains
- Non-Rotating vibration/acoustic emission testing on Single Gear Tooth Bending Test Rig
- Sensor validation / development testing for metallic, ceramic, and other material debris (oil monitor)