DATA FUSION APPLIED TO HELICOPTER CONDITION ASSESSMENT

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OVERVIEW

Background

- Helicopter Transmission Condition Indicators
- Health Usage Monitoring System Challenges
- Data Fusion

Objective

Condition Indicators (CI)

- Gear/Bearing Vibration CI, Oil Debris CI

Data Fusion Analysis

- Gear/Bearing Examples

Summary

BACKROUND

Helicopter safety is heavily dependent on the reliability and integrity of the mechanical components in the transmission.

Damage in transmission components produce specific fault patterns in vibration signatures.

Vibration-based **condition indicators** (**CI**) are used to assess transmission health and diagnose component damage.

Various vibration signature analysis methods developed to detect damage to bearings, gears, etc.

Appropriate vibration analysis techniques must be use for the range of fault detection capability required.

BACKROUND

Oil analysis of wear debris is also used to indicate abnormal wear related conditions in the transmission

Gear/bearing fatigue failures produce significant wear debris in oil lubrication systems.

Oil debris monitoring for gearboxes: off-line oil analysis, plug type chip detectors, in-line inductance type sensors.

Tradeoffs between CI threshold sensitivity to damage and false alarms.

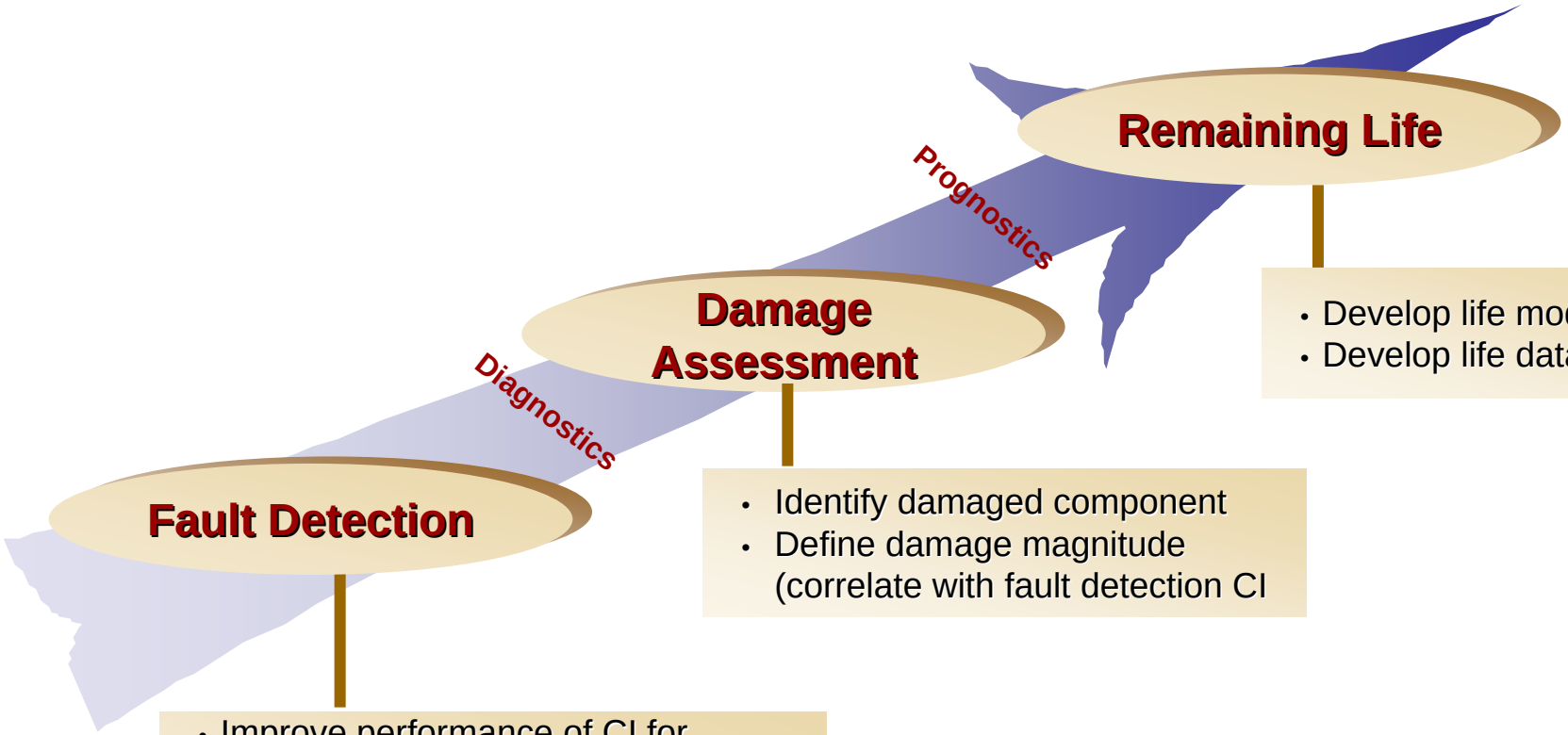
BACKROUND

Commercial Helicopter HUMS (Health Usage Monitoring Systems) providing safety and economic benefits.

Challenges that still need addressed:

- Increase the fault detection coverage from today's rate of 70 %
- Decrease false alarm rates
- Develop technology to assess severity of damage magnitude
- Develop life prediction technologies
- Integrate health monitoring outputs with maintenance actions
- Process diagnostic information with minimal expert interpretation
- Correlate failure under seeded fault tests with operational data
- In-flight pilot cueing/warning of catastrophic failures

BACKROUND



- Develop life models
- Develop life database

- Identify damaged component
- Define damage magnitude (correlate with fault detection CI

- Improve performance of CI for component/fault type
- Establish CI performance standards
- Establish thresholds with limited fault data
- **Develop Health Indicators by fusing CI from multiple sensors**

BACKROUND

Data fusion: Data from multiple sensors are combined to perform inferences that are not possible from a single sensor.

Data fusion analysis has been applied to vibration and oil debris condition indicators.

Similar to how we integrate data from multiple sources and senses to make decisions.

Sensor data can be fused at the raw data level, CI level, or decision level**.**

Decision level fusion the most flexible, does not limit the fusion process to a specific CI.

OBJECTIVE

Provide examples of multi-sensor data fusion applied to vibration and oil debris CI to detect mechanical component health.

Demonstrate integration of two measurement technologies, oil debris analysis and vibration, provide clear information to the end user on the health of the transmission.

GEAR VIBRATION CI

Traditional methods are based on the statistical measurement of vibration energy.

Vibration signature analysis methods utilize synchronous averaging. - Gears produce vibration signals synchronous with speed

Time synchronous averaging
-Divide signal into 1 revolution segments, then average

Reinforces vibration periodic with shaft speed.

GEAR VIBRATON CI

Time synchronous averaged (TSA)vibration data

INPUT Sensor Data

Fast Fourier Transform

Filter

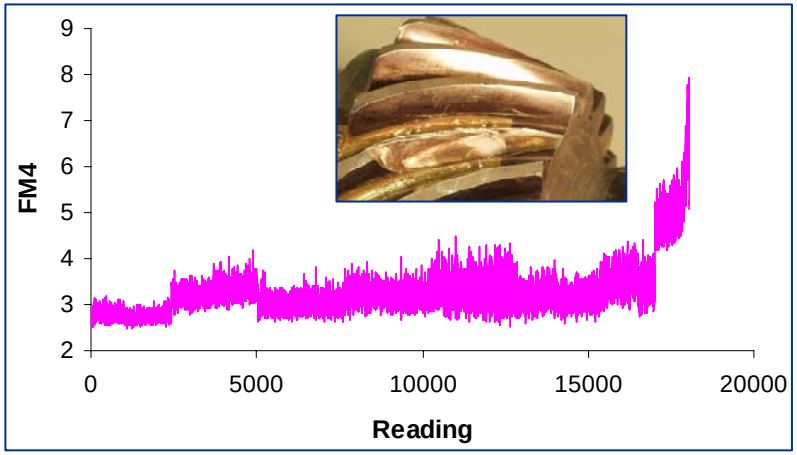
FM4 - Gear Meshing Frequency Harmonics, 1st Order Sidebands

Inverse Fast Fourier Transform

Difference Signal(Filtered TSA) = d

$$CI = \frac{\frac{1}{N}\sum_{n=1}^{N}\left(d_n - \bar{d}\right)^4}{\left[\frac{1}{N}\sum_{n=1}^{N}\left(d_n - \bar{d}\right)^2\right]^2}$$

OUTPUT CI FM4



BEARING CI

Fault/defect frequencies generated when bearing fails.

Calculated by bearing dimensions and speed.

Frequency Domain:

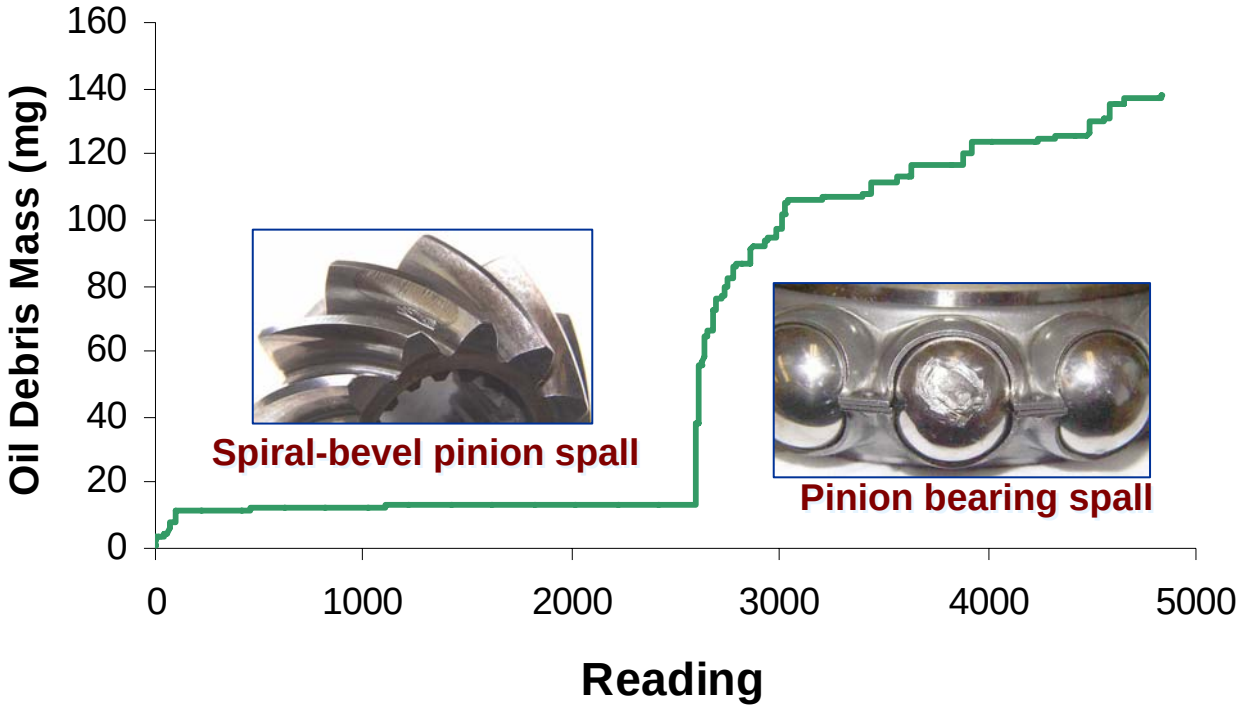
- FFT used to identify characteristic bearing defect frequencies and their change in amplitude.
- Envelope analysis used to identify bearing resonances excited by periodic impacts (correlate to defect frequencies) when defect contacts another bearing surface.

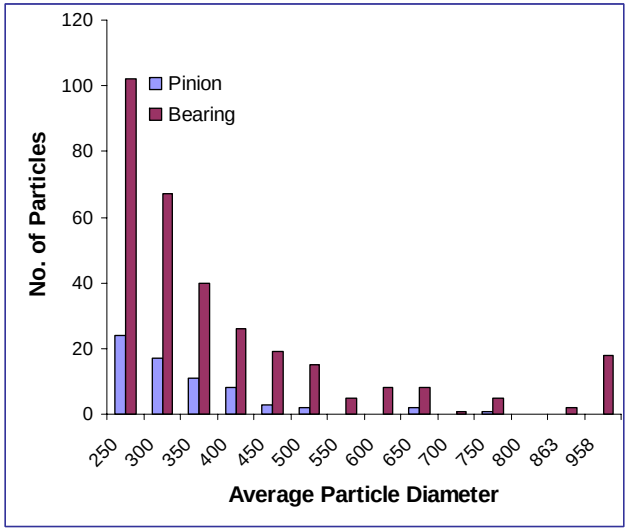
Time domain:

- Statistical parameters: RMS, peak, kurtosis.

OIL DEBRIS CI

- Inductance type, in-line, full flow, oil debris sensor
- Particle causes disturbance to magnetic field
- Measures number, size and accumulated mass of particles
- Size (150-1016 micron diam.) distributed in 16 bins
- CI – mass or counts

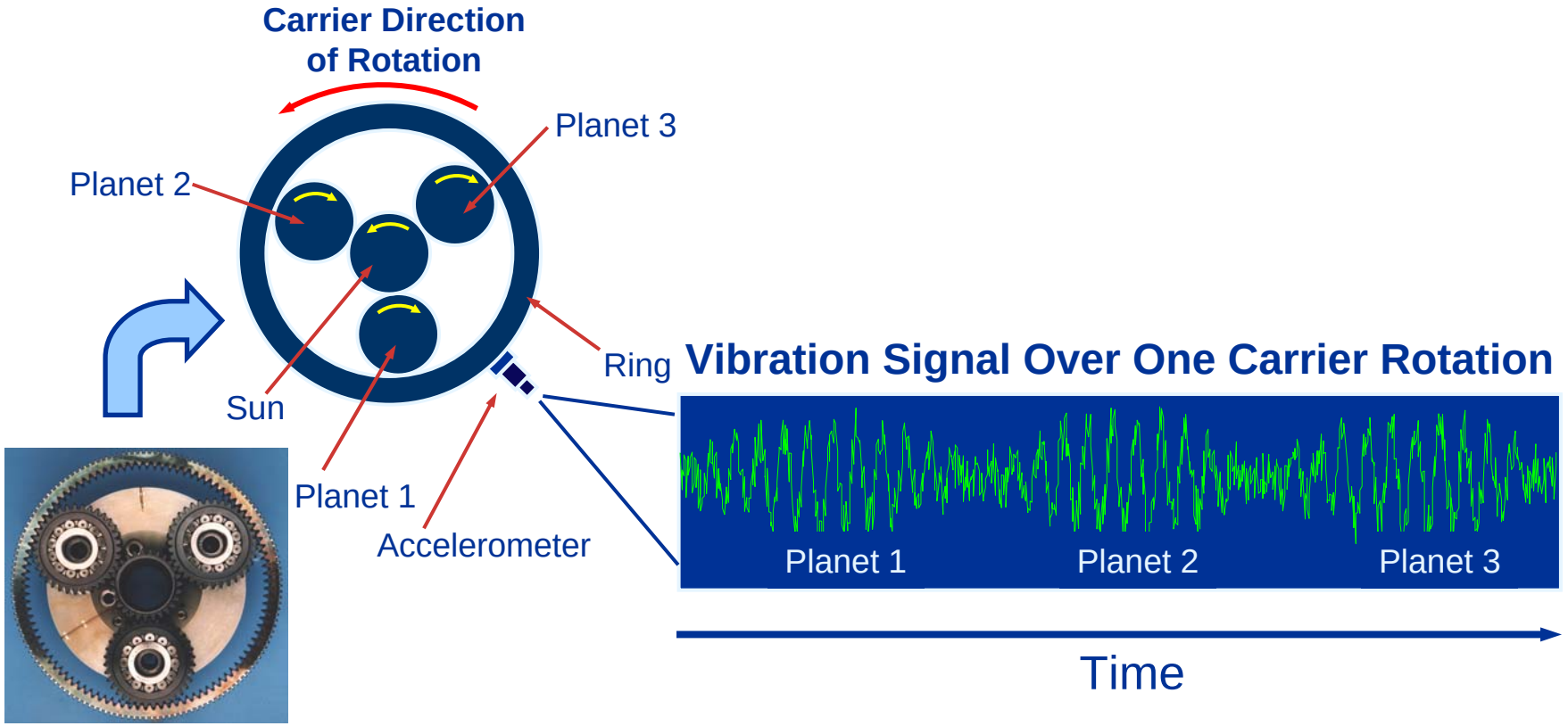




PLANETARY GEAR CI

Vibrations measured by the sensor are dominated by the meshing of the planet gear with the ring gear and the sun gear.

Methods under development for separating vibration signatures of individual sun, planet, and ring gears.



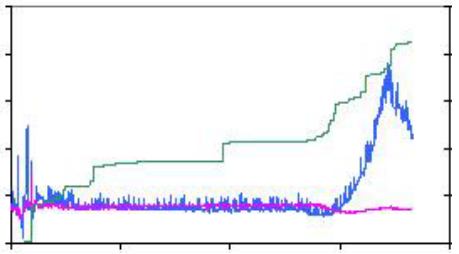
DATA FUSION ANALYSIS

- Data fusion used to integrate vibration and oil debris CI
- Data fusion performed at the decision fusion level to determine gear health.
- Fuzzy logic used to identify damage level and integrate CI
- Fuzzy logic is used to translate imprecise knowledge into a rule based system.
- Extends Boolean logic to handle partial truths (continuous values 0 to 1).
- Data belongs to a set based on its degree of membership.
- Fuzzy membership functions defined by analysis of CI and damage level
- Rules defined by data analysis and experts.
- Decision level fusion integrates membership functions with rules.
- Health of the mechanical component (O.K., Inspect, Shutdown) is the output.

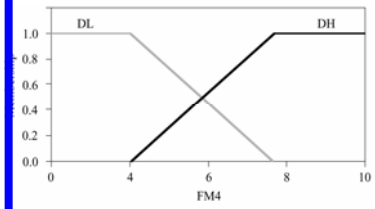
DATA FUSION ANALYSIS

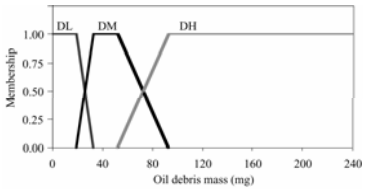
Sensors
Accels
1X/Rev
Oil Debris

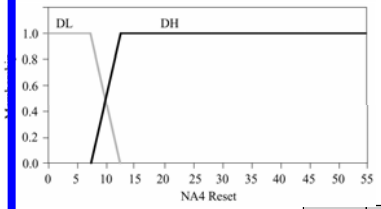
CI's –Inputs
FM4, NA4, Debris



Damage Level Fusion
Membership Functions





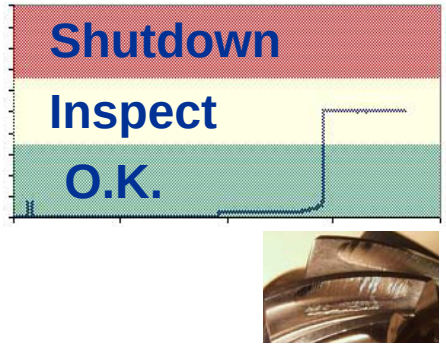


Rules
Damage Levels

Rule	FM4	NA4	Debris	Output
1	DL	DL	DL	O.K.
2	DH	DH	DH	Shutdown
3	DL	DL	DM	Inspect
4	DL	DH	DL	O.K.
5	DL	DL	DH	Inspect
6	DH	DL	DL	O.K.
7	DH	DL	DM	Inspect
8	DH	DH	DL	Inspect
9	DH	DL	DH	Shutdown
10	DH	DH	DM	Inspect
11	DL	DH	DH	Shutdown
12	DL	DH	DM	Inspect

Decision

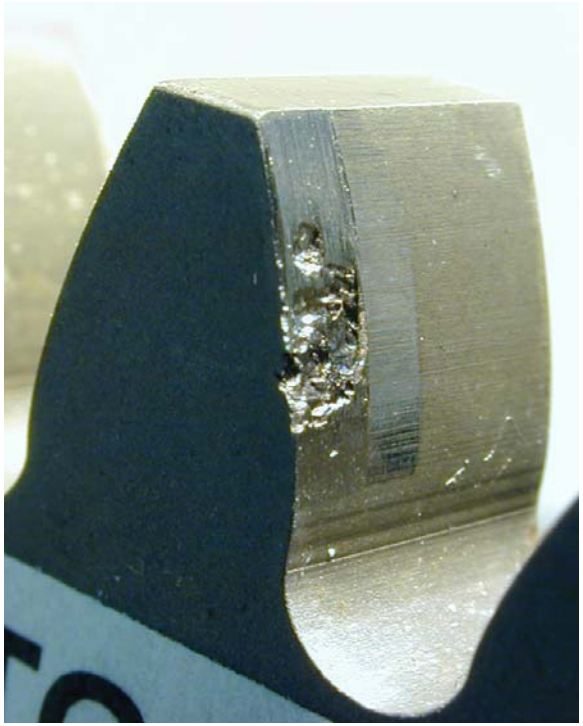
Gear Health



FAILURE MODE: PITTING FATIGUE

Spiral Bevel Gear Pinion

Spur Gear

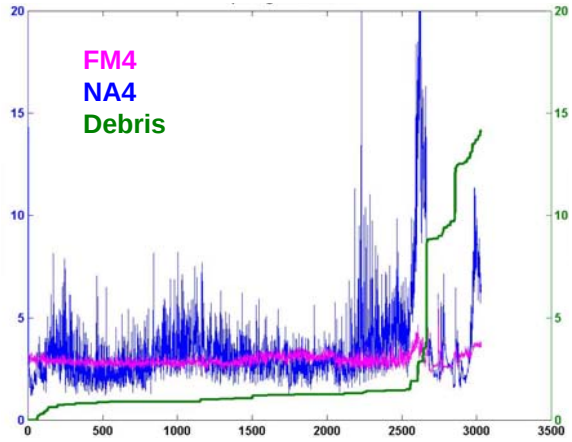


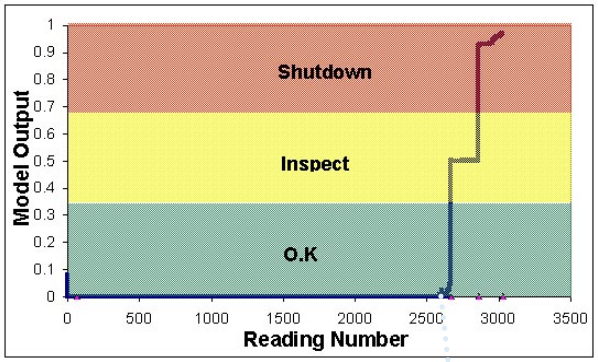
Destructive Pitting:

Pits > 0.4 mm and > 25% tooth area

GEAR EXAMPLES

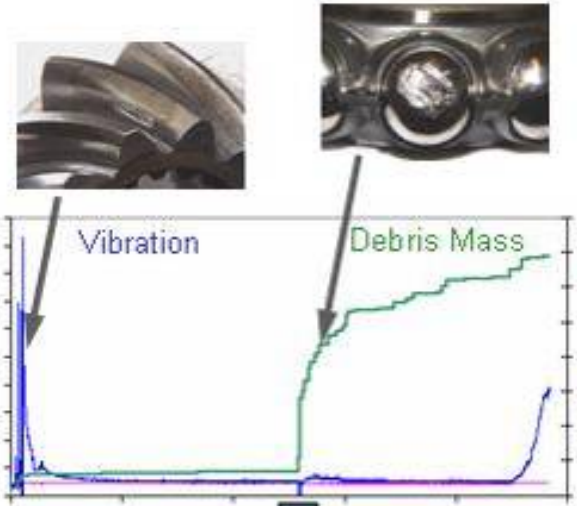
Spur Gear



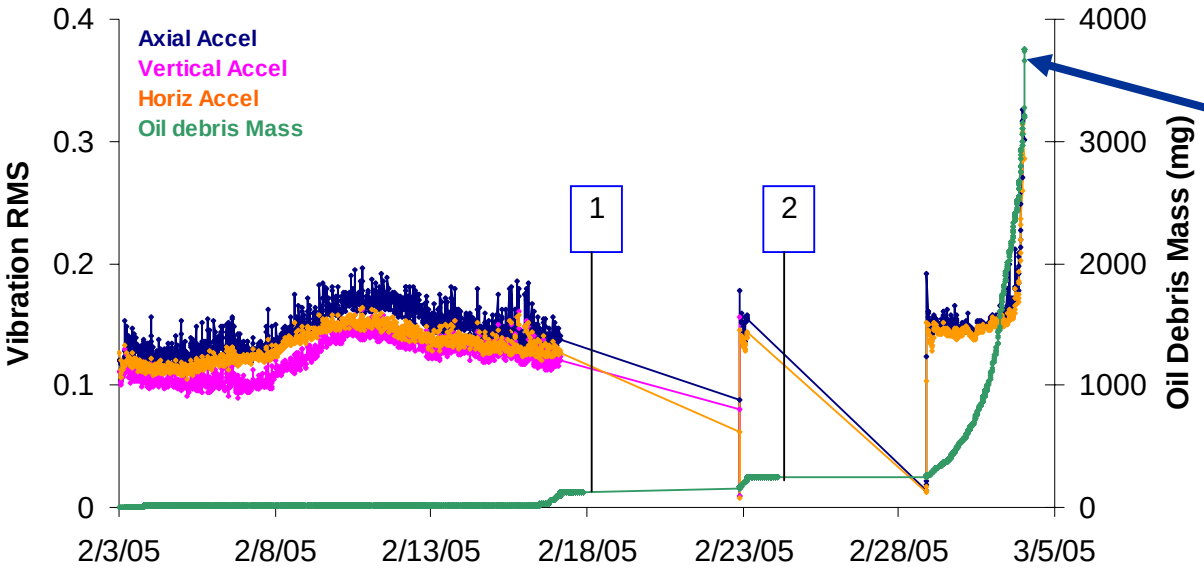


- Wear debris and vibration signatures generated during failures.
- Data fusion concept validated in ground tests on Spur/Spiral Bevel Gears.
- Oil debris membership function rescaled to correlate gear tooth surface contact area.
- Fusing oil debris and vibration CI improved damage detection and decision-making.
- Unanticipated bearing failure reinforces importance of data fusion

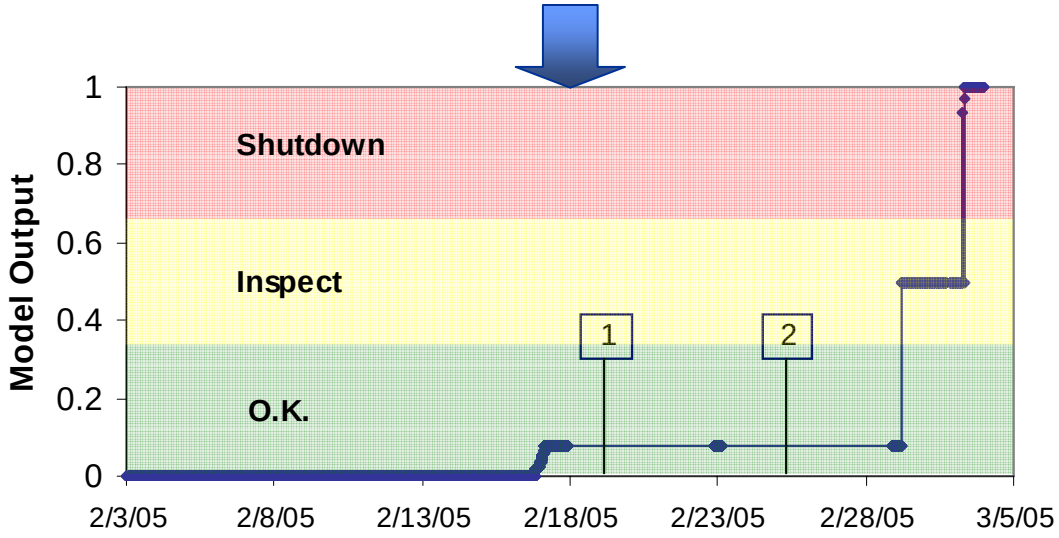
Spiral Bevel Gear



BEARING EXAMPLE



Tapered Roller Bearing Cone Damage



Cone (inner ring)

SUMMARY

Improved diagnostic tool damage detection and decision-making performance using fused system over individual CI

Validation of the diagnostic tools is required to diagnose damage severity and component remaining life.

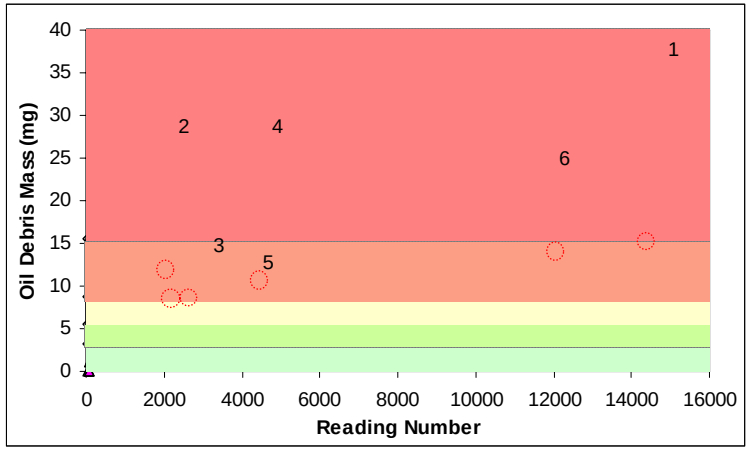
Strengths, weaknesses and constraints of each measurement technology must be identified to capitalize on CI strengths.

Knowledge can be incorporated into the system relieving the end user of interpreting large amounts of sensor data.

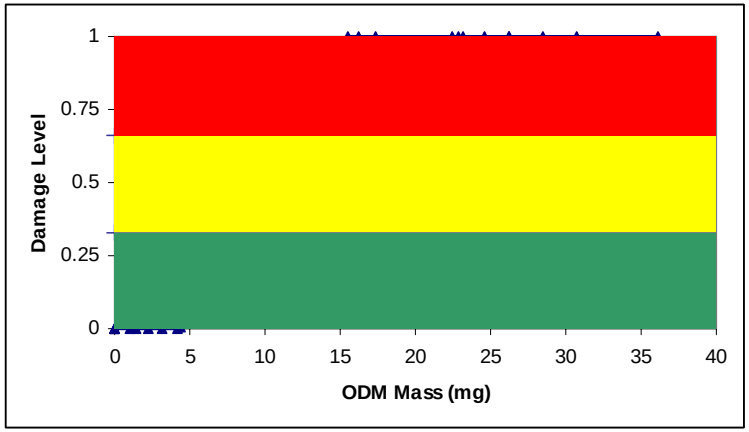
ADDITIONAL INFORMATION

OIL DEBRIS ANALYSIS

Oil Debris Mass
For Levels of Damage



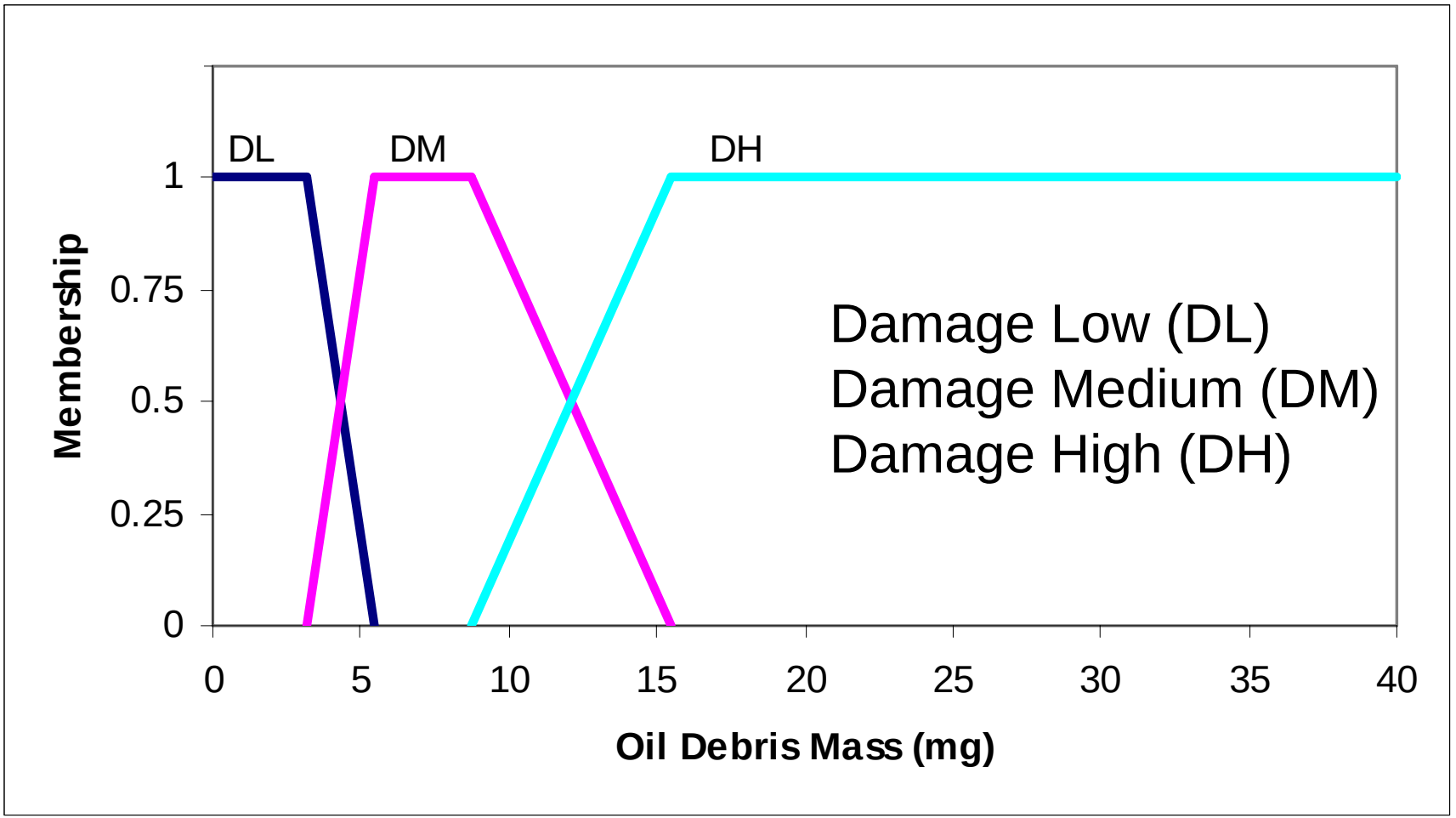
Output of
Fuzzy Logic Model



Benefits

- Eliminates the need for an expert diagnostician
- Logic built-in to minimize operational effects

MEMBERSHIP FUNCTIONS



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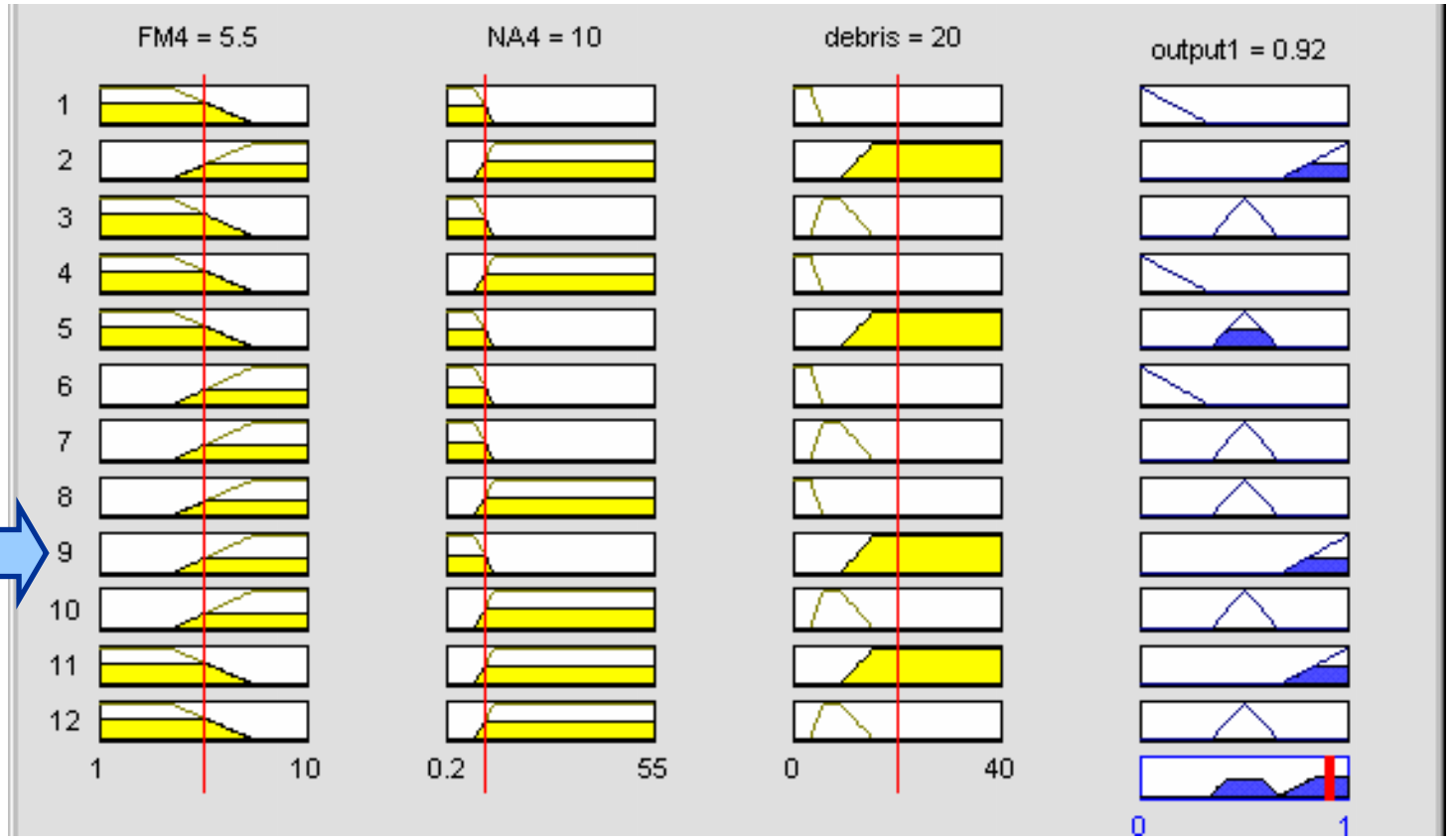

Rule 9 for 1 Reading:

If FM4 is DH and NA4 is DL and Debris is DH then Shutdown