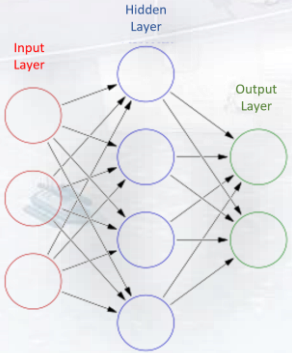
From Run-to-Failure to Run-to-Insight

AI-Driven Early Failure Detection in Powertrain & e-Axle R&D

TOYO



The Paradigm Shift in R&D Testing

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	Traditional Testing (Run-to-Failure)	MIG16 EFD (Run-to-Insight)
Test Conclusion	Catastrophic Breakdown	**Controlled Shutdown** at targeted damage level.
Prototype Status	Completely Destroyed	**Preserved.** Housings, shafts, and adjacent gears are saved and reusable.
Data Quality	Post-Mortem Guesswork	**High-resolution damage propagation tracking** captured in real-time.
Cost Impact	Total Loss of Specimen	**Intensive, multi-cycle testing** using a **single** prototype investment.

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The MIG 16 Early Failure Detection (EFD) System

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24-bit multi-channel data acquisition.

100 Khz digitization for ultra-precise NVH analysis.

Real-time AI-NVH classification without segmentation constraints.

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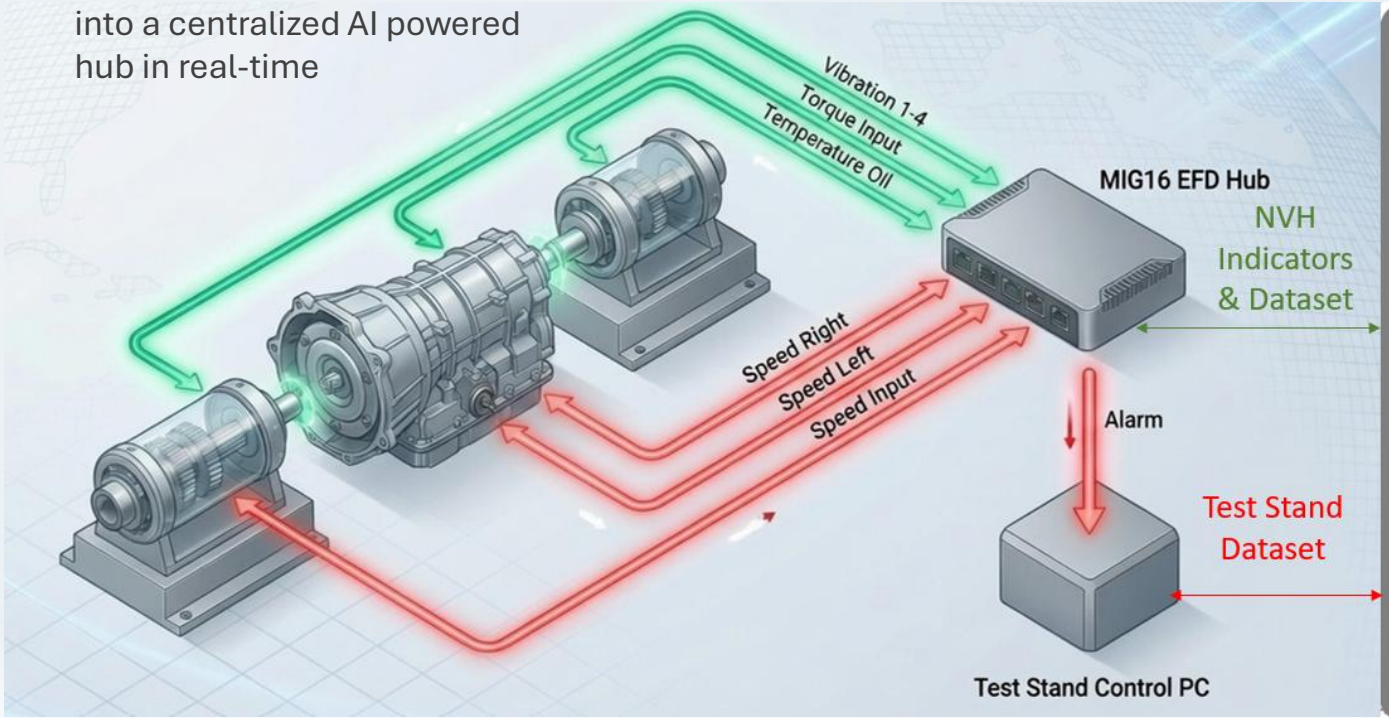
Architecture Mapping: Capturing the Physical State

The EFD system routes complex mechanical inputs into a centralized AI powered hub in real-time



Big Data Solution
On/off Premise Cloud
Data Lake

AQS Server and tools

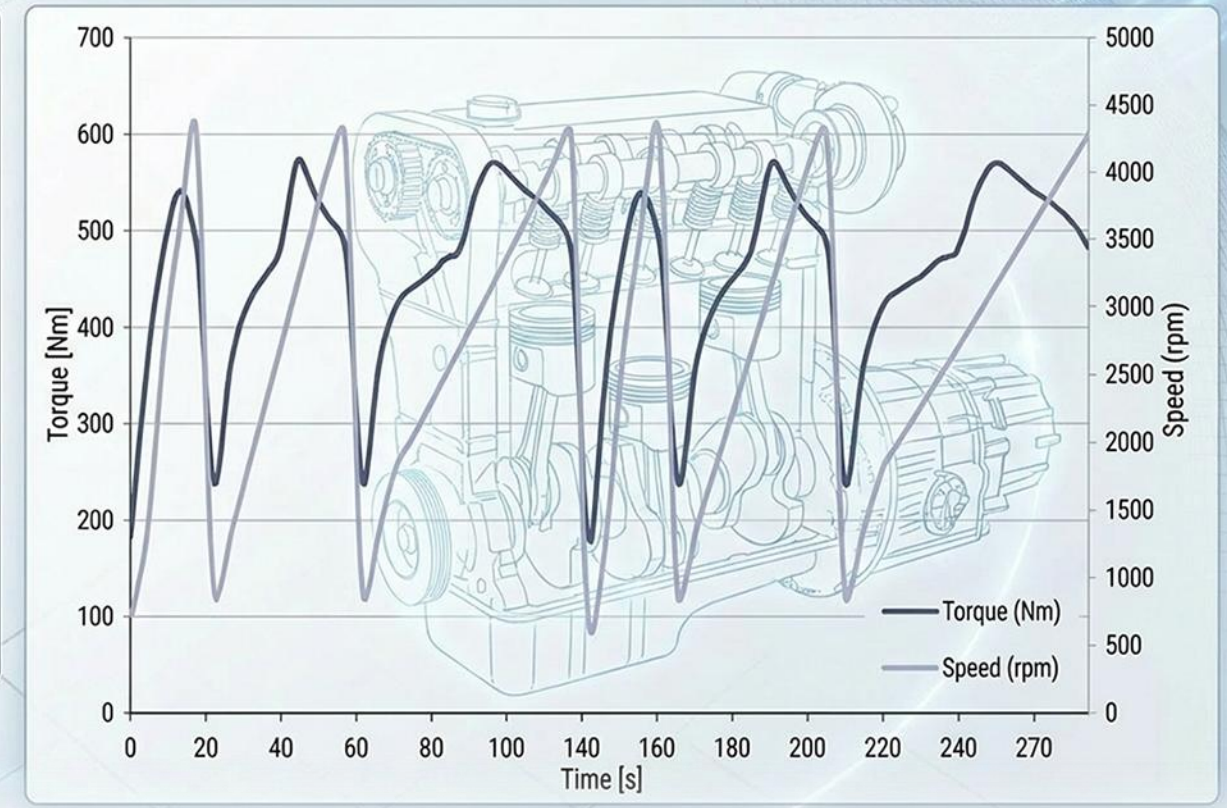
Machine Learning, AI platforms

Data Scientist access frameworks

Customer specific solution and DBs

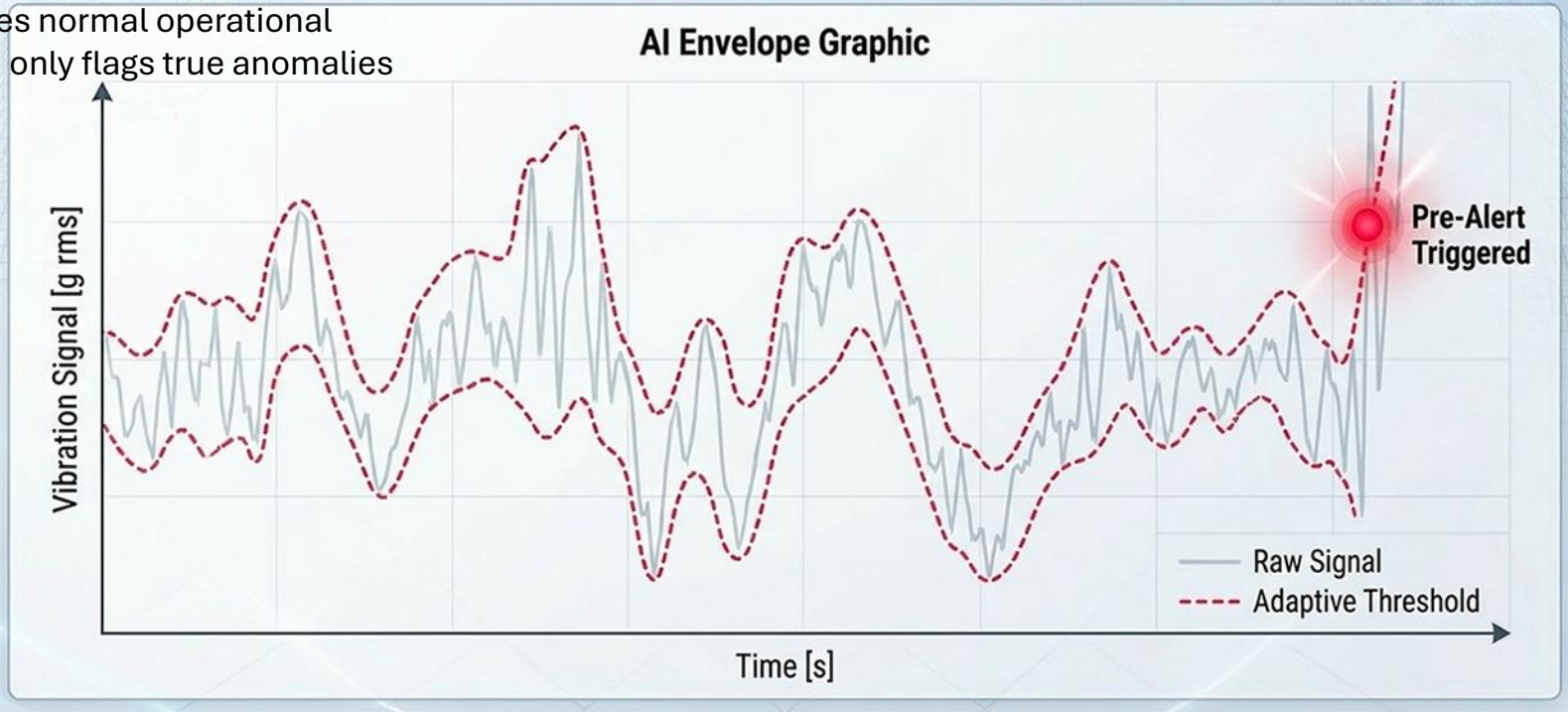
Focus: Transient Dynamic Load Ramps & Powertrains

Engine testing requires navigating complex transmission interactions and aggressive acceleration phases. The MIG16 tracks limits dynamically across these intense load profiles, safely monitoring engines, transmissions, and hybrid turbochargers without missing a micro-failure.



Adaptive Limits, Not Static Thresholds

The AI learns conformity based on specific operating points (torque, speed, temperature) automatically. It recognizes normal operational spikes and only flags true anomalies



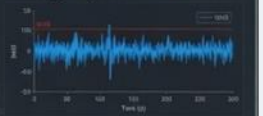
A Triple-Dimensional Perspective on Diagnostic Telemetry

The EFD system calculates real time NVH Indicators in three distinctive domains

Time Domain

Method: Digital band-pass filters and Root Mean Square (RMS) algorithms over 100ms timebases.

Diagnostic Target: General vibration energy tracking; ideal for spotting slow-growing, systemic friction.



Frequency Domain

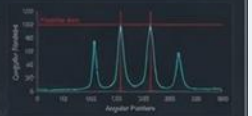
Method: High-resolution Spectrums (down to 0.1 Hz resolution and up to a maximum frequency of 100 kHz) using digital integration and FFT-Filters.

Diagnostic Target: Extracting specific, characteristic damage types hidden beneath engine noise.

Angular Domain

Method: Vibration signals are digitally resampled to a 360-sample-per-rotation (1° resolution) angular domain.

Diagnostic Target: Pinpointing irregular combustion events precisely mapped to the crankshaft's physical position.



NVH Indicator Selection Matrix in EFD for Powertrain Testing

Indicator Name	RMS (Root Mean Square)	SF (Speed Fluctuation)	OS (Order Spectrum)
Core Mechanism	Computes the short-time effective value of raw vibration signals.	Applies a band-pass filter (30-300 Hz) to isolate deviations in mean speed.	Resamples time-based data into angular-synchronous data via Fourier transform.
Integration/Reaction	100ms (**Very Fast**)	100ms (**Very Fast**)	**Continuous Tracking**
Primary Target Defect	Overall noise indicator; catches **sudden, catastrophic defects**.	Shaft health; isolates **torsional vibrations and partial shaft fractures**.	Pinpoints **specific mechanical noise sources** (gears, individual bearings).

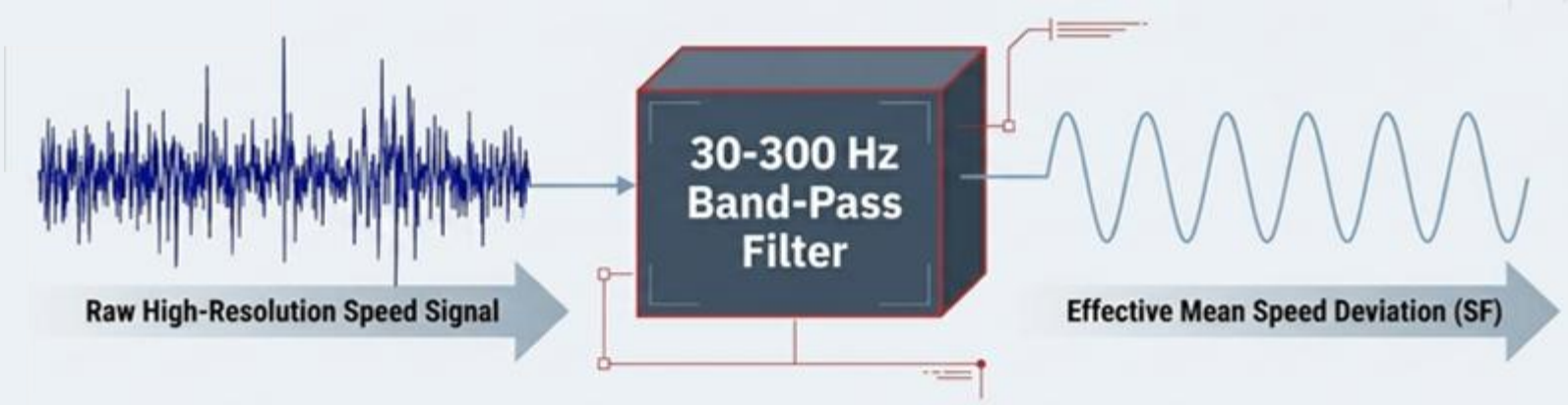
Indicator 1: Root Mean Square (RMS) for Immediate Health Monitoring

$$s_{\text{eff}} \approx \sqrt{\frac{1}{T}\sum_{i=1}^{n} x_i^2 \Delta t_i}$$

$$= \sqrt{\frac{1}{T}[x_1^2\Delta t_1 + x_2^2\Delta t_2 + x_3^2\Delta t_3 + \cdots + x_n^2\Delta t_n]}$$

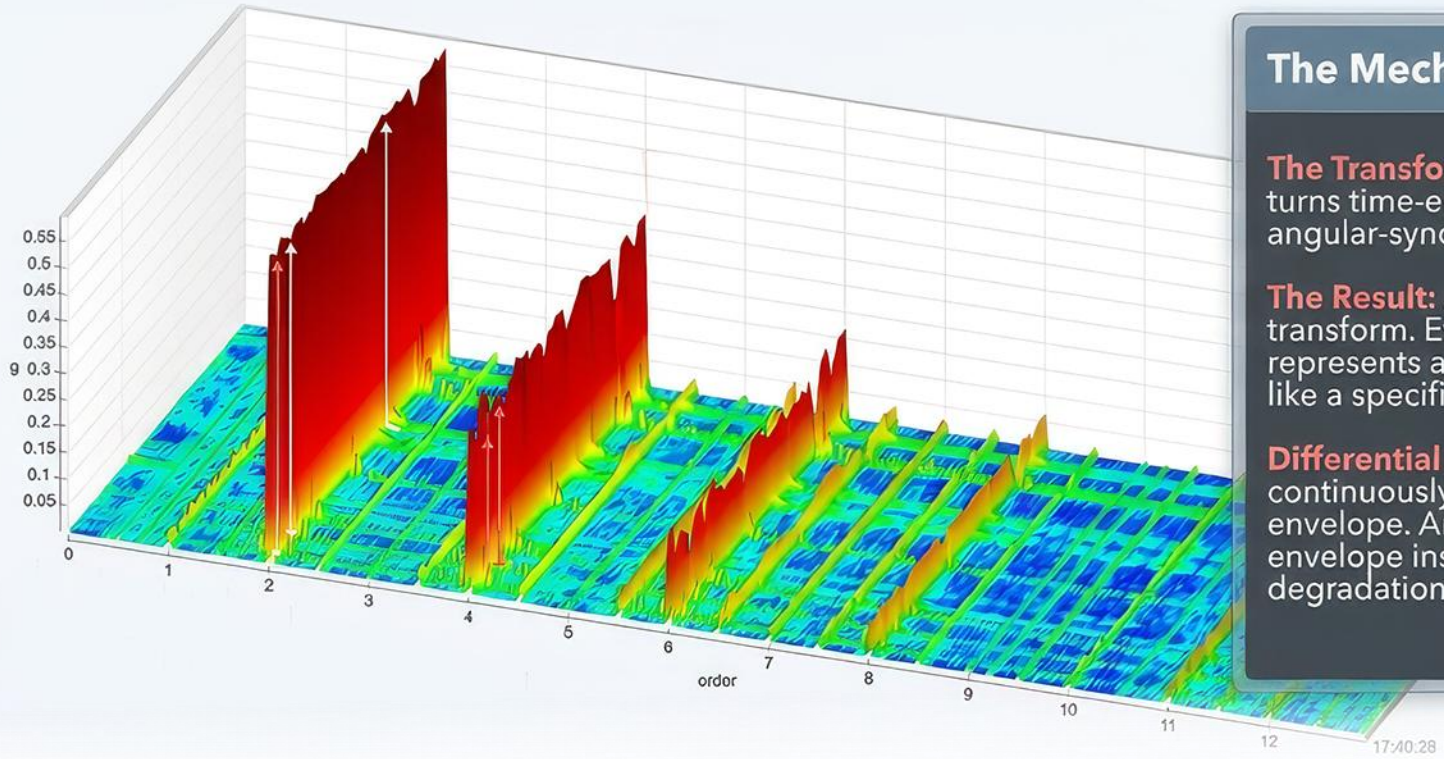
- Acts as the primary overall health guard dog.
- Continuously calculates effective value over a 100ms integration time.
- Guarantees an immediate reaction to sudden mechanical anomalies.

Indicator 2: Speed Fluctuation (SF) Isolates Torsional Oscillation



- While overall vibration captures loud, obvious damage, SF looks for subtle hesitations in the shaft's rotation.
- By applying a strict band-pass filter, the system calculates the effective deviation of the mean speed.
- **Primary Application**: Instantly flags partial shaft fractures before complete structural failure occurs.

Indicator 3: Order Spectrum (OS) Maps Noise to Specific Components



The Mechanics of OS

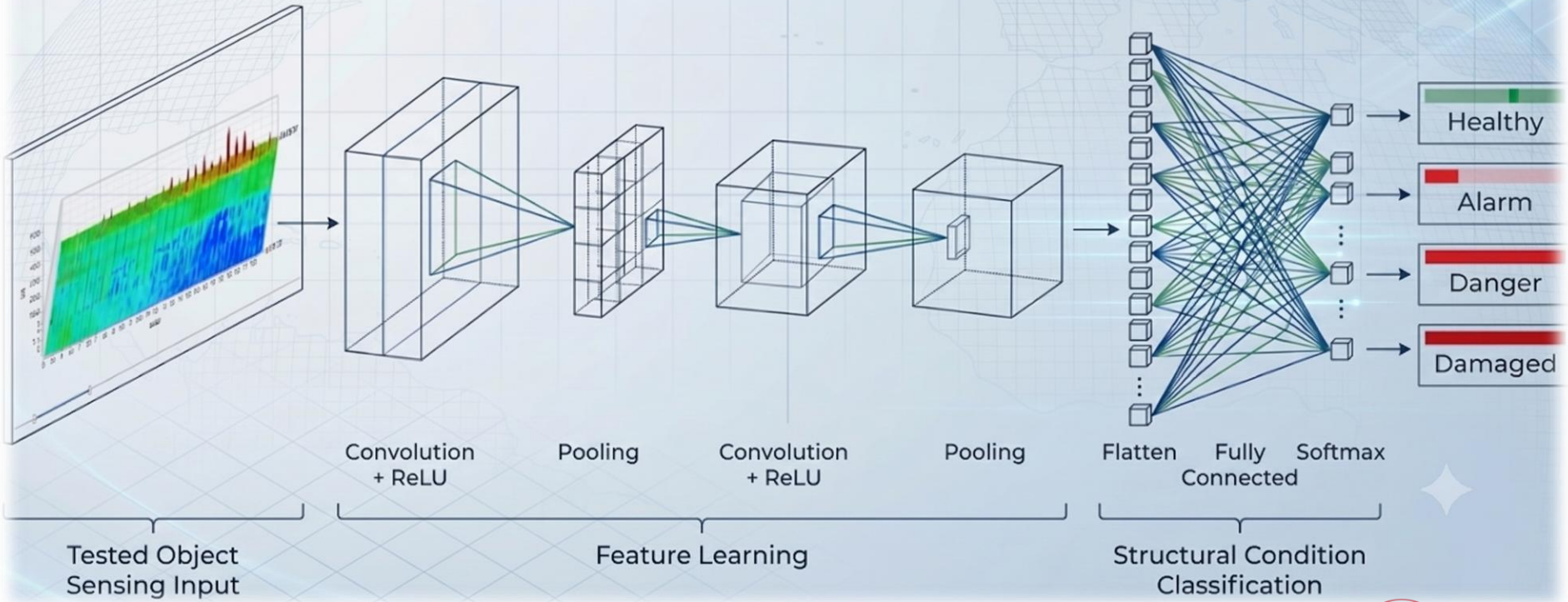
The Transformation: Digital resampling turns time-equidistant signals into angular-synchronous signals.

The Result: A high-resolution Fourier transform. Every 'order' (peak) represents a distinct mechanical source like a specific gear or bearing.

Differential Tracking: The system continuously builds an operational envelope. Any deviation from this envelope instantly flags component degradation.

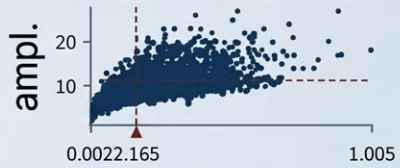
Deep Learning Pipeline

Transforming raw acoustic data into classified structural states via Convolutional Neural Networks.



Automated Fault Classification

Definitive Root Cause Isolation.
The AI does not just detect failure; it classifies the origin. By evaluating multi-sensor vibration scatter-plots, the system pinpoints specific microscopic defects—from gear tooth pitting to bearing damage.



MIG16 Fault Detected
(Amplitude outlier threshold crossed)

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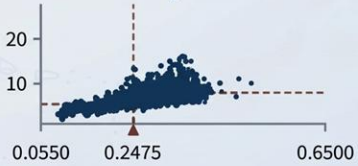

Electrical Anomaly

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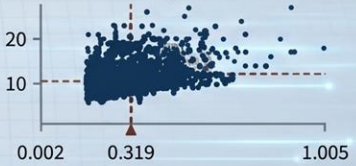
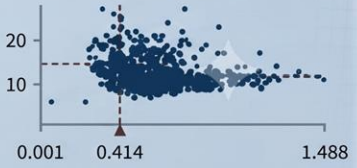


Mechanical Anomaly

Inverter

Motor

Gear



Bearing

The EFD Protection Loop

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1. Acquisition: Digitizing NVH, speed, and torque at high frequencies.

2. Calculation: Real-time time, frequency, and angular domain algorithms.

3. Learning: AI generates dynamic limits for each specific test phase.

6. Shutdown: Controlled test bed halt before catastrophic failure.

5. Validation: Logic-based rules filter out false pre-alerts.

4. Monitoring: 24/7 continuous comparison against active thresholds.

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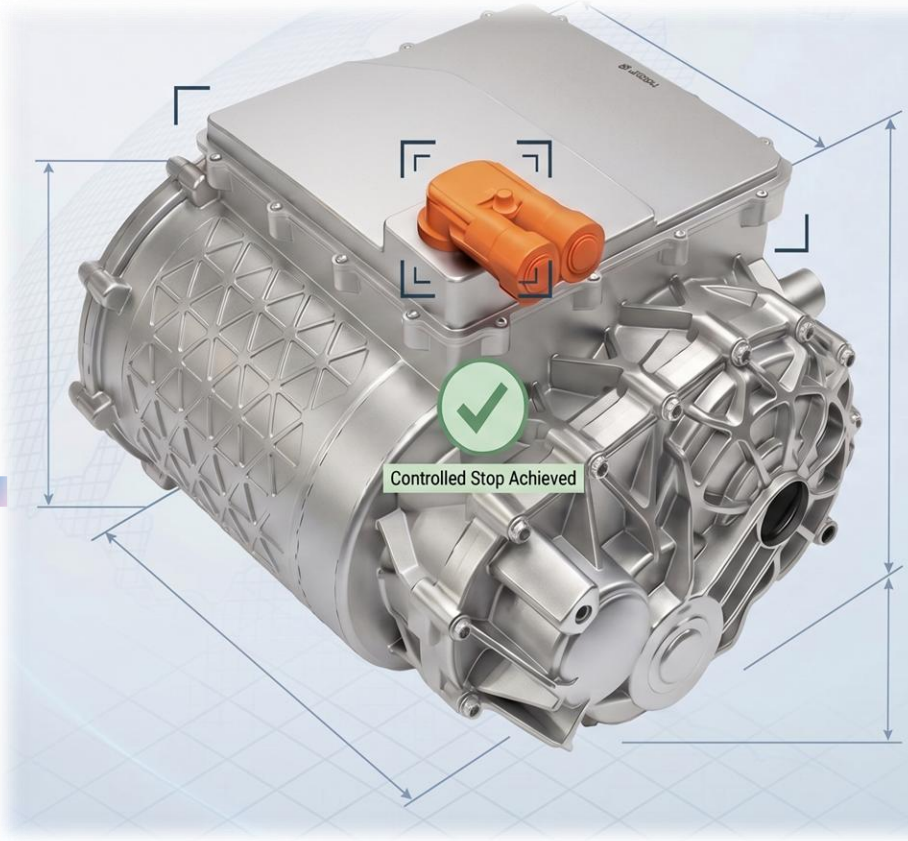
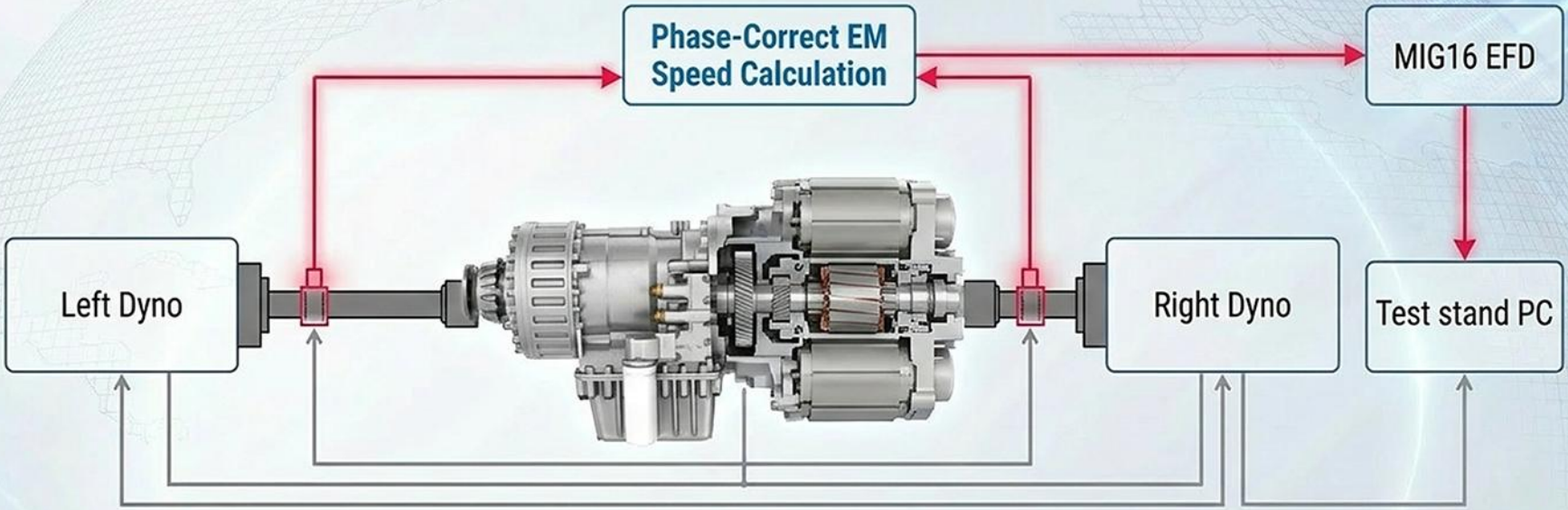
Run-to-Insight: From Execution to Insight with Data-Driven Protection



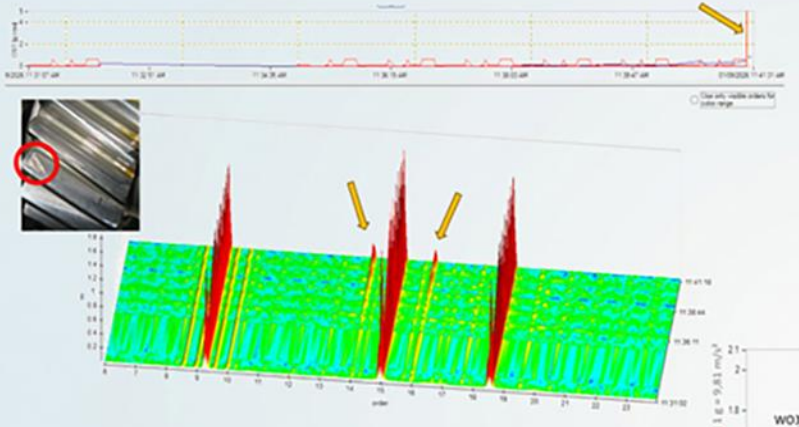
- Micro-second shutdown commands protect expensive test specimens from collateral destruction.
- Housings, shafts, and adjacent gears are saved and reusable for intensive analysis.
- Enables automated test tracks with up to 10 vehicles running simultaneously without cascading failure risks.
- Subjective human NVH sensitivity is replaced by deterministic, objective digital signatures.

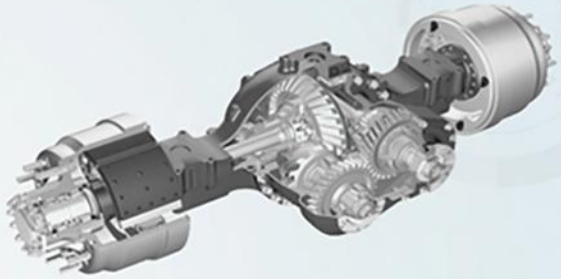
Use Case 1: E-axle & Electrification Powertrains

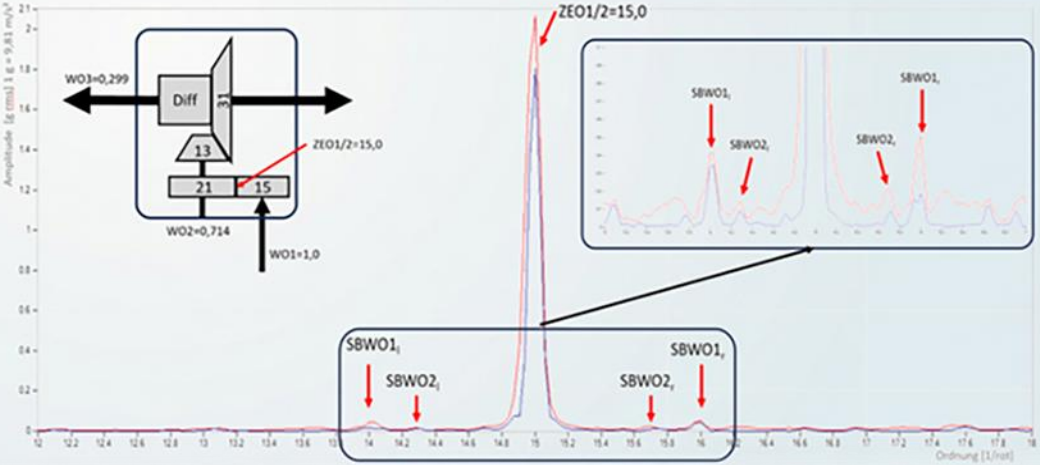


In an E-Axle testing setup, the MIG16 calculates differential speed and average speed to generate an exact, phase-correct EM speed. This cuts through high electrical noise environments to detect microscopic gear pitting or inverter housing vibrations in real-time, protecting multi-million dollar e-axle prototypes.

Shutdown Diagnosis in relation to Sideband Growth

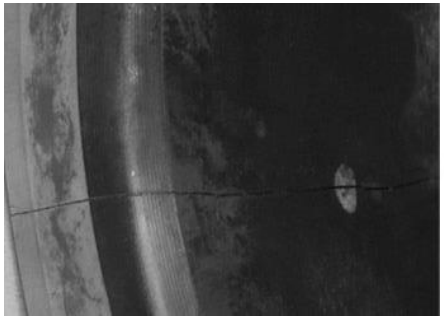


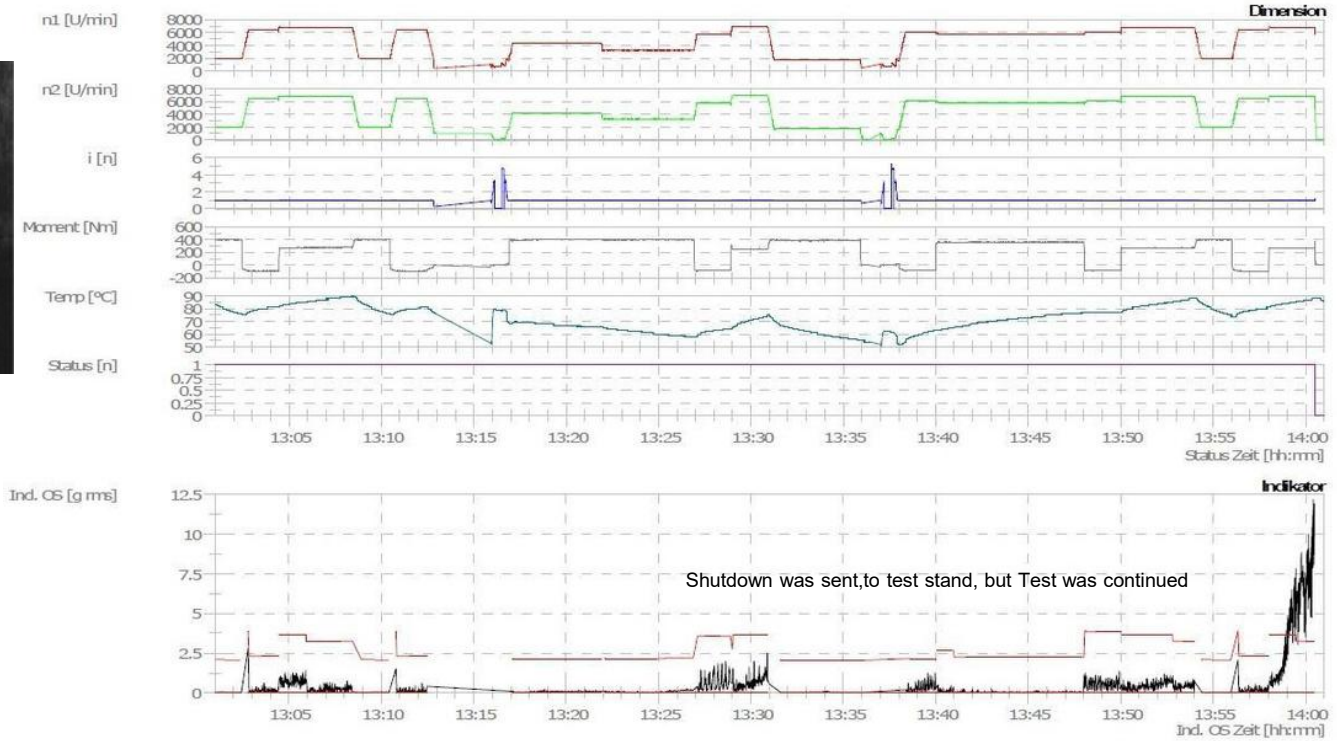




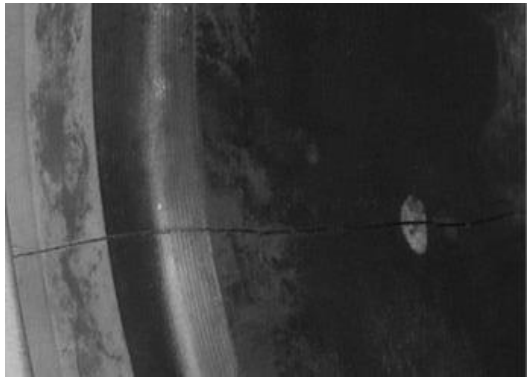
ZEO: Tooth mesh order
WO: Shaft order
SBWO: Side band shaft order

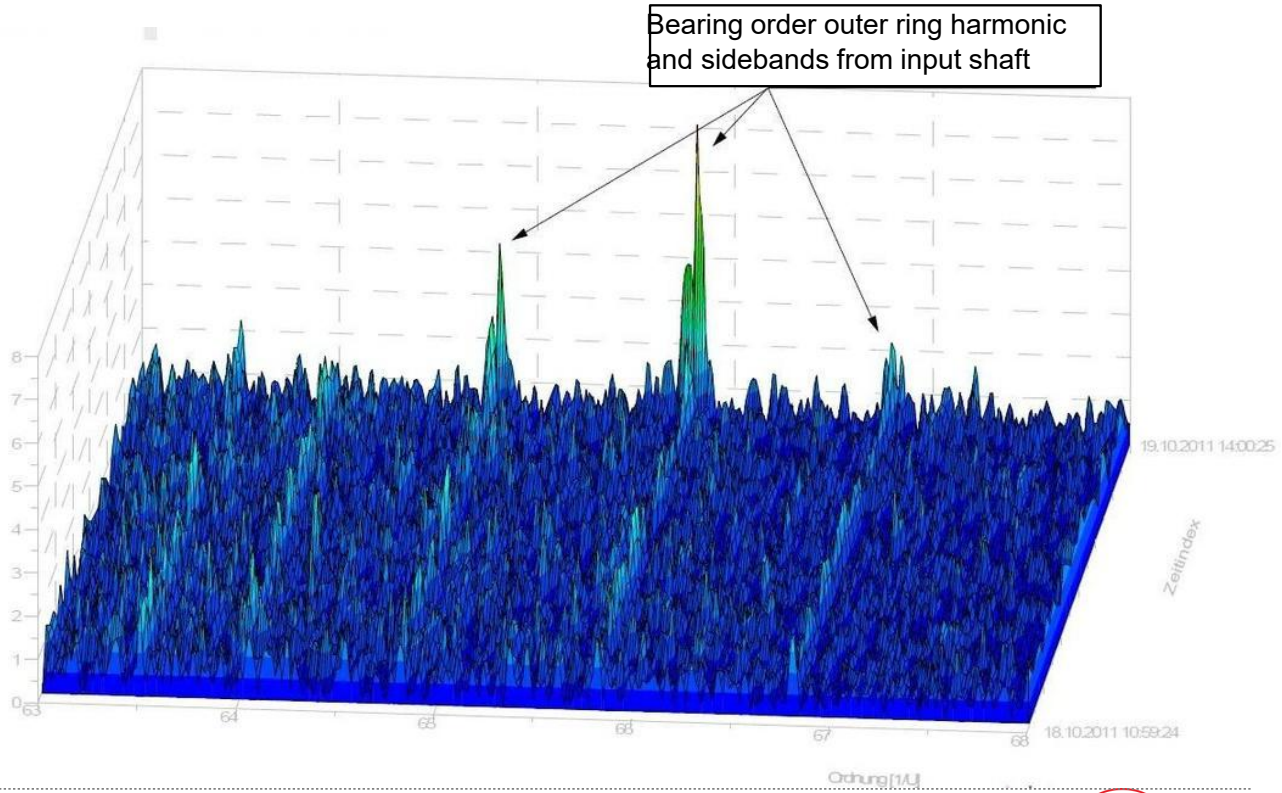
Input Shaft Bearing Defect (8-speed transmission with hybrid powertrain) 1/2



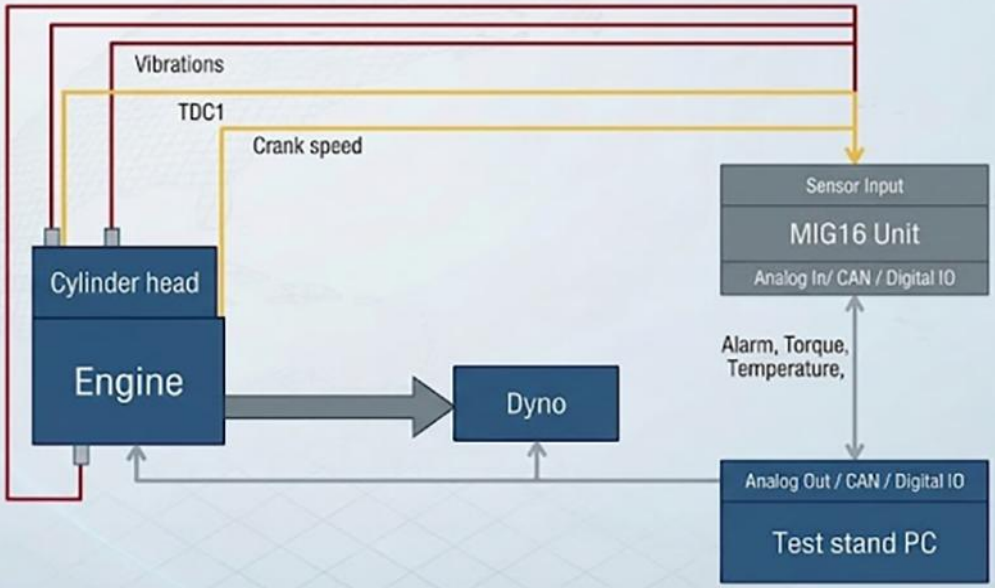


Input Shaft Bearing Defect (8-speed transmission with hybrid powertrain) 2/2





Use Case 2: Internal Combustion Engine Durability Testing



[TAG: VIB_01]
500g, Crank Housing

[TAG: VIB_02/03]
1000g, Cam Cap Housings

[TAG: TDC]
Current clamp,
Injector 1

Symptom to Diagnosis: Catching a Cylinder 4 Failure in Real-Time (1/2)

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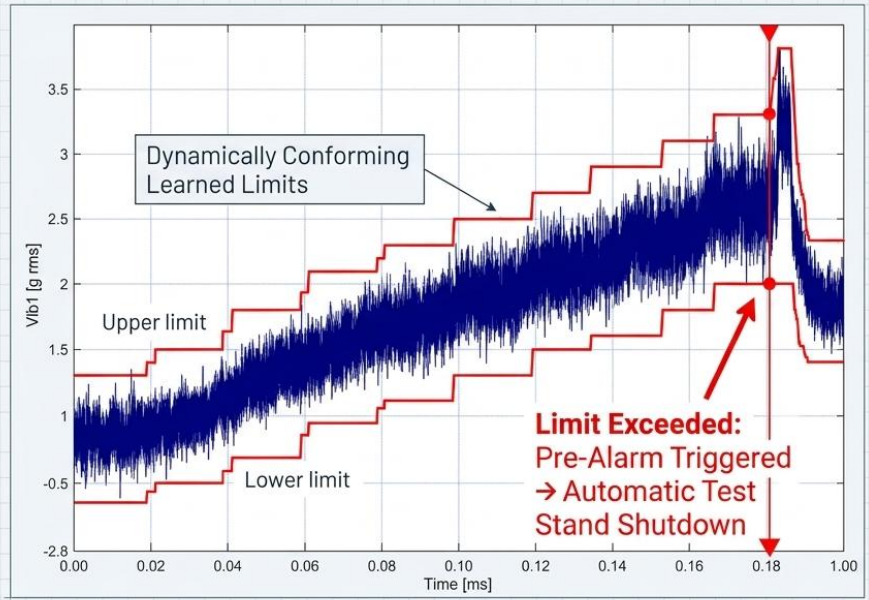
The Envelope of Safety Concept



Real World Impact

DIAGNOSTIC EVENT 20250807:
Bearing failure allowed piston to travel beyond tolerance, slapping the cylinder head. Caught via envelope breach.

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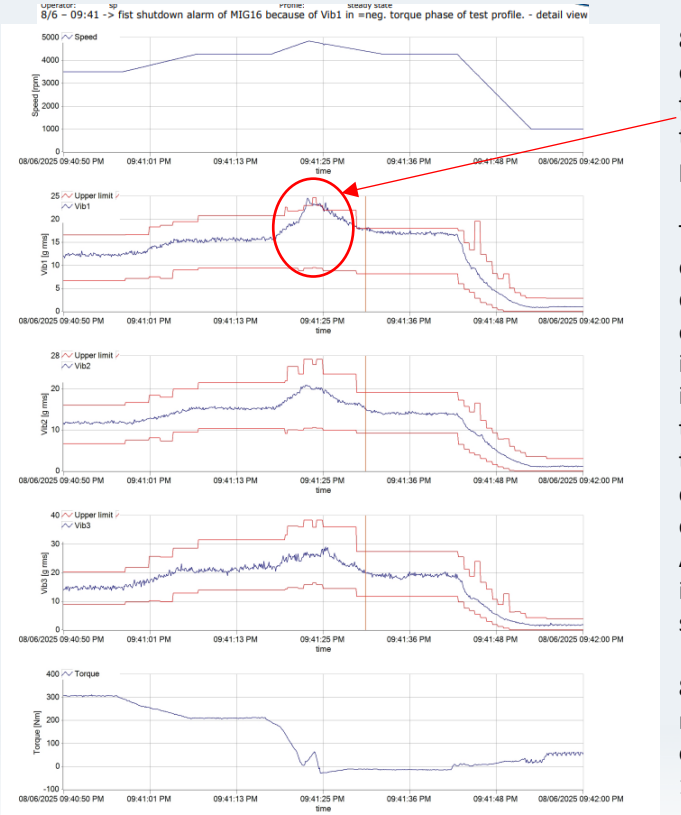
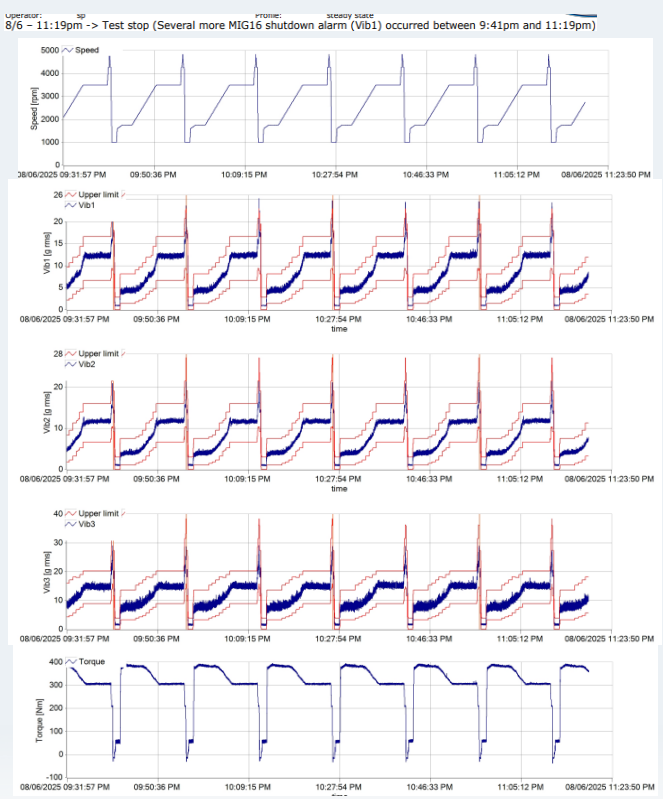
Symptom to Diagnosis: Catching a Cylinder 4 Failure in Real-Time (2/2)



8/6 – 09:41pm -> first shutdown alarm of MIG16 because of Vib1 in neg. torque phase of test profile. A clear trend increase of Vib1 over the previous test hours can be seen.

This increasing trend is particularly evident on Vib1. An analysis of the raw data shows that no combustion event or similar is responsible for this increase. Rather, it is a general increase in overall noise. This trend increase is typical of a wear damage. The fact that the trend is only visible on Vib1 is consistent with the assumption of a clutch failure.
All Vib sensors do not show any increasing trend in pos. torque load steps.

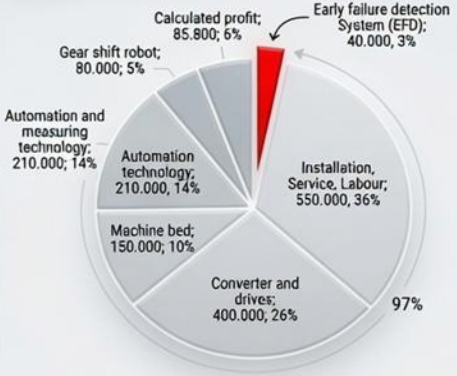
8/6 – 11:19pm -> Test stop (Several more MIG16 shutdown alarm (Vib1) occurred between 9:41pm and 11:19pm)



Business Impact & ROI

Test Bed Utilization: 65% → 90%

Eliminates catastrophic downtime and allows precise test-stop targeting.



Capital Efficiency

The EFD system represents only 3% of total expenditure, yet protects 100% of the capital investment.

ROI < 12 Months

Pays for itself within one year through prototype preservation alone.

Advantages

Agility

Setup to Monitoring in Minutes

Standard screwed/glued sensors and CAN-bus integration allowed the Instrumentation team to prep the TDC trigger in under 10 minutes.

Precision

Beyond Catastrophic Failure

MIG16 EFD detects microscopic wear and irregular combustions via high resolution order tracking and 1° angular resolution. Don't wait for parts to break.

Proven Integration

A Decade of Trust

The Transmission Lab in Livonia has successfully relied on the MIG16 EFD system for over 10 years.

Leverage red-ant onsite training today to integrate Early Failure Detection into all standard durability testing workflows.

Headquarter Munich, Germany

- **Tokyo & Nagoya, Japan, TOYO Corp.**
- **Fremont CA & Detroit MI , USA, TOYOTech**

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