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Condition Based Monitoring For Industrial Machines

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System Applications Manager,
Analog Devices

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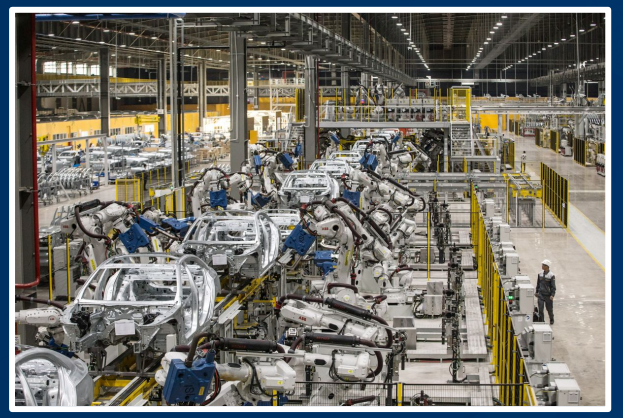
Introduction

- Richard Anslow is a System Applications Manager within the Industrial Automation Business Unit at Analog Devices.
- His areas of expertise are condition-based monitoring, motor control, and industrial communication design.
- He received his B.Eng. and M.Eng. degrees from the University of Limerick, Limerick, Ireland. Recently he completed a postgraduate program in AI and ML with Purdue University.
- He can be reached at richard.anslow@analog.com

Agenda

- ***Background for Condition based Monitoring (CbM) and Predictive Maintenance (PdM)***
  - What is CbM and how is it different to PdM?
  - What are the benefits?
  - Real life examples.
  - How do i spot faults from FFT signatures of a motor?
- ***Insights from Different CbM Sensor technologies***
  - Vibration
  - Audio
  - Magnetic
  - Others
- ***Complete Sensor Solutions***
  - Wireless sensor examples
  - Wired sensor examples
  - Cloud and Edge Artificial Intelligence
- ***Summary***
- ***Q&A***

Why is CbM important for Industrial Motors?



450Mu
Installed Motors

52Mu/Y
New Installations

30% of
Total Energy
used by Industry

70% of
Industrial Energ
used by Motors

ementing Smart Motors reduces total Global energy by

Ref ABB : IE4 vs IE1 motor upgrade

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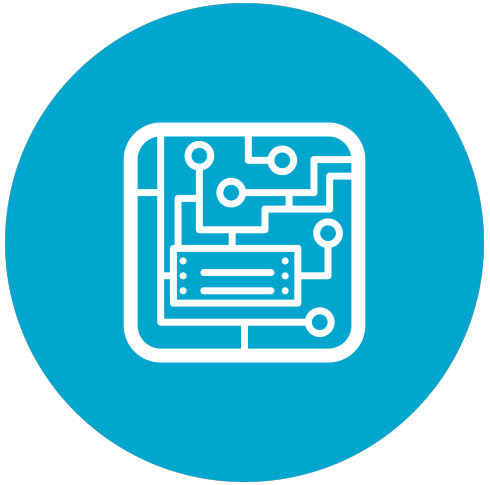
Background for CbM and PdM

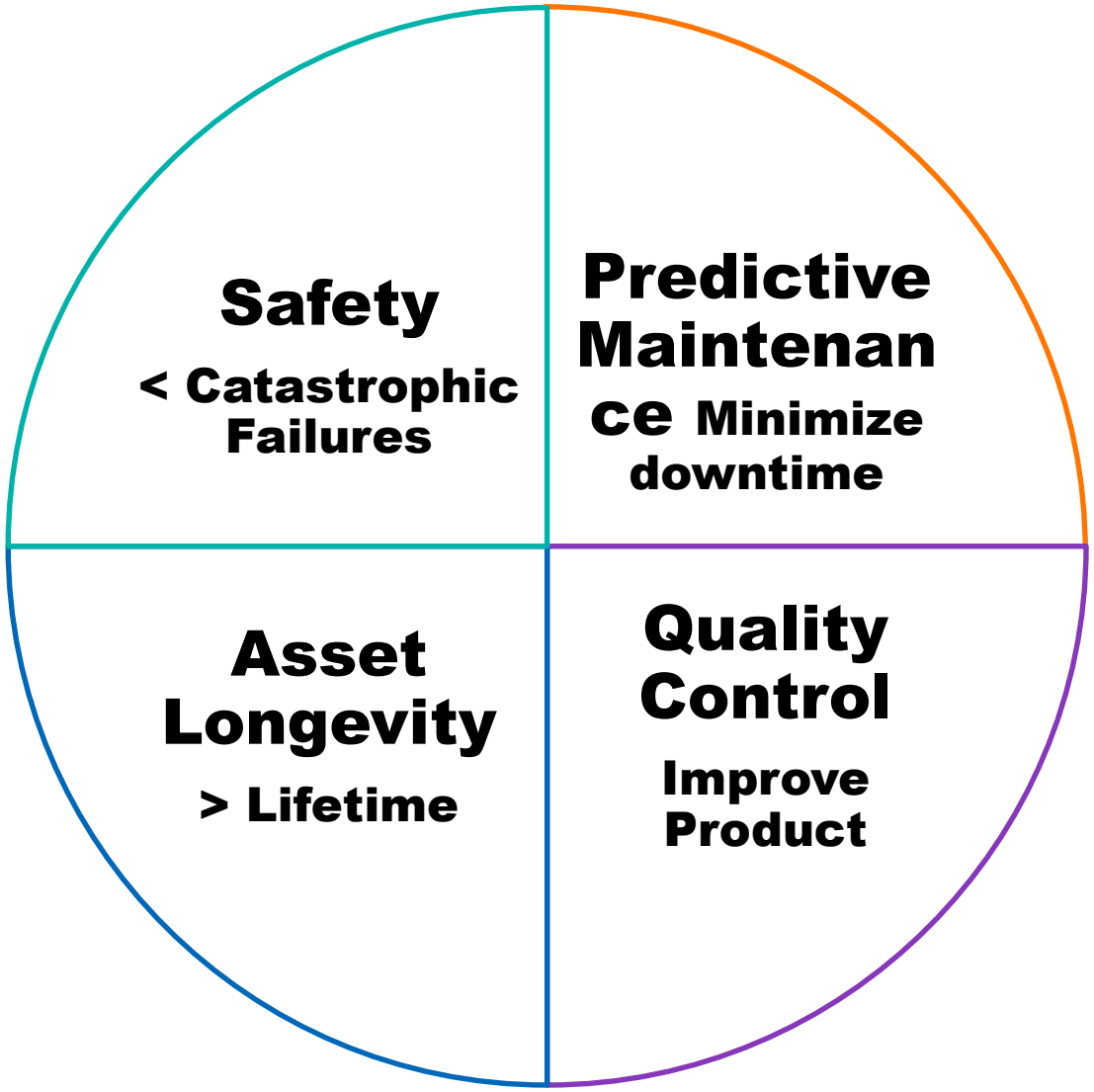
Definitions: What do we mean when we say…

CbM – Condition based Monitoring



PdM – Predictive Maintenance

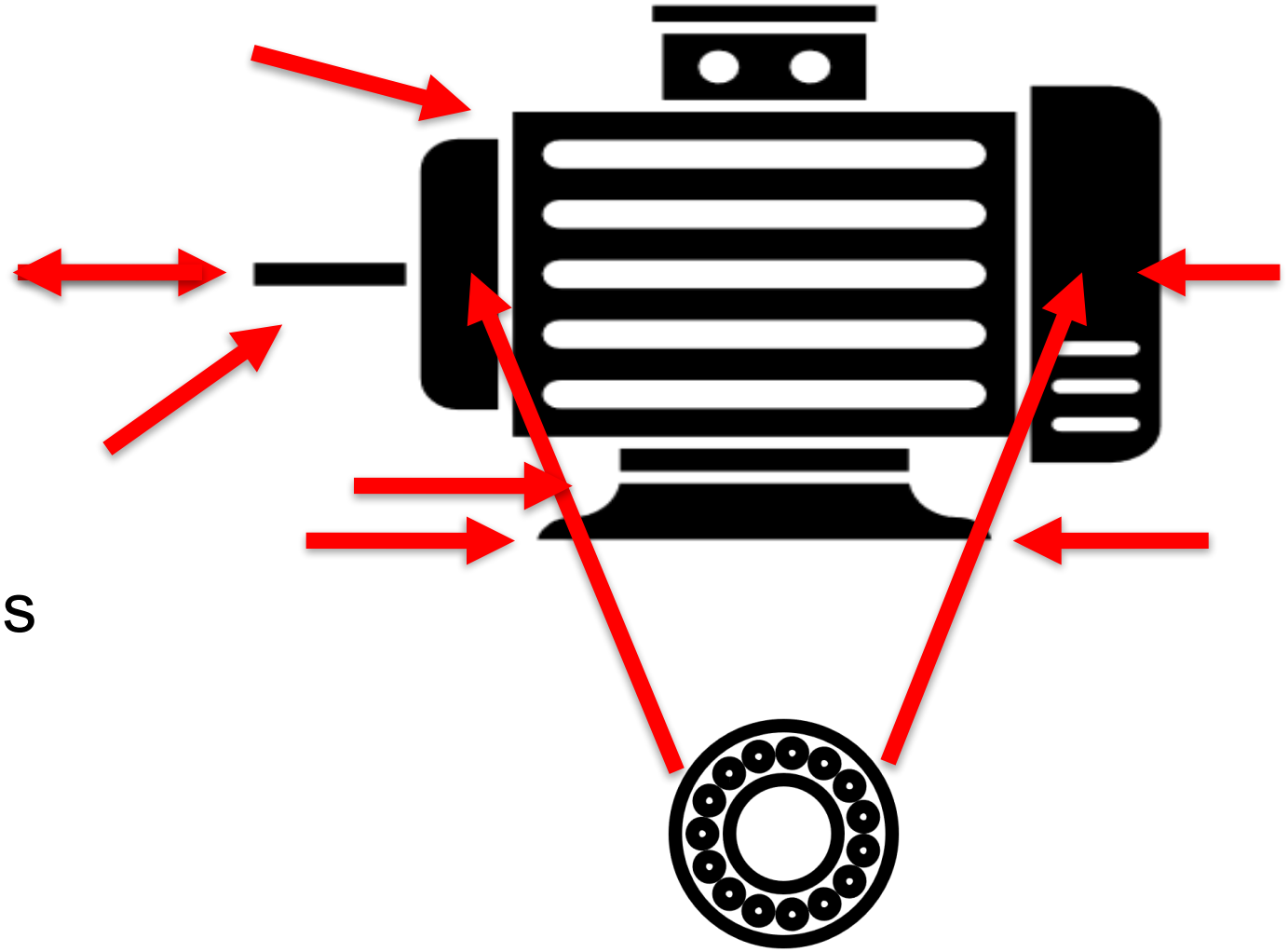
Why does PdM Matter and what are the Benefits?



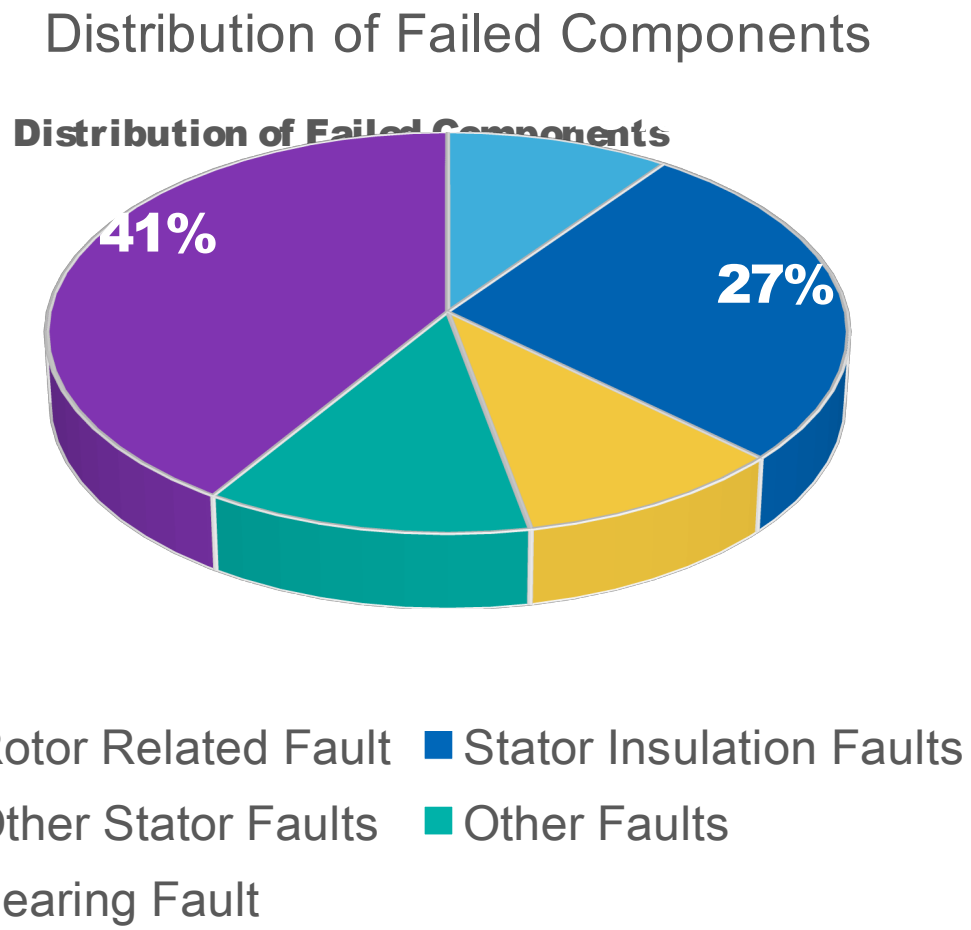
What is a CbM/PdM System Trying to Measure?

Motor Faults:

- Bearings
- Imbalance
- Misalignment
- Mechanical looseness
- Soft footing
- Load Issues/Irregularities



What Are The Most Common Failures In Rotating Machinery?



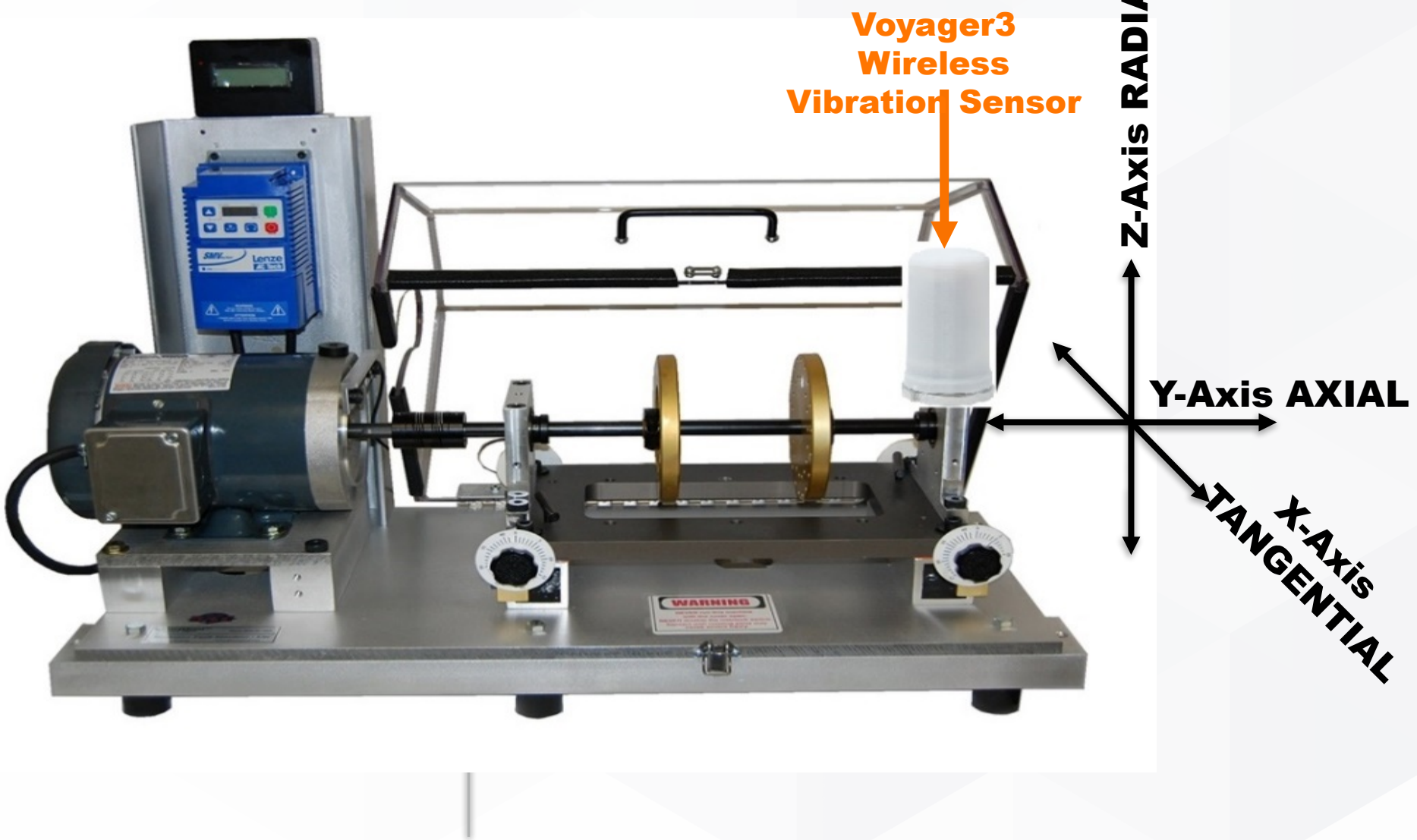
Pratyay Konar, R. Bandyopadhyay, and Paramita Chattopadhyay. "Bearing Fault Detection of Induction Motor Using Wavelet and Neural Networks." *Proceedings of the 4th Indian International Conference on Artificial Intelligence*, IICAI 2009, Tumkur, Karnataka, India, December 2009.

>90% of rotating machinery in Industrial & Commercial applications use rolling-element bearings*

** Graney, Starry, "Rolling Element Bearing Analysis"*

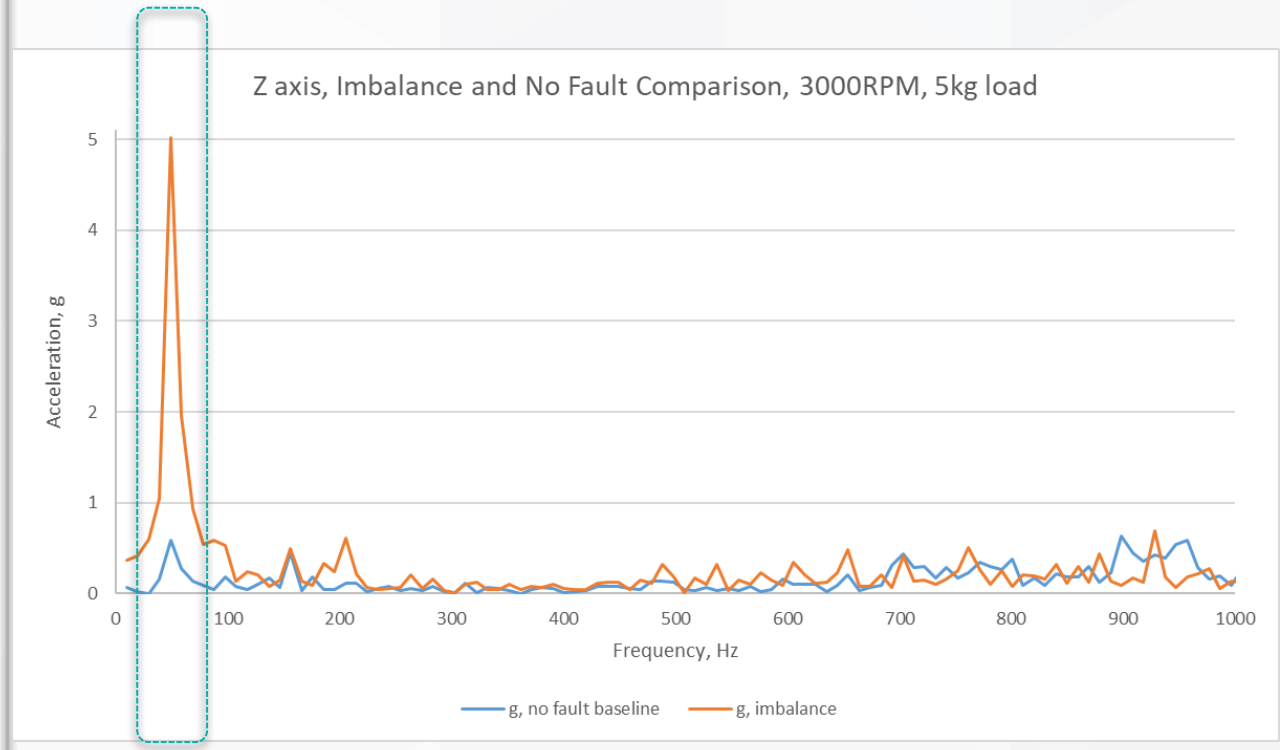
Spectra Quest Fault Simulation Rig

- Controlled Fault Simulation rig
- Simulates several common machine faults such as imbalance
- Consists of AC motor, VFD, shaft, and load
- Voyager Wireless module can be mounted on near or far end from the motor
- Voyager triaxial MEMS measures vibration signal radially and axially as shown



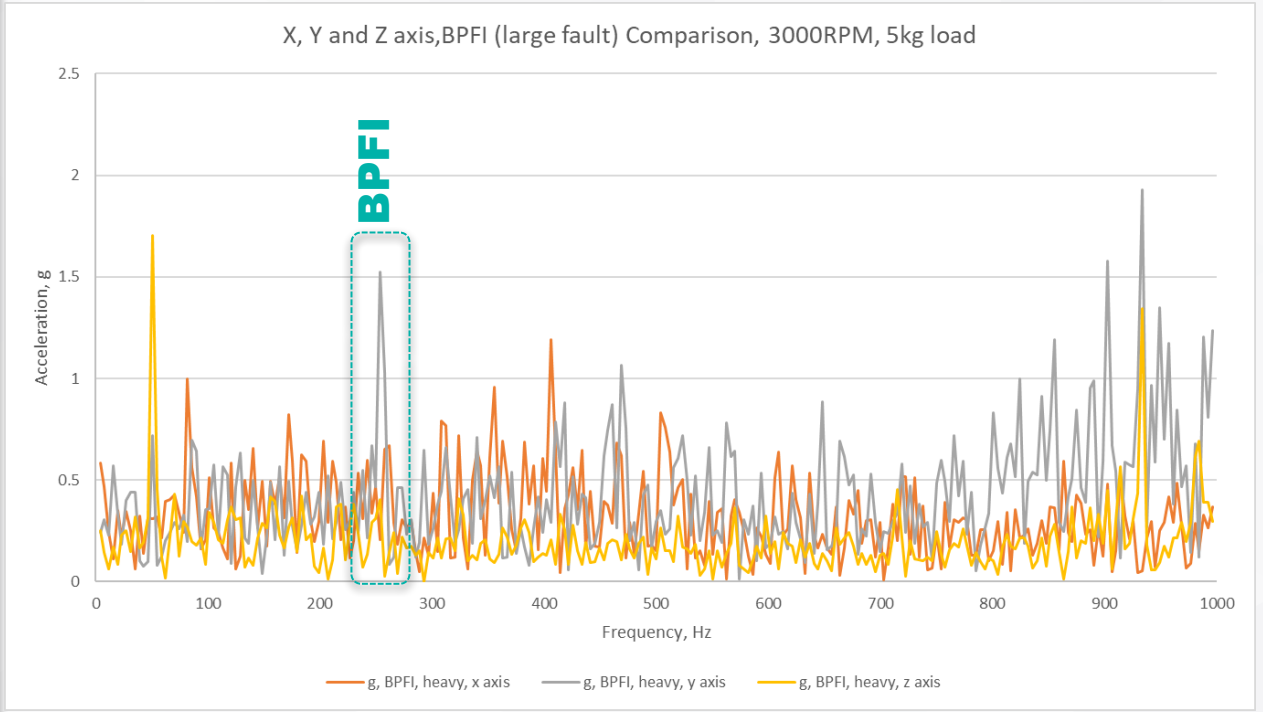
Imbalance

- What is Imbalance?
  - an unequal distribution of mass that causes the load to shift the centre of mass away from the centre of rotation
- Why is an unbalance system a concern?
  - Unbalanced systems create excess vibrations that mechanically couple to and deteriorate other components that are in good operating condition
- How to detect Imbalance?
  - an increased vibration amplitude at the rotational rate (1x) compared to the baseline background vibration noise.
- How to simulate Imbalance using the SpectraQuest or other test Rig?
  - load with added mass at its extremity is placed on the rig shaft



Bearing Defect – Inner Ring (BPFI)

- The BPFI can be calculated using
  - where F is the frequency, N is the number of balls, B is the ball diameter, ϴ is the contact angle and P is the pitch diameter.
- For the SpectraQuest rig the user manual provides the calculation for you. Based on 8 rolling elements used in a 5/8” rotor bearing, with rolling element diameter of 0.3125”, and a pitch diameter of 1.318”, **the BPFI is calculated at 4.95x the fundamental rotation rate.**



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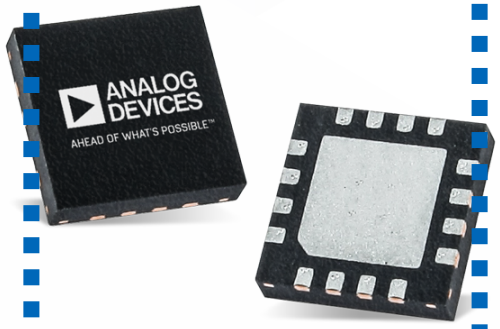
Insights from Different CbM Sensor technologies

A CbM Sensor consists of 3 or 4 key blocks

- The defacto industry standard sensor is IEPE, which is analog out (3/4 blocks)
- *With the rapid digitization of assets edge microcontrollers and AI are gaining market share (4 blocks)

Sensor + Connectivity + Housing + uC/AI Algorithm*

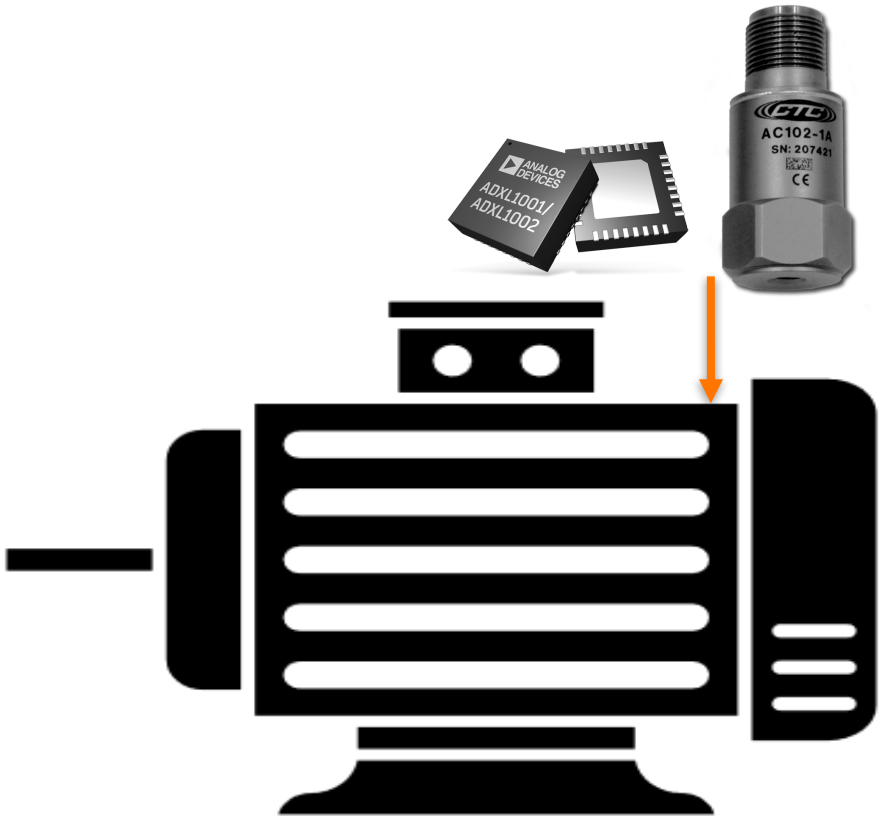


Sensors used on Existing Wireless PdM Solutions

Vendor	Sensors				
	VIBRATION	TEMPERATURE	MAGNETIC	SOUND	OTHER
A	✓	✓	✓	✗	✓
B	✓	✓	✗	✗	✗
C	✓	✓	✗	✗	✗
D	✓	✓	✓	✗	✗
E	✓	✓	✓	✓	✓
F	✓	✓	✓	✗	✗

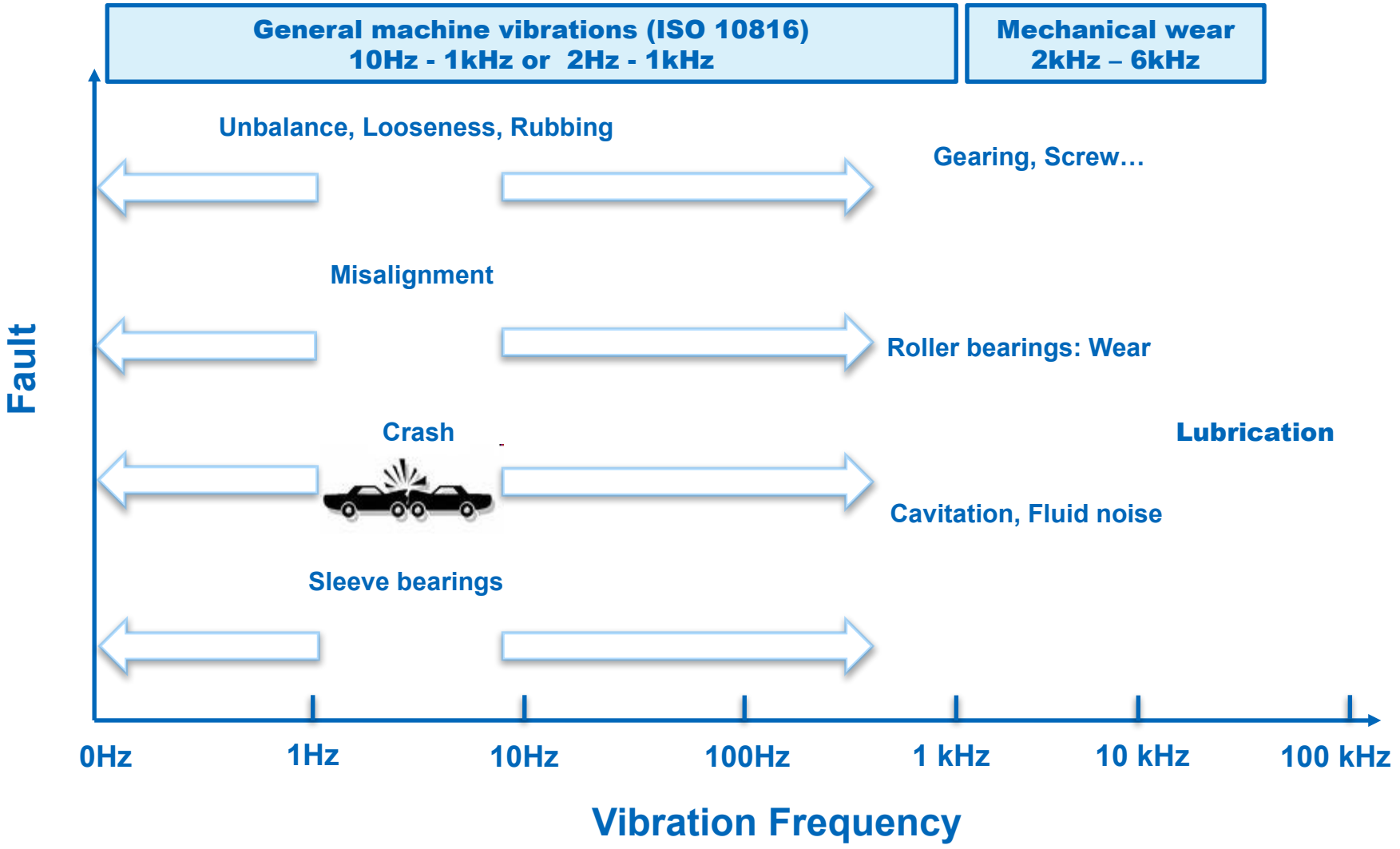
- Vibration - 100%
- Temperature - 100%
- Sound - 17%
- Magnetic - 67%

Accelerometers



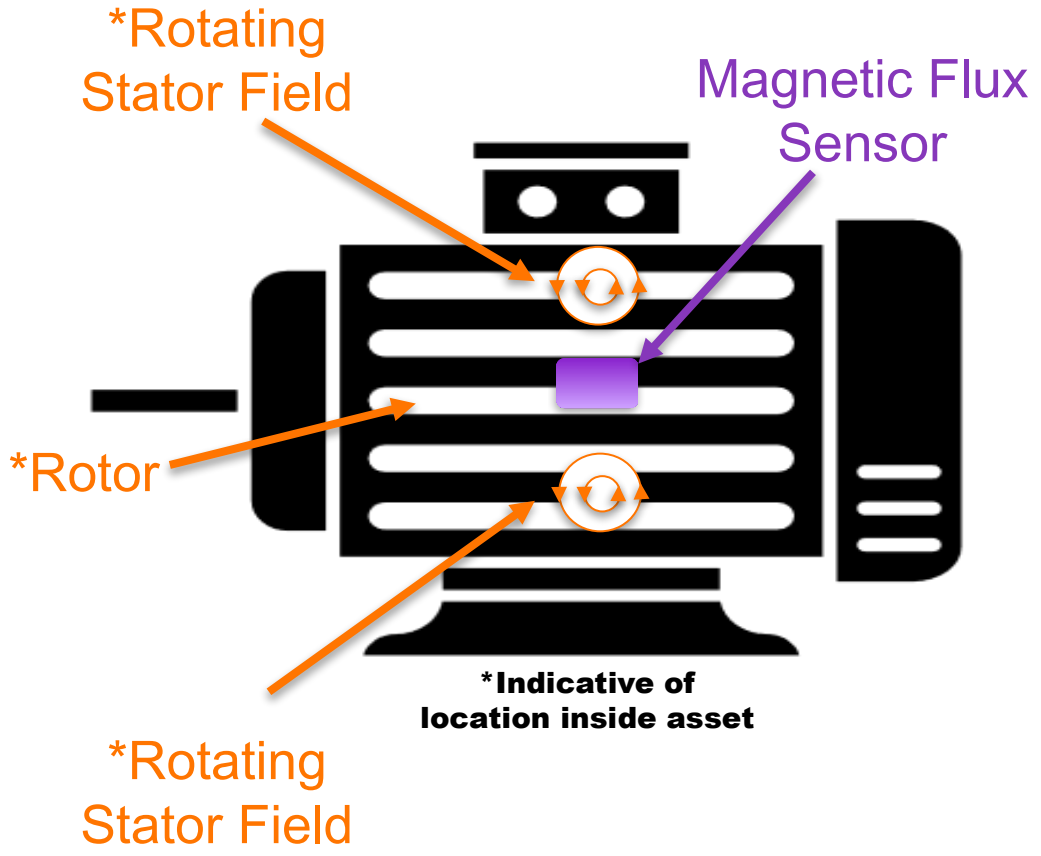
- Sensor Location is key
- Detects mechanical/electrical faults
- Best technique for fault identification

Accelerometer Bandwidth



Magnetic Field Sensors

- Non-Invasive
- Small
- Fault Diagnosis



Oil & Lubrication Analysis

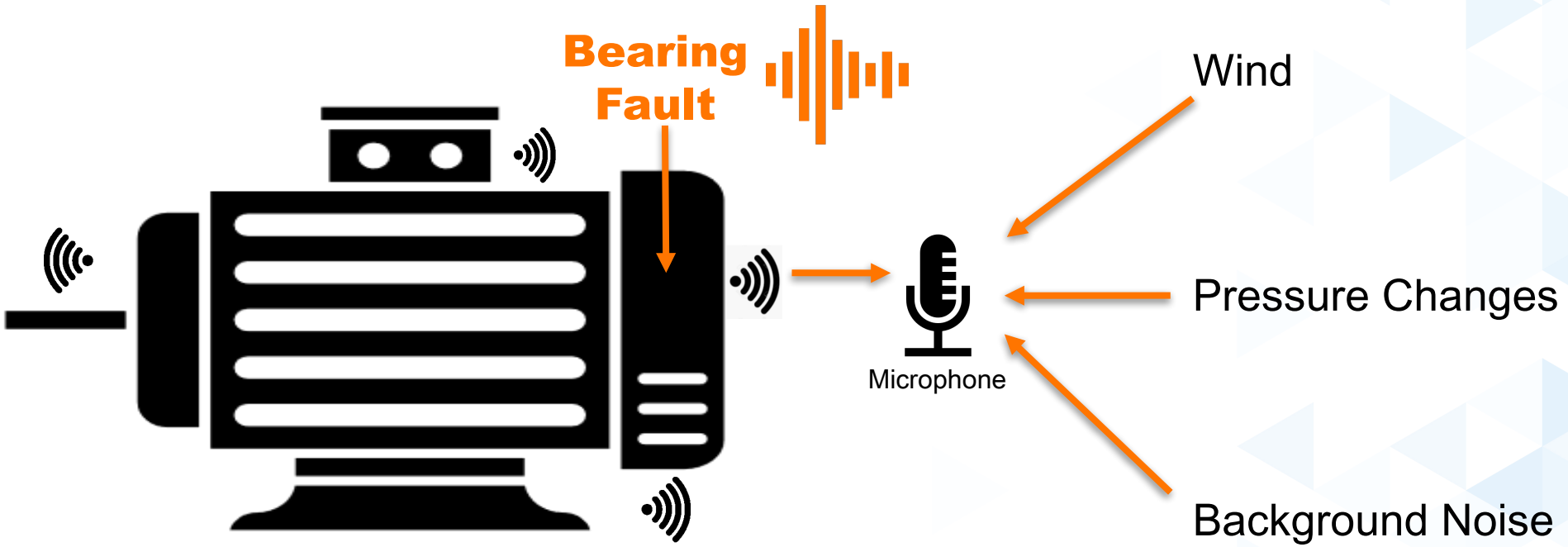
- Identify Source of failure
- Not suited to remote sites
- Expensive

73% of lubrication professionals use multiple predictive maintenance technologies at their plant.

https://www.machinerylubrication.com/Read/29819/predictive-maintenance-technologies

MEMS Microphones

- Non-Intrusive
- Robustness issues
- Can detect some faults earliest



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Complete Sensor Solutions

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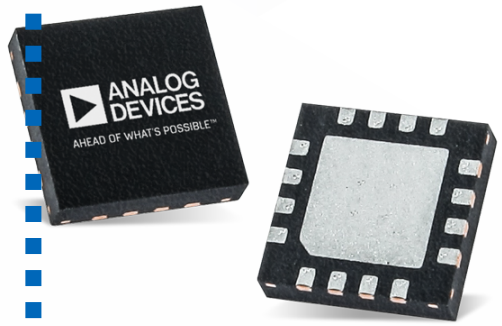
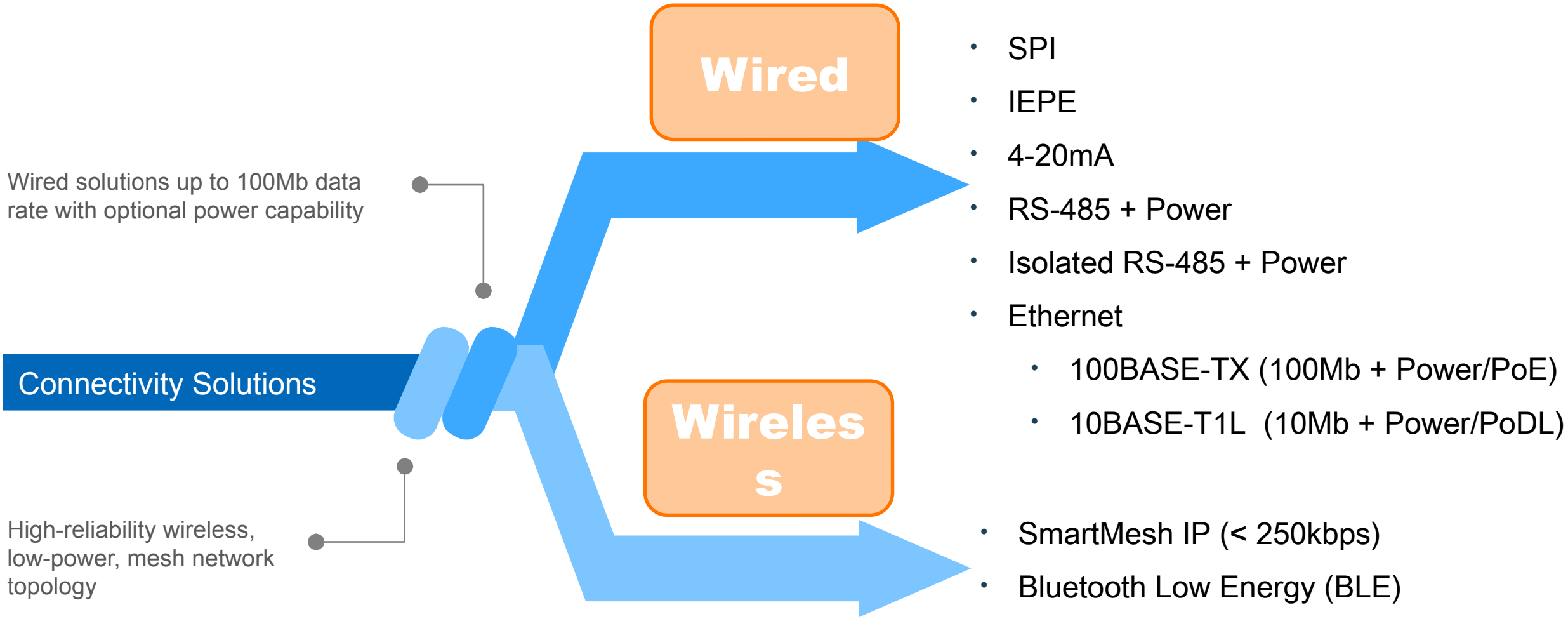
Sensor + Connectivity + Housing + uC/AI Algorithm*



Wired / Wireless CbM/PdM Connectivity Options



Single Pair Ethernet (SPE) & Condition base Monitoring (CbM)

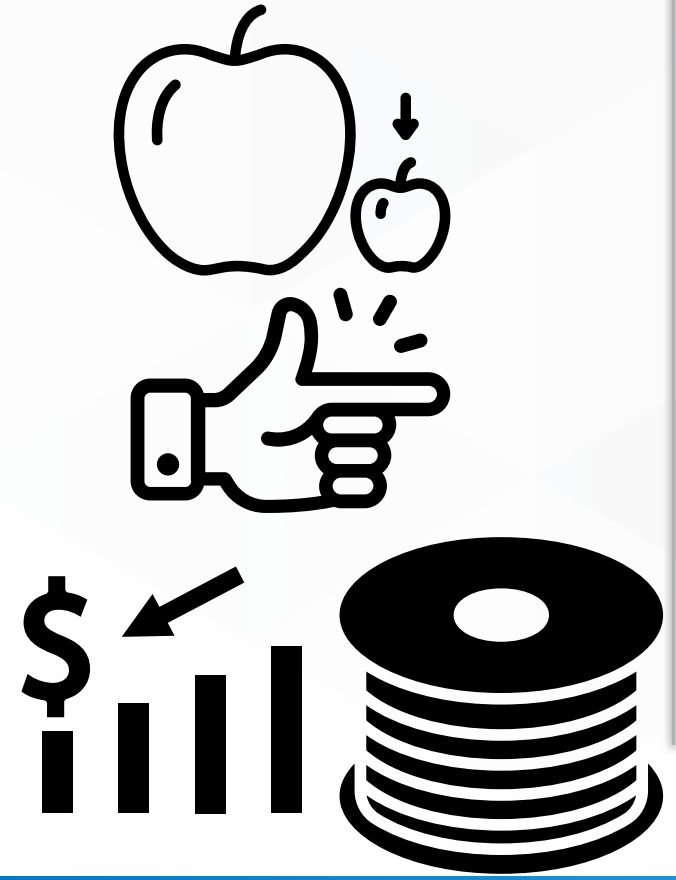
Wired

- For CbM sensor development SPE offers significant advantages compared to standard ethernet

Reduced Sensor Size

Reduced Complexity

Low cost cabling



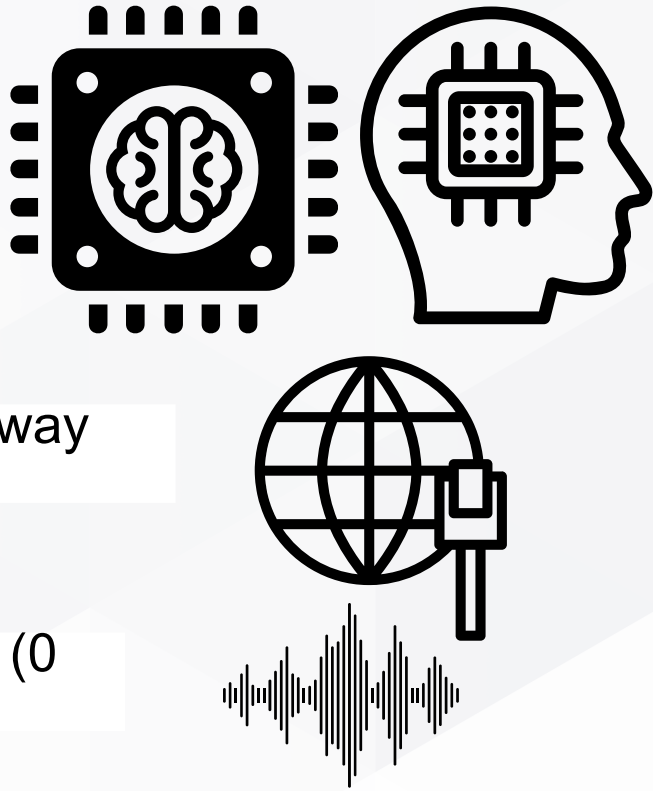
- Digital SPE sensors with MEMS have several advantages compared to Piezo (analog out) CbM sensors

Asset Health Memory

Edge AI Capability

IP Addressable (no gateway needed)

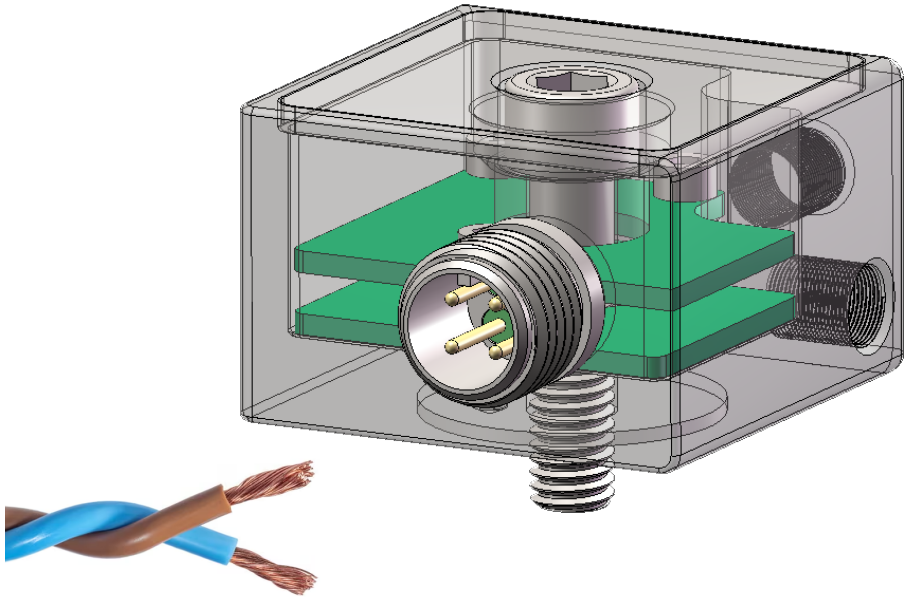
Measure low Frequency (0 Hz)



Galileo: Wired Vibration CbM over 10BASE-T1L

Wired

- Low power, 3-axis MEMS vibration sensor, with a SPE MAC-PHY transceiver, and embedded microcontroller to deliver **high quality asset health history** and **IP addressability.**
- Common motor faults generate **vibration signatures**, which can be measured using Condition based Monitoring (CbM) sensors.



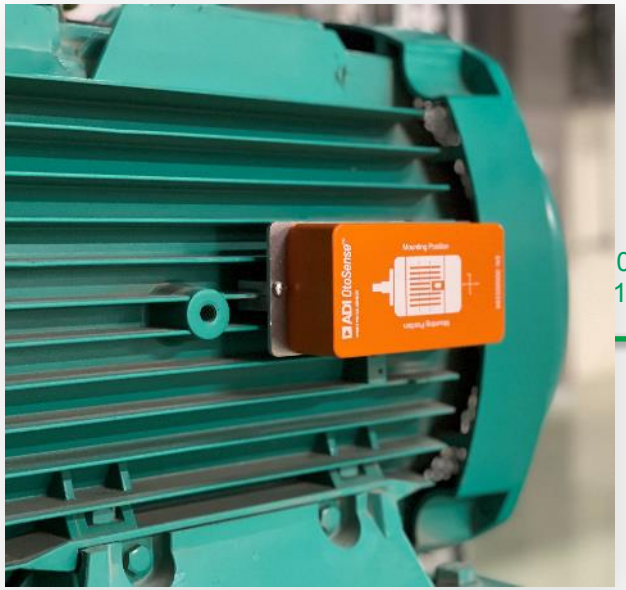
GALILEO: Vibration Sensor prototype with Single Pair Ethernet (SPE) Connectivity

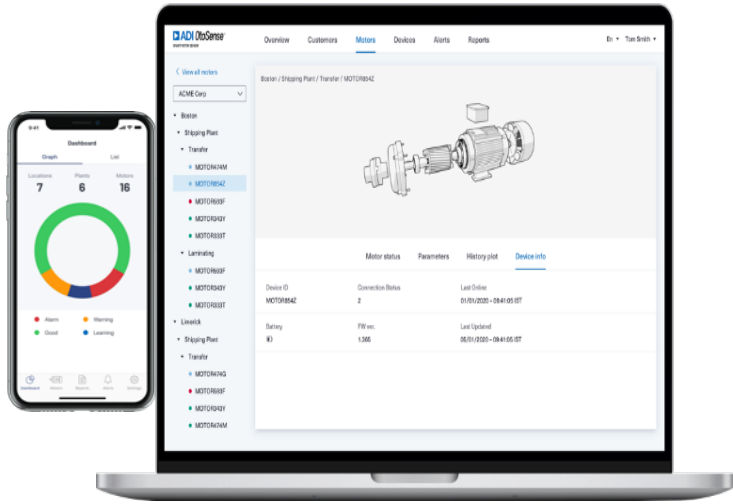
ADXL359	Low noise, low drift, low power, 3-axis MEMS accelerometer
ADIN1110	Robust, industrial, low power 10BASE-T1L Ethernet MAC-PHY
MAX32670	Ultra-low power, Cortex-M4 Microcontroller with FPU
LT8604	High efficiency 42 V/120 mA synchronous buck
LT3042	20 V, 200 mA, ultralow noise, ultrahigh PSRR linear regulator

- Reduced sensor size
- Edge AI capability
- Measure low frequency (0 Hz)
- Low-cost cabling
- IP addressable (no gateway needed)

Smart Motor Sensor (SMS): AI-based Turnkey PdM Solutio

Wireles s





Sensing Technologies

High performance sensors deliver higher quality data for analysis

Machine Learning

Securely sends data to the cloud to diagnose critical electrical and mechanical motor faults

Advanced Diagnostics

Notifications, diagnostic updates and recommendations provided through web and mobile applications

ADI OtoSense™

SMS Device Highlights

Wireless

Sensors

Best-in-class robust sensors and processing technologies to deliver high quality data

Vibration : 2 ADI high frequency bandwidth and low noise accelerometers for Z-, X-dual-axis vibration measurement

Temperature : 2 ADI sensors for motor frame and ambient temperature measurement

Magnetic flux : motor magnet flux sensor for motor rotation speed measurement

Power

Sustainable device, powered by 4 × replaceable AA lithium batteries

ADI OtoSense™

SMS Working Principle

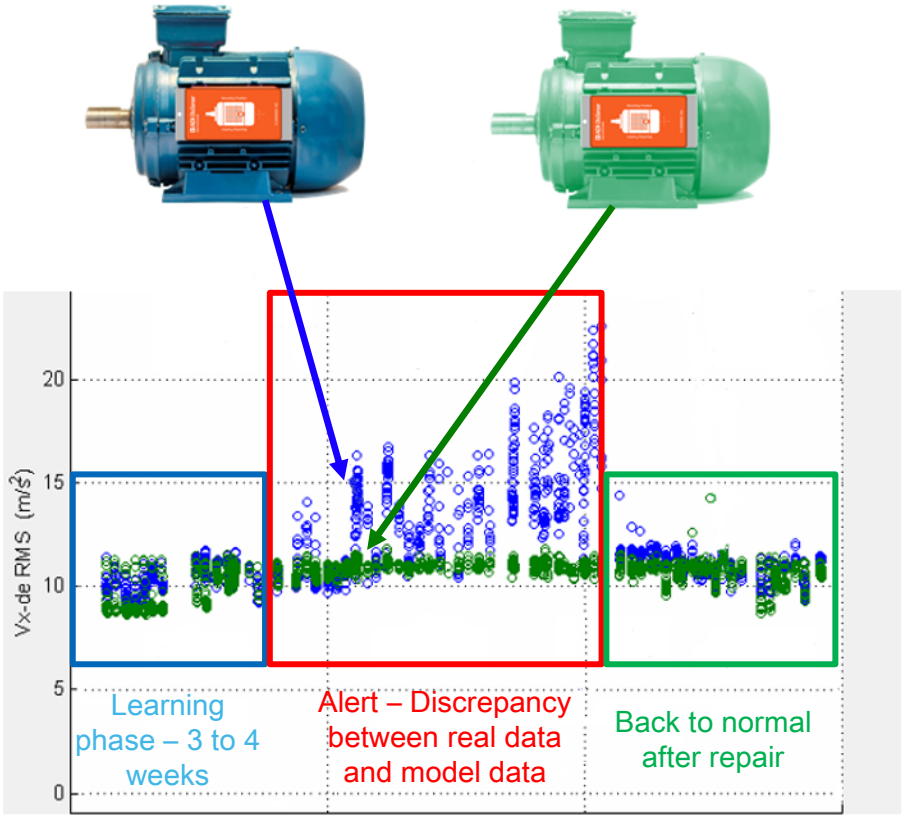
Wireless

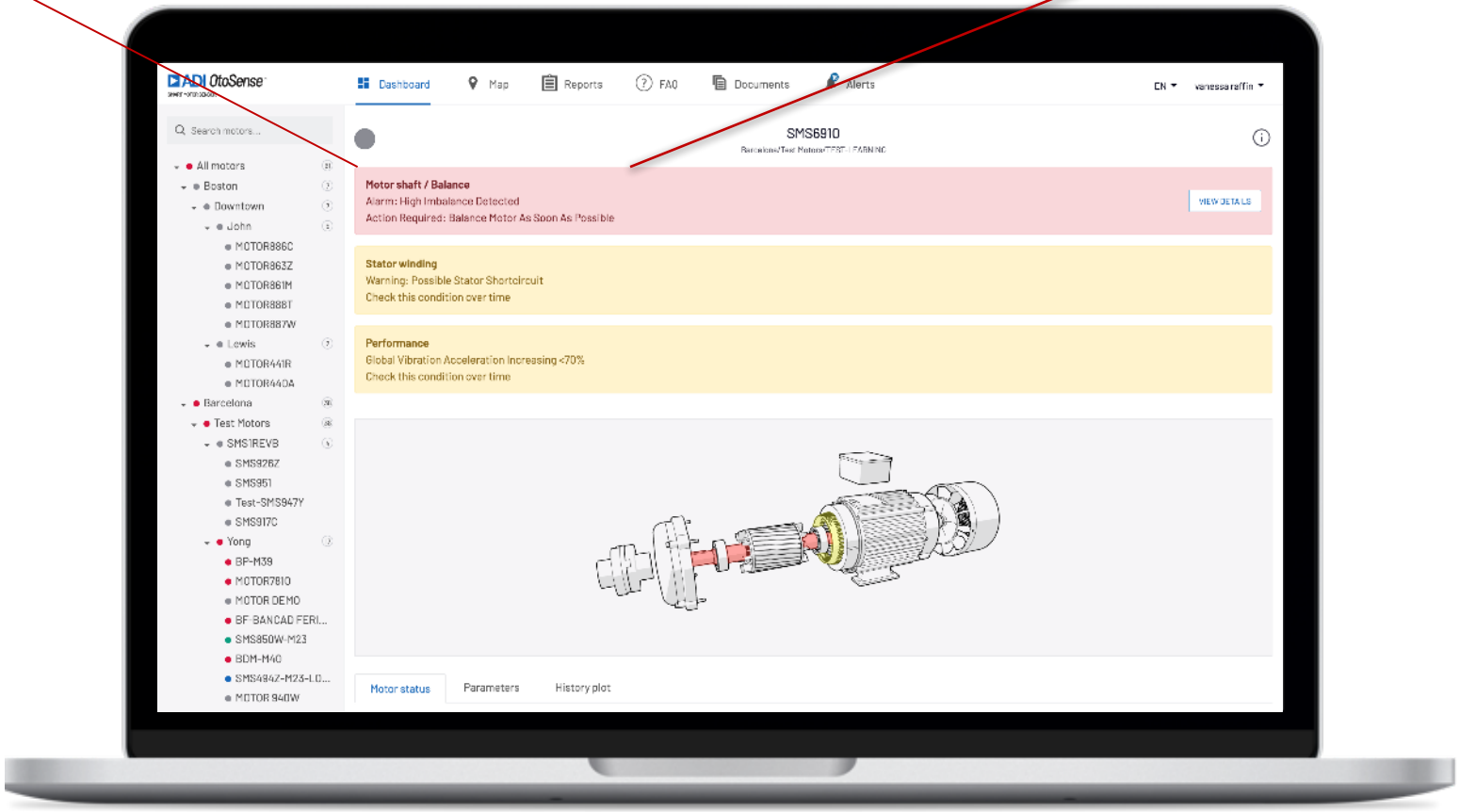
Motor shaft / Balance

Alarm: High Imbalance Detected

Action Required: Balance Motor As Soon As Possible

Real Motor Data **Motor Model Data**





Case Studies: Food and Beverage

Wireless

Challenge: Save repair and downtime costs of a centrifugal machine

2

Years of operating without breakdown

Early warning signs sent by the Smart Motor Sensor enable the maintenance of the machine before it breaks.

€100k

Downtime and repair costs avoidance /year

Smart Motor Sensor prevents 3 weeks of downtime and the high costs involved in the repair (material, crane, men hours…)

- 90%

Preventive activities

Reduce route-based activities such as regreasing, cleaning of the machine's filters, vibration analyses.

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Conclusions

Key Takeaways

- Energy efficiency and sustainability trends in Motor drives are driving market growth of CbM and PdM solutions
- Vibration, magnetic, and temperature sensors are widely used for CbM
- CbM devices include sensor, connectivity, housing, and edge intelligence
- There are several choices in CbM and PdM with Edge intelligence and new connectivity technologies
- Industrial Ethernet, and Single Pair Ethernet offer a simplified and unified interface for CbM sensors
- Complete PdM solutions like Analog Devices Otosense SMS provide artificial intelligence insights, increasing asset uptime and useful life

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Thank You !

Q&A

Credit to Analog Devices Engineers - Chris Murphy, Renan DePadua, and Tom Sharkey for providing supporting content.