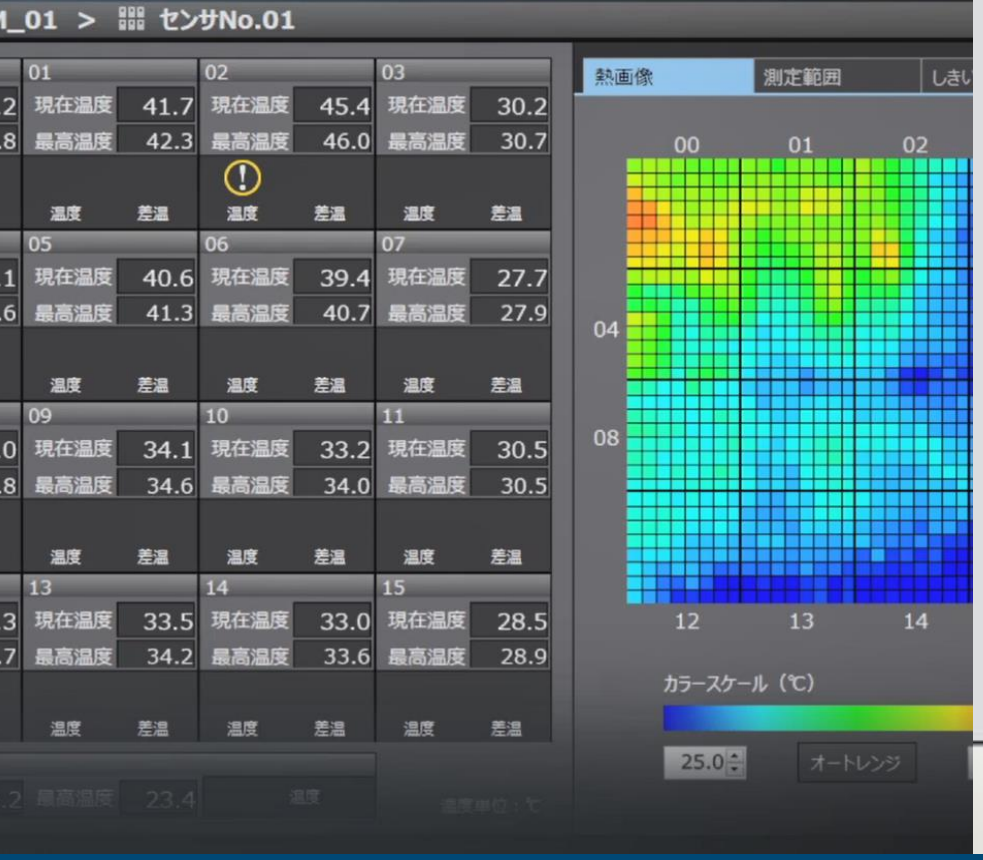
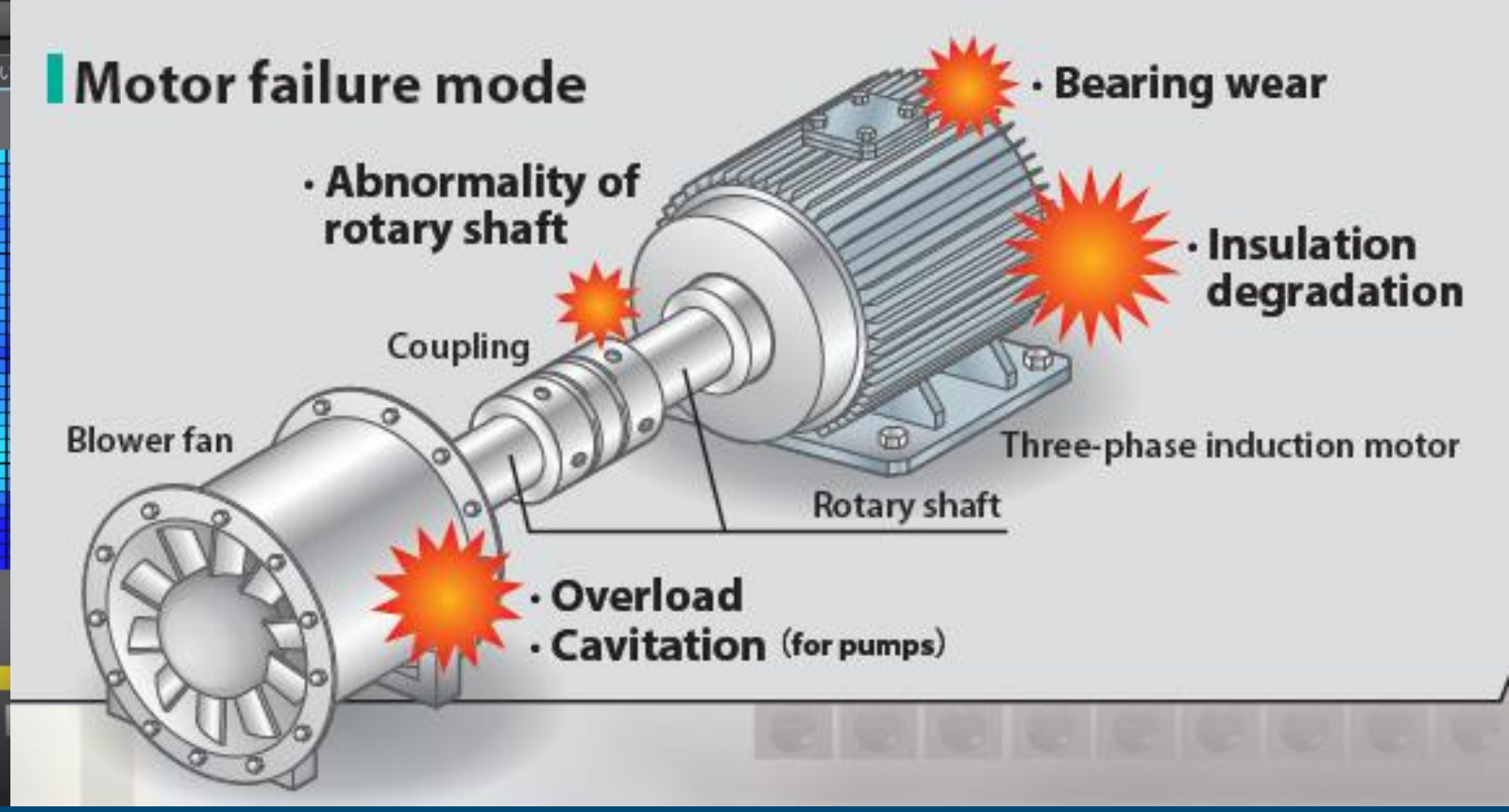




Predictive Maintenance (PdM) Solutions

Real time monitoring of motors and other equipment using new sensor technologies

STLE Toronto Workshop Nov 27, 2019 – Chris Barnes, P.Eng.,MBA, Omron Canada Inc.

Agenda

- Why Predictive Maintenance (PdM)?
- What is Predictive Maintenance (PdM)?
- Sensor Technologies for Live Monitoring
  - Vibration Analysis
  - Current Analysis
  - Insulation Resistance Monitoring
  - Thermography
- Analyzing PdM data with Artificial Intelligence (AI)
- Case Studies and Examples

Why predictive maintenance?

Unplanned downtime can be extremely expensive for our economy.

Industry	Cost of downtime (per min.)	Cost of downtime (per hr.)
Automotive – Assembly	$15,000	$900,000
Automotive – Powertrain	$5,000	$300,000
Semi-conductor	$4,167	$250,020
Processed Food Production	$312	$18,720
Bottled Water Production	$50	$3,000

This does not include the cost to repair or replace the issue!

Why Predictive Maintenance (PdM)?

"Unplanned downtime costs industrial manufacturers an estimated $50 billion annually. Equipment failure is the cause of 42 percent of this unplanned downtime."

Wall Street Journal

US Department of Energy's Federal Energy Management Program found that PdM provided:

- ✓ 30-40% savings vs. reactive maintenance
- ✓ 8-12% savings vs. preventative maintenance
- ✓ potential to yield a tenfold increase in ROI
- ✓ 25-30% reduction in maintenance costs
- ✓ 70-75% decrease in breakdowns
- ✓ 35-45% reduction in downtime

Source: Predictive Maintenance Explained, ReliablePlant.com

Why Predictive Maintenance (PdM)?

Deloitte study of several facilities revealed:

- ✓ 5-10% cost savings in operations and maintenance, repair and operations (MRO) material spend
- ✓ 5-10% reduction in overall maintenance costs; and reduced inventory-carrying costs.

"As far as maintenance costs are concerned, preventive maintenance costs $13 hourly pay per annum while predictive maintenance costs $9 hourly pay per annum, making predictive maintenance a cheaper option"

(Ulbert, "The Difference Between Predictive Maintenance and Preventive Maintenance").

Source: Predictive Maintenance Explained, ReliablePlant.com

Predictive Maintenance Value

What if you could prevent costly production downtime by knowing the status of your assets?

What if a component could be added to your infrastructure to help predict the replacement time of assets?

New sensors are bringing practical Industrial Internet of Things (IIoT) to the component level to improve predictive maintenance routines!

What is Predictive Maintenance (PdM)?

- PdM is maintenance that **monitors** the performance and condition of equipment during normal operation to reduce the likelihood of failures.
- Also known as "Condition-Based Maintenance"
- The goal of PdM is:
  - ✓ to predict <u>when</u> equipment failure could occur
  - ✓ followed by preventing the failure by:
    - ❑ Regularly scheduled maintenance and/or
    - ❑ Corrective maintenance
- PdM requires Condition Monitoring

Source: Predictive Maintenance Explained, ReliablePlant.com

What is Condition Monitoring?

- The continuous monitoring of machines during process conditions to ensure the optimal use of machines.
- The application of monitoring technologies, sensors, statistical process control or equipment performance for early detection and elimination of equipment defects that could lead to unplanned downtime or unnecessary expenditures.
- Condition Monitoring can be:
  - ✓ Periodic = regular testing (e.g. monthly)
  - ✓ Online = continuous "live" monitoring of machines or production processes

    This **data enables**:
    - ❑ Trending (to see patterns and abnormalities/spikes) and recording
    - ❑ Remote monitoring
    - ❑ Alarm paging to mobile phones for immediate response to prevent downtime
    - ❑ Analysis (including by Artificial Intelligence) to find patterns, solutions, root causes…
    - ❑ Early detection to prevent downtime and minimize repair costs

Source: Predictive Maintenance Explained, ReliablePlant.com

What is the **Difference** between

Predictive Maintenance and Preventive Maintenance?

- ✓ inspecting and performing maintenance regardless of whether the equipment needs it
- ✓ maintenance schedule based on usage or time (e.g. kilometers or run hours)
- ✓ determined by using the average life cycle of an asset
- ✓ does not need condition monitoring
- ✓ does not involve as much capital investment in technology and training (short term $ savings)
- ✓ manual data-gathering and analysis

- ✓ performed based on preset and predetermined conditions of specific pieces of equipment, utilizing different technologies.
- ✓ requires investments in people, training and equipment to assess and implement a PdM schedule
- ✓ Increases reliability and reduces downtime
- ✓ uses maintenance labour more efficiently (long term $ savings)

Source: Predictive Maintenance Explained, ReliablePlant.com

What is Reliability Centered Maintenance (RCM)?

Wikipedia: “Reliability-centered maintenance (RCM) is a concept of maintenance planning to ensure that **systems continue to do what their users require** in their present operating context. Successful implementation of RCM will lead to increase in cost effectiveness, reliability, machine uptime, and a greater understanding of the level of risk that the organization is managing.”

RCM offers five principal options among the risk management strategies:

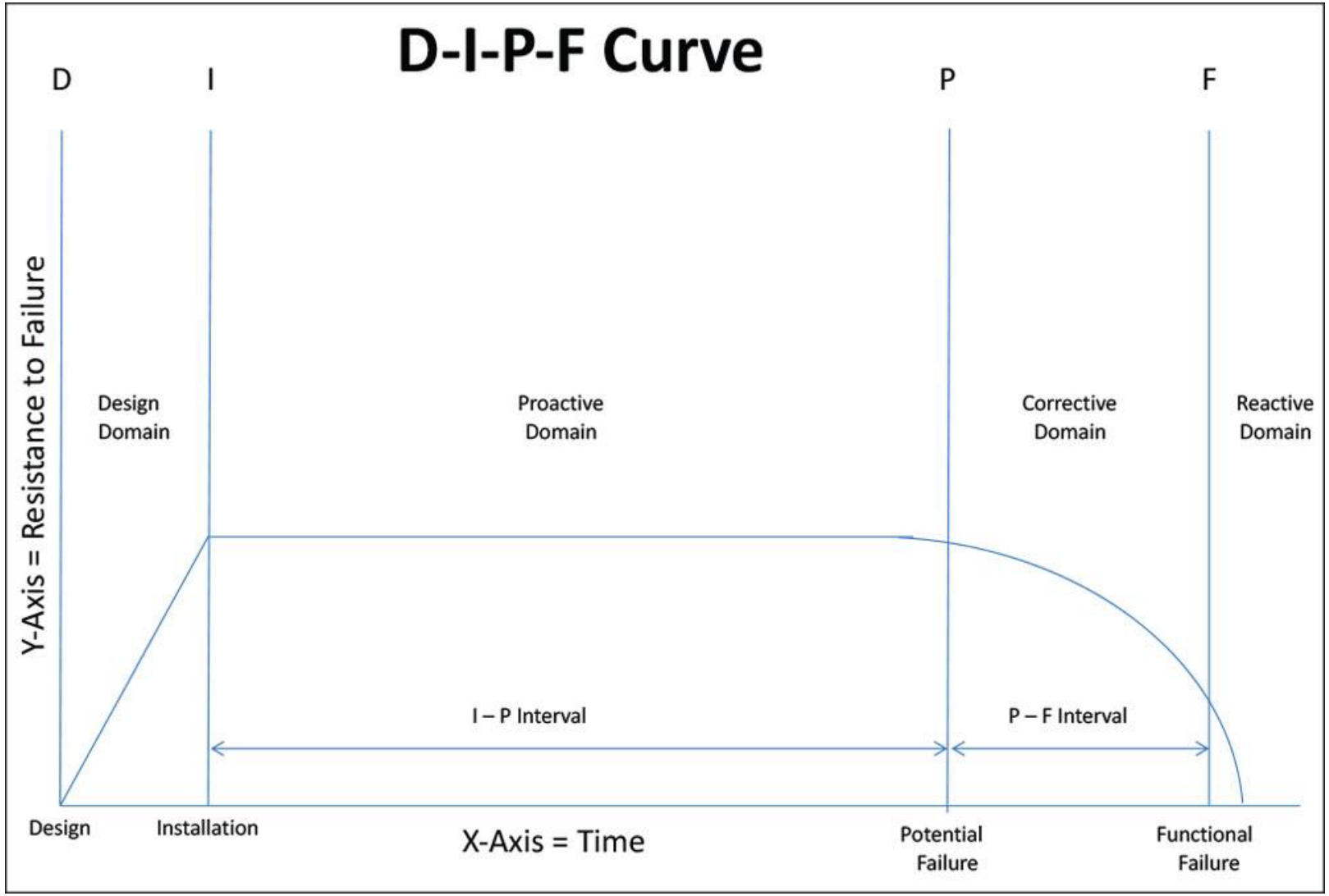
- **Predictive maintenance tasks,**
- Preventive Restoration or Preventive Replacement maintenance tasks,
- Detective maintenance tasks,
- Run-to-Failure, and
- One-time changes to the "system" (changes to hardware design, to operations, or to other things).

After being created by the commercial aviation industry, RCM was adopted by the U.S. military (in the 1970s) and by the U.S. commercial nuclear power industry (in the 1980s).

Design, Installation, Potential and Functional Failure (D-I-P-F) Curve: Asset Lifecycle Curve:

Different defect inspection techniques determine the presence of a defect at different places along the P-F curve.

A failure modes, effects and criticality analysis (FMECA) can help you determine which inspection techniques should be applied, how often and with what degree of redundancy.



Sources: Predictive Maintenance Explained, ReliablePlant.com RCM Blitz® training materials 2006.*(D. Plucknette, Reliability Solutions Inc.)*

Motors are often a **critical single point of failure** for a facility

Elevators / Escalators
Moving Walkways

Water Pumps
Sump Pumps

Dryer motors

Production Lines

Fans, Roof Top Units, HVAC

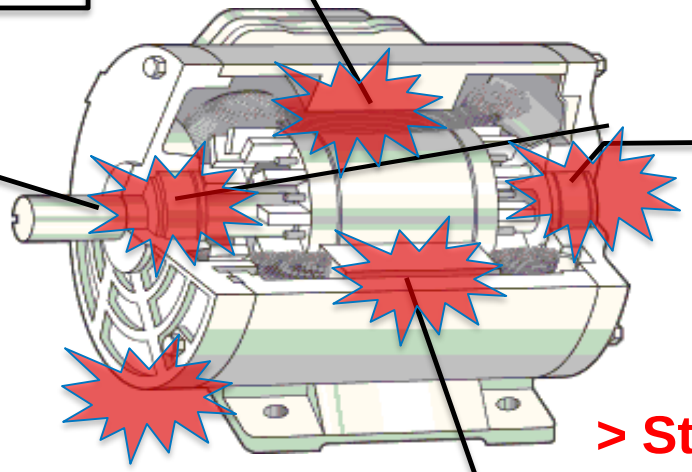
Electric Motor Failure Modes that we want to Detect

> Rotor break

Rotor
The rotor is the part of the motor that rotates

> Bearing failure
> Bearing scratch
> Inadequate lubrication

Rotary shaft
Power transmission to Load side



Bearing
Reduces wear on rotating parts
There are two motor bearings

> Motor burn out

> Electrical leakage

> Stator break
> Insulation aging

Stator
Generates the force to turn the rotor

Condition Monitoring & Predictive Maintenance Technologies

Rapidly evolving as more sensors become real time = “live data”

- ✓ **Vibration Analysis**
- ✓ **Current Analysis**
- ✓ **Insulation Resistance Monitoring**
- ✓ **Infrared Thermography**
- ✓ Acoustic Monitoring
- ✓ Ultrasonic Inspection
- ✓ Oil Analysis (particle counts, chemistry of additives, contaminants, etc).

Using live data, the industrial internet of things (IIoT) is able to create “advanced prediction models and analytical tools to predict failures and address them proactively. Additionally, over time, new machine-learning technology can increase the accuracy of the predictive algorithms, leading to even better performance”

Source: Predictive Maintenance Explained, ReliablePlant.com, Coleman et al., “Predictive Maintenance and the Smart Factory”

The traditional way…

Periodic manual checking of the condition of a 3 phase motor

Using Human Senses

Hear abnormal noise, feel vibration

Using Hand Held Tools

Vibration tester

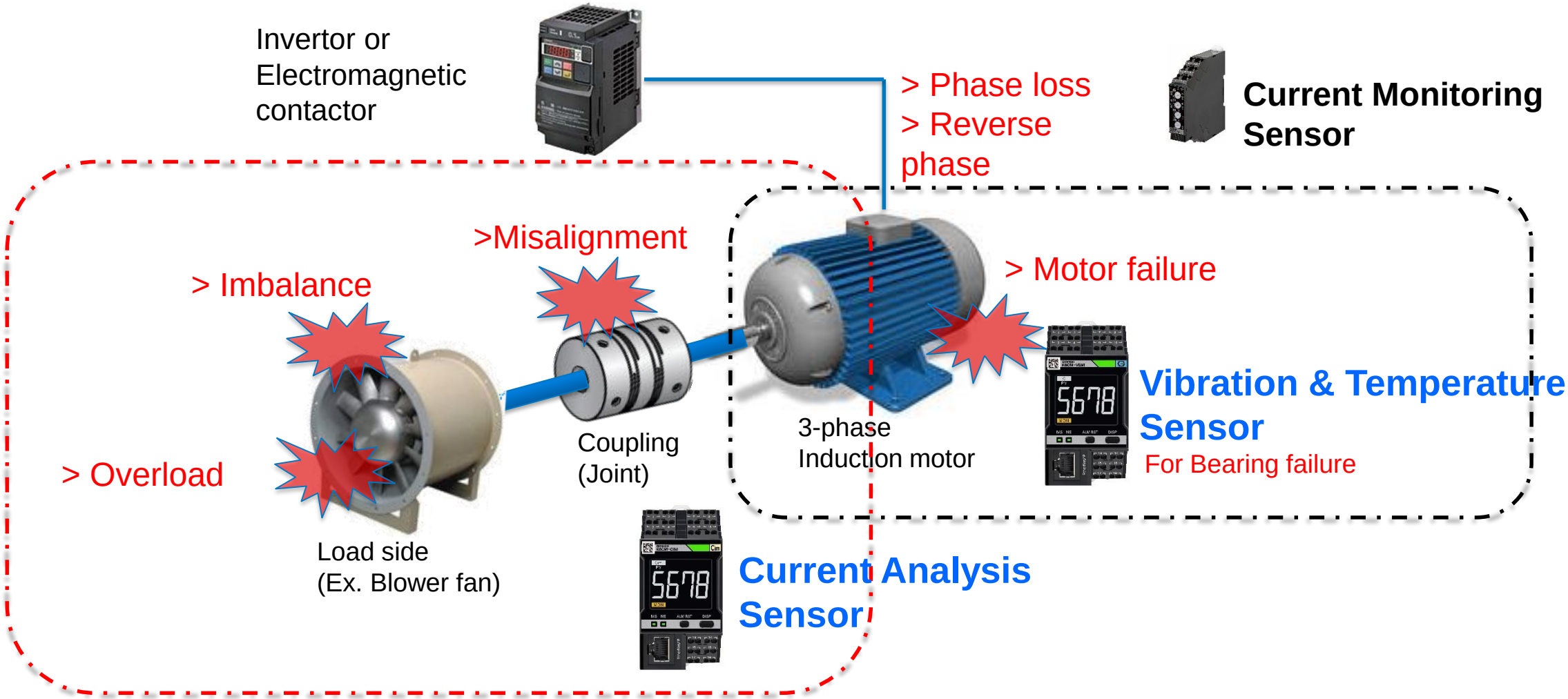
Thermo camera

Mega-ohm tester

Examples of Common Manual Motor/Pump Checks

Check point	How to check	Issues
Abnormal Noise	➢ Human Ear ➢ Acoustic tester	➢ Empirical knowledge ➢ Hands-on experience ➢ Arbitrary judgment, varies by machine type and motor speed etc.
Vibration	➢ Examination by touch ➢ Vibration tester	➢ Depends on machine type and motor speed etc. ➢ "Examination by touch" is arbitrary and relies on empirical knowledge and experience
Insulation Resistance	➢ Mega-ohm tester	➢ Cannot check while motor is running. (Mega-ohm tester should be set for motor after power on and disconnecting all motor wires)
Over Current	➢ Ammeter ➢ M&M Relay (Current relay)	➢ Motor current level might be changed by motor load, as it's difficult to define motor failure and workload change ➢ It might be too late, when detecting over current by motor failure
Temperature	➢ Touch ➢ Temperature probe ➢ Thermo camera	➢ When the motor temperature is too high, that motor might already be in a terminal condition

Motor Failure Modes



*** The Current Analysis Sensor can detect both Motor failure and abnormal Load side condition, but it cannot tell you which side (motor or load) might be the problem.**

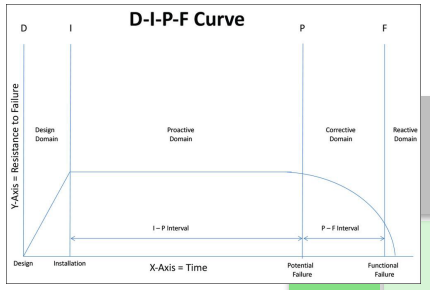
Motor Failure Modes and Measurement Parameters for Motor Condition Monitoring

Motor Failure Mode		Measurement Parameter				
Failure factor	Event probability	Abnormal Noise	Vibration	Insulation Resistance	Over Current	Temperature
Bearing Wear	32.5%	○	○			
Insulation aging	20.5%			○		
Overload	15.1%	○	○			
Phase-loss	12.1%					
Flood	7.1%					
Disconnection	6.9%					
Outside impact	5.7%					

These 2 measurement parameters often change when a motor is in a terminal condition

It's hard to detect motor degradation condition caused by "Phase-loss", "Flood", "Disconnection" and "Outside impact" However when a Motor is almost in a terminal condition caused by these failure factors, it might have abnormal noise and/or vibration, over current etc.

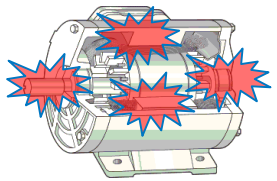
Predictive Maintenance Sensor Types by Motor Failure Modes



Worker can't sense ⟷ Worker can sense - noise, vibration

Failure Mode	Installation	Motor Running	Motor Degradation	Motor Failure
Inside Motor Failure				
Insulation Degradation			Insulation Degradation	Insulation Breakdown
			Insulation Resistance Sensor	
Bearing Failure	Rotary Shaft & Load side condition may damage Motor bearing	Dried Grease	Bearing Wear	Bearing Failure
			Vibration Acceleration Sensor	
			Vibration Velocity Sensor	
			Current Analysis Degradation	
Rotary Shaft Condition (Imbalance /Misalignment /Rotor&Stator break)	Motor System Setting	Running Start	Motor Aging	
	Current Analysis Degradation Sensor			
			Vibration Velocity Sensor	
Outside of Motor Failure				
Load Side Condition (Cavitation for Pump/Overload)		Running Start	Load Side Aging	
		Current Analysis Degradation Sensor		
			Electric Current Sensor	
			Vibration Velocity Sensor	

Electric Current Sensor
Temperature Sensor



Inside Motor

Load Side

Predictive Maintenance Sensor Types by Motor Failure Modes

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Inside Motor Failure	Insulation Degradation			Insulation Degradation	Insulation Breakdown
				Insulation Resistance Sensor	
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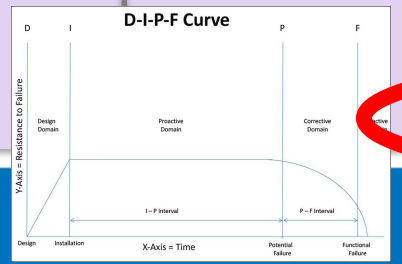
				Electric Current Sensor	
				Vibration Velocity Sensor	

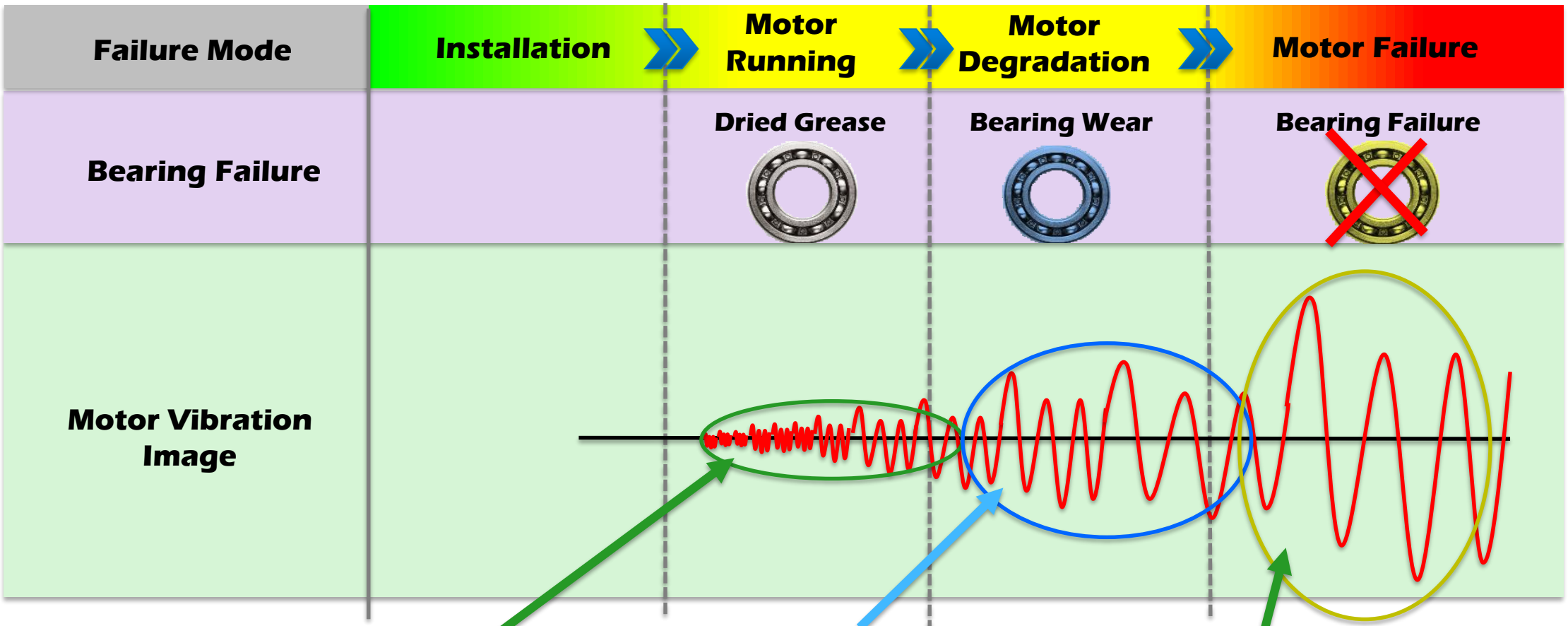
Electric Current Sensor
Temperature Sensor



PdM **Vibration Sensors** for Motor Bearings

Failure Mode	Installation	Motor Running	Motor Degradation	Motor Failure
Bearing Failure		Dried Grease 	Bearing Wear 	Bearing Failure 
Motor Vibration Image	Amplitude of Vibration			Vibration Wavelength
Vibration Wavelength		High Frequency (Over 20 or 30kHz)	Middle Frequency (around 1 to 20kHz)	Low Frequency (Below 1kHz)
Type of Vibration Sensor and Range			Acceleration Sensor 10kHz	Velocity Sensor

Why do we need 2 vibration sensors (**Acceleration & Velocity**) ?



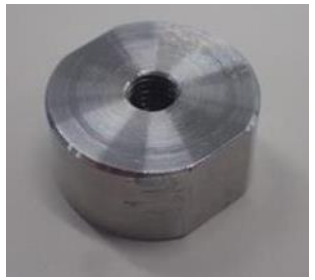
Wavelength and Amplitude of Vibration are too small to detect

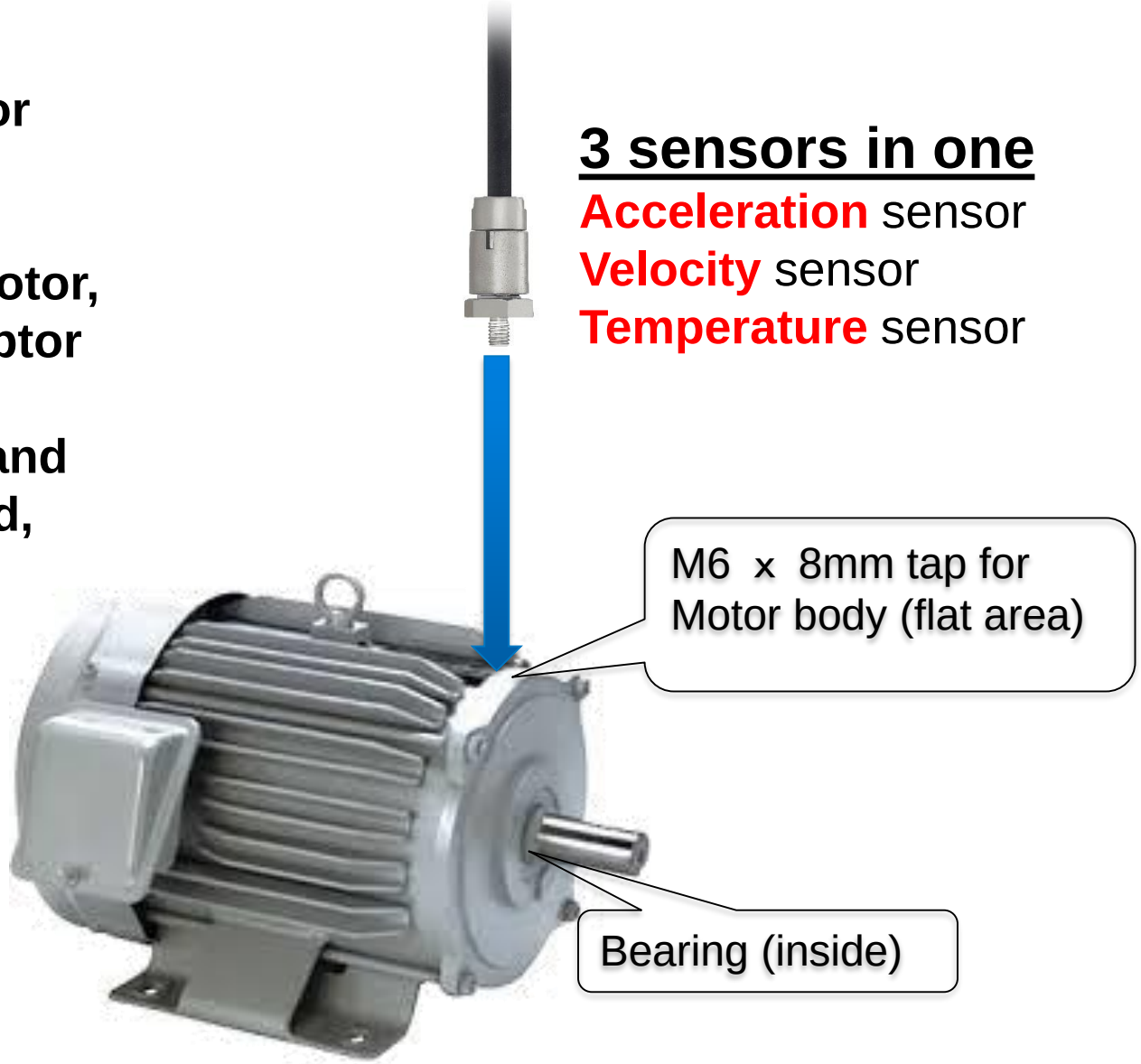
"Acceleration Sensor"
"Acceleration" is like a intensity of velocity change for vibration.
(from 1kHz to 10kHz range it is too fast for the velocity sensor to detect).

"Velocity Sensor" can detect vibration speed. (below 1kHz range the velocity change is too small for the acceleration sensor to detect the vibration).

Installation of an On-line Motor Vibration Sensor Head

- ✓ **Drill a hole (M6 x 8mm tap) for the sensor perpendicular to the rotary shaft**
- ✓ **If you don't want to drill a hole on the motor, the sensor head (with the magnetic adaptor attached) should be glued / siliconed in place. Detection of motor temperature and high frequency vibration will be impeded, impairing early stage bearing failure.**





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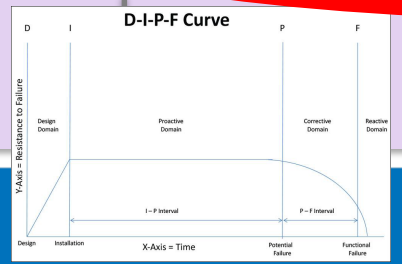
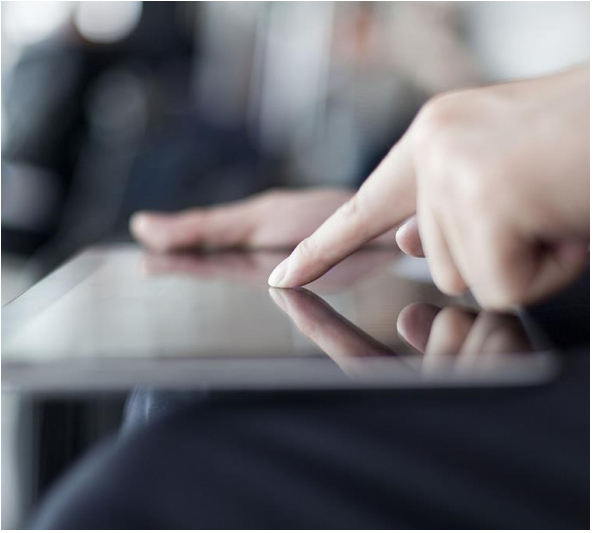
				Vibration Velocity Sensor	
Outside of Motor Failure	Load Side Condition (Cavitation for Pump/Overload)		Running Start	Load Side Aging	
			Current Analysis Degradation Sensor		
				Electric Current Sensor	
				Vibration Velocity Sensor	

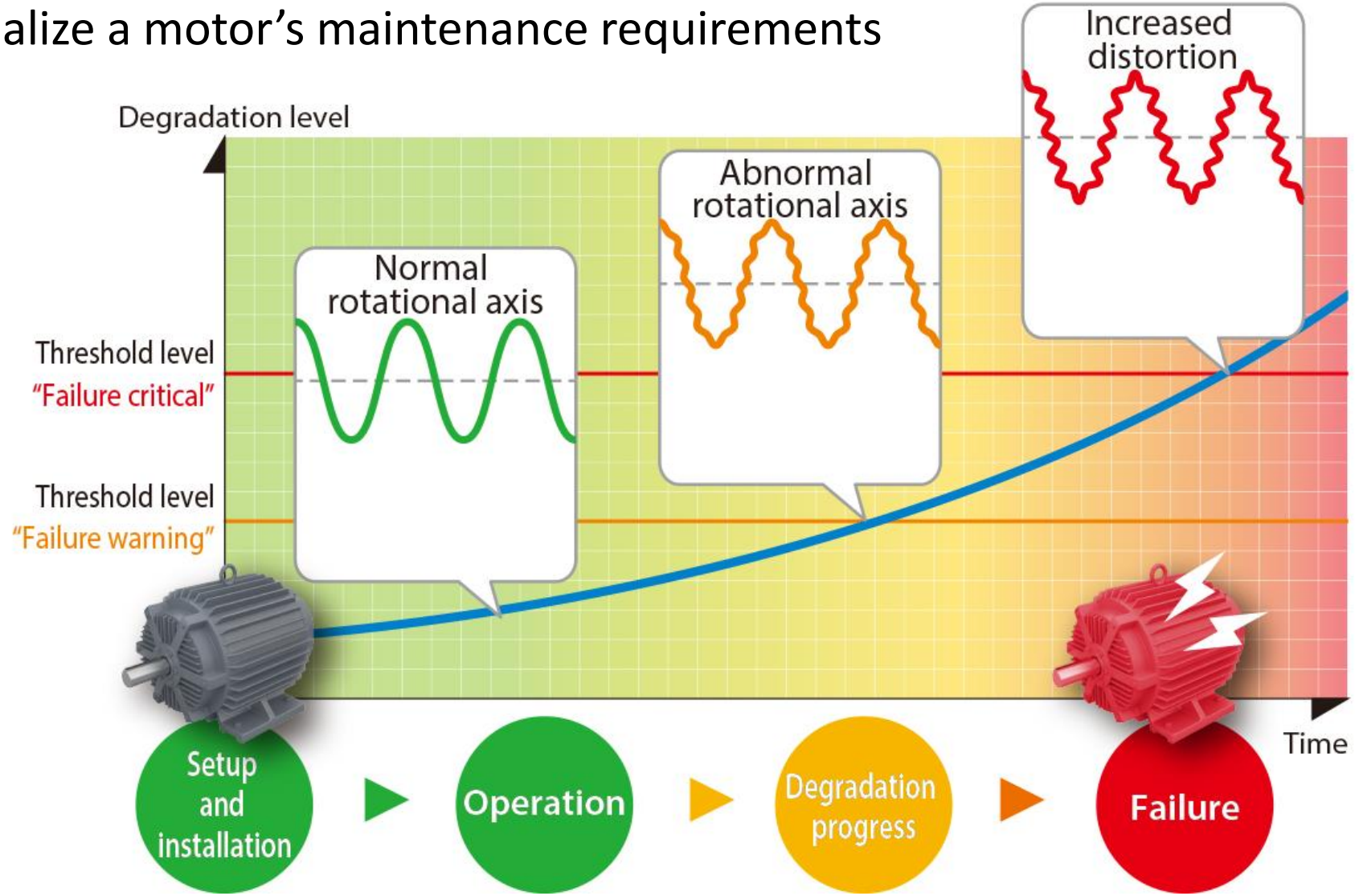
Electric Current Sensor
Temperature Sensor



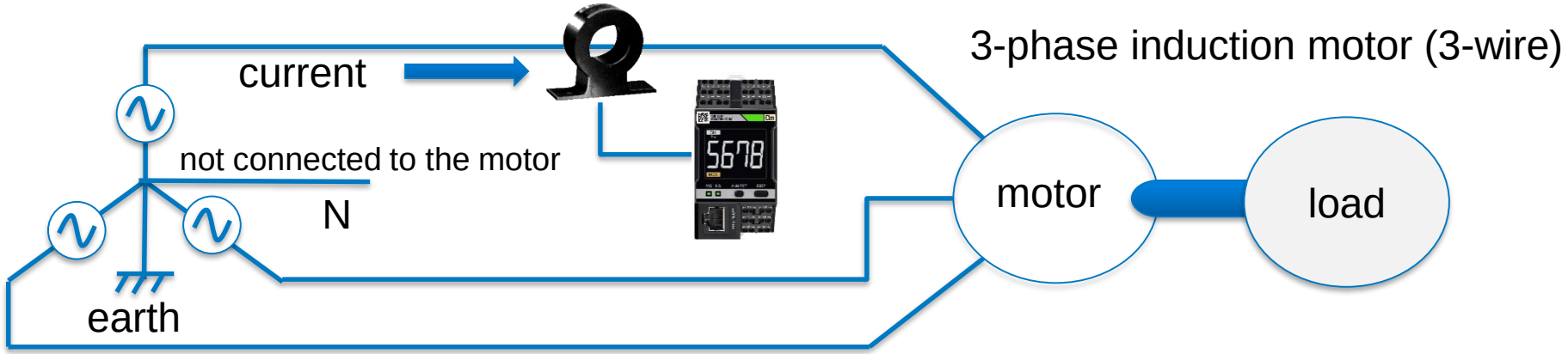


3 Phase Induction Motor Monitoring Sensors

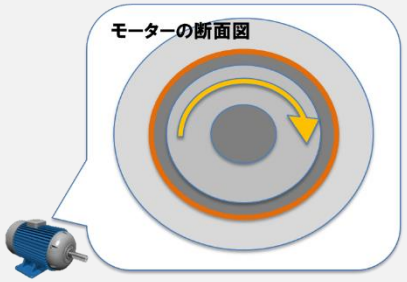
Visualize a motor’s maintenance requirements



Basic Principle of **Current Analysis** Sensors

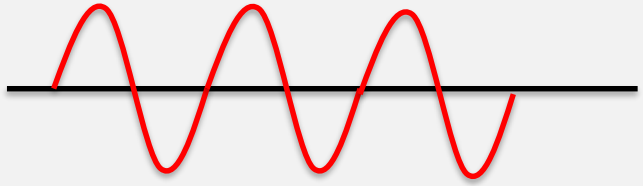


(1) Healthy Motor current waveform

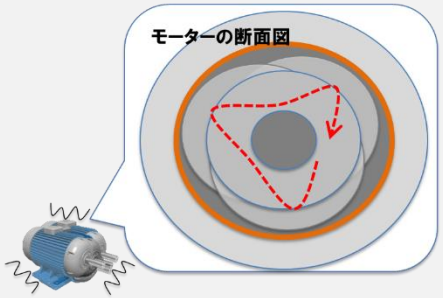


Smooth rotation

"PURE" sine current waveform

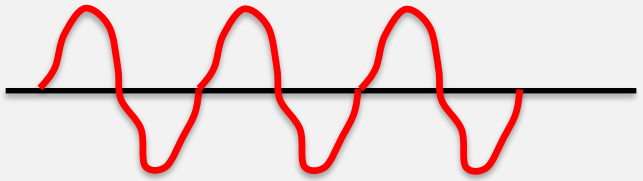


(2) Unhealthy Motor current waveform

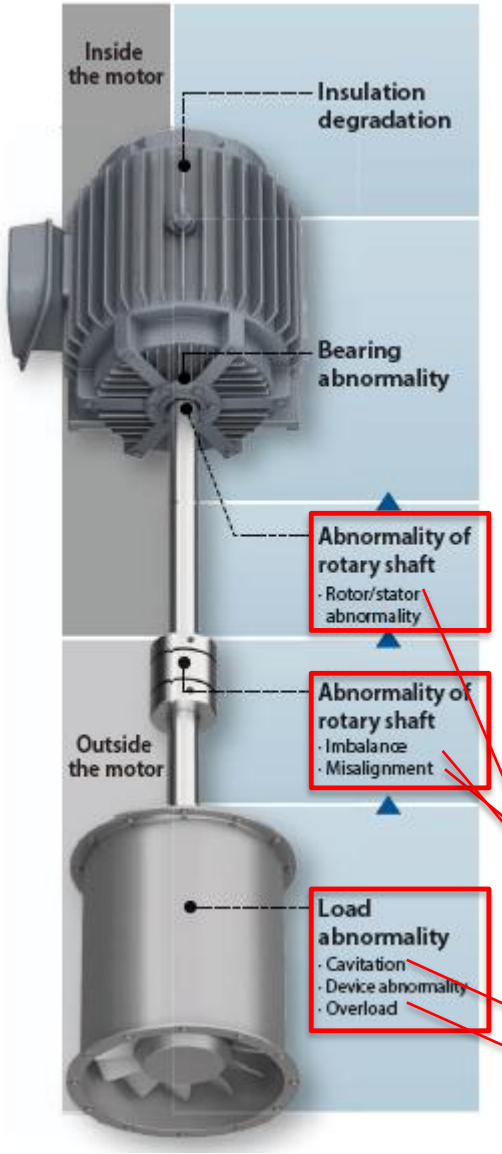


Abnormal vibration

"DISTORTION" with sine current waveform



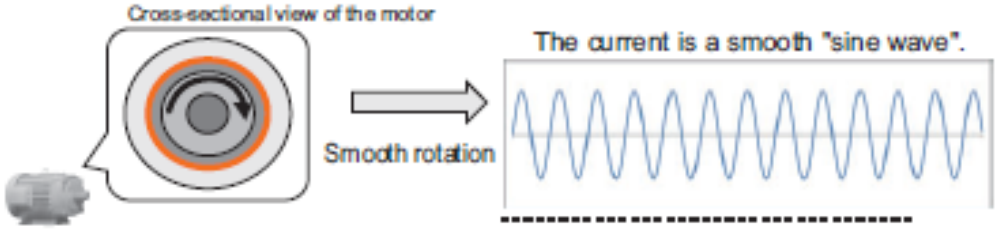
Predictive Maintenance with **Current Analysis** Sensors



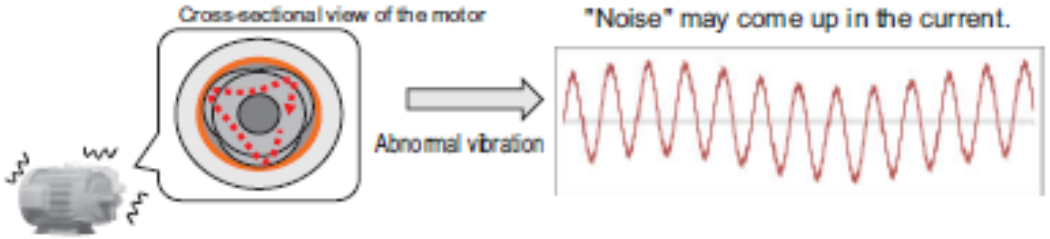
Can detect abnormal motor loads

If the motor and load are abnormal, noise appears in the current waveform as shown below. A value that expresses this state numerically is the degree of degradation that can be monitored with the Comprehensive current diagnosis type.

(1) Motor and load are normal.

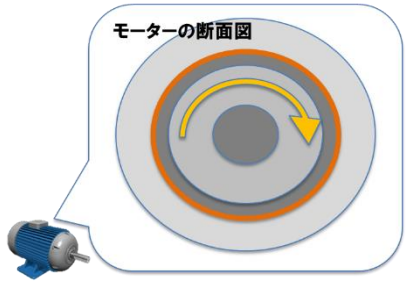


(2) An abnormality is occurring.

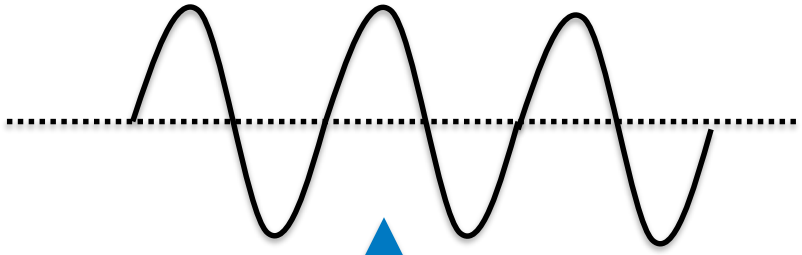


Abnormality affecting degradation level	Major factors
Misalignment	Coupling abnormal, centering shortage, etc.
Load imbalance	Unbalance of rotating objects such as fans
Motor insulation error	Insulation deterioration inside the motor
Rotor abnormality	Breakage inside the motor
Cavitation	Vacuum bubbles in water stream
Overload	Excessive rotational load

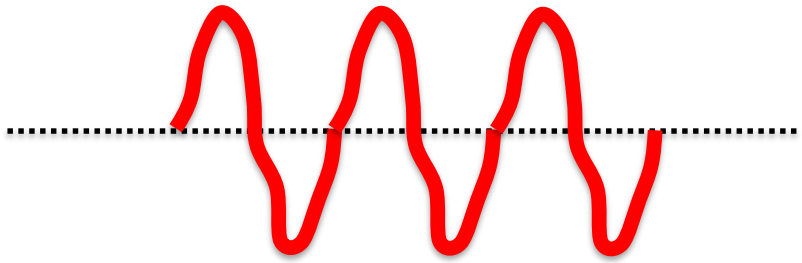
Degradation Level = measurement of change in the current waveform

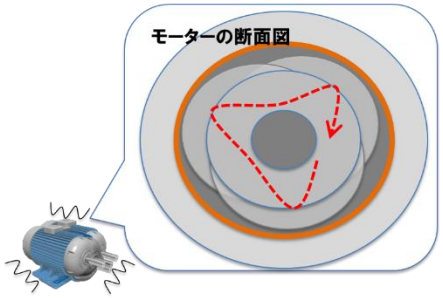


“PURE” sine current waveform (Healthy Motor)



Current Analysis can measure (digitally quantify) the current waveform gap between “PURE” and “DISTORTION”
=“Degradation Level”



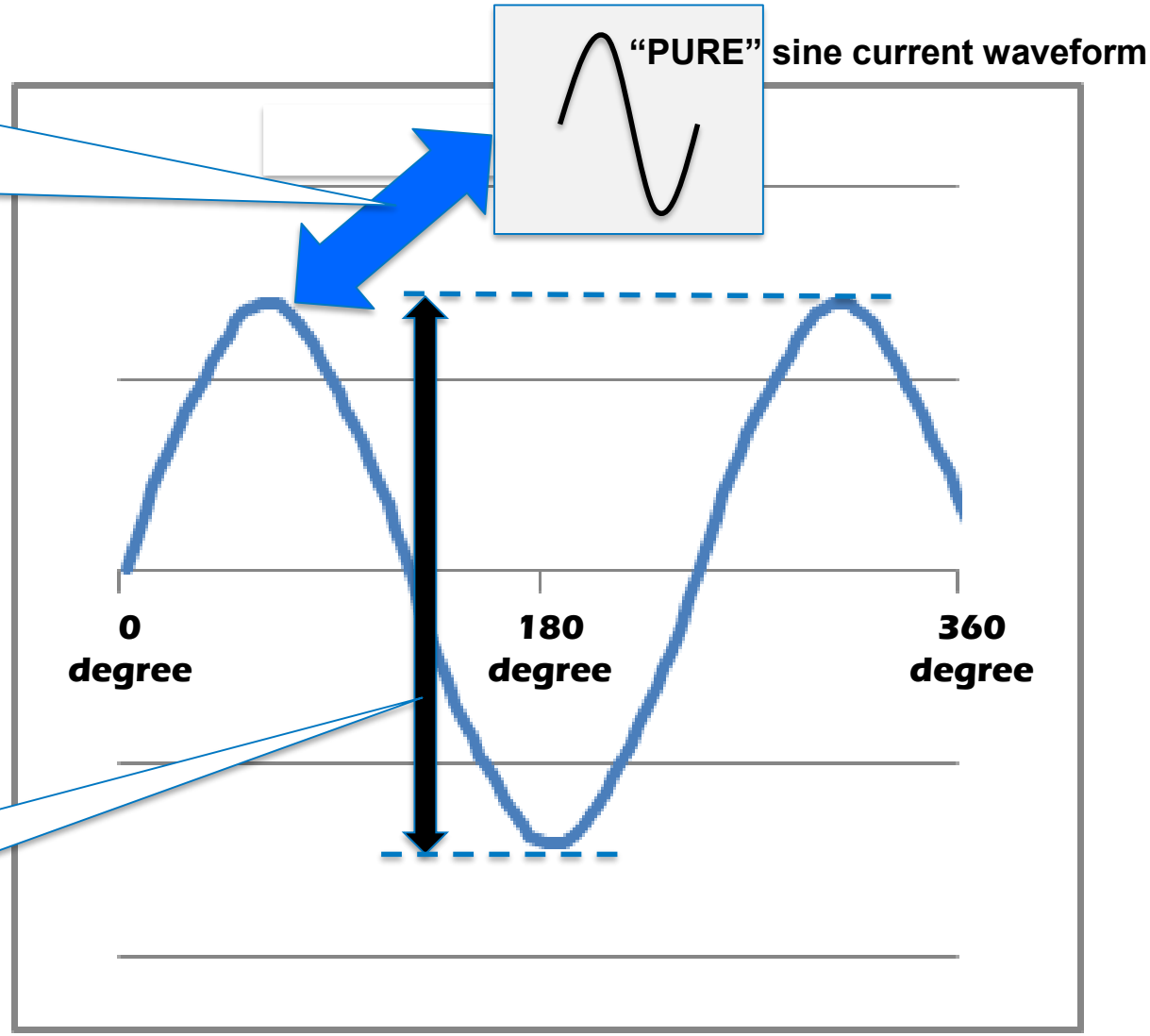


“DISTORTION” with sine current waveform (Unhealthy Motor)

“Degradation Level” is from waveform shape
“Ampere” is amplitude

“Degradation Level”

Calculated by an algorithm comparing “PURE sine current waveform” and “K6CM measuring sine current waveform”

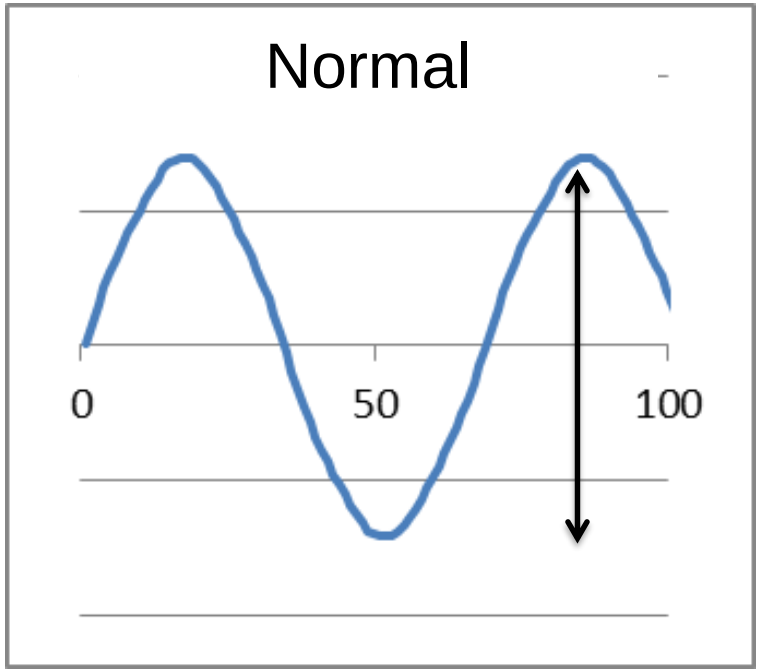


“Current Ampere”

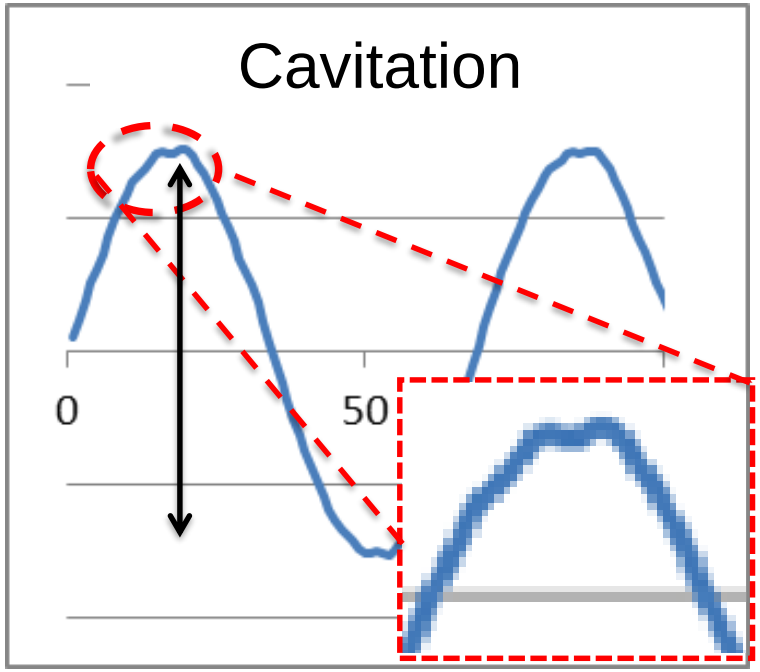
Measure current wave amplitude

Example : Water Pump failure by “Cavitation”

“Degradation Level” increased from “13” to “41” due to “Cavitation” (like a load side failure), however current wave amplitude is not changed. (almost same “Current Ampere”)



Degradation Level “13”



Degradation Level “41”

Set- up: Choose Current Transformer (CT) and install

2 types of input voltage
100-240VAC
24VAC/DC

Invertor

or

Conductor

CT

You can clamp CT for
any 1 wire of motor cable

* Clamp type CT
Permissible attachment/removal
frequency : up to 100 times

How to calculate “Motor Ampere” to choose CT size

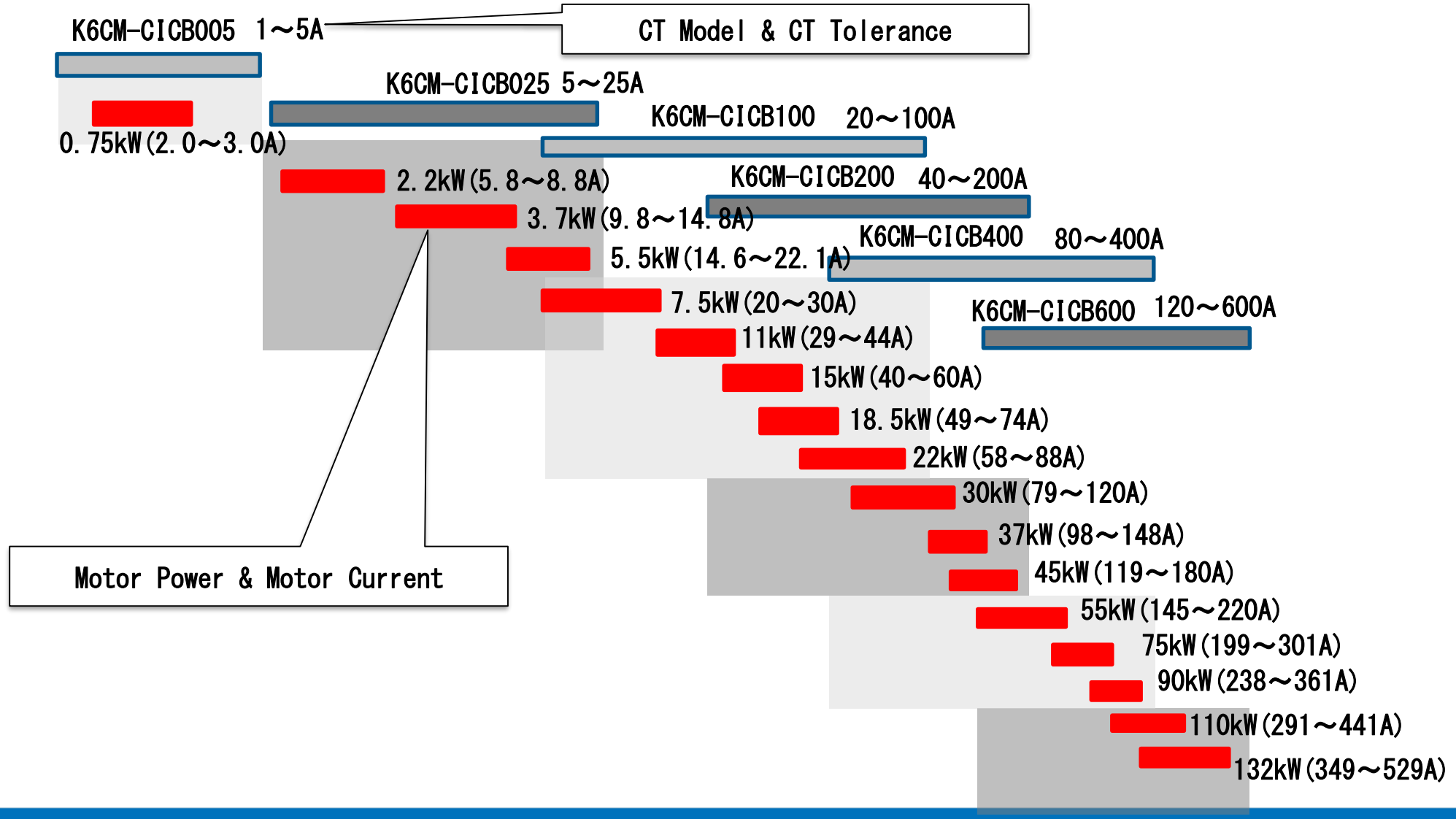
$$\text{Motor Ampere (A)} = \frac{\text{Motor Power (kW)} \times 1{,}000}{\sqrt{3} \times \text{Motor Voltage (V)} \times \text{Power Factor (0.9)} \times \text{Efficiency (0.8)}}$$

CT Model	CT Tolerance	Recommendation Motor (AC200V)	Recommendation Motor (AC400V)
K6CM-CICB005 5A	from 1.00A to 5.25A	0.75kW	from 1.5kW to 2.2kW
K6CM-CICB025 25A	from 5.00A to 26.25A	from 1.5kW to 5.5kW	from 3.7kW to 11kW
K6CM-CICB100 100A	from 20A to 105A	from 7.5kW to 22kW	from 15kW to 45kW
K6CM-CICB200 200A	from 40A to 210A	from 30kW to 45kW	from 55kW to 90kW
K6CM-CICB400 400A	from 80A to 420A	from 55kW to 90kW	from 110kW to 200kW
K6CM-CICB600 600A	from 120A to 630A	from 110kW to 150kW	from 250kW to 300kW

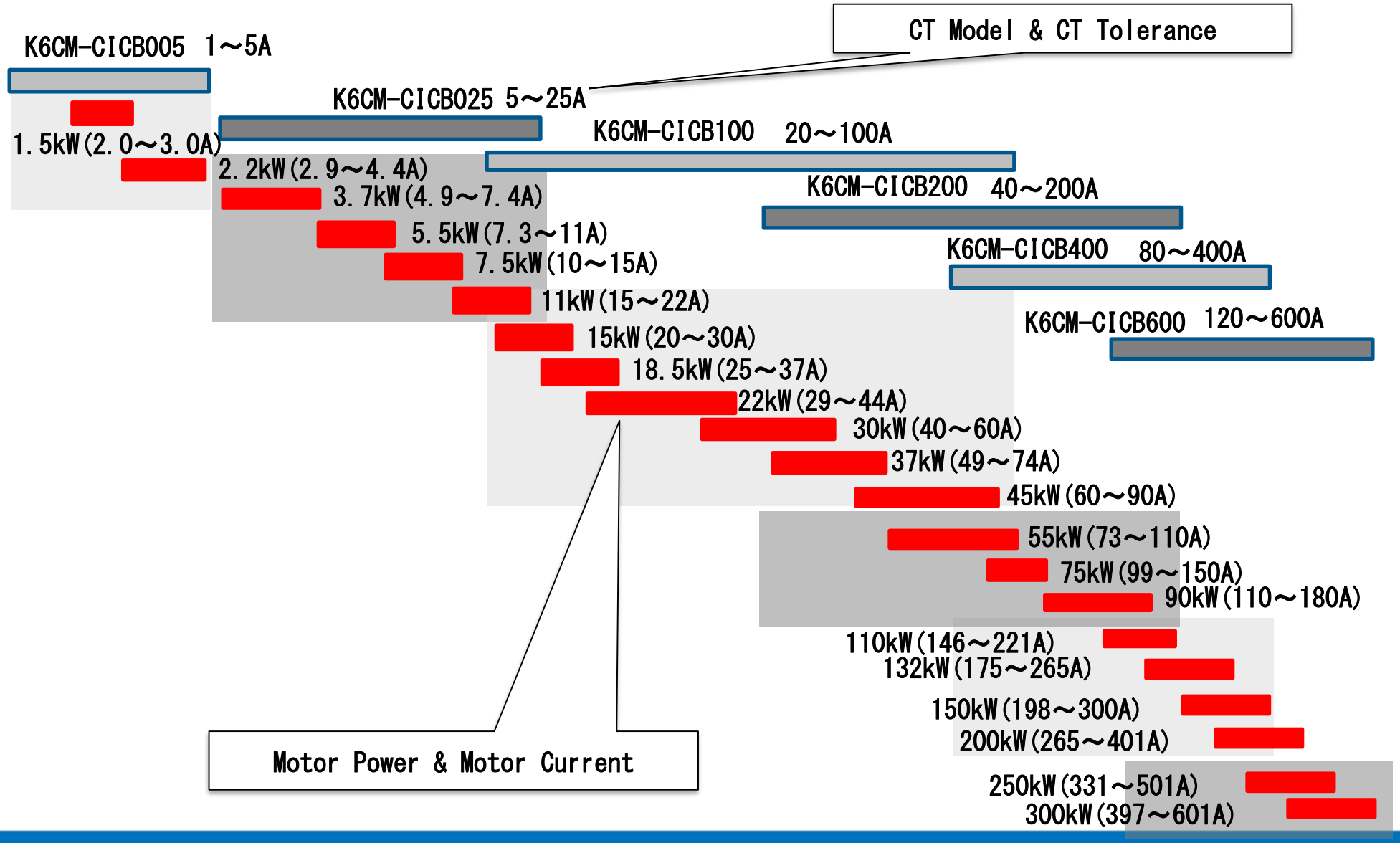
Clamp type CT for K6CM Current Analysis

Motor current might be almost half of calculated ampere without motor load.
Hence “CT” should be detected from 50% through 100% of calculated motor ampere.

Reference: CT selection table for AC200V motor



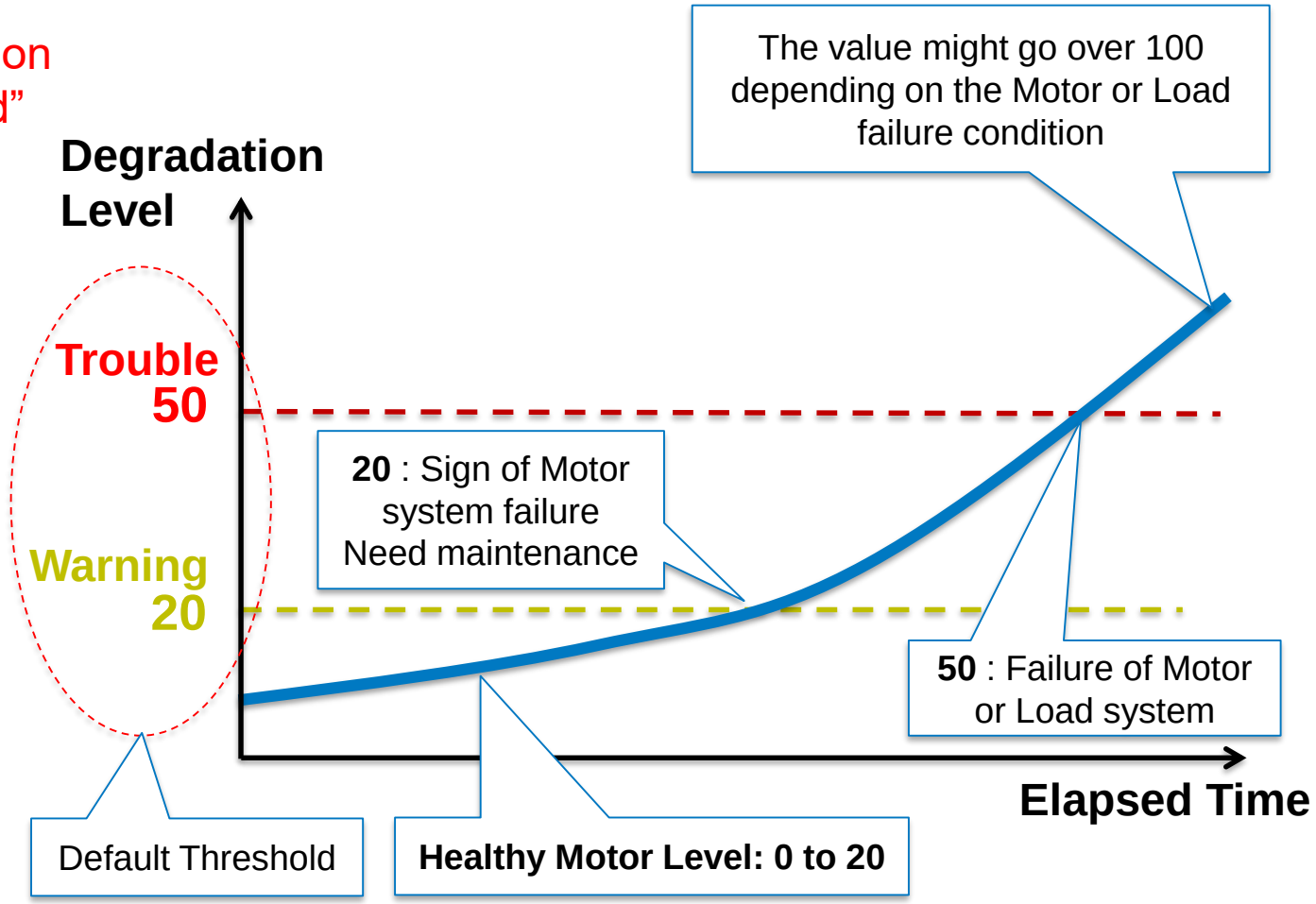
Reference: CT selection table for AC400V motor



Current Analysis "Degradation Level" without Invertor

Problems are detected by the "Degradation Level" when the "Motor" and/or the "Load" have these failure factors:

"Degradation Level" influence factor	Failure factor examples
Bearing failure	Abnormal Bearing
Rotor break	Motor inside broken
Misalignment	Motor coupling failure (misalignment/ maladjustment)
Load Imbalance	Load Imbalance like a Fan motor
Motor Insulation failure	Motor Insulation aging
Cavitation	Water flow vacuum bubble (for water pump)
Overload	Excess rotational load

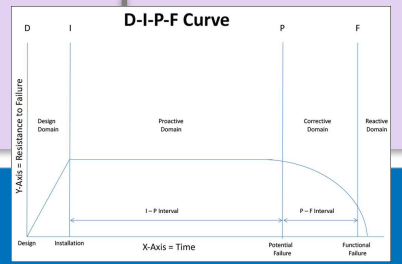


* "Degradation Level" might still be a high number for a healthy motor, depending on the motor. Trend and baseline, and adjust the "Threshold" for each motor system with Invertor.

Predictive Maintenance Sensor Types by Motor Failure Modes

	Failure Mode	Installation	Motor Running	Motor Degradation	Motor Failure
Inside Motor Failure	Insulation Degradation			Insulation Degradation	Insulation Breakdown
				Insulation Resistance Sensor	
	Bearing Failure	Rotary Shaft & Load side condition may damage Motor bearing	Dried Grease	Bearing Wear	Bearing Failure
				Vibration Acceleration Sensor	
				Vibration Velocity Sensor	
				Current Analysis Degradation	
	Rotary Shaft Condition (Imbalance /Misalignment /Rotor&Stator break)	Motor System Setting	Running Start	Motor Aging	
		Current Analysis Degradation Sensor			
				Vibration Velocity Sensor	
Outside of Motor Failure	Load Side Condition (Cavitation for Pump/Overload)		Running Start	Load Side Aging	
			Current Analysis Degradation Sensor		
				Electric Current Sensor	
				Vibration Velocity Sensor	

Electric Current Sensor
Temperature Sensor



Insulation Resistance Sensors (actually measuring current leakage)

2 types of input voltage
100-240VAC
24VAC/DC

ZCT

Invertor

or

Conductor

You can clamp ZCT for all 3 wires of motor cable

Up to 7.5kW motor

The **insulation resistance** is the **resistance** in ohms of wires, cables and electrical equipment. It is important to guard against electric shocks and avoid equipment damage from accidental discharges.

3 phase connections for installation of Insulation Resistance Sensors

Insulation resistance sensors can be installed in Delta or Star connection configurations:

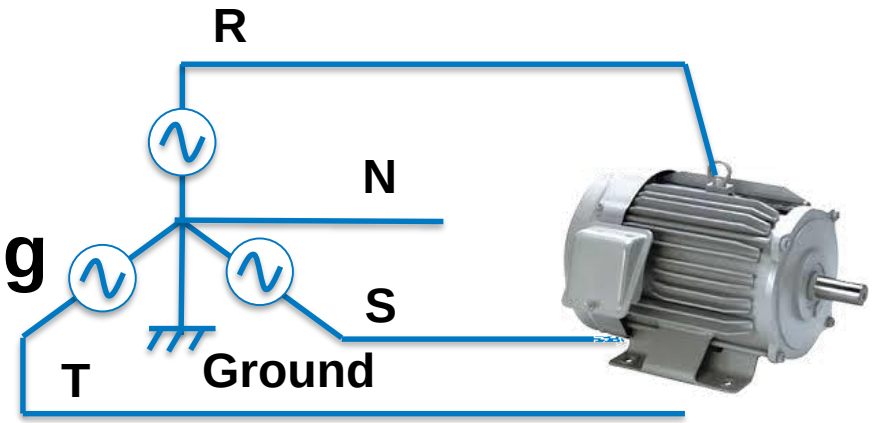
3 phase 3 wires S-grounding

(with/without Invertor)

Delta connection

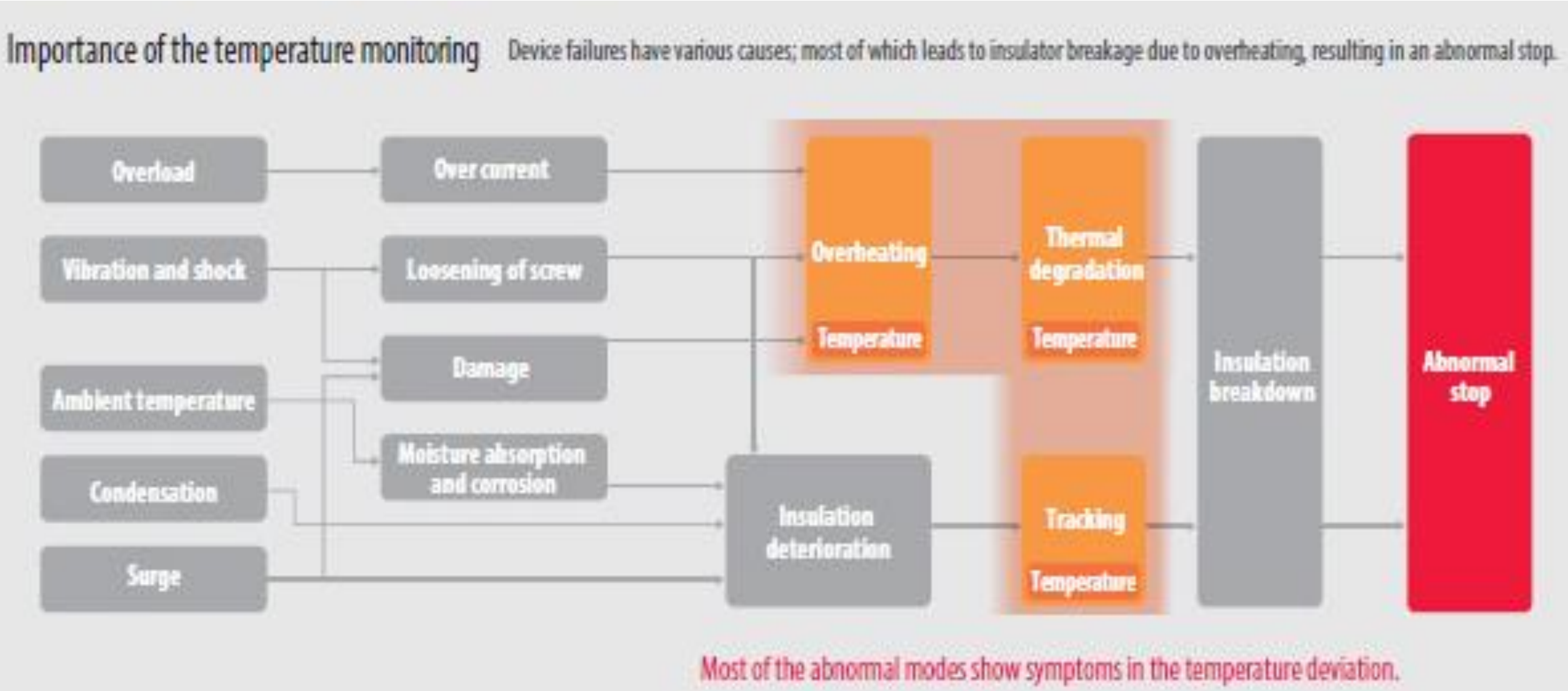
3 phase 4 wires N-grounding

(without Invertor)



Star connection

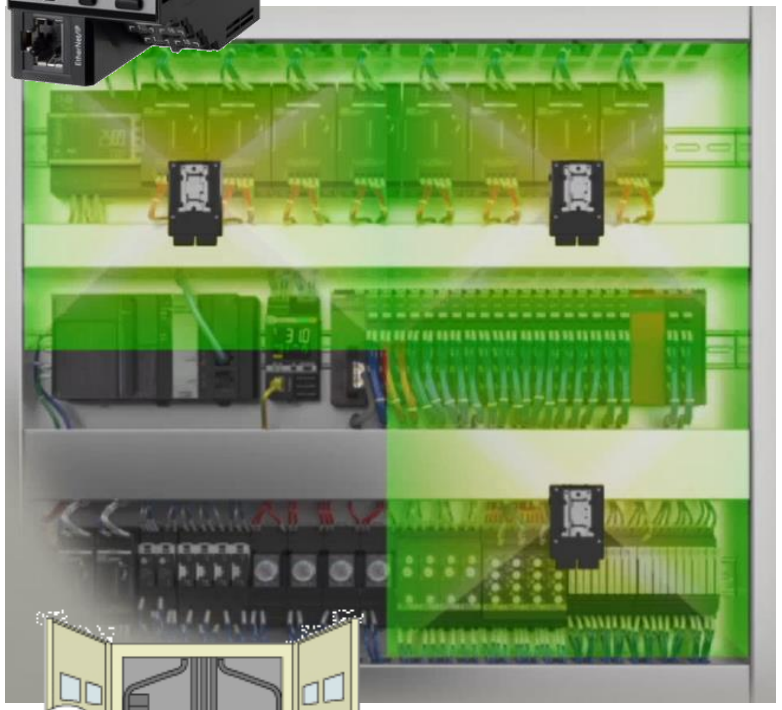
Infrared Thermography - Thermal Monitoring Sensors for PdM



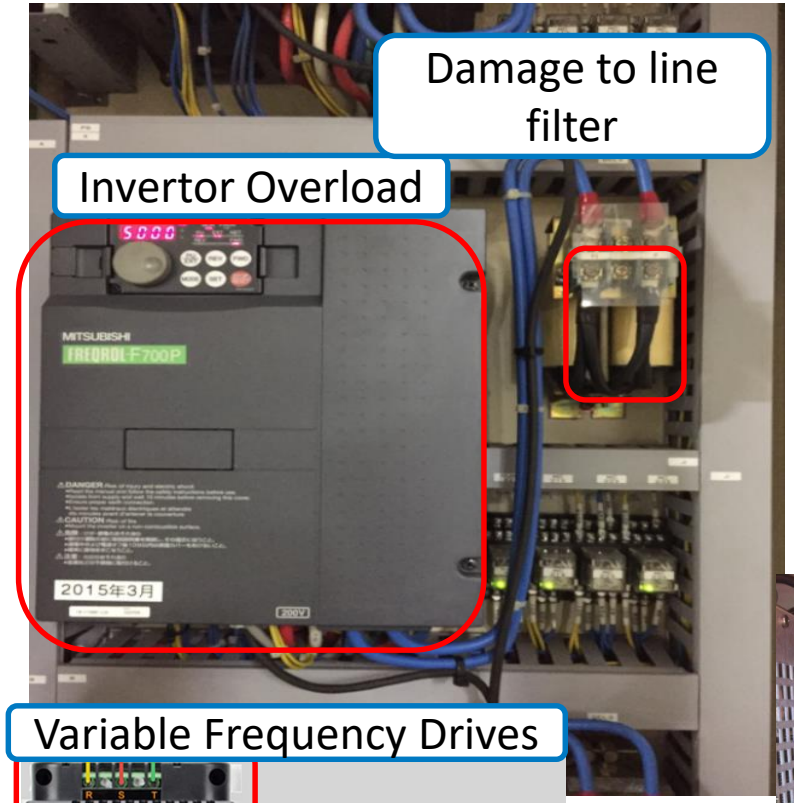
Thermal Monitoring Sensors

Remotely monitor and analyze thermal condition of equipment

- ✓ Prevent panel fires from overheating components
- ✓ Offer a product with thermal imaging technology
- ✓ Reduce manual inspections
- ✓ 24/7 thermal condition monitoring of critical components
- ✓ Measure specific point temperatures in panel vs. ambient temperature
- ✓ Reduced manual inspections
- ✓ Enable Predictive Maintenance
- ✓ Live DATA for trending/alarming/AI
- ✓ Reduce downtime

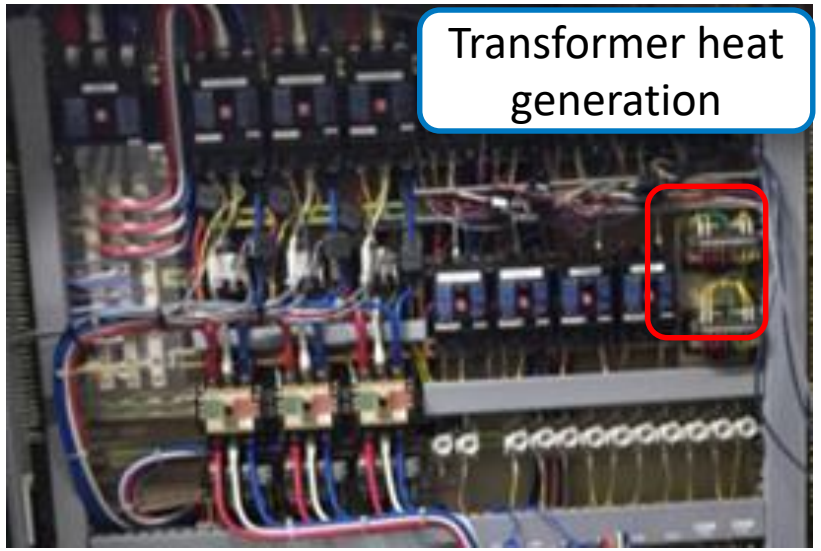


Critical heat generation areas in panels to monitor

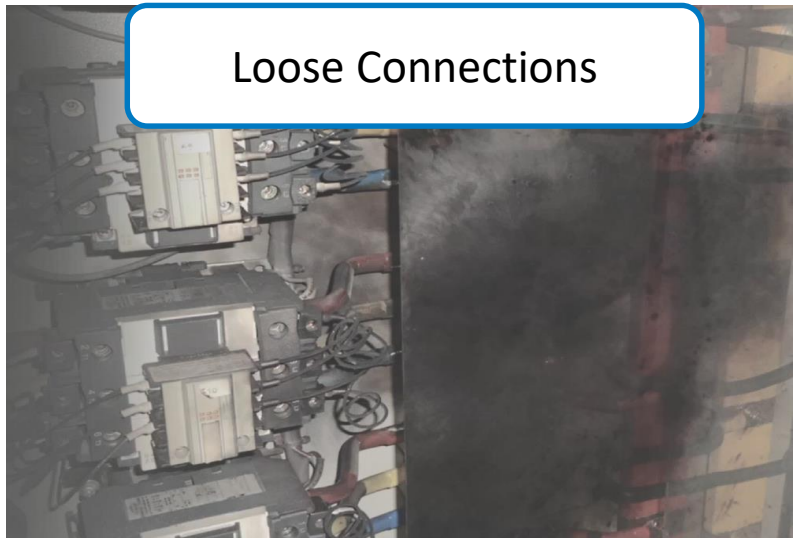


Damage to line filter

Invertor Overload

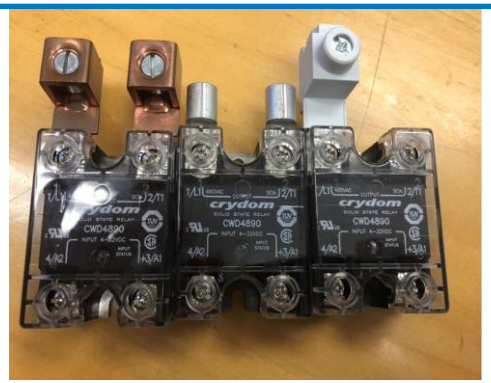


Transformer heat generation



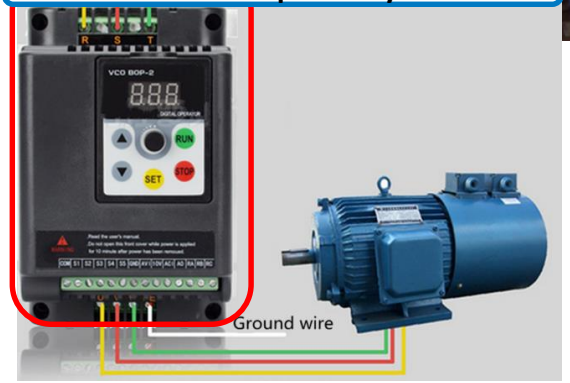
Loose Connections

High voltage contactors



Solid State Relays

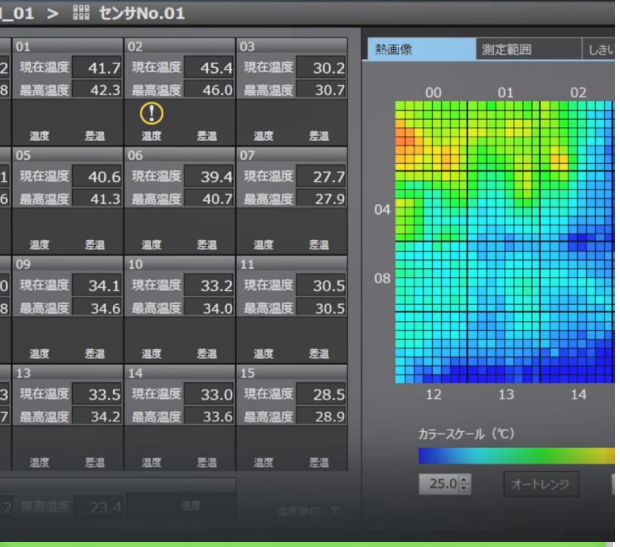
Insulation breakdown

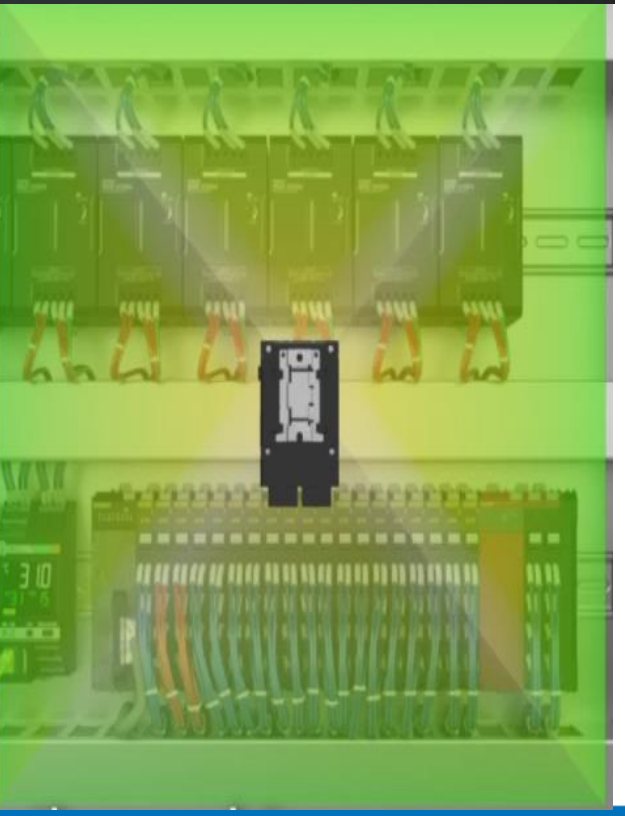


Variable Frequency Drives

Common methods of measuring panel temperature

	Method	Pro	Con	Comments
Periodic manual inspections using temperature gun or thermal imager	  	Simple to perform. Cost effective	No continuous monitoring, method only monitors temperature at time of inspection. Limited maintenance staff available for inspection. Few data points No live trending, alarming	Hiring a contractor to inspect panel = $2500+ annually  Temperature gun ~$500  Thermal imager ~$2000  Thermal imaging camera ~$3000  Thermal imaging camera ~$20,000
Smoke detector		Cost effective, simple to install	Unable to predict thermal events. Damage has already been done once smoke has been detected	$50-$100 + labor
Thermo-couple		Cost effective, can use to monitor panel temperature continuously	Can only measure ambient vs. specific component temperature. Requires additional programming and setup time.	$110-$400 + labor





Live On-Line Thermal Monitoring Sensors for PdM

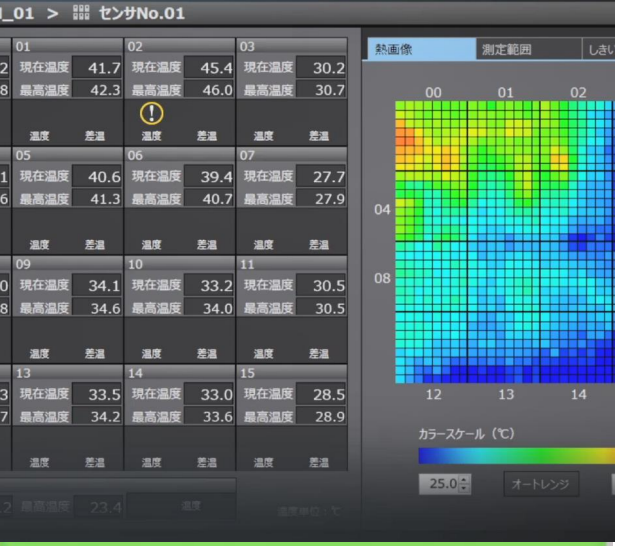
- ✓ Infrared (IR) Thermal imaging camera
- ✓ Detects temperatures from 32°-392°F (0-200°C)°
- ✓ Built-in abnormal detection algorithms
  - ✓ Predict overheating based on rate of rise in temperature
- ✓ 90 degree viewing angle
- ✓ Digital display with 3 alarm level
- ✓ Magnetic back for easy panel mounting
- ✓ RS-485 connection
- ✓ Ethernet IP/Modbus Connectivity
- ✓ Push-in Plus Terminals for wiring
- ✓ 31 cameras/sensors per controller
- ✓ Free PC monitoring software included

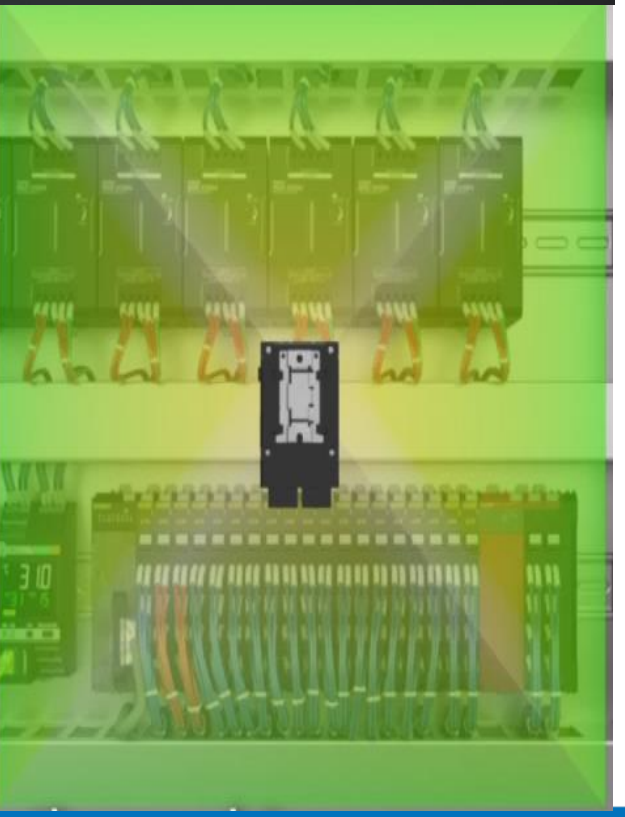
K6PM-THS3232
IR Sensor

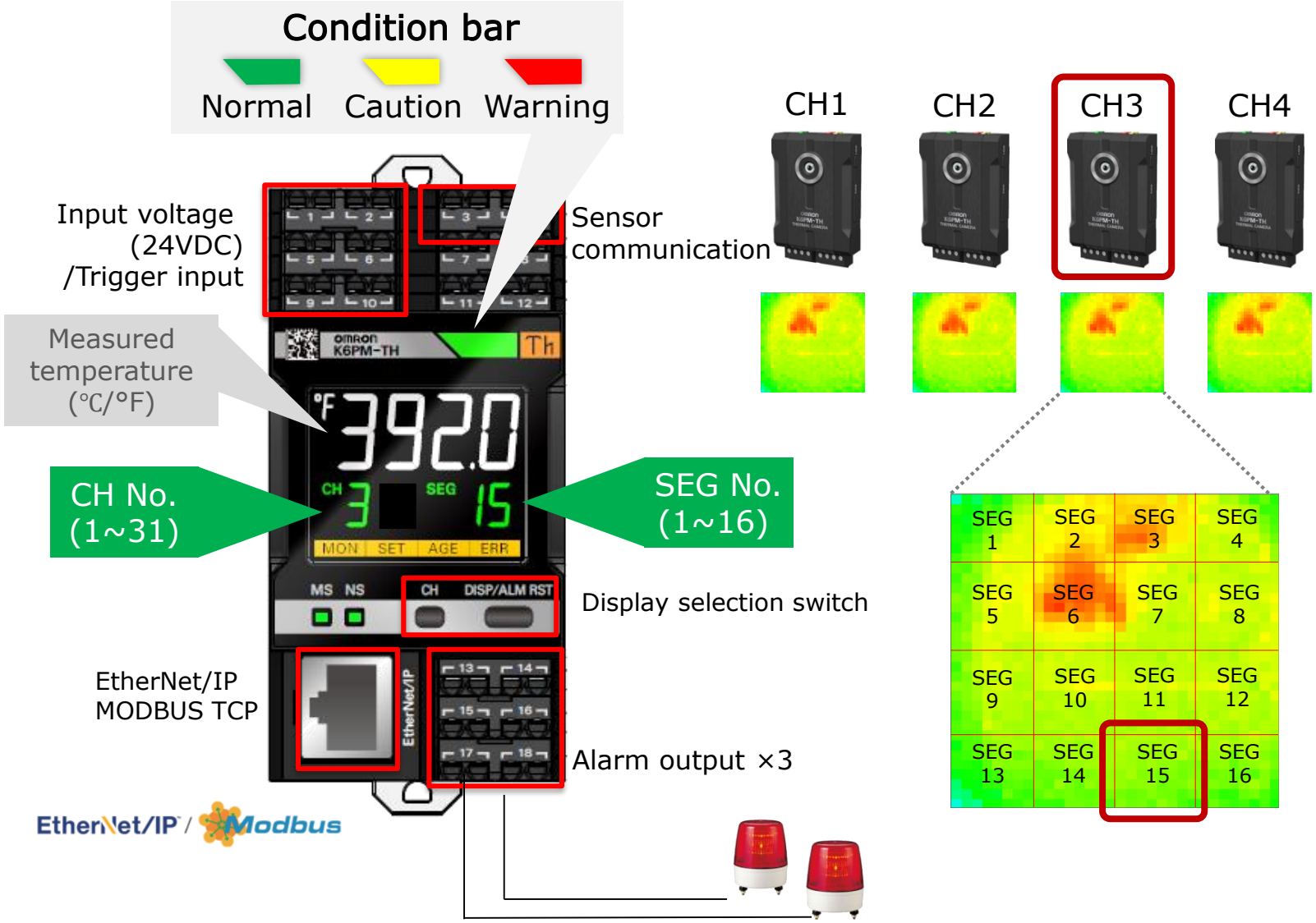
EtherNet/IP / Modbus

K6PM-THMD-EIP
Controller

Infrared (IR) Thermal Monitoring Sensor + Display

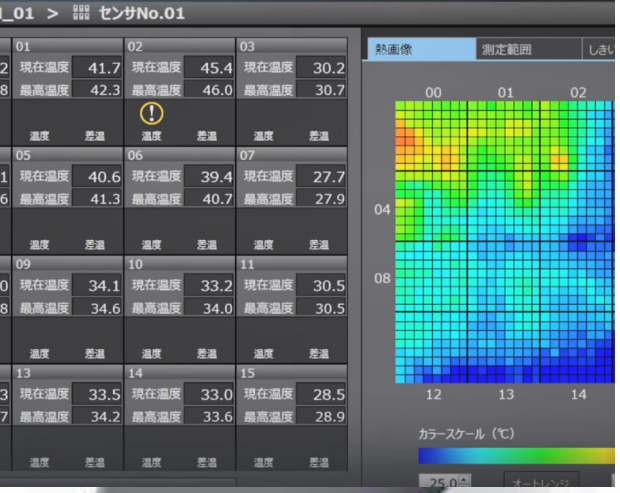


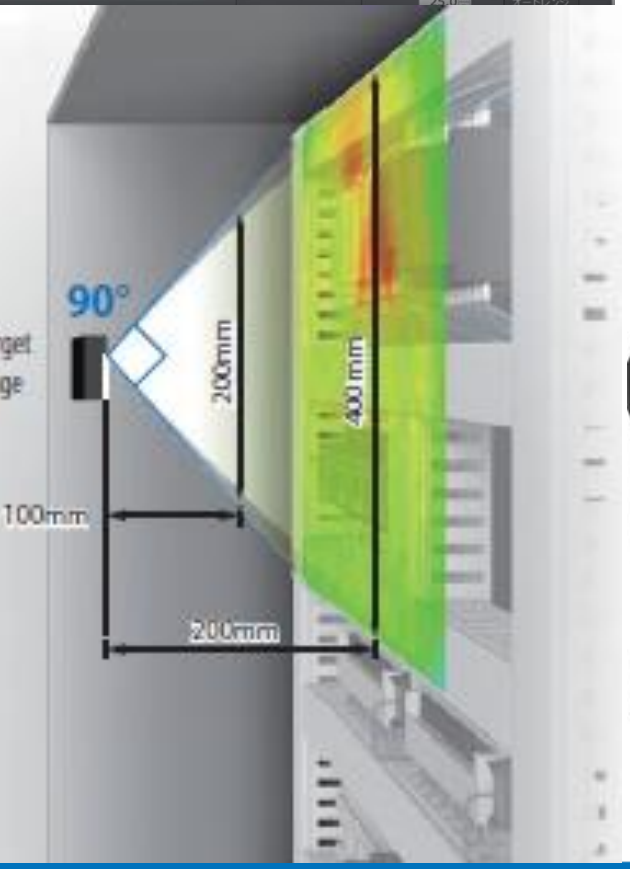


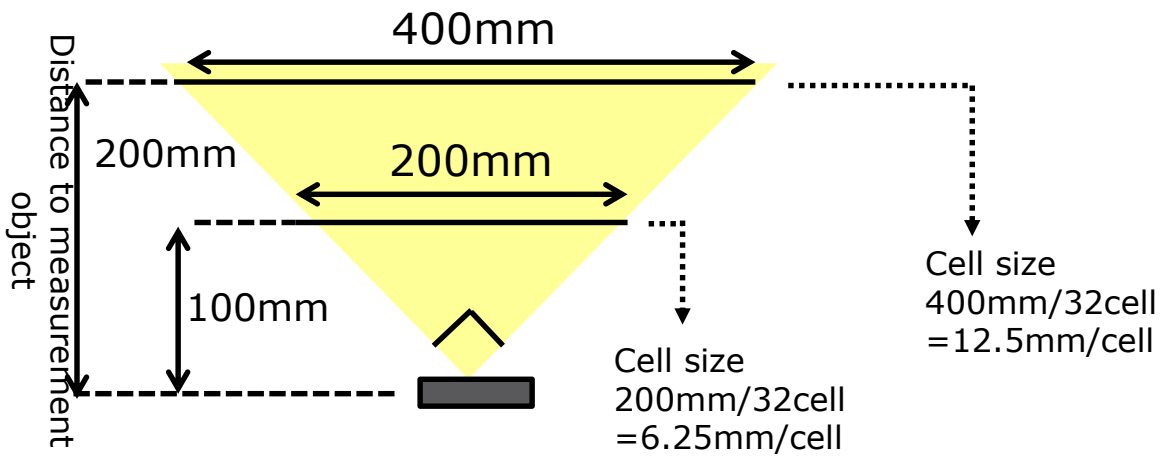


EtherNet/IP / Modbus

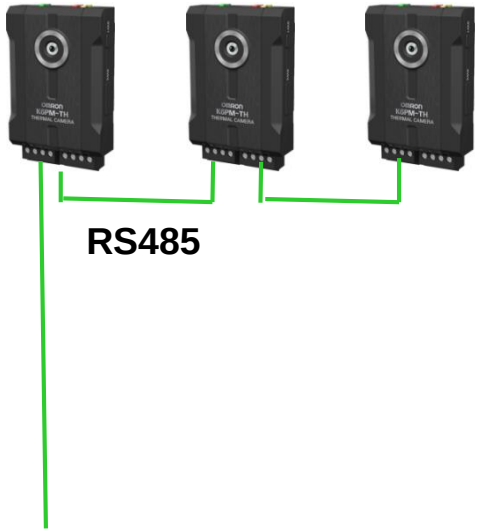
Infrared (IR) Thermal Sensors





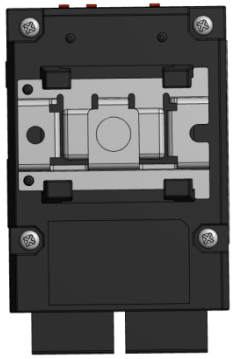


31 sensors

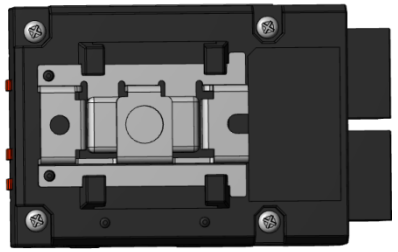


Built-in ambient temperature sensor

Vertical Mount



Horizontal Mount



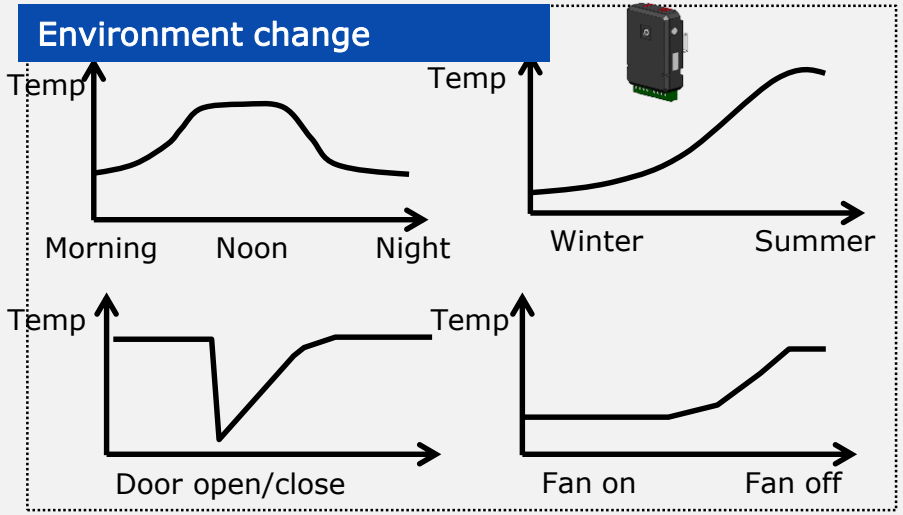
Aftermarket mount

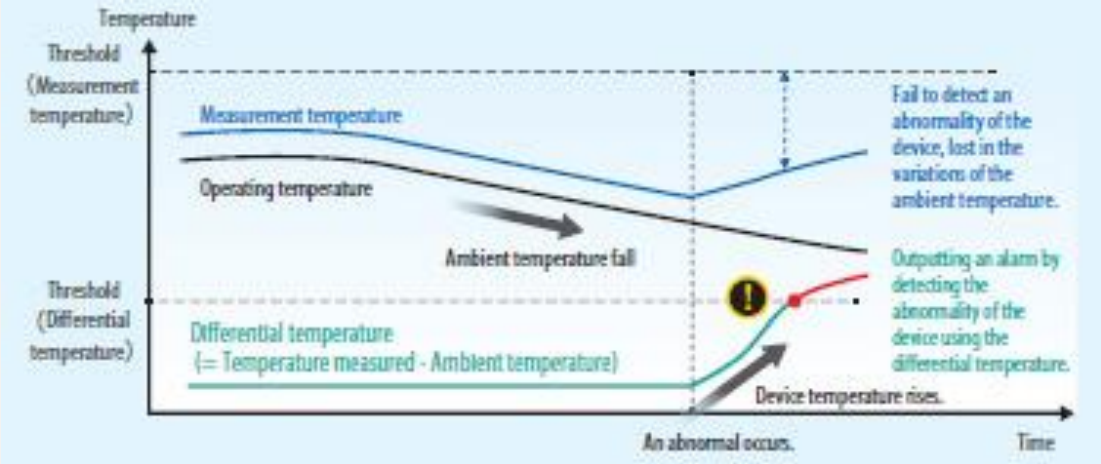
Patented Abnormality Detection Algorithms for Thermography

■ Differential Temperature

Patent

Allows accurate thermal monitoring in environments that have frequent changes in ambient temperature. Uses IR, ambient temp sensor and thermal sensor to calculate warning level

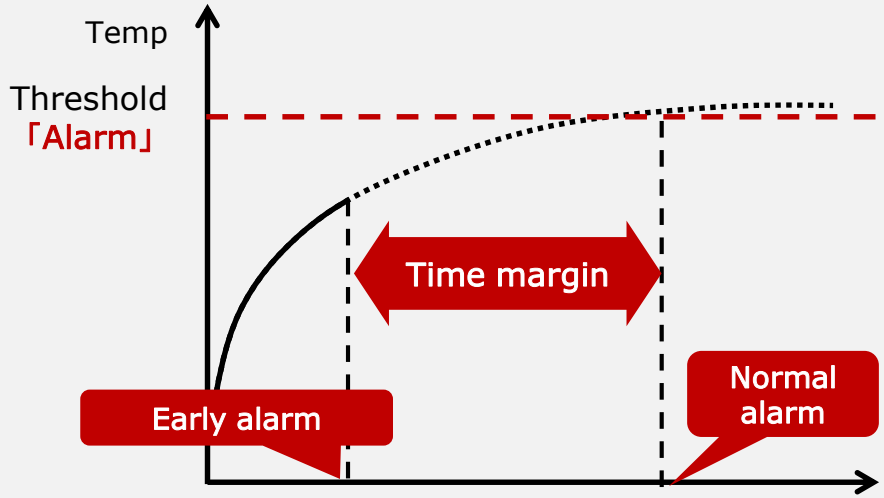


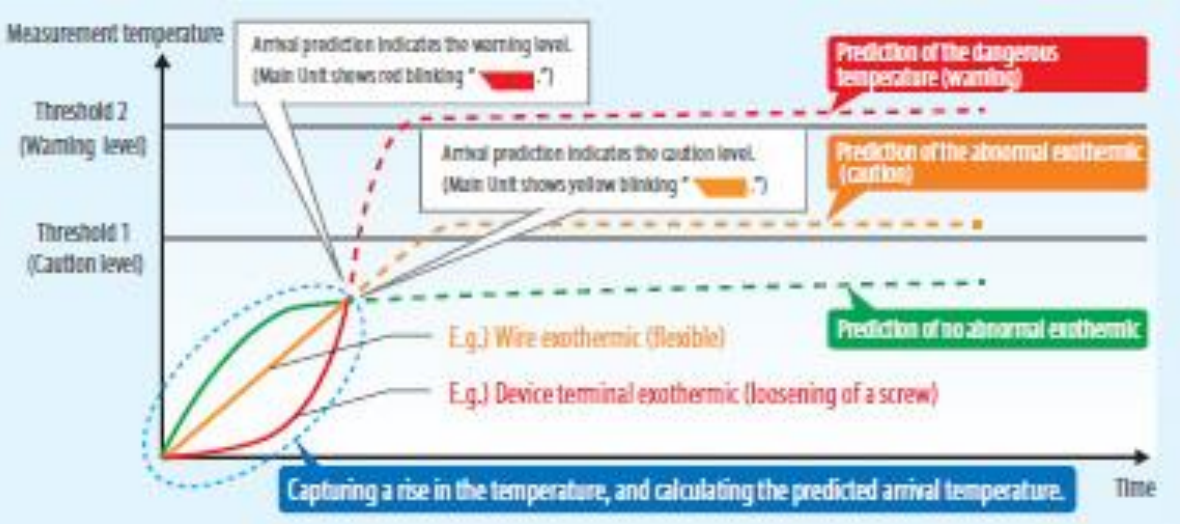


■ Temperature Prediction

Patent

Monitors temperature trends and can predict a warning level before it reaches the threshold. Notifies the user by sending an early alarm.





Patented Thermography Abnormality Detection Algorithms

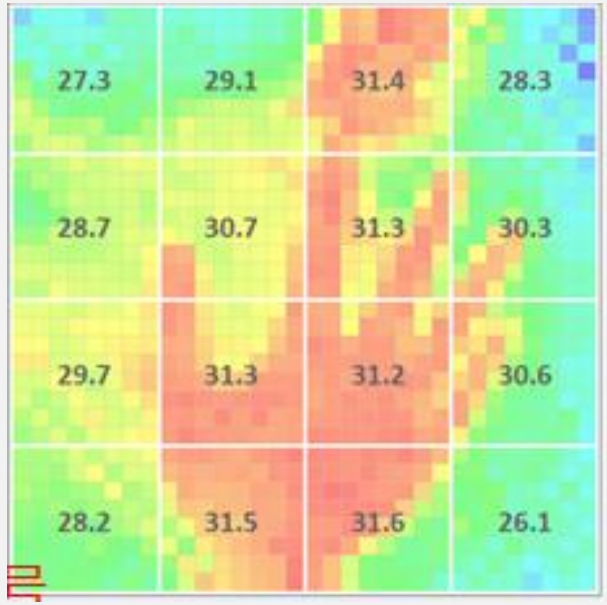
■ Automatic Threshold Setting

Patent

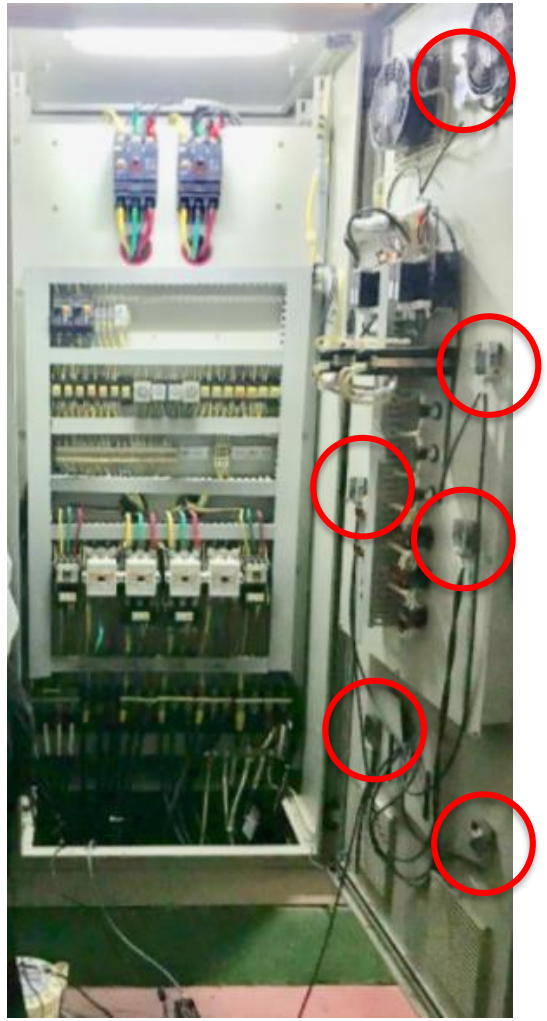
A built in feature that automatically calculates the caution and warning levels based on a maximum ambient temperature. Helps reduce setup time.

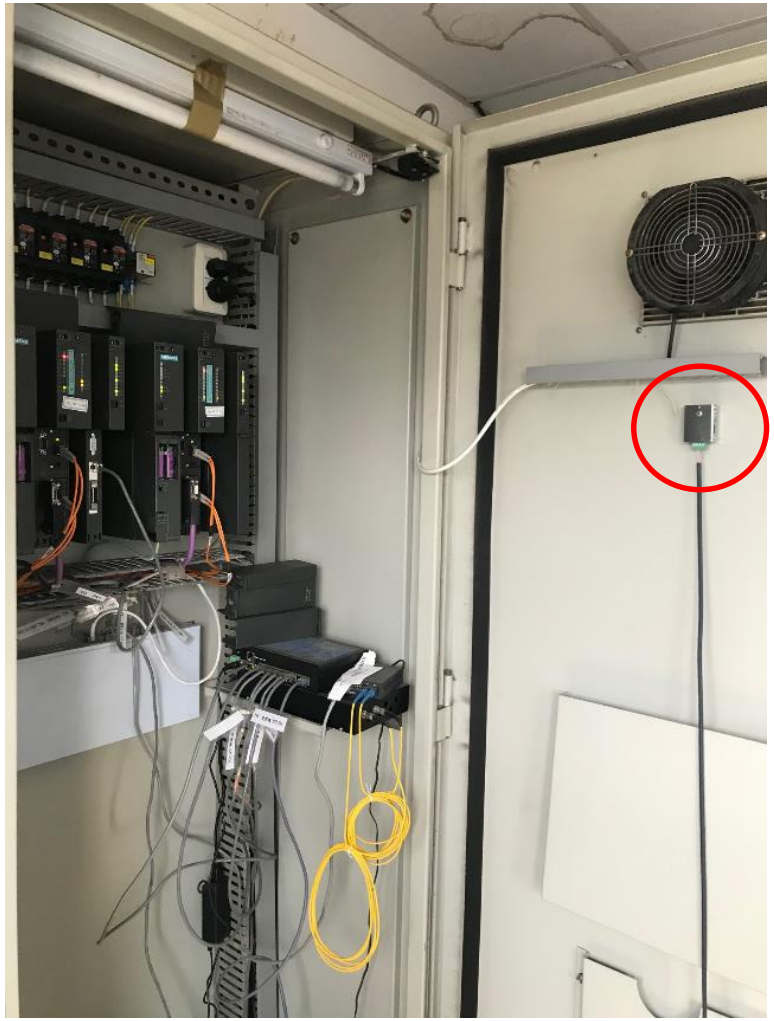
This feature will set the caution threshold when approaching 10%, and a warning threshold when approaching 50%.

	現在温度	最高温度	温度		差温	
			しきい値1	しきい値2	しきい値1	しきい値2
01	70.0	120.0	100.0	110.0	60.0	70.0
02	70.0	120.0	100.0	110.0	60.0	70.0
03	70.0	120.0	100.0	110.0	60.0	70.0
04	70.0	120.0	100.0	110.0	60.0	70.0
05	70.0	120.0	100.0	110.0	60.0	70.0
06	70.0	120.0	90.0	110.0	60.0	70.0
07	70.0	120.0	100.0	110.0	60.0	70.0
08	70.0	120.0	100.0	110.0	60.0	70.0
09	70.0	120.0	100.0	110.0	60.0	70.0
10	70.0	120.0	100.0	110.0	60.0	70.0
11	70.0	120.0	100.0	110.0	60.0	70.0
12	70.0	120.0	100.0	110.0	60.0	70.0
13	70.0	120.0	100.0	110.0	60.0	70.0
14	70.0	120.0	100.0	110.0	60.0	70.0
15	70.0	120.0	100.0	110.0	60.0	70.0
16	70.0	120.0	100.0	110.0	60.0	70.0
内部	70.0	120.0	100.0	110.0		

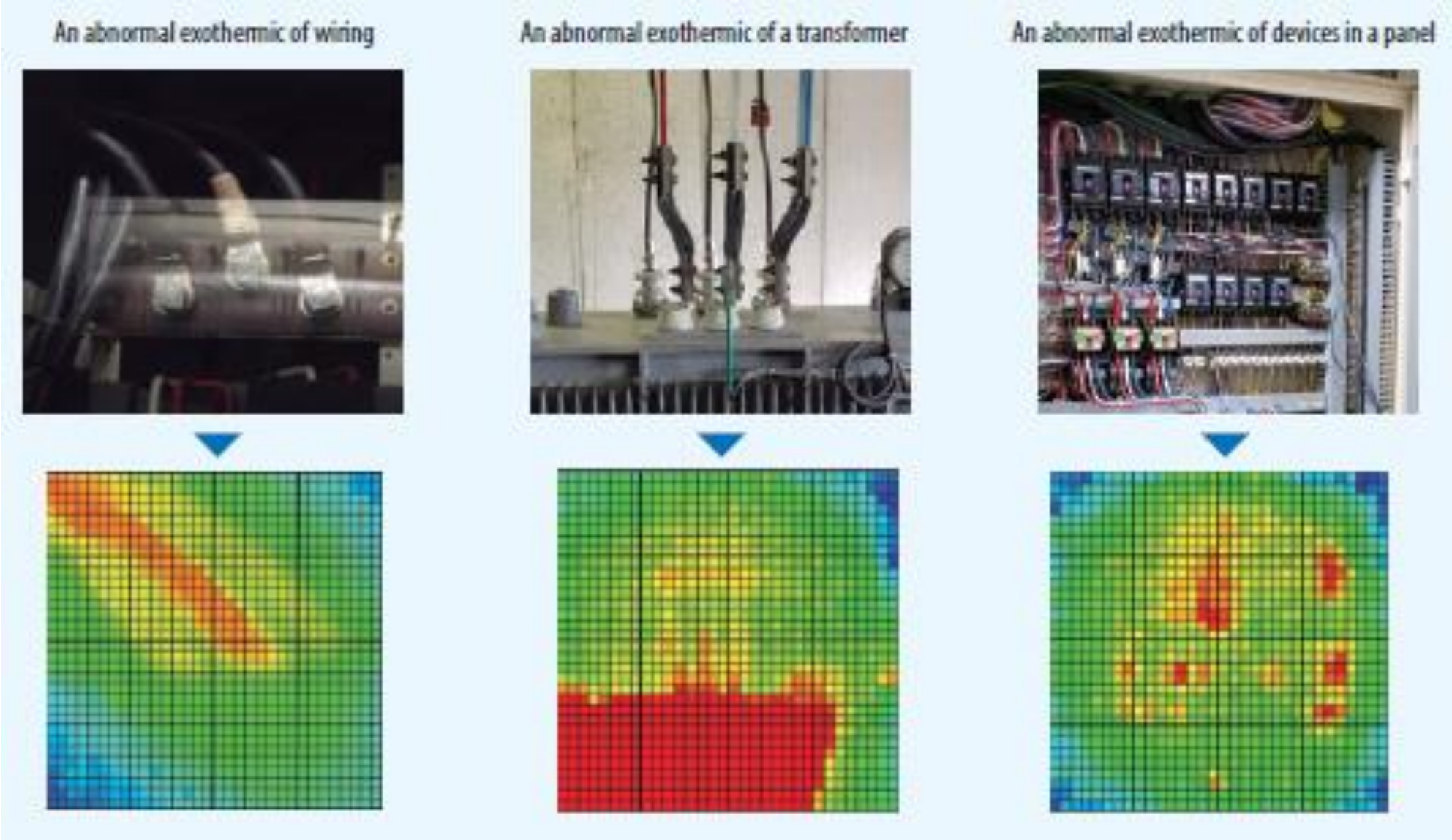


Examples of Thermal Sensors installed in Panels for Live Monitoring





Examples of Thermal Sensors installed in Panels for Live Monitoring



Applications for On-line Thermography Sensors

High voltage motor applications + High voltage switchgear panels

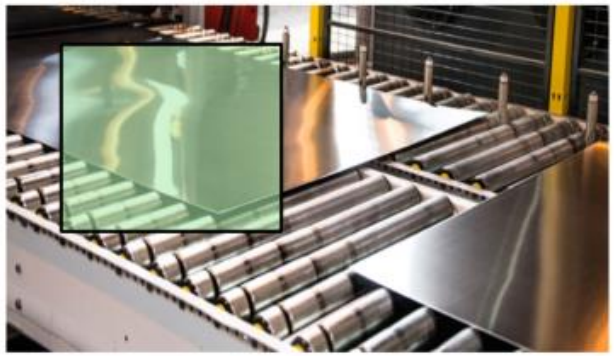
Refiners, large extruders, mills, crushers, air separation plants, blast-furnace blowers, gas compressor stations and gas liquefaction, generator plants.

Data centers

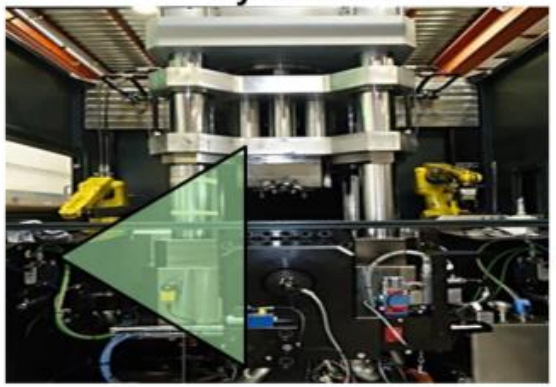
R&D Test Cells

Transformers

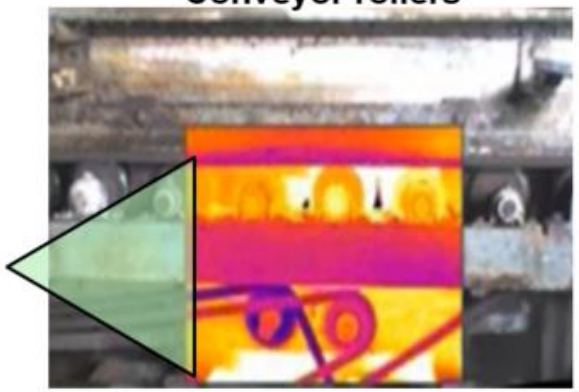
Product



Hydraulics



Conveyor rollers



Live Data can be Collected, Monitored, Trended, Shared (Industrial Internet of Things – IIoT) Analyzed (including by Artificial Intelligence), Used for Alarm Paging, Reporting (pharma, data centres)

PdM Sensor Monitoring Example

"Conveyor M-2" motor has failed!

"Water Pump" is operating in "Normal" condition

Local alarm display at motor draws attention and identifies which one to avoid errors!

Maintenance is needed for "Stamping-2" Motor

"Motor No.9" may be in normal condition but a communication error has occurred

Alarm Event History Example for 3 PdM Sensor Types

Vibration Sensor
- **Velocity**
- **Acceleration**
- **Motor Temperature**
- **Delta T vs. ambient**

Insulation Resistance Sensor

Current Analysis Sensor

Example: Data Trending Graph for Vibration (Velocity + Acceleration)

Threshold (Abnormal) Alarm

Threshold (Notice) Warning

Threshold (Abnormal) Alarm

Threshold (Notice) Warning

What is an “Edge” device?

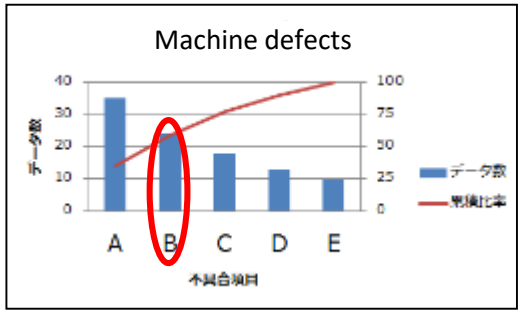
Within the Machine or Production Line, without any separate Windows® PC or remote server (Cloud) or Internet

Computing	Collect Data Collection → Processing	Analyze Storing → Modeling	Utilize Real-time Monitor → Control FB Long-term Monitor → Visualize
Cloud	✓ -	✓ +	Real-time Monitor → Control FB ✓ - Long-term Monitor → Visualize ✓ +
Fog	✓	✓	✓
Edge	✓ +	✓ -	Real-time Monitor → Control FB ✓ + Long-term Monitor → Visualize ✓ -

What does an “Edge” Artificial Intelligence “AI” Controller do?

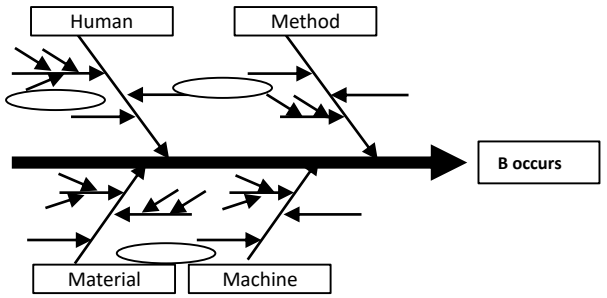
Detects outliers (failures, defectives) by learning from historical data in the machine

1) Issue definition



Based on failure impact and feasibility study of AI Controller utilization, define issue

2) Cause identification



Based on Cause and Effect Diagrams, identify cause of machine defect

3) Prepare sensors

Based on the cause, add necessary sensors to machine

Human

Machine

AI Controller fully covers the data collection, analysis, and utilization.

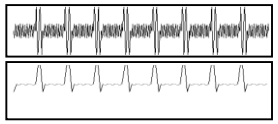
Omron also offers startup support for the entire process.

4) Collect

Data collection

Collect the raw sensor and machine data

Pre-processing



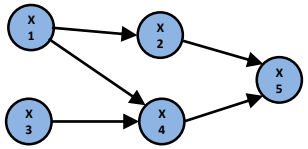
Eliminate noise, create and collect the features of normal/abnormal state

5) Analyze

Storage

Store the characteristics data

Causal analysis, modeling



Create model data after causal analysis

6) Utilize

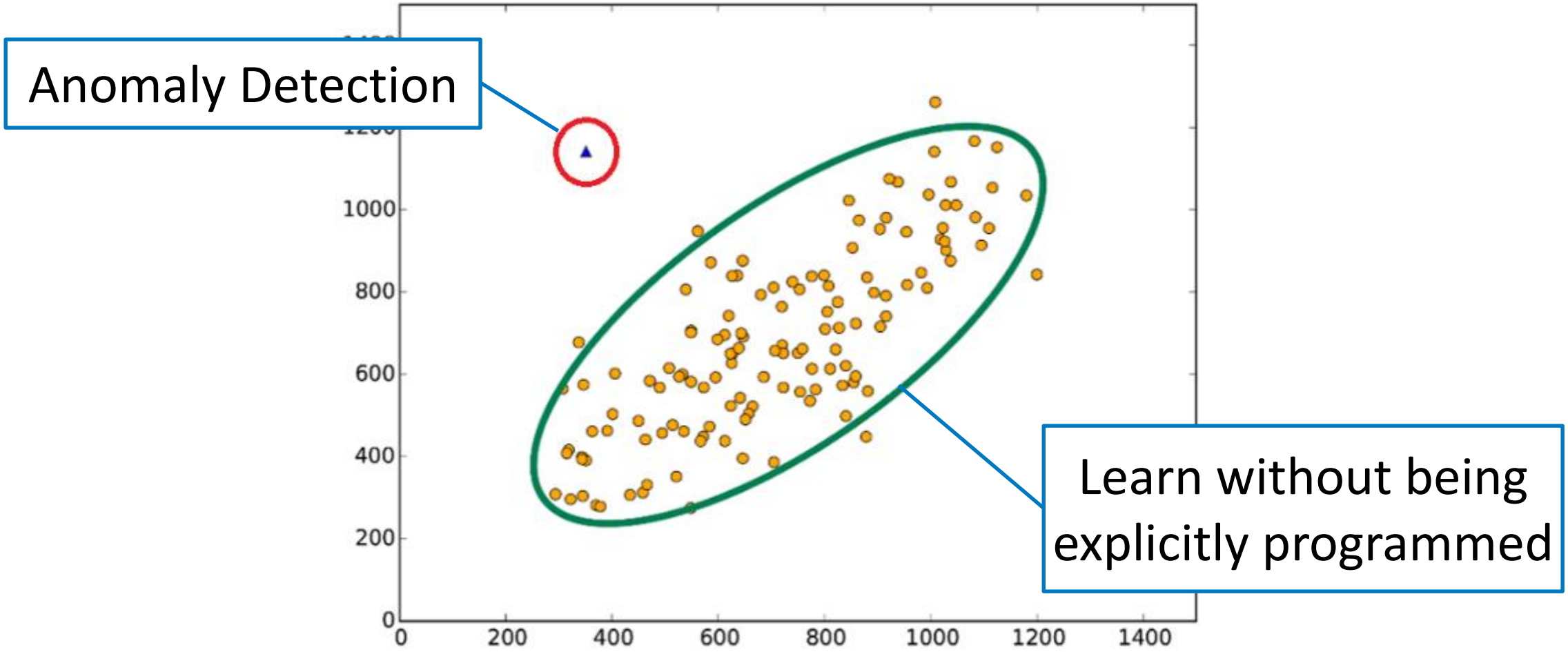
Monitoring

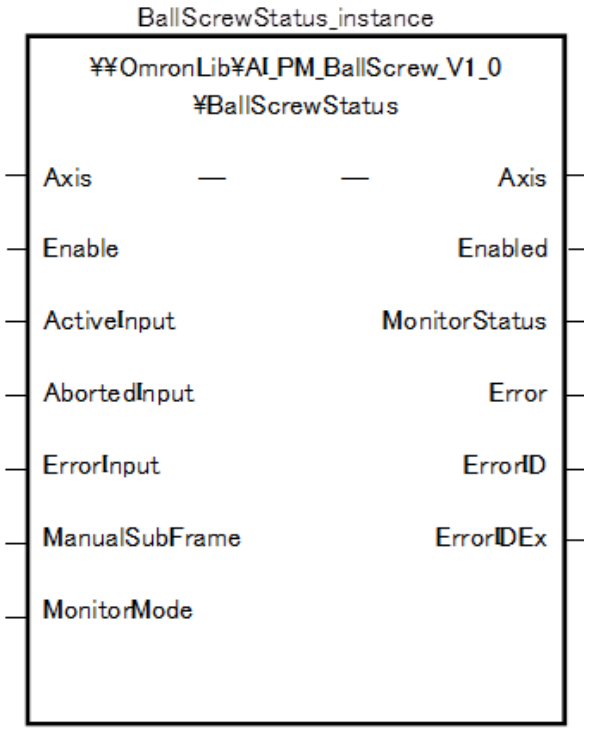
Visualization

Control FB

Status monitoring and control function block based on *model data*

AI Machine Learning for Anomaly Detection





AI Application Components

Pre-made Controller Programming Function Blocks (FB) for…

Mechanism	Failure Type	Machine event (failure causes)
Air Cylinder	Operation stop	Rubber Gasket broken (Rod/Piston)
	Over speed	Speed Controller broken
	Over vibration	Air Cushion broken
	Operation stop	Contamination
Ball Screw	Operation stop	Guide broken
	Operation stop	Ball Bearings falling out
	Operation stop	Contamination
Conveyor Belt or Pulley	Vibration and low accuracy	Contamination
	Operation stop	Belt loosen
	Operation stop	Belt broken
	Operation stop	Pulley broken

Value of an “edge” AI Controller

Helps improve OEE at the machine level by increasing uptime

OEE

Overall Equipment Effectiveness

=

Availability

x

Performance

x

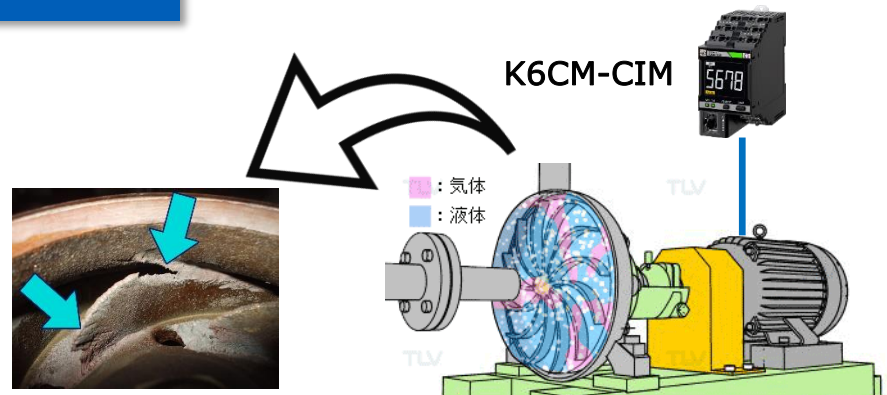
Quality

Uptime	Downtime
Operating time	Stoppage Loss
Net operating time	Performance Loss
Value operating time	Defect Loss

Loss types	Improved by AI Controller
1: Equipment failure	1: ✓
2: Changeover	2:
3: Part replacement	3: ✓
4: Waiting for material	4:
5: Minor stoppage/idle	5: ✓
6: Deceleration/slowing	6:
7: Defect/modification	7: ✓

Preventing Sudden Stops, Downtime, and Production Defects

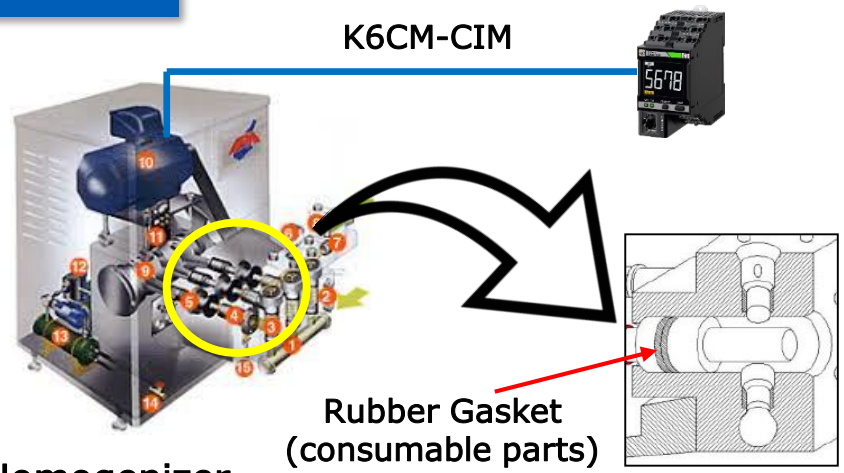
Customer	Textile/Chemical industry
Application	Liquid pump
Customer Demand	Monitor "Bubble" (Cavitation /Air lock) in Pump system
Customer Issue	Cavitation damages impeller & pump and "defective product" has bits of metal from impeller



Damaged impeller by cavitation

Pump

Customer	Food & Beverage industry
Application	Homogenizer
Customer Demand	Rubber Gasket (consumable parts) condition monitoring
Customer Issue	Failure of rubber gasket produces "defective product"



Homogenizer

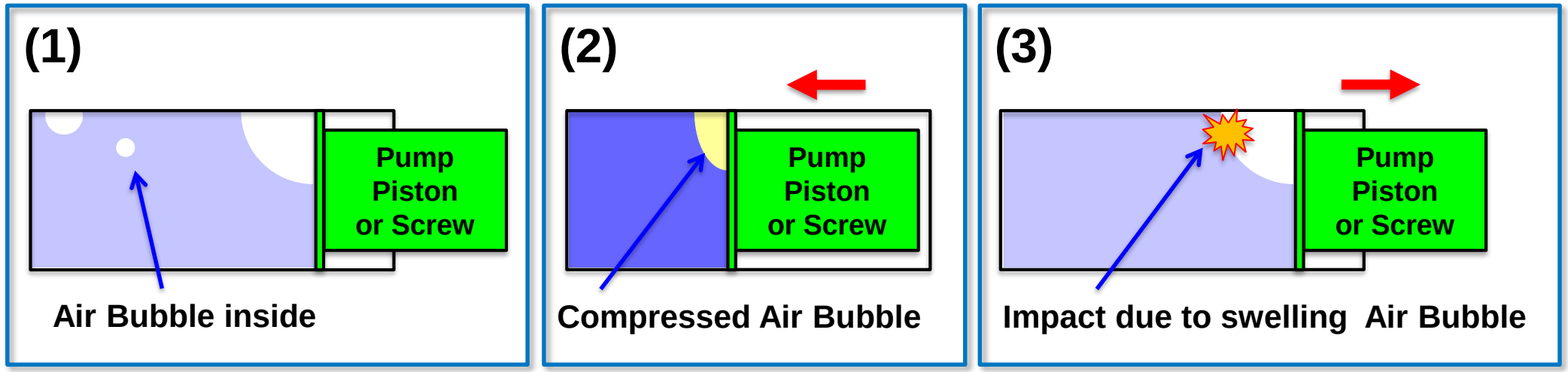
Rubber Gasket (consumable parts)

Detecting “Air Lock” and “Cavitation” in Water Pumps

Situation

A “Bubble“ gets into the Pump system.
“Air Lock” means “Air Bubble” in the Pump, and “Cavitation” is occurs when there is a “Vacuum Bubble” in the Pump system.
“Bubbles” in the Pump system decrease water pressure and damage the Pump Piston or Screw.

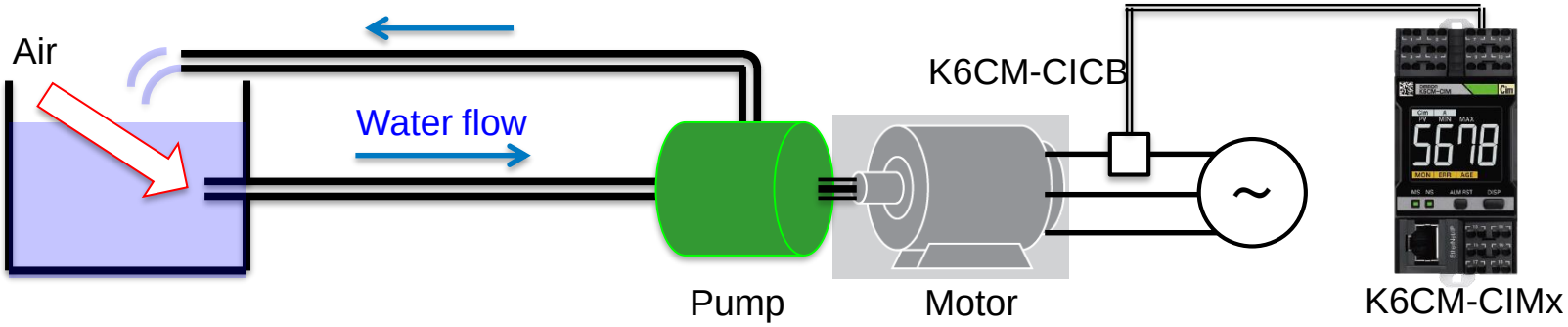
Example of Air Lock



Detecting Pump "Air Lock" with Current Analysis Sensors

Bottle Washing Machine

3 phase AC200V /11kW motor with Inverter
Water pressure 10MPa Pump system



Test result

Normal mode : K6CM-CIM "Degradation Level" 20.4 (average)
"Current Level" 36.7A (average)
Water Pressure : 10MPa

Air Lock mode : K6CM-CIM "Degradation Level" 74.7 (average)
"Current Level" 22.3A (average)
Water Pressure : 4MPa
* Pump system has abnormal noise and vibration

Comparison of Motor Current Waveforms

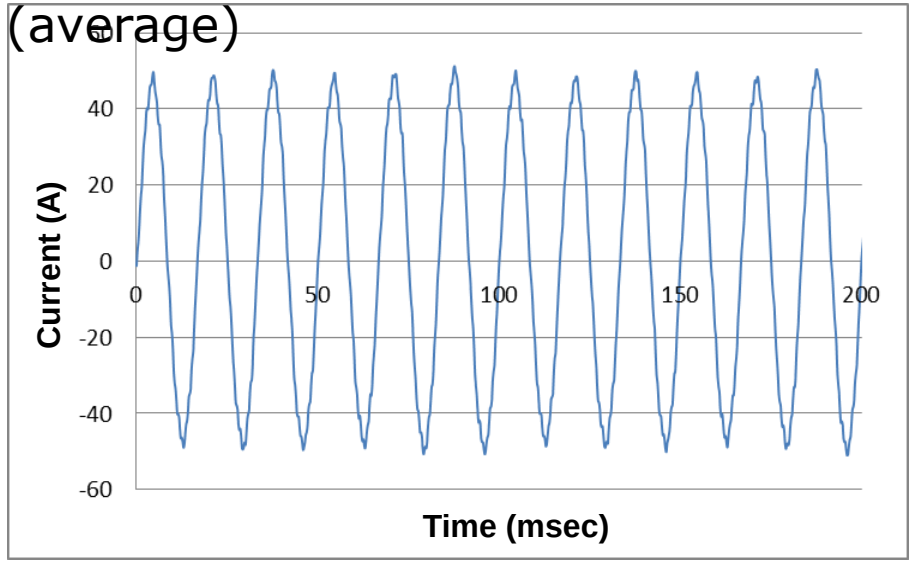
Normal Mode

K6CM-CIM "Degradation Level" 20.4

(average)

"Current Level" 36.7A

(average)



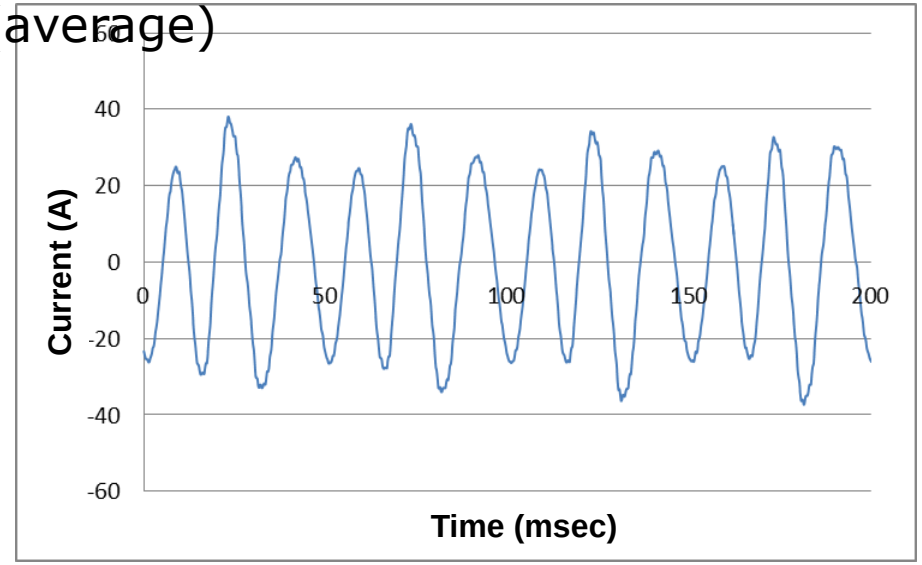
Air Lock Mode

K6CM-CIM "Degradation Level" 74.7

(average)

"Current Level" 22.3A

(average)



* Exact Degradation Level value differs by application. This is one example.

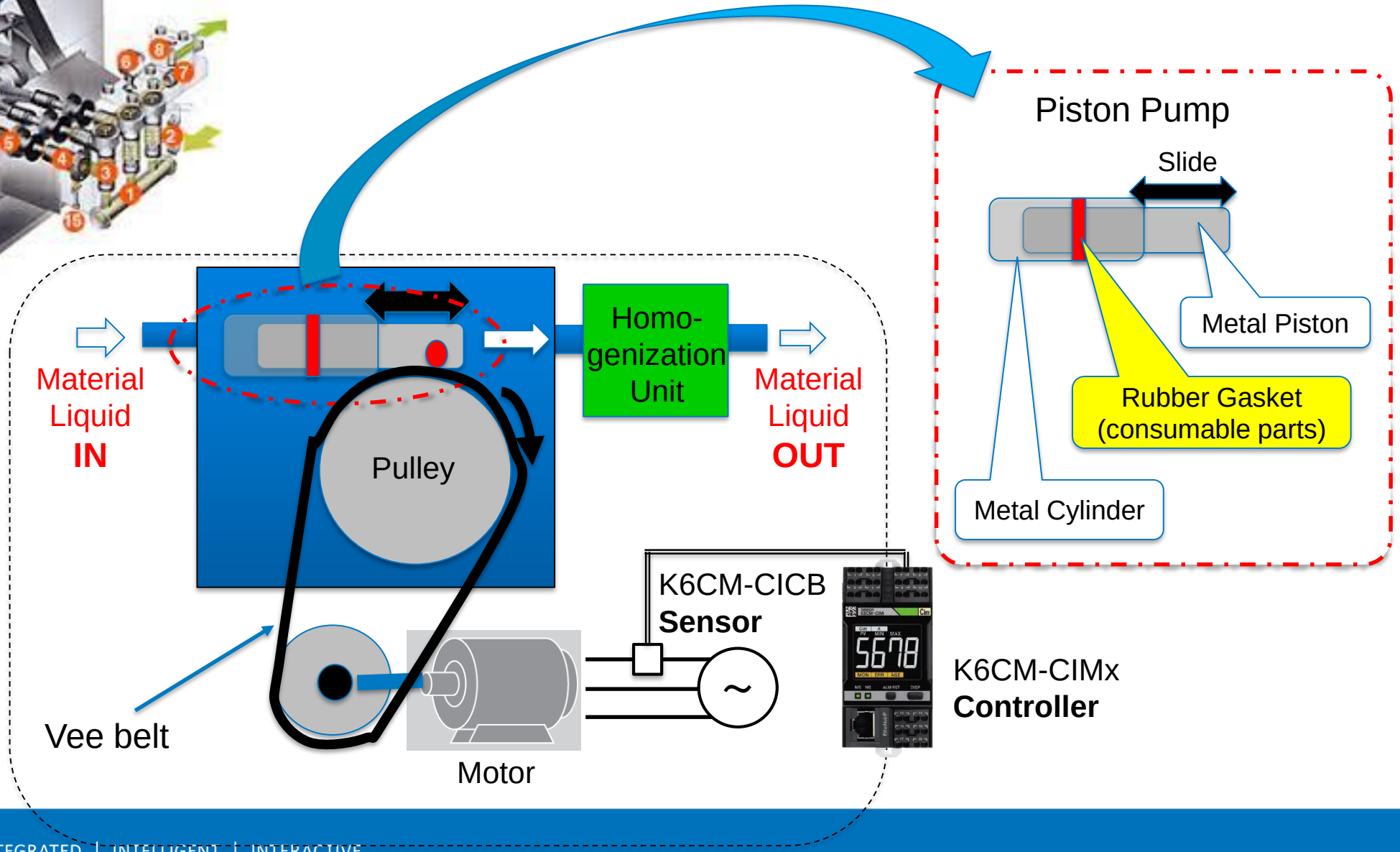
Example: “Homogenizers” and “Whirring Machines”

Homogenizers and Whirring Machines are commonly used in the Food & Beverage industry and the Pharmaceutical industry.

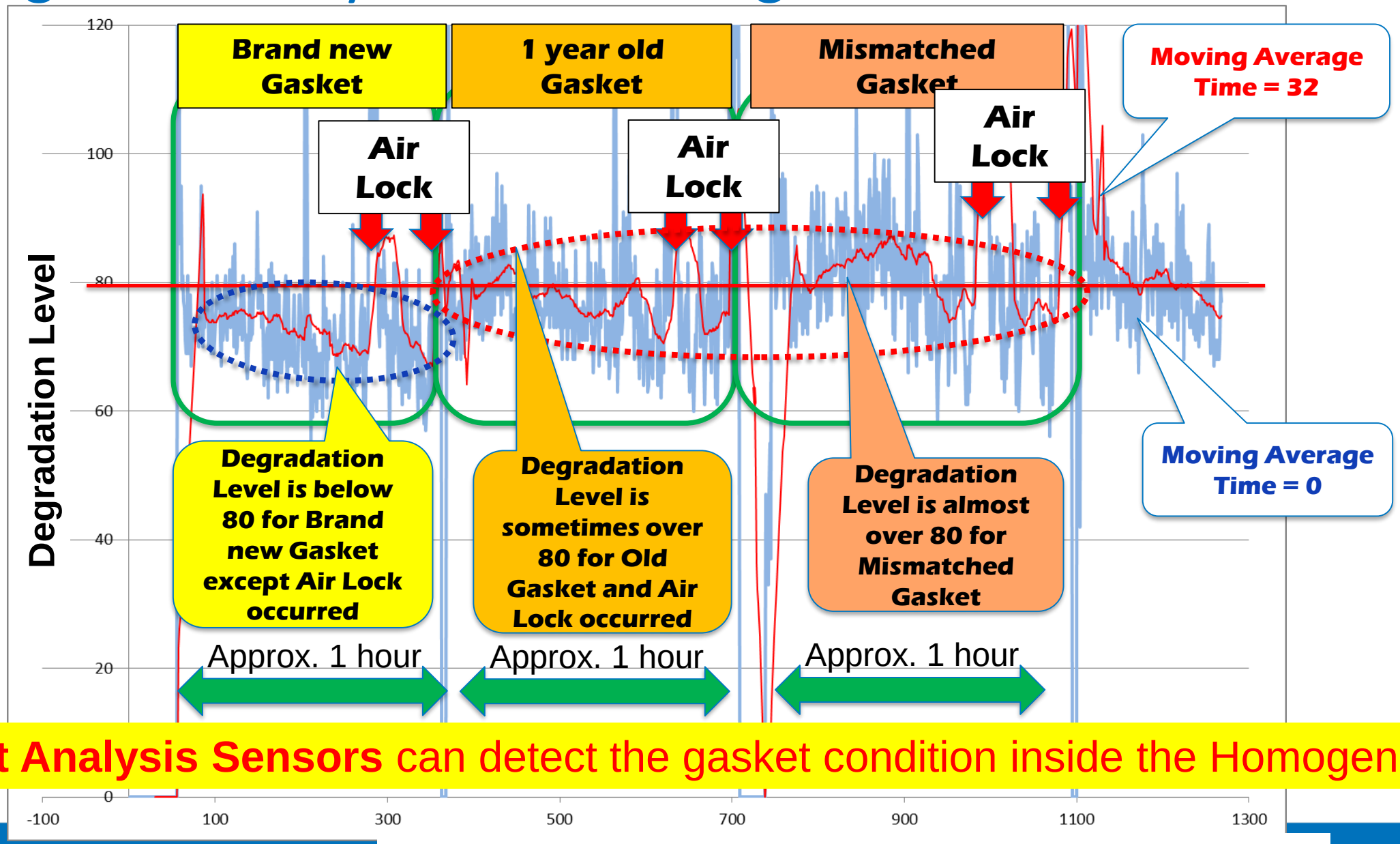
Many OEMs produce these machines, whose main purpose is mixing and/or homogenizing material for food and medicine.

When Homogenizers and Whirring machines stop due to motor and/or consumable parts failures, production plants have to scrap material and product and it takes a few hours of downtime to replace the motor.

Current Analysis Sensor on a Homogenizer



Homogenizer – Early Detection of Degradation with a PdM Sensor



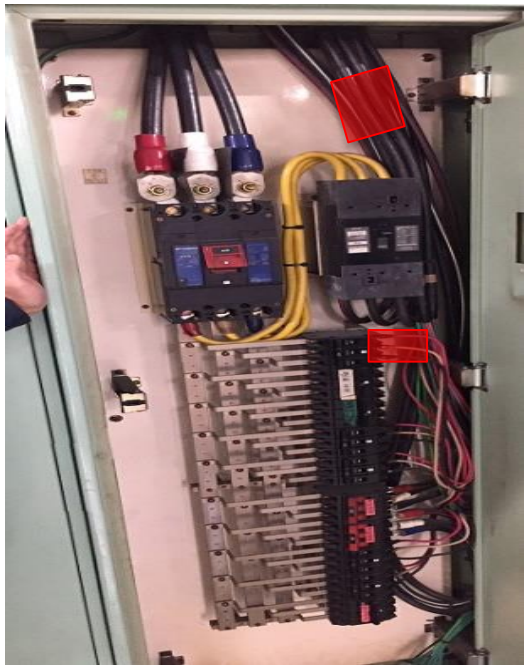
Current Analysis Sensors can detect the gasket condition inside the Homogenizer

*Exact Degradation Level depends on application. This is one example.

Predictive Maintenance Case Studies – IR Temperature Sensors

Panasonic (Facility management div.)

- Distribution board on production line equipment in service 24/7 for 30+ years
- Wiring overloaded and wire temperature exceeded 60°C
- 100 similar boards, but difficult to repair due to 24 hour operation
- Solution = temperature monitoring



Taiyo Nissan Engineering (Production Technology Div.)

- Power board on panel of OEM equipment
- Abnormal power system overload
- Quick and easy retrofit to predictive maintenance by using magnetic thermography sensors
- Provides IoT implementation for OEM's equipment

Predictive Maintenance Case Studies – IR Temperature Sensors

LION (Facility management div.)

- Electrical fire on 30+ year old control panel
- Loose contactor terminal wires
- Abnormal terminal screw loosening due to low frequency vibration
- Need to protect panels against a repeat

Electrical Security Association

- High voltage panels
- Streamline building maintenance by using IoT PdM sensors for insulation and temperature monitoing
- Abnormal temperature abnormality in general

Predictive Maintenance Case Studies – IR Temperature Sensors

Nissan

- Monitoring temperature of hydraulic valve
- Clogging due to abnormal deterioration
- Live thermography sensors replaced reading manually with a hand held device
- Now able to trend and graph data

Bridgestone

- Control board for a critical conveyor that collects from 8 conveyors from 250 vulcanizers and transports them to the next process
- Frequent sudden temperature-induced stoppage occurs and causes a production bottleneck.
- Preventative maintenance inspections are too late to catch the issue due to the lack of humanpower / maintenance workers.

Predictive Maintenance Sensor Application Examples

Detecting water pump cavitation

- ✓ Buildings
- ✓ Water and wastewater treatment
- ✓ Food and beverage

Remote pump monitoring

- ✓ Water and wastewater treatment
- ✓ Food and beverage

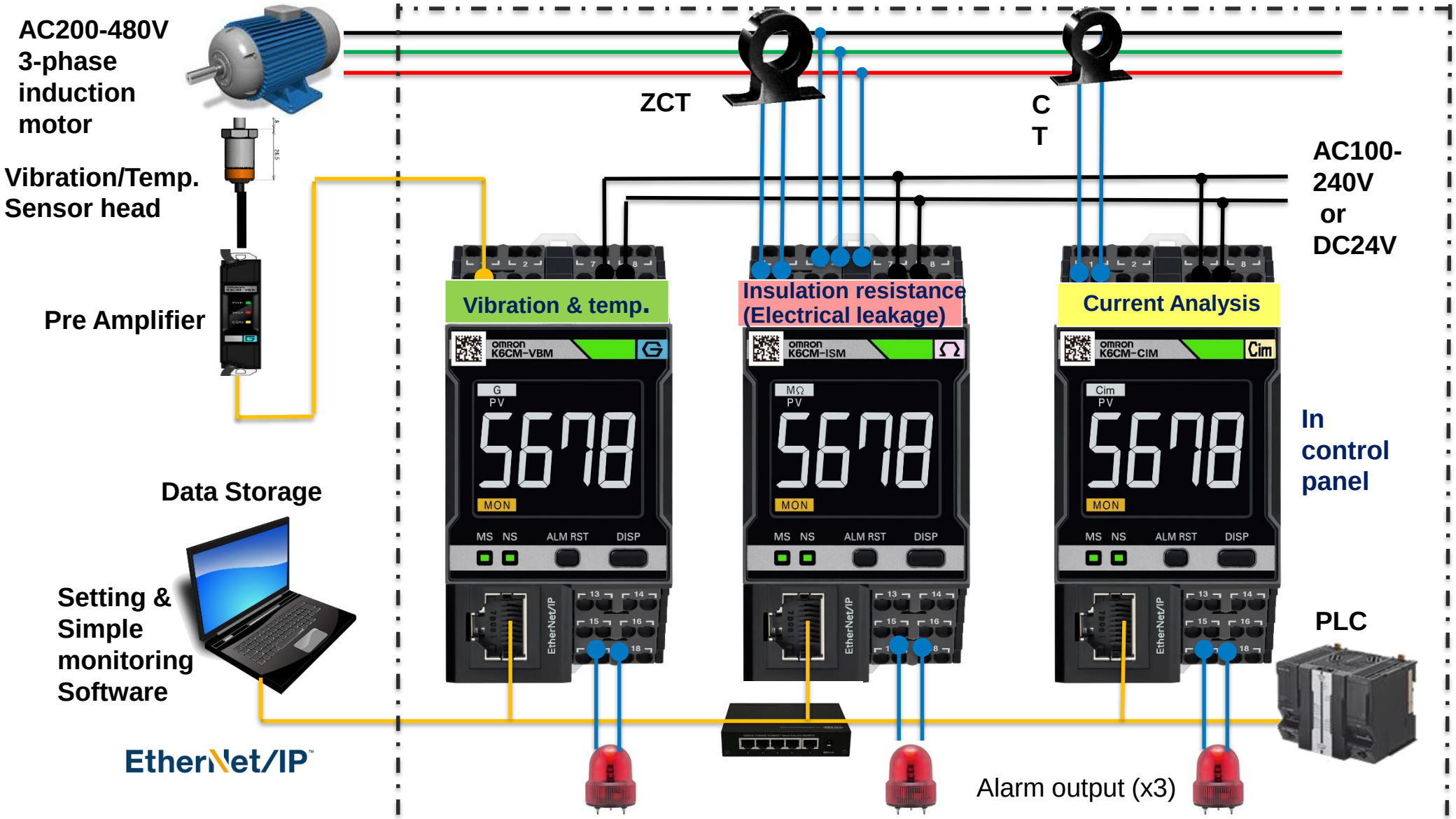
Motor monitoring in Food Processing

- ✓ Scraped surface heat exchangers (crystallization process)
- ✓ Baking ovens

Detecting fan issues on HVAC equipment

- ✓ Buildings, hospitals, manufacturing plants

Reference: Set-up for 3 Motor Condition Monitoring Sensors



Making Change Happen – Predictive Maintenance is a Process

	+	Skills	+	Incentives	+	Resources	+	Action Plan	= **Confusion**
Vision	+		+	Incentives	+	Resources	+	Action Plan	= **Anxiety**
Vision	+	Skills	+		+	Resources	+	Action Plan	= **Resistance**
Vision	+	Skills	+	Incentives	+		+	Action Plan	= **Frustration**
Vision	+	Skills	+	Incentives	+	Resources	+		= **False Starts**
Vision	+	Skills	+	Incentives	+	Resources	+	Action Plan	= **Change**

Source: David Naylor adapted from Knoster, Villa & Thousand's A framework for thinking about systems change.

Thank You!

Questions?