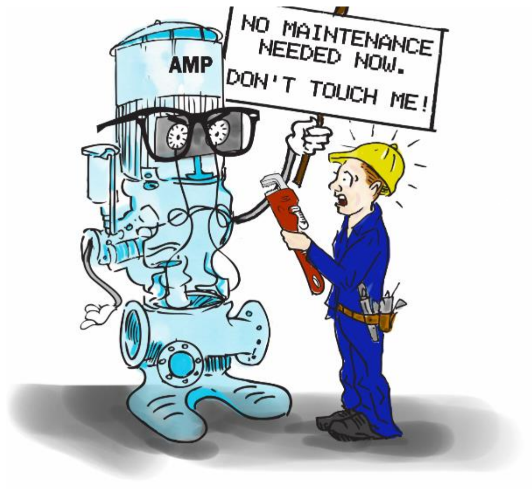
The DEI Group, Inc

AutonomousMotorPump (AMP)

AI Approach to Managing Motor driven Pumps



From measurement collection to dynamic remaining useful life (RUL) estimation in one single package

AMP provides the first in the market, user configurable application that defines a diagnostic-prognostic frame for optimal advance maintenance planning and scheduling of equipment

Overview of AutonomousMotorPump (AMP)

Many maintenance groups investigate use of IoT technologies and online measurements only to be met with the reality that they can't fully extract the value from the data mining using ML techniques, without the continuous help of subject matter experts – and industry is losing SMEs.

Automating the process of converting data to knowledge and *reasoning* is a major need. Traditional approaches consist of multiple systems, each designed to measure and monitor singular machines or small groups of equipment for specific attributes.

AMP provides a simplified Integration - Matches Sensor Measurements to Analytics

AMP Analytics Engine uses reliability engineering context, machine learning, and AI based reasoning approaches to automatically calculate equipment current health, current & future reliability, dynamic remaining useful life (RUL) of the motor and driven pump components. It identifies what and when specific maintenance actions need to be done.

It provides the built-in digital Subject Matter Expert (SME) that continuously monitors conditions and transforms data into reasoning-based actionable insights, while fostering collaboration and knowledge across the organization.

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Challenges Faced by Today's Operators that AMP provides solution for:

- Unplanned downtime with lost productivity and high cost of emergency repairs.
- Costly and often unnecessary time-based preventive maintenance that introduces risk and decreases availability.
- A lack of asset level visibility — not knowing what specific problems are about to occur, and when.
- High spare parts inventory levels.
- Loss of SME's as the existing workforce approaches retirement.
- Delay in critical information reaching those that need to respond to events — maintenance technicians, operators, and managers.

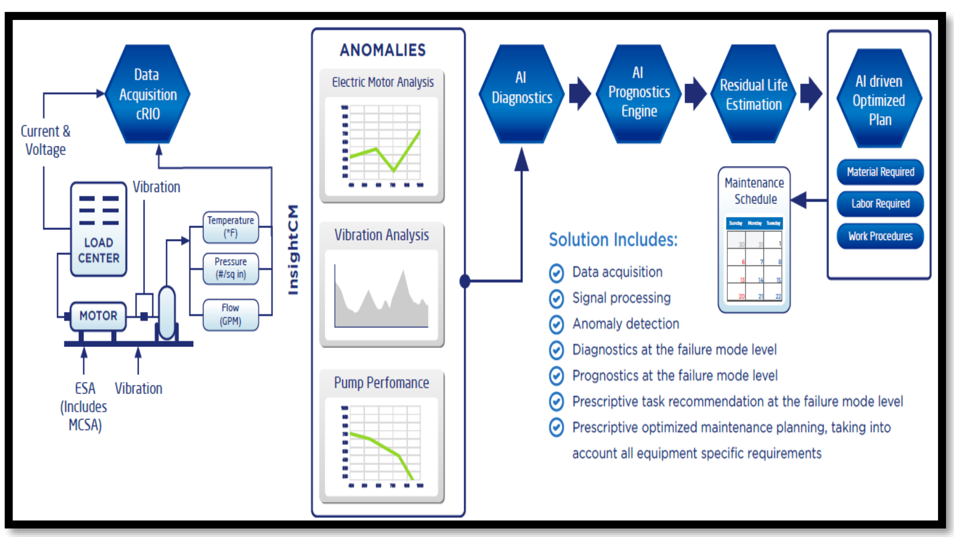
Smart, Accessible and Secure Information - Combining NI hardware with extensive embedded SME Engineering Knowledge, Machine Learning and AI

AMP Solution Overview

Embedded edge intelligence - using the NI monitoring hardware with the Voltage and Current sensors, the AI analytics engine of AMP combines the deep SME engineering knowledge embedded in the software, with data science and physics of failure methods, taking into account equipment performance as compared to design characteristics, externally induced stresses, environmental conditions, and operational variances.

Based on automated analysis of information, the system efficiently collects, consolidates, analyze, and archives data to provide anomaly detection, diagnostics and dynamic remaining useful life (RUL) of all components. Based on RUL, it supports decision management related to advance planning, scheduling, and execution of maintenance tasks and logistics. Calculation of Dynamic Remaining Useful Life (RUL) of each component allows implementing an adaptable and dynamic advance maintenance planning and scheduling process, based on future production process risk caused by predicted equipment degradations.

AMP takes the guesswork out of selecting sensors for predictive maintenance. For motor-driven pumps, AMP requires only 3-phase voltage and current measurements.



Note:
When available, the integration of vibration and process sensor information into AMP provides additional evidences to the diagnostic engine for reinforcing the confidence factor into reasoning related to mechanical degradations.

AMP-3-phase voltage and current measurements

Split-core current sensors are typically installed in the motor control cabinet

Note: Safety First. Always de-energize the asset/cabinet for install

AMP takes advantage of the information available in the current/voltage time-waveform to extract features pertinent to the condition of both electrical, as well as mechanical components of the motor driven pump.

Concurrent high-speed time-waveform measurements of Voltage and Current provide for feature extractions such as DQ0 attributes, phase imbalance, negative sequence, torque ripples, and frequency domain harmonics (narrow band) measurements that are appropriately analyzed to detect anomalous behavior, and combined within the AMP's probabilistic diagnostic engine, will detect early stage degradation of failure modes such as broken rotor bars, static/dynamic air gap issues and worn insulation.

AMP continuously evaluates the change in the electro-magnetic pattern exhibited through analysis of the current/voltage time waveforms, as impacted by the physical defects causing a slight shift in the air-gap eccentricity between rotor and stator, such as worn motor bearings. In addition, rotational disturbances, as caused by worn pump impeller, are seen through ripples in torque and power spectra. Since the physical degradations are being analyzed as features on the current/voltage time wave-forms, the characteristics are seen relative to line frequency, off-set by ratio of rotational frequency.

In essence, AMP is using the motor as a highly sensitive sensor, providing numerous features on the current/voltage time-waveforms caused by inceptions of both electrical and mechanical failure modes.

User Configuration of AMP- Easy User configuration with only a few steps using a GUI (graphical user interface) based questionnaire

- Input equipment design attributes (name plate data)
- Equipment service use and operating profile
- Existing available sensors connected to the machine
- Maintenance history - last time overhauled, last time components replaced
- Existing Maintenance Strategy with last time performed
- Maintenance availability periods over the next periods of interest

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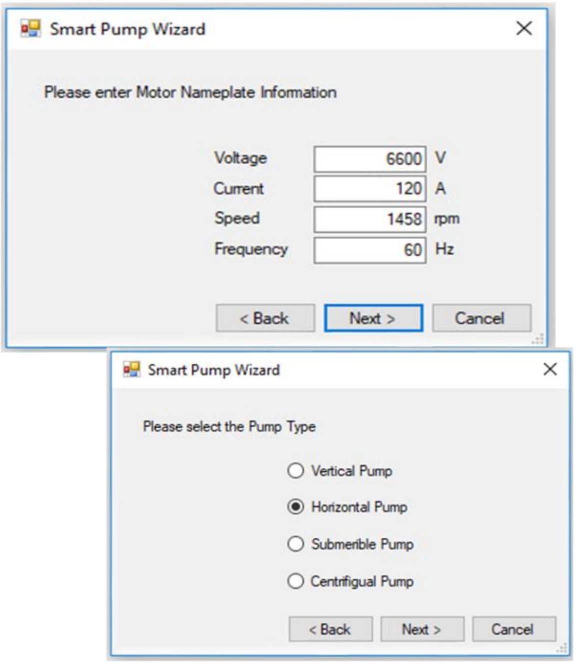

Pump Specification Questionnaire	Motor Specification Questionnaire
Make & Model	Make & Model
Description/Type	Description
Flow	Power
Stages	Speed
Impeller/Diffuser #Vanes	Current FLA
NPSHA	Voltage
NPSHR	P.F. FL
Total Head	Stator RTD
Header Pressure	Winding Temp (A/W/T)
Discharge Pressure	Efficiency
Speed	UGB/NDE Bearing
BHP	Thrust Bearing (NDE)
Bearing Type	LGB/DE Bearing
Seal	UG/TH/LG Temp (A/W/T)
Design Temp	RTD
Shaft Coupling	Motor Heating/Cooling
Efficiency	Poles
Available Sensors	Rotor Bars / Stator Slots
Duty Cycle	Insulation Class
Service use	Available sensors
Last Repair Date	Last Repair Date

AMP's Artificial Intelligence (AI) based Analytics Engine will perform a machine learning process, after it is provided with the information related to the physical configuration of the equipment being monitored. This approach provides the context for a supervised learning process, since the AI based Analytic Engine will automatically build the anomaly detection, diagnostics, and prognostic models from the preconfigured set of motor/pump engineering models.

The analytic models comprise a fusion of statistical, physics of failure, and design characteristic related attributes for managing both short term/rapid degradations, as well as long term estimation of component remaining useful life (RUL). The learning process requires that the Analytic Engine observes the equipment operation through its expected operating range over a sufficient time period as to allow building a high confidence baseline model.

Note: The time duration for the learning process depends on the type of equipment, and the operating range to be observed (constant load/variable load)

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Use the reliability dashboard to interactively explore risk to operations now and in the future. Individual component (impellers, bearings, etc.) risk assessment is also available at this level

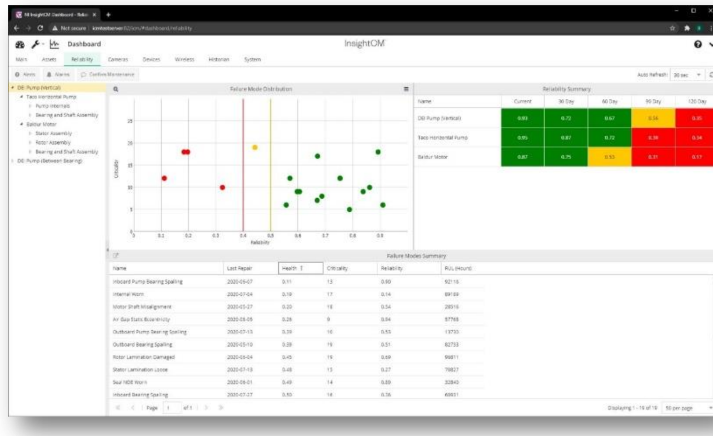
View overall asset health scores in real-time and 30/60/90/120-day risk assessments on the Reliability Dashboard

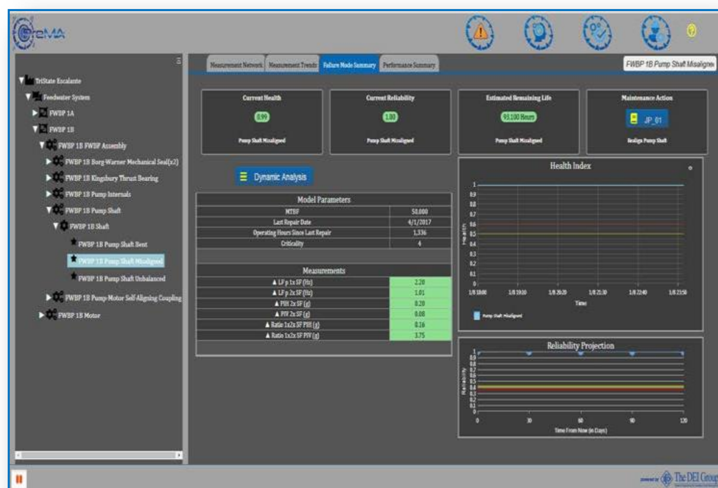
Drill down to better understand the measurements driving the results or zoom in on a failure mode of interest

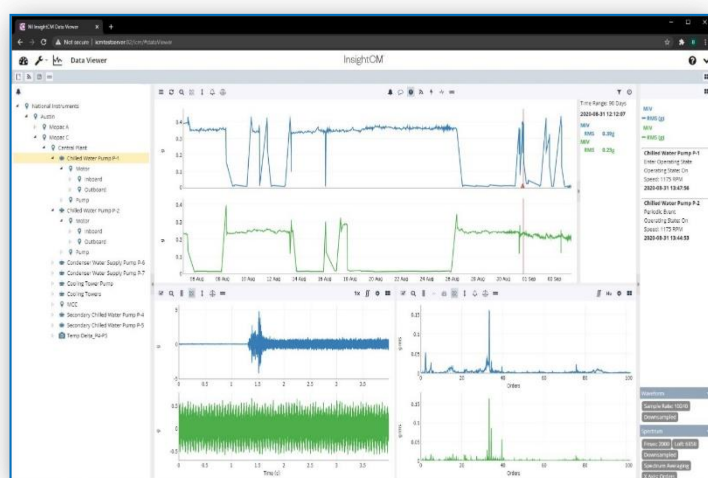
Access raw data, troubleshoot sensor issues, and confirm a diagnosis from the analytics engine

It includes industry-standard calculations and analysis tools that engineers use for diagnosing their fleet of equipment from plants around the world

Interacting with Your Data







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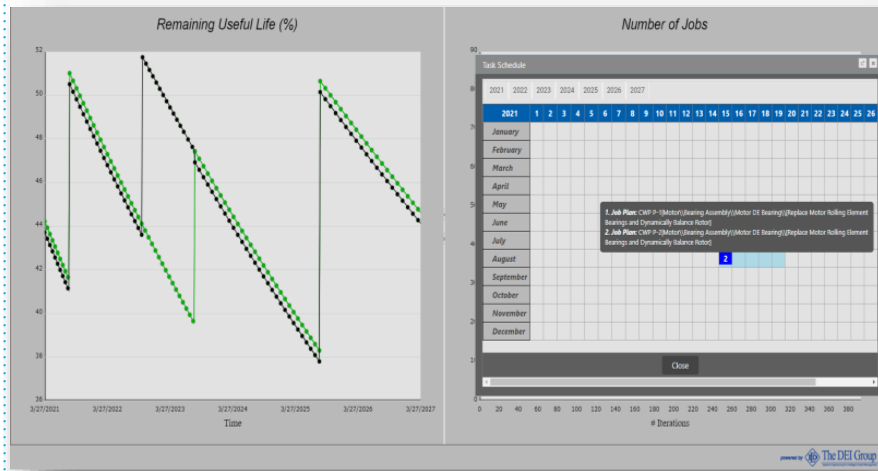
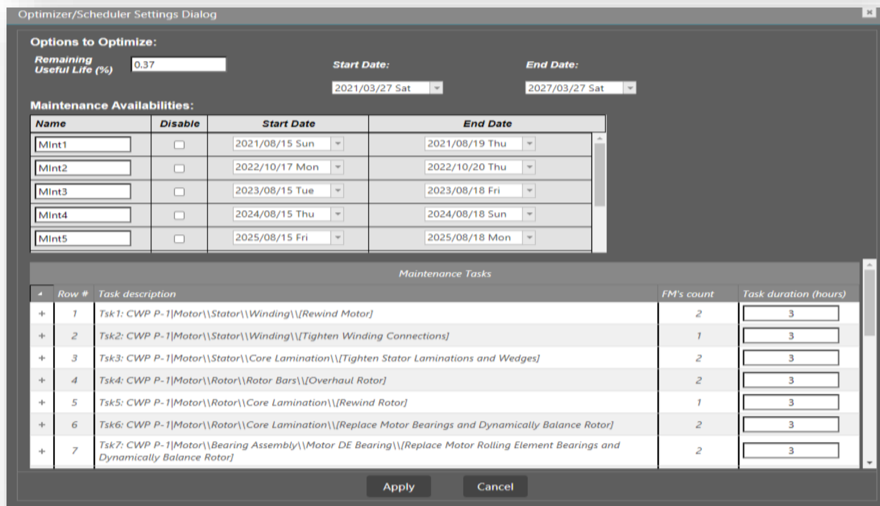
Maintenance Optimization function provides the results of the AI Genetic Algorithm (GA) based recommendation of work scope during the predefined maintenance availabilities, such that Component Remaining Useful Life (RUL) does not drop below a predetermined risk level



Maintenance Optimization function allows the user to define the maintenance availability periods, as well as the duration of the pre-defined maintenance tasks based on local process requirements



AMP Key Benefits

Improve reliability — advanced proprietary analytics that predict future equipment reliability risks with enough lead time to effectively plan and schedule maintenance at the right time

Improve availability — accurate diagnosis of equipment issues that enables faster repairs and shortens outage duration

Reduce maintenance costs —reducing the amount of maintenance activities performed –right maintenance at the right time with the right scope

Maintain technical expertise — Digital SME, capturing engineering expertise, for continuous use

Lower inventory costs by reducing inventory levels through prediction of the reorder point

Increase rate of return on assets by predicting failures before they occur

Control cost of maintenance by enabling just-in-time maintenance operations

Provide KPIs (key performance indicators) such as health scores for asset conditions & availability

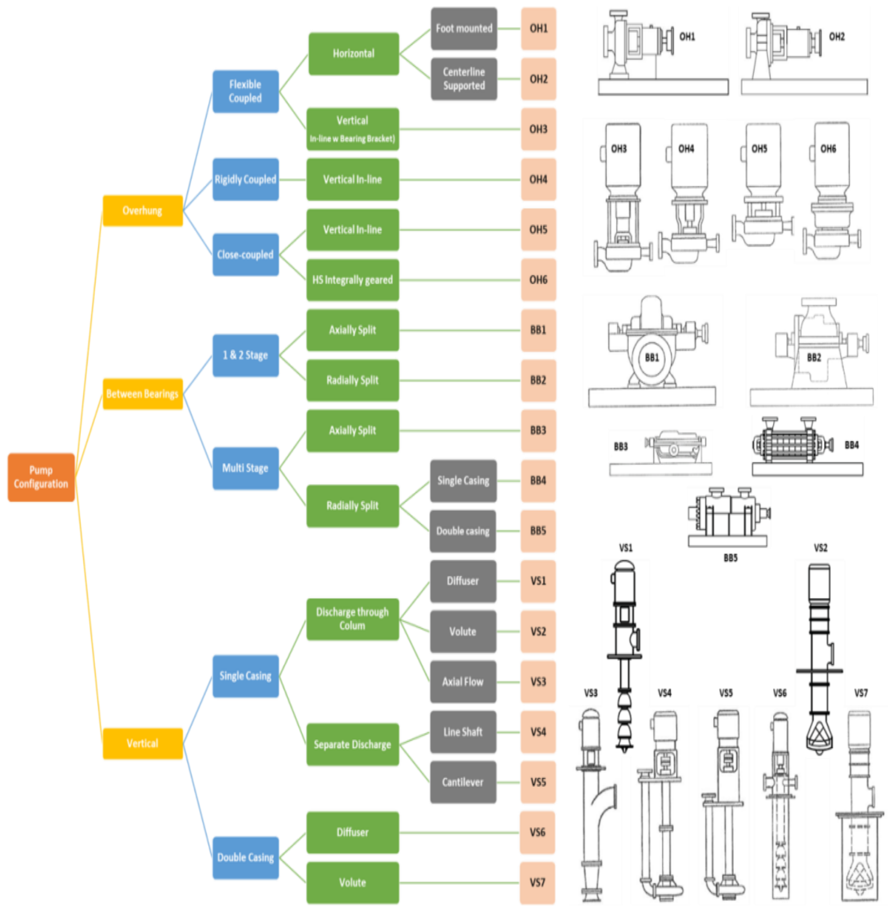
Estimate remaining lifespan of motor pumps down to Lowest Replaceable Units

Recommend timely maintenance activities

Using RUL enables just in time inventory by estimating order dates for replacement of parts

Applicable Centrifugal Motor Driven Pumps

The deep engineering context is embedded within the preconfigured set of motor/pump engineering models in the application software to provide faster scalability into the plants – for example the embedded model for a vertical, multi-stage, axially split, pump is different than the embedded model for vertical, single casing pump with discharge through an axial flow column.



About The DEI Group, Inc

The DEI Group Inc. has been helping customers such as U.S Navy, Chevron Shipping, GE Power, Chevron Power, TVA, Duke Energy, and others to deploy reliability engineering solutions that take advantage of **engineering** derived, Artificial Intelligence based data science applications for optimizing asset life cycle management for over 38 years. Development and application resources combine PhD-level analytic expertise and industry experience from fields such as: data science; reliability engineering; electrical engineering; nuclear engineering; mechanical engineering; software engineering; plant engineers; equipment maintenance professionals. **Do you want to know more? Please contact us at: MGelato@dei-group.com**

Terms:

Diagnostics- is the classification of observed anomalous equipment behavior to one of its known failure modes. In other words, which equipment component degradation (failure mode) is causing an observed deviation from design performance.

Prognostics – is a prediction of how much time is left before a failure occurs (of one or more faults or "potential failures") given the current machine condition and the past (and future) operating profile.

RUL- Remaining Useful Life

The machine operating time remaining before reaching the high risk point in an equipment component's life (37% remaining life) is called "remaining useful life

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