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# Condition Monitor

## Brüel & Kjær Vibro names Volker Polonyi as CEO and President

**Brüel & Kjær Vibro (B&K Vibro), one of the leading worldwide independent suppliers of condition monitoring solutions for rotating machinery, has named Volker Polonyi as its new CEO and President.**

Volker joins from B&K Vibro's parent company, NSK, a global organisation specialising in researching, designing and manufacturing motion and control solutions. Most recently at NSK, Volker was Director of the European Technology Centre (ETC), a state-of-the-art regional research and development facility that developed advanced bearing technologies to ensure that customers could respond effectively to challenges in their business environment.

**Volker Polonyi joins Brüel & Kjær Vibro as the new CEO and President** *Image courtesy of Brüel & Kjær*

Overall, Volker Polonyi brings with him 35 years of experience in bearing and linear technology, having also previously served as NSK's Managing Director for Industrial Bearing Sales, Sector Manager for Wind Power Technology and Head of Application Development.

Dai Kodama, Chief Integration Officer for NSK, said: "In his many years with NSK, Volker Polonyi has successfully developed and executed commercial and digital strategies that create customer value through technology. The expertise that he brings from NSK, coupled with his industry knowledge and leadership skills, are exactly the right combination to drive the condition monitoring business of Brüel & Kjær Vibro to the next level. His appointment marks an exciting milestone for Brüel & Kjær Vibro."

Volker commented: "There are clear synergies between B&K Vibro and NSK, with a huge degree of shared talent and knowledge, and we have been working together successfully to deliver exciting, innovative business and engineering solutions. As CEO and President of B&K Vibro, I am looking forward to working with our customers, colleagues and partners to expand our business, capture new markets and drive long-term growth."

## Metso Outotec teams up with Dynamox

Metso Outotec and Dynamox have entered into a global cooperation agreement based on the usage of Dynamox's condition monitoring platform in mining and aggregates processes. Metso Outotec is offering the solution to its own installed equipment base; the partner agreement also enables third-party equipment monitoring, further strengthening the company's digital scalability and solution flexibility.

"Dynamox is an important addition to Metso Outotec's partner ecosystem and is complementing our goal of developing and providing easy-to-use and sustainable digital solutions to our customers. We also see significant opportunities for further development in the field of artificial intelligence (AI) and analytics," said Tuomas Martinkallio, Vice President of Digital Services at Metso Outotec.

"The new technology will become a seamless part of the Metso Outotec Metrics solution. For example, screening customers use Metrics to obtain real-time condition monitoring data that can be used to continuously improve production efficiency and achieve maximum output," stated Jan Wirth, Director of RTD and Engineering, Screening Business Line at Metso Outotec.

By combining Metso Outotec's original equipment manufacturer (OEM) expertise with the digital solution offered by Dynamox, it is possible to provide customers with modern, easy-to-install instrumentation that can be complemented with comprehensive value-added services in the customer's value chain. When the innovative monitoring capability is combined with Metso Outotec's Performance Centers' remote monitoring services and global field service network, the company can further support customers in achieving reliable plant performance.

"We are delighted to collaborate with Metso Outotec for the customer benefit. For us, the strategic partnership is a significant recognition of the development of innovative and high-quality maintenance solutions that are different from those of other solution providers," said Guillaume Barrault, CEO at Dynamox.

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# Stratio announces a global agreement with Keolis

Stratio, a leading predictive fleet maintenance platform, and Keolis, a world leader in shared mobility, have announced the signing of a global framework agreement to enable predictive maintenance and provide remote diagnostic technologies to Keolis's networks. As part of the agreement, Keolis Group, which operates in 14 countries, may use the Stratio Platform and benefit from predictive fleet maintenance and remote diagnostics for buses and coaches.

The Stratio Platform, which is powered by advanced, agnostic artificial intelligence (AI) and machine learning models, can monitor, analyse and predict failures in real time, in vehicles of any type, brand and model. This shift from preventative to predictive maintenance results in increased vehicle uptime and optimised depot operations, ultimately saving costs and improving the service offered to the public.

"The Stratio solution, which is already deployed on several Keolis networks in France, allows maintenance staff to view and address vehicle failures. This eliminates costly downtime, enabling us to provide an even more reliable, efficient and safe service for passengers, while helping our operations staff to improve their eco-driving," declared Pierre Gosset, Industrial Division Director at Keolis Group.

"Keolis's commitment to innovating, automating and digitalising their maintenance operations goes to show how much they value their own customers. We are pleased that they chose Stratio to help them to deliver on their objective of connecting people with opportunities and resources with a public transport service that is safe, reliable and future-proof," said Rui Sales, Co-Founder and President of Stratio.

"Partnering on a global scale with one of the largest fleets in the world accelerates the realisation of our goal of creating a zero-downtime future that benefits everyone," Rui added.

# SkySpecs integrates advanced AI capabilities

With the launch of SkySpecs' Horizon CMS platform, wind turbine operators can now unlock the full potential of their fleet data in order to lower operation and maintenance (O&M) costs and focus on optimising for maximum uptime. The advanced condition monitoring platform is enhanced with Kaleidoscope AI, a cutting-edge fault detection technology that uses artificial intelligence (AI) for early and robust fault detection of critical drivetrain components, such as gearboxes, generators and main bearings. The Horizon CMS platform is disrupting the software paradigm that engineers have relied on for over a decade.

"We built the platform so operators can unify sensor data from across their entire fleet and radically improve predictive performance and efficiency," said Danny Ellis, CEO at SkySpecs. "True diagnostic AI has been a critical development path to help asset operators achieve a step change in monitoring efficiency. Through that effort, we realised early that asset owners also just need better CMS tools to improve efficiency and performance. CMS's slow evolution has been holding the industry back. Horizon CMS is the leap forward the industry needs."

Horizon CMS is a cloud-based platform for condition monitoring of renewable energy assets using sensor data streams from the already existing CMS hardware. It is built to enable the deployment of the Kaleidoscope AI library for advanced fault detection. The AI models are trained using CMS domain knowledge, mechanical data and past failure data. This ensures that operators receive early and robust warnings on any developing faults. The work experience for CMS engineering teams will be revolutionised with a highly performant diagnostic toolbox and powerful alarm management workflows.

The software platform works across multiple CMS brands and seamlessly interfaces with existing hardware. It enables asset operators to unify condition monitoring across data streams into a single powerful platform. This is especially important for engineers and data scientists that are monitoring fleets with multi-brand wind turbines.

The resulting package is a high-performance cloud platform optimised for large-scale and advanced condition monitoring.

Horizon CMS was developed through industrial innovation partnerships with two of the top five largest wind farm operators in the world, which have provided the operational environment and contributed the data and expert knowledge needed to develop the platform.

The off-the-shelf Software as a Service (SaaS) solution provides many key benefits to operators and engineers, such as:

- Reduced drivetrain-related downtime and better O&M planning;
- Turbine efficiency gains due to earlier and more robust fault detection, resulting in reduced downtime;
- Up to 10× monitoring performance compared to classic CMS methods;
- Unified CMS data streams in one user-friendly cloud platform; and
- Drastically simplified alarm management.

"Horizon CMS is a part of setting the industry up to take a big step into the future," added Ellis. "Access to actionable data is a key part of that next step. Operators know that data is crucial for performance management and long-term maintenance of fleets. Horizon CMS puts all the necessary data at their fingertips."

# Geospace Technologies awarded US$4m contract

Geospace Technologies Corporation has announced a US$4 million (approximately £3.4 million) rental contract with an international marine geophysical services provider that will rent OBX-750E seabed ocean bottom wireless seismic data acquisition nodes for a shallow offshore seismic survey.

"During our recent exhibition at the European Association of Geoscientists and Engineers in Madrid, we experienced a significant increase in discussions surrounding the use of our wireless ocean bottom node products for both deep and shallow water applications," said Walter R Wheeler, President and CEO at Geospace Technologies. "This follows the announcements in our previous quarter of OBX-related commerce that included a US$10 million sale and US$7 million in rental contracts (approximately £8.5 million and £5.9 million, respectively). This contract provides further evidence of increased activity in offshore markets, where our versatile ocean bottom node products can provide the high-quality data needed to reliably make critical exploration decisions."

Geospace principally designs and manufactures seismic instruments and equipment. The company markets seismic products to the oil & gas industry to locate, characterise and monitor hydrocarbon-producing reservoirs. The company also markets seismic products to other industries for vibration monitoring, border and perimeter security and various geotechnical applications. Geospace designs and manufactures other products of a non-seismic nature, including smart water connectivity tools, imaging equipment and specialty contract manufactured products.

# Prophesee's free release

Prophesee, a developer of neuromorphic vision systems, has announced that the newest release of its Metavision Intelligence suite will be offered in its entirety for free, including all modules.

The suite is intended to deliver an accelerated path to explore and implement differentiated machine vision applications that leverage the performance and efficiency of event-based vision.

The Metavision suite, which Prophesee claims is industry's most comprehensive suite of software tools and code samples, will be available for free from initial adoption use, through to commercial development and the release of market-ready products.

With this advanced toolkit, engineers will be able to develop computer vision applications on a PC for a wide range of markets, including industrial automation, Internet of Things (IoT), surveillance, mobile, medical, automotive and more.

The free modules in Metavision Intelligence 3.0 are available through C++ and Python APIs and include a comprehensive machine learning toolkit. The suite also offers a no-code option through the Studio tool, which enables users to play prerecorded datasets for free, without needing to own an event camera. With an event camera, users can stream or record events from their event camera in seconds.

In total, the suite consists of 95 algorithms, 67 code samples and 11 ready-to-use applications. Plug-and-play provided algorithms include high-speed counting, vibration monitoring, spatter monitoring, object tracking, optical flow, ultra-slow-motion, machine learning and others. It provides users with both C++ and Python APIs, as well as extensive documentation and a wide range of samples organised by its implementation level to incrementally introduce the concept of event-based machine vision.

The latest release includes enhancements to help speed-up time to production, allowing developers to stream their first events in minutes or even build their own event camera from scratch using the provided camera plug-ins under an open-source licence as a base.

They now also have the tools to port their developments on Windows or Ubuntu operating systems. Metavision Intelligence 3.0 features also allow access to the full potential of advanced sensor features (for example anti-flickering or bias adjustment) by providing source code access to key sensor plug-ins.

The Metavision Studio tool has also enhanced the user experience with improvements to the onboarding guidance, user interface (UI), return on investment (ROI) and bias set-up process.

The core ML modules include an open-source event-to-video converter, as well as a video-to-event simulator. The event-to-video converter utilises the pretrained neural network to build greyscale images based on events. This allows users to make the best use of their existing development resources to process event-based data and build algorithms upon it.

The video-to-event pipeline breaks down the barrier of data scarcity in the event-based domain by enabling the conversion of conventional frame-based datasets to event-based datasets.

# TK Elevator rolls out cloud-based solution

German company TK Elevator has rolled out a cloud-based real-time monitoring and predictive maintenance platform called Max. It collects data on components, systems and performance to assist building owners and managers in increasing elevator and escalator uptime. Max also assists facility staff in monitoring and controlling their equipment, as well as improving passenger safety using digital emergency services.

Max uses cloud technology, big data and machine learning to provide property owners and managers with operational and maintenance insights. Through real-time diagnostics, this Internet of Things (IoT) system improves overall elevator availability by eliminating out-of-service situations. Max can predict maintenance issues and send alerts to elevator engineers to replace components and systems before the end of the product lifecycle. It collects data from Max-connected elevators all over the world, including door movements, trips, power-ups, car calls and problem codes. This information is transferred to the cloud, where special algorithms look for trends and calculate the equipment's operation and remaining lifetime. It can provide the technician with exact and predictive diagnoses in real time, showing where intervention is required.

With Max's data-driven maintenance technology, TK Elevator intends to transform the elevator business by cutting downtime by up to 50%. It provides real-time alerts to service engineers and technicians on pre-issue repairs, making property owners more proactive with customers. This involves arranging repair tasks ahead of elevator breakdowns and during periods when the building is least crowded. It can also assist building managers and users in avoiding the frustration and inconvenience associated with out-of-service elevators. Max also comes with Max Link, a digital emergency communications system that eliminates the need for costly analogue phone lines.

# NI develops the ActiveUptime

NI has launched ActiveUptime, a Maintenance-as-a-Service (MaaS) solution for condition monitoring and predictive maintenance of test equipment and test facilities. This turnkey solution is tailored to the user's environment and provides the information needed to proactively monitor system health and prevent critical test equipment from failing. As part of the ongoing service, a dedicated technician from NI's maintenance team will remotely monitor system health, provide support and adapt the solution based on the customer's needs. This solution advances the user's capabilities to proactively predict outages before they happen.

Equipment failure accounts for 42% of unplanned downtime costs and an estimated annual US$50 billion (approximately £40.8 billion) in losses globally to manufacturers, yet 52% of manufacturers report using spreadsheets to monitor and manage equipment. ActiveUptime delivers a ready-to-use service that includes the hardware and software necessary to collect valuable environmental and system data and edge-based preprocessing to speed-up data collection, aggregation and movement. The outcome-specific dashboards for both condition monitoring and predictive maintenance monitor system health in real time and identify critical areas needing attention, thereby eliminating the disruption caused by unexpected equipment failures.

"One of the key challenges faced by manufacturers is having visibility into physical systems to keep them running smoothly and avoiding any reputation-damaging product failures," said Josh Mueller, SVP & GM of NI's Portfolio Business Unit. "ActiveUptime provides the most accurate picture of these systems. With the assistance of our maintenance experts, our customers get to the root of the problem quickly, achieve fast resolution and implement measures to prevent it from happening again."

ActiveUptime delivers the monitoring tools needed by maintenance teams, from intelligent environmental sensor boards and optimised data processing to intuitive real-time dashboards and predictive modelling, with the addition of having maintenance experts at the ready. The complete service can be up and running in days rather than months, turning a test into a strategic asset.

"Predictive maintenance and CM are becoming key pillars in the broader digital transformation of manufacturing," Josh explained. "Real-time continuous monitoring maximises total asset uptime, reduces the costly expense of spares and optimises maintenance costs by moving from time-based to usage-based maintenance."

# Vibration sensor for wind power turbines

Effective monitoring of slow-speed rotating industrial applications, such as wind power generation, is a critical requirement, just as it is on standard-speed applications, especially given the expansion of 'green-energy' alternatives. Reliable and effective vibration measurement of low-speed machinery (typically less than 300 r/min) helps to ensure that the machinery and plant is functioning at optimal levels and is one of the areas that condition monitoring specialist Sensonics provides effective solutions for.

For all wind power applications, the focus should be to understand the dynamic behaviour, establish a baseline vibration performance and then detect the early onset of failure in rotating parts. As with all condition monitoring applications, if machinery is left unchecked there is increased potential for more serious damage, which could affect overall performance.

While using accelerometers is commonplace on standard-speed machinery (usually 1500 r/min), this becomes problematic at lower speeds as the absolute accelerations measured are much smaller in value for similar vibration displacements. Sensonics recognised the need for a sensor to meet these specific requirements and it is why it has developed its low-frequency VEL/GLF velocity vibration sensor, which is ideal for wind energy machinery.

The VEL/GLF is an electrodynamic sensor that provides a superior performance compared to piezoelectric devices by combining high measurement sensitivity with a frequency response down to 0.5 Hz. This makes it ideally suited to measuring velocity vibration on equipment with speeds below 300 r/min.

The sensor offers a standard IEPE type interface to enable easy integration with existing plant protection and monitoring equipment. Furthermore, the VEL/GLF provides advantages over traditional piezoelectric-based velocity vibration sensors, which are susceptible to many forms of interference in low-frequency applications that can result in spurious readings and alarms.

Due to its robust design, the VEL/GLF offers high noise immunity due to the low impedance electrodynamic nature of the sensor assembly. In addition to the filtering of high-frequency events and since no electronic integration is required, the design is immune to the saturation problems that impair the reliability of piezoelectric devices.

# Development of a maintenance framework for modern manufacturing systems – a case study across UK manufacturers

A Shaalan, D Baglee and D Dixon

Paper presented at CM 2022, the Eighteenth International Conference on Condition Monitoring and Asset Management, 7-9 June 2022, London, UK.

*Modern manufacturing organisations are designing, building and operating large, complex and often 'one of a kind' assets that incorporate the integration of various modern control systems. Due to such complexities, machine failures have become more difficult to interpret and rectify and the existing maintenance strategies have become obsolete without development and enhancement. As a result, there is a need for more advanced strategies to ensure effective maintenance applications that provide high operational efficiency. The current research aims to investigate the existing maintenance strategies and the levels of machine complexity and automation within manufacturing companies of different sizes within different sectors, including oil & gas, food & beverages, automotive, aerospace and original equipment manufacturers. Analysis results support the development of a modern maintenance framework that overcomes the highlighted results and suits modern manufacturing assets, using systematic approaches and utilisation of pillars from total productive maintenance (TPM), reliability-centred maintenance (RCM) and Industry 4.0.*

## 1. Literature review

Modern maintenance can be categorised into two main areas: corrective maintenance and preventative maintenance. Corrective maintenance is a type of maintenance action that takes place after a breakdown happens and includes replacement and repair tasks, depending on the severity of the breakdown. Corrective maintenance generally causes an interruption to production, which results in a negative impact on production output, efficiency and machine availability[4].

The aim of preventative maintenance is to mitigate for any potential machine failure by addressing performance or functionality issues before a breakdown occurs. This protects the system from unscheduled stoppages due to sudden breakdowns.

### *1.1 Total productive maintenance (TPM)*

Total productive maintenance (TPM) is considered to be an effective organisational maintenance philosophy as it improves machine reliability and the morale of employees[20]. TPM was introduced in the 1950s in Japan as a structured concept for maintaining and preserving machines and organising the workplace. The main target of TPM, similar to other maintenance strategies, is to increase productivity and equipment efficiency[6]. TPM focuses on staff engagement, waste elimination, increased productivity (while maintaining high-quality products), cost reduction and effective defect-free product delivery to customers. It is considered to be a unique maintenance strategy as it has a high focus on the human aspect at the organisation, rather than focusing solely on machines to improve practices. TPM facilitates the engagement of operators by allowing involvement in simple maintenance tasks and improving communication and the working environment through the engagement of management with shopfloor staff[22,2].

The primary metric for the effectiveness of TPM is the overall equipment effectiveness (OEE). The OEE represents the efficiency of the complete manufacturing system, which is a function of machine availability, performance rate and quality[4]. One of the main reasons for the widespread use of OEE among researchers is its simplicity in measuring internal efficiency[10]. TPM uses eight main pillars, which are considered to be its foundation[10]. These are: 5S; autonomous maintenance; focused maintenance; planned maintenance; quality maintenance; education and training; safety, health and environment; and office TPM and development management[23].

### *1.2 Reliability-centred maintenance (RCM)*

The reliability-centred maintenance (RCM) concept was developed in the aviation industry to reduce machine downtime and maintenance costs and to improve flight safety. Subsequently, it started to be implemented in military applications, mining, railway services and many other areas. Standards were then developed to suit the different applications and place more attention on specific tasks[16,17], which led to the current standards for different industrial applications. These include IEC 60300-3-11, SAE-JA1011 and SAE-JA1012.

RCM analysis can be defined as a sequence of activities. The following steps explain the RCM analysis process:

- Define the system and explore its boundaries;
- Identify the most significant items (MSI). MSIs are the items that have the most significant economic, operational or safety impact on the system. The items could be systems, subsystems, components or parts;
- Identify the failure causes of each MSI;
- Predict the effects;
- Develop failure mode and effects analysis (FMEA). The main goal of FMEA is the identification process of the item's functions in alignment with the failure mode of the MSIs and their failure causes and effects;
- Apply simulations for reliability on the system for the development of the best intervals to enable maintenance tasks to take place;

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- Apply an RCM logic decision, as each MSI failure cause and effect is decided by the RCM decision logic chart. The specified preventative maintenance policy and the associated intervals are applied according to reliability data;
- Identify practical and suitable maintenance tasks, which include the initial maintenance plan;
- Equipment or process redesign with the occurrence of no suitable tasks being found to match the needs of the equipment; and
- Combine the PM policy and the development of the PM schedule.

FMEA is a methodology that aims to identify and analyse each potential failure mode that might take place in a system. Furthermore, the objective is to quantify the possible effects on the system, assuming that the system is in optimal condition[24]. It is considered to be a semiqualitative reliability approach that is applied systematically to evaluate the system at component level for failure mode and effects identification. It also provides support for fault-tolerant design, safety, testability and related functions[5].

Additionally, FMEA is considered to be a systematically structured tool in its evaluation of potential failure modes and their effects. The main goal of FMEA is to eliminate or reduce potential failures as much as possible, starting from the highest priority failures[21].

## 1.3 Condition-based maintenance (CBM)

Condition-based maintenance (CBM), on the other hand, presents a new perspective for developing the desired machine maintenance schedule relying on modern technology for sensing and identifying the current machine's internal conditions. Sensing tools include vibration, temperature, pressure and noise measurements. These tools suit different machines depending on their criteria and operating conditions. Some machines could be from a rotating type of equipment, where vibration analysis would be most applicable. Other machines could be associated with certain pressure or temperature measurements as performance indicators for certain parts[12,15].

CBM generally focuses on scheduling maintenance activities based on real-time data from the field using condition monitoring tools. CBM mainly eliminates unnecessary maintenance tasks that could be scheduled to take place, in which the current state of the real-time machine measurements indicate that it is unnecessary to carry out the planned maintenance tasks. In return, this has a high impact on saving costs associated with spare-part replacement labour costs and costs incurred due to machine stoppage[12].

CBM is associated with three main aspects that are the central pillars in defining the necessary maintenance tasks and schedules[3]:

- Failure diagnosis – the stage that associates failure detection and the allocation of irregular behaviour with its cause and the related parts in the equipment;
- Failure prognosis – the prediction of the future state of the equipment, which provides an estimate of the predicted failure times; and
- Maintenance optimisation – a critical part of CBM that is related to establishing the connection between the expected failure times and maintenance schedule and determining the necessary types of maintenance to take place with each expected failure.

Maintaining an automation system presents the maintenance applications for the three main elements of any automation system: the power, programme of instruction and control system. Two main aspects are highlighted as the primary indicators for the quality of the automation system within an organisation: product features and freedom of deficiencies. Product features result from the design stage of the products, while freedom of deficiencies indicate the quality of the final product and the accurate execution of the input parameters of the system[8].

## 1.4 Maintenance of the programme of instruction

The system programme that controls the entire system's process must initially be written in a clear systemic way that allows for the intervention of different programmers in fault finding and diagnostic applications. A clear programme in a complex system saves a large amount of time and effort that could be spent detecting issues. For maintenance and diagnostic applications for individual systems, particular modes of operation should be implemented, such as automated mode, manual mode, putting mode and inching mode, where the automated mode is the standard mode of operation. Manual mode requires an operator to be present to activate specific buttons, while the putting and inching modes present the testing of individual sensors or actuators alongside the reduction of the speed of the system for accurate testing and diagnostics of individual parts. Additionally, different modes should be implemented based on the need and suitability of the existing equipment.

The architectural levels highlighted for the structure of the programme of instruction include[9]:

- The plant module;
- The facility module;
- The application module; and
- The basic module.

A plant module resembles a whole production plant and consequently exists mostly in the plant manufacturing industry. It usually contains several facility modules, which represent machines or plant parts, such as a press or a storage system. Each facility's module consists of one or more application modules, which are materials that might be used in other machines, such as the material feed of a machine or the filling unit of a machine. Application modules are composed of basic modules that represent, for example,

**Table 1. Maintenance generations**

| | First generation (1940s-1950s) | Second generation (1960s-1970s) | Third generation (1980s-present) |
|---|---|---|---|
| **Description** | ■ Run-to-failure | ■ Simple maintenance schedules<br>■ Systems for planning and controlling work<br>■ Slow computers | ■ Condition monitoring<br>■ Failure mode and effects analysis<br>■ Reliability and maintainability design<br>■ Effects analysis<br>■ Hazard studies<br>■ Expert systems<br>■ High skills and teamwork |
| **Technical definition** | ■ Corrective maintenance | ■ Preventative maintenance | ■ Reliability-centred maintenance<br>■ Total productive maintenance<br>■ Condition monitoring |

individual drives or sensors. Basic and atomic basic modules represent the most fine-grained architectural level and refer to basic modules that cannot decompose into a further module, such as bolts, nuts and belts.

### 1.5 Conclusion

TPM, RCM and CBM were developed with a focus on specific areas of existing assets. TPM focuses on the organisational and human factors of the maintenance application, examining the level of engagement, skills and the existing workforce culture. Alternatively, RCM and CBM concentrate on the machine or system, including the failure analysis process. This allows for deeper understanding and control of an asset[11,13,14].

Roda *et al* argued that the utilisation of an existing, predefined strategy will not provide the desired improvements. They identified the need for the user to select certain pillars from various strategies, including tools that reflect technological advancements[18]. Furthermore, they acknowledged this research and concluded that recent studies broadly considered the modernisation of maintenance strategies through the integration of digital technologies.

The implementation of any new or improved maintenance strategy revealed barriers and inhibitors, which restricted any positive impact. This included a lack of engagement by the senior management team and significant issues with the existing organisational culture[7]. Furthermore, the inhibitors also revealed that any advances in maintenance technology and techniques highlighted a significant lack of training, skills and experience to deal with modern asset management[1,19].

## 2. Methodology

The research was conducted on a selection of manufacturing companies from different industries and of different sizes to allow for the examination of maintenance practices that exist across five companies from oil & gas, food & beverages, automotive and original equipment manufacturer (OEM) sectors. Data collection was conducted using multiple sources, including semistructured open-end interviews with maintenance managers, maintenance engineers and operators, collection of maintenance data records and observation of maintenance applications in real time. The analysis of various sources of data supported each other in each extraction and provided certainty for the existing conditions. As a result, a framework was developed utilising pillars of existing maintenance strategies with the support of digital technologies. Developed framework validation was conducted on three manufacturing companies, two from the initial investigation and a newly added company to the research.

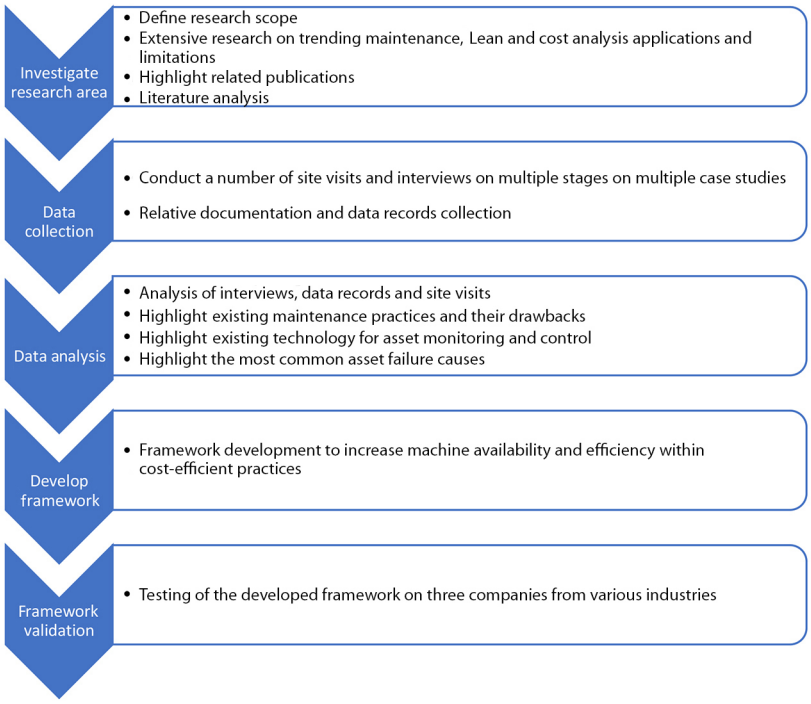


**Figure 1. Case study methodology**

## 3. Results

### 3.1 Failure records investigation

A review of the recording mechanism of maintenance task information was undertaken with the case study partners. Table 2 highlights several concerns. As can be seen, case study 3 and case study 5 do not possess the ability to benchmark or plan effectively. This improves with case study 2 and case study 4 which, on the surface, appear to acknowledge the need for data collection, despite the methodology used. Case study 1 is the only one that utilises a modern maintenance management system.

The summary presented in Table 2 may be expanded upon by revealing the following:

- Incorrect or no classifications to most of the data regarding machine failure;
- Ineffective or no description of the occurred failures or the actions carried out;
- Conflicting maintenance information relating to the same task;
- Superficial costing and resource details for maintenance actions; and
- Inaccurate overall equipment effectiveness, mean time between failures (MTBF) and mean time to repair (MTTR) calculations.

**Table 2. Existing maintenance recording tools**

| | Case study 1 | Case study 2 | Case study 3 | Case study 4 | Case study 5 |
|---|---|---|---|---|---|
| No data records | | | × | | × |
| Paper-based | | | | × | |
| Computerised spreadsheets | × | × | | × | |
| CMMS | × | | | | |

### 3.2 Existing maintenance strategies

Identifying the deployed maintenance strategy for each case study company revealed a mixture of approaches with varying degrees of implementation. A major concern appeared to be the lack of implementation of a complete framework to support the maintenance applications, with the majority relying on reactive and planned maintenance. Strategies such as TPM, RCM and CBM were not fully utilised and only specific areas of each strategy were used.

### 3.3 Breakdown overview

Breakdowns took place due to multiple reasons that could be summarised by the following:

- Unreliability of machines from the OEM due to poor build quality;
- Obsolescence of the machines due to old age and poor maintenance applications;
- Overloading beyond machine capability due to production requirements;
- Operator disregard for standard operating instructions;
- Poor knowledge of the assets and their modes of operation; and
- Poor planning and execution of maintenance tasks.

### 3.4 Factors influencing the success of an applied maintenance strategy

- Financial – the impact of financial barriers was highlighted in various elements regarding the availability and quality of machines, starting with the purchase of the assets from unreliable sources that supply companies with low-integrity or faulty new machines with design issues. In addition, financial barriers impact the development of suitable training programmes for employees to increase their skills and knowledge level.
- Limited knowledge – a lack of training within an organisation led to a gap in technical knowledge for several key production assets. This gap resulted in mistakes being made regarding maintenance monitoring, planning and execution. This was compounded by incomplete standard operating procedures for machine operation.
- Insufficient design for maintenance – a common practice in the manufacturing sector is to include bespoke machines developed specifically for the manufacturer by a specialised OEM. A major drawback of this is if special-purpose machines suffer from design issues that permanently affect the performance of the machine, which can lead to continuous breakdowns or defected products. This is demonstrated in case study 1, where the main asset suffered from design issues, causing a high number of breakdowns and product deficiency.

The investigation revealed that new, bespoke manufacturing assets integrate several complex subsystems, which result in a highly complex manufacturing machine. As a result, there is a need for a comprehensive training and development package for all stakeholders. The commissioning of a technologically advanced asset to improve business performance must be complemented by a 360 degree awareness of the needs of all stakeholders, otherwise the asset will fail to fulfil its potential.

## 4. Development of a modern maintenance framework

The results section presented four main areas of major impact on the quality of maintenance practices, which were financial barriers, limited skillset, limited time and machine reliability. Based on these main aspects, a framework was developed to tackle such issues efficiently using various tools from all existing maintenance frameworks.

The pillars of this framework were developed from the case study research and include critical elements, which address recognised inhibitors. Moreover, it includes recently developed technology to support maintenance tasks.

### 4.1 Management

Managerial aspects are the main drive for the development and stability of effective maintenance practices, as they pave the way for systematic controlled maintenance practices. Several aspects were highlighted as vital elements for the support and management of maintenance applications.

#### 4.1.1 Workforce-related aspects

This area focuses on engaging members of staff, which are the maintenance team and the operators, with the assets. The workforce has a high impact on the lifetime and deterioration level of the assets. Such an impact could result from misuse by the operator or reduced maintenance applications.

#### 4.1.2 Organisational-related aspects

The initial establishment of metrics supports the establishment of the current state of the machinery and operational performance. The metrics utilised are OEE, MTTR, MTBF, maintenance costs and ROI.

### 4.2 Technical

Focusing on the technical side of the framework, much attention is given to the appropriate in-depth investigation of the different elements that have a direct effect on the efficiency and production quality of the assets. The technical side of the framework covers three main phases:

- Existing maintenance strategies evaluation;
- Document evaluation; and
- Site and asset evaluation.

#### 4.2.1 Existing maintenance strategies

Examination of the existing maintenance strategies that might exist and are followed by the organisation for their reliability applications must be carried out. Different strategies could vary from run-to-failure, preventative or proactive strategies that could have been utilised by the company under improvement.

The existence of such data provides great assistance to the operators and the maintenance team for determining the appropriate operating sequences and guidance of the different connections and parts of the internal components, as well as quick parts reference for replacements or maintenance applications.

**Table 3. Applied maintenance strategies**

| | Case study 1 | Case study 2 | Case study 3 | Case study 4 | Case study 5 |
|---|---|---|---|---|---|
| Reactive | × | × | × | × | × |
| Preventative | × | × | | × | |
| Condition monitoring | × | | | | |

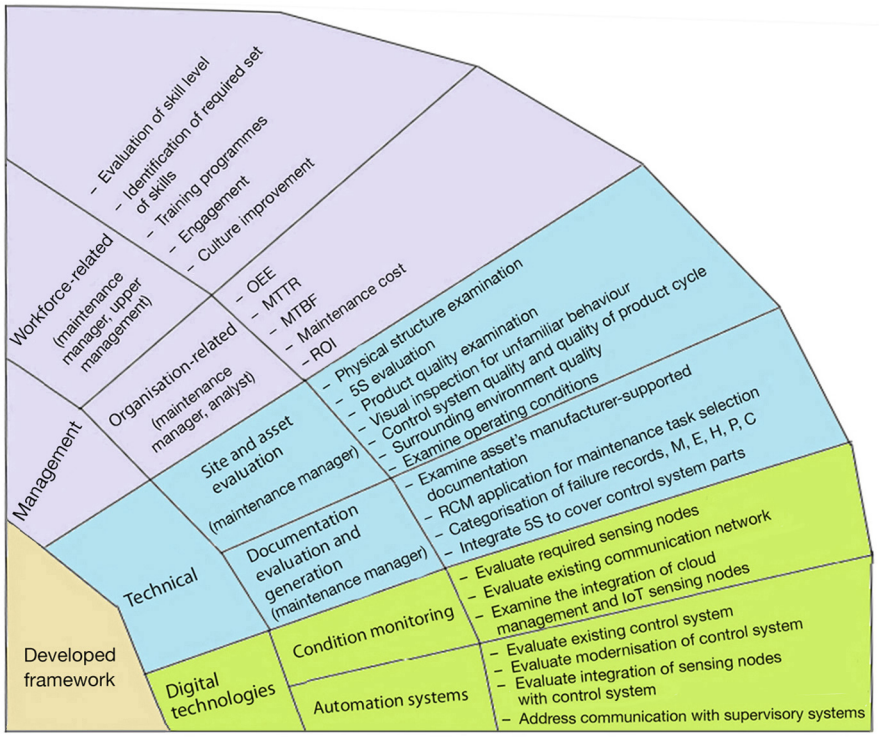


**Figure 2. Developed framework**

### 4.2.2 Site and asset evaluation

The importance of the site and asset evaluation phase lays in the ability to identify the existing conditions on site from different aspects. Such a practice highlights the areas that require improvement in efficiency and availability. The evaluation includes the following:

- Physical structure reliability – the investigation of the physical structure of the asset under examination. Such an investigation focuses on the presence of any deformations, cracks or breaks in the different structure's parts. The early identification of any abnormal deficiencies on the assets could be useful in different ways, as it could help with the early identification of failures that are difficult to identify, which could have a significant impact on the asset and product deficiencies.
- Control system reliability – advanced manufacturing assets integrate a high number of technological advancements in the production cycle that, in return, result in a complex network of different types of connection between the different integrated parts. Such control systems are vulnerable to being affected by the poor surrounding environment.
- Product quality – the quality of the existing system and its performance is reflected. Product deficiencies take place due to misalignment or failure of minor components that do not halt the manufacturing process.
- Visual inspection for unfamiliar behaviour – a visual inspection could provide significant assistance in early failure detection applications. Unfamiliar noise that could be pneumatic-related or screeching sounds could indicate a source of failure in an inner component or connection in the system.

### 4.2.3 Document evaluation and generation

The high integration of technology and control systems within advanced manufacturing assets creates complexity in the connections and wiring of the internal components. Relevant referencing documentation of each asset must exist, such as schematics diagrams, wiring diagrams, a control programme, operating guidance, suggested maintenance applications and a components list.

Within the current framework, integration of the following documentation is considered a key aspect in supporting the operators and maintenance team in executing their tasks efficiently:

- Categorisation of failure records, M, E, H, P and C;
- RCM application for maintenance task selection;
- Guidance for operators and maintenance staff for selected applications; and
- Integrating 5S to cover control system parts.

## 4.3 Digital technologies

Advancements and complexities within current manufacturing assets require advanced tools to assist the maintenance staff with accurate and more accessible failure detection processes. Advanced technologies present measurements and analytical advancements that measure the behaviour of the machinery based on their types and actuation mechanisms. Each mechanism has specific indicators that differ from temperature, vibration or pressure, for example.

### 4.3.1 Condition monitoring

The use of technological advancements to facilitate and improve the quality of maintenance applications has become essential. Such needs are required due to the complexity and advancements that exist in modern manufacturing assets. Advancements in inspection and detection tools emerged widely to provide more insight into the internal parts of machinery. Temperature, ultrasound, vibration, current and voltage monitoring and object detection devices are examples of the essential sensing technologies that should be utilised for failure identification.

## 4.4 Framework validation

The application of this research demonstrates the ability of the framework to address the multi-sector challenges for a successful maintenance plan. This includes cost, knowledge, machine performance and technology.

Case study 1 in the validation application presented high deficiencies in multiple areas, including machine design, the technology integrated, knowledge and skill levels and organisational and maintenance application level. The framework presents efficiency in the auditing and establishment of improved maintenance practices through machine failure root cause detection, improving data record quality and setting recommendations for the adjustments needed to improve quality and availability. The framework lacked efficiency in case study 1. This was due to the initial lack of clarity regarding the framework. The framework impact on the data collected from case study 1 did not provide the required quality of data for sufficient analysis, although it did help in providing more insight into the targeted area of interaction that requires attention.

Case study 2 showed highly advanced systems with similar deficiencies in knowledge, maintenance applications and machine performance. The framework provided detailed guidance to investigate and explore the required maintenance and adjustments, alongside performance indicators and condition monitoring tools for high-quality maintenance applications. The framework highly supported the examination and determination of the current status of the assets, as well as the application required to improve the availability and performance of the system. With maintenance and automation

knowledge transfer delivered to the maintenance team and operators, the operational performance and the quality of the engagement of the operators with machines reduced the workload on the maintenance team and improved productivity. The framework supports the tackling of essential drawbacks that exist within modern manufacturing systems and improves the quality of the applied maintenance practices.

## 5. Conclusion

The development of a modern maintenance strategy has become an essential requirement with the continuous modernisation of manufacturing assets and the integrated level of technology. The current research focused on an investigation into the existing maintenance practices and their drawbacks within the local manufacturing sector in the north east of England. With results highlighting the majoring of reactive maintenance associated with finance, skills and poor machine quality, a modern framework utilising modern technologies and addressing major impacting findings from the research was developed. The framework has been validated by three local manufacturing companies, proving its ability to tackle essential points of interest to improve maintenance practices.

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# Condition monitoring paper abstracts

**The following papers have been published recently in a variety of peer-reviewed academic and scientific journals. Titles, authors, volume, issue and page references have been given, along with the abstract where available.**

## Health state estimation and remaining useful life prediction of power devices subject to noisy and aperiodic condition monitoring

| | |
|---|---|
| ***S Zhao et al*** | *IEEE Transactions on Instrumentation and Measurement, Vol 70, pp 1-16, 2021* |

Condition monitoring of power devices is highly critical for safety and mission-critical power electronics systems. Typically, these systems are subjected to noise in harsh operational environments, contaminating the degradation measurements. In dynamic applications, the system duty cycle may not be periodic and may result in aperiodic degradation measurements. Both of these factors negatively affect the health assessment performance. In order to address these challenges, this article proposes a health state estimation and remaining useful life prediction method for power devices in the presence of noisy and aperiodic degradation measurements. For this purpose, three-source uncertainties in the degradation modelling, including the temporal uncertainty, measurement uncertainty and device-to-device heterogeneity, are formulated in a gamma state-space model to ensure health assessment accuracy. In order to learn the device degradation behaviour, a model parameter estimation method is developed based on a stochastic expectation-maximisation algorithm. The accuracy and robustness of the proposed method are verified by numerical analysis under various noise levels. Finally, the findings are justified using accelerated ageing test data from SiC metal-oxide-semiconductor field-effect transistors (MOSFETs). *©2021 IEEE.*

## Fault detection and diagnosis of linear bearings in autocore adhesion mounting machines based on condition monitoring

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| ***P Chommuangpuck et al*** | *Systems Science & Control Engineering, Vol 9, No 1, pp 290-303, 2021* |

This study aims to increase machine reliability, thereby preventing product defects from adhesive dispense and slider attachment using a fault detection and diagnostic technique. The experiment was set up to investigate the vibration signal and motor current. Six fault conditions of a linear bearing were set up. The approaches, including spectrum analysis, crest factor and analysis of variance, are used for data analysis. It was found that spectrum analysis was suitable for classifying the frequency domains and the statistics tool was successful in measuring the current. Fault detection and diagnosis results can forecast the status of the linear bearings. *©2021 The author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.*

## Condition monitoring and life prediction of the turning tool based on extreme learning machine and transfer learning

| | |
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| ***Z Gao et al*** | *Neural Computing and Applications, 2021* |

A turning tool will break if it continues to be used for processing when it has worn and failed. This can cause the workpiece to be scrapped or can even cause damage to the machine tool. In order to avoid the loss caused by turning tool wear, remaining useful life (RUL) prediction of turning tool wear has become a hot research topic in recent years. For RUL prediction in turning tools, the traditional machine finds it difficult to acquire sufficient degradation data and inconsistent data distribution among different turning tools in engineering. To some extent, they cannot provide better prediction accuracy. To solve the above problems, this paper proposes a multi-granularity feature extraction (MGFE) method based on the grey-level co-occurrence matrix (GLCM) and random forest (RF). Moreover, a health indicator (HI) of turning tools in the source domain was obtained. The common representative features in a HI sequence of the target domain was transferred to the source domain and builds the condition monitoring and life prediction system of turning tools based on extreme learning machine and transfer learning. Finally, an extreme vector machine (ELM) is used to construct the RUL prediction model. The research results show that the model constructed in this paper is effective in RUL prediction and can significantly improve the prediction accuracy of remaining useful life. *©2021 The author(s), under exclusive licence to Springer-Verlag London Ltd, part of Springer Nature.*

## Condition monitoring in additive manufacturing using a support vector machine

| | |
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| ***D Nainwal et al*** | *Lecture Notes in Mechanical Engineering, pp 119-126, 2021* |

Additive manufacturing (AM) involves the deposition of materials to form a three-dimensional object by printing. Fused deposition modelling (FDM) is presently one of the most widely used AM techniques due to its ease of operation and lower cost. To achieve better part quality, there is a need to identify and monitor any process failure during 3D printing. In this paper, the experimental data for the faulty and healthy condition of the printed specimen is collected using an accelerometer at different process parameters. During time-domain feature selection, root mean square (RMS), interquartile range (IQR) and mean absolute deviation (MAD) were identified as key features for classification. When RMS and MAD were used as the main features for training the FDM model based on a quadratic support vector machine algorithm (SVM) and a *K*-fold cross-validation approach, an accuracy of 78.6% was achieved. Such a technique is capable of preventing faulty components and helping to save the material by diagnosing the machine at an early point. *©2021 Springer Nature Singapore Pte Ltd.*

## Hankel matrix-based condition monitoring of rolling element bearings: an enhanced framework for time-series analysis

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| ***W Sun et al*** | *IEEE Transactions on Instrumentation and Measurement, Vol 70, 2021* |

Robust bearing fault detection is significant in the reduction of machinery downtime and for the prevention of catastrophic failure. Many algorithms have been proposed for fault feature extraction, but it remains challenging to monitor the condition of mechanical systems in a short response time due to signals that contain overwhelming interference noise. To address this problem, as an extension of the authors' recent work, this article introduces an enhanced framework using acquired time-series signals. Specifically, an improved Hankel matrix-based method is proposed for the identification of the state from the sampled vibration signal for each spindle turn, where matrix similarity is employed for mechanical operation state monitoring. The experimental results indicate that the proposed method performs considerably well in fault identification (100% identification accuracy in three tests), even with a few data samples and a phase shift. This work, therefore, would provide more hopeful prospects in a variety of engineering fault detection applications. *©2021 IEEE.*

## Numerical modelling of vibration responses of helical gears under progressive tooth wear for condition monitoring

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| ***X Sun et al*** | *Mathematics, Vol 9, No 3, pp 1-17, 2021* |

Gear wear is a common fault that occurs in a gear transmission system that degrades the operating efficiency and may cause other catastrophic failures, such as tooth breakage and fatigue. The progressive wear of a helical gear and its influences on vibration responses are rarely investigated due to the combined effects of the complicated lubrication state and the time-varying characteristic. To fill this gap, a numerical study was put forward to investigate the interactions between gear wear and dynamic response. In this study, an Archard's wear model with elastohydrodynamic lubrication (EHL) effect is adopted to simulate the helical gear wear, which is incorporated with an eight degrees of freedom dynamic model for understanding the gear dynamic at different wear degrees. The wear model shows that the gear wear mainly occurs at the gear root due to the relatively high slide-to-roll ratio. The dynamic modelling results demonstrate that the wear causes a reduction in time-varying gear mesh stiffness, which leads to further vibration. Besides, the simulated vibration responses and experimental validation show that the wear causes increases in the amplitudes of the gear mesh frequency and its harmonics. This can reflect the evolution of progressive gear wear and can be used for monitoring features of gear wear. *©2021 The authors. Licensee MDPI, Basel, Switzerland.*

## Data-driven condition monitoring of mining mobile machinery in non-stationary operations using wireless accelerometer sensor modules

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| ***P Aqueveque et al*** | *IEEE Access, Vol 9, pp 17365-17381, 2021* |

This paper presents the development of an easy-to-deploy and smart monitoring Internet of Things (IoT) system that utilises vibration measurement devices to assess the real-time condition of bulldozers, power shovels and backhoes in non-stationary operations in the mining industry. According to operating experience data and the type of mining machine, the total loss failure rates per machine fleet can reach up to 30%. Vibration analysis techniques are commonly used for condition monitoring and early detection of unforeseen failures to generate predictive maintenance plans for heavy machinery. However, this maintenance strategy is intensively used only for stationary machines and/or mobile machinery in stationary operations. Today, there is a lack of proper solutions to detect and prevent critical failures for non-stationary machinery. This paper presents a cost-effective solution proposal for implementing a vibration sensor network with wireless communication and machine learning data-driven capabilities for condition monitoring of non-stationary heavy machinery in mining operations. During machine operation, three-axis accelerations are measured using two sensors deployed across the machine. The machine accelerations (amplitudes and frequencies) are measured in two different frequency spectrums to improve each sensing location's time resolution. Multiple machine learning algorithms use the machine data to assess conditions according to manufacturer recommendations and operational benchmarks. Proposed data-driven machine learning models classify the machine condition in states according to the ISO 2372 standards for vibration severity: good, acceptable, unsatisfactory or unacceptable. After performing field tests with bulldozers and backhoes from different manufacturers, the machine learning algorithms are able to classify the machine health status with an accuracy between 85%-95%. Moreover, the system allows for early detection of 'unacceptable' states between 120 h to 170 h prior to critical failure. These results demonstrate that the proposed system will collect relevant data to generate predictive maintenance plans and avoid unplanned downtimes. *©2021 IEEE.*

## Forest path condition monitoring based on crowd-based trajectory data analysis

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| ***F Arcas-Tunez and F Terroso-Saenz*** | *Journal of Ambient Intelligence and Smart Environments, Vol 13, No 1, pp 37-54, 2021* |

The development of road information acquisition systems (RIASs) based on the mobile crowdsensing (MCS) paradigm has been widely studied over recent years. Most of the existing MCS-based RIASs focus on urban road networks and assume a car-based scenario. However, a scarcity of approaches exist that pay attention to rural and country road networks. Forest paths are used for a wide range of recreational and sporting activities by many different people and they can also be affected by different problems or obstacles blocking them. As a result, this work introduces Samaritan, a framework for rural road network monitoring based on MCS. Samaritan analyses the spatio-temporal trajectories from cyclists extracted from the fitness application Strava to uncover potential obstacles in a target road network. The framework has been evaluated in a real-world network of forest paths in the city of Cieza, Spain, showing quite promising results. *©2021 IOS Press. All rights reserved.*

## Application of wavelet analysis in condition monitoring of induction motors

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| ***A Sharma et al*** | *Lecture Notes in Mechanical Engineering, pp 795-807, 2021* |

In the era of globalisation, manufacturing industries are facing intense pressure to prevent unexpected breakdowns, lower maintenance costs and improve machine availability. Due to the increasing trend of condition monitoring (CM), numerous sensors deployed on industrial apparatus around the world and several monitoring techniques available for fault diagnosis of induction motors are growing at a rapid pace. This article provides a state-of-the-art review of past and recent developments taking place in wavelet analysis-based CM and failure diagnosis in three-phase induction motors. The utilisation of different CM techniques in data processing and the application of wavelet-based automatic failure prediction in induction motors for timely scheduling of the maintenance holds great research potential in the future. *©2021 Springer Nature Singapore Pte Ltd.*

## Condition monitoring of ship propulsion systems: state-of-the-art, development trend and role of digital twin

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| ***A R Nejad et al*** | *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering – OMAE, Vol 7, 2021* |

This paper describes the current implementations and development trends of condition monitoring as it pertains to ship propulsion systems. In terms of total incidents in the shipping industry in the last five years, failures relating to the propulsion system represent the majority. Condition monitoring offers effective early detection of failure, which translates to increased reliability and decreased maintenance costs. Current industrial practices are often limited to performance monitoring, rather than condition monitoring. Special focus is afforded to how condition monitoring is implemented on board ships, which regulatory codes are relevant and the summary of state-of-the-art research in marine machinery. Moreover, operation and monitoring in extreme environmental conditions, such as the Arctic and Antarctic with ice impact on the propulsion, has been discussed. The new developments, in particular digital twin approaches in health and condition monitoring, have been highlighted considering its pros and cons and potential challenges. *©2021 ASME.*

## A free-standing electromagnetic energy harvester for condition monitoring in smart grids

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| ***H Wang et al*** | *Wireless Power Transfer, 2021* |

Wireless energy harvesting is an effective way to power condition monitoring sensors, which are the basis of smart grids. In this paper, a new free-standing I-shaped core is designed to scavenge electromagnetic energy from large alternating current. An I-shaped core can guide more magnetic flux by adding a pair of magnetic flux collector plates at both ends of the rod core. It weakens the core demagnetisation field and enables more energy to be collected. Since a magnetic field line can be bent with high-permeability soft magnetic materials, a highly efficient grid-shaped coil is proposed. Compared with the I-shaped coil, its weight is lighter and its power density is higher. A Mn-Zn ferrite with high relative permeability and ultra-low conductivity can effectively reduce eddy current loss and proves to be the most suitable material. The measured open-circuit voltage agrees well with the theoretical value. The experimental results show that the output power can reach 4.5 mW when the I-shaped coil is placed in a magnetic flux density of 6.5 $\mu T_{rms}$. The power density is 7.28 $\mu W/cm^3$. Therefore, the proposed design can be very effective for supplying condition monitoring sensors. *©2021 The authors.*

## Forecasting time-series change of the average enhanced vegetation index to monitoring drought condition by using Terra/MODIS data

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| ***S Sangpradide et al*** | *Agriculture and Forestry, Vol 67, No 4, pp 115-129, 2021* |

Drought condition is a natural disaster that has caused considerable economic and social damage, including a shortage of consuming water, and has been a hindrance to agricultural production and industrial development. Currently, the drought condition tends to be severe in the Yasothon Province of Thailand, thus affecting plantation in the area. The purpose of this study was to monitor the drought condition of Yasothon Province by using enhanced vegetation index (EVI) data from 2010-2019, obtained from the Terra MODIS Satellite, and studying the change in time series from the average EVI during 2010-2019, for the forecast in 2020-2022, by using the moving averages method and exponential smoothing method in order to compare the differences between the original data of the average EVI and the data of the average EVI adjusted by a smoothing algorithm using the RMMEH method. Statistics used in examining the forecasting accuracy were mean absolute deviation (MAD) and mean absolute percentage error (MAPE). It was found from the study that the MAD and MAPE of the forecast of the original average EVI and the average EVI adjusted using the RMMEH method were slightly different, in that the average EVI adjusted using the RMMEH method and forecasted by moving averages method was the most accurate. In addition, according to the time-series change forecast of EVI, it was found that the original average EVI and the EVI that was smoothed using the RMMEH method of the forecasting year during 2020-2022 using the moving average method and exponential smoothing method were very low in each year, indicating that droughts would occur again in the future. *©2021 University of Montenegro. All rights reserved.*

## Piezoelectric rod sensors for scour detection and vortex-induced vibration monitoring

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| ***M L Funderburk et al*** | *Structural Health Monitoring, 2021* |

As extreme events increase in frequency, flow-disrupting large-scale structures become ever more susceptible to collapse due to local scour effects. The objective of this study was to validate the functionality of passive, flow-excited scour sensors that can continue to operate during an extreme event. The scour sensors, or piezorods, feature continuous piezoelectric polymer strips embedded within and along the length of slender cylindrical rods, which could then be driven into the soil where scour is expected. When scour erodes away foundation material to reveal a portion of the piezorod, ambient fluid flow excitations would cause the piezoelectric element to output a voltage response corresponding to the dynamic bending strains of the sensor. The voltage response is dependent on both the structural dynamic properties of the sensor and the velocity of the excitation fluid. By monitoring both the shedding frequency and flow velocity, the exposed length of the piezorod (or scour depth) can be calculated. Two series of experimental tests were conducted in this work: (1) the piezorod was driven into sediment around a mock pier to collect scour data; and (2) the piezorod was used to monitor its own structural response by collecting vortex-shedding frequency data in response to varied flow velocities to establish a velocity-frequency relationship. The results showed that the piezorod successfully captured structural vortex-shedding frequency comparable to state-of-practice testing. A 1D numerical model was developed using the velocity-frequency relationship to increase the accuracy of voltage-based length prediction of the piezorod. 2D flow modelling was also performed for predicting localised velocities within a complex flow field. These velocities, in conjunction with the velocity-frequency relationship, were used to greatly improve length-predictive capabilities. 

## In-belt vibration monitoring of conveyor belt idler bearings using wavelet package decomposition and artificial intelligence

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| ***W A Roos et al*** | *International Journal of Mining and Mineral Engineering, Vol 12, No 1, pp 48-66, 2021* |

Visual and acoustic methods are commonly used to identify faulty or failing idler bearings; however, these methods can become tedious and time consuming in practice. While vibration monitoring might look like an obvious choice to explore, the instrumentation of individual idler bearings would be prohibitively expensive. The potential for using an accelerometer that moves with the belt while tracking the condition of all bearings encountered along the way is therefore quite interesting. This possibility is explored in this work on a laboratory scale test-rig. Wavelet package decomposition is used to extract the bearing features and present it to an artificial neural network and support vector machine to identify and classify faulty idler bearings. The system could not only identify faulty bearings but also classify the faults accurately. 

## A tool wear condition monitoring approach for end-milling based on numerical simulation

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| ***Q Zhu et al*** | *Eksploatacja i Niezawodnosc, Vol 23, No 2, pp 371-380, 2021* |

Tool condition monitoring (TCM) has attracted much attention as an important research area of modern manufacturing, especially artificial intelligence (AI)-based TCM methods. However, the training samples obtained in practical experiments raise the issues of missing samples and sample insufficiency. A numerical simulation-based TCM method is proposed to solve this problem. First, a numerical model based on the Johnson-Cook model is established and the model parameters are optimised through orthogonal experimental technology, in which the Kullback-Leibler (KL) divergence and cosine similarity are used as the evaluation indexes. Second, samples under various tool wear categories are obtained by the optimised numerical model above to provide missing samples not present in the practical experiments and expand the sample size. The effectiveness of the proposed method is verified by its application in end-milling TCM experiments. The results indicate the classification accuracies of four classifiers (support vector machine (SVM), random forest (RF), decision tree (DT) and general regression neural network (GRNN)) can be improved significantly by the proposed TCM method. 

## The importance of feature processing in deep learning-based condition monitoring of motors

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| ***D K Soother et al*** | *Mathematical Problems in Engineering, 2021* |

The advent of deep learning (DL) has transformed diagnosis and prognosis techniques in industry. It has allowed for tremendous progress in industrial diagnostics, has been playing a pivotal role in maintaining and sustaining Industry 4.0 and is also paving the way for Industry 5.0. It has become prevalent in the condition monitoring of industrial subsystems, a prime example being motors. Motors in various applications start deteriorating due to various reasons. Thus, the monitoring of their condition is of prime importance for sustaining operation and maintaining efficiency. This paper presents a state-of-the-art review of DL-based condition monitoring for motors in terms of input data and feature processing techniques. Particularly, it reviews the application of various input features for the effectiveness of DL models in motor condition monitoring in the sense of what problems are targeted using these feature processing techniques and how they are addressed. Furthermore, it discusses and reviews advances in DL models, DL-based diagnostic methods for motors and hybrid fault diagnostic techniques, points out important open challenges to these models and signposts the prospective future directions for DL models. This review will assist researchers in identifying research gaps related to feature processing so that they may effectively contribute towards the implementation of DL models as applied to motor condition monitoring. 

## Vibration monitoring for composite structures using buckypaper sensors arrayed by flexible printed circuit

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| ***X W Jiang et al*** | *International Journal of Smart and Nano Materials, Vol 12, No 2, pp 198-217, 2021* |

Fibre-reinforced resin-based plastics are widely used in structural composites for aerospace and automotive applications and they often face extreme load conditions in actual working environments. It is challenging to monitor the damage of a structure during the vibration process. This study aims to use buckypaper (BP) sensors to monitor the structural health status of composite structures under ambient vibrations. First, the feasibility of a flexible printed circuit instead of wire is verified by the tensile experiment. Then, the vibration monitoring experiment of the composite cantilever beam is systematically carried out using BP sensors. The sweep-frequency experiment determines the excitation frequency of the cantilever beam. Low-period vibration fatigue cycle experiments and high-period vibration fatigue cycle experiments are designed to verify the vibration monitoring method using BP sensors. Besides, the signal response of BP sensors in the vibration experiment is analysed and the relationship between $\Delta R/R_0$ and vibration acceleration is obtained. Finally, through the change law of $\Delta R/R_0$ of the sensor, the cumulative damage caused by vibration fatigue is visualised. It is demonstrated that the monitoring method based on BP sensors can be applied to study the damage behaviour of composite structures under the vibration environment. 

## Gearbox condition monitoring using sparse filtering and parameterised time-frequency analysis

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| ***S Wang et al*** | *Lecture Notes in Mechanical Engineering, pp 105-113, 2021* |

It is challenging to monitor the condition of a gearbox being operated under variable conditions. Considering that numerous variable conditions have a non-stationarity nature, a time-frequency analysis (TFA) approach is very well suited to analysing the frequency components of interest. As an emerging TFA method, parameterised TFA utilises further parameters to parameterise kernel functions, so a complex signal can be characterised more accurately. However, it is an issue to estimate the instantaneous frequency with the interference of background noise. This paper presents a method to solve this problem by using the sparse filtering method, as sparse filtering is capable of enhancing a particular desired feature to achieve the desired effect. With sparse filtering, the parameterised TFA is used to achieve signal decomposition and clarify the signal spectrum structure. Finally, these interferential frequencies are extracted and removed and the processed signals are used to monitor the gearbox. The availability of this method was verified by simulated and experimental signal analysis in gearbox condition monitoring. 

# Patent summaries

**Full copies of the original patent documents can be obtained from:**

- **The British Library, 96 Euston Road, London NW1 2DB, UK.**
- **US Patent and Trademark Office, 600 Dulany Street, Madison East, Concourse Level, Alexandria, VA 22314, USA.**
- **The Japanese Patent Office, 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan.**

*WO/2022/066867*

**Adjustment of indirectly determined values of a tyre monitoring system**

*Date:* 31.03.2022
*Applicant:* Sensata Technologies Inc
*Inventor:* William D Stewart

Methods, systems, apparatus and computer program products for adjustment of indirectly determined values of a tyre monitoring system are disclosed. In a particular embodiment, adjustment of indirectly determined values of a tyre monitoring system includes identifying an indirectly determined value associated with a tyre. The tyre monitoring controller also identifies one or more tyre parameters from one or more direct measurement devices. The tyre monitoring controller uses the one or more tyre parameters from the one or more direct measurement devices to adjust the indirectly determined value. The tyre monitoring controller uses the adjusted indirectly determined value to indirectly determine a wear condition value for the tyre.

*WO/2022/085610*

**Condition monitoring system for metal recovery device**

*Date:* 28.04.2022
*Applicant:* Asahi Pretec Corporation
*Inventor:* Makoto Nagata

Provided is a system for monitoring the condition of a metal recovery device. The condition monitoring system comprises a metal recovery device and a control device. The metal recovery device comprises a voltage measurement unit for measuring the voltage between a negative electrode and a positive electrode. The control device comprises a data calculation unit for processing measured voltage data received from the voltage measurement unit. The data calculation unit calculates, as a feature amount, a derivative value on the basis of the voltage data, compares the feature amount against a prescribed threshold value and when the feature amount is the threshold value or greater, diagnoses the positive electrode as being in a maintenance-required state.

*US 11338796*

**Apparatus and methodology for wheel stability monitoring system**

*Date:* 24.05.2022
*Applicant:* GM Global Technology Operations LLC
*Inventor:* Yubiao Zhang

A traction control module includes a sensor/estimation module configured to output wheel stability data based on a plurality of wheel condition inputs and a wheel stability monitoring module configured to calculate a plurality of wheel stability predictors based on the wheel stability data. Each of the wheel stability predictors is independently indicative of a wheel slip condition. The traction control module further includes a wheel stability data fusion module configured to receive each of the plurality of wheel stability predictors, combine selected wheel stability predictors from the plurality of wheel stability predictors to generate combinations of the wheel stability predictors, and selectively output a torque reduction request based on the combinations of the wheel stability predictors.

*US 20220163061*

**Bearing condition monitoring device, turbocharger and bearing condition monitoring method**

*Date:* 26.05.2022
*Applicant:* Mitsubishi Heavy Industries Engine & Turbocharger Ltd
*Inventor:* Seigi Yano

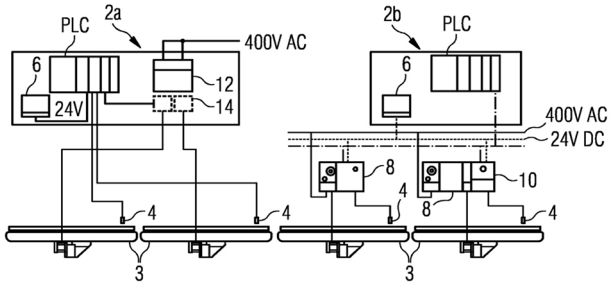
A bearing condition monitoring device is a device for monitoring a condition of a thrust bearing for holding a rotational shaft in a thrust direction. The bearing condition monitoring device includes a first temperature sensor for measuring a temperature of the thrust bearing and an arithmetic device for counting a frequency at which an evaluation index of a thrust load on the basis of a measurement value by the first temperature sensor exceeds an allowable value and for outputting an abnormality in the condition of the thrust bearing if the counted frequency exceeds a threshold. The arithmetic device may count, as the frequency, only a case where a state in which the thrust load exceeds an upper limit load continues for not less than a predetermined time.

*EP 3997021*

**System and method for condition monitoring during the operation of a conveyor system**

*Date:* 18.05.2022
*Applicant:* Siemens AG
*Inventor:* Ivan Castelino

The invention relates to a system and a method for condition monitoring during the operation of a conveyor system, in particular an airport baggage handling system, comprising conveyor units (3). The invention also comprises a background system. A conveyor unit comprises a single conveyor line and/or a group of conveyor lines. It is possible to detect an individual flow characteristic of a single conveyor unit. Each single conveyor unit has a defined flow characteristic during fault-free operation and the background system is designed to register said defined flow characteristic and the actual flow characteristic of said conveyor unit. The background system is designed to analyse the actual flow characteristic of this conveyor unit and to signal, on the basis of said analysis, an imminent wear and/or a malfunction of the conveyor system, in particular of a conveyor line of said conveyor unit.



*WO/2022/094699*

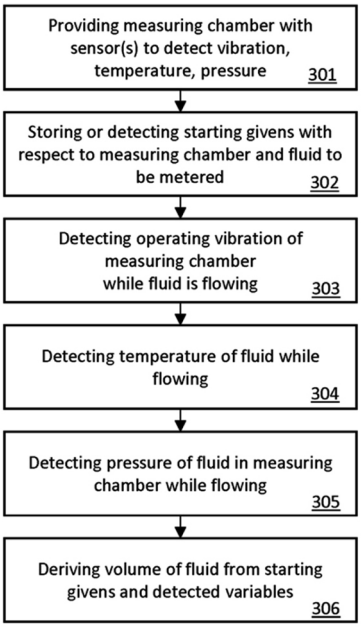
**Fluid metering/monitoring system using vibration**

*Date:* 12.05.2022

*Applicant:* Romet Limited

*Inventor:* Brent Collver

A fluid monitoring system is provided, which includes at least one fluid vibration sensing unit to provide at least one fluid vibration signal from at least one location on a measuring chamber of a meter to be monitored. The system also includes one or more display units, and a control unit configured to be coupled to the at least one fluid vibration sensing unit and the one or more display units. The control unit is configured to detect a condition from the respective location using the at least one fluid vibration sensing unit and communicate to at least one or more display units to provide a display of the condition. A meter with a fluid monitoring system is also provided.




*WO/2022/073844*

**Method and system for monitoring objects and equipment by thermal imaging and data analysis**

*Date:* 14.04.2022

*Applicant:* Idletechs AS

*Inventor:* Harald Martens

The invention provides a method of and system for monitoring an object using thermal video data. The method comprises capturing thermal video images of a scene comprising the object using one or more thermal imaging cameras and outputting a thermal video data stream to a processing apparatus. In the processing apparatus, the thermal video data stream is processed by performing a multivariate analysis of the thermal video data stream to generate one or more models of the behaviour of the object. The one or more models include modelling of temporal development of a thermal signature of the object and modelling of covariation of the thermal signature between different parts or regions of the scene. The processing comprises establishing one or more normal states of the object using observed data from the thermal video data stream and the one or more models and comparing observed data from the thermal video data stream with the one or more normal states of the object to determine whether the object is a known condition or an unknown condition. An output signal from the processing apparatus is generated if the object is determined to be in an unknown condition.

*US 20220163428*

**Damper condition monitoring for a damper of a gas turbine engine**

*Date:* 26.05.2022

*Applicant:* General Electric Company

*Inventor:* Kanahayya Dudhale

Systems, methods and a gas turbine engine that includes features for condition monitoring of a damper thereof are provided. In one aspect, a gas turbine engine includes a rotary component, a bearing operatively coupled with the rotary component and a damper associated with the bearing. The gas turbine engine also includes sensors and a controller. The controller receives data that includes sensed and/or calculated parameter values. The controller generates a damper severity index based on the parameter values. The damper severity index indicates a health state of the damper. The controller determines whether the damper severity index exceeds a threshold. When the damper severity index exceeds the threshold, a notification indicating the health state of the damper is generated. A computing system can determine a fault type and a remaining useful life of the damper and can update controller logic based on field data received from engines in a fleet.

*EP 3970288*

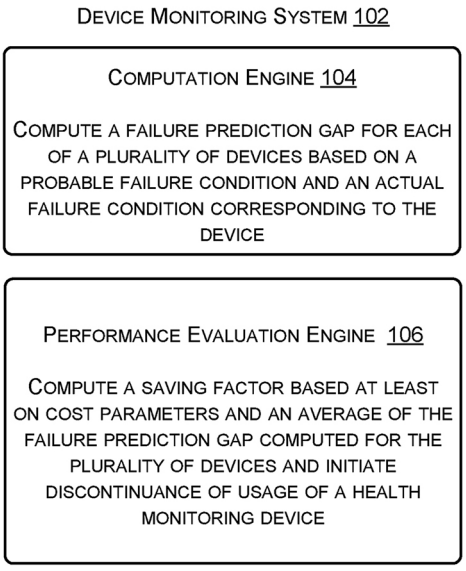
**Device monitoring systems**

*Date:* 23.03.2022

*Applicant:* Hewlett Packard Development Co

*Inventor:* Damera Venkata Niranjan

A device monitoring system comprising a computation engine to obtain, for each of a plurality of devices, an actual failure condition indicating actual device failure and a probable failure condition predicted by a health monitoring device. The health monitoring device monitors the health of the plurality of devices and the probable failure condition indicates when the device is predicted to stop functioning. The computation engine is to compute a failure prediction gap for each of the plurality of devices. The failure prediction gap indicates a difference between the probable failure condition and the actual failure condition. A performance evaluation engine computes a saving factor based at least on cost parameters and an average of the failure prediction gap computed for the plurality of devices and initiates discontinuance of usage of the health monitoring device based on a comparison of the saving factor with a threshold.



*WO/2022/105340*

**Sound wave-based pipe monitoring system and monitoring method**

*Date:* 27.05.2022

*Applicant:* Huaneng Clean Energy Research Institute

*Inventor:* Weidong Li

A sound wave-based pipe monitoring system and a monitoring method. The monitoring system comprises a sound signal acquisition module, a signal transmission module, a sound wave monitoring and analysis platform and a data storage module; the sound signal acquisition module is configured to acquire a sound wave signal of a monitoring object in a pipe system in real time; the signal transmission module is configured to transmit an electric signal to the sound wave monitoring and analysis platform; the sound wave monitoring and analysis platform is configured to perform conversion, noise reduction and storage on the electric signal and analyse the signal subjected to the noise reduction to obtain an operating condition of the monitoring object in the pipe system; the data storage module is configured to store the electric signal obtained by the sound wave monitoring and analysis platform and the result of processing by the sound wave monitoring and analysis platform. According to the monitoring system, leakage online monitoring for a pipe network and fluid devices can be implemented in real time and continuously by means of cheap sound wave sensors and states of the devices such as start, stop and breakdown can be detected in real time.

*WO/2022/076450*

**Health assessment and monitoring system and method for clean fuel electric vehicles**

*Date:* 14.04.2022

*Applicant:* Alakai Technologies Corporation

*Inventor:* Brian D Morrison

A system and method for fuel cell and motor trend monitoring, including recording signals from fuel cell and motor system-condition sensors or sets of on-board sensors and periodically analysing results to examine fuel cell and motor system performance trends to predict the need for fuel cell or motor system maintenance. Various analyses can be performed, separately or in parallel, including: comparing the current parameter values with recorded parameter values in previous instances of similar operating conditions; comparing parameter values to predetermined nominal ranges; and detecting sensed parameter values that exceed recommended fuel cell or motor system operating conditions or that exhibit trends over time that, if continued, can result in exceeding fuel cell or motor system operating conditions or producing out-of-bound readings. Results of the analyses inform fuel cell, motor and aircraft system maintenance scheduling and provide alerts to users regarding the recommended fuel cell, motor and aircraft system performance trends and/or operating condition exceedances, enhancing safety and improving maintenance efficiency.