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MAN-ES: Navigating connectivity, cyber security and AI at sea

Digitalizatiion, Connectivity, Artificial Intelligence & Cyber Security

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ABSTRACT

Since 1 July 2024, with the introduction of the class requirements following IACS UR-E26/27, the maritime industry has faced requirements for cybersecurity, regular updates to OT equipment, and recovery procedures. This paper outlines how the authors' company, MAN Energy Solutions (MAN ES), supports the maritime industry by ensuring safety, security, and regulatory compliance. It provides examples of how 20 years of online data and experience are utilised to develop AI-based tools and products.

This paper shares the initial experience with a new MAN ES product, called "EngineExtra", which provides over-the-air (OTA) updates to the engine control system. This includes measures to ensure a resilient and secure network protecting the engine and vessel against cyberthreats. OTA updates enable engine enhancements throughout the lifetime of the vessel.

Fleet analytics is a further key element in the advanced data infrastructure. Operation profiles and operational statistics combined with service data can be used to calibrate wear prediction and design tools in the development process. Data science methods can be applied to extract application-specific-characteristics and outliers. Historical data from more than 20 years of online monitoring will be combined with actual sources.

This paper also describes a new onboard application server and shares the insights from two new products on the market. The Advice on Vessel assists the crew in optimising engine operation through data collection and advice, and the Engine Observation System assists the crew during scavenge air inspections, and other tasks.

Although manual and especially visual inspection remains a key element in condition assessment, some advanced digital tools are also described in this paper. The potential of AI using deep learning and computer vision for component wear assessment to support the process of condition monitoring and virtual component modelling with machine learning methods are demonstrated. Data science methods for large data evaluation are discussed.

In conclusion, the paper gives a peek into the future – a future where the authors believe that AI will be an essential part of fault-finding, troubleshooting, and operational assistance both onshore and onboard the vessel.

1 INTRODUCTION

In recent years, the development of new technologies and regulations has accelerated at an unprecedented speed. This has provided companies with new opportunities for product innovation, but it has also increased the risk of cyberattacks as systems become more connected and online [1].

As a result, the regulations to protect users, infrastructure, and systems against malicious cyberattacks have been expanded.

As of 1 July, 2024, the IACS UR-E26/E27 was introduced as a mandatory requirement for all new vessel orders [2]. This marks the maritime industry's first step towards ensuring that original equipment makers (OEMs) and shipowners protect their assets against malicious attacks. These new requirements are based on IEC 62443-3-3 and 62443-4-1, largely matching the so-called Security Level 1 in this standard [3].

This paper outlines how MAN ES ensures compliance with these regulations and also explores the next steps in meeting customer expectations for cyber resilience.

Cybersecurity is an ongoing task, and ensuring the best possible protection requires continuous monitoring and patching of systems. The authors' company has developed a product called EngineExtra, for remote over-the-air (OTA) updates, enabling us to respond to threats before they are exploited by attackers [4], [5].

New opportunities arise with new technologies, and this paper describes some of the new products. These products leverage the latest engine control system functionalities, not only on newbuild ships but also on the existing fleet.

New products can be hosted on a so-called App server, thereby improving assistance to the vessel crew. This paper provides an example of how a new product, the Engine Observation System (EOS), can support the crew in measuring component wear and planning maintenance.

Over the last decades, extensive data, pictures, and experience have been collected from the operation of MAN ES engines in the field. This has led to new product offerings that utilise this extensive knowledge and experience to help the crew and vessel owners ensure the optimum engine operation.

For example, preliminary results are shared from the use of deep learning[1] and computer vision to detect and assist operators during scavenge port inspections, helping them classify potential wear issues based on the piston ring condition.

The development of technology in recent years has dramatically changed the way users interact with computer-based systems.

The introduction of generative AI and the subsequent opportunities to develop new types of products will undoubtedly impact how we interact with systems in the future.

These advancements have given companies the opportunity to develop products using these new technologies, making their usage even more user-friendly and autonomous.

2 CYBERSECURITY

Risks imposed by cyberattacks are growing. In the past five years, cyberattacks have been ranked among the highest short-term risks in the annual Global Risks Report from the (World Economic Forum, 2024). The attack surface has grown 1034% from January 2022 to January 2025 [7]. This underlines the need for all owners, builders, and OEMs in the marine industry to invest in and focus more on cybersecurity.

As of 1 July, 2024, new cybersecurity requirements have become mandatory for all new vessels signed after that date, as the IMO introduced the IACS UR-E26 and E27 requirements for all ships.

These requirements are the first to specifically target the need for cybersecurity on ships covering both operational and information technology (OT/IT) OT and IT equipment.

As an OEM in the marine industry, MAN ES and its products must adhere to these new requirements.

To secure our engines against cyberattacks, continuous updates are needed. However, there is currently no safe option for updating via remote access. Instead, a service technician has to visit the vessel to install updates on-site. This process is costly and time-consuming, which is particularly problematic for such a time-critical issue. Additionally, limited resources result in slow processes and delayed service attendance.

These issues create an "online connectivity paradox".

[1] Deep learning is a type of machine learning that uses artificial neural networks to learn from data

a) Online vessels are increasingly vulnerable to cyberattacks. .
b) To allow continuous updates, and leverage modern technologies, an online connection is essential. The following section explores how MAN ES is addressing this paradox.

Furthermore, some customers in the maritime business are already looking beyond the IACS UR-E26 and E27 requirements, striving for higher security levels. Specifically, our four-stroke division is already designing engines for plants that meet Security level 2 on the IEC-62443 standard.

3 MAN ASSET+

MAN Asset+ is a group of digital products comprising a range of engineering and software solutions designed to improve the functionality of the propulsion system on board a vessel. The purpose of these digital products is to support the maritime transformation and to achieve digitalisation and decarbonisation goals for years to come. This by enabling our customers to cherry-pick the needed functionality for them and adapt the engine functionalities to their need throughout the lifetime of the ship [8].Examples of MAN Asset+ products will be described in Sections 3 and 4 in this paper.

The EngineExtra service is the core of MAN Asset+, EngineExtra facilitates remote updates to the engine control system and associated systems. These updates protect against cyber threats and ensure that the latest firmware and software are installed. This way addressing the previously mentioned “online connectivity paradox” by patching the systems making them robust and protected against any Cyber Treats enabling the Engine to be safely and securely online.

MAN Asset+ also includes the possibility of enhancing the control system and its features through on-demand upgrades, either by implementing smaller enhancements or unlocking new functionalities of the engine, these so called “on demand products” will be described in section 3.2.

3.1 EngineExtra

EngineExtra is a critical solution to ensure cybersecurity and access to the latest functionalities of the engine control system and its surrounding systems.

Updates will be available 2–4 times per year, depending on system configuration, update availability, and relevance to the given system. These updates include:

- Security updates to the operating system: These updates patch security gaps in the operating system and include other enhancements (e.g., updates to Windows, Linux, or other systems).
- Engine control system (ECS) updates: Provide the latest ECS control and safety functionalities, including enhancements to system usability. This ensures that the latest products are available. When the ECS is up-to-date, new functionalities can be pushed out and installed remotely.
- Engine management system (EMS) updates: Provide the latest UI improvements, functionality enhancements, and the latest data visualisation and data sharing with MAN CEON [9] for PrimeServ Assist.
- Other updates: EngineExtra will also provide updates to firmware for the Managed Switch, mGuard Firewall, and other software components on the system. These updates will ensure both the cybersecurity and the functionality of the system.

EngineExtra includes the new ExchangeGateway device, which will be installed as part of the ECS. This device will act as a server on the vessel, hosting the update functionality and storing the files required for updates and possible recovery. The ExchangeGateway will be connected to the internet via the MAN-ES firewall and the vessel internet connection. This way all communication is going through the vessel firewall as well as the MAN-ES dedicated firewall. This connection is utilizing latest encryption mechanisms and through the VPN tunnel, it is ensured this can only be used for the dedicated purpose. This traffic is initiated by the client (vessel) from the ExchangeGateway to the MAN-ES infrastructure. This way, no two vessels will be able to communicate with each other.

Vessels that are part of an EngineExtra service agreement will benefit from the latest improvements of the various systems on their assets and have access to the latest functionalities.

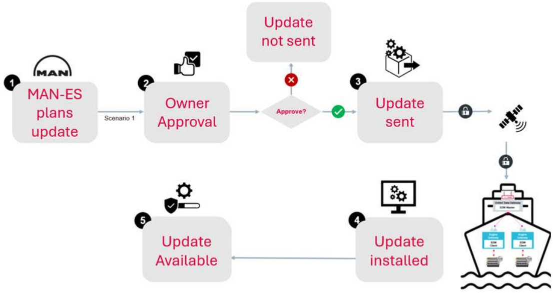


Figure 1. EngineExtra and remote updating.

Vessel owners will receive notifications about new updates. MAN ES expects 2–4 updates per year. The installation will involve both the operational management of the vessel and the crew on board. See Figure 1. A notification will be sent to the operational management of the vessel for pre-approval before the artifacts required for the update are transferred to the ExchangeGateway device on the vessel.

Once the files are available locally on board, the system will check for all preconditions. If these are met, it will prompt the local user with a “New update available” icon on the control panel for the engine, the ECS-MOP-B. The crew can then decide when to perform the update. The engine must be stopped, the vessel must be in a safe state, and sufficient time must be available for the update.

Once approved by the local operator, the installation will start automatically without further user interaction. If anything goes wrong, the system will automatically diagnose the issue and, if required, initiate an automated recovery process. This ensures that the system will resume an operational state without any need for user interference from the local operators.

3.2 On-demand upgrades

On-demand Asset+ upgrades will provide the possibility to upgrade the functionality of the engine control system throughout the engine’s lifetime.

In a modern two-stroke engine, the majority of engine functionalities are integrated with the engine control system. This allows for significant upgrades and the introduction of new functionalities through ECS software upgrades, which can be delivered over the air.

This way, existing vessels can be continuously modernised, and vessel operators can upgrade older vessels to match the functionality of new ones, with much less effort than what is required to upgrade the engine control system today.

The Asset+ catalogue of upgrades will be continuously expanded with functionalities that can improve efficiency, reliability, costs, and ease of use.

Moving forward, the goal is to further utilise our automation software to provide new functionalities developed in our automation teams to existing vessels sailing around the globe. This enables our customers, the ship operators, to use the latest developments in our automation portfolio for their entire fleet of MAN ES engines. Consequently, MAN Asset+ allows updates over the entire lifetime of the vessel, allowing it to use state-of-the-art technology at any given time.

Furthermore, our solution allows the addition of functions on demand, making it easy and affordable to uniquely optimise an engine. For instance, using a product like ACC (four-stroke engines), ACCo (two-stroke engines). These two products introduces an improved way of controlling the cylinder combustion pressure and automates the adjustment of this during the operations of the engine. By doing so, the fuel consumption is lowered.

MAN-ES is committed to continue and expand the development of new products which will be categorised as shown in Figure 2. These products will target different focuses the ship owners such as, emission reductions, Security updates, safety updates and less manual tasks.

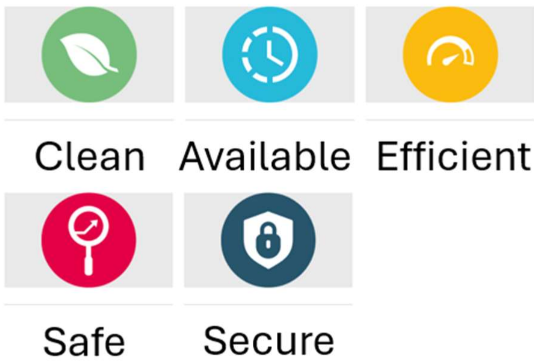


Figure 2. Categorisation of products.

Ultimately, MAN Asset+ ensures cheaper, safer, and more reliable operation of the engine and helps to reduce costs and emissions. Once purchased, updates are automatically rolled out via the solution, with an “agent” on the electronic device ensuring secure software installation on the vessel. However, before installing the software, approval from both the owner and the local crew is required to ensure that the update will not interfere with the vessel’s operation.

3.3 Field test experience

The EngineExtra product and its general infrastructure are currently being installed and tested on a series of field test vessels. This aims to verify and adjust the system's functionalities and usability, ensuring a reliable solution as well as a high level of usability for the operators.

The field test involves installing the required infrastructure, including the ExchangeGateway and the required software components.

The system's performance, the data transfer reliability, crew usability, and installation process are currently being tested. These tests aim to collect feedback and metrics on service quality before this new product is introduced to the market.

During the CIMAC conference, preliminary outcomes and results of the field test will be shared with the audience.

4 APP SERVER

The app server will be installed as part of the updating mechanism to ensure the cybersecurity of the ECS, offering the opportunity to locally run some applications on the vessel. This will make it possible to build a classic IoT platform on the vessel, which will be preinstalled on all future engines.

Such a platform provides an environment for all assets – where asset-supportive software can run without disturbing the operation of the asset.

MAN ES has chosen to base its solution on available third-party products that are already well-established on the market and in use in millions of consumer devices, vehicles, and other business areas. Among other technologies, the AppServer is based on the use of AWS IoT Greengrass [10] and containerization of software.

This approach provides an opportunity to develop various applications for decision optimisation and support, and a platform for running advanced on-site analytics.

4.1 Onboard engine observation system

The above-explained app server opens many possibilities for on-edge applications to assist the crew with engine operations.

Component inspections are one of the foundations of engine maintenance. In the ongoing digitalisation efforts, this area is also being developed. The new Engine Observation System (EOS) delivers inspection data support to the connected vessel. The EOS enables the crew to record and access the inspection data and evaluate the resulting graphs in the system.

The EOS app for onboard use is accessed through a web browser on the EMS computer. The most used observation types will be available in the initial version.

Data is available in the reporting panels, based on the inspection type, while graphs are available in the dashboard panels, based on the component type (Figure 3).

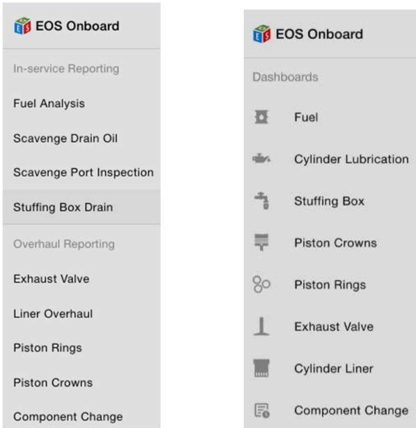


Figure 3. Reporting and dashboard panels.

In addition to the inspection reports, a component replacement report is also included. This enables easy tracking of running hours, dates, and markings of the installed components.

All reporting is done in the same way for the different inspections. The user flow is described in figure 4. The reporting sheets are in line with the ones used historically, so the crew feels comfortable when filling them.

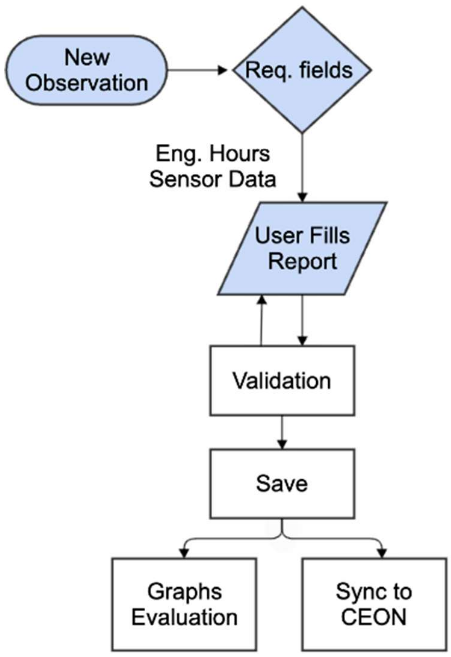


Figure 4. User flow.

The data available from the ECS will be prefilled in reports, where as the manual measurements are typed in the template (Figure 5). For example, the drain oil analysis report contains engine load, scavenge pressure, feed rates, sulphur content, etc.

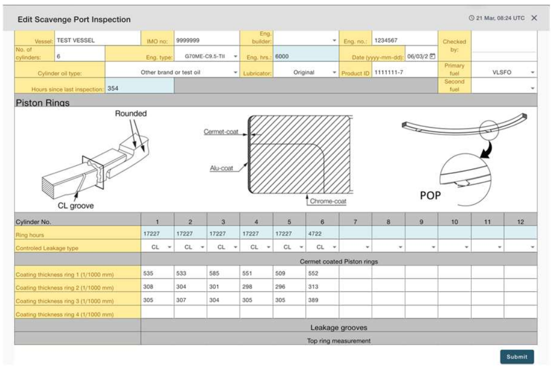


Figure 5. Inspection sheet.

The data submitted will be automatically validated by the system to eliminate typing mistakes. Once the observation has been saved, the new data can be evaluated within the dashboard (Figure 6).

The system also issues alerts with inspection reminders based on the recommended guideline intervals.

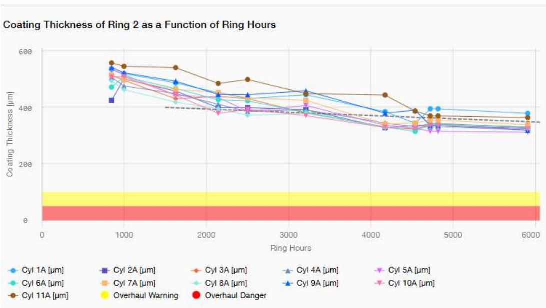


Figure 6. Data is available in the dashboard.

Once the data has been saved, it will be saved automatically to the cloud via the CEON platform where the shipowner's superintendents and staff can access the data. See Figure 7.

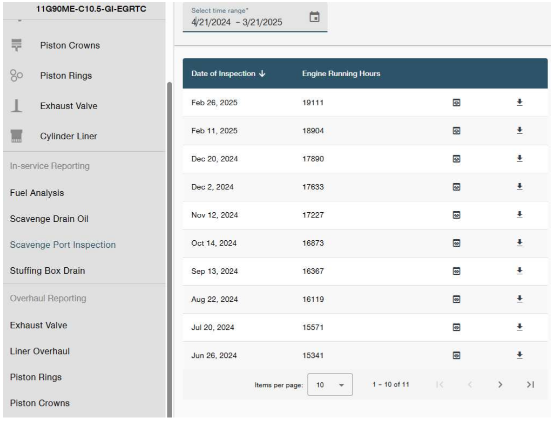


Figure 7. Data available in the cloud.

EOS increases the quality of inspection data, facilitates easy information transfer and crew changes, and enables follow-up on the inspection and condition by the superintendent. By having the wear data in a single system on shore, spare parts planning is improved.

Additionally, EOS on the app server will enable support from the engine designer who will have access to the information.

5 DATA-DRIVEN FIELD SUPPORT – DIGITAL INFRASTRUCTURE AND ANALYSIS

Being able to add context to online time-series sensor data expands the use and enriches the data and thus the value for customers through comprehensive analysis and expertise. This ensures the best advice to the operator of the equipment through efficient, fast, and high-quality advice.

The key elements are the interoperability of high-quality data sources, integrating factory backend data with online engine data, and on-site condition assessments.

The engine automation, safety, and control systems play a central role. By providing high-quality time series signals at both low and high frequencies, the automation and control systems define setpoints, limits, and key sources of reference data. The safety systems react immediately to alarming and safety-critical situations. In addition to the described ad hoc path, engine sensor data will be processed and analysed in the software platform MAN CEON.

MAN CEON operates as a central cloud-based data platform to retrieve and store time series data, metadata, and a documentation library. It also hosts analytical models and AI tools, and acts as an interactive, central customer communication platform. An Edge Server option is provided, allowing CEON to operate all functionalities on-site, including an AI chatbot to support advanced content search. Customer and expert interaction are facilitated on MAN CEON as well.

The interoperability of data sources is the success factor of the process illustrated in Figure 8. Stringent and consistent data modelling represents the backbone and enabler in that respect.

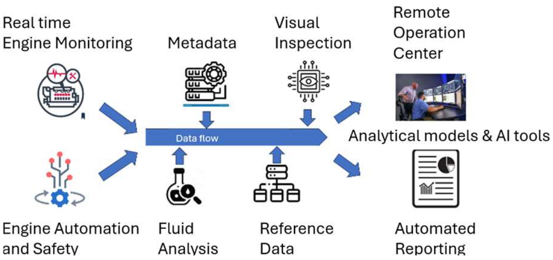


Figure 8. Field data analysis – data source infrastructure.

Advanced digital tools and analytical models are the enablers for next-level engine real-time condition monitoring (CM) and condition-based maintenance (CBM) with concepts for operator support. The interconnection of onboard and factory backend infrastructure allows the transfer of expert knowledge between the operators and the experts at the engine designer or builder. MAN CEON, the central software platform acts besides data sampling, analytics and cloud storage also as bidirectional communication channel between to operators and experts. Online data – as single source.

Engine configuration knowledge together with component traceability over engine lifetime is essential in that context (Figure 9). Marking and coding of components will be rolled out worldwide to newbuildings and to engine plants in service.

Figure 9. Matrix code marking on critical components.

5.1 Integration of analytical models and AI tools for comprehensive analysis and advice

Degradation of engine subsystems due to, for example, fouling, mechanical wear, filter clogging, and off-spec fuel has a negative impact on performance (efficiency, emissions). The performance indicator continuously evaluates normalised sensor data versus its nominal reference value. The references are retrieved from component specifications, automation setpoints, and factory test bed results (Figures 10 and 11).

The performance score incorporates:

- Automation system setpoints and maps
- Alarm history
- Test bed and service history performance
- Actual ambient conditions

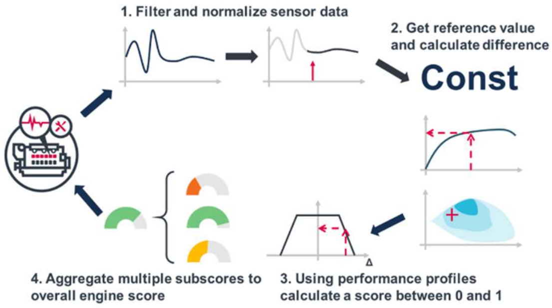


Figure 10. Performance score – how it works.

The performance score evaluates the main engine thermodynamic performance parameters continuously 1/min. e.g. as one of the subscores turbocharger efficiency is monitored and trended. Performance degradation, which effects fuel efficiency directly, will be highlighted long before critical operation conditions will be alarmed. On the one hand data driven support to assessment of engine availability is provided (no degradation) – in case of performance degradation corrective service activities can be planned well in advance.

5.2 AI – computer vision – deep learning for visual component inspection

The integration of deep learning technologies offers a promising field data analysis and advice solution. By using deep learning, assessments can be standardised and carried out independently of the individual experience of technicians or engineers. See Figure 11.

Figure 11. Scavenge port inspection.

The computer vision process is divided into two parts. The first part is the development of the object recognition model, which is also used to create a new dataset (Figure 12). The second part uses the newly created dataset to develop the classification models. These models consist of several wear detection models, one for each characteristic wear mechanism.

Figure 12. Highlighted yellow boxes indicate successful component image detection – the next step in the process is condition assessment analysis in real time.

When assessing the condition of critical engine components, the reliability and explainability of the results are of great importance. This is particularly challenging due to the high complexity of the image data, which is caused by varying imaging conditions and different types of wear.

There is no single network perfectly suited to all aspects of this task. Therefore, the main focus is to identify the best neural network for balancing these factors for the specific use case. To identify the best-performing network, two network architectures (vision transformer and CNN[2]) have been selected and trained, and their performance has been evaluated using test data unknown to the algorithm. When developing this, it is essential to carefully optimise the algorithm and ensure proper test data.

In order to get good classification results, the neural networks are pre-trained with the ImageNet dataset and are then finetuned with the existing image data of piston rings.

The pre-training was not part of our work, the weights of the pre-trained neural networks are publicly available. In the referenced work two types (ResNet50 and ViT_B_16) of neural networks were trained to detect wear types that characteristically appear on piston ring surfaces.

Testing the finetuned neural networks is done by calculating statistical performance metrics on the test dataset. Explainable AI such as grad-CAM also gives more information on misclassified parts. After that grad-CAM is used for more explainability and to exactly see where the finetuned neural networks "looks at", when they classify specific types of wear.

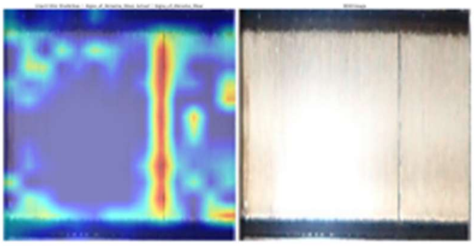
5.2.2 Condition assessment workflow

An object recognition model is used in this work to cut out all visible piston ring parts. This process standardises the dataset, as only the piston ring parts are visible in the newly created images. This process allows each piston ring part to be assessed individually. Another advantage offered by object recognition is the increase in the number of training images. Each processed image generates new individual images that correspond to the number of visible piston ring parts. A deep learning model is then trained.

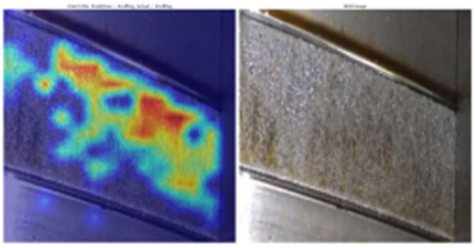
If no oil can be recognised on the piston ring parts, the image is forwarded to the wear assessment, which in this work is limited to the assessment of the running-in coating and the more precise assessment of the ring surface. The deep learning/model training is based on a wide range of existing historical in-house expert knowledge in combination with digital image documentation. The basis for the deep learning process is a training data set, which involves labeling over 1000 images of defined wear mechanisms.

Out of 80 images in the test dataset, only two were predicted incorrectly. Incorrect predictions are related to poor image quality or extreme edge cases.

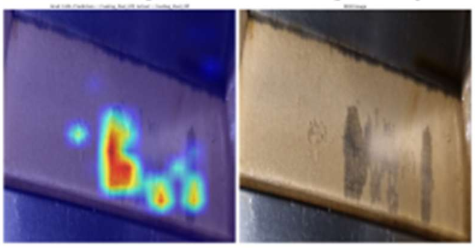
[2] Convolutional Neural Network (CNN) is a type of artificial neural network used primarily for image recognition and processing



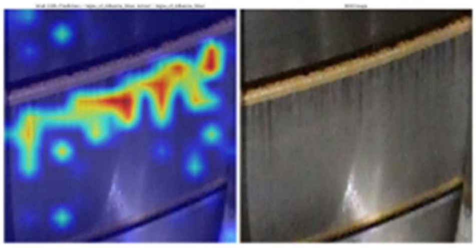
(a) Correct prediction of a piston ring with signs of abrasive wear



(b) Correct prediction of a scuffed piston ring



(c) Correct prediction of a piston ring with coating peel-off



(d) Correct prediction for a piston ring with signs of adhesive wear

Figure 13. Grad-cam heatmap of correct wear predictions for different wear mechanisms.

An iterative feedback process, including results verification, will ensure the continuous improvement of the automated assessment. Fleet statistics also contribute to ensuring a high prediction quality.

6 CONCLUSION

The authors' company is committed to leveraging new technologies and opportunities to assist vessels in service.

Protecting vessel assets against cyber threats and ensuring compliance with regulations is more important than ever. With the recent regulations from IACS UR-E26 and E27, the industry has taken its first step towards regulating this area. However, this is just the beginning.

New technologies also enable the possibility of updating functionality via an over-the-air platform, thereby increasing the engine efficiency and usability even more. With this product, the engine control system and associated systems can be safely updated, which helps vessel owners and operators reduce their fuel consumption and emissions, and ensures a high level of cyber resilience for the engines.

With the new application server and products like the Engine Observation System, the authors' company can assist the vessel crews in reporting and tracking the wear and tear of components and, thus, optimise engine maintenance. In addition, the application of deep vision and AI enables automated diagnostics of the pictures taken of wearing components, providing prompt and qualified recommendations to the vessel crew.

For decades, metrics, pictures, and operational experience have been collected from two-stroke engines, and with vessels coming online and new technology, engine designers can develop new digital products to assist their customers.

MAN Energy solutions is committed to leveraging the latest technology together with its extensive knowledge to assist vessel owners and operators in operating their assets in a protected, safe, efficient, and effortless way, thereby also helping the environment towards the zero-emissions goal.

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