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On-Board Diagnostic: The new onboard tool for Main Engine condition monitoring with special focus on Cylinder Condition

11 Users Aspects Maintenance & Monitoring - Marine Applications

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This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country.

The Congress programme centres around the presentation of Technical papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The topics of the 2016 event covered Product Development of gas and diesel engines, Fuel Injection, Turbochargers, Components & Tribology, Controls & Automation, Exhaust Gas Aftertreatment, Basic Research & Advanced Engineering, System Integration & Optimization, Fuels & Lubricants, as well as Users' Aspects for marine and land-based applications.

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ABSTRACT

Abstract: On-Board Diagnostic (OBD) is a tool for the condition based monitoring of MAN B&W Diesel two-stroke engines. Based on the data collected, expert advice is given to Chief Engineers, Owners and/or Managers via real time systems, and operational reports, on the reliability and economic operation of the main engine.

The main component is the OBD software, which collects data from CoCos, PMI Auto-tuning, ships alarm system, external sensors, on-board and shore based laboratory measurements as well as wear measurements from scavenge port inspections, and liner calibrations.

Uniquely amongst on-board systems, OBD compares and correlates this information to provide new and vital knowledge on the detailed engine condition, such as predicting ring packages lifetime and assessing the optimal cylinder lubricating oil feed rate.

Unlike most real-time systems, the data from OBD is automatically replicated to the owners/managers office for further analysis and actions without expensive communication cost; additional expert systems can monitor and advise on main engine performance by correlating the data received from the vessel with current best practice and operational data.

This paper focuses on the use of OBD in relation to Cylinder Condition. One example is the correlation between scavenge air temperature, wear measured manually and drain oil analysis to optimise the cylinder oil consumption and time between overhaul; both important issues for the operators in relation to reliability and cost.

Other operational examples are given in the paper, such as documenting the relation between fuel quality, fuel treatment and engine tuning.

The OBD system is also intended for the use of ship operators home office, offering an unique opportunity for the superintendents to get documentation of the main engine condition on individual ships and on the whole fleet under the superintendent's supervision.

In connection with condition based maintenance OBD could automatically provide the information required by Classification society.

INTRODUCTION

On-Board Diagnostic (OBD) is an innovative project initiated by MAN Diesel & Turbo and developed in cooperation with one of the authors, Jonathan Hodges. The aim of the project was to unify the diverse information systems available to engineering teams, consolidate and optimise their display, and allow advanced knowledge based analysis and comparison of that data to help the team better manage the operation of the main engine, and other systems, on board.

Combining real time information with periodic measurements by the crew, on-board inspections and laboratory analyses, OBD delivers a unified view of engine operation both in the engine room, elsewhere on board, in the office of the superintendents, fleet management and, if required, owners.

By delivering detailed information to those who need it, OBD is a powerful tool for condition based monitoring (CBM), predictive maintenance and lubrication control. This paper looks at how OBD has been used in the real world to answer questions of cold corrosion, ring and liner wear, optimal cylinder oil feed rate control, and to provide support and advice to engineering and management teams.

The system has been trialled since August 2014 in cooperation with the ship owner Seaspan Ship Management Ltd. on their vessel Hanjin Buddha, a 10.000 TEU container ship with a main engine of the latest super long stroke engine type (10S90ME-C9.2 TII), and the results of that trial are reported in this paper.



FIG.1 HANJIN BUDDHA

The results of the trial have allowed early diagnosis of potential problems and have enabled the engineering team to safely reduce lubrication rate with more confidence than might otherwise have been possible.

1. ON-BOARD DIAGNOSTIC

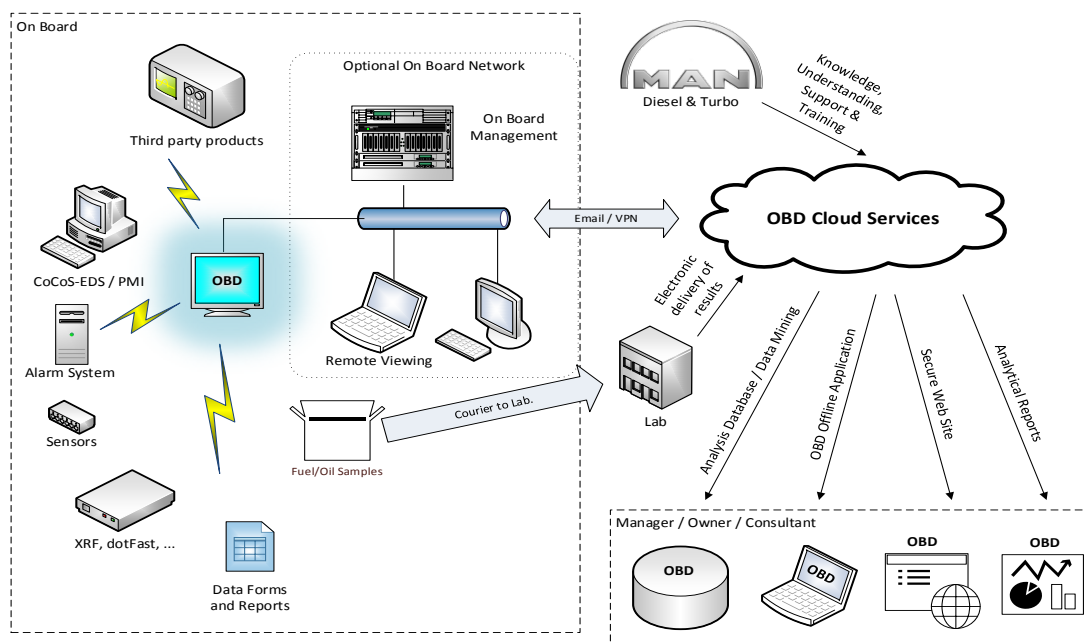


FIG.2 SCHEMATIC FOR OBD

OBD is a network of software systems that link information systems on-board with shore based services, knowledge from MAN Diesel & Turbo and other stakeholders. Fig.2. This information can be viewed

around the ship (subject to networking) and provides a single consolidated display of all integrated systems. The information collected by OBD is highly compressed using innovative proprietary software (<100KB/week)

and sent to the OBD Cloud Services, using existing infrastructure of email or VPN, where it is stored securely and delivered to the customer.

OBD allows the user to easily configure screens with data required by the Chief Engineer (C/E) and provided by OBD. In addition to displaying data in the time (or engine hours) domain, OBD also contains all reports generated from data taken by the crew and the drain oil analyses.

An “On-Board Diagnostic Report” (Fig.3) showing partial front page is generated each time drain oil samples are sent ashore. The report combines drain oil data, engine performance data and wear measurements.

Numerous assessments are automatically performed upon the data by expert systems; such as assessing condition (Fig.4) or projecting component lifetimes. Projection of component lifetime is dealt with in more detail in a later section.

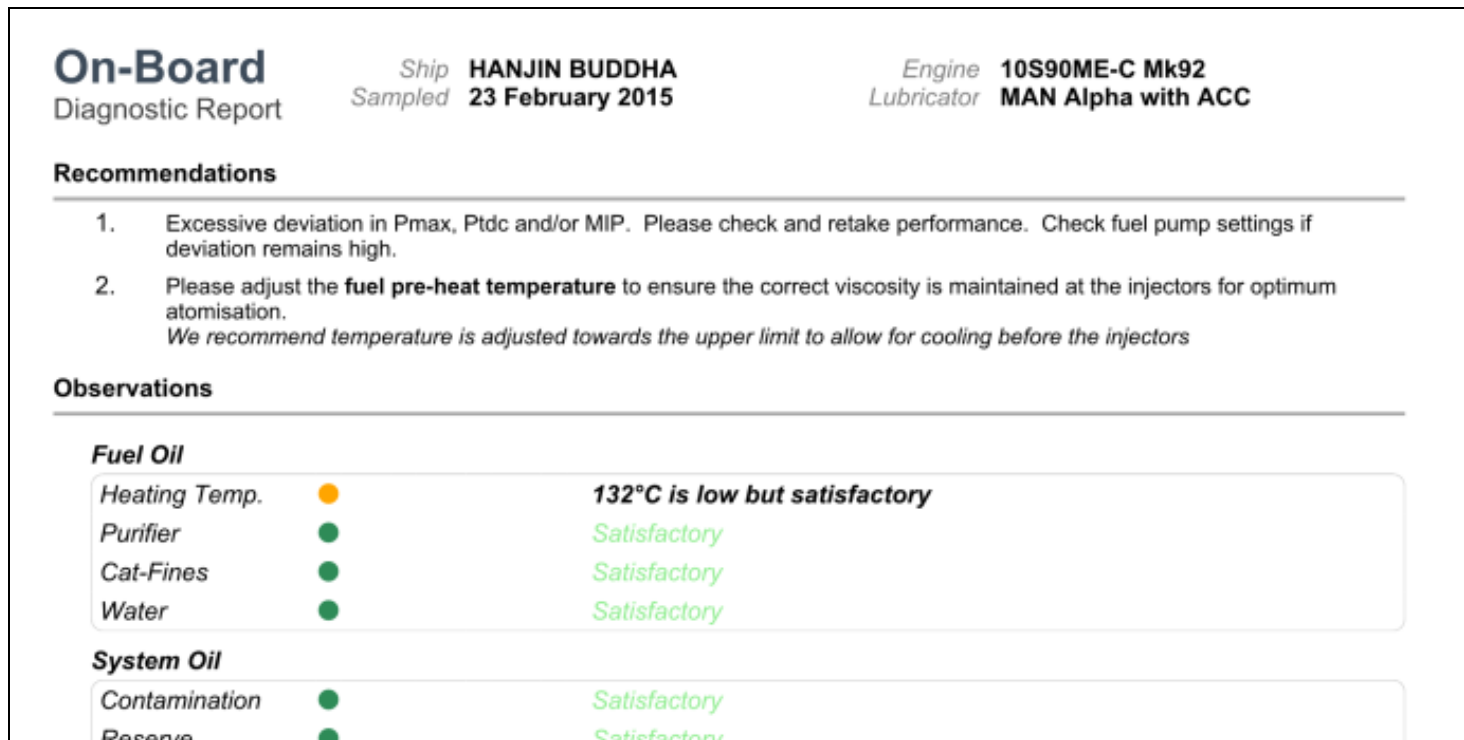


FIG.3 ON-BOARD DIAGNOSTIC REPORT

The system is designed to be extensible (by authorised third parties) to extend the functionality of the system beyond that provided by MAN Diesel & Turbo using a simple Application Programming Interface (API).

Such ‘plugins’ can leverage the authentication, presentation, transport and storage systems.

2. OPTIMISING CYLINDER OIL DOSAGE

With the continuing drive towards improving fuel efficiency and reducing operating costs, the correct dosage of cylinder lubricating oil is vital to maintain the good operation of the engine. Under lubrication, low liner temperatures, high scavenge air temperatures or the use of too low BN lubricating oil, can all lead to increased wear from cold corrosion. Over lubrication can result in bore polishing leading to increased wear and operating costs.

Cylinder oil is essential for the two-stroke engine. Today’s cylinder oils are made with a complex

chemistry, and the individual feed rate must therefore be assessed for each oil brand, viscosity class and BN level. A cylinder oil is designed with the necessary level of detergency and dispersancy to keep the piston rings and crown clean, and with an alkaline reserve (indicated as Base Number) required to neutralise the acids formed during combustion. The cylinder oil not only serves to lubricate the moving parts, but is also used to control the degree of corrosion on the liner surface; too much reduces component lifetime and too little leads to bore polishing.

This is defined in the feed rate guide for the engine, which sets the minimum feed rate to the level needed to keep the parts moving within a safe margin. However, in order to ensure the necessary lubrication effect, an increased formation of acid would call for a higher BN level than specified at the minimum feed rate. This is compensated for by calculating a feed rate on the basis of an ACC factor.

MAN Diesel & Turbo recommends using cylinder lube oils characterised primarily by its BN number and SAE viscosity, and to use a feed rate according to the BN in the cylinder oil and Sulphur content of the fuel. MAN Diesel & Turbo is aware that some engines may be operated satisfactorily at even lower feed rates than specified. Hence feed rates should always be based on practical experience rather than pre-calculated figures so as to find the correct ACC value for the actual engine configuration, operational conditions and engine load.

Case study: Hanjin Buddha

Seaspan has experienced over lubrication on their fleet of KMC-C engines. The optimal ACC factor for these engines was well below 0.20 g/kWh/S%. As a consequence, Seaspan has been operating these

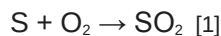
The best way to establish the optimum ACC factor is to measure the engine wear. If the wear rate of the liner and piston rings is too high, because of corrosion, the ACC factor must be increased to reduce the wear. We recommend starting out with an ACC factor in the upper end of the range, and then slowly reducing it when the engine wear response has been confirmed by measurements.

OBD provides several tools to assess cylinder lubricating oil dosage and provide feedback to decide whether it may be adjusted. For example, OBD provides an easy overview of drain oil Iron/BN results (Fig. 5) in combination with wear measurements and key performance data. In this way the crew is always aware of the impact of the actual cylinder oil dosage.

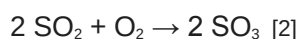
engines at a fixed cylinder oil feed rate of 0.55 g/kWh for the last ten years. This resulted in huge cost savings. Using OBD, the feed rate for Hanjin Buddha has been reduced from 0.29 to to 0.25 g/kWh x %S

2.1 Iron/TBN

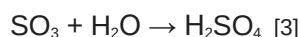
During combustion, the fuel sulphur is oxidised and oxygen in the air reduced to form sulphur dioxide.



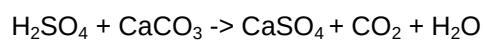
Some of the Sulphur dioxide is further oxidised into Sulphur trioxide



The sulphur trioxide reacts with water additively to form sulphuric acid.



In summary,



From the standard reduction series, calcium (Ca) has a higher reactivity than iron (Fe) [4]. Thus, the acid reacts with the calcium carbonate buffer rather than corrode the iron cylinder liner wall and piston.

Therefore, by monitoring the Iron and TBN using both on-board equipment and laboratory analysis, it is possible to determine the optimal cylinder lubrication oil dosage. Fig 5

2.2 Sweep Test

As discussed in MAN Diesel & Turbo Service Letter [5], a good way to determine the initial cylinder oil dosage is to perform a stress test called "feed rate sweep" or *Sweep Test*.

In OBD, a Sweep Test Report is generated each time a sweep test is performed. An example of the sweep test graph, from the OBD report is shown in Fig.4. The

Sweep Test is based on a fast five-day test at steady load and, preferably, running on fuel in the high sulphur range of 2.8-3.5 % sulphur content. The cylinder oil feed rate is adjusted to set values, i.e. 1.4, 1.2, 1.0, 0.8 and 0.6 g/kWh. Each feed rate must be applied for 24 running hours before taking a sample and switching to the next feed rate.



Recommended Feed Rate Factor [ACC] (see note):

0.26 g/kWh x %S

Comments:

A set of 5 drain oil samples were collected starting on 12 Feb 2016 with a range of cylinder lubricating oil feed rates from 0.52 g/kWh to 1.00 g/kWh. From the results of the laboratory analysis, the recommended feed rate factor [ACC] indicating a drain oil TBN greater than 20 mg KOH/kg and wear less than 200 mg/kg of iron is 0.26 g/kWh x %S.

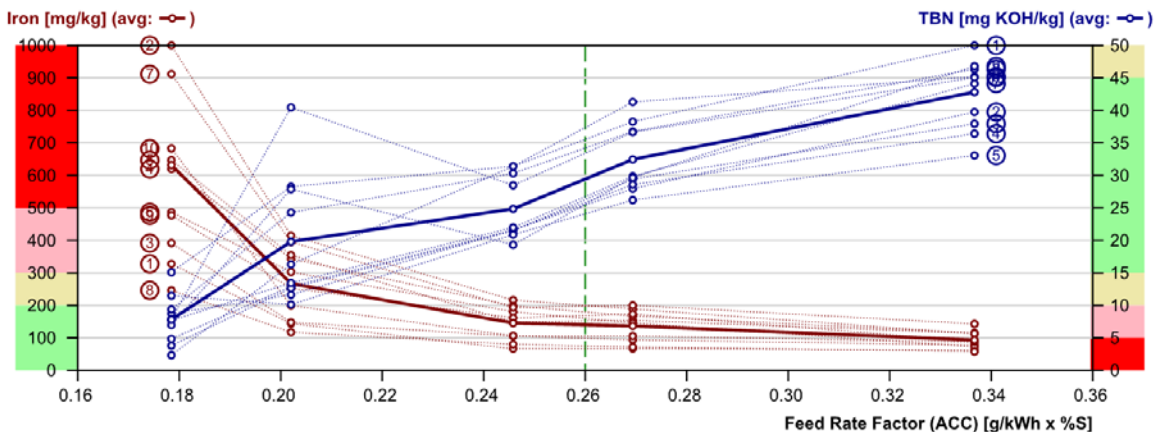
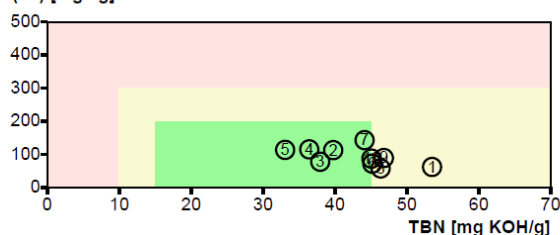


FIG.4 SWEEP TEST

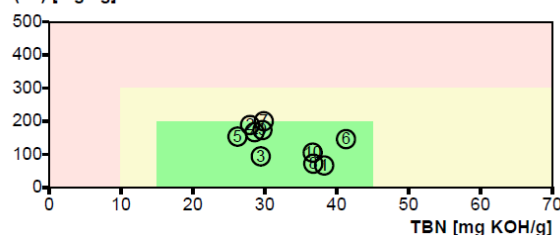
In Fig.5 we can clearly see the change in acids neutralised (by the reduction in TBN) and the increase in iron as the feed rate is reduced. As is typical in acid corrosion cases, iron wear increases significantly once the BN of the oil has been depleted as seen in the last illustration of Fig. 5.

The Sweep Test should be used to determine the optimal initial feed rate whenever there is a significant change in operating conditions, such as a change in fuel sulphur, cylinder oil BN or operating condition.

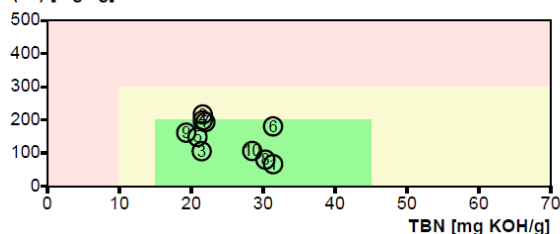
Feed Rate: 1.00 g/kWh
Iron (Fe) [mg/kg]



Feed Rate: 0.80 g/kWh
Iron (Fe) [mg/kg]



Feed Rate: 0.73 g/kWh
Iron (Fe) [mg/kg]



Feed Rate: 0.60 g/kWh
Iron (Fe) [mg/kg]

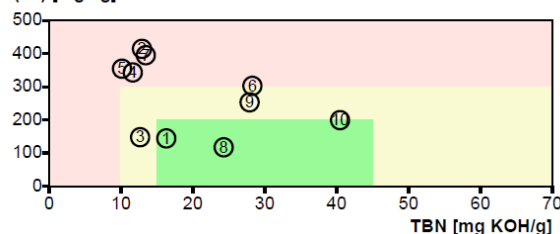


FIG.5 SWEEP TEST IRON/BN CHART

2.3 Scavenge Air Temperature

As described in a MAN Diesel & Turbo *Market Update Note* [6], formation of acids is a function of fuel sulphur concentration, water concentration in the combustion chamber and the liner temperature. MAN Diesel & Turbo research has shown a strong relation between the total water content during combustion and the level of corrosive wear. Defining a low set point for the central cooler is crucial to keep wear as low as possible. The lower temperature reduces the air's ability to contain water therefore more water is condensed and removed from the combustion process by the water mist catcher.

OBD highlights this issue by indicating the lowest possible scavenge air temperature. As OBD receives all the needed data for this calculation in real time, the C/E can be made aware when the scavenge air temperature should be lowered in order to decrease wear and Fuel

Oil consumption. [5] and [7]. Despite the fact that the MAN Diesel recommendation has always been to have a set point of the central cooler of 10°C, most engines are running with a fixed set point of 36°C.

Case study: Hanjin Buddha

The lowest possible scavenge air temperature is indicated in Fig.6 based on a central cooler set point of 10 °C.

Fuel oil savings is possible by running at lowest possible scavenge air temperature but for this vessel, modifications of the cooling system would be required to achieve this temperature.

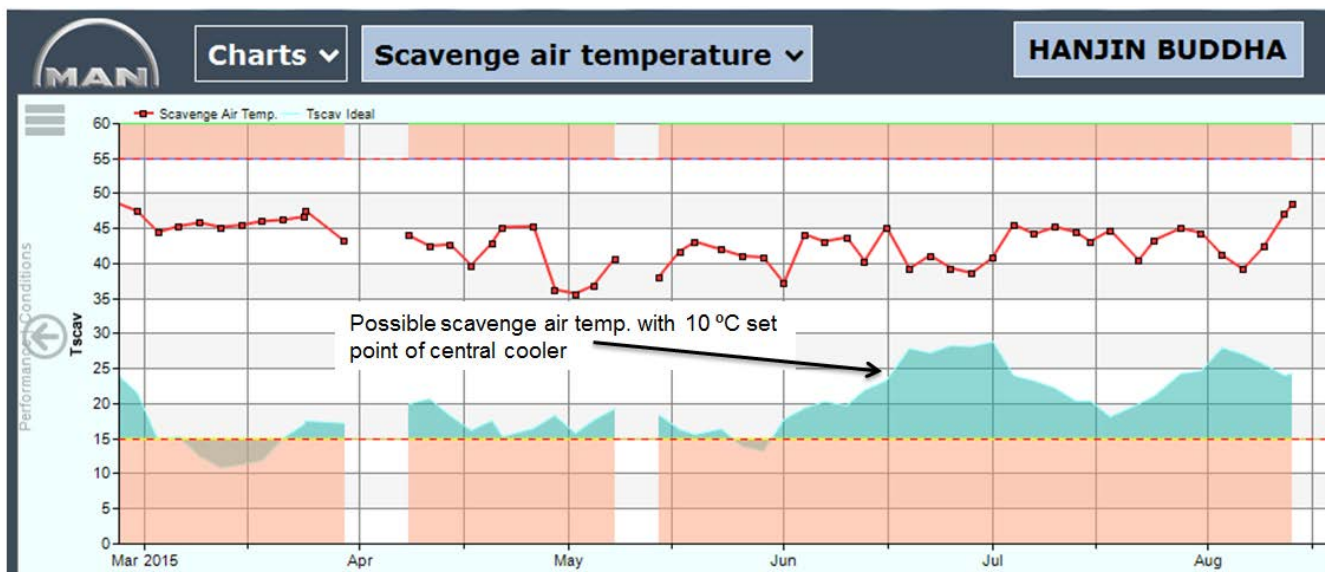


FIG. 6 SCAVENGE AIR TEMPERATURE CHART

2.4 Fuel Temperature

The fuel viscosity at the injectors is a parameter for the correct atomisation of fuel during injection. To allow for heat loss between the viscometer and the injectors, it is suggested that the fuel temperature is maintained at the upper level with the viscosity maintained close to 10cSt

Continuous monitoring of fuel temperatures by OBD provides real time diagnosis of fuel temperature to reach the optimum viscosity at the injectors (10-15 cSt).

Case study: Hanjin Buddha

Fig.7 shows how OBD is used to monitor the viscosity and temperature of the fuel at the viscometer. The condition displayed is good, as both iron and viscosity are well within limits displayed on the charts.

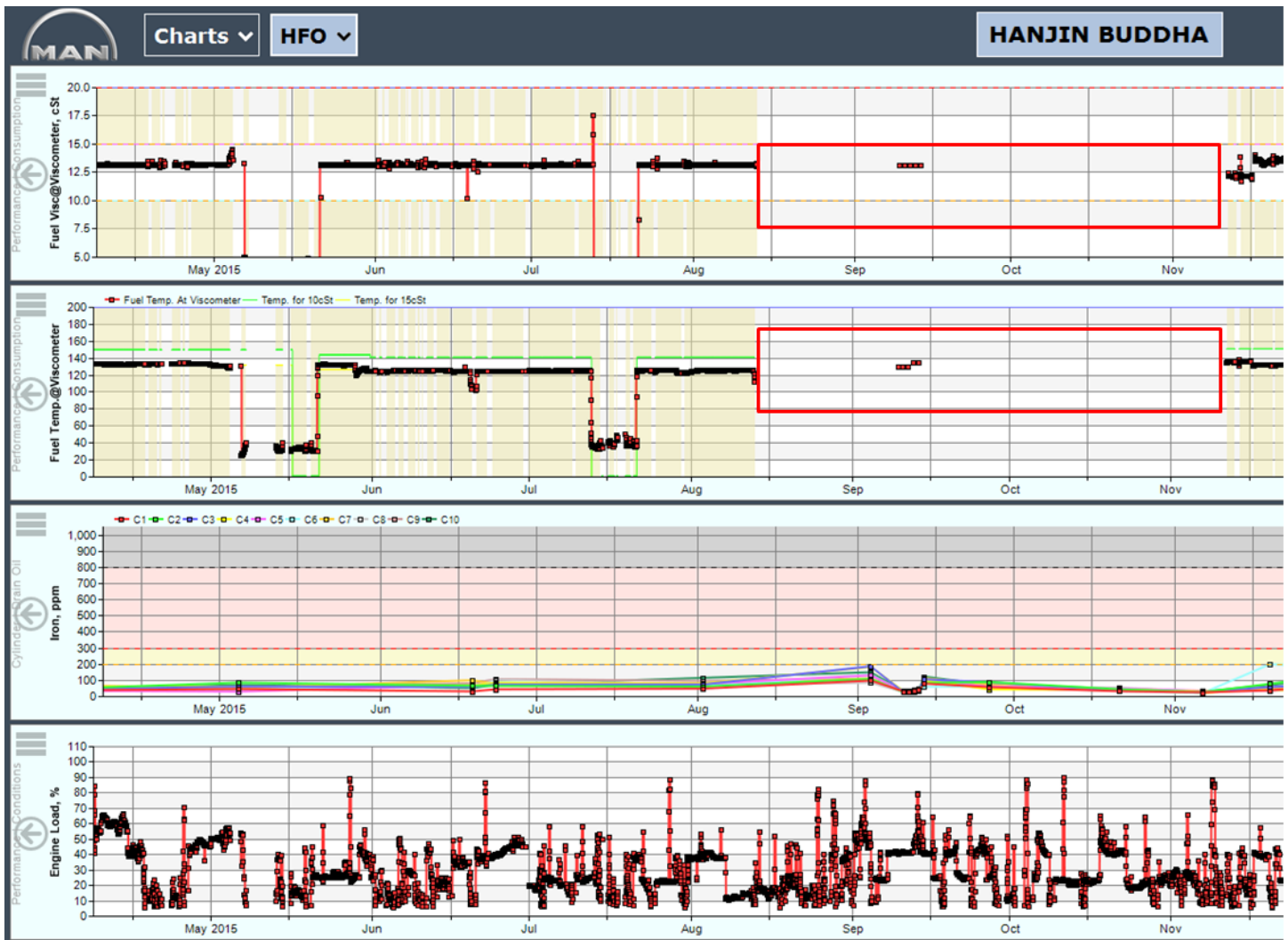


FIG.7 FUEL TEMPERATURE CHART

3. DIAGNOSING SENSOR FAILURE

Periodically, sensors will fail. However, the failure may not become apparent unless the outputs from the sensors are monitored regularly. Due to the large amount of data generated by various systems monitoring the engines, a sensor fail can be left unnoticed unless an

alarm is triggered. With all data being collected to a central source, failure can be monitored and actions taken to rectify when, on-board during normal operation, those failures might not be observed.

Case study: Hanjin Buddha

With the OBD installed, cylinder pressure sensor for unit 7 was found failing (Fig. 8) and no pressure increase could be detected in cylinder 7.

The crew became aware of the situation due to data missing from the alarm system (illustrated by the red boxes in Fig.7)

In one case, a group of sensors failed.

Further investigation revealed that a system failure had occurred between the alarm system and the OBD.

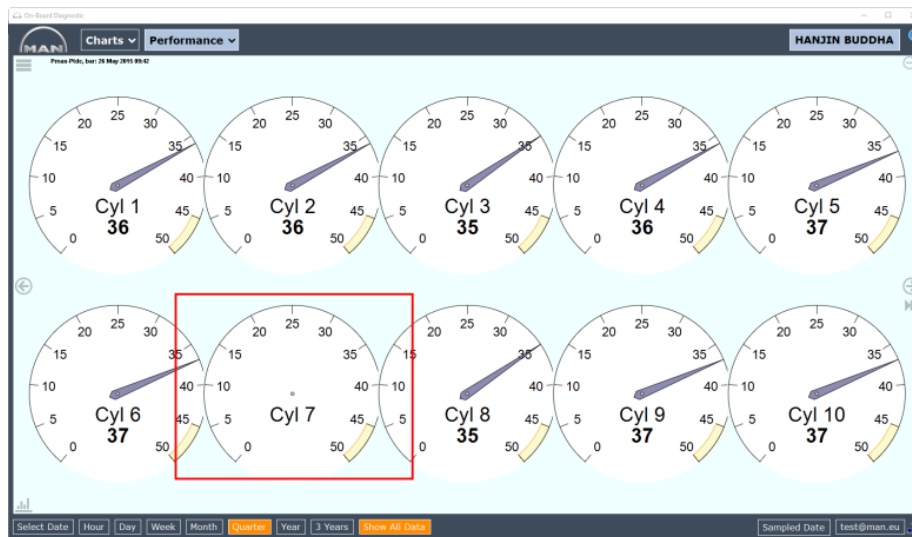


FIG.8 PRESSURE RISE (P_{MAX}-P_{COM})

4. CONDITION BASED MONITORING

Overhauling cylinder units is a part of engine maintenance. From a cost perspective, it is generally preferred to extend the period between overhauls to the maximum without jeopardising safe running of the engine.

One recommended technique for increasing the period between overhauls is to use condition based monitoring where overhauls are scheduled based on the actual condition of the engine components. OBD provides valuable information for assessing the components lifetimes.

Expected life time of components, combined with scavenge port inspections, allows the crew to plan the optimal time of overhaul.

Case study: Component Lifetimes

As part of regular engine inspections, crews should be measuring piston ring and liner wear. Numerous tools are commercially available to make this task relatively straightforward.

Whilst drain oil analysis will give essential feedback on the operating conditions within the engine, piston ring coating, ring groove clearance and liner wear measurements will provide the information needed to assess the effect of the operating condition on the physical condition of the engine. Every time a set of measurements during a scavenge port inspection is

OBD has the functionality to create a report giving the needed information in accordance with MAN Diesel & Turbo Service Letter [8] to satisfy the requirements of the classification societies on Condition Based Overhaul.

The following sections will illustrate how OBD makes use of some of the data obtained from scavenge port inspections.

carried out, OBD can read the data show the data in different formats.

One such report shows all cylinder units and a general assessment of the piston ring wear (ref Fig. 9). Other reports show the individual cylinder unit and the expected lifetime is calculated based on a projection from the latest measurements (as illustrated in Figs. 10 and 11). In this way, the crew receives a good indication about when to plan an overhaul. In case the indicated lifetime is lower than expected, it enables appropriate countermeasures to be taken at an early stage.

Top Ring Coating Wear Rate

Piston Ring Coating (top ring)

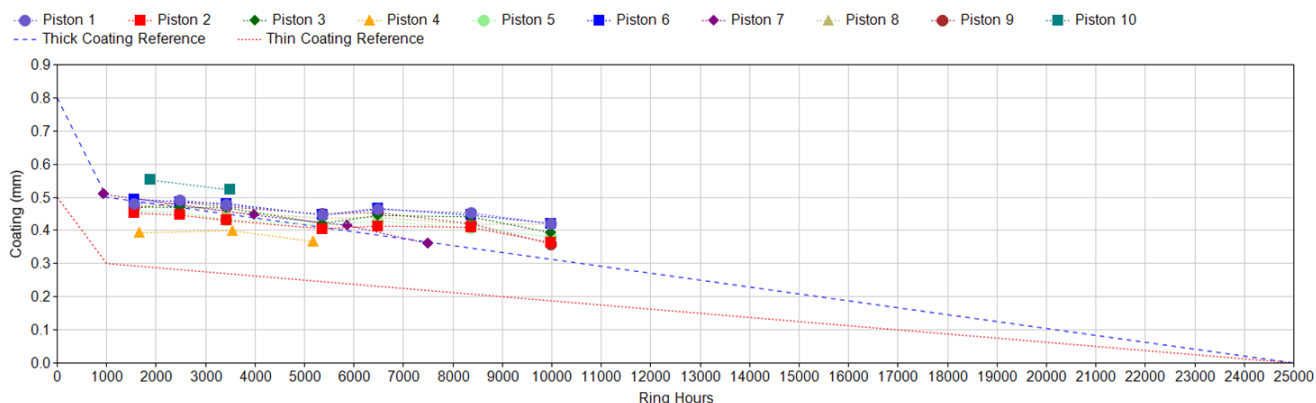


FIG.9 PISTON RING COATING LIFETIME PREDICTION

As can be seen from Fig. 9 and Fig. 10, prediction of the ring lifetime is straightforward once a reasonable number of measurements have been entered into OBD

The information for assessing component lifetime is easily collected and entered into the standard MAN Diesel Cylinder Condition Forms, which are read by OBD, to provide instant feedback on operational lifetime of the components.

Seaspan has experienced an increase in time between overhauls of up to 50,000 running hours on vessels with KMC-C engines, due to very close condition based monitoring achieved through use of OBD.

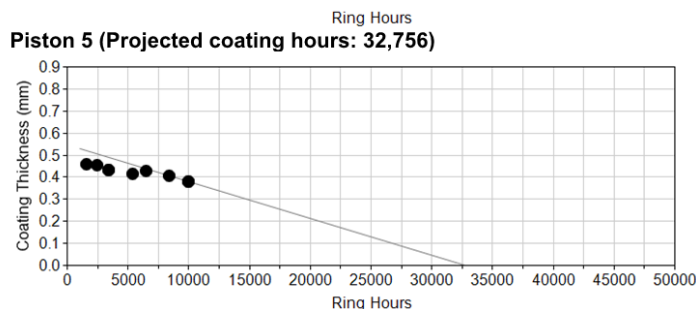


FIG.10 PISTON RING COATING LIFETIME PREDICTION

Liner 6 (Projected liner hours: >80,000)

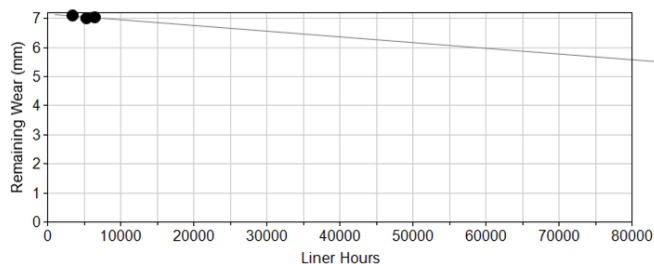


FIG.11 LINER WEAR/LINER LIFETIME

In the same way, the prediction for liner wear and liner lifetime can also be assessed using the reports, as seen in fig. 11

6. EXTENSIBILITY

OBd can be expanded through the use of 'plugins'. These are modules that integrate with OBd and use the

application to display results and synchronise data from the ship to the OBd Cloud Service.

6.1 Strain Gauge Data

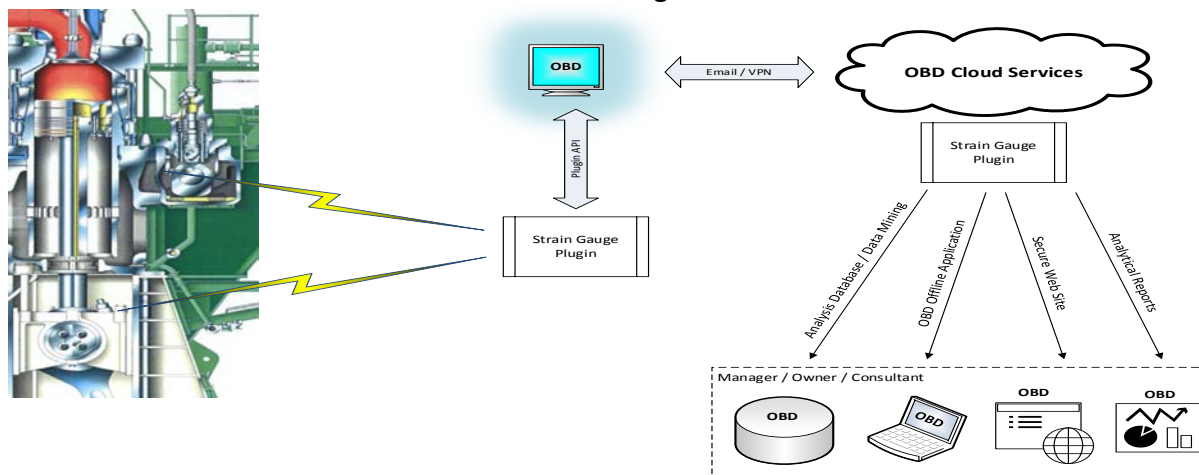


FIG.12 STRAIN GAUGE DATA COLLECTION

The strain gauge system periodically monitors strain in the engine and uses the data collection process of OBd to render that information to the OBd Cloud Services where it is made available for detailed analysis. Fig.12 On-board, when strain thresholds are exceeded, notifications may be optionally raised in OBd.

Opportunities exist for third party equipment suppliers to develop plugins to leverage the User Interface (UI) and communications facilities in OBd to further enhance their products.

7. DATA ANALYSIS

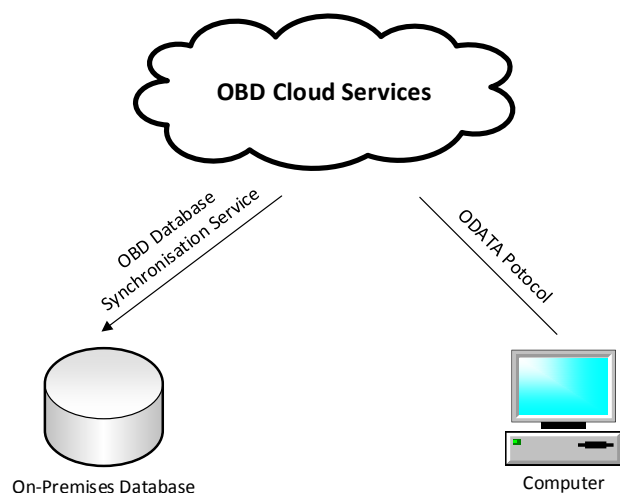
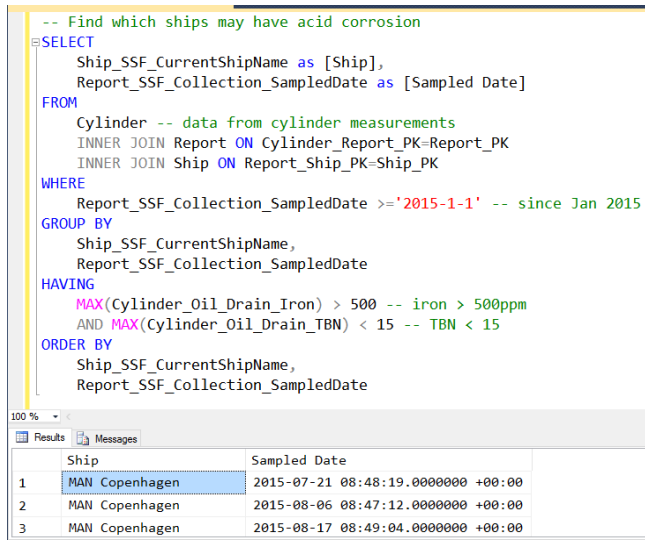


FIG.13 DATA ANALYSIS

OBd data is stored in an industry standard Microsoft SQL Server database. Numerous third party software systems can access this data which can be provided to customers as an on-premises database using the OBd Database Synchronisation service or directly from the OBd Cloud Service using the industry standard ODATA protocol (for light use only) Fig. 13



Detailed analysis can be performed using industry standard SQL with Microsoft's data mining extensions. In Fig.14, an analysis is being run to determine the cases where it is probable that wear is caused by acid corrosion

FIG. 14 DETAILED ANALYSIS

CONCLUSION

On-Board Diagnostic is a unique tool for monitoring and investigating engine operation, and providing feedback on engine performance and condition via the inbuilt expert system. By combining real-time information from the engine with laboratory, engineering and other measurements, correlations that previously were difficult to reconcile become clear.

In the paper, various concrete cases were discussed which demonstrated the utility for the on-board engineering team and the potential for shore based support by the management technical team and/or MAN Diesel where both the team on-board and the shore based support view the same information.

Further, the ability for owners, managers and technical teams to interrogate the data that is collected provides additional opportunities for efficiency management and cost controls. Because of the open and industry standard protocols, organisations, and third parties, can develop further solutions for more detailed analysis or integrate with interested parties, such as classification societies, for increased efficiency and lower operating costs. The in-built extensibility of the system assures implementers that as new on-board systems become available, these can be integrated to provide a holistic solution to engine information.

The authors are grateful for the cooperation of Seaspan Ltd. in the development of this system.

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