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Diploma Thesis

by

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Electronic Marine Diesel Engine operating data management
An approach to components' failures forecasting

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ABSTRACT

Currently, the Electronic Diesel Engines are prevailing in the Marine Industry. Systems have been adopted by Electronic Engines' Manufacturers which are continuously monitoring a wide range of operational data. These systems are embedded in order to support automatic adjustment of specific parameters, so as optimize engine operation.

Computer tools are also incorporated, enabling the recording of the data measured. The acquisition of these data provides the opportunity of their analysis for the purpose of fault diagnosis and establishment of specific faults trend curves.

The main objective of the present study is to examine the feasibility of managing the available data for the purpose of components' failures forecasting. It is investigated whether the degradation of the condition of a single component creates a specific trend on engine operating parameters, thus enabling failure prediction. The effect of automatic tuning function is also taken into consideration.

The analysis focuses on events that fall under one of the following cases resulting in a reduction of cylinder compression pressure:

- Case No.1: Wear of cylinder liner
- Case No.2: Wear of exhaust valve
- Case No.3: Wear of piston rings

ΠΕΡΙΛΗΨΗ

Τα τελευταία χρόνια, οι ηλεκτρονικοί κινητήρες Diesel έχουν επικρατήσει στις ναυτικές εφαρμογές. Οι κατασκευαστές ηλεκτρονικών κινητήρων έχουν υιοθετήσει συστήματα για τη διαρκή παρακολούθηση ενός μεγάλου αριθμού λειτουργικών παραμέτρων. Τα συστήματα αυτά υποστηρίζουν την αυτόματη ρύθμιση ορισμένων μεταβλητών, ώστε να βελτιστοποιείται η λειτουργία του κινητήρα.

Επιπλέον, έχουν ενσωματωθεί στους κινητήρες υπολογιστικά συστήματα που επιτρέπουν την καταγραφή των μετρούμενων δεδομένων. Η διαθεσιμότητα των στοιχείων αυτών καθιστά δυνατή την ανάλυσή τους, με σκοπό την πρόγνωση βλαβών και τη συσχέτιση μεταβολών των παραμέτρων λειτουργίας με συγκεκριμένες αστοχίες.

Ο κύριος στόχος της παρούσας εργασίας είναι η διερεύνηση τρόπων διαχείρισης των διαθέσιμων δεδομένων για την πρόβλεψη βλαβών συγκεκριμένων εξαρτημάτων. Εξετάζεται, δηλαδή, αν η φθορά ενός μεμονωμένου εξαρτήματος επιδρά με συγκεκριμένο τρόπο στις λειτουργικές παραμέτρους του κινητήρα, οπότε κατ’ επέκταση δύναται να προβλεφθεί. Κατά τη μελέτη λαμβάνεται υπόψη και η επίδραση της λειτουργίας αυτόματης ρύθμισης στις τιμές των παραμέτρων.

Η μελέτη επικεντρώνεται σε περιστατικά βλαβών που είχαν ως επακόλουθο τη μείωση της πίεσης συμπίεσης, και εμπίπτουν σε μία από τις ακόλουθες περιπτώσεις:

- Περίπτωση No.1: Φθαρμένο χιτώνιο
- Περίπτωση No.2: Φθαρμένη βαλβίδα εξαγωγής
- Περίπτωση No.3: Φθαρμένα ελατήρια εμβόλου

1. INTRODUCTION

In the last decades, diesel engines have been prevailing in marine applications. As the prime propulsion systems, it is imperative to be kept running reliably and uninterrupted to the best possible extend. Hence, enhancing the reliability and efficiency of marine diesel engines is an active field of research. Early detection and diagnosis of faults is essential to ensure scheduled completion and safety of voyages. Towards this direction, many methodologies have been proposed to detect impending faults of marine diesel engines.

The most commonly used technique for failures prediction employs lubricating oil analysis. The wear condition of engine components is evaluated based on the element concentration obtained from oil analysis [1, 2, 3].

Additionally, vibration analysis has been used for the purpose of detecting developing failures [4]. However, the marine environment may affect the results of this technique and lead to misdiagnosis. Furthermore, systems have been developed in order to categorize wear particles and identify the wear mode of marine diesel engines [5]. Experiments have proven that systems integrating vibration analysis and wear debris analysis offer superior fault diagnosis ability for marine power systems [6].

Another proposed diagnostic method employs the use of instantaneous angular speed [7, 8], according to which the patterns of the engine are identified from the measured signal using the time frequency analysis. Other approaches contribute to failure occurrence prediction through the retrieval of engine noise sources such as combustion and valve operation [9]. Methods based on thermodynamic modeling have been proposed as well [10], however the model parameters have to be determined correctly. Moreover, intelligent algorithms have been developed for wear state identification such as artificial neural networks [11, 12].

It is worth noting that research has been conducted for detection of failures affecting the cylinder's compression pressure. D. Watzenig et al. have developed a model-based approach for identification and clear separation of two common failures of large diesel engines that cause very similar changes in the cylinder pressure [13, 14]. Based on thermodynamical models, the symptoms due to changes in the compression ratio and increased blow-by are determined by measuring only cylinder's pressure traces with low sampling interval (1 degree of crankshaft angle).

In addition, D.T. Hountalas et al. investigated experimentally the effect of various parameters on the cylinder compression pressure diagram during motored operation in order to develop a methodology for estimating the actual cause for reduced compression ability of Direct Injection Diesel engines [15].

The main objective of all methods is the evaluation of engine's condition without stopping or dismantling so as degradation of certain components to be early diagnosed and imminent failures to be predicted right in time for implementation of corrective actions.

In view of the above, the present study aims to contribute to detecting and identifying different engine failures of Electronic Marine Diesel Engines, which are getting remarkable share in the marine industry the recent years. Electronic Engines are embedded with condition monitoring systems that enable the control and recording of various operating parameters. The use of these systems provides the opportunity of continuous measurement and acquisition of a great range of operating data, thus databases can be created with engine's operating characteristics throughout its life.

The main objective of this study is to examine the feasibility of managing the available data for the purpose of components' failures forecasting. In other words, it is investigated whether the deteriorating condition of a single component has a specific effect on engine operating parameters and therefore failures can be predicted.

In the frame of this study, existing data of a 61,000 DWT bulk carrier, built in 2015 and equipped with Electronic Main Diesel Engine by MAN Diesel & Turbo Type 6S50ME-B9.3 (Mark 9), are analyzed. The data are mainly derived from the Pressure Measuring Instrument (PMI) and Computer Controlled Surveillance – Engine Diagnostics System (CoCoS – EDS).

The analysis focuses on events that occurred during operation of the vessel resulting to reduction of cylinder compression pressure. The cases considered are:

- Wear of cylinder liner
- Wear of exhaust valve
- Wear of piston rings

The whole procedure was rather changeling considering that Electronic Engines incorporate systems for automatic tuning. Information on tuning functions are not available in the literature, so the present analysis pursues also an approach to the effects of auto tuning system on engine operating parameters.

2. ELECTRONIC ENGINE GENERAL OVERVIEW

The two-stroke Main Diesel Engine installed on our case study vessel belongs to the family of Electronic Engines (or ME) designed by MAN. The term "Electronic" refers to the electronically controlled fuel injection.

The specific type of this engine is ME-B9.3, which means that the exhaust valve opening is controlled by a camshaft and that it is capable of variable exhaust valve closing. The variable exhaust valve closing timing is utilized in order to reduce combustion temperature and consequently NOx emissions. The specific model is 6S50ME-B9.3, the characteristics of which are listed in the following table (Figure 1).

6S50ME-B9.3	
Number of cylinder units	6
Stroke	Super long stroke
Bore (m)	0.50
Connecting Rod Length (m)	2.21
Stroke (m)	2.21
P_{comp} / P_{scav}	39.8
Firing order	1-5-3-4-2-6 (clockwise)
Maximum continuous output (MCO)	8,130 kW at 108 rpm
Normal continuous output (85% MCO)	6,910 kW at 102 rpm
Tier II compliant	NOx emissions less than 14.9 gr/kWh
Fitted with exhaust gas turbocharger (T/C)	One ABB T/C Model A265

Figure 1: Specifications of case study engine

A general overview of an ME-B Engine can be seen in Figures 1.1 and 1.2. Systems and components are described in detail in the following sections.

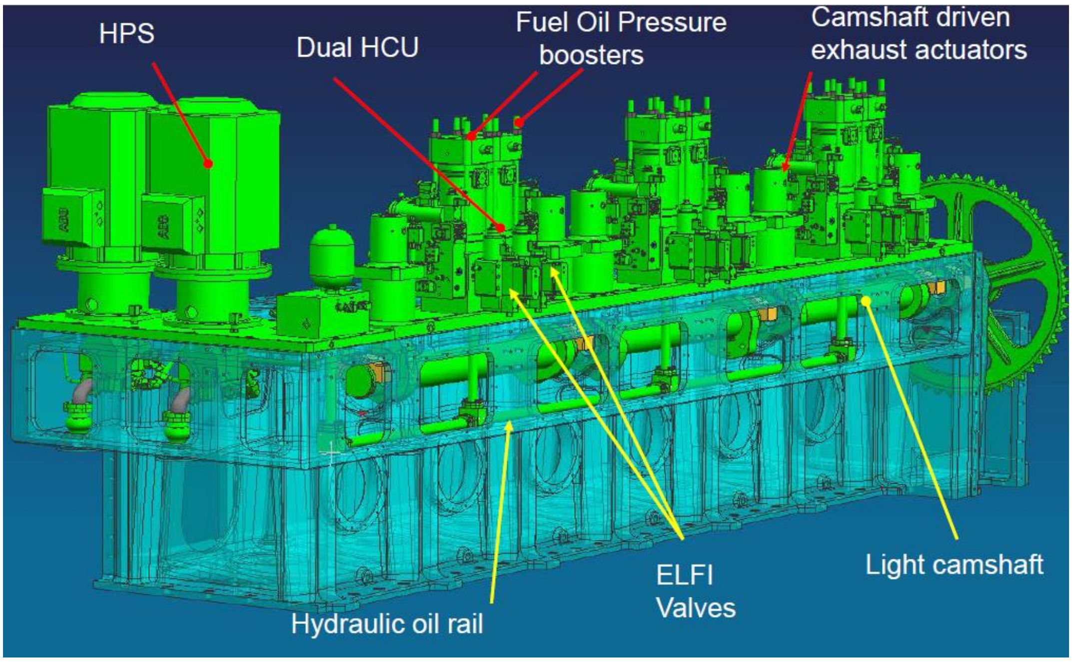


Figure 1.1: ME-B Engine System and components – General Overview [18]

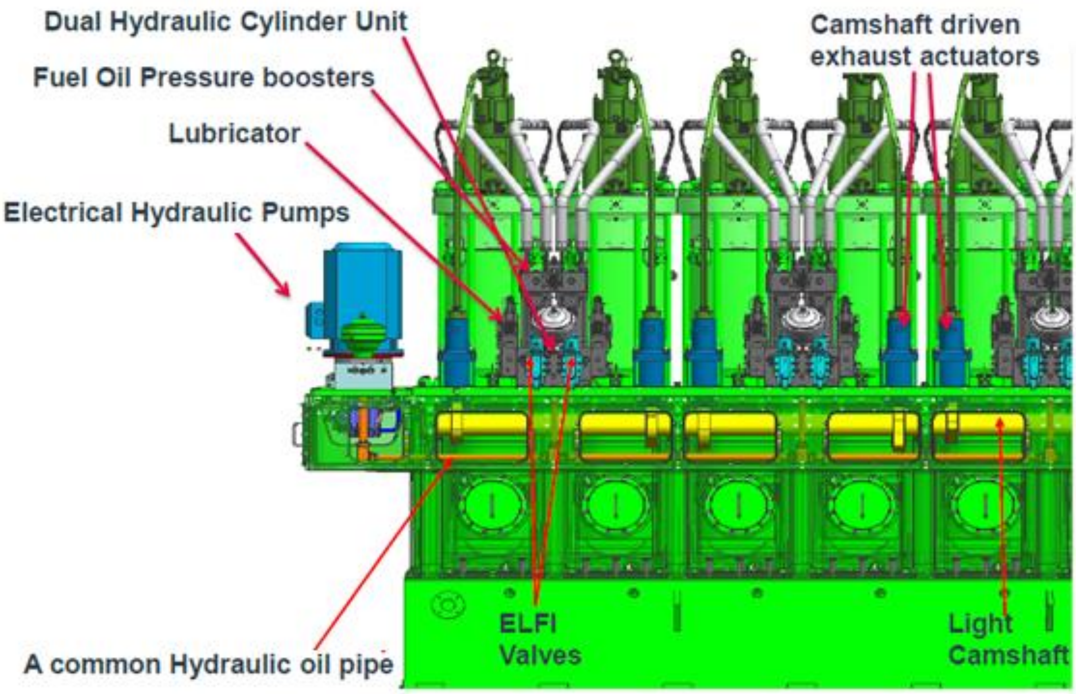


Figure 1.2: ME-B Engine System and components – General Overview [18]

The main components and systems of an ME-B9.3 Engine are described herein next.

2.1 Hydraulic Power Supply

The Hydraulic Power Supply (or HPS) unit consists of two electrically driven hydraulic pumps and one membrane accumulator as seen in Figure 2.1.

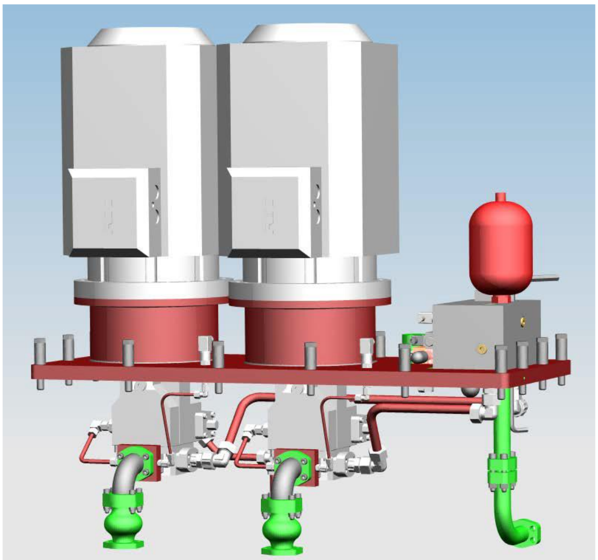


Figure 2.1: Hydraulic Power Supply Unit [18]

Low pressure hydraulic oil stored in Sump tank is delivered by the pumps to the accumulators at 300 bar pressure.

Every time the HPS is stopped, the system measures the time required for the hydraulic pressure to drop by 60 bars from normal running pressure point. This time period is called Decay time. This value is displayed on the MOP as a bar graph (Figure 2.2).

The first bar is fixed and it is called Reference Bar which is defined during engine commissioning. Each time the HPS is stopped, a new bar appears next to the fixed Reference Bar. Decay time should be between 15 and 20 seconds and the bar should end in the green area.

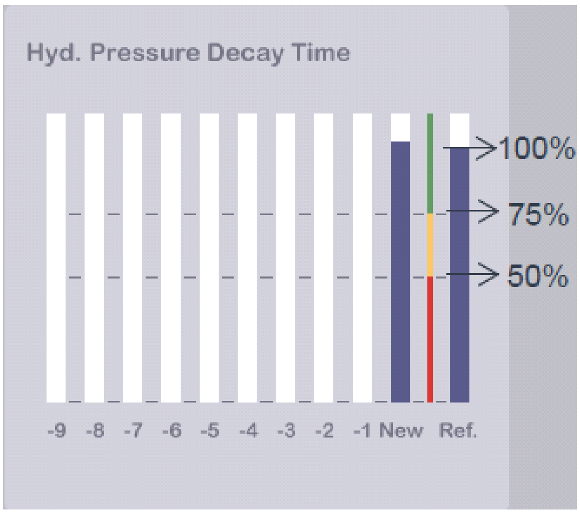


Figure 2.2: Decay Time Bar Graph [18]

The use of this graph helps identifying leakages in the hydraulic system. For example, in case of a small growing leakage in the hydraulic system, a set of bars decreasing in length (from left to right) will be produced, falling from the green area to the yellow area.

2.2 Dual Hydraulic Cylinder Unit

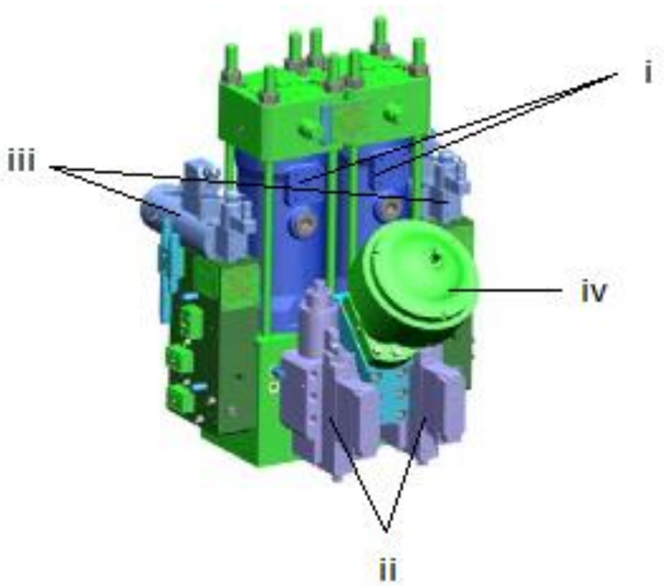


Figure 2.3: Hydraulic Cylinder Unit [18]

The Hydraulic Cylinder Unit (or HCU) consists of the following components as depicted in Figure 2.3:

i. two fuel oil pressure booster pumps
ii. two Electronic Fuel Injection Valves and Exhaust Valve Actuation control valves (or ELFI-V)
iii. two cylinder lubricators
iv. one membrane accumulator

One HCU operates two cylinder units. Its intended use is to optimize Specific Fuel Oil Consumption.

The high pressure hydraulic oil stored in the accumulator is used for the control of fuel injection, as well as the control of exhaust valve closing (i.e. the activation of exhaust valve actuator) through the ELFI-V valves.

The variable fuel injection timing allows the adjustment of cylinder maximum combustion pressure and therefore affects the fuel consumption. The greater the maximum pressure, the lower the fuel consumption. However, the maximum pressure cannot exceed engine design limits.

The Exhaust Valve Actuator Timing Unit regulates the cylinder compression pressure through the adjustment of the exhaust valve opening interval. It can be mounted either on the HCU (Figure 3) or on the exhaust valve actuator (Figure 4).

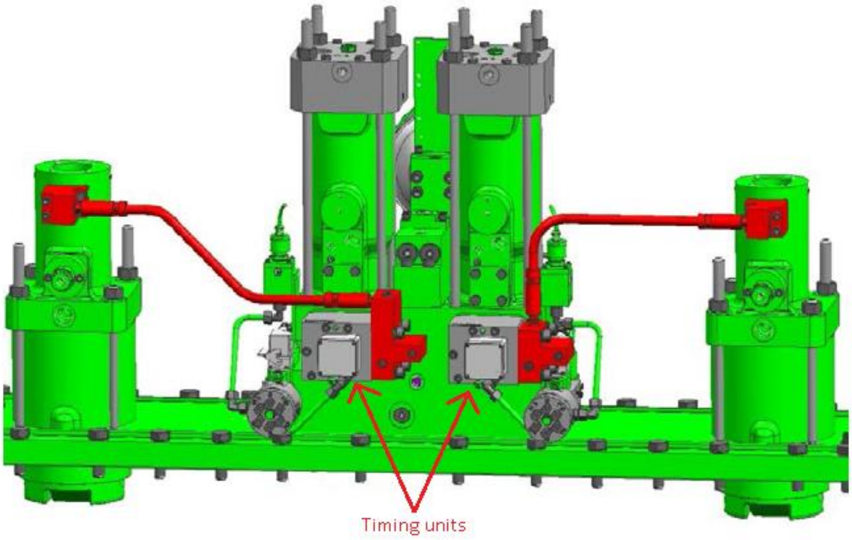


Figure 3: Exhaust Valve Actuator Timing Unit mounted on the HCU [22]

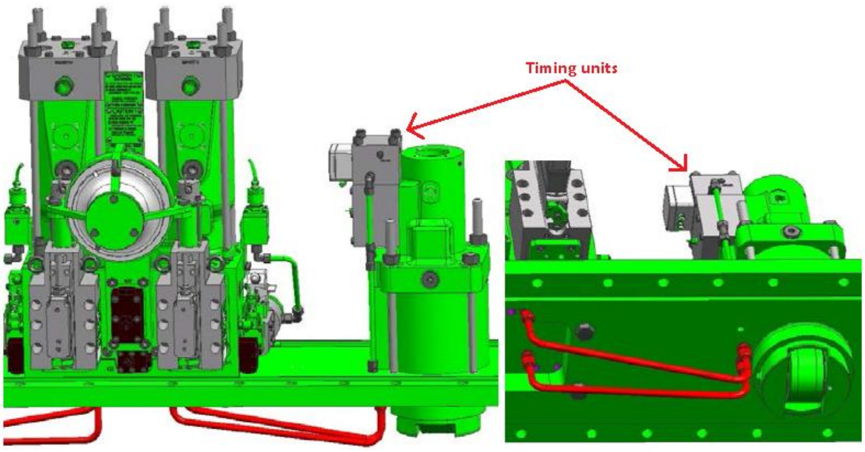


Figure 4: Exhaust Valve Actuator Timing Unit mounted on the exhaust valve actuator [22]

The flow of the hydraulic oil is carried out through the red pipe lines. In the case of Figure 3, the pipes are double-wall for safety reasons. In the case of Figure 4, the pipes are single-wall since they are located inside the camshaft box.

Applicable to our case is the arrangement depicting in Figure 3.

The ME-V system is always active when the engine is running astern whilst it becomes active above 55% load when the engine is running ahead.

2.3 Engine Control System

The Engine Control System (or ECS) consists of a set of controllers or Multi-Purpose Controllers (MPC), as depicting in Figure 5. There are two types of controllers/cards, the Engine Interface Control Unit (EICU) and the Cylinder Control Unit (CCU). The functions of the controllers are described briefly thereinafter.

There are three available Control Stations. The Engine Side Control (ESC) and the Remote Control System (RCS) which includes the Bridge Control panel and Engine Control Room panel.

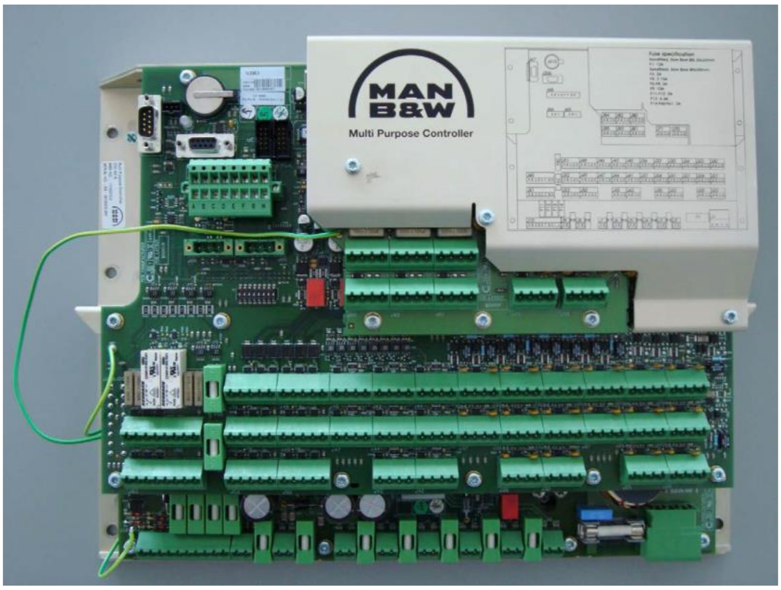


Figure 5: Multi-Purpose Controller (MPC card) [21]

2.3.1 Engine Interface Control Unit

Engine Interface Control Unit (or EICU) handles the interface to external systems, i.e. it acts as translator of signals received from external systems, and:

- commands the Hydraulic Power Supply (HPS) setpoint according to engine speed and load
- calculates the lubrication oil feed rate based on engine load, fuel characteristics (sulphur content) input from user and minimum requirements for lubrication levels
- controls the engine Running Mode (Economy or Emission)
- controls commands for automatic engine slow down

Engine Control Room panels and Bridge Control panels are connected to EICU. All calculations by the EICU are conducted based on navigational inputs and commands received from the control stations. The main navigational command is the speed setpoint which is the engine rpm requested by the Operator. The speed setpoint is processed by a series of protective algorithms, such as the desired Pressure-Rise as a function of engine running mode.

If the EICU fails, engine control is only possible from the Engine Side Console (ESC).

2.3.2 Cylinder Control Unit

One Cylinder Control Unit (or CCU) operates one cylinder unit and controls:

- the fuel injection profile and timing through the activation of ELFI valves
- the Fuel Index Limiters
  The Fuel Index Limiters are algorithms which define a maximum or minimum amount of fuel to be injected for the next combustion according to specified settings. More details are described hereunder.
- the governor mode
  This type of engine does not have a typical mechanical governor. Governor functions electronically in three different modes (rpm control, torque control or index control) in order to limit the fuel index command according to the actual engine operating conditions.
- the Starting Air System
- the activation of cylinders' lubricators according to the feed rate amount derived from the EICU
- commands for automatic engine shut down

Crankshaft position sensing system (or Tacho System as described in the next section) is connected to CCU of cylinders No.1 and No.2.

Engine Side Control panel is connected to CCU of cylinder No.1.

On completion of each combustion cycle, the CCU receives signals of cylinder's parameters. Based on this input and the selected engine running mode, the CCU defines the injection profile and timing for the next combustion cycle so as to maintain the engine speed setpoint. The output from the CCU is a "request" for fuel amount to be injected. This request is run through algorithms which are called "fuel limiters" and produce the command for fuel amount to be injected. Available Fuel Limiters are listed herein under.

START LIMITER
The start limiter defines a fixed minimum amount of fuel to be injected for the first injections during start.

CHIEF LIMITER
The chief limiter defines a maximum amount of fuel to be injected according to the settings done by the Operator on the MOP.

SCAVENGE AIR PRESSURE LIMITER
The scavenge air pressure limiter defines a maximum amount of fuel to be injected based on the actual scavenge air pressure. This is to ensure that the engine will not be over fueled.

TORQUE LIMITER
The torque limiter defines a maximum amount of fuel to be injected according to actual engine speed. This is to ensure that the engine torque does not exceed recommended levels.

HYDRAULIC POWER SUPPLY LIMITER
The hydraulic power supply pressure limiter defines a maximum amount of fuel to be injected according to actual hydraulic power supply requirements. This is to ensure that the hydraulic power supply pressure does not drop below a minimum operation limit. This limiter is active only in case of malfunction of the HPS.

Figure 6 depicts the MOP screen where fuel index limiters can be displayed.

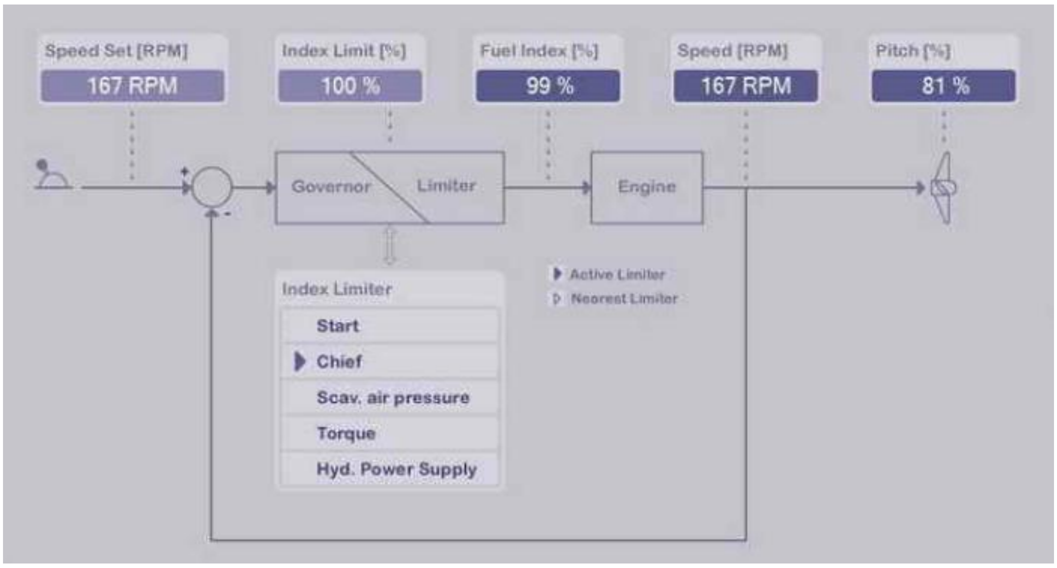


Figure 6: Main Operating Panel (MOP) Process Information screen - Fuel Limiters [17]

2.3.3 Main Operating Panel

Main Operating Panel (or MOP) is the Operator's interface to the ECS (Figure 6.1).

Figure 6.1: Main Operating Panel (MOP) Engine Operation screen [17]

All operating parameters can be displayed and adjusted on the MOP. There are two panels A and B in the Engine Control Room as seen in Figure 6.2. The MOP B is the master whilst the MOP A is the slave.

Figure 6.2: Engine Control Room Console [21]

In addition, all alarms activated either by the ECS or by external systems are displayed on MOP. The complete list of alarms can be extracted from the MOP B. This back up file can be displayed on the office computers using a software provided by MAN.

2.3.4 Scavenge Air Control Unit (SCU)

Scavenge Air Control Unit (or SCU) handles the control of Exhaust Gas By-pass Actuators.
Exhaust Gas By-pass valve (or EGB) is fitted on exhaust gas receiver between Cylinders No.3 and No.4. Partial opening commences at 75% engine load so as to adjust the scavenging air. Valve is fully open above 90% engine load.

2.4 Crankshaft Position Sensing System

Crankshaft position sensing system (or Tacho System) consists of a shaft, mounted on the forward part of the engine, with two angle encoders A (inside) and B (outside) for redundancy.

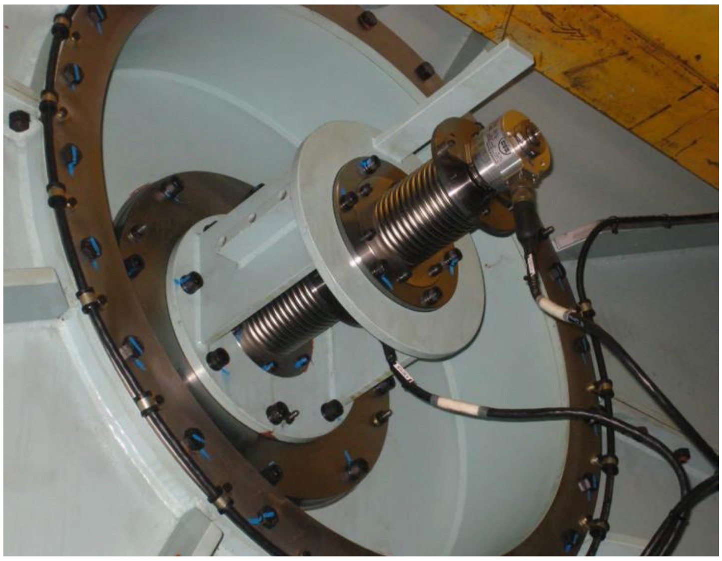


Figure 7: Angle encoders of Tacho System [21]

The Angle Encoder is a sealed unit fastened to a free end of the crankshaft via a special flexible coupling. It contains an externally driven, optically encoded disc, mounted between an internal light source and a detector. It produces a train of electrical pulses per revolution which are used to detect the absolute position of the crankshaft.

Both Angle encoder A (or Tacho A) and Angle encoder B (or Tacho B) are connected to piston No. 1 and they monitor the rotation of unit No.1 only. Tacho A sets the TDC of unit No.1.

The Tacho System transfers the position of the crankshaft to the CCUs, determines the firing order and sets up the injection profile start angle.

3. PRESSURE MONITORING SYSTEM

The Engine is equipped with a Pressure Monitoring Instrument (PMI). The purpose of the PMI System is to monitor the pressure in the cylinders throughout the combustion cycle so as to follow alterations in the combustion conditions, cylinder condition and general engine condition in order to catch out any operational disturbances.

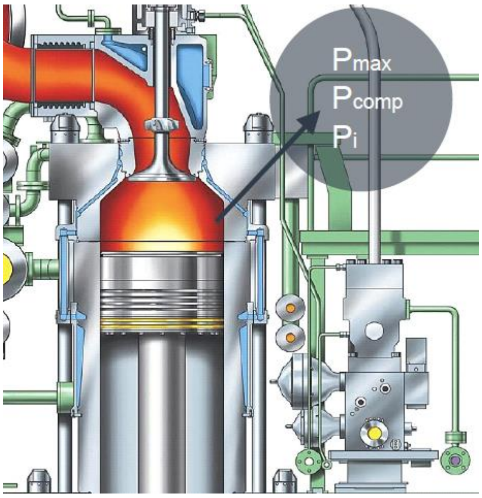


Figure 8.1: Pressure values monitored by the PMI system [20]

Based on the PMI measurements, the Engine Operator is able to optimize engine performance by adjusting various parameters so as to optimize/decrease fuel consumption.

There are two versions of the system, the Offline and the Online, which are described in the following sections. In our case, the Engine is fitted with the Online version of the system.

3.1 PMI Offline

The Offline version employs a piezo-electric transducer (Figure 8.2) which is attached to a portable device called PMI Controller. This device connects to a Junction Box near the Engine.

Figure 8.2: PMI Offline measuring device [20]

The transducer is manually mounted on the indicator cock of each cylinder head (Figure 9) by the Engine Operator in order to take a set of measurements. The procedure from one cylinder to another can be carried out with random sequence.

Figure 9: Indicator cock on cylinder head [20]

Figure 10.1 depicts a schematic of PMI Offline system. The measurements that are collected and stored in the database pf the PMI system can be viewed on a PC through a relevant application provided by the Engine Maker.

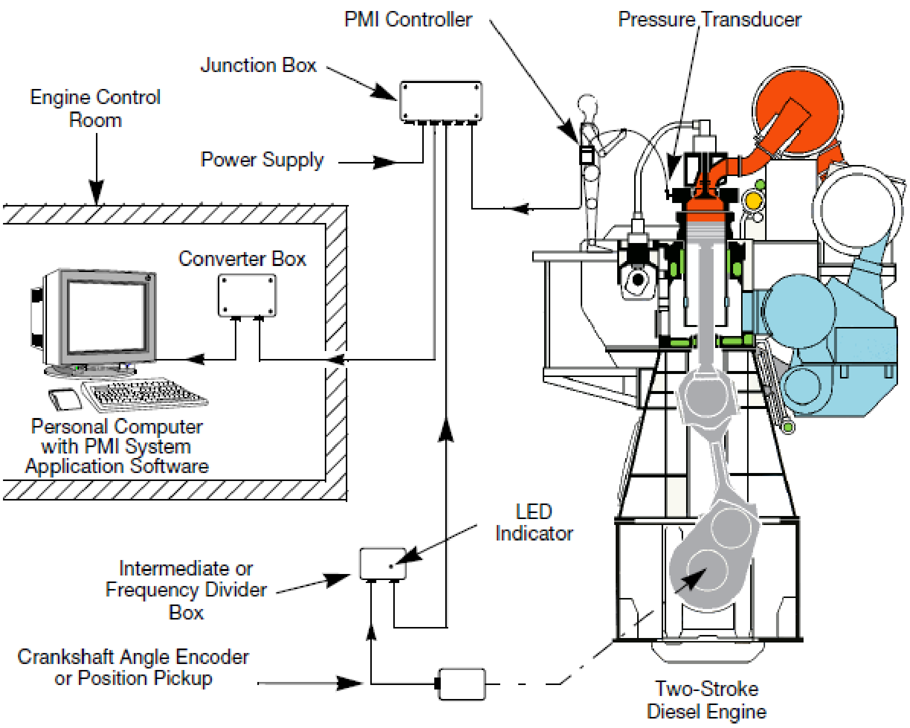


Figure 10.1: PMI Offline system arrangement [28]

3.2 PMI Online

The Online version of the system employs a series of measurement sensors which are permanently mounted on the cylinder head covers of the engine's cylinders. The sensors measure the cylinder pressure indirectly by detecting the strain experienced by the cylinder covers throughout the combustion cycle. They are manually calibrated to provide an output which is proportional to the instantaneous pressure inside the cylinders.

Figure 10.2 depicts a schematic of PMI Online system. All measurements are displayed in real time on a PC inside the Engine Control Room. This computer is called PMI PC and can be seen in Figure 6.2. The Operator can select to save the values. Clicking the "save" button practically means that the Operator takes a screenshot of the latest combustion cycle values. These values can be extracted to a pdf file.

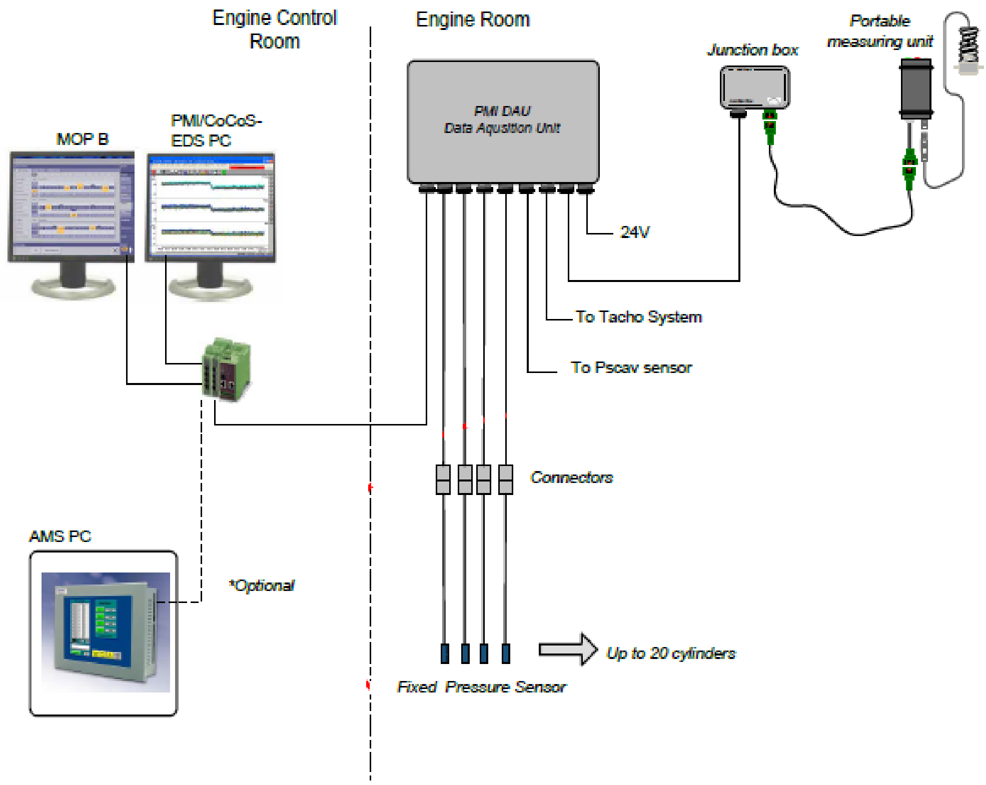


Figure 10.2: PMI Online system arrangement [20]

The complete PMI database with all saved pressure measurements can be extracted as well. This back up file can be displayed on the office computers using an .exe program provided by MAN.

For both Online and Offline version, the pressure detected by the transducer must be synchronized with the motion of the engine in order to obtain a pressure indication which accurately describes the change in cylinder pressure throughout each work cycle. For this purpose, the PMI System is designed to be used in connection with a crankshaft position pickup system. In our case this function is achieved via the Tacho System. The Angle Encoder produces a separate pulse which is used to synchronize the PMI System with the TDC position of Cylinder No. 1.

3.3 Pressure Measurement Views

The cylinder pressure measurements can be displayed with three different graphic presentation modes which are P-T Diagrams or pressure curves (pressure against crankshaft angle), P-V Diagrams (pressure against the relative volume [%] of the cylinder) and Balance Plots (bar charts showing pressures deviation from the mean value) as seen in Figures 10.3, 10.4, 10.5 respectively.

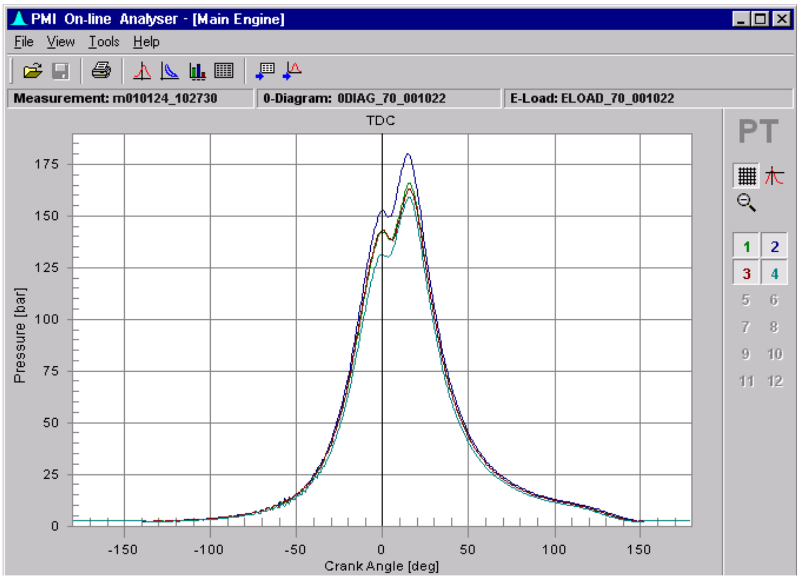


Figure 10.3: P-T diagram on PMI Online computer [27]

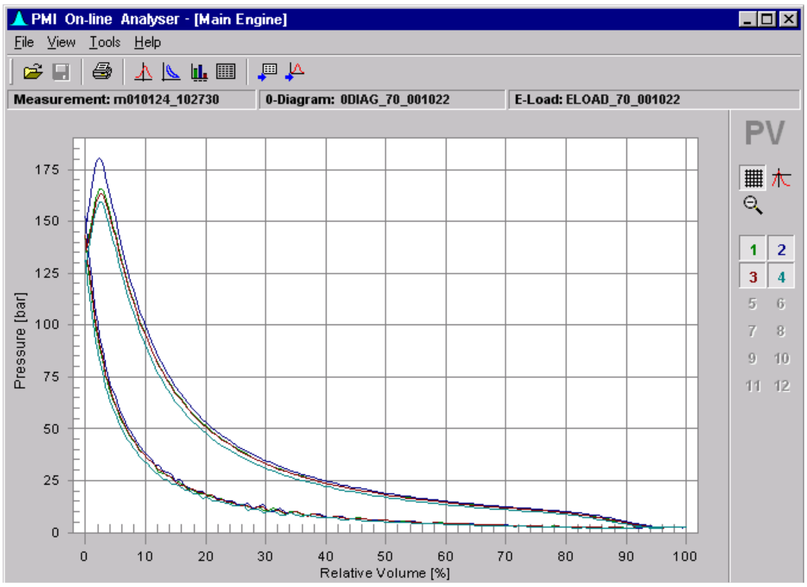


Figure 10.4: P-V diagram on PMI Online computer [27]

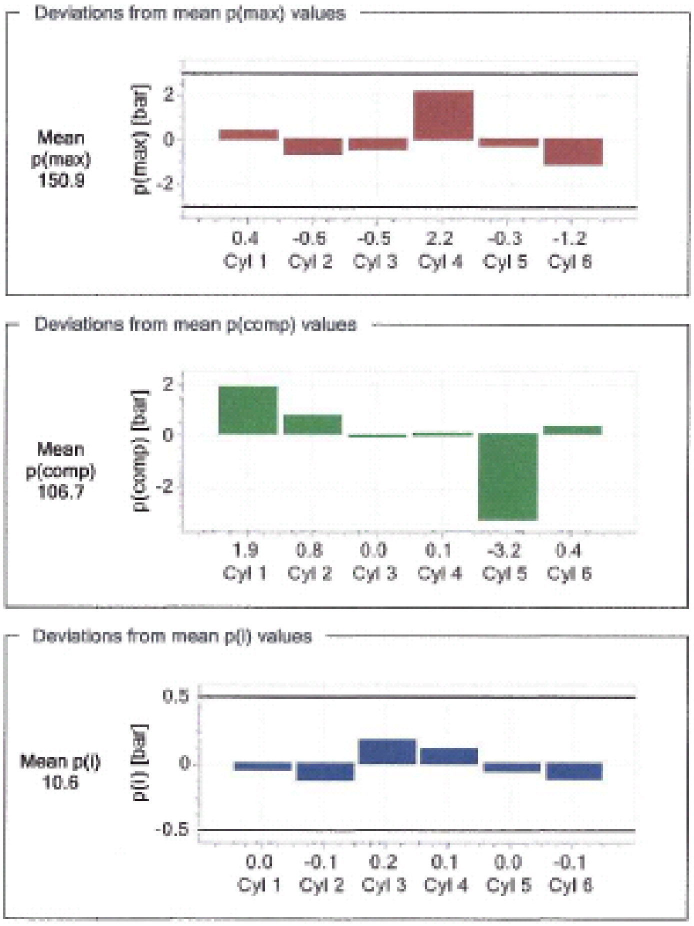


Figure 10.5: P-T diagram on PMI Online computer [27]

4. PMI AUTO-TUNING

The PMI On line version provides the option of Auto-tuning which is also applicable to our case study Engine. The PMI Auto-tuning system is a function that changes engine operating parameters in order to achieve the ordered pressure values according to the Estimated Engine Load. In specific, the system automatically adjusts the following two parameters based on the live-measurements from the PMI sensors installed on each cylinder:

- the injection timing and therefore the individual cylinder's P_{max}
- the exhaust valve closing and therefore the individual cylinder's P_{comp}

Engine Operator's input is required as described in the following section so as the Auto tuning to be initiated.

4.1 Tuning Method

The result of a successful tuning is that the Engine is running balanced. Engine balancing is achieved through the steps described hereunder.

4.1.1 Adjustment of Estimated Load

The Estimated Load is a theoretical load which is used by the ECS for all calculations. It is rarely equal to the actual load.

The Operator aims to make the Estimated Load shown on the MOP almost equal (±2%) to the value shown on the PMI PC in order to optimize fuel oil and cylinder oil consumption. To be noted that PMI load deviates from actual by about 1%.

The Estimated Load can be adjusted by changing the quality characteristics of the fuel on MOP. This process is called Fuel Quality Adjustment or FQA. The Operator puts in the system the Calorific value and the density of the fuel oil that is to be consumed, as indicated in the Fuel Oil Analysis Results. Then, the system compares these values with the ones used in shop trials and calculates a suggested Fuel Quality Offset [%] as depicted in Figure 11.1. The Operator applies this offset and the Estimated Load value changes. By making trials with different Fuel Quality Offsets, the desirable value should be achieved.

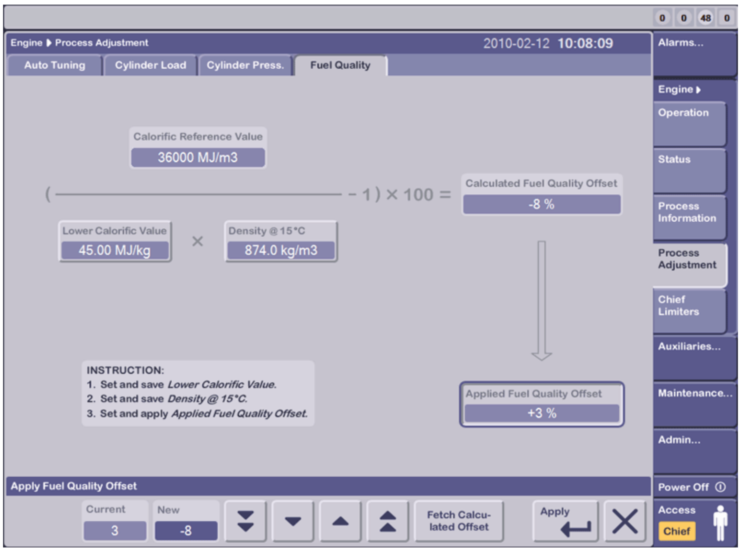


Figure 11.1: MOP Process Adjustment screen for Fuel Quality Offset [17]

However, it should be pointed out that the allowable offset is from -20% to 20%. If the Operator cannot achieve almost equal value within this range, then there are mechanical problems on the fuel equipment.

4.1.2 Adjustment of indicated pressure Pi

The Operator adjusts the P_i for each cylinder at High Load section (Figure 11.2), i.e. above 50% load, relatively to mean reference value $P_{i,mean}$ based on the following formula:

$$\mathrm{Pi, x, adj} = \frac{\mathrm{Pi, mean} - \mathrm{Pi, x}}{\mathrm{Pi, mean}} \times 100\ [\%]$$

where x is the number of the cylinder unit.

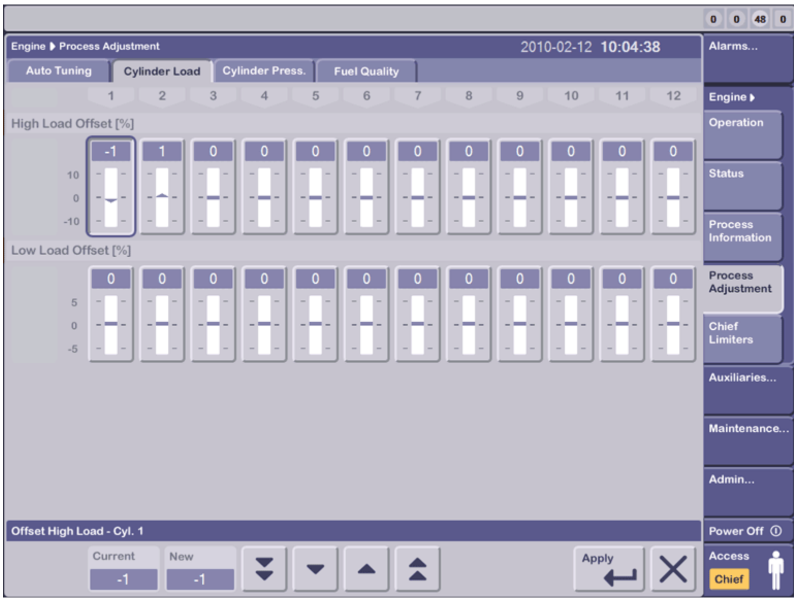


Figure 11.2: MOP Process Adjustment screen for Pi [17]

Then, the Operator selects Auto-tuning in order the system to carry out adjustment of Pi deviation and Mean Value (Figure 11.3).

Figure 11.3: MOP Process Adjustment screen – Auto tuning for Pi [17]

4.1.3 Adjustment of compression pressure Pcomp

The Operator can adjust the P_{comp} for each cylinder relatively to mean reference value $P_{comp,mean}$, however Engine Maker strongly recommends to skip this step and allow only authorized Service Engineers to adjust the Exhaust Valve Opening Timing Offset (Figure 11.4).

Deviations in Pcomp reveal mechanical problems with cylinder unit parts, such as piston rings, piston crown grooves, exhaust valve seat, cylinder liner.

However, Engine Operator can adjust the compression pressure as a ration of scavenging pressure. Allowable adjustment range for P_{comp}/P_{scav} ratio is from -2 to 2.

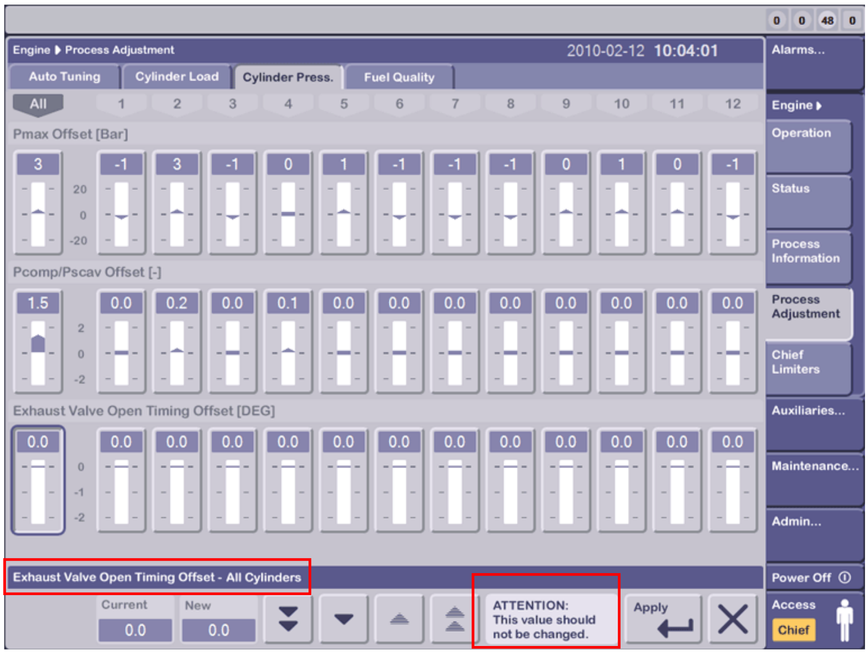


Figure 11.4: MOP Process Adjustment screen for Pcomp [17]

4.1.4 Adjustment of maximum pressure Pmax

The Operator adjusts the P_{max} for each cylinder relatively to mean reference value $P_{max,mean}$ (Figure 11.5) so as the maximum deviation from Mean Value to be ± 3 bar. Allowable adjustment range is from -20 bar to 20 bar.

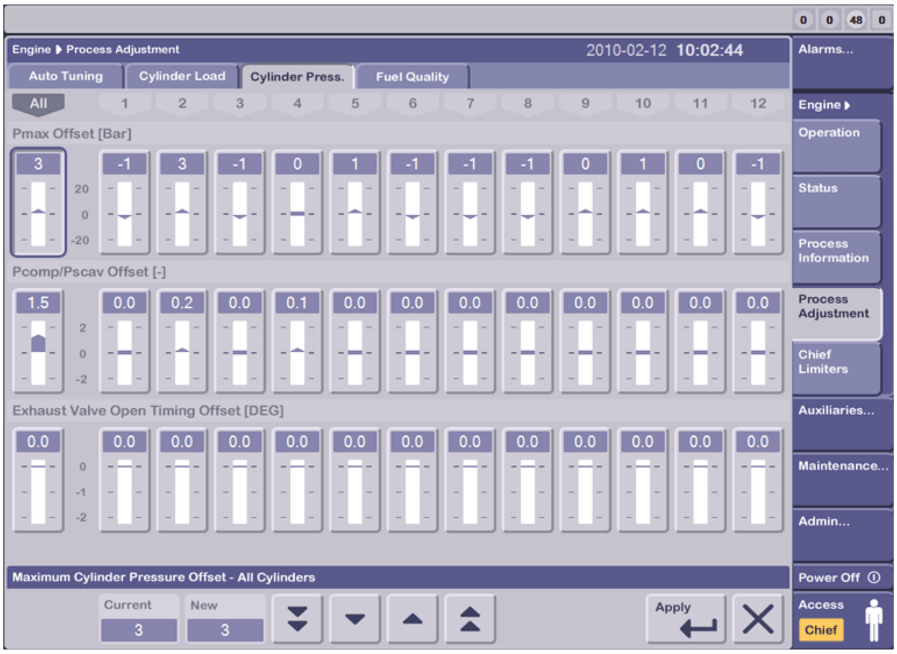


Figure 11.5: MOP Process Adjustment screen for Pmax [17]

Then, the Operator selects Auto-tuning and the system tries to equalize the actual P_{max} with the P_{max} ordered.

It is very important to note that any process for adjustment of P_i and P_{max} must be carried out while the Governor is in RPM Mode. If the Governor is in Index Control Mode, the adjustments will not take effect since the Index Mode freezes all variables in order to give steady conditions for PMI measurements. Therefore, the Operator shall choose RPM Mode for conducting engine adjustments and Index Mode for taking PMI measurements.

Figure 12 shows the difference between balanced and unbalanced engines. The correct adjustment of mean values contributes to fuel economy, whilst the adjustment of the balance can reduce the costs of maintenance (efficient combustion leading to a clean engine with less carbon deposits).

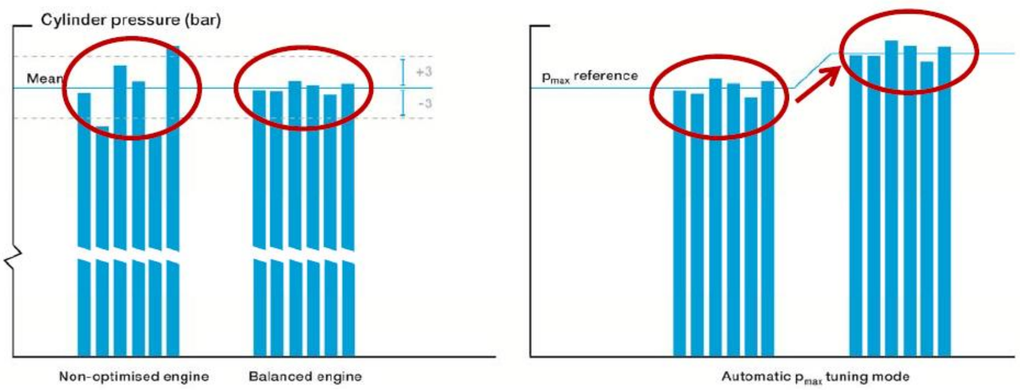


Figure 12: Engine Balancing and adjustment of Balancing [20]

After completion of the aforementioned steps, the Operator should select the button for Continuous Auto-tuning. However, there are prerequisites for the Auto-tuning system to run successfully. The sensors of PMI system must be calibrated and the Fuel Index must be over 40% and must not fluctuate more than ± 5%. If the aforementioned requirements are not met, the tuning can be conducted manually by the Operator, like in the case of PMI Offline system. Figure 13 depicts the Engine Tuning Process.

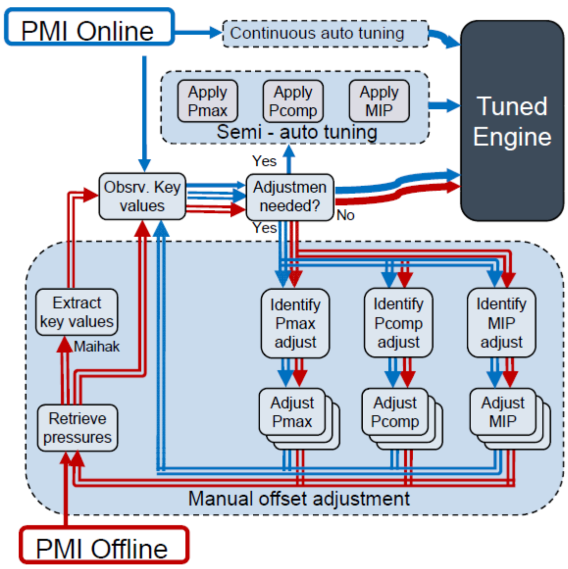


Figure 13: Engine Tuning Process [20]

5. CoCoS-EDS

Computer Controlled Surveillance – Engine Diagnostics System or CoCoS-EDS is a tool that facilitates monitoring and troubleshooting of the engine. It is a software that runs continuously while the Engine is running. It uses the data from ECS, as well as the data collected by the PMI. Selected data are displayed in real time on the PMI PC in the Engine Control Room (Figure 14.1).

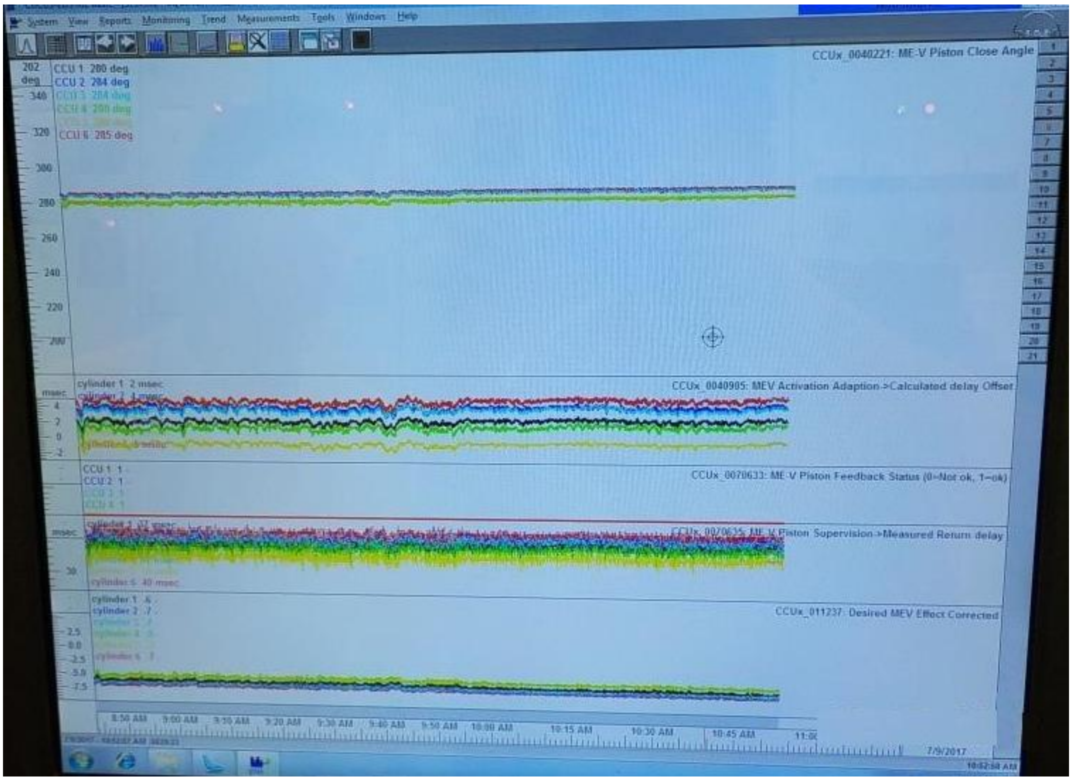


Figure 14.1: CoCoS-EDS program running on PMI computer in Engine Control Room

The collected data are either measured (e.g. injection crankshaft angle), or calculated by the system (e.g. Engine Power) or manually input by the Engine Operator (e.g. Jacket Cooling Water outlet temperature).

CoCoS-EDS helps identifying unusual engine behavior, suggests possible causes and recommends corrective actions (Figure 14.2).

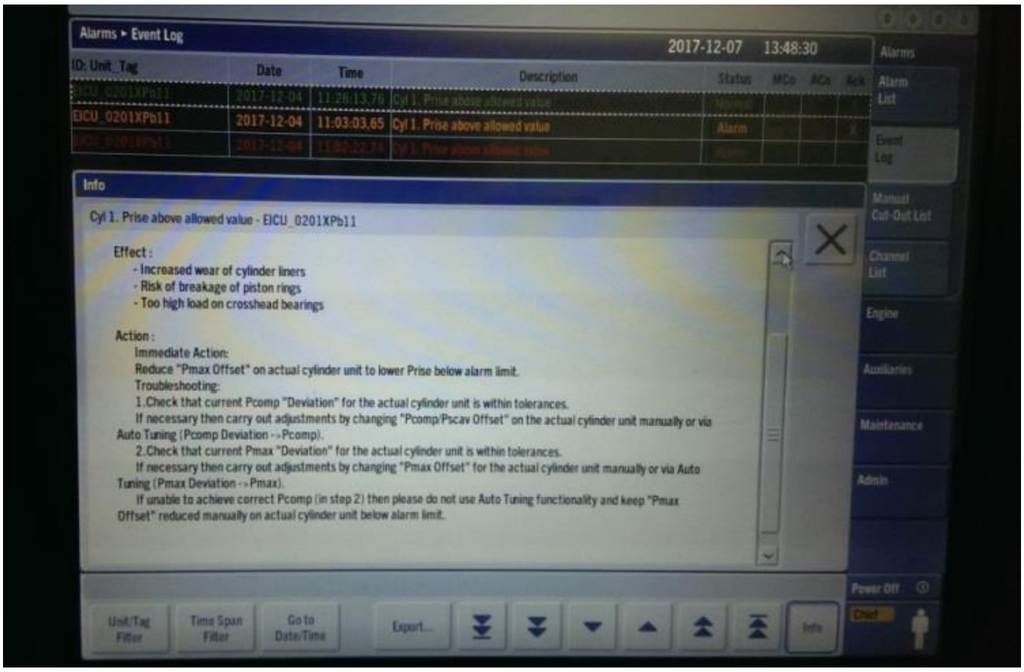


Figure 14.2: Alarm troubleshooting instructions by CoCoS-EDS

Two versions of the CoCoS-EDS system are available, the ME Basic version which is mandatory for all electronic engines and the Full version which is optional. The main difference is that the Full version provides the option of interface towards other systems and includes also the reference measurements of the engine (model curves) for enhanced troubleshooting, performance analysis and diagnostics. In our case study engine, the ME Basic version is applicable.

It should be pointed out that the data displayed on CoCoS-EDS are not stored. The Operator has to select to save data at specified time intervals so as to create a data base with all monitored parameters.

The database of CoCoS-EDS can be extracted as well. This back up file can be displayed on the office computers using a software provided by MAN (Figure 15).

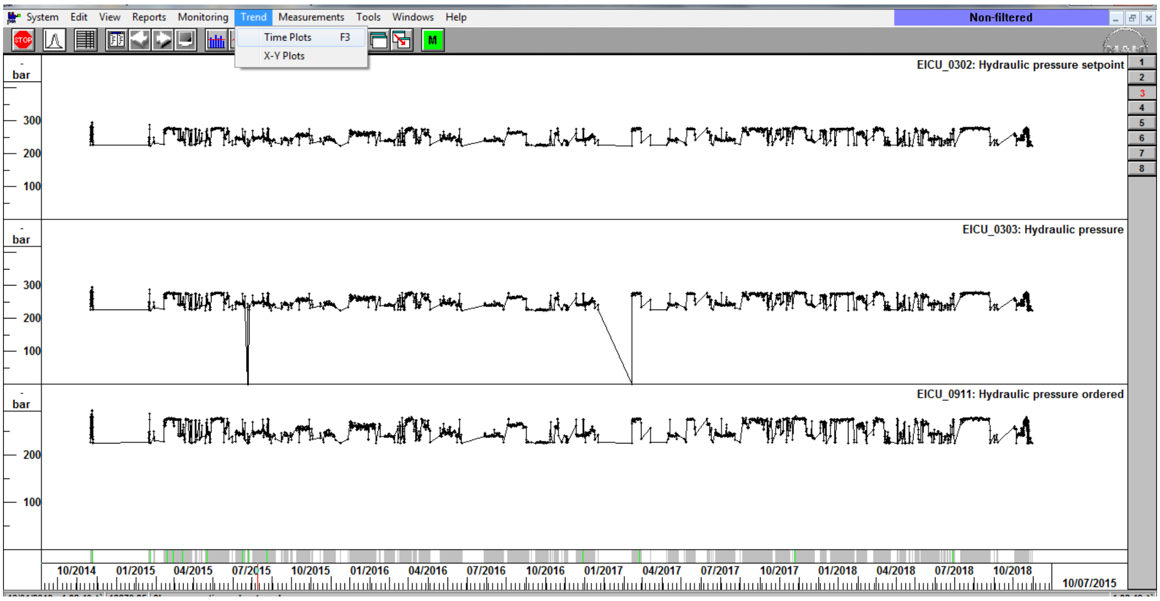


Figure 15: Display of CoCoS-EDS data at Office computer

Apart from the time plots shown above, CoCoS-EDS provides additional monitoring views of the available data. The user can create:

- **Performance Sheet Report with Fuel Oil Consumption calculation**

  The pressure related values are retrieved from PMI data. Other information is either manually input by the Operator or calculated by the system (Figures 16.1 and 16.2). This report is a standard form of MAN for engine performance measurements. It is provided by MAN also in excel format so as to be completely manually filled out.

SERVICE DATA ME-B					
Engine type:	6S50ME-B9	Name of vessel:			MAN
Eng. builder:	Hudong Heavy Machinery	Engine No.: D2382A	Yard: Nacks shipysrd		
Layout Power: 8,130 kW	Layout Speed: 108 RPM	Engine Mode: Economy	Sign.:	Test No.: 010	
Turbocharger(s)	No. T/C 1	Serial No.	No. Cyl: 6	Bore: 500 mm	Stroke: 2,214 mm
Make: ABB	Type: A265-L	1	Cylinder Constant: 0.7245	Mean Friction. Press.: 1.0 bar	
Max. Speed: 20,340 RPM	Max. Temp.: 550 °C	2	Lubrication Oil System (Tick box)		
Compr. Slip factor: -	Compr. Diameter:- mm	3	☑ Internal	☐ External from M.E. System	☐ External from Gravity Tank
T/C Specification:		4			
Observation No.:					

Bunker Station:	BALBOA,PANAMA			Brand	Type
Oil Brand:	DMALS		Cylinder Oil	SHELL	ALEXIA S-6
Viscosity at 50ºC: 3 cSt	Heat Value:	42.71 MJ/kg	Circulating Oil	SHELL	MELINA S-30
Density at 15°C: 851 kg/m³	Sulphur:	0.1 %	Turbo Oil	SHELL	MELINA S-30

Test Date	Test hour (hh:mm)	Engine speed (RPM)	Load (%)	Indicated Power (kW)	Indicated Fuel Consumption (g/kWh)	Speed Setting		Draft Fore	Log Speed
								4.8 m	15.0 knot
								Draft Aft.	Obs. Speed
7/12/2015	8:00 PM	95.3	54.6	4,852.6	186.8	95		7.3 m	13.7 knot
Total running hours (hh:mm)	**Ref. Pmax (bar)**		**Fuel index (%)**	**Effective Power (kW)**	**Eff. Fuel Consumption (g/kWh)**	**Ambient pressure (mbar)**		**Wind**	**Wind Direction**
								4.0 knot	348 deg
								Wave Height	Wave Direction
1222:58	155.0		66.3	4,438.4	204.2	1,030		0.5 m	348 deg

Cylinder No.		All	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Ave.
Pi	bar		11.7	11.7	11.7	11.7	11.7	11.7									11.7
Pmax	bar		151.9	151.4	151.4	152.4	150.8	151.4									151.6
Pcomp	bar		134.7	136.8	134.5	134.4	136.0	136.4									135.5
Pmax Offset	bar	5	1	-2	-0	2	1	-1									
Fuel Quality Adj.	%																
Pi - High Load Offset	%		-3.5	-3.6	0.2	0.7	5.6	0.5									
Pi - Low Load Offset	%		0.0	-0.5	0.0	0.0	1.0	0.0									
Chief Index Limit	%	115	115	115	115	115	115	115									
Exhaust Gas Temp.	°C		320.0	315.0	330.0	335.0	345.0	340.0									330.8
C.W. Outlet Temp.	°C		88.0	88.0	88.0	88.0	88.0	88.0									88.0
Piston Lub. Outlet Temp.	°C		54.0	54.0	55.0	53.0	53.0	55.0									54.0

Cooling Water Temp				Exhaust Gas Temp		Exhaust Gas Press.		Turbo Charger	T/C Nozzle Ring	Scavenge Air Pressure		
Main Engine		Air Cooler		Turbine		Receiver	Turb. Outl.			Δp Filter	Δ p Cooler	Receiver
Inlet	T/C Out	Inlet	Outlet	Inlet	Outlet	bar	mbar	RPM		mbar	mbar	bar
82	1	1	1	1	1	1.88	1	1	1	1	1	2.04
Seaw Temp.	-/-	35.0	45.0	375.0	225.0		120	16,333	-/-	80	30.0	
	2	2	2	2	2		2	2	2	2	2	
30.0												
	3	3	3	3	3		3	3	3	3	3	
	4	4	4	4	4		4	4	4	4	4	
	Ave.	Ave.	Ave.	Ave.	Ave.		Ave.	Ave.	Ave.	Ave.	Ave.	
	-	35.0	45.0	375.0	225.0		120	16,333		80	30.0	

Scavenge Air Temp.				Lub Oil Temperature			Lub oil Pressure	Aux. Blower	F.O. Pressure	Swash Plate pos.	Hydraulic Pressure
Scav. Rec.	Blower Inlet	Air Cooler		Turbocharger		Engine Inlet	System Oil	OFF=0 ON=1	Filter Inlet		
		Inlet	Outlet	Blower inlet	Turbine Outlet						
42.0	1	1	1	1	1	45.0	2.23	0	7.9	1	Pump inlet
	45.0	175.0	42.0	45	60.0	Thrust Segm.	Cooling Oil	Axial Vibr.	Filter Outlet	-/-	260.0 bar
	2	2	2	2	2	55	2.2	0.46	7.8	2	Main pressure
							Turbine Oil		F.O. Temp	-/-	255 bar
	3	3	3	3	3		1.90		Pump Inlet	3	Decay time ref.
									41.0		30 sec
	4	4	4	4	4				F.O. Visc.		
									Pump Inlet		
	Ave.	Ave.	Ave.	Ave.	Ave.				3.6		
	45.0	175.0	42.0	45	60.0						

Remarks

LEMAG DATA: TORQUE :454 KN-m RPM: 95.1 POWER: 4532 KW
BASIS ON ABB MASS FLOWMETER :
M/E FUEL OIL CONS: 19.98 MT , D/G FUEL OIL CONS : 1.79 MT AT 386 kW ,
CYL. OIL CONS: 151 L / DAY AT ACC FACTOR 0.40 g/kWh , FEED RATE : 1.28g/kWh , SULPHUR CONTENT : 0.07%
AVE. SPD.: 13.7 KNOTS

Figure 16.1: Performance Sheet Report produced by CoCoS-EDS

Fuel Oil Consumption

[Performance Sheet]

Fuel Oil Properties

Density (15 Deg.C):	851	kg/m³
LCV:	42.71	MJ/kg
Sulpher:	0.1	%
F.O. Temp. at reading:	41.0	
Corrected Density:	832	kg/m³

Fuel Oil Readings

Volume:	Volume reading, start:	1,335.54	m³
	Volume reading, end:	1,339.90	m³
	Volume, calculated:	4.36	m³
Mass:	Mass reading, start:	-/-	kg
	Mass reading, end:	-/-	kg
	Mass, calculated	3,630	kg

Measurement Period

	Date: Day [dd] / Month [mm] / Year [yyyy]	Time: Hour [hh] : Min. [mm] : Sec. [ss]
Reading start:	12 / 7 / 2,015	18 : 0 : 0
Reading end:	12 / 7 / 2,015	22 : 0 : 0
Duration:		4 : 0 : 0

Flow:	Volume flow, calculated	1.089	m³/h
	Mass flow, calculated:	0.3	kg/s

Specific Fuel Oil Consumption

Engine Power:	4,438.4	kW
SFOC, calculated:	204.2	g/kWh
SFOC (LCV):	204.3	g/kWh
SFOC (LCV,Amb):	196.7	

Field text in RED : EDS value manually overwritten by User
Field text in Gray : Value NOT used in calculation of SFOC

Figure 16.2: Fuel Oil Consumption calculation produced by CoCoS-EDS

- **Load Diagram**

The power and speed limit for continuous as well as overload operation of the engine are defined (Figure 17).

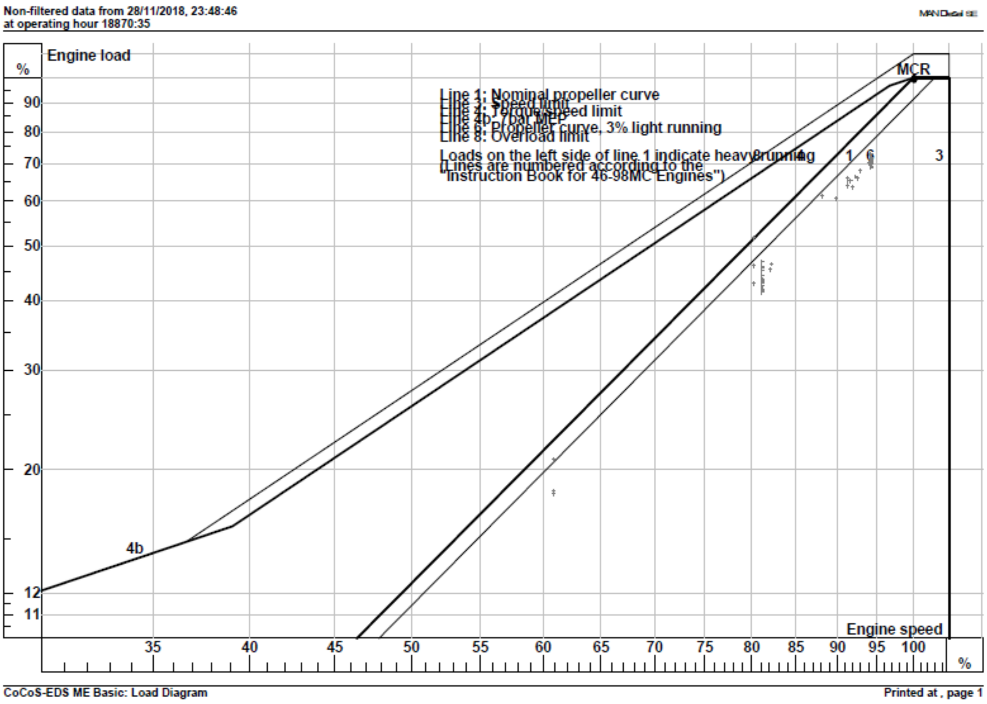
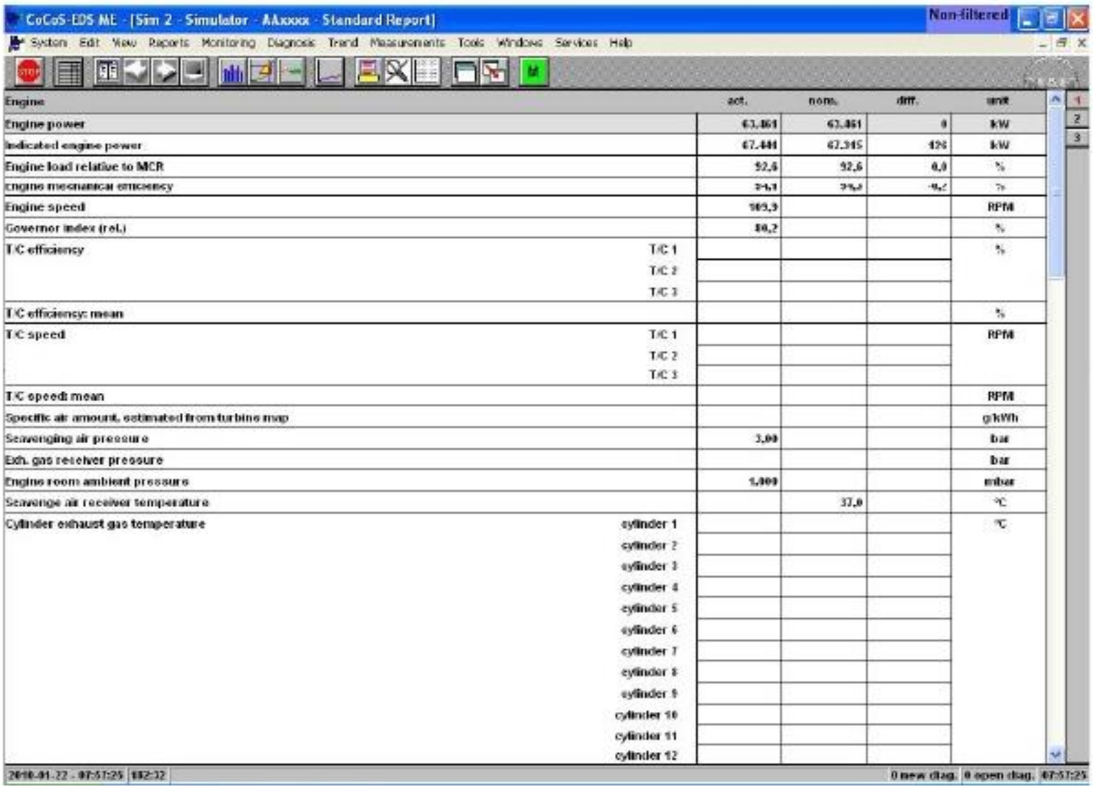


Figure 17: Load Diagram produced by CoCoS-EDS

❖ Standard Report of EDS

It contains a list of selected operating parameters compared to nominal values which are described in detail in Annex A (Figure 18).



Engine		act.	nom.	diff.	unit
Engine power		63.461	63.461	0	kW
Indicated engine power		67.441	67.315	126	kW
Engine load relative to MCR		92,6	92,6	0,0	%
Engine mechanical efficiency		[illegible]	[illegible]	[illegible]	
Engine speed		109,3			RPM
Governor index (rel.)		80,2			%
T/C efficiency	T/C 1				%
	T/C 2				
	T/C 3				
T/C efficiency: mean					%
T/C speed	T/C 1				RPM
	T/C 2				
	T/C 3				
T/C speed: mean					RPM
Specific air amount, estimated from turbine map					g/kWh
Scavenging air pressure		3,00			bar
Exh. gas receiver pressure					bar
Engine room ambient pressure		1.000			mbar
Scavenge air receiver temperature			37,0		°C
Cylinder exhaust gas temperature	cylinder 1				°C
	cylinder 2				
	cylinder 3				
	cylinder 4				
	cylinder 5				
	cylinder 6				
	cylinder 7				
	cylinder 8				
	cylinder 9				
	cylinder 10				
	cylinder 11				
	cylinder 12				

Figure 18: Standard Report produced by CoCoS-EDS

6. DATA ANALYSIS

6.0 Cases Considered

During day to day operation of the vessel, the information from engine performance monitoring systems are used in order to assess the condition of the Main Engine at the time the data are produced. The assessment is based on the comparison of the value of engine operating parameters with shop test data, as well as the last performance measurements. The goal of this analysis is to examine ways to use all these data not only to assess engine condition, but also to predict same.

The study is focused on three different cases of component's failures that all result to reduction of compression pressure P_{comp}.

- Case No.1: Wear of cylinder liner
- Case No.2: Wear of exhaust valve
- Case No.3: Wear of piston rings

It should be repeated that P_{comp} is a parameter that cannot be adjusted by the Operator, but it is affected by the auto tuning system.

As a first step, the maintenance history of the vessel was examined in order to find failure events that fall into each case. For Case No.1, one event has been identified whilst for Cases No.2 and No.3, two and four events have been identified respectively.

Performance data from the date the problem was observed up to 5 months earlier, were examined in an effort to identify possible trends.

Due to the wide range of information in CoCoS-EDS and PMI, it was imperative to shortlist specific parameters for examination. Therefore, the following raw data during the specified periods are used for this study:

- compression pressure P_{comp} as extracted from PMI database
- scavenging pressure P_{scav} as extracted from PMI database
- injection crankshaft angle as extracted from CoCoS-EDS database
- injection close time as extracted from CoCoS-EDS database

Cylinder pressure throughout the combustion cycle was also extracted from PMI database, so as to create the cylinder's pressure curve and evaluate the exhaust valve closing crankshaft angle.

As a standard practice, the ship sends to the office Main Engine performance measurements as obtained by PMI at the beginning of each voyage, at the end of each voyage and at least once per month, subject to favorable weather conditions. Performance measurements are also obtained after maintenance or troubleshooting activities. Reporting of the vessel consists of CoCoS-EDS Performance Sheet Report and PMI Balance Plot showing pressures deviation from the mean value.

The PMI database was complete with all performance measurements stored for the specified periods. The same was not applicable to CoCoS-EDS database. The stored data were much less and they were not necessarily corresponding to the dates of stored PMI measurements. It appears that crew was usually using the Performance Sheet Report in excel format instead of extracting it from CoCoS-EDS. As a result, they did not save data frequently.

6.1 Case No.1: Cylinder Liner Wear

6.1.1 Event No.1

On 25 October 2017, Main Engine automatically slowed down due to exhaust gas high temperature alarm on Cylinder No.1. This alarm is triggered at 450°C. At that time, the Engine was running at 82% load having estimated Effective Power 6700 kW at 101.8 rpm. The ship was in laden condition.

According to MAN troubleshooting guide for increased exhaust gas high temperature level, the fuel injection equipment is to be initially suspected. Therefore, the corrective actions applied were the replacement of fuel injection valves at first stage and the replacement of fuel oil pressure booster pump at second stage which did not resolve the issue.

Then, the cylinder condition was examined for potential exhaust gas blow by. Piston rings, piston crown and exhaust valve were checked and found in good condition. The problem was finally rectified on 16 June 2018 by replacing the cylinder liner of Cylinder No.1 which found with high wear. In specific, the wear was at 3.80 mm whilst the maximum acceptable wear limit by MAN is 4.00 mm.

As a countermeasure until rectification of the problem, the ship was reducing the sailing rpm every time the alarm was triggered.

6.1.1.1 Data Analysis

Having in mind that the cause of alarm is the wear of cylinder liner, the parameter of compression pressure is firstly examined. The Pcomp of Cylinder No.1 is plotted for a period up to five months before the activation of the alarm at about same rpm and estimated Effective Power, i.e. 101.8 rpm and 6700 kW respectively (Figure 19).

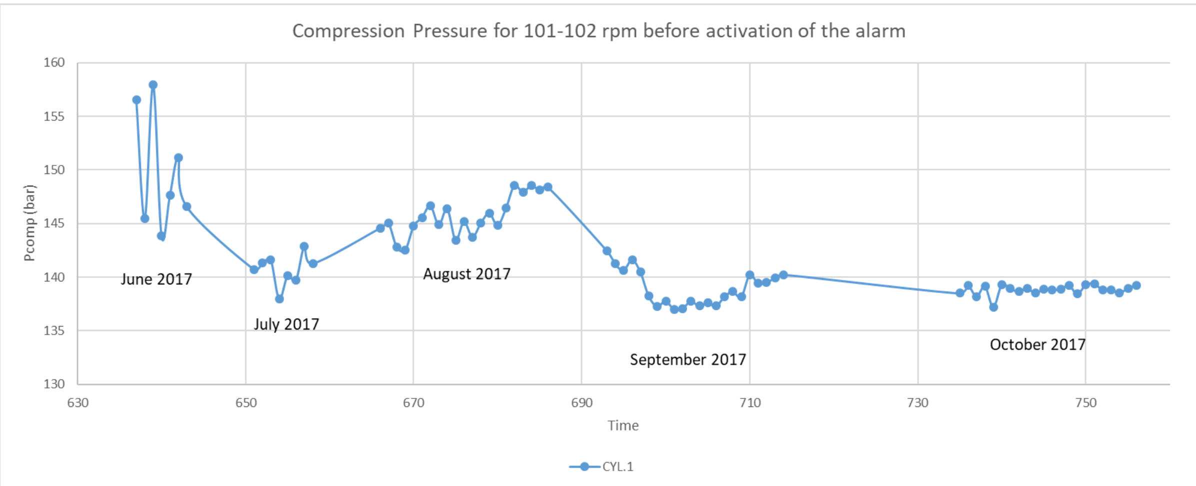


Figure 19: Compression pressure trend of Cylinder No.1

From July onwards, the value of Pcomp is at lower levels compared to June. However, this ascending and descending trend does not provide clear sign of liner wear.
In order to assess more accurately the behavior of Cylinder No.1, the trend of its compression pressure is compared to that of Cylinder No.4 for the exact same dates and times of performance measurements. Cylinder No.4 is selected because there is not any issue reported for the specified time frame (Figure 20).

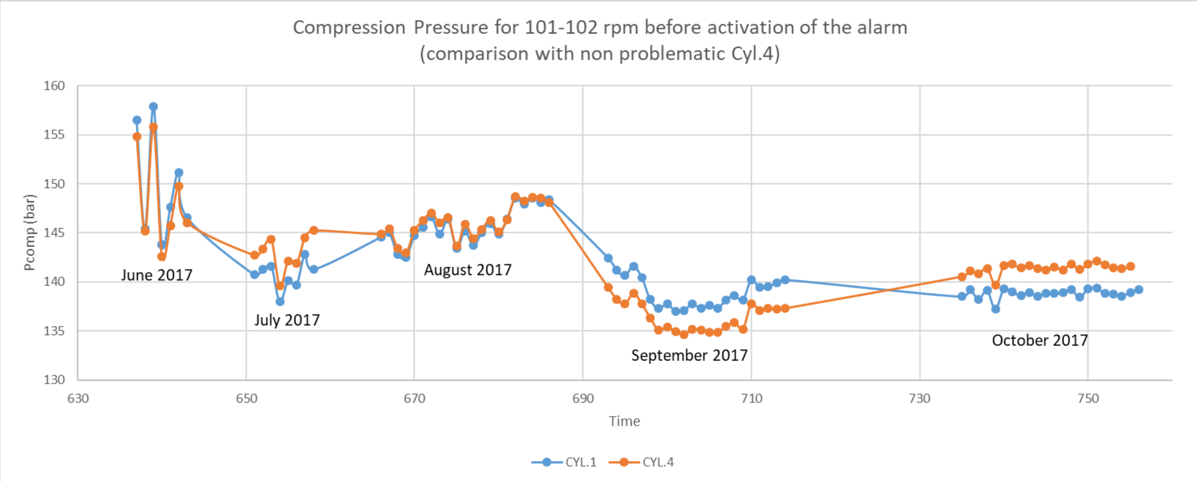


Figure 20: Compression pressure trend of Cylinder No.1 compared to No.4

It is observed that the compression pressure for both cylinders follow the same trend in different levels. This can be justified by the function of Auto tuning to adjust the pressure around the mean value. Although the Auto tuning system affects the individual cylinder, the system has an impact on the other cylinders as well, since it has to keep the engine balanced.

However, one month before the alarm, the compression pressure of Cylinder No.1 is at higher level compared to the non-problematic Cylinder No.4. This unexpected finding reveals that the Auto tuning system acted in such a way that the performance measurements did not reflect the actual condition of the engine.

The following table includes the monthly variation of Pcomp on both cylinders.

Pcomp monthly average variation %	**Cyl.1**	**Cyl.4**
from June to July	-6.12%	-3.76%
from July to August	3.54%	2.15%
from August to September	-4.59%	-6.58%
from September to October	-0.14%	3.62%

The value of scavenging pressure is also plotted for the exact same dates and times of performance measurements (Figure 21). Pscav has a gradually decreasing trend. Considering that the turbocharger is maintained and cleaned properly by the crew, the decreasing trend of Pscav can be deemed as an indication of blow by in individual cylinders.

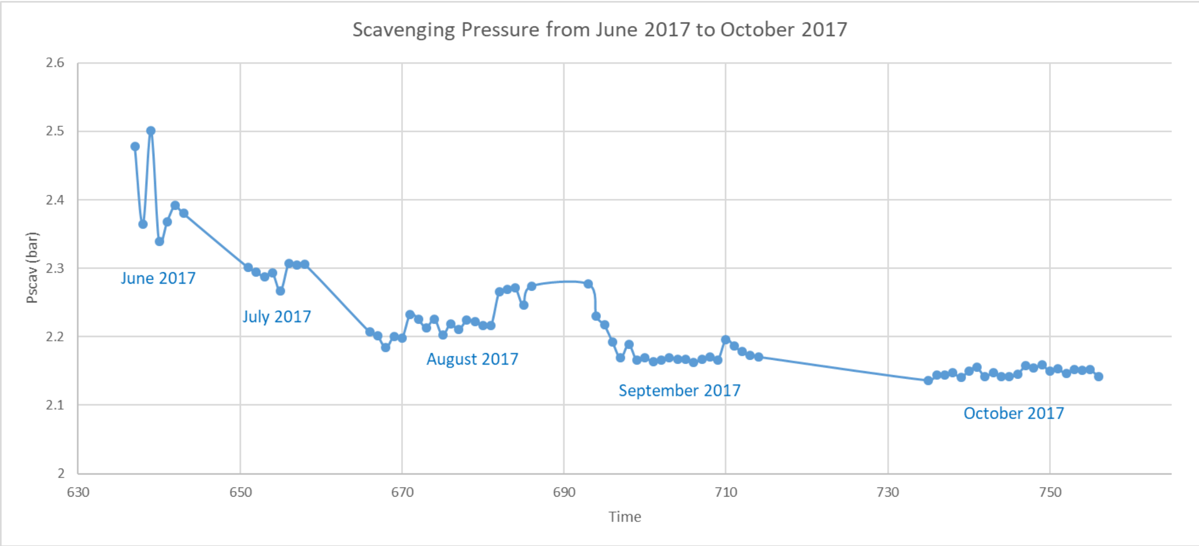


Figure 21: Scavenging pressure trend

Additionally, the ratio between the absolute compression pressure (P_{comp} + $P_{barometric}$) and the absolute scavenging pressure (P_{scav} + $P_{barometric}$) is examined (Figure 22) for individual Cylinders No.1 and No.4, considering $P_{barometric}$ = 1 bar (Figure 4). However, it has to be pointed out that the ratio Pcomp/Pscav is a parameter that can be adjusted by the Engine Operator for individual cylinders.

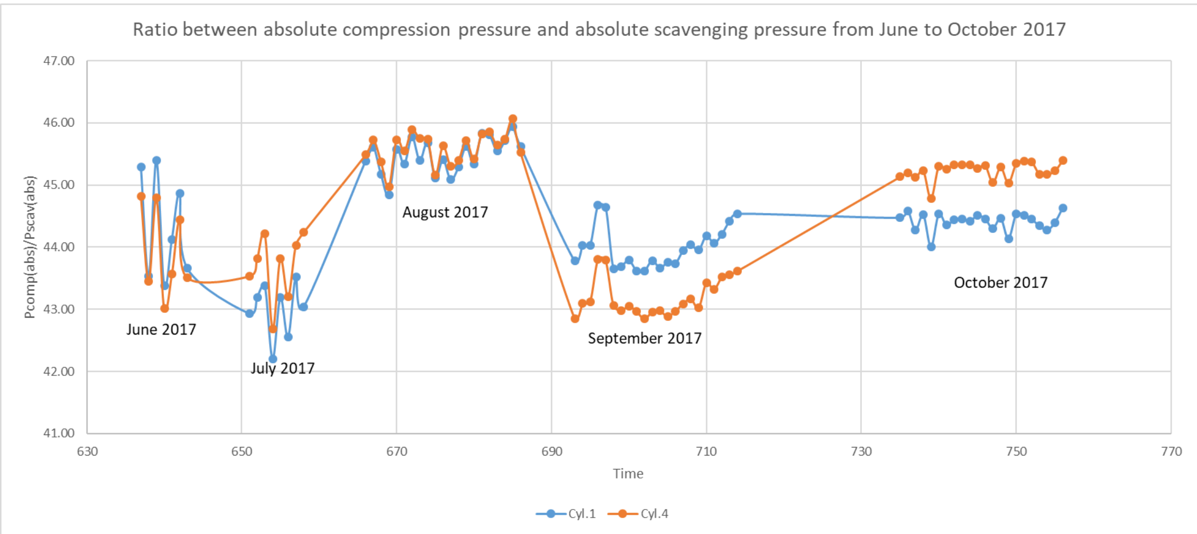


Figure 22: Pcomp/Pscav Ratio Comparison between Cylinders No.1 and No.4

Furthermore, it was observed in the Alarms Log List that, on the day of first activation of exhaust gas high temperature alarm, another alarm was also triggered: “Cyl.1 Prise above allowed value”. Therefore, the Pressure Rise (i.e. Pmax – Pcomp), as well as the maximum combustion pressure, are plotted for individual Cylinders No.1 and No.4 (Figures 23 and 24).

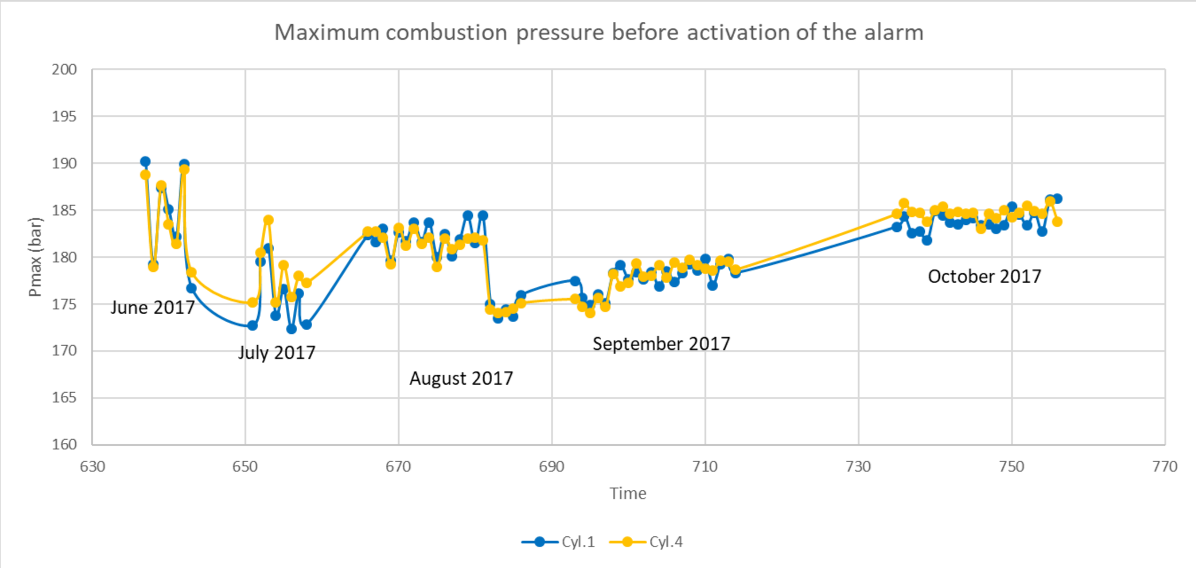


Figure 23: Maximum combustion pressure trend of Cylinder No.1 compared to No.4

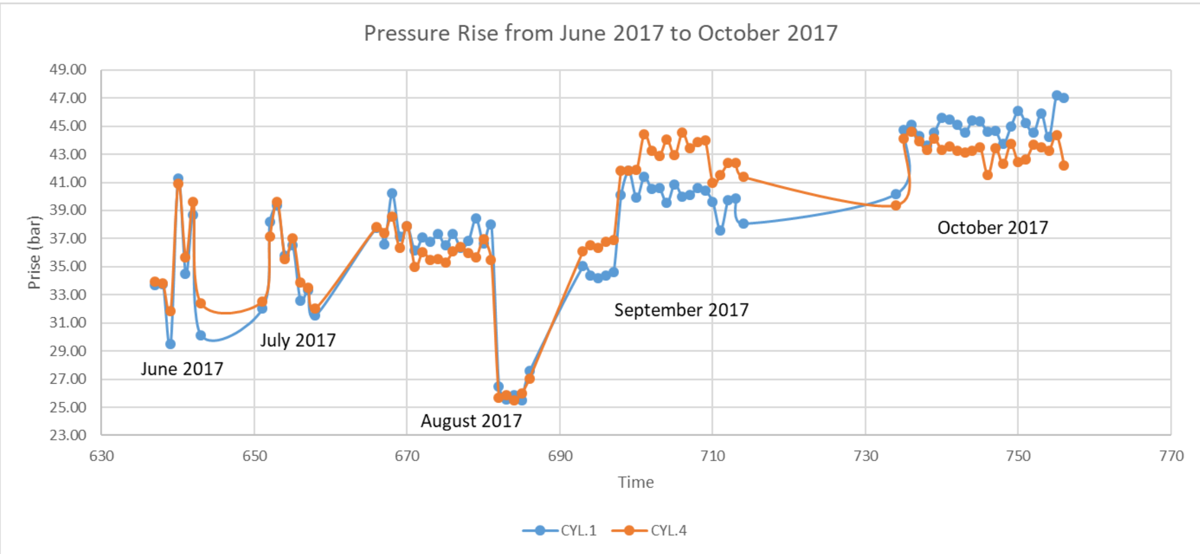


Figure 24: Pressure Rise trend of Cylinder No.1 compared to No.4

It is noticed that Pmax values almost match for both cylinders throughout the period of examination. It is also remarkable that, from September onwards, Pmax has an ascending trend contrary to Pcomp. Consequently, pressure rise is fluctuating above normal service values (i.e. 35 - 38 bar). For Cylinder No.1 in particular, Prise exceeds the limit of 45 bar and triggers alarms.

Taking the above into consideration, it becomes clear that engine operator does not have clear signs of Cylinder No.1 underperformance so as to suspect wear on cylinder's components and take precautionary measures. It is therefore perceived that Auto tuning system's intervention on the operating parameters in order to maintain good performance of the engine, conceals the mechanical defects.

In the effort to predict failures on this type of engines, it is imperative to clarify how the Auto tuning system intervenes on fuel injection timing and exhaust valve closing timing.

As far as the fuel injection timing is concerned, CoCoS-EDS provides data for injection crankshaft angle (i.e. crankshaft angle at the time the ELFI valve is activated) and injection close time (i.e. duration of the injection).

Due to the limited stored data in CoCoS-EDS database, the period of examination is extended until rectification of the issue which was carried out in June 2018 by replacing the Cylinder liner. In addition, the available measurements for November and December 2017 have been taken at 98.5 rpm whilst all other measurements have been carried at 101.8 rpm.

Figures 24 and 26 depict injection crankshaft angle before Top Dead Center (TDC) and injection close time for Cylinder No.1 respectively. All the countermeasures applied are also marked on the diagrams.

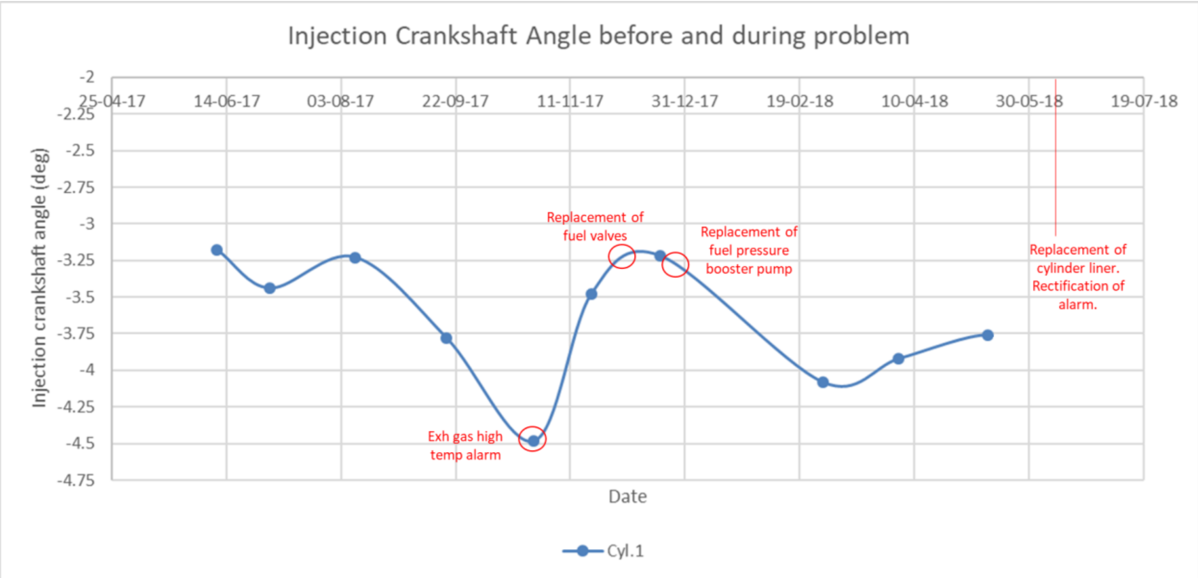


Figure 25: Start of injection crankshaft angle of Cylinder No.1

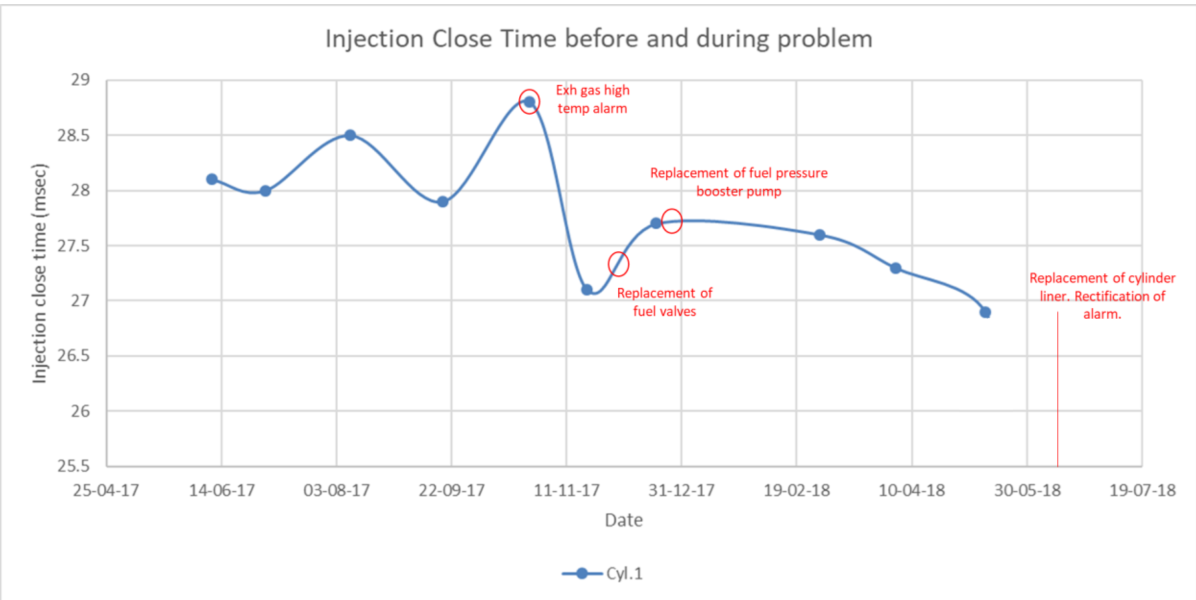


Figure 26: Duration of injection for Cylidner No.1

It is remarkable that, the earliest injection timing in terms of crankshaft angle before TDC and the maximum injection duration in terms of closing timing coincide on the day of first activation of high exhaust gas temperature alarm.

In order to assess more accurately the impact of Auto tuning on Cylinder No.1, the parameters are compared to the ones of Cylinder No.4 for the exact same dates and times of measurements (Figures 27 and 28).

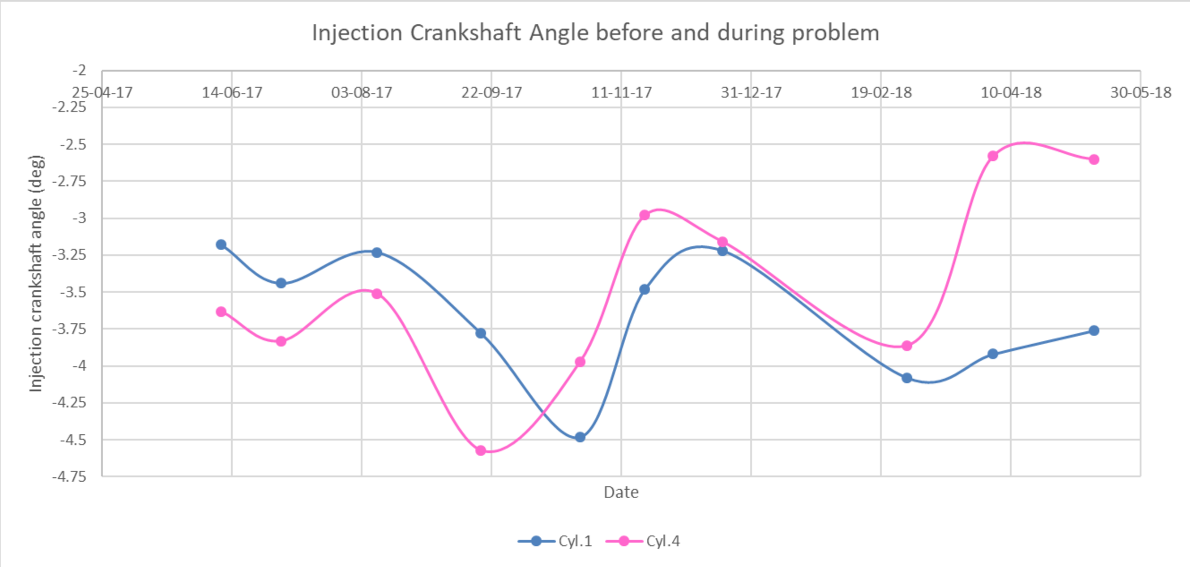


Figure 27: Start of injection crankshaft angle of Cylinder No.1 compared to No.4

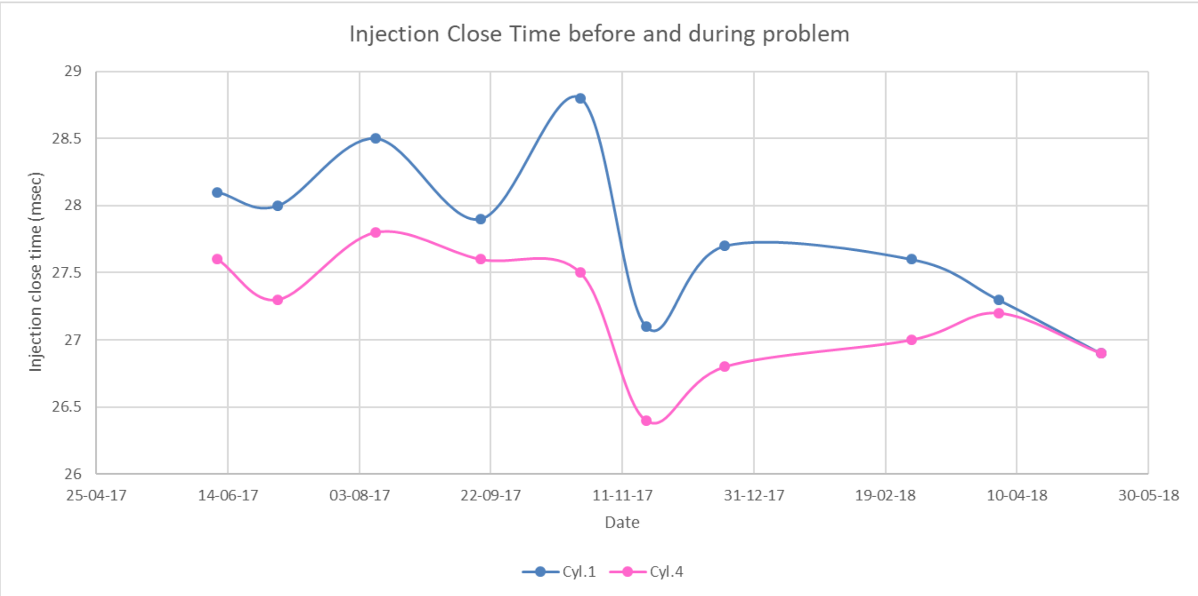


Figure 28: Duration of injection of Cylinder No.1 compared to No.4

It is observed that, before activation of the alarm, injection on Cylinder No.1 is activated at a later crankshaft angle compared to the non-problematic Cylinder No.4. On top of that, the injection on

Cylinder No.1 always lasts longer compared to the non-problematic Cylinder No.4 during the period of examination.

The injection close time is related to the Fuel Index. As depicted in Figure 29, the trends of Injection close time simulate the trend of Fuel Index during the period of examination.

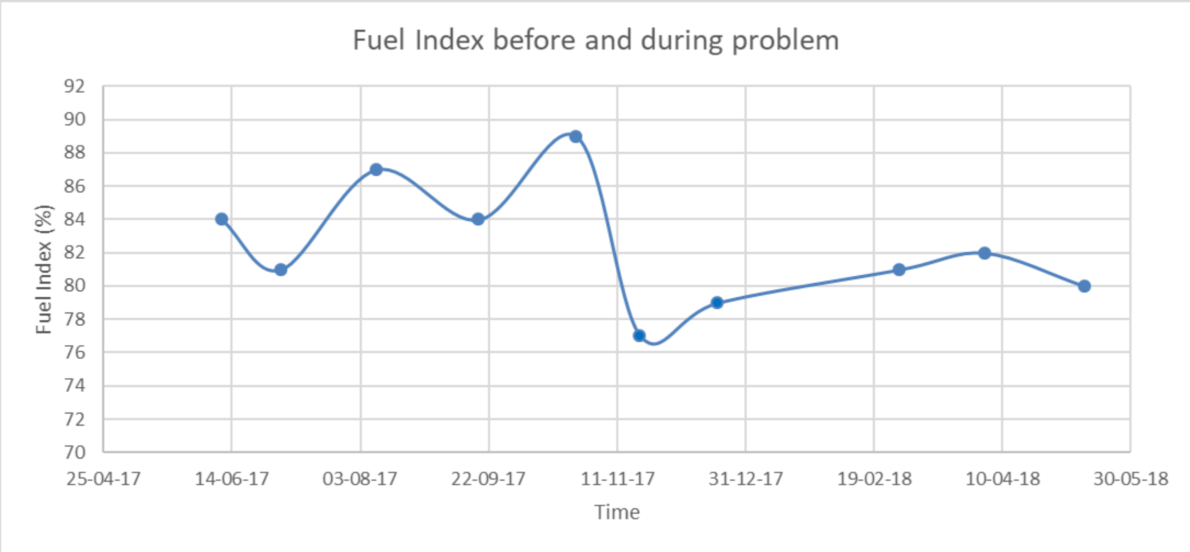


Figure 29: Fuel Index trend

As far as the exhaust valve closing timing is concerned, there are not any related measurements in the databases. Therefore, a qualitative assessment is made based on the Pressure Curves of Cylinder No.1 and No.4.

Pressure curves of Cylinder No.1 for the period before the alarm appear in Figure 30. Based on the curves' gradients (marked in red area), the earliest closing of exhaust valve appears on the day of the initial activation of exhaust gas high temperature and the latest closing appears 20 days before.

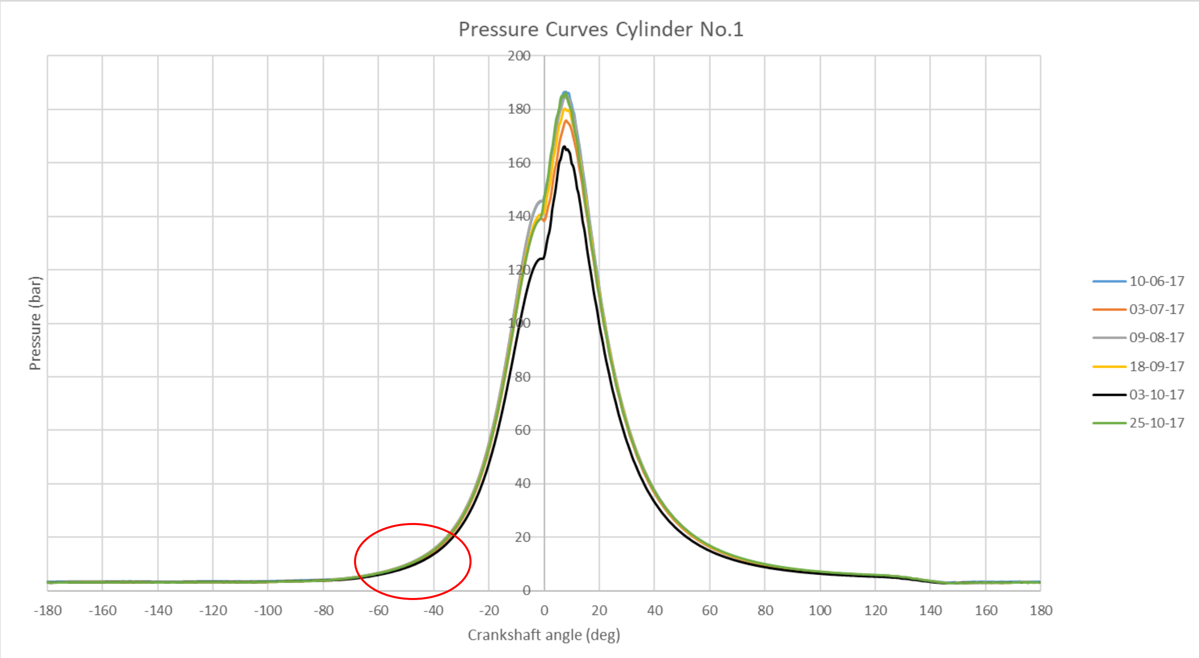


Figure 30: Pressure curves of Cylinder No.1

Pressure curves of Cylinder No.4 for the period before the alarm appear in Figure 31. Similarly, based on the curves' gradients (marked in red area), the earliest closing of exhaust valve appears on the day of the initial activation of exhaust gas high temperature and the latest closing appears 20 days before.

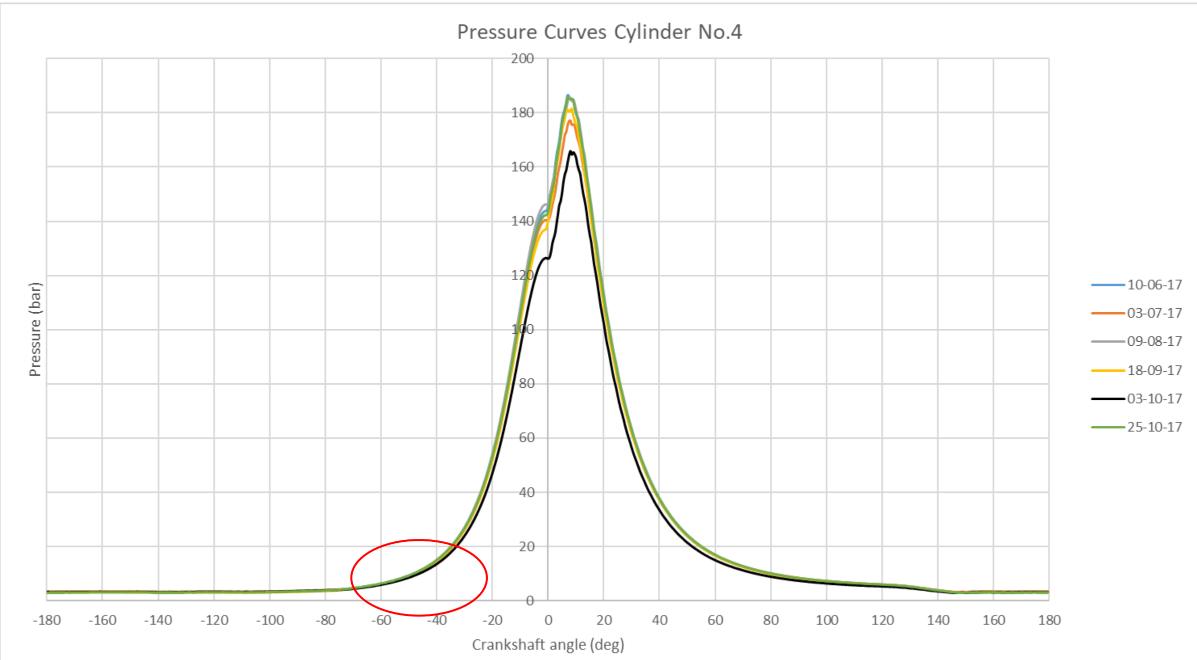


Figure 31: Pressure curves of Cylinder No.4

The pressure curves of the two cylinders for the same dates are also plotted in Figures 32, 33, 34, 35, 36 and 37. However, the gradients seem to match in the area of exhaust valve closing so any differences cannot be identified qualitatively.

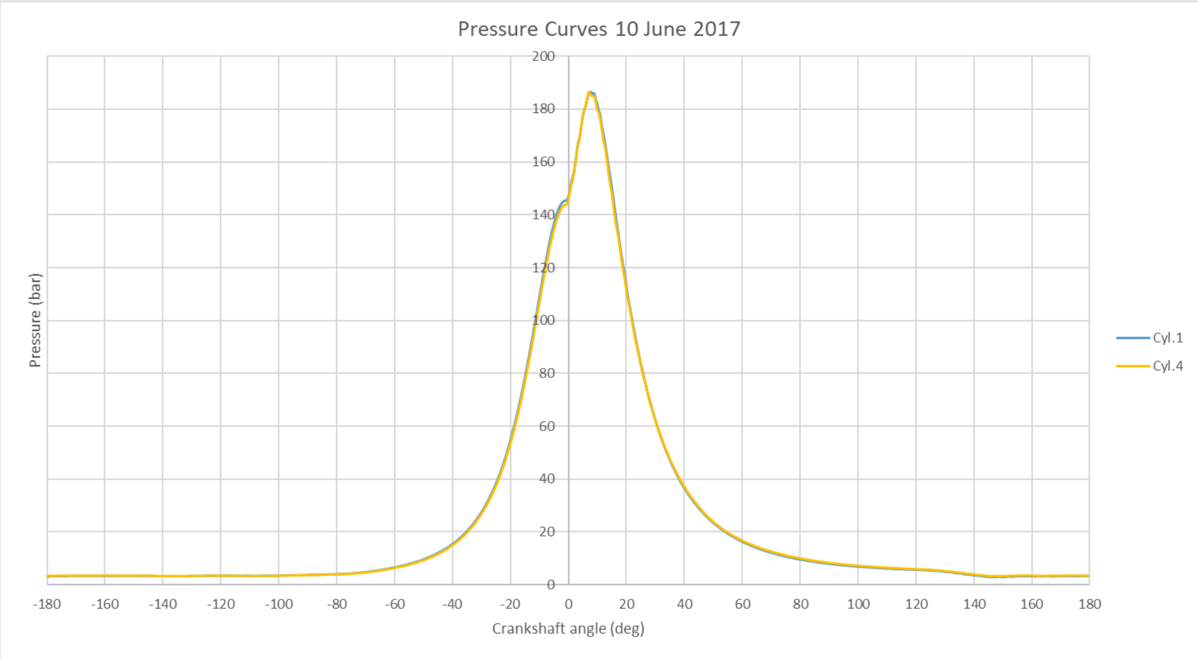


Figure 32: Pressure curves of Cylinders No.1 and No.4 on 10 June 2017

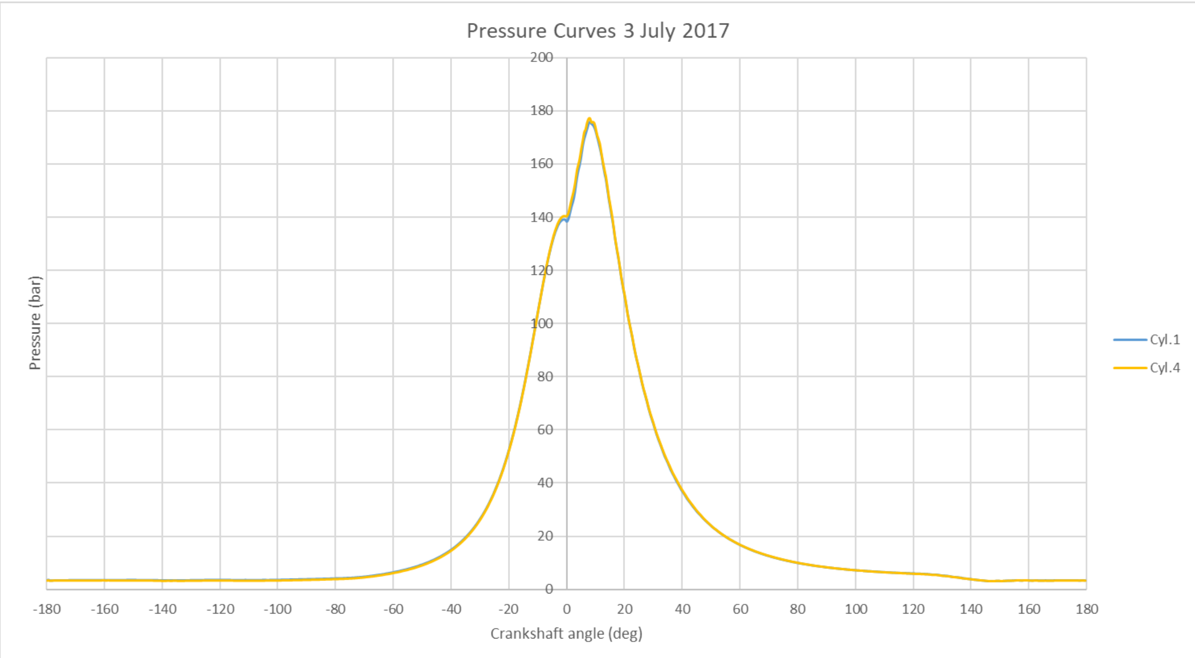


Figure 33: Pressure curves of Cylinders No.1 and No.4 on 3 July 2017

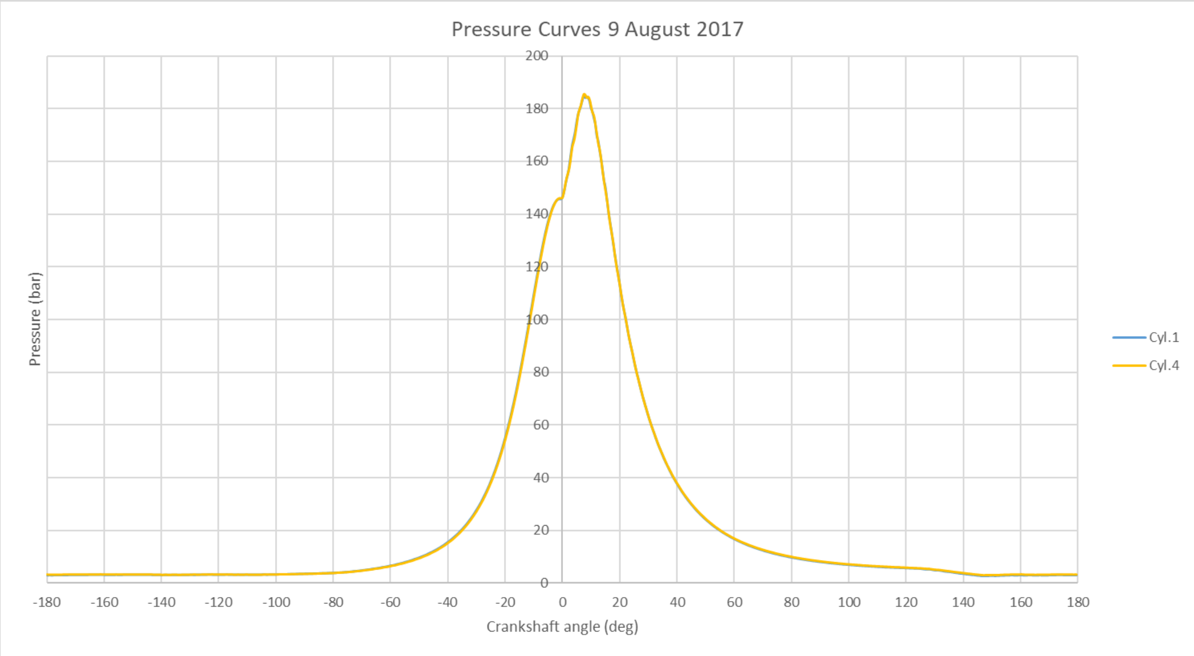


Figure 34: Pressure curves of Cylinders No.1 and No.4 on 9 August 2017

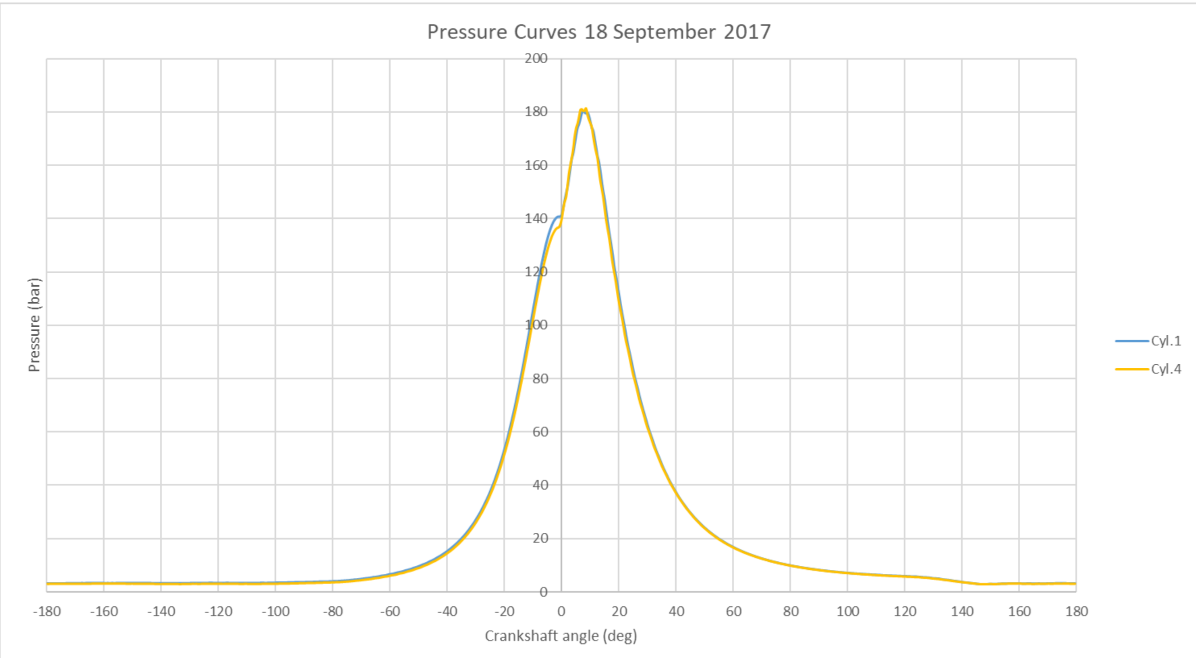


Figure 35: Pressure curves of Cylinders No.1 and No.4 on 18 September 2017

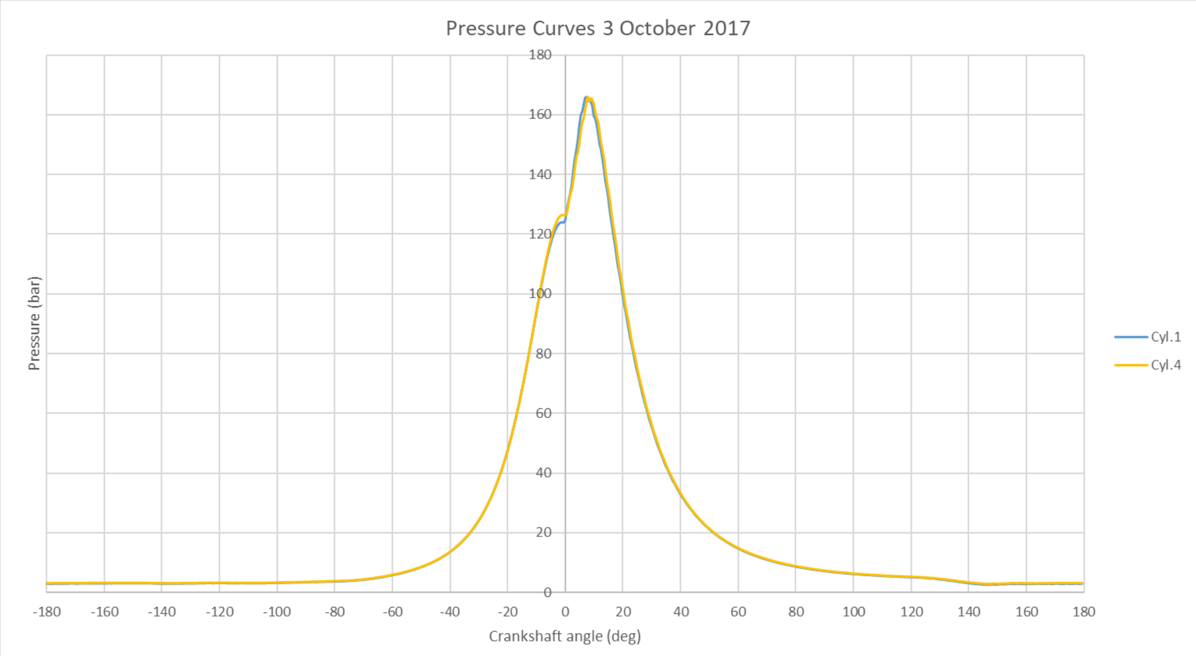


Figure 36: Pressure curves of Cylinders No.1 and No.4 on 3 October 2017

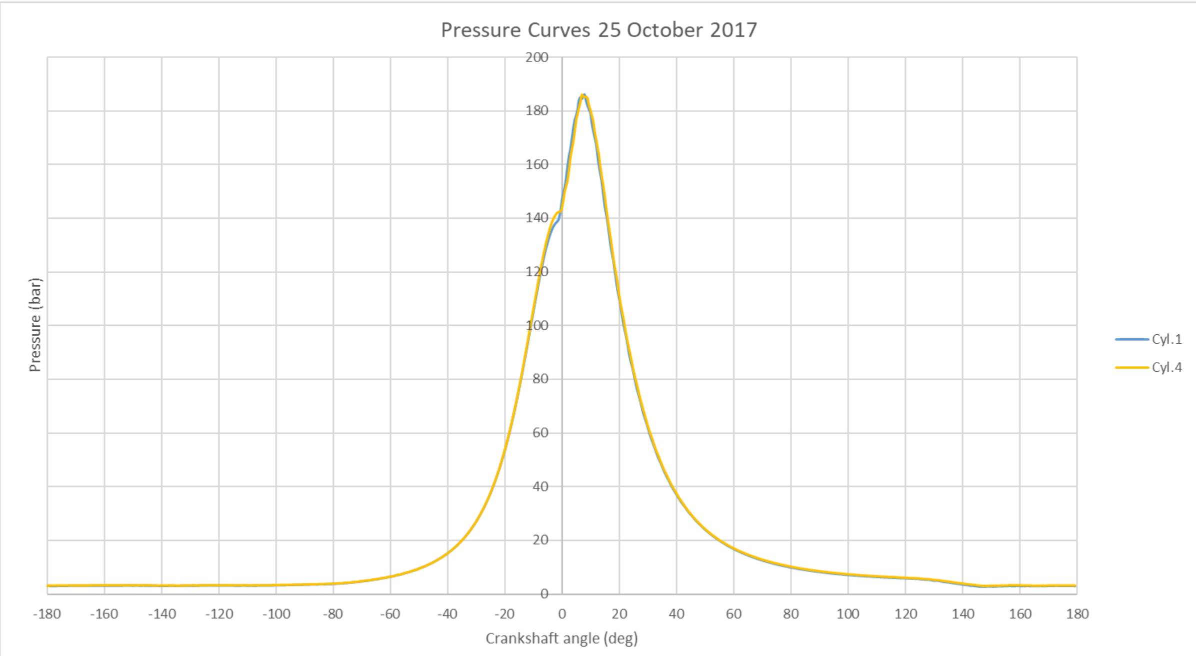


Figure 37: Pressure curves of Cylinders No.1 and No.4 on 25 October 2017

6.2 Case No.2: Exhaust Valve Wear

6.2.1 Event No.1

On 22 December 2017, alarm was triggered for Cylinder No.2 compression pressure deviation from mean value more than allowed limit (i.e. 3 bars). Actual deviation was 15 bar above mean value. Exhaust gas temperature on Cylinder No.2 was about 415 ^{o}C.

At that time, the Engine was running at 80% load having estimated Effective Power 6500 kW at 101 rpm. The ship was in ballast condition.

The problem was rectified on 3 January 2018 by replacing the exhaust valve of Cylinder No.2 which found damaged (Figure 38).

Figure 38: Photo of damage on exhaust valve spindle of Cylinder No.2

6.2.1.1 Data Analysis

The Pcomp of Cylinder No.2 is plotted for a period up to three months before the activation of the alarm against the Pcomp of Cylinder No.4 (Figure 39). Engine's rpm and estimated Effective Power were not stable during this period of time.

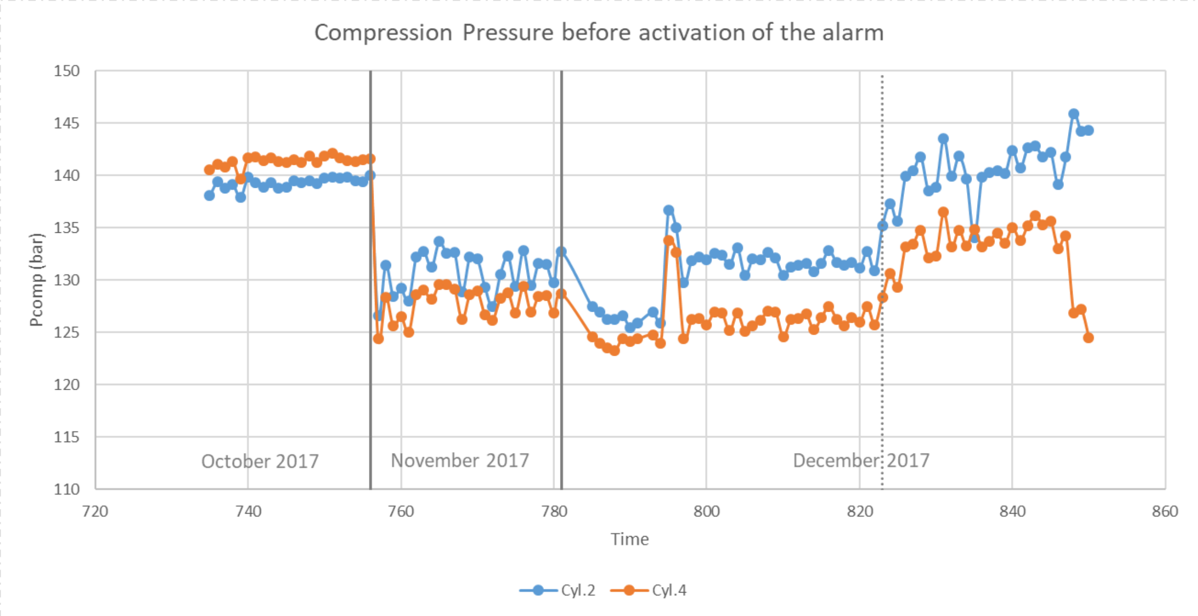


Figure 39: Compression pressure trend of Cylinders No.2 and No.4

It is observed that the compression pressure for both cylinders follows the same trend in different levels. The drop in Pcomp values of both cylinders in November should be due to reduction of engine's rpm from 101 to 98. Engine's rpm are increased again to 101 in the middle of December and Pcomp starts to increase as well. However, the compression pressure of Cylinder No.2 is fluctuating at higher level compared to the non-problematic Cylinder No.4 from November onwards. It seems that the Auto tuning system is trying to compensate the loss of pressure due to the broken exhaust valve spindle.

The following table includes the variation of Pcomp on both cylinders.

Pcomp average variation %	Cyl. 2	Cyl.4	Remarks
from October to November	-6.12%	-9.64%	rpm reduced from 101 to 98
from November to beginning December	-0.09%	-1.34%	98 rpm
from beginning December to end December	7.59%	5.39%	rpm increased from 98 to 101

The value of scavenging pressure is also plotted for the exact same dates and times of performance measurements (Figure 40). It is remarkable that Pscav has almost the same value in October at 101 rpm and in beginning of December at 98 rpm.

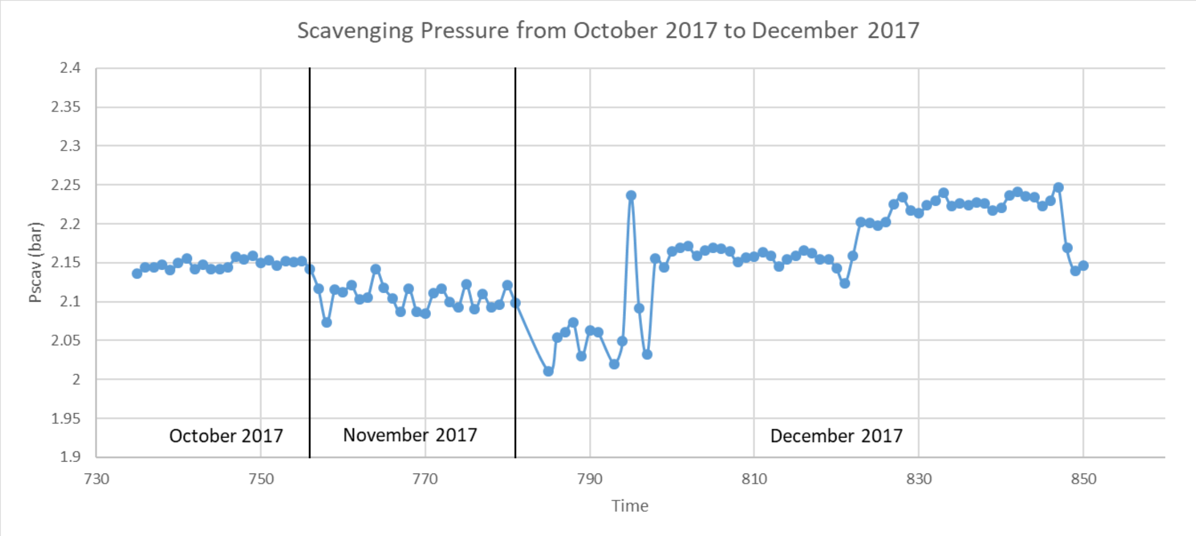


Figure 40: Scavenging pressure trend

Additionally, the ratio between the absolute compression pressure (P_{comp} + $P_{barometric}$) and the absolute scavenging pressure (P_{scav} + $P_{barometric}$) is examined for individual Cylinders No.2 and No.4, considering $P_{barometric}$ = 1 bar (Figure 41).

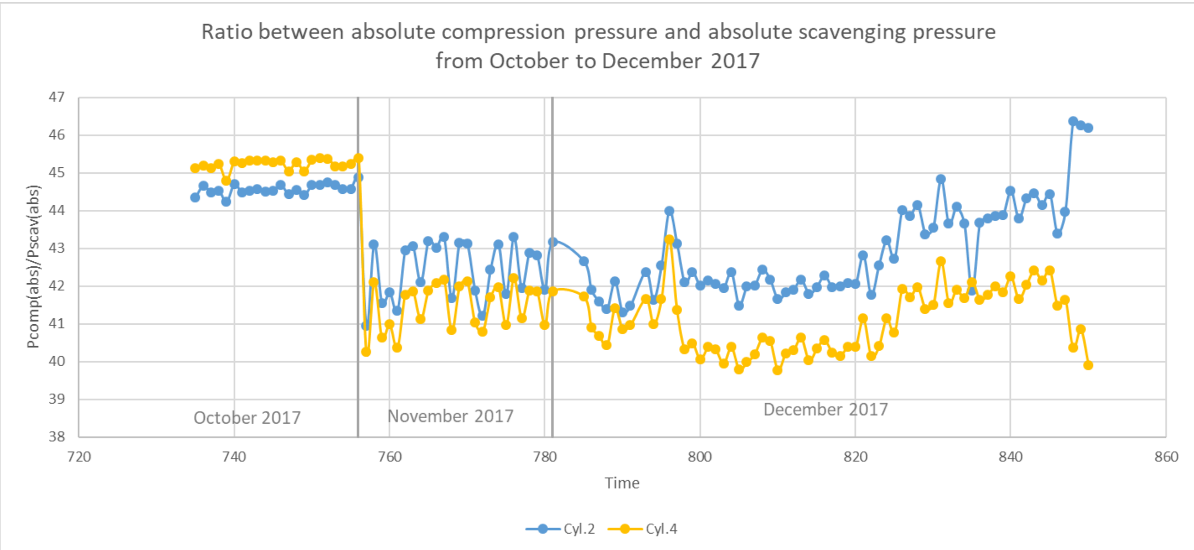


Figure 41: Pcomp/Pscav Ratio trend of Cylinders No.2 and No.4

Figures 42 and 43 depict injection crankshaft angle before TDC and injection close time respectively for the individual Cylinders No.2 and No.4 before activation of the alarm. The available data are limited for the specific time period. However, they reveal that before the activation of the alarm, injection on the problematic Cylinder No.2 is activated at a later crankshaft angle compared to the non-problematic Cylinder No.4. This finding coincides with the respective finding in Case No.1.

As far as the duration of injection is concerned, there is not any considerable deviation between the two cylinders in the available data.

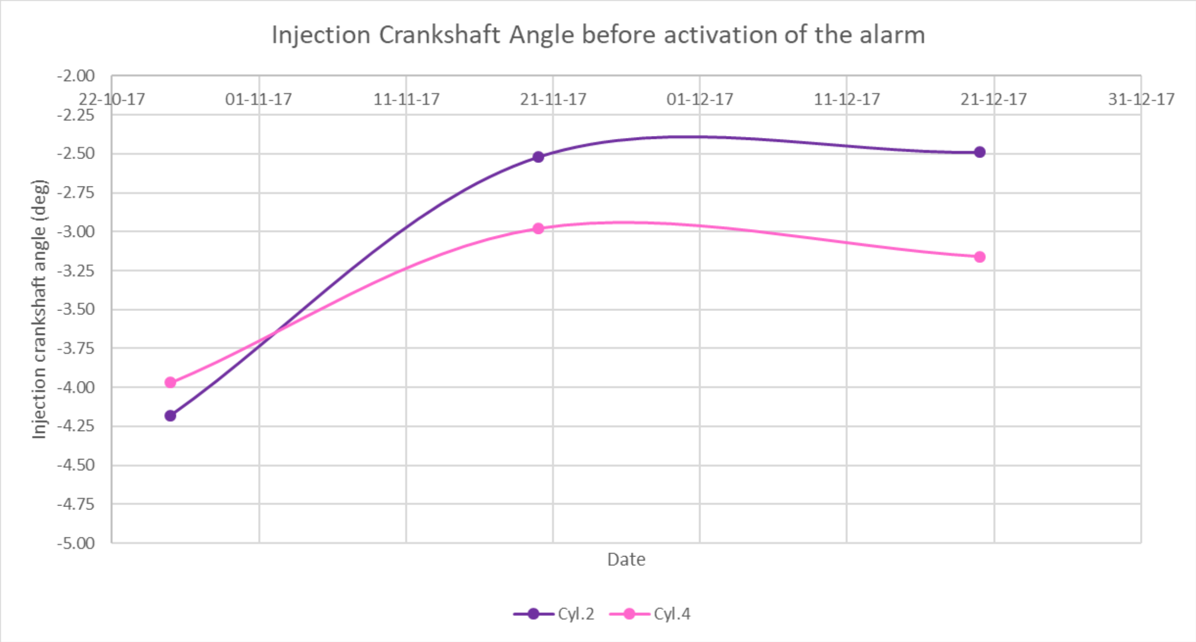


Figure 42: Start of injection crankshaft angle of Cylinders No.2 and No.4

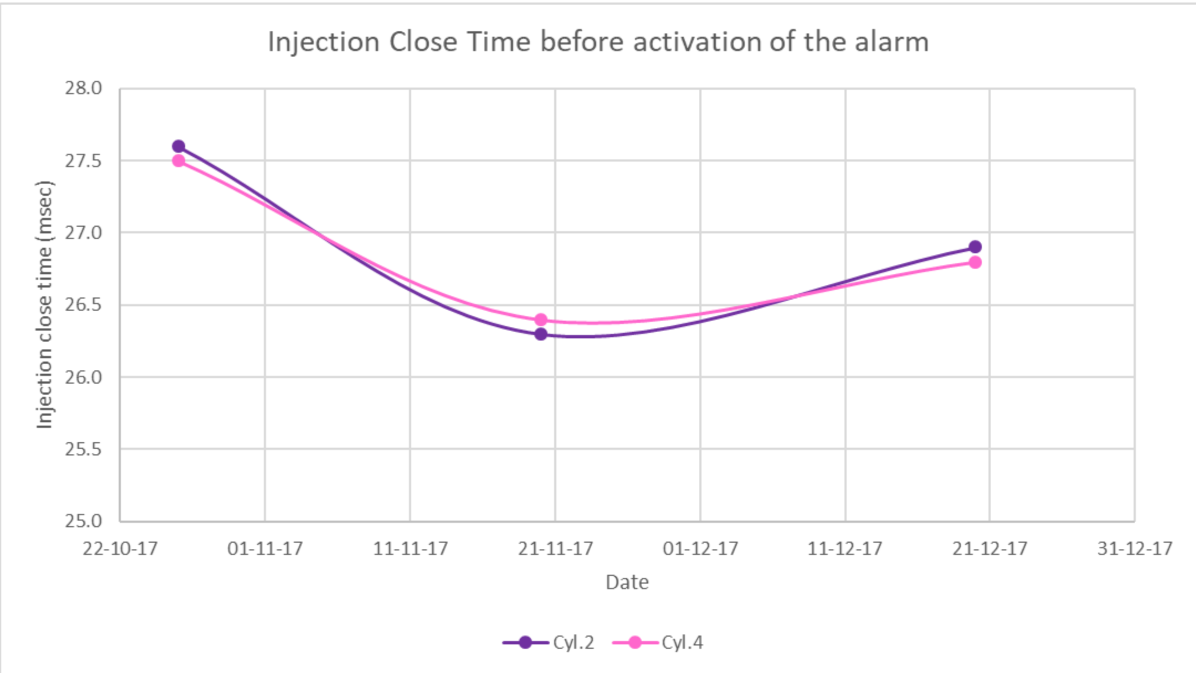


Figure 43: Duration of injection of Cylinders No.2 and No.4

6.2.2 Event No.2

On 7 January 2018, Main Engine automatically slowed down due to exhaust gas high temperature alarm on Cylinder No.5. At that time, the Engine was running at 78% load having estimated Effective Power 6300 kW at 101 rpm. The ship was in laden condition.

The problem was rectified on the same date by replacing the exhaust valve of Cylinder No.5 which found damaged (Figure 44).

Figure 44: Photo of damage on exhaust valve spindle of Cylinders No.5

6.2.2.1 Data Analysis

The Pcomp of Cylinder No.5 is plotted for a period up to three months before the activation of the alarm against the Pcomp of Cylinder No.4 (Figure 45). Engine's rpm and estimated Effective Power were not stable during this period of time.

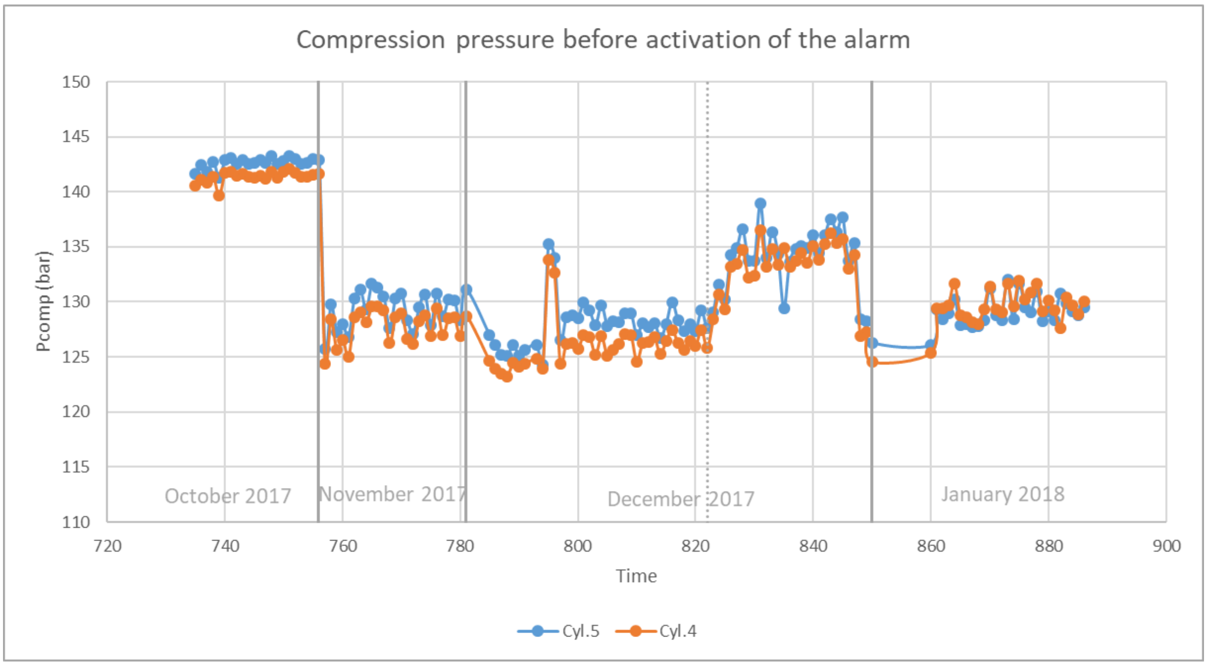


Figure 45: Compression pressure trend of Cylinders No.5 and No.4

It is observed that the compression pressure for both cylinders follows the same trend in different levels. The drop in Pcomp values of both cylinders in November is due to reduction of engine's rpm from 101 to 98. Engine's rpm are increased again to 101 in the middle of December and Pcomp starts to increase as well. However, just a few days before the alarm, the compression pressure drops even though the rpm are stable. As a matter of fact, the difference between Pcomp value in January and Pcomp value in October is more than 10 bars for the same engine rpm.

Again the problematic Cylinder No.5 is fluctuating at higher level compared to the non-problematic Cylinder No.4. It is understood that the Auto tuning system intervenes to compensate the loss of pressure due to the damaged exhaust valve spindle.

The following table includes the variation of Pcomp on both cylinders.

Pcomp average variation %	**Cyl.5**	**Cyl.4**	**Remarks**
from October to November	-9.33%	-9.64%	rpm reduced from 101 to 98
from November to beginning December	-1.06%	-1.34%	98 rpm
from beginning December to end December	4.55%	5.39%	rpm increased from 98 to 101
from end December to January	-3.47%	-2.44%	101 rpm

The value of scavenging pressure is also plotted for the exact same dates and times of performance measurements (Figure 46). It is remarkable that Pscav has almost the same value in October at 101 rpm and in beginning of December at 98 rpm.

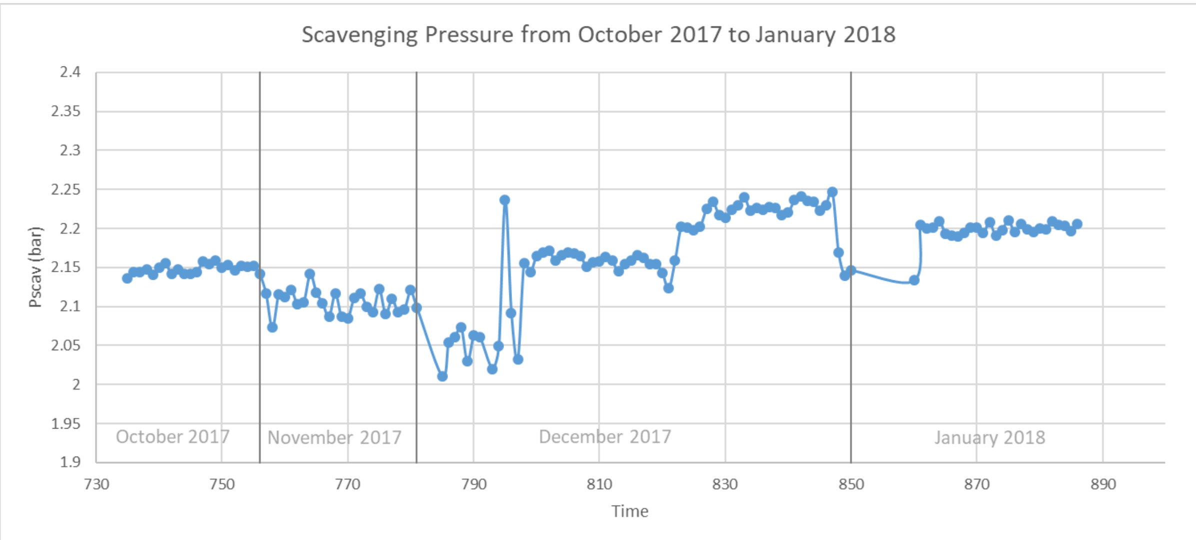


Figure 46: Scavenging pressure trend

Furthermore, the ratio between the absolute compression pressure (P_{comp} + $P_{barometric}$) and the absolute scavenging pressure (P_{scav} + $P_{barometric}$) is examined for individual Cylinders No.5 and No.4, considering $P_{barometric}$ = 1 bar (Figure 47).

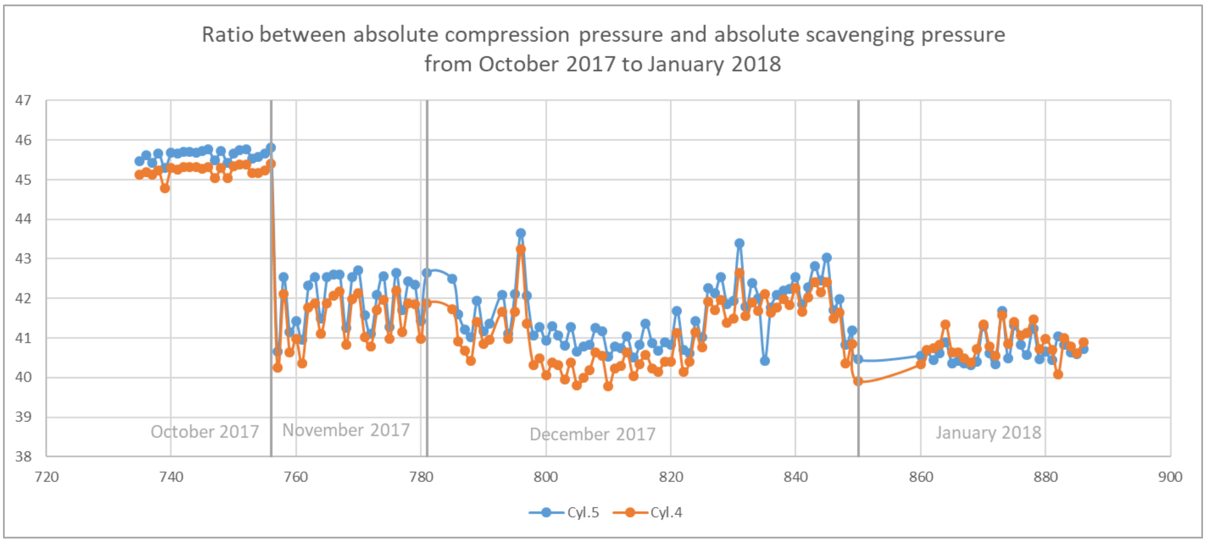


Figure 47: Pcomp/Pscav Ratio trend of Cylinders No.5 and No.4

Figures 48 and 49 depict injection crankshaft angle before TDC and injection close time respectively for the individual Cylinders No.5 and No.4 before activation of the alarm.

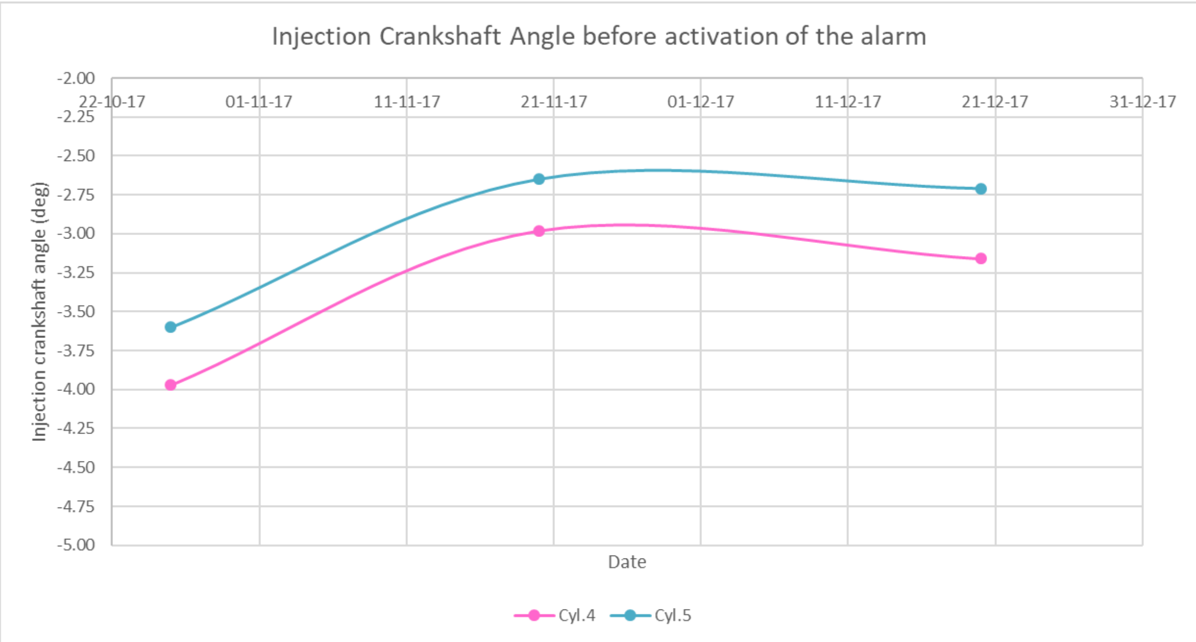


Figure 48: Start of injection crankshaft angle of Cylinders No.5 and No.4

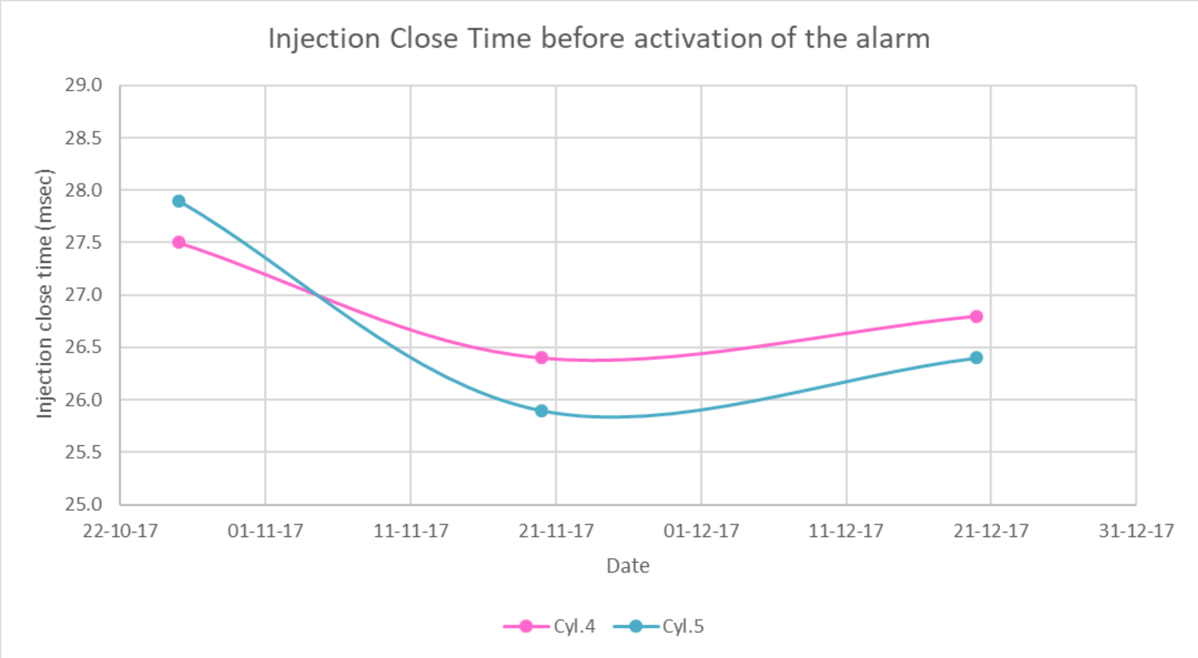


Figure 49: Duration of injection of Cylinders No.5 and No.4

The available data are limited for the specific period of time. However, they reveal that before the activation of the alarm, injection on the problematic Cylinder No.5 is activated at a later crankshaft angle compared to the non-problematic Cylinder No.4. This finding coincides with the outcome of the aforementioned events.

Contrary to the previous cases, the duration of injection on the problematic Cylinder No.2 (in terms of close time) is shorter that the injection duration on the non-problematic Cylinder No.4.

6.3 Case No.3: Piston Rings Wear

6.3.1 Event No.1

On 12 October 2017, during regular scavenge port inspection, the second piston ring of Cylinder No.2 was found broken.

Before the inspection, the Engine was running at 71% load having estimated Effective Power 5700 kW at 98 rpm. The ship was in ballast condition.

The problem was rectified on the same date by replacing the piston rings of Cylinder No.2.

6.3.1.1 Data Analysis

The Pcomp of Cylinder No.2 is plotted for a period up to five months before the scavenge port inspection against Pcomp of Cylinder No.4 (Figure 50). Measurements from June to September correspond to 101 rpm and 6500 kW estimated Effective Power, whilst measurements in October correspond to 98 rpm and estimated Effective Power of 5700 kW.

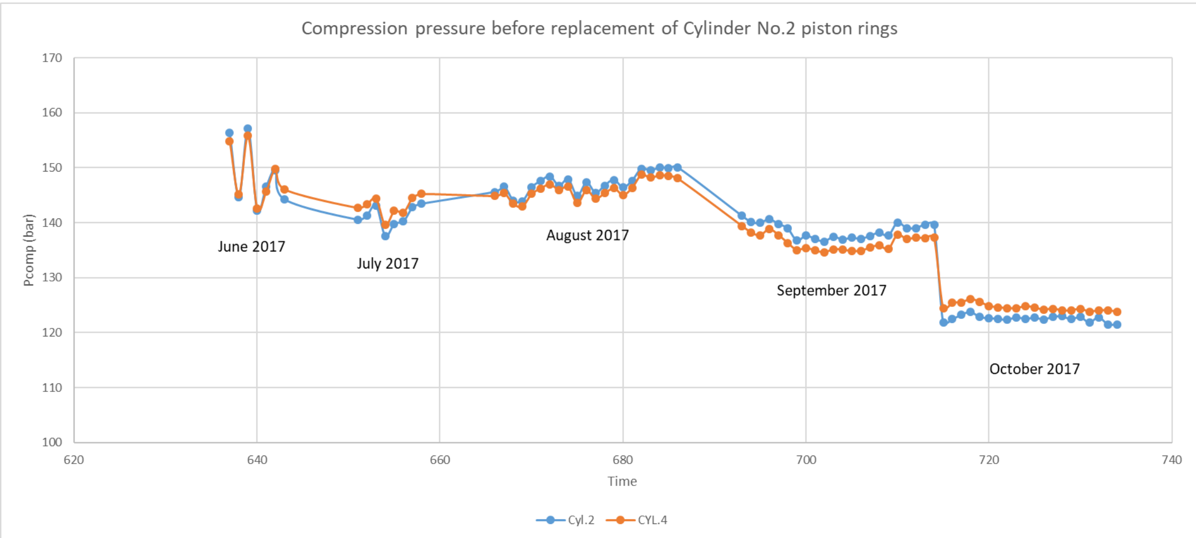


Figure 42: Compression pressure trend of Cylinders No.2 and No.4

It is noticed that the compression pressure of both cylinders follows the same trend in different levels. The drop in Pcomp values of both cylinders in October should be due to reduction of engine's rpm from 101 to 98. The compression pressure of Cylinder No.2 in August and September is slightly higher compared to the non-problematic Cylinder No.4. It appears that the Auto tuning system is trying to compensate the loss of pressure due to the broken piston ring.

The following table includes the monthly variation of Pcomp on both cylinders.

Pcomp monthly average variation %	Cyl.2	Cyl.4	Remarks
from June to July	-5.09%	-3.76%	101-102 rpm
from July to August	4.37%	2.15%	
from August to September	-5.92%	-6.58%	
from September to October	-11.56%	-8.71%	rpm reduced to 97

The scavenging pressure during the same period of time is depicted in Figure 11. Pscav has a constant descending trend.

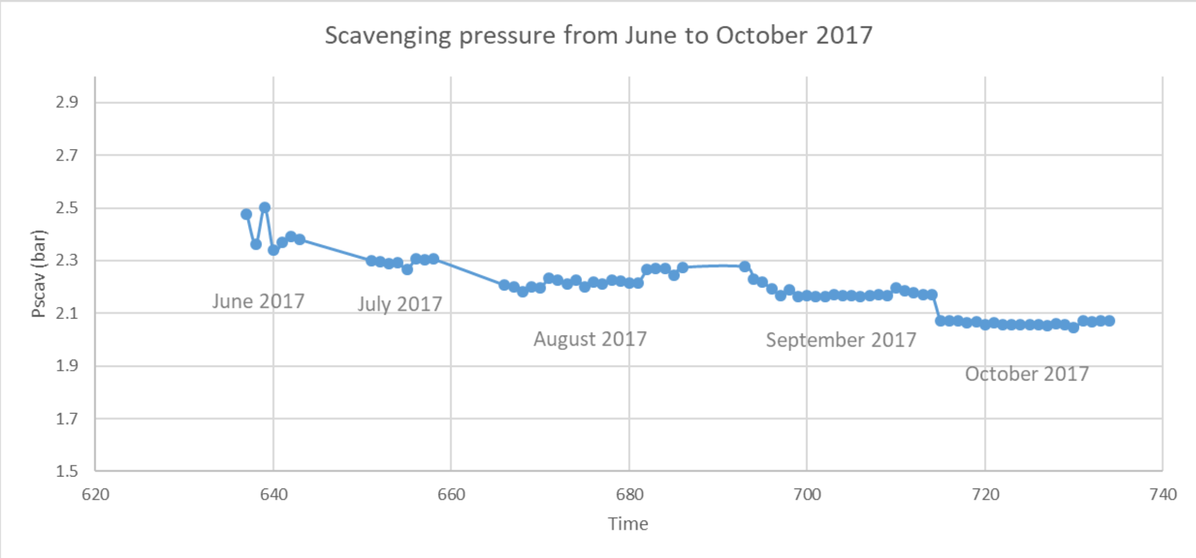


Figure 51: Scavenging pressure trend

Additionally, the ratio between the absolute compression pressure (P_{comp} + $P_{barometric}$) and the absolute scavenging pressure (P_{scav} + $P_{barometric}$) is examined for individual Cylinders No.2 and No.4, considering $P_{barometric}$ = 1 bar (Figure 52).

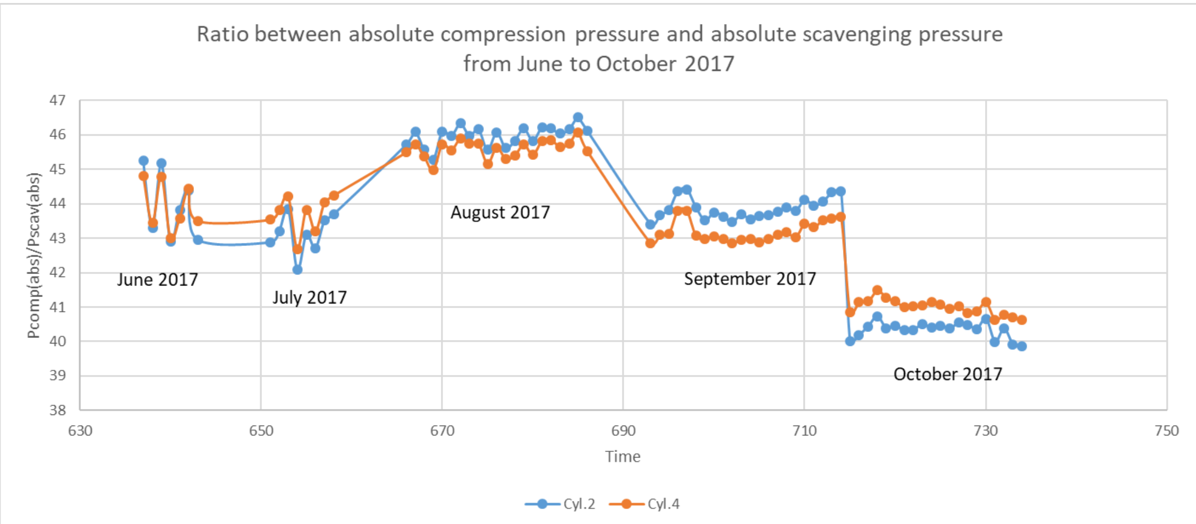


Figure 52: Pcomp/Pscav Ratio trend of Cylinders No.2 and No.4

Figures 53 and 54 depict injection crankshaft angle before TDC and injection close time respectively for the individual Cylinders No.2 and No.4 before the inspection. According to the available data, before the replacement of piston rings, injection on the problematic Cylinder No.2 is activated at a later crankshaft angle compared to the non-problematic Cylinder No.4. Furthermore, the duration of injection on the problematic Cylinder No.2 (in terms of close time) is shorter than on the non-problematic Cylinder No.4. These findings coincide with the respective findings in previous events.

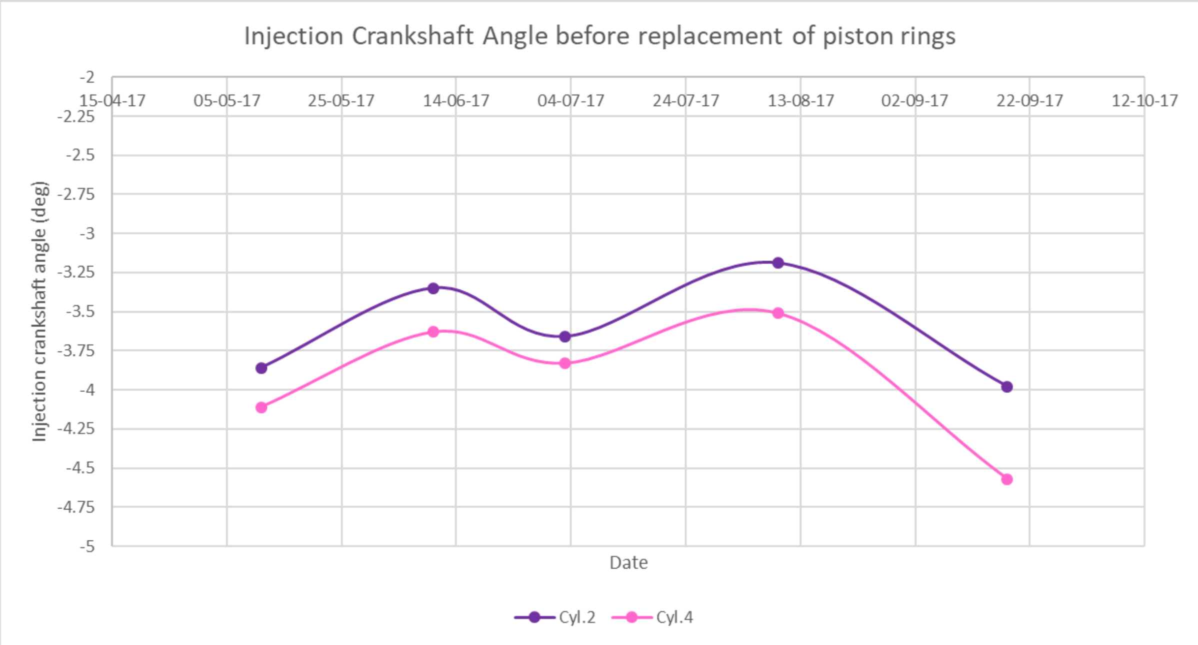


Figure 53: Start of injection crankshaft angle of Cylinders No.2 and No.4

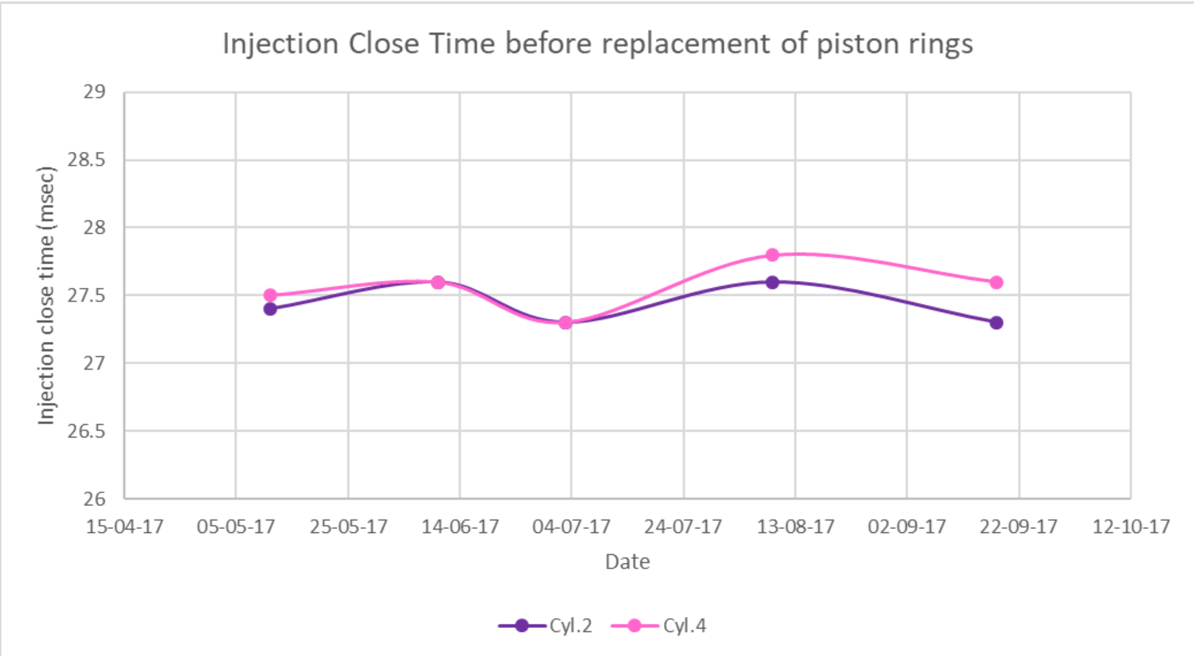


Figure 54: Duration of injection of Cylinders No.2 and No.4

6.3.2 Event No.2

On 12 October 2017 during regular scavenge port inspection, the third piston ring of Cylinder No.5 found broken.

Before the inspection, the Engine was running at 71% load having estimated Effective Power 5700 kW at 98 rpm. The ship was in ballast condition.

The problem was rectified on the same date by replacing the piston rings of Cylinder No.5.

6.3.2.1 Data Analysis

The Pcomp of Cylinder No.5 is plotted for a period up to five months before the scavenge port inspection against Pcomp of Cylinder No.4 (Figure 55). Measurements from June to September correspond to 101 rpm and 6500 kW estimated Effective Power, whilst measurements in October correspond to 98 rpm and estimated Effective Power of 5700 kW.

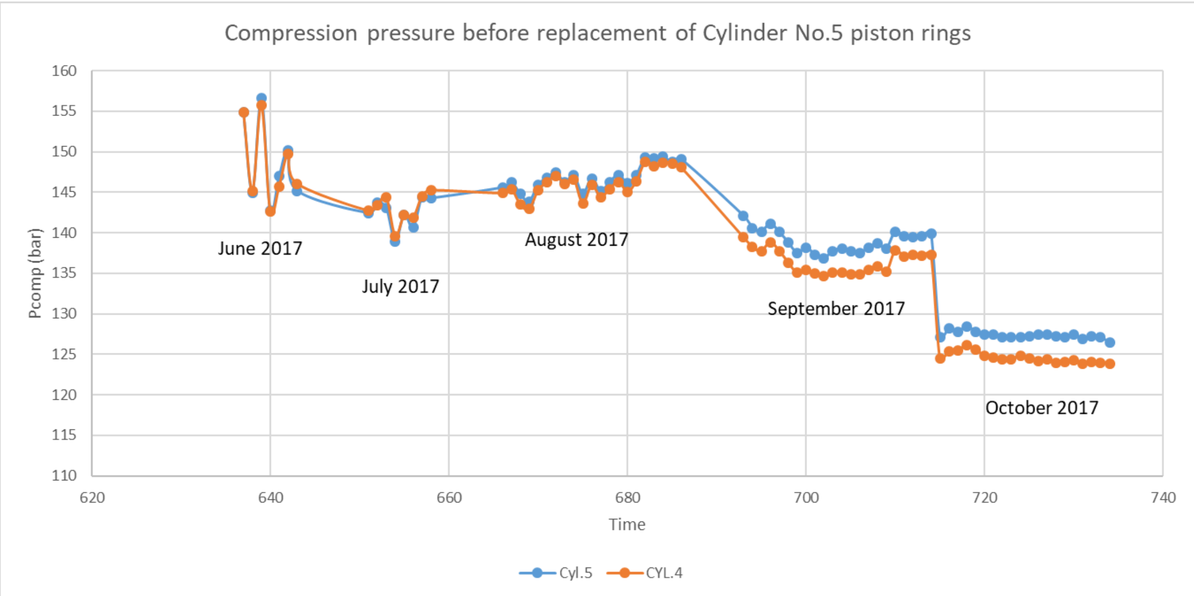


Figure 55: Compression pressure trend of Cylinders No.5 and No.4

It is observed that the compression pressure for both cylinders follows the same trend in different levels. The drop in Pcomp values of both cylinders in October is due to reduction of engine's rpm from 101 to 98. Again Pcomp of the problematic Cylinder No.5 is fluctuating at higher level compared to the non-problematic Cylinder No.4. It is understood that the Auto tuning system intervenes to compensate the loss of pressure due to the broken piston rings.

The following table includes the variation of Pcomp on both cylinders.

Pcomp monthly average variation %	Cyl.5	Cyl.4	Remarks
from June to July	-4.26%	-3.76%	101-102 rpm
from July to August	3.04%	2.15%	
from August to September	-5.34%	-6.58%	
from September to October	-8.36%	-8.71%	rpm reduced to 97

The value of scavenging for the exact same dates and times of performance measurements is depicted in Figure 56. It is remarkable that Pscav has almost the same value in October at 101 rpm and in beginning of December at 98 rpm.

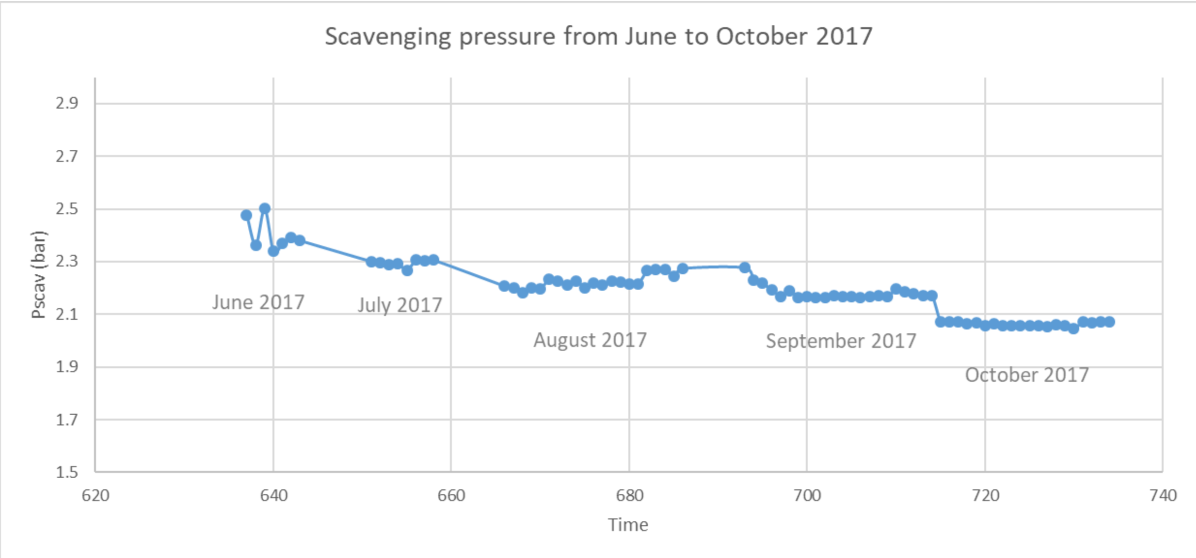


Figure 56: Scavenging pressure trend

Furthermore, the ratio between the absolute compression pressure (P_{comp} + $P_{barometric}$) and the absolute scavenging pressure (P_{scav} + $P_{barometric}$) is examined for individual Cylinders No.5 and No.4, considering $P_{barometric}$ = 1 bar (Figure 57).

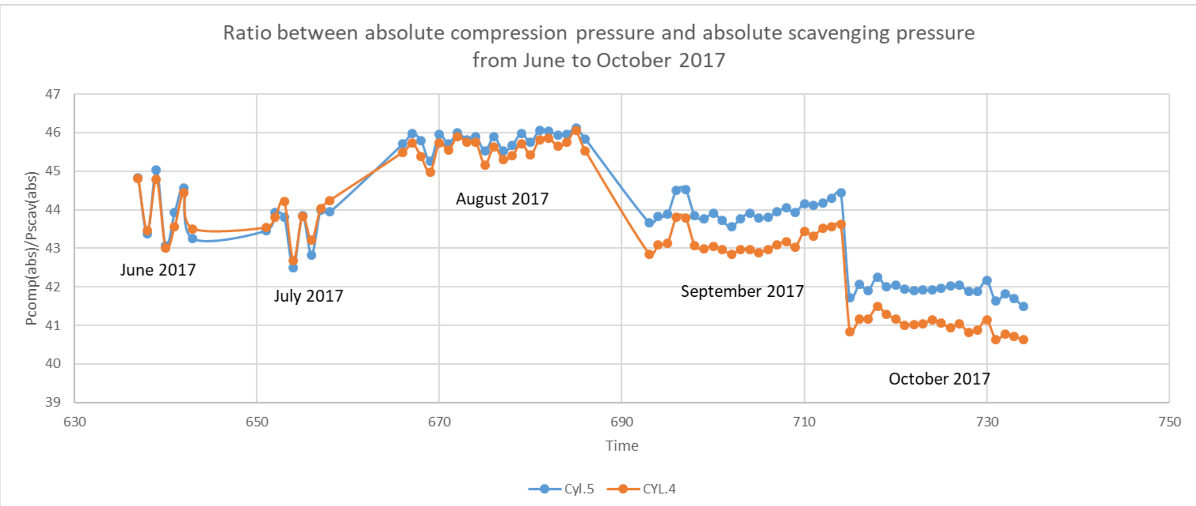


Figure 57: Pcomp/Pscav Ratio trend of Cylinders No.5 and No.4

Figures 58 and 59 depict injection crankshaft angle before TDC and injection close time, respectively, for the individual Cylinders No.5 and No.4 before the inspection. According to the available data, before the replacement of piston rings, injection on the problematic Cylinder No.5 is activated at a later crankshaft angle compared to the non-problematic Cylinder No.4. Furthermore, the duration of injection on the problematic Cylinder No.5 (in terms of close time) is shorter that on the non-problematic Cylinder No.4. These findings coincide with the respective findings in previous events.

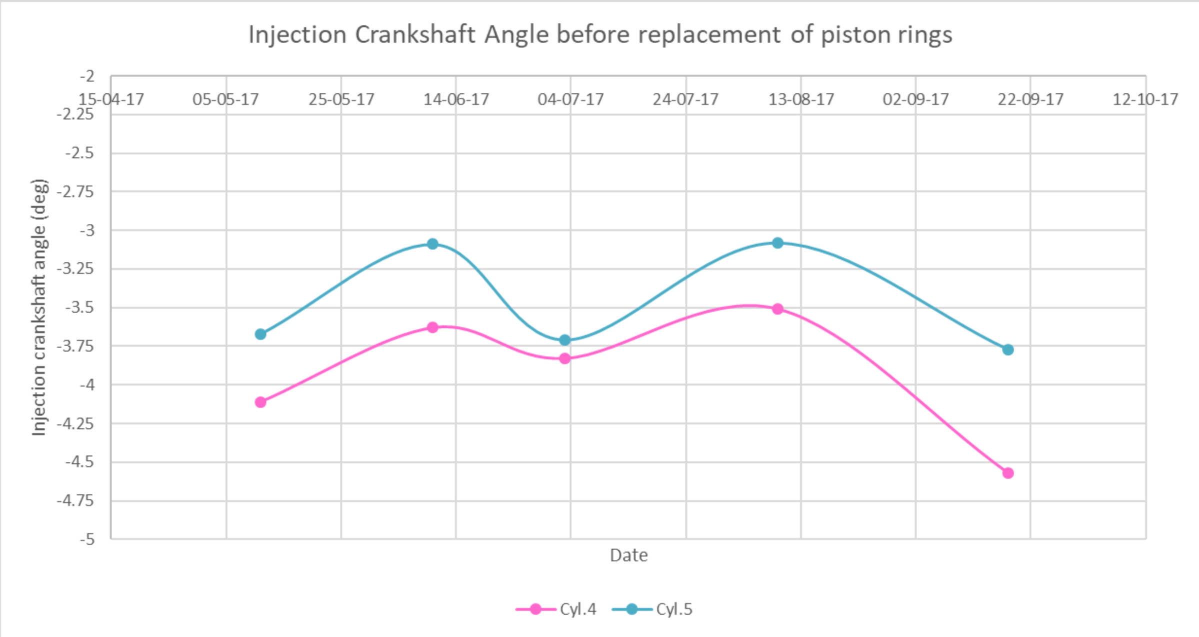


Figure 58: Start of injection crankshaft angle of Cylinders No.5 and No.4

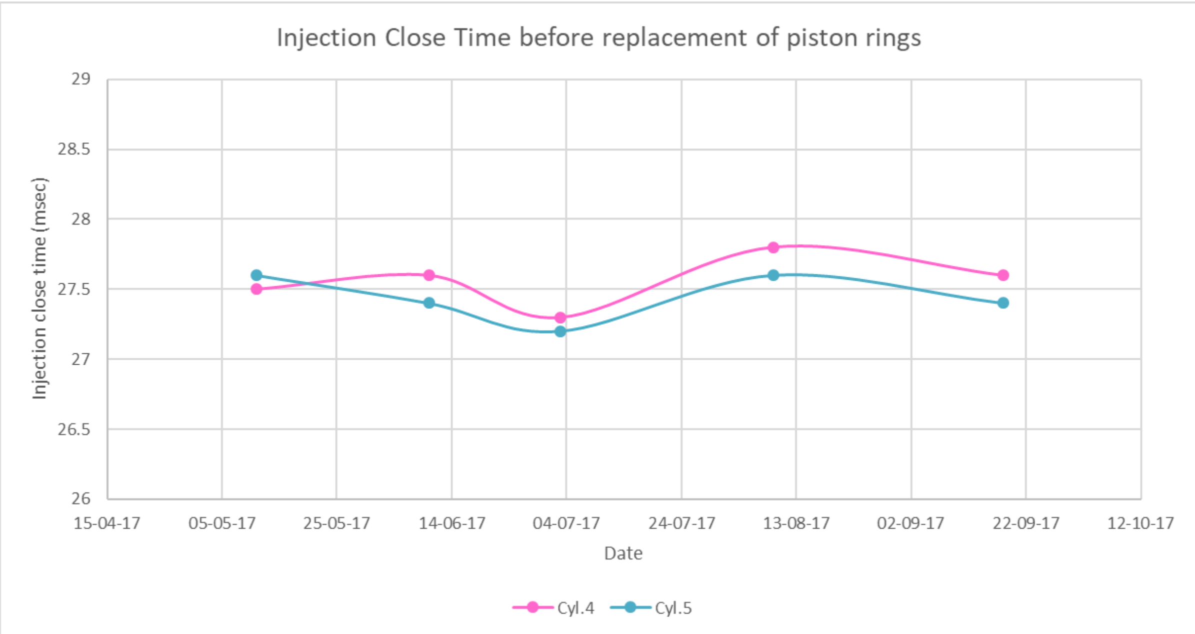


Figure 59: Duration of injection of Cylinders No.5 and No.4

6.3.3 Event No.3

On 28 November 2017 during regular scavenge port inspection, the second piston ring of Cylinder No.3 was found broken.

Before the inspection, the Engine was running at 73% load having estimated Effective Power 5900 kW at about 98 rpm. The ship was in laden condition.

The problem was rectified on the same date by replacing the piston rings of Cylinder No.3.

6.3.3.1 Data Analysis

The Pcomp of Cylinder No.3 is plotted for a period up to five months before the scavenge port inspection against Pcomp of Cylinder No.4 (Figure 60). Measurements from June to October correspond to 101 rpm and 6500 kW estimated Effective Power, whilst measurements in October correspond to 98 rpm and estimated Effective Power of 5700 kW.

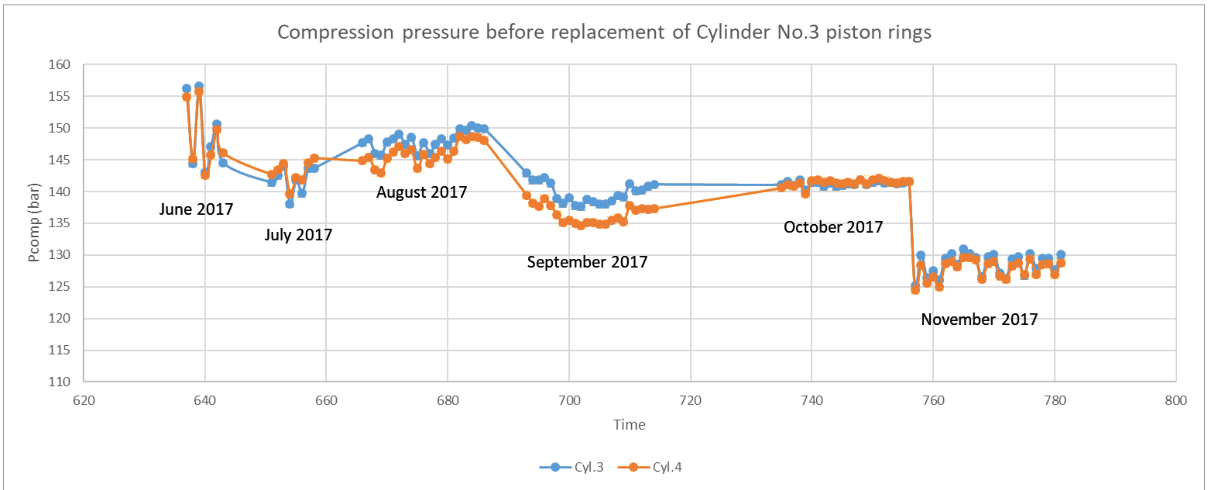


Figure 60: Compression pressure trend of Cylinders No.3 and No.4

It is observed that the compression pressure for both cylinders follows the same trend. The drop in Pcomp values of both cylinders in November is due to reduction of engine's rpm from 101 to 98. Pcomp of the problematic Cylinder No.3 is fluctuating at slightly higher level compared to the non-problematic Cylinder No.4 and again there are no signs of malfunction.

The following table includes the monthly variation of Pcomp on both cylinders.

Pcomp monthly average variation %	Cyl.3	Cyl.4	Remarks
from June to July	-4.74%	-3.76%	101-102 rpm
from July to August	4.37%	2.15%	
from August to September	-5.60%	-6.58%	
from September to October	1.05%	3.62%	
from October to November	-8.97%	-9.64%	rpm reduced to 98

The value of scavenging for the exact same dates and times of performance measurements is depicted in Figure 61. It is remarkable that in November with reduced rpm, the value of Pscav remains at the same level.

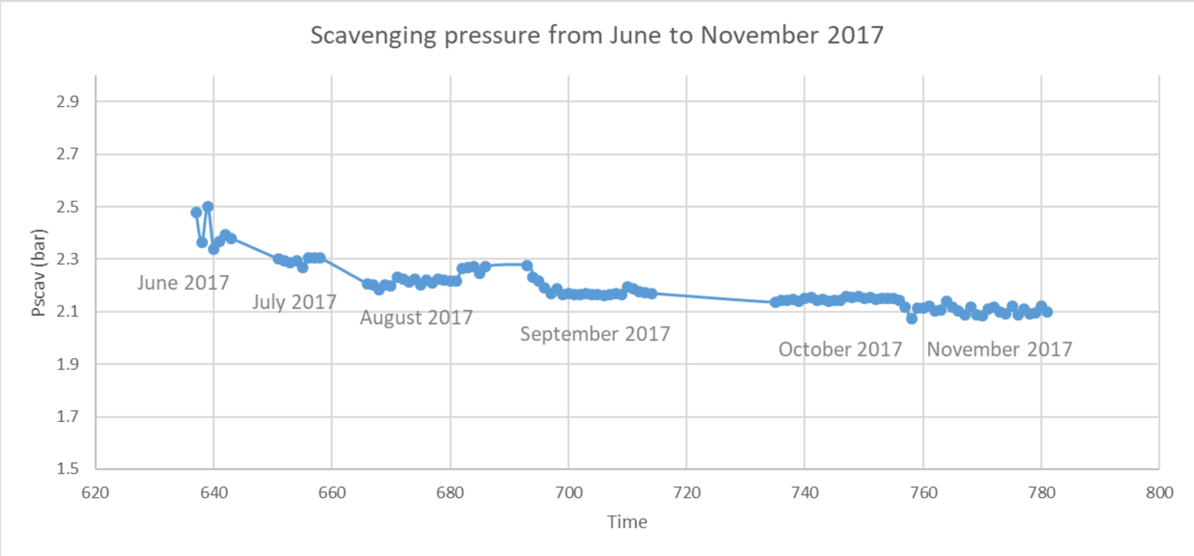


Figure 61: Scavenging pressure trend

Additionally, the ratio between the absolute compression pressure (P_{comp} + $P_{barometric}$) and the absolute scavenging pressure (P_{scav} + $P_{barometric}$) is examined for individual Cylinders No.3 and No.4, considering $P_{barometric}$ = 1 bar (Figure 62).

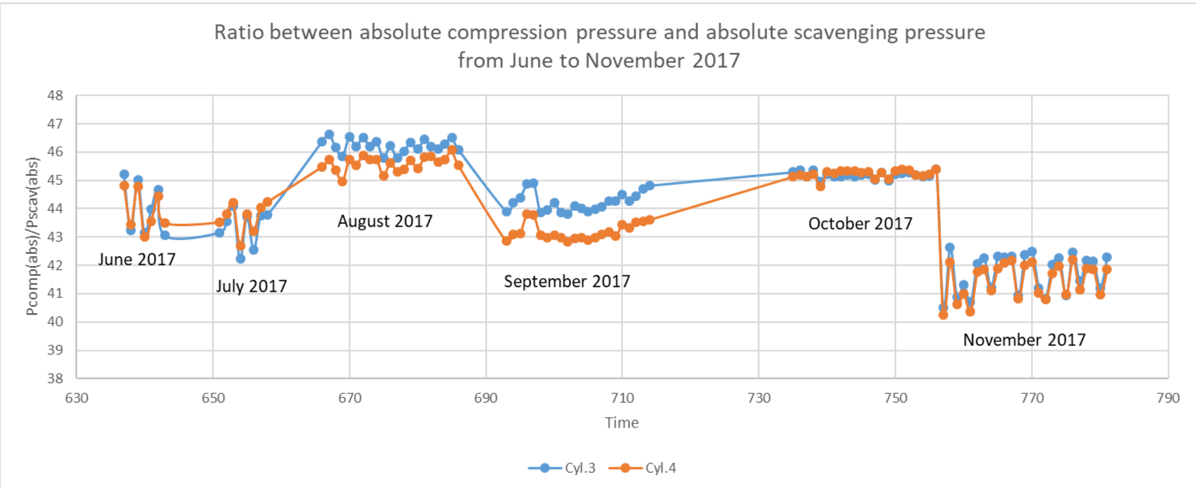


Figure 62: Pcomp/Pscav Ratio trend of Cylinders No.3 and No.4

Figures 63 and 64 depict injection crankshaft angle before TDC and injection close time respectively for the individual Cylinders No.3 and No.4 before the inspection. According to the available data, before the replacement of piston rings, injection on the problematic Cylinder No.3 is activated at a later crankshaft angle compared to the non-problematic Cylinder No.4. Furthermore, the duration of injection on the problematic Cylinder No.3 (in terms of close time) is shorter that on the non-problematic Cylinder No.4. These findings coincide with the respective findings in previous events.

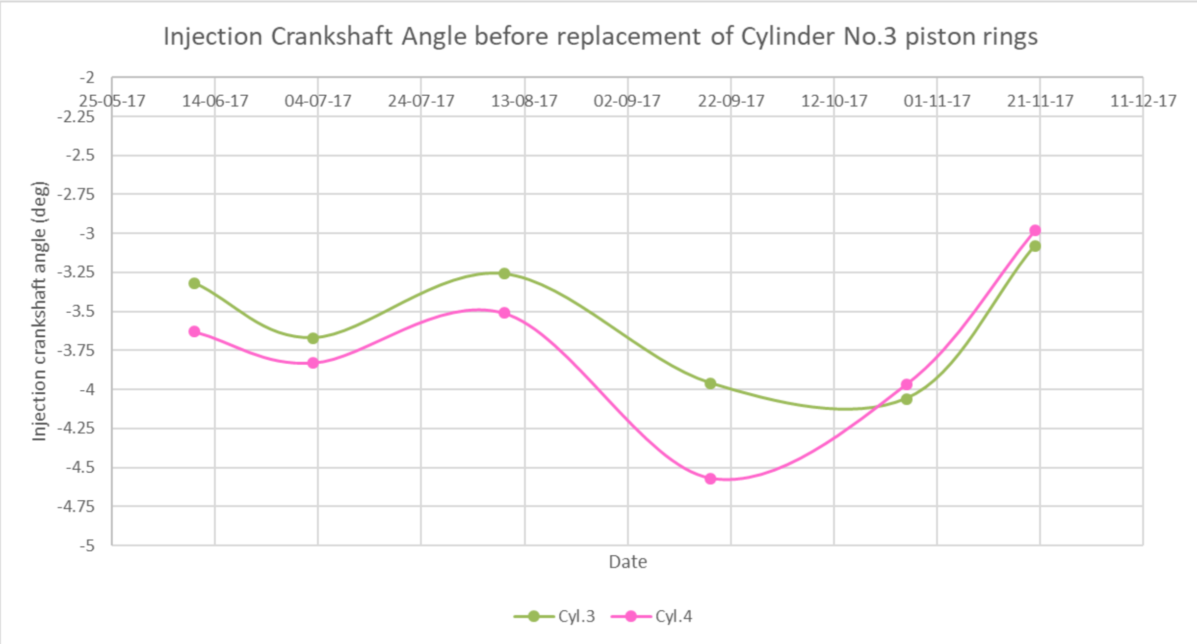


Figure 63: Start of injection crankshaft angle of Cylinders No.3 and No.4

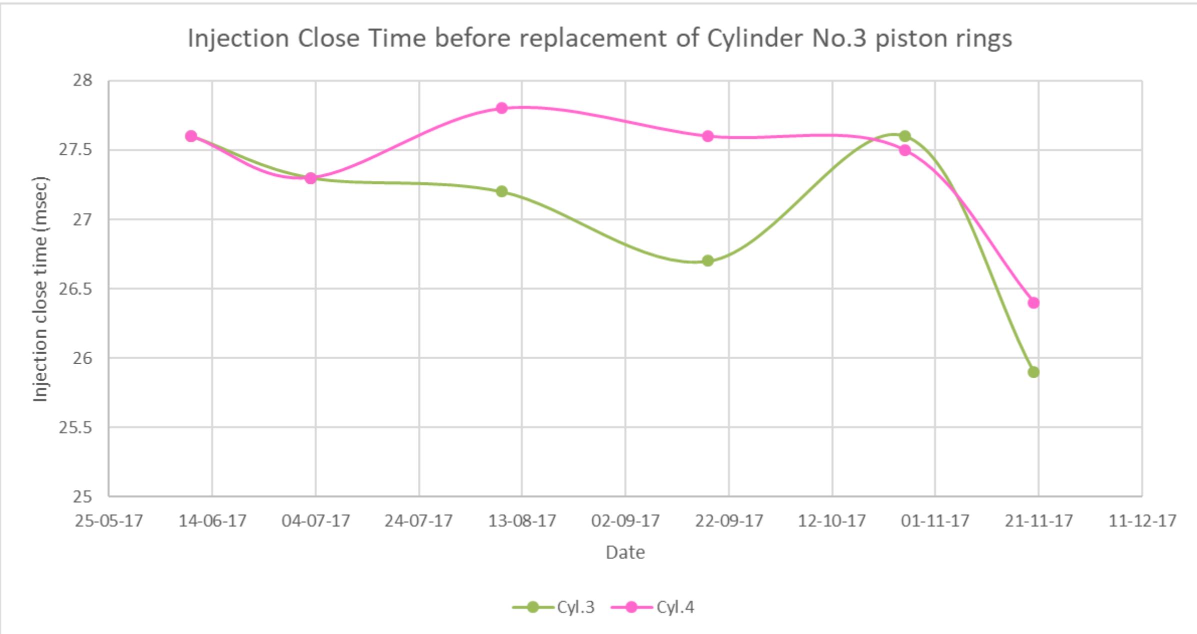


Figure 64: Duration of injection of Cylinders No.3 and No.4

7. CONCLUSIONS

Taking all analysis results of the present study into consideration, the conclusions that are reached for the electronic engine of our case study are highlighted in this chapter.

First, it becomes evident that the auto tuning system can conceal mechanical defects. The goal of auto tuning function is to continuously adjust the operating parameters, so that the engine runs balanced. As a consequence, defects or wear on mechanical components of individual cylinders cannot be detected, especially at the initiation of the problem. Eventually, the defect will be revealed since all adjustments have specified range limits. However, any incident that will occur unexpectedly due to the defect may affect the safe operation of the vessel (for example slow down during bad weather conditions in open sea or during a canal passage).

It becomes apparent that the pressure and performance data solely can be misleading. Therefore, the review of the parameters affected by auto tuning is essential for the evaluation of the engine's state. The variable fuel injection timing parameters can provide information on the cylinder's condition.

The injection on a cylinder with worn liner, exhaust valve or piston rings commences at a later crankshaft angle (i.e. closer to TDC) compared to a non-problematic cylinder. The common effect in all events is the reduction of compression pressure. Consequently, the auto tuning system delays the start of the injection in order to allow time for the desired value of compression pressure to be reached in the combustion chamber.

Furthermore, the injection on a cylinder with worn liner lasts longer compared to a non-problematic cylinder, whilst the injection on a cylinder with worn exhaust valve or piston rings lasts less, in comparison to the non-problematic cylinder.

It appears that the auto tuning system selects a specific combination of injection crankshaft angle and close time for each cylinder so as to achieve the desired maximum combustion pressure within engine design limits.

At the events of worn exhaust valves and piston rings, the injection commences closer to the TDC and the duration of the injection is reduced. This combination recovers effectively the loss of pressure in the chamber, and keeps the fuel consumption at normal levels.

At the events of worn liner, the injection commences closer to the TDC and the duration of the injection is increased. It seems that the increase of fuel injection (in terms of injection duration) is required in order to overcome the reduction of pressure due to blow by from a worn cylinder liner.

8. SUGGESTED MEASURES

As an outcome of the present study, it is recommended to turn off the auto tuning system in case abnormalities are suspected. When adjustment values exceed the specified limits or the Engine Operator observes irregularities like temperature rise, the auto tuning function should be deactivated for a short period of time in order to monitor the fluctuation of engine parameters and identify potential issues associated with mechanical components.

In addition, it is strongly recommended to save CoCoS-EDS data each time PMI measurements are taken.
CoCoS-EDS data saving is a matter of a button clicking, so crew on board ships should be instructed to save these valuable data at specified time intervals, and certainly concurrently with PMI measurements.

Back up of all databases should be sent periodically to the Office Operators, so as to be used for evaluation of the engine condition.

9. SUGGESTIONS FOR FUTURE WORK

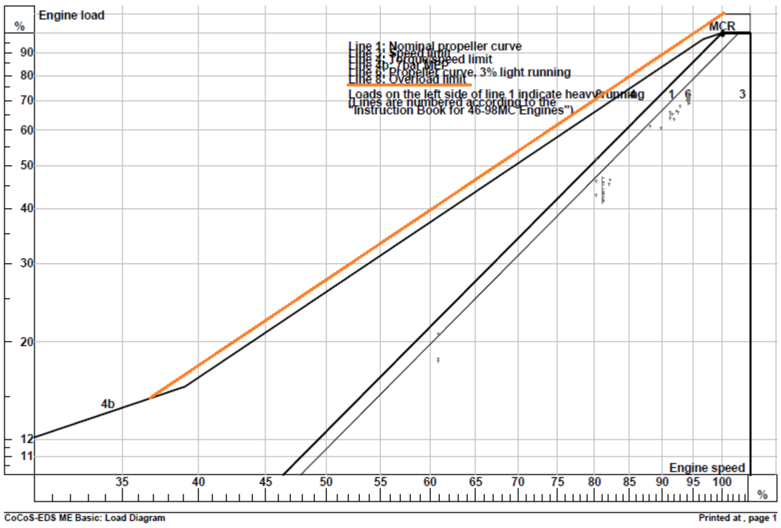
As a continuation of the present study, it is suggested to examine similar cases on vessels with the same engine type. Specific trends of engine operating parameters have been observed, however the investigation of additional similar events is required, so as the trends to be confirmed.

Although this study approaches the effect of auto tuning on injection timing, it would be beneficial to elaborate on these parameters by examining periods of time with dense data.

Finally, the effect of auto tuning on exhaust valve closing timing should be determined, in order to have a clear view of engine’s behavior at each case.

The deconstruction of auto tuning function, in conjunction with the ability of measuring a great range of operating data, can significantly enhance the attempts for forecasting of mechanical malfunctions on modern electronic engines.

ANNEX A: EDS STANDARD REPORT – LIST OF PARAMETERS

ME-B ENGINE		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
EICU_010216: Engine speed	RPM	
EICU_010209: Fuel index	%	The fuel index can give information for the condition of the fuel injection equipment. Increased index reveals possible wear on fuel pumps or leakages in suction valves. It is dependent on: • The viscosity of the fuel oil at the preheating temperature. Low viscosity will cause leakages in the fuel pump and thereby necessitate higher indexes for injecting the same amount of fuel. • The calorific value and the specific gravity of the fuel oil. These will determine the energy content per unit volume and can therefore also influence the index. • Parameters that affect the fuel oil consumption (e.g. ambient conditions, Pmax)
EICU_0926: Index at 10% power (propeller curve)	%	Fuel Index in case of 10% increase in power [Line 8 (red) of Load Diagram] 
EICU_0908: ECS power before calibration	%	Estimated Engine Load before using fuel quality offset for load adjustment
EICU_0909: ECS power after calibration	%	Estimated Engine Load after using fuel quality offset for load adjustment

CCUx_0628: Injection close time all cylinders	ms	Duration of injection
CCU 1		on Cylinder No.1
CCU 2		on Cylinder No.2
CCU 3		on Cylinder No.3
CCU 4		on Cylinder No.4
CCU 5		on Cylinder No.5
CCU 6		on Cylinder No.6
CCUx_060618: Estimated injection angle all cylinders	deg	Crankshaft angle of injection
CCU 1		on Cylinder No.1
CCU 2		on Cylinder No.2
CCU 3		on Cylinder No.3
CCU 4		on Cylinder No.4
CCU 5		on Cylinder No.5
CCU 6		on Cylinder No.6
EICU_010206: Scavenge air pressure	bar	Pscav measured by the sensors.
EICU_0924: Scavenge air pressure [bar Abs]	bar	$P_{scav(abs)} = P_{scav} + P_{barometric}$ where $P_{barometric}$ assumed 1 bar
EICU_0906: Ordered Pcomp/Pscav	-	The system orders this ratio based on the Estimated Load.
EICU_0922: Ordered Pcomp	bar	The system orders this value of Pcomp based on the Estimated Load.
EICU_0923: Ordered Pmax	bar	The system orders this value of Pmax based on the Estimated Load.
EICU_0912: Ordered Prise	bar	Pressure Rise: Prise = Pmax - Pcomp Normal range 35-38 bar. Alarm is triggered at 45 bar The system orders this value of Prise based on the Estimated Load.
EICU_0201XPU : Engine balance	0=Not OK, 1=OK	

ME-B GOVENOR		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
EICU_0914: Current engine running mode	1= Economy, 2=Emission	Economy Running Mode: Low SFOC , High Nox Emission Running Mode: High SFOC , Low Nox
EICU_010202: Engine side speed set	RPM	Speed setpoint through Local Operating Panel or Engine Side Control Console
EICU_010203: Active speed set	RPM	Speed setpoint
EICU_0412: ECR control station, speed setpoint	RPM	Speed setpoint through Engine Control Room station
EICU_0512: RCS control station, speed setpoint	RPM	Speed setpoint through Remote Control System (Bridge station)
EICU_010207: Value of nearest fuel index limiter	%	The limiter defines the maximum amount of fuel to be injected.

ME-B TACHO SYSTEM (or Crankshaft position sensing system)		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
CCU2_01010329: Tacho set A, marker edge adjustment	-	Marker A set point to be adjusted within 0.4-0.7 degrees
CCU2_01010429: Tacho set B, marker edge adjustment	-	Marker B set point to be adjusted within 0.4-0.7 degrees
CCU2_010118: Delta tacho B	deg	Angle difference between Encoder A & Encoder B. Maximum limit is 1 degree.
CCU2_010121: Tacho alignment deviation	deg	Deviation between Reference sensor of flywheel and angle encoders mounted on the common shaft. Maximum limit 0.5 degrees.

ME-B HPS (Hydraulic Power Supply)		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
EICU_0911: Hydraulic pressure ordered	bar	Pressure of hydraulic oil stored in HPS accumulator (order to hydraulic pumps)
EICU_0302: Hydraulic pressure setpoint	bar	Theoretical hydraulic pressure automatically calculated by the system to drive the engine (ie exhaust valve actuation & fuel injection). This order/request goes to the hydraulic pumps.
EICU_0303: Hydraulic pressure	bar	Manually input value
EICU_0304: Hydraulic pressure adaption	bar	The ability of the HPS to adapt deviations between hydraulic pressure set point and actual hydraulic pressure. Normal range +/- 7 bar
EICU_0356: Hydraulic pressure adapted setpoint	bar	Set point of the hydraulic pressure according to Estimated Load
EICU_1201_102: Pressure, P2-A 277 bar	bar	Actual hydraulic pressure in the main line of HPS
EICU_030601: MOP manual pressure setpoint command on MOP	bar	Theoretical hydraulic pressure manually set by the Chief Engineer to drive the engine (i.e. exhaust valve actuation & fuel injection).
EICU_0307: MOP hydraulic oil pressure upper range	bar	Maximum. Automatic pressure relief valve set at 315 bar (hydraulic shut down).
EICU_0308: MOP hydraulic oil pressure lower range	bar	Minimum. Lower hydraulic pressure can lead to hydraulic shut down.
EICU_0310: Hydraulic power supply, decay time	s	Decay time = The time required for the hydraulic pressure to fall by 60 bar after HPS stops.
EICU_0342: Hydraulic power supply, decay time reference for MOP	s	Decay time at engine commissioning which is used as reference point.
EICU_0343: Hydraulic power supply, yellow limit for MOP	%	Decay Time Bar Graph yellow area maximum limit
EICU_0344: Hydraulic power supply, red limit for MOP	%	Decay Time Bar Graph red area maximum limit
EICU_1219_102: Pump 1 running	0=No, 1=Yes	Electrically driven pump No.1 of HPS
EICU_1219_202: Pump 2 running	0=No, 1=Yes	Electrically driven pump No.2 of HPS
EICU_0379: Slave pump run command	0=Stop, 1=Run	
EICU_038102: Master/slave pump running alarm active	0=No, 1=Yes	
EICU_037801: Slave pump start load limit	%	
EICU_037802: Slave pump hysteresis offset	%	Chief Engineer can select one pump as master and the other as slave.

Pump inlet pressure, mean	bar	Manually input value
Hydraulic oil pressure, deviation from setpoint	bar	Calculated value
ME-B FUEL		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
EICU_100615: Calorific reference value	MJ/kg	Calorific value of the fuel in use at shop trial – reference point
EICU_100612: Lower calorific value - LCV	MJ/kg	Calorific value of the fuel in use as per analysis results.
EICU_100613: Fuel Oil density @ 15 Degrees	kg/m³	Density of the fuel in use as per analysis results.
EICU_100616: Reference Fuel Oil density @ 15 Degrees	kg/m³	Density of the fuel in use at shop trial – reference point
EICU_100614: Fuel Oil Temperature	°C	
EICU_100617: Reference Fuel Oil Temperature	°C	
EICU_100620: Current_Index_Adjustment	-	Shows the adjustment of the fuel index from Chief limiters screen
ME-B LUBRICATION		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
EICU_0215: Total oil flow 6.3 l/h	ltr/hr	Ordered lubrication oil amount in liters per hour
EICU_0216: Total oil 1,588 ltr	ltr	Total ordered amount of lubrication oil used since last power up of the EICU involved. Both of the values Flow and Total are based on the actual feed rate of all the cylinders. Minor differences are to be expected between total and measured feed rate value.
EICU_0201: Sulfor % 3.00 %	%	Sulphur content of the fuel in use as per analysis results.
EICU_0203: Minimum feed rate MCR	gr/kWh	Minimum Feed rate. 0.60 as per MAN requirements.
EICU_0210: Feed rate factor	gr/kWh S%	ACC factor
EICU_02O: Basic feed rate (Feed rate factor * Sulfor %)	gr/kWh	Basic feed rate = Feed rate factor * Sulphur content in fuel %
EICU_0208: Mass/injection per cylinder	gr	
EICU_0209: Oil density	gr/cm³	Density of cylinder oil in use
EICU_02xx: Feed rate cylinder 1 cylinder 2 cylinder 3	gr/kWh	Actual Feed rate (after the influence of limiters, load control, etc) Actual Feed rate = Basic Feed rate * Feed rate adjust factor

cylinder 4 cylinder 5 cylinder 6		
EICU_0218xx: Feed rate adjust factor cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	-	It enables adjustment of the feed rate for each cylinder separately. Recommended by MAN to be 1. Higher factor increases the lubrication. For example, we can increase it in case of cold climates.
EICU_0219xx: Feed rate running in factor cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	gr/kWh	Manual input value that the system follows irrespectively of the other parameters. It is used for the first running hours of new cylinder liners.
EICU_021121: Lubricator state	1=Lubricator stopped 2=Running 3=Prelub	Pre-lubrication is recommended by MAN only after long stoppages. During pre-lubrication, oil is injected at a preset number of times at the fastest possible speed.
EICU_0214: LCD active	0=No, 1=Yes	Load Change Dependent function. When it is activated, it increases the feed rate by 25% for 20 minutes. Recommended by MAN during maneuvering.
EICU_02D: Low load active	0=No, 1=Yes	If the feed rate due to low load exceeds the maximum display capacity, a “Low Load” warning appears on the MOP.
EICU_021xx: Test activation active cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	0=No, 1=Yes	Activation of Lubricator Test Sequence which starts a continuous activation of the lubricator at fixed injection rate (different from Prelube). This feature is used after repairs, etc. on the lubricator(s), so as to manually check the lubricator for leaks and injection

ME-B ENGINE ADJUSTMENTS		
DESCRIPTION	UNITS OF MEASUREMENT	REMARKS
EICU_091001: Pmax adjustments table, max press. offset, all	bar	Pmax adjustment = adjustment of timing of fuel injection Maximum allowable deviation from mean Pmax
EICU_0910xx: Pmax adjustments table, max press. Offset cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	bar	Pmax adjustment = adjustment of timing of fuel injection Maximum ΔPmax from mean Pmax
EICU_1001: Chief index limit, all cylinders	%	Chief Fuel index limiter, ie Chief Engineer has inserted this value for the amount of fuel required for injection.
EICU_101x: Chief index limit cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	%	This feature allows the operator to cut-out fuel injection on a chosen cylinder and re-enable it. In case of 'ELFI feedback alarm' resulting in fuel injection cut-out on a cylinder, re-enabling fuel injection is done using this feature.
EICU_103x: High load offset cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	%	Index offset of Pi at High Load (ie above 60%) in %. Allowable values [-10, 10] according to MAN
EICU_105x: Low load offset cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	%	Index offset of Pi at Low Load (ie below 40%) in %. Allowable values [-5, 5] according to MAN.

ME-B SCU (Scavenge Control Unit)		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
SCU1_1536: Min Pscav Limit	bar	
SCU1_1631: Relative flow area	%	
SCU1_1138x: T/C Speed	RPM	Turbo Charger Speed
SCU1_160132: Limiters Active	0=No, 1=Yes	Scavenge air pressure limiter is not active
SCU1_1411: Torque Meas Gain	kNm/mA	sensor
SCU1_1412: Torque Meas. ZeroOffs.)	mA	sensor
SCU1_1413: SCU1-1413 Torque at MCR	kNm	Torque at engine's Maximum Continuous Rate (ie 8,130 kW at 108 rpm)
SCU1_140121: Max Positive FQA MOP Adjustment	%	Maximum FQA = Fuel Quality Adjustment. As per MAN 20%
SCU1_140122: Min Negative FQA MOP Adjustment	%	Minimum FQA = Fuel Quality Adjustment. As per MAN -20%
SCU1_140118: Max Change pr. sample (2Hz)	%	

ENGINE		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
Engine power	kW	Calculated value
Indicated engine power	kW	Calculated value
Engine load relative to MCR	%	Engine load relative to Maximum Continuous Rate. Manually input value
Engine mechanical efficiency	%	Calculated value
Engine speed	RPM	
Governor index (rel.)	%	
T/C speed	RPM	Turbo Charger Speed (Manually input value)
Scavenging air pressure	bar	
Exh. gas receiver pressure	bar	Manually input value
Engine room ambient pressure	mbar	
Scavenge air temperature	°C	
Scavenge air receiver temperature	°C	Manually input value
Cylinder exhaust gas temperature cylinder 1 cylinder 2 cylinder 3 cylinder 4	°C	Manually input value

cylinder 5 cylinder 6		
Cylinder exhaust gas temperature: mean	°C	
COMPRESSOR		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
T/C air intake temperature	°C	Turbo Charger air intake temperature (Manually input value)
TURBINE		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
Turbine back pressure	mbar	Manually input value
Turbine pressure ratio	-	
Turbine inlet temperature	°C	Manually input value
Turbine outlet temperature	°C	Manually input value
SCAVENGE AIR COOLER (or A/C)		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
A/C efficiency	%	
A/C air inlet temperature	°C	Manually input value
A/C air outlet temperature	°C	
A/C CW inlet temperature	°C	Cooling Water inlet temperature (Manually input value)
A/C CW outlet temperature	°C	Cooling Water outlet temperature (Manually input value)
A/C CW inlet to air outlet temperature difference	°C	Temperature difference between Air outlet and Water inlet. This value is an indication of the cooling ability and as such an important parameter for the thermal load on engine.
FUEL SYSTEM		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
FO lower caloric heat value	MJ/kg	Manually input value
FO density, at 15 °C	kg/m³	
FO density corrected for fuel temperature	kg/m³	
FO sulphur content	%	Manually input value
FO viscosity (50°C)	cSt	Manually input value
SFOC (indicated)	gr/kWh	Manually input value
FO filter pressure inlet	bar	Manually input value
FO pressure before engine (after filter)	bar	Manually input value

FO inlet temperature engine	°C	Manually input value
FO viscosity engine inlet	cSt	Manually input value

LUBRICATION OIL (or LO)		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
Main LO inlet pressure	bar	Manually input value
T/C LO inlet pressure	bar	Turbo Charger Lubrication Oil inlet pressure (Manually input value)
PCO inlet pressure	bar	Cylinder Oil - Manually input value
PCO outlet temperature	°C	Manually input value
cylinder 1		
cylinder 2		
cylinder 3		
cylinder 4		
cylinder 5		
cylinder 6		
PCO outlet temperature: mean	°C	
Thrust bearing pad temperature	°C	Manually input value
COOLING WATER		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
JCW inlet temperature (HT)	°C	Jacket Cooling Water Manually input value
JCW outlet temperature cylinder 1 cylinder 2 cylinder 3 cylinder 4 cylinder 5 cylinder 6	°C	Manually input value
JCW outlet temperature: mean	°C	
T/C CW outlet temperature	°C	Turbo Charger Cooling Water outlet temperature (Manually input value)
ENVIRONMENT AND AMBIENT CONDITIONS		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
Draft fore	m	(Manually input values)
Draft aft	m	
Wave height	m	
Wave direction	deg	
Ship speed	knots	

Log speed	knots	Speed log speed
Wind speed	m/s	
Wind direction	deg	
Sea water temperature	°C	
ENGINE SETUP		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
Cylinder constant	kW/(RPM x bar)	Calculated value
Engine constant	kW/(RPM x bar)	Calculated value
MEASUREMENT PERIOD		
DESCRIPTION	**UNITS OF MEASUREMENT**	**REMARKS**
Measurement start hour	-	
Measurement start minute	-	
Measurement start second	-	
Measurement start day	-	
Measurement start month	-	
Measurement start year	-	
Measurement end hour	-	
Measurement end minute	-	
Measurement end second	-	
Measurement end day	-	
Measurement end month	-	
Measurement end year	-	

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