Combustion Control and Monitoring of two-stroke engines

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Intelligent Combustion Monitoring (ICM) is an established means of measuring and evaluating cylinder pressure data. Intelligent Combustion Control (ICC) now ensures that the engine is operated as intended, and with maximum safety and efficiency.

Fig. 1 – Intelligent Combustion Monitoring and Intelligent Combustion Control are available options for two-stroke engines.

Engine control parameters, such as start of injection or exhaust valve timing, are currently optimized manually within their allowed range, depending on the measured peak firing and compression pressures.

Lately, many vessels powered by Wärtsilä main engines have been equipped with Intelligent Combustion Monitoring (ICM), which measures the real time in-cylinder pressure in all engine cylinders.

This package offers a broad range of data processing tools for evaluating performance and for helping to determine engine malfunctions (extensive blow by, exhaust valve operation, fuel injection).

The ICM system represents a significant improvement compared to having just one pressure sensor available on board a vessel. Nevertheless, the potential of this system for achieving more efficient engine operation is often not utilized. For example, in practice, the Fuel Quality Setting (FQS) is often found to be zero.

So the manual readjustment procedure is not carried out regularly, and thus there remains further optimization potential. This can be exploited by use of a permanently working "closed loop control" system – in other words, Intelligent Combustion Control (ICC).

The ICC system is optionally integrated into the latest Wärtsilä Engine Control System (WECS-9520) version for the electronically controlled RT-flex engine series. The system is also available as a retrofit for existing vessels. Adjustments to the engine firing pressure are made in reference to set-point values derived from the engine shop test, which are then site corrected taking ambient variations into account.

For such a control system it is important to have very reliable and highly accurate pressure sensors with a long lifetime, especially when using heavy fuel oil (HFO). The ICC system balances the compression and firing pressures of all cylinders. This results in an equal exploitation of each unit, and thus reduces torsional vibrations of the complete engine. Additionally, the system protects the engine against potential manual operating errors, for example by limiting the maximum cylinder pressure rise.

Due to this functionality, the engine operation is always optimized. This is of even greater significance if the fuel has to be changed when entering SO_X Emission Control Areas, or when fuels of different qualities are used.

Compared to an engine operated with a Fuel Quality Setting (FQS) of zero, activated ICC onboard a vessel achieved measured reductions in fuel oil consumption of approximately 2.5g/kWh across the entire engine load range. Consequently, overall CO_2 emissions were also notably reduced.

ICM – Introduction

Almost all two-stroke diesel engines in service are operated in an "open loop control" mode. Manual adjustments to the injection timing and exhaust valve operation, for example after engine overhaul or the use of a different fuel, are based on the actual in-cylinder pressure and engine performance data.

Often, the vessel has only a single portable cylinder pressure measurement device and simultaneous measurements of all cylinders are, therefore, not possible. It is unlikely, during a certain measurement time of multiple cylinder engines that no engine speed or torque variations will occur.

Wärtsilä Intelligent Combustion Monitoring for two-stroke diesel engines is based on the sophisticated technology of the well-known ABB Cylmate® system, and is a comprehensive method for continuous engine performance measurement and monitoring. A unique combination of cylinder pressure measurements and crankshaft position detection, together with advanced mathematical modeling of dynamic engine operation (crankshaft deflection model), provides highly accurate, real-time data for monitoring and diagnostic analysis.

The quality of the data provided ensures significant benefits for the operators. These include improved reliability, reductions in operating costs, and the minimizing of off-hire costs.

The cylinder pressure vs. crank angle is measured in each cylinder, continuously and in parallel, under all operating conditions. The risk of mechanical or thermal overload of individual cylinders, or of the engine itself, can be avoided thanks to the Cylmate analysis and monitoring functions. Furthermore, the cylinder conditions can be optimized, and the engine can easily be balanced and tuned manually by the crew in order to improve running performance.

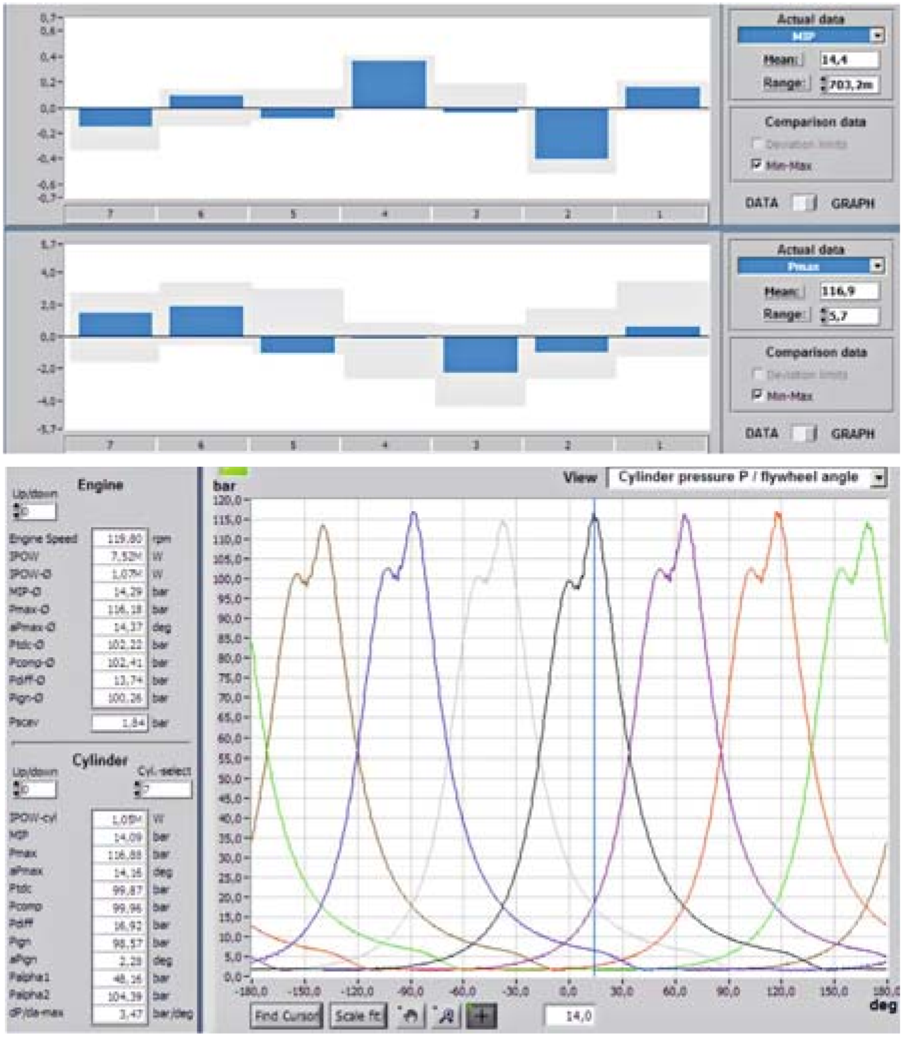
ICM – Key components

The ICM system consists of a pressure transducer on each cylinder unit and an angle transducer at the engine flywheel, which are all connected to the transducer bus. The controller collects all the measured data within each engine's working cycle. The data can be evaluated with the help of a built-in computed mathematical engine model.

The ICM system has a comprehensive on-screen presentation (Figure 2) of all the collected data, both current and historical. Alarm, event and trend pages, as well as graphic and tabular forms of the engine parameters, are available. These include, for example, Pcomp, Pmax, αPmax, MIP, Indicated Power, engine speed, SFOC, and more. →

TERMINOLOGY	
ICC	Intelligent Combustion Control
ICM	Intelligent Combustion Monitoring
HFO	Heavy Fuel Oil
FQS	Fuel Quality Setting
WECS-9520	Wärtsilä Engine Control System
T/C	Turbocharger
SSUK	Slow Steaming Upgrade Kits
SFOC	Specific Fuel Oil Consumption
°CA	Degree crank angle
TDC	Top Dead Center
BDC	Bottom Dead Center
ISO	International Organization for Standardization

Fig.2 – ICM screen examples.



■ Fig. 3 – ICM pressure transducer.

Deviations are continuously alarm monitored against performance references. The ICM Viewer is the first commercial tool on the market that provides all information regarding the combustion process, stroke-by-stroke, before the alarm, at the alarm, and after the alarm. In this way it is possible to see the development of a fault, and to understand the mechanism that led to the fault.

The ICM system is available for all two-stroke engines, both mechanical and electronically controlled.

Pressure transducers

The ICM pressure transducers (Pressductor® technology) chosen for two-stroke engine applications are based on a magneto-elastic measuring principle, and are mounted on the cylinder cover just below the indicator cocks (one on each cylinder).

The ICM transducers have a unique blow through design, as illustrated in Figure 3. Usually, before starting the main engine, the indicator cocks are opened while slowly turning the engine. During that time, all potential combustion residuals (especially from HFO usage) are blown out.

This cleaning function guarantees precise measurement data over a long operational period (mean time between failure exceeds 10 years with roughly 6500 yearly operating hours for the main engine), and reduced maintenance effort.

Another benefit of this type of transducer is the independence of temperature (heat flash). As a result, no compensation or re-calibration is required in service.

Option for ICM

ICM is one of Wärtsilä's performance and condition monitoring solutions, supporting the operators directly onboard the vessel. The ICM solution can also be integrated into a complete condition monitoring system and connected services. Use of this integrated solution enables automated data to be transferred to Wärtsilä, as periodically summarized data sets in XML format (if no broad-band internet connection is available), or on a continuous basis. The transferred data from this integrated monitoring solution are pre-processed and compared to dynamic reference performance values, which will detect deteriorating trends.

The trends are also evaluated by engine performance and component experts, who will summarize the key findings in a monthly report and highlight areas for improvements or required counter-actions.

ICC – Introduction

The main concern for today's vessel owners and operators is to find ways for reducing fuel oil consumption and maintenance costs, as well as to comply with current and pending emissions legislation.

The Wärtsilä Intelligent Combustion Control system ensures that the engine in service operates according to its original shop test performance. This is done automatically, in real time, and independent of the fuel used at any time, be it HFO or MDO. As mentioned earlier, this is of particular importance when fuel of different quality is bunkered, or when the fuel has to be changed in certain exhaust gas emissions control areas.

The system optimizes the engine's operational performance over the entire engine load range, and not only on one single operating point as is the case with manual adjustments, which are only seldom made.

ICC – Key components

The precise and continuously measured in-cylinder pressure of all units forms the basis of the ICC system.

The raw data relating to the cylinder pressure of each unit is taken as an analogue input signal from the ICM pressure transducer into Wärtsilä's Engine Control System (WECS-9520), as illustrated in Figure 4.

The engine speed signal, as well as the crank angle position with 0.1 °CA resolution, already exists in the WECS-9520.

The ICC temperature and pressure sensors are installed at the T/C compressor inlet and in the scavenge air receiver, and are directly connected to the WECS-9520.

ICC – Functionality

The ICC function is an integrated optional part of the latest version of WECS-9520, which adjusts the peak firing pressure of the engine according to the engine design criteria. Furthermore, the firing and the compression pressure of all cylinders are balanced by modifying the injection timing and exhaust valve closing timing within their allowed operation range. All modifications of the engine control parameters by an activated ICC, are compliant with the vessel's IMO certificate.

In-cylinder pressure evaluation
In order to get the cylinder pressure trace vs. crank angle, the raw signal for the in-cylinder pressure is evaluated and processed by the ICC part of the WECS-9520. From this data, the compression and firing pressures are determined with polynomical formulas in the software, as illustrated in Figure 5.

When the ICC system is switched on, it also limits the pressure rise (difference between firing pressure and compression pressure) with a built-in safety functionality. This also reduces excessive wear to the engine components, lowers the risk of overloads, and avoids potentially incorrect manual adjustments in the case of open loop control.

Pressure set-point site correction
The desired firing pressure, derived from shop tests, is converted back (by a reverse ISO correction) to site conditions at each actual operating point of the engine. This ensures that the engine's firing pressure is adjusted according to its design criteria, and that the engine is not overloaded while the full potential is exploited.

This real time continuous ambient condition adaptation takes care of the regional climate, diurnal variations, and the engine's current overall performance.

ICC - Installation and control
The analogue input signal itself is drift compensated (certain logic of the ICM transducer) and equal to the separate bus communication based signal processed in the ICM system.

The signal is initially filtered in the WECS-9520 and further routed into a controller. Adjustments of this actual measured pressure value to its corrected set-point value at a certain engine load, are made accordingly. This real time site correction and comparison, shown in Figure 6, is performed for each individual engine cycle.

The ICC system was initially installed on the 4RT-flex60C laboratory engine in Winterthur, Switzerland, where it was extensively tested. After completion of all necessary tests, the ICC system was installed on two vessels (one with a 7RT-flex96C and the other with a 12RT-flex96C →

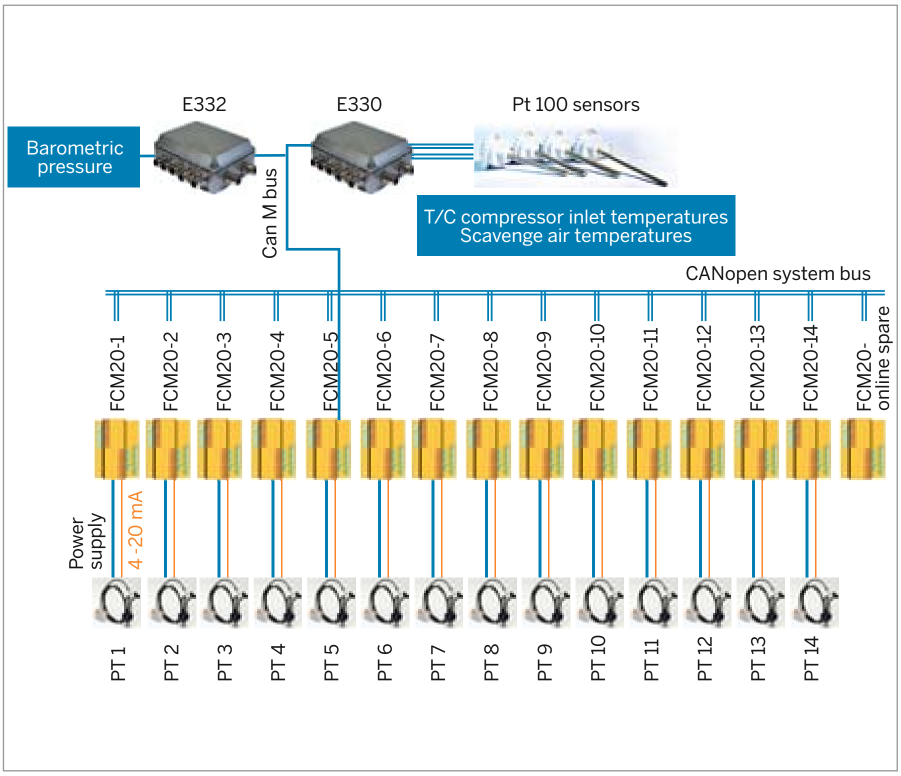


Fig. 4 – ICC installation overview (example for 14-cylinder engine).

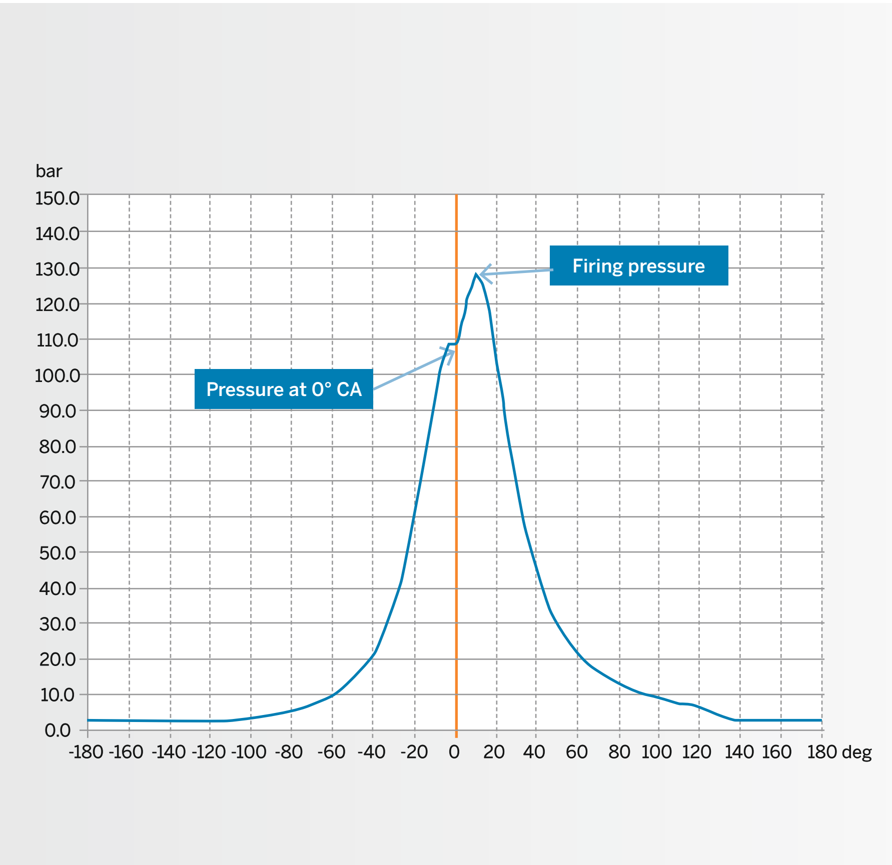


Fig. 5 – Cylinder pressure graph for a two-stroke engine.

[MARINE / IN DETAIL]

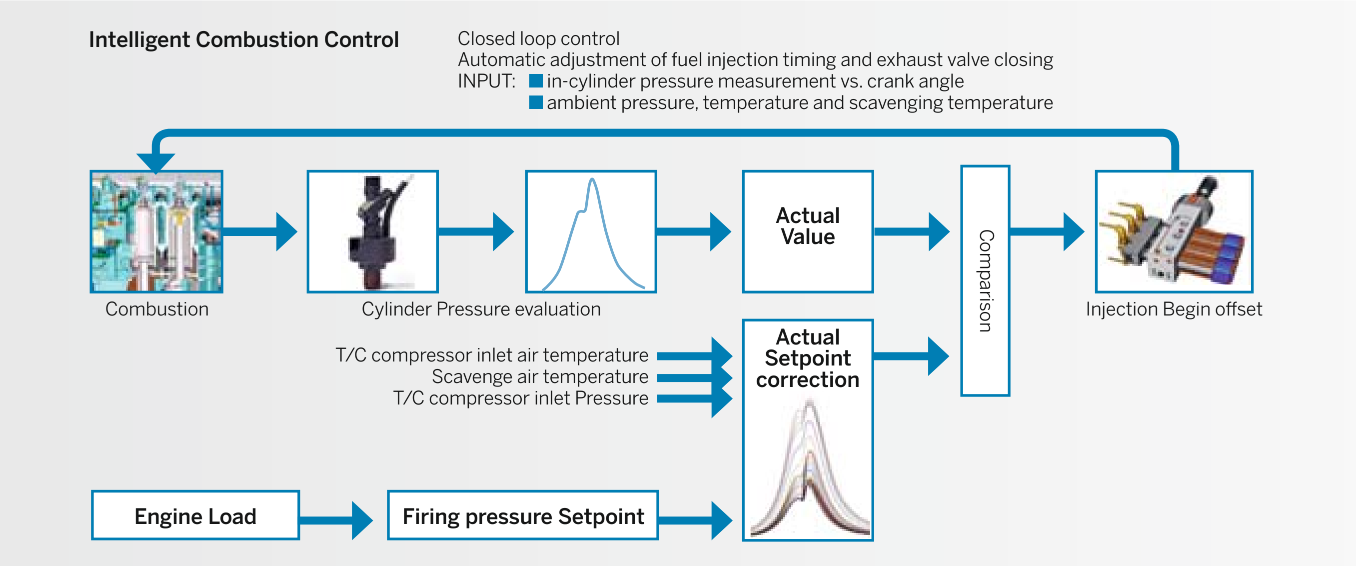


Fig. 6 – Firing pressure control strategy.

engine). The complete installation took place during the vessels' port stays, and the ICC system was commissioned during a short voyage between European ports without interfering with the sailing schedules. The commissioning included functionality checks and performance testing. The FQS was in use on just one of the vessels before the Wärtsilä engineers installed the ICC.

An increase in firing pressure, which depends heavily on the ignition delay (mainly fuel influenced), is equivalent to the Specific Fuel Oil Consumption (SFOC) reduction. Thus, it is most important that the firing pressure is correctly adjusted by means of FQS during engine operation.

WECS-9520 display

Balanced compression and firing pressures are achieved by individually adjusting the exhaust valve timing and injection timing of each unit. The resulting differences between the mean exhaust valve and the injection timings of each unit, and their respective mean values, are also shown in Figure 7.

Significant differences in the single unit values for the exhaust valve operation and injection timing, as compared to other units, are clear hints of hardware-related issues within certain cylinder units, and should be further investigated.

ICC installation options

ICC can be installed as an option on all Wärtsilä RT-flex newbuild engines, as well as a retrofit solution on RT-flex engines in service.

Some engines in service were previously installed with the ICM system (or former Cylmate® system). Such engines can continue to use the already installed pressure transducers and easily upgrade the ICM system to a combined ICC/ICM system. The combined ICC/ICM system can also be installed from the beginning. The combination of ICC with ICM provides an extended data viewing, trending and downloading functionality for more detailed condition monitoring of combustion chamber components. Furthermore, it enables the earlier mentioned integration into the Wärtsilä condition monitoring system and services.

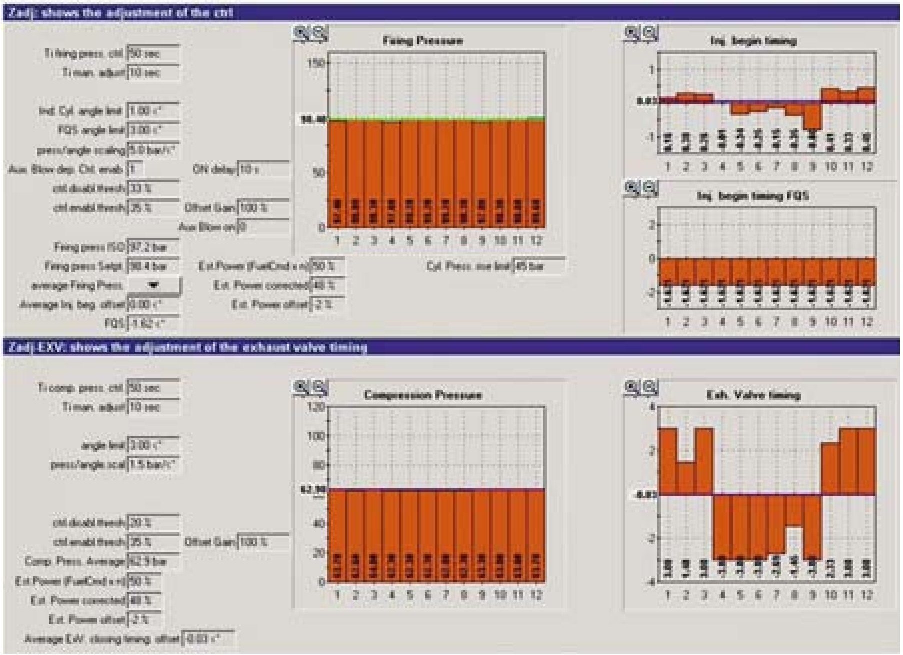


Fig. 7 – WECS-9520 ICC adjustment card.

Results

Figure 8 outlines the changes in compression and firing pressures while activating ICC at a constant engine speed / load operating point. It is evident that the deviations between cylinders are reduced. An activated ICC also raises the mean value of the firing pressure to the set-point value.

In Figure 9, the deviation trend is illustrated for the twelve cylinder engine (cylinder vs. cylinder), whereas in "open loop control" at 82% load, one cylinder is already at a pronounced high firing pressure. This balancing of the firing pressure results in an equal exploitation of each cylinder unit.

Figure 10 shows the measured fuel oil consumption with an activated ICC compared to the original setting with zero FQS of the standard "open loop control". The main reason for the reduced SFOC with activated ICC is the increased peak firing pressure (according to the set-point curve from the engine's shop test) at each speed / load point, expressed in Figure 11.

CONCLUSION

The equal exploitation of each cylinder unit of the engine by balancing the compression and firing pressures, reduces the potential overload and abnormal wear rates of the engine components. ICC ensures that the engine is always operated according to its design criteria, and as safely and efficiently as possible. The ICC system helps not only to reduce the workload of the crew on board, but also the data evaluation work in the offices of vessel owners, since all adaptations are done automatically and with all ambient corrections. The installation of ICC is not only beneficial as a retrofit on engines already installed in vessels or power plants. Already during engine commissioning before the shop test, it reduces the engine's running time (with diesel fuel) needed to balance the compression and firing pressures.

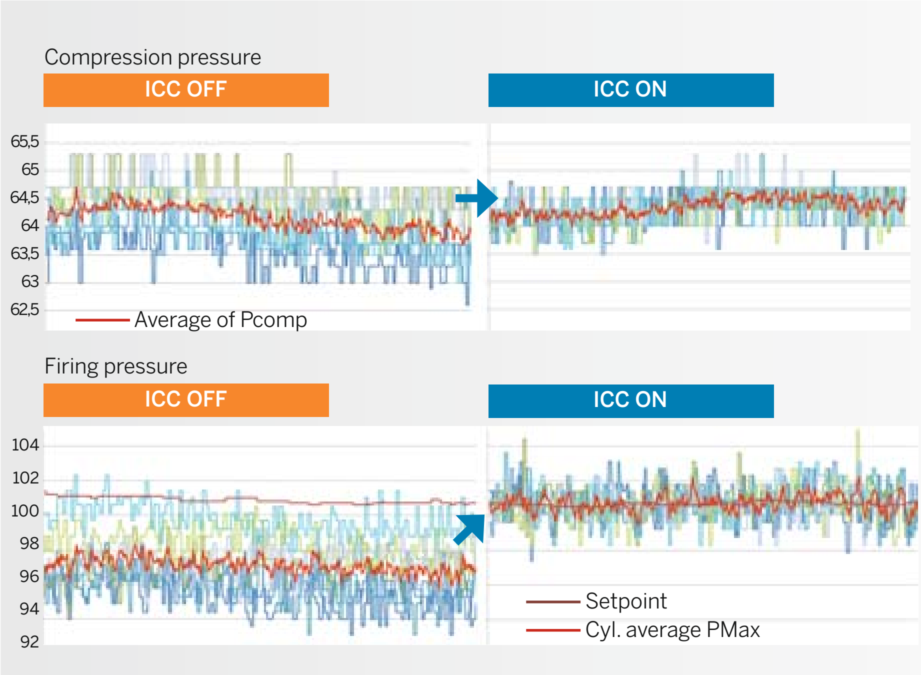


Fig. 8 – Activation of ICC (7RT-flex96C).

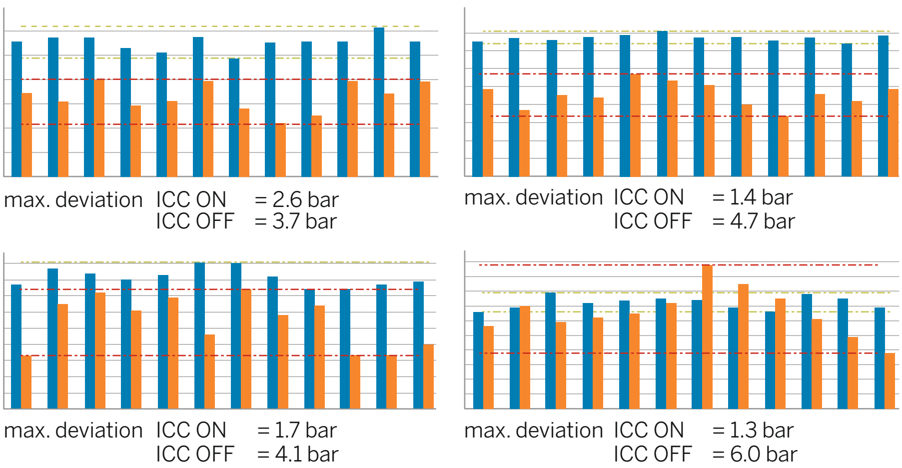


Fig. 9 – Firing pressure deviation over 25 cycles (12RT-flex96C).

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Fig. 10 – SFOC measurement on board.

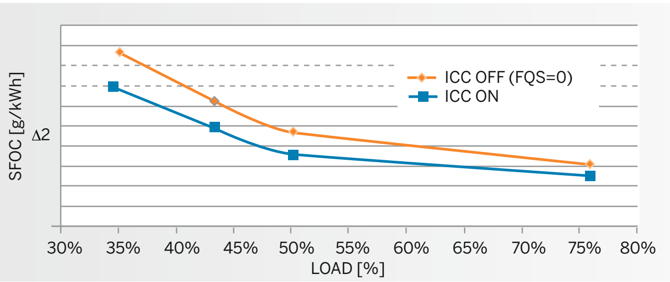

Fig. 11 – ISO corrected firing pressure.