**General document**

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# Conceptual report on distributed cycle-to-cycle control method

Engine development is constantly striving to increase engine output and efficiency. In this strive amongst others peak firing pressures have increased in from 60bar in the 1960's to over 200bar in 2010's.The trend is shown in Figure 1.

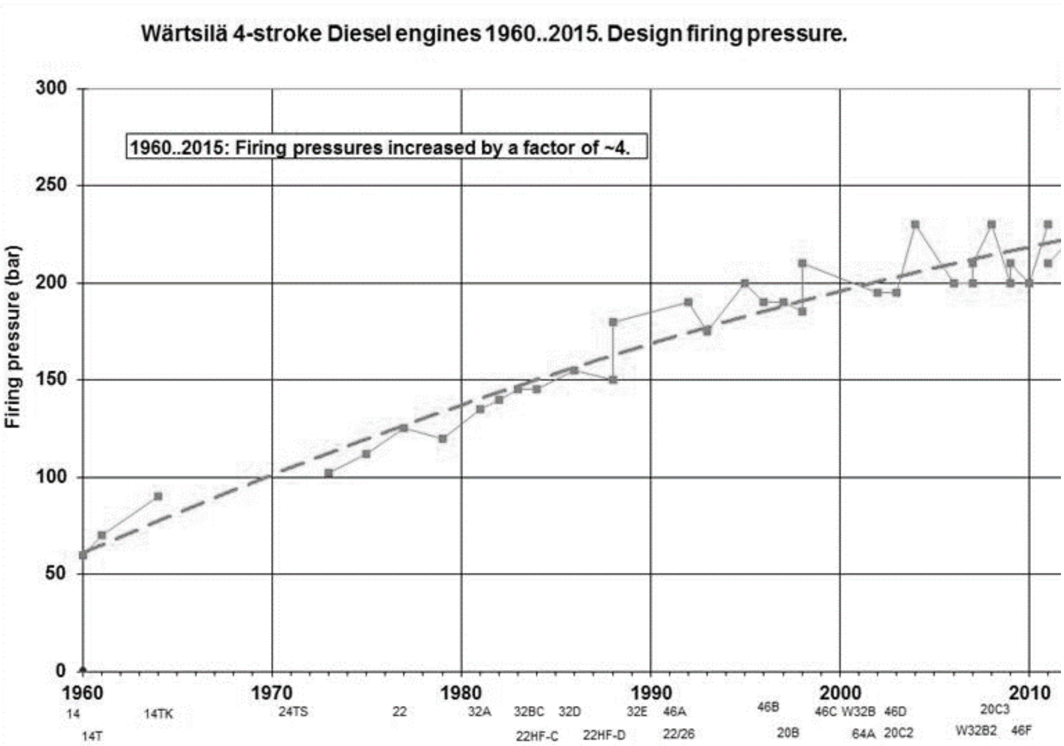


Figure 1. Peak pressure development from 1950...2010

A consequence of the increased firing pressures is that the durability of the engine components must keep phase with the increasing pressures. Typically design need to be updated and more expensive materials must be used. As product costs are important to keep up in competition engine designers are eager to decrease the safety margins for the mechanical components. Safety margins are designed based on best available knowledge of the parameters affecting the durability of an engine. Knocking cycles and high firing pressure cycles (abnormal combustion) are two examples of these parameters. By avoiding knocking cycles and removing high peak pressure cycles together with other development safety margins of engine design can be decreased.
Field experience have shown that in fault situation when ex. air fuel ratio of a gas engine is not controlled correctly may rapidly result in a situation where components are damaged. It is generally

believed that precise execution of relevant control algorithms will prevent consequential damage in these situations.

With these boundaries set the task for the engine control team was to develop new engine control algorithms to control away knock as soon as first signs are seen and to avoid high firing pressures. This development work was facilitated by *Flexible energy systems* (FLEX-E) -project.

## Initial analysis and solution development

The development work started by analyzing which control parameters need to be adjusted in situations of abnormal firing. Analysis showed that there are parameters which immediately need to be controlled in a situation of abnormal combustion. These parameters are however also dependent on less critical computations designed to stabilize engine operation. For optimal engine control in situations of abnormal combustion all control functions affecting the critical parameters were prioritized and based on this priory control functions were grouped to critical and less critical groups. Further analysis showed that an essential parameter affecting how efficiently the critical controls succeed are the communication delays. Engine control systems typically consist of several modules, all with their own purposes.

A completely new software layout of the control algorithms were developed based on previously done analysis. An essential new feature was the distribution of control algorithms to all cylinder control modules. In this new approach communication delays for time critical controls are completely omitted by execution of critical functions in same module. In the new approach combustion parameters measurement, control outputs calculation and actuator control is executed in same physical model. This critical control loop include only the algorithms needed for further prevention of abnormal combustions. Other less critical algorithms may be run in same module or centralized based on what is feasible to avoid communication delays and system complexity. Introduction of the new design have made it possible to control critical parameters to the next cycle after an abnormal combustion is detected. An overview of the new and old design is shown in Figure 2 and Figure 3.

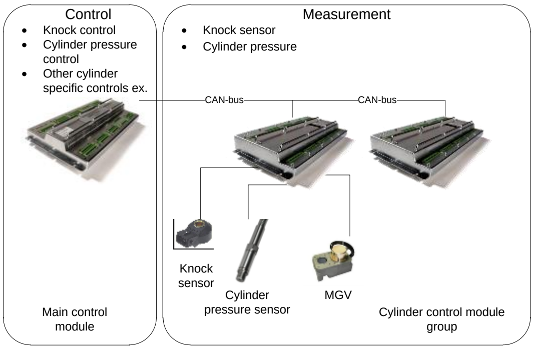


Figure 2 Layout of current state of the art combustion control system

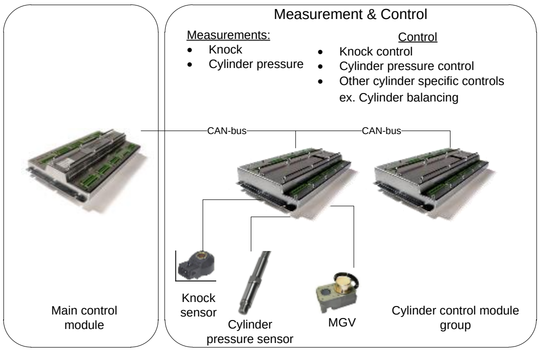


Figure 3. Layout of new concept for combustion control

## Prototype development and results

Proving the superiority of this new control require long term engine testing of the old and new concepts. Due to time constraints put to the project long term testing was not feasible within the project. Instead it was decided to create a prototype controller and prove that a distributed control functionality –wise is feasible and performs reliably on an engine. The potential of the control algorithm was analyzed by evaluating the success-rate in rapid actuation of the control output based on measured abnormal combustion.

First engine to see these new controls was a 6 cylinder spark ignited gas engine. Engine test showed that all essential functions from the previous state of the art control system were executed in a reliably matter. Engine operation was not harmed by the new controls. Control of critical parameters in case of abnormal combustion was on an improved level. Testing showed an increase in cycle to cycle control accuracy by 24…55%. The prototype controllers have later on also been validated on a larger 10 cylinder engine. Also on these engine the new distributed layout of the cylinder controls have shown reliable performance.

This new control concept also had a positive side effect on the distribution of computation capacity and memory utilization in the control system. In the previous design most parameters and the related controls were stored and executed in the main control module. In the new approach most of the parameters and controls are distributed to several modules which significantly reduces the payload of each module. Decreased memory and CPU-utilization is significantly increasing the reliability of the control system.

With the results in hand it has been proposed that these new controls will be implemented to Wärtsilä’s standard engine control system. Development of a control design that enables cycle to cycle control opens the door for investigation of new parameters to control. Future research is needed to identify possible new measurements and control parameters that could be controlled based on the new concept developed in this project. This new concept is seen as an essential development in reduction of cycle to cycle variations in a gas fired engine.