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HERCULES-2 Project

Fuel Flexible, Near Zero Emissions, Adaptive Performance Marine Engine

Deliverable: **D11.2**

Report on Dissemination Activities at Mid-Term

Revision Final

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Work Package Leader Responsible:	Nikolaos Kyrtatos (National Technical University of Athens)

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Grant Agreement No: **634135-HERCULES-2**

HORIZON 2020

The EU Framework Programme for Research and Innovation

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1 Summary

Work Package 11 of the HERCULES-2 Project covers the Dissemination Activities of the Project. The objectives are the communication of the results to the scientific community and the general public. The contents of Deliverable 11.2 focus on the Dissemination Activities of the HERCULES-2 Project from the beginning to the Mid-Term of the Project (Month 1-18).

2 Introduction

The European Commission places a lot of emphasis on the Dissemination Activities of the Projects that receive funding from the European Union Horizon H2020 Programme. The communication of the results of the Projects to public is of great importance, because:

- it proves what European collaboration can achieve
- it contributes to competitiveness and solving of societal challenges
- it shows how the outcomes are relevant to everyday life
- it is helpful for better exploitation of the foreground.

According to the communication policy of European Commission, the Dissemination Activities can take various forms, such as news updates transmitted through the official website of the programme, publications and press releases, interface with EC publicity services and presentations.

The aim of this report is to illustrate the ways, with which the progress and results of the HERCULES-2 Project are disseminated to the public.

3 HERCULES-2 Website

The HERCULES-2 official website (http://www.hercules-2.com/) has been the main gateway for publication and dissemination of the results and progress of the Project.

General information about the programme can be gained through the Public Area of the website, which consists of the following categories: Structure, Partners, Details, News, Progress updates and Publicity information, such as articles, presentations, publications etc. The Progress updates section is refreshed every 6 months with summaries of developments in every Work Package of the Project.

In addition, access to Public Deliverables is open to the public through the HERCULES-2 website. A table with the public Deliverables (M1-M18) can be found below.

Del. #	Deliverable Title	WP #	Delivery Date (Month)	Status
D2.1	A method for measuring in-cylinder λ-distribution in medium- speed DF engines	2	8	Uploaded
D6.1	Study the result quality of existing subspace-search methods on uncertain data	6	12	Uploaded
D7.1	Literature review regarding SCR engine integration and particulate abatement	7	13	Uploaded
D10.1	Progress review of all Work Packages	10	12	Uploaded
D11.1	Public section of Project Website complete and operational	11	6	Uploaded

The public Deliverable D11.1, titled "Public section of Project Website complete and operational", which is already completed and uploaded, offers a detailed description of the HERCULES-2 website.

4 Publications

As depicted in the table below, 8 scientific publications have been already produced from the work of HERCULES-2 in period Month 1 to Month 18. These papers refer to important achievements of the Project and have been presented in Congresses, Conferences and Meetings worldwide.

No.	Title	WP	Authors	Date Approved	Conference / Journal
1	Adaptive power-split control design for marine hybrid diesel powertrain	5	ASME Journal of Dynamic Systems, Measurement and Control	11/5/2016	Samokhin S., Topaloglou S., Papalambrou G., Zenger K., Kyrtatos N.P.
2	A Model of a Marine Two-Stroke Diesel Engine with EGR for Low Load Simulation	6	EUROSIM 2016, Oulu, Finland, September 2016	11/5/2016	Llamas X., Eriksson L.
3	SCR under pressure - pre-turbocharger NOx abatement for marine 2-stroke diesel engines	7	28th CIMAC, Helsinki, Finland, June 2016	19/5/2016	Sandelin K., Peitz D.
4	From HERCULES A-B-C to HERCULES-2 : A classic cooperative programme in large engine R&D	10	28th CIMAC, Helsinki, Finland, June 2016	19/5/2016	Kyrtatos N.P., Stiesch G., Kallio I.
5	Investigation of Different Piston Ring Curvatures on Lubricant Transport along Cylinder Liner in Large Two-Stroke Marine Diesel Engines	6	17th Nordic Symposium on Tribology, June 2016	19/5/2016	Overgaard H.C., Klit P., Voelund A.
6	Engine Knock Margin Estimation Using In-Cylinder Pressure Measurements	5	IEEE-ASME Transactions on Mechatronics	14/6/2016	Panzani G., Ostman F., Onder C..
7	Iterative Learning Control for Engine Control of Ships in Heavy Seas	5	FISITA 2016 Congress Korea, September 2016	14/6/2016	Zsiga N., Onder C.
8	Parameterizing compact and extensible compressor models using orthogonal distance minimization	6	ASME Journal of Engineering for Gas Turbines and Power	27/6/2016	Llamas X., Eriksson L.

The first page of each publication is presented below.

Adaptive power-split control design for marine hybrid diesel powertrain

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It is known that mechanical wear and tear of components of large marine engines throughout their lifetime can cause the engine dynamics to alter. Since traditional control systems with fixed parameters cannot deal with this issue, the engine performance may degrade. In this work, we introduce adaptive control algorithms capable of adapting the control system in order to preserve the engine performance once its dynamics deviate from the nominal ones. Particularly, direct and indirect model reference adaptation mechanisms are studied. In this work, the case of degraded oxygen sensor is investigated as an example of engine components deterioration throughout its lifetime. The controllers are implemented in Simulink and their performance is evaluated under both nominal and degraded sensor conditions. Specifically, the sensor degradation is imitated by altering its time-delay. In such conditions, adaptive controllers demonstrate a notable improvement in tracking performance compared to the fixed parameters PI controller. Finally, the designed controllers are validated on the hybrid marine engine testbed using dSpace rapid prototyping system.

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1 Introduction

During the last decades, marine diesel engine emission regulations have become increasingly stringent due to stricter environmental requirements imposed by the International Maritime Organization (IMO) [1]. As a result, achievement of near-zero emissions has recently become one of the key targets for marine engine manufacturers [2, 3].

Recently, the combination of an internal combustion engine with an electric motor has emerged as a powerful approach for reducing emissions within the automotive industry [4]. A large number of research papers has been devoted to evaluating various aspects of hybrid electric vehicles (HEVs), including components sizing, control systems design and topologies investigations. The control of HEVs is usually categorized into rule- and optimization-based algorithms [5]. Various optimization-based algorithms have been proposed for HEVs control, including model-predictive control [6], optimal control based on Pontryagin's minimum principle [7, 8], and genetic algorithms [9]. Typ-

A Model of a Marine Two-Stroke Diesel Engine with EGR for Low Load Simulation

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***Abstract*—A mean value engine model of a two-stroke marine diesel engine with EGR that is capable of simulating during low load operation is developed. In order to be able to perform low load simulations, a compressor model capable of low speed extrapolation is also investigated and parameterized for two different compressors. Moreover, a parameterization procedure to get good parameters for both stationary and dynamic simulations is described and applied. The model is validated for two engine layouts of the same test engine but with different turbocharger units. The simulation results show a good agreement with the different measured signals, including the oxygen content in the scavenging manifold.**

I. Introduction

The marine shipping industry is facing increased demands in the reduction of harmful exhaust gas emissions. Stricter emission limits of Sulphur Oxides (SOx) and Nitrogen Oxides (NOx) are imposed in certain Emission Control Areas (ECAs). The emission values to fulfill in these ECAs are set by the IMO Tier III limits [1] that came into play in January 2016. One of the available technical solutions to achieve the targeted reduction in NOx emissions is Exhaust Gas Recirculation (EGR). An EGR system recirculates a fraction of the exhaust gas into the scavenging manifold, providing burned gases in the combustion chamber that directly decreases the production of NOx during the combustion.

EGR technologies for two-stroke engines are still at the initial phases of its development. In addition, there are not many available vessels with an EGR system installed and thus performing tests is often difficult. Furthermore, testing any new system in marine two-stroke engines is also very costly mainly due to the fuel cost associated with the sizes of such engines. Hence, in order to improve the performance of the EGR control systems, a fast and accurate simulation model is a very valuable tool.

Mean Value Engine Models (MVEMs), are a very common approach for control oriented modeling of internal combustion engines. In particular, EGR systems have been also modeled using this approach. Many interesting research articles about EGR modeling in automotive applications can be found in the literature, some examples are, [2] and [3]. On the other hand, marine two-stroke engines have not been widely studied. Nevertheless, some research papers focused on MVEMs for two-stroke engines are [4], [5] and [6]. In addition, in [7] the modeling of the low load operation of a two-stroke engine without EGR is studied.

The work presented here is an extension of the model proposed in [8], which enables the model to simulate low engine loads. The low load operation is very relevant for the EGR control since the Tier III emission limits have to be fulfilled near certain coasts, e.g. harbors, where the vessel is normally operating at low loads. The main new component that needs to be introduced for this low load simulation is the auxiliary electrical blower. Its mission is to ensure that there is enough scavenging pressure at low loads when the turbocharger is not capable to provide it. Moreover, the turbocharger model will be required to simulate at low speeds and pressure ratios. This area is normally not measured in the provided performance maps, so a model that can extrapolate to this area is also required.

The developed model is, as in [8], based on the 4T50ME-X test engine from MAN Diesel & Turbo. The 4T50ME-X is a two-stroke uniflow diesel engine, turbocharged, with variable valve timing and direct injection. Its maximum rated power is 7080 kW at 123 rpm. Also, it is equipped with an EGR system and a Cylinder Bypass Valve (CBV).

II. Experimental data

The targeted test engine is constantly being rebuilt to test new components and new control strategies. This implies that it is difficult to find measurement data from the same engine configuration. Most of the measurement data available is from the same layout as the data used in [8]. For layout number 1 the oxygen sensors were not properly calibrated and thus cannot be used for validating the oxygen levels at the manifolds. For the model parameterization 30 different stationary points are extracted from the measurement data. another 24 stationary points are saved for the validation.

Some more data is available from another layout of the engine and will be used for validation of the oxygen level in the scavenging manifold. However, in this layout, number 2, the turbocharger was changed and some sensors where removed. Moreover, there is much less data available, and only 18 stationary points could be extracted for the parameterization and the validation of the model.

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SCR under pressure - pre-turbocharger NOx abatement for marine 2-stroke diesel engines

Topic 07 Exhaust Gas Aftertreatment

Kristoffer Sandelin, Winterthur Gas & Diesel

Daniel Peitz, Winterthur Gas & Diesel

This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country.
The Congress programme centres around the presentation of Technical papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The topics of the 2016 event covered Product Development of gas and diesel engines, Fuel Injection, Turbochargers, Components & Tribology, Controls & Automation, Exhaust Gas Aftertreatment, Basic Research & Advanced Engineering, System Integration & Optimization, Fuels & Lubricants, as well as Users' Aspects for marine and land-based applications.

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From HERCULES A-B-C to HERCULES-2 : A classic cooperative programme in large engine R&D

Topic 08 Basic Research & Advanced Engineering

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GUNNAR STIESCH, MAN DIESEL & TURBO,
ILARI KALLIO, Wärtsilä

This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country.
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Investigation of Different Piston Ring Curvatures on Lubricant Transport along Cylinder Liner in Large Two-Stroke Marine Diesel Engines.

Hannibal Christian Overgaard*, Peder Klit*
and Anders Vølund†

April 25, 2016

Abstract

A theoretical investigation of the hydrodynamic lubrication of the top compression piston ring in a large two-stroke marine diesel engine is presented. The groove mounted piston ring is driven by the reciprocal motion of the piston. The ring shape follows a circular geometry and the effect of changes in radii is analysed.

A numerical model based on the finite difference method in 1D has been developed for solving Reynold's equation in combination with the load equilibrium equation together with flow continuity between the piston ring surface and liner for analysis of the lubricant transport.

The cyclic variation throughout one stroke is presented for the minimum film thicknesses at different interesting locations of the piston ring surface together with the friction and the pressure distribution history. The before mentioned parameters have been investigated numerically. The numerical results are presented and discussed.

Keywords: lubricant transport, Reynold's equation, piston ring lubrication, finite difference method, perturbation of Reynold's equation, hydrodynamic lubrication, flow continuity, lubricant starvation.

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Engine knock margin estimation using in-cylinder pressure measurements

Giulio Panzani, Fredrik Östman and Christopher Onder

***Abstract*—Engine knock is among the most relevant limiting factors in the improvement of the operation of spark ignited engines. Due to an abnormal combustion inside the cylinder chamber, it can cause performance worsening or even serious mechanical damage. Being the result of complex local chemical phenomena, knock turns out to have a significant random behaviour but the increasing availability of new on-board sensors permits a deeper understanding of its mechanism. The aim of this paper is to exploit in-cylinder pressure sensors to derive a knock estimator, based on the logistic regression technique. Thanks to the proposed approach it is possible to explicitly deal with knock random variability and to define the so-called *margin* (or *distance*) from the knocking condition, which has been recently proven to be an effective concept for innovative knock control strategies. In a model-based estimation fashion, two modelling approaches are compared: one relies on well-known physical mechanisms while the second exploits a principal component analysis to extract relevant pressure information, thus reducing the identification effort and improving the estimation performance.**

***Index Terms*—Engine knock estimation, knock control, in-cylinder pressure sensors, logistic regression, principal component analysis**

I. Introduction and Motivation

THE combustion process in SI engines is normally triggered by the spark, whose timing is accurately defined in order to achieve the desired engine performance. In particular engine operating conditions, a too early spark timing may cause an abrupt unburned mixture (end-gas) self-ignition, due to the high temperature and pressure conditions reached inside the cylinder chamber. This event is usually termed *knock*, recalling the typical metallic sound caused by the shock waves generated by the spontaneous detonation of the air/fuel mixture. Such event limits the improvement of engine performance, being responsible for some undesirable effects: while it can cause serious cylinder damages, less dramatic consequences are powertrain oscillations, a general decrease of engine efficiency and an increase of pollutant emissions [1]. An accurate control of SI timing has thus lately become a crucial issue in the development of advanced combustion control systems.

In the scientific literature specific attention has been paid to the knock event due to its applicative relevance. The air/fuel self ignition is the result of complex local phenomena in the cylinder chamber and as such shows significant experimental random nature. For this reason, the first research efforts have been devoted mainly to knock sensing and detection [2], [3], with the development of techniques and technologies that, flanked with efficient signal processing algorithms, could be able to reliably discriminate knocking from not knocking cycles (and, if possible, to quantify the detonation severity).

Knock control strategies developed consequently: the standard approach, which has been widely adopted in series production, can be classified as event-based where, based on simple [4] or more complex [5] rules, a single measured knock occurrence causes a controller intervention. In order to cope with knock random nature, stochastic knock control strategies have been recently proposed. Their main idea is to compare the statistic knock properties of the current engine operating point (rather than considering each event individually) with a target value and to adapt the control action accordingly. In [6] the feedback statistic is established as a cumulative sum of knocking events over a certain number of cycles, whereas in [7] a likelihood ratio approach is employed. In [8] a nonlinear transformation is used to shape the random distribution of the knock events as a Gaussian variable whose mean and variance are recursively estimated and used as feedback signals for the knock control strategy. The advantage of stochastic approaches is the fact that reckoning with the stochastic knock behaviour leads to better mean engine running conditions and to less cyclic variability. The drawback of the mentioned strategies lays in the fact that the feedback statistic signal is built in real-time, which requires several cycles. Given a single engine cycle, out of the current operating point history, no statement about the expected knock rate is possible.

The control strategy proposed by Lezius et al. in [9] approaches the problem differently. It is based on the evidence that cycles with a higher peak pressure are more likely to knock. Engine knock is thus closed-loop regulated tracking a peak pressure reference that is a compromise between engine output torque and engine knock tendency. The distinguishing feature of this approach is the fact that a *margin* (or *distance*) from the knocking condition is defined for any single cycle. In this specific case the cycle peak pressure is used to estimate engine knock and its distance, computed as the error between the measured and the target peak pressure value.

Proper models are required to design such a knock margin estimator. In Lezius' work, the model is implicitly enclosed in the experimental evidence of a more frequent knock occurrence for higher peak pressure cycles. With respect to the real-time stochastic approaches described previously, the additional modelling effort compensates for the advantage of a cycle-to-

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Iterative Learning Control for Engine Control of Ships in Heavy Seas

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Abstract

The control of the engine speed is an important control task for ship engines. This can be a difficult task when the ship is sailing in heavy seas. Especially for large vessels, the propeller can even move out of the water when the ship is on the crest of a wave which can lead to overspeeding of the engine. Due to the repetitive nature of waves, iterative learning control (ILC) can be used to stabilize the engine speed. In this problem the engine is never in steady state and there is no break between the iterations. This study shows that in a general case, the F-ILC algorithm must be modified to deal with varying initial conditions as well as nonzero initial or final errors. A simulation study shows the benefits of these modifications. The implementation of the algorithm is discussed and measurements are carried out on an internal combustion engine test bench, which allows the emulation of a ship in heavy seas.

Keywords: Iterative Learning Control, Initial Conditions, Engine Control

1. Introduction

Learning from experience is important for humans to improve skills and abilities for a variety of tasks in everyday life. For repetitive tasks, iterative learning control (ILC) algorithms cause a learning process for technical systems. The deviation of the system output from a specified reference trajectory is calculated after an iteration (trial). The error is used to calculate a modified input signal for the next iteration to improve the system performance.

ILC is used for a variety of control processes in research and industry such as chemical batch reactors [1], [2], high-performance maneuvers of quadrocopters [3], [4], 3D printing [5], suppression of residual vibrations [6], and industrial robots [7], [8]. For further areas of application, the reader is referred to the recent survey papers [9], [10], [11] and [12].

As mentioned in [9], ILC is typically used in batch processes, i.e. a process is repetitively performed over a period of time. Also in [9], it is mentioned that

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Parameterizing compact and extensible compressor models using orthogonal distance minimization

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A complete and compact control oriented compressor model consisting of a mass flow submodel and an efficiency submodel is described. The final application of the model is a complete two-stroke mean value engine model which requires to simulate the compressor operating at the low flow and low pressure ratio area. The model is based on previous research done for automotive-size compressors and it is shown to be general enough to adapt well to the characteristics of the marine-size compressors. A physics based efficiency model allows, together with the mass flow model, to extrapolate to low pressure ratios. The complexity of the model makes its parameterization a difficult task, hence a method to efficiently estimate the nineteen model parameters is proposed. The method computes analytic model gradients and uses them to minimize the orthogonal distances between the modeled speed lines and the measured points. The results of the parameter estimation are tested against nine different standard marine-size maps showing good agreement with the measured data. Furthermore, the results also show the importance of estimating the parameters of the mass flow and efficiency submodels at the same time to obtain an accurate model. The extrapolation capabilities to low load regions are also tested using low load measurements from an automotive-size compressor. It is shown that the model follows the measured efficiency trend down to low loads.

1 Introduction

The marine propulsion industry is facing new and more strict regulations on the engine exhaust emissions. For example, the Tier III regulations [1] have to be fulfilled for new vessels built from January 2016 on certain emission control areas. For the case of the low speed two-stroke marine engines, industry is developing and testing technologies that have potential in achieving such emission limits. One of these technologies is the Exhaust Gas Recirculation (EGR) that has been widely used in the automotive industry to reduce NO_x formation during combustion and thus exhaust emissions.

Testing is required for the development of the EGR technology. However, performing tests on such big engines is limited mainly due to two reasons. First, there is a lack of available engines to perform such tests, the production numbers are much lower than the automotive case. The second issue is the very high economic cost required to perform tests in those large engines, mainly associated to fuel consumption. Due to these limitations, a reliable and fast dynamic engine model would be a valuable tool for the development of EGR systems and control strategies. A common approach for control oriented engine models is the Mean Value Engine Model (MVEM), which has the particularity that the model is based on average values of the engine cycle. For more information see e.g. [2–4]. Furthermore, [5] contains an overview of the targeted type of two-stroke engine as well as the current modeling status. Such engines contain several components that need to be modeled, and obtaining a reliable control oriented compressor model is one of the first challenges.

A compressor model consists of a mass flow model and an efficiency model, normally more emphasis is found for the mass flow-pressure ratio model in literature. Many different compressor models can be found in literature, in particular many different modeling approaches are investigated for automotive compressors, see e.g. [6,7]. For the much bigger compressors used for turbocharging the low speed two-stroke engines there is less research done. Nevertheless some different models can be found in the literature. In [8] the compressor model is based on the fact that marine engines are loaded following the propeller law, and thus the compressor model has to be accurate only on the projected propeller

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5 Press Releases

At the beginning of the Project, in July 2015, the 3 principal partners of the Project, MAN Diesel & Turbo SE, Wärtsilä and Winterthur Gas and Diesel Ltd., issued a common press release. The topics, which were addressed in it, referred to the continuation of cooperation between the three companies in the fourth Phase of the HERCULES Project and the objectives of it. The Press Release was widely reported in the international Media. The Press Release text is quoted next:

QUOTE

A major cross-industry initiative led by Winterthur Gas & Diesel, Wärtsilä and MAN Diesel & Turbo to develop basic technologies for use in 2- and 4-stroke marine engines has been officially launched. The Hercules-2 project is aimed at fostering environmentally sustainable and more efficient shipping. It is in line with general European Union policy and is partly funded by the EU. Altogether, 32 marine industry partners from 11 different companies, 16 universities, and five research organisations are cooperating in this project, with NTU Athens as coordinator. The R&D efforts focus on four main areas. These are; the application of alternative fuels and the optimisation of fuel flexibility to facilitate seamless switching between different fuels; the development of new materials to support hightemperature component applications; the development of adaptive control methodologies to significantly improve an engine's performance throughout its life span; and to achieve near-zero emissions via combined, integrated, after-treatment of exhaust gases. Winterthur Gas & Diesel's Vice President R&D, Rien Hoogerbrugge, sees Hercules-2 as an important opportunity: "This project enables the partners to combine know-how by bringing together scientists from various fields and institutions to investigate concepts, and to develop robust technologies for application on different types of engines. We are pleased to be part of the Hercules consortium and we are looking forward to jointly developing environmentally friendly products for a sustainable future of merchant shipping." "The greatest of the many benefits stemming from Hercules-2 will be the development of new technologies that have a positive impact on our customers' profitability. Another is the significant contribution this project will make to more environmentally sustainable shipping," says Ilari Kallio, Vice President, R&D, Engines, speaking on behalf of Wärtsilä. "Hercules-2 is a strong platform that will create a basis for the development of technologies applicable to ship engines in four to five years time. We have, therefore, positive expectations and look forward to collaborating with so many cross-industry partners," says Søren H. Jensen, Vice President and Head of R&D at MAN Diesel & Turbo. Winterthur Gas & Diesel's Vice President R&D, Rien Hoogerbrugge, sees Hercules-2 as an important opportunity: "This project enables the partners to combine know-how by bringing together scientists from various fields and institutions to investigate concepts, and to develop robust technologies for application on different types of engines. We are pleased to be part of the Hercules consortium and we are looking forward to jointly developing environmentally friendly products for a sustainable future of merchant shipping." The Hercules-2 project is scheduled to run for three years. It represents the follow-up phase of the Hercules R&D programme for large engine technologies, which was originally conceived in 2004 by Wärtsilä and MAN Diesel & Turbo. The Hercules-2 technologies will eventually be employed aboard large ships.

UNQUOTE

6 HERCULES-2 in Press and Media

Before the official start of the HERCULES-2 Project and throughout the Period 1 (M1 to M18), several articles have been published in the in the international press about the Project, its partners and its aims. A list of these articles is found overleaf.

Source	Title	Date
Marine Power& Propulsion supplement to The Naval Architect-RINA	Hercules alliance set to break new ground	October 2016
MTZ Industrial	Editorial: The end of Two Eras	September 2015
MTZ Industrial	Hercules-2. Engine R&D Programme	September 2015
Diesel & Gas Turbine Worldwide	EU-Funded Project Hercules-2 Launched	August 2015
Wärtsilä Corporation, Trade Press Release	Wärtsilä, MAN Diesel & Turbo and Winterthur Gas & Diesel to collaborate on major, EU-funded project	July 2015
MAN Diesel & Turbo, Press Release	Wärtsilä, MAN Diesel & Turbo and Winterthur Gas & Diesel to collaborate on major, EU-funded project	July 2015
Winterthur Gas & Diesel , Press Release	Winterthur Gas & Diesel, Wärtsilä and MAN Diesel & Turbo to collaborate on major, EU-funded project	July 2015
NafsGreen Word Shipping News	Wärtsilä, MAN Diesel & Turbo and Winterthur Gas & Diesel to collaborate on major, EU-funded project	July 2015
The motorship	Engine makers collaborate in milestone project	July 2015
Ship & Bunker	Wärtsilä, MAN Diesel & Turbo and Winterthur Gas & Diesel to Lead Project for Ship Engine Efficiency	July 2015
Ship & Bunker	Wärtsilä, MAN Diesel & Turbo and Winterthur Gas & Diesel to Lead Project for Ship Engine Efficiency	July 2015
Ship Efficiency	All hail HERCULES	July 2015
Ship Technology	Wärtsilä, MAN, and Winterthur to jointly develop marine engine technologies	July 2015
Marine Log	European diesel leaders launch Hercules2 initiative	July 2015
The Marine Professional	Engine builders prepare for Hercules sequel	July 2015
Reuters	Wärtsilä, MAN Diesel & Turbo and Winterthur Gas & Diesel to collaborate on major, EU-funded project	July 2015
Wärtsilä Corporation, Trade Press Release	Wärtsilä and MAN Diesel & Turbo initiate HERCULES-2 research project aimed at minimizing emissions	September 2014
MAN Diesel & Turbo, Press Release	Wärtsilä and MAN Diesel & Turbo initiate HERCULES-2 research project aimed at minimizing emissions	September 2014
Maritime Propulsion	Wärtsilä, MAN Diesel & Turbo Renew Emissions Reduction Research	September 2014
Marine Engines and Fuels	Wartsila and MAN Launches Hercules-2 Research Project	September 2014
Seatrade Maritime News	MAN D&T and Wärtsilä team up to reduce fuel use, emissions for large engines	September 2014

7 Interface with EC publicity services

Upon request from the EC Officer, slides with the general description of the Project and photos that illustrate parts of the progress made, were prepared and sent on July 2015 for publicity and communication reasons.They focused mainly on the objectives, partners, WorkPackage Areas and Project Structure without reference on specific technical details for a more general public with some knowledge on the topic.

Moreover, a Project Fiche of HERCULES-2 was prepared to be included in the Project Fiches for the Horizon 2020 Transport Projects which INEA is managing, providing details for the Project description and the website.

Project Number 634135

HERCULES –2

Project description

Top sentence:

The HERCULES-2 is targeting at a fuel-flexible large marine engine, optimally adaptive to its operating environment.

First paragraph:

The project HERCULES-2 is the next phase of the R&D programme HERCULES on large engi technologies. HERCULES was conceived in 2002 to develop new technologies for mari engines:

- To increase engine efficiency, thus reduce fuel consumption and CO2 emissions.
- To reduce gaseous & particulate emissions.
- To increase engine reliability.

The targets of HERCULES-2 build upon and surpass the targets of the previous HERCULES projects, going beyond the limits set by the regulatory authorities. Some of the integrated solutions are expected to quickly mature into commercially available products. The project also includes several full-scale prototypes and shipboard demonstrators.

Second paragraph:

The project HERCULES-2 with 25 M€ budget, is targeting at a future fuel-flexible large marine engine, optimally adaptive to its operating environment. The consortium comprises 32 partners of which 30% are Industrial and 70% are Universities / Research Institutes. The Budget share is 63% Industry and 37% Universities. Two of the world's largest shipping companies shall provide ships as full-scale testing and demonstration platforms. The project HERCULES-2 comprises 4 R&D Work Package Groups (WPG), namely WPG I: Fuel flexible engine, WPG II: New Materials (Applications in engines), WPG III: Adaptive Powerplant for Lifetime Performance, WPG IV: Near-Zero Emissions Engine. The objectives of the HERCULES-2 project are associated to 4 areas of engine integrated R&D:

- Improving fuel flexibility for seamless switching between different fuel types, including non-conventional fuels.
- Formulating new materials to support high temperature component applications.
- Developing adaptive control methodologies to retain performance over the powerplant lifetime.
- Achieving near-zero emissions, via combined integrated aftertreatment of exhaust gases.

Project website

www.hercules-2.com

Project picture

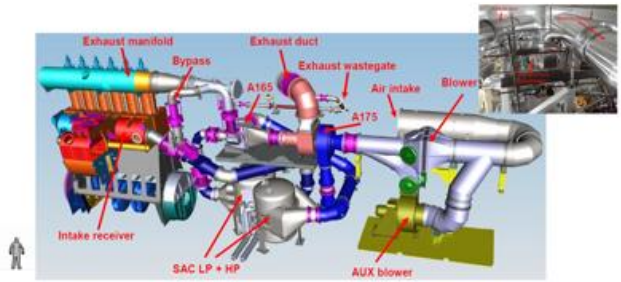


Figure: Full scale experimental setup of large marine engine with complete variability of turbocharging system combined with Exhaust Gas Recirculation for reduced emissions.

The HERCULES-2 Project is also open to public via the Transport Research & Innovation Portal (TRIP). TRIP is a database that gives an overview of transport research and innovation activities at European and national level. On TRI Portal, there is brief description of the HERCULES-2 outline, objectives, partners and other details,. A screenshot of the portal content related to the HERCULES-2 Project follows:

8 Presentations of the overall Project Results

Apart from the presentations that describe achievements of separate objectives in individual Work Packages, there has also been a presentation that offers an overview of the progress of the Project. This overview of the HERCULES R&D programme was presented in the 28th World CIMAC Congress, which took place in Helsinki, June 2016. The CIMAC Congress, which takes place every 3 years, is of great importance, as it has worldwide recognition and is attended by more than 1000 international experts in the field of large engine research.

The paper referred to all the milestones that have been achieved during the whole HERCULES Project, as well as the latest accomplishments of the HERCULES-2 programme.

Beneath is the first page of the paper.

CIMAC CONGRESS
HELSINKI | JUNE 6–10, 2016

2016 | 017

From HERCULES A-B-C to HERCULES-2 : A classic cooperative programme in large engine R&D

Topic 08 Basic Research & Advanced Engineering

Nikolaos Kyrtatos, National Technical University of Athens
GUNNAR STIESCH, MAN DIESEL & TURBO,
ILARI KALLIO, Wärtsilä

This paper has been presented and published on the occasion of the 28th CIMAC World Congress 2016 in Helsinki. The CIMAC Congress is held every three years, each time in a different member country. The Congress programme centres around the presentation of Technical papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The topics of the 2016 event covered Product Development of gas and diesel engines, Fuel Injection, Turbochargers, Components & Tribology, Controls & Automation, Exhaust Gas Aftertreatment, Basic Research & Advanced Engineering, System Integration & Optimization, Fuels & Lubricants, as well as Users' Aspects for marine and land-based applications.

9 Posters

9.1 HERCULES-2 1st Partners' Forum, Copenhagen 2015

The Partners' Forum is an informal assembly of representatives of all partners. It convenes annually, organised by the Project Coordinator, to exchange views, present results and assist in bottom-up coordination and assessment of objectives. The Forum includes also a Poster Session with presentations of all project Work Packages.

In the 1st Partners' Forum, which convened in October 2015, in Copenhagen, Denmark, Posters were exhibited in the venue of the Forum, which illustrated the progress of each Work Package during the first six months of the Project. Each poster contains Objectives, Expected Outcomes, Progress and Plans for each Work Package.

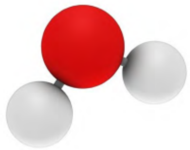
The eight posters of the respective Work Packages which are uploaded in the HERCULES-2 website, and visible to the general public, are presented in the section 9.3

9.2 HERCULES-2 2nd Partners' Forum, Helsinki 2016

The 2nd Partners' Forum took place in Helsinki, Finland, in October 2016. During the Poster Session, the Posters of the individual Work Packages were exhibited.

The Posters of the 8 Work Packages, which show in an explicit way the results that have been achieved at Mid-Term of the Project, so that they can be displayed to the general public, are presented in the next sections 9.3, 9.4.

9.3 Posters from Copenhagen Partners' Forum, October 2015



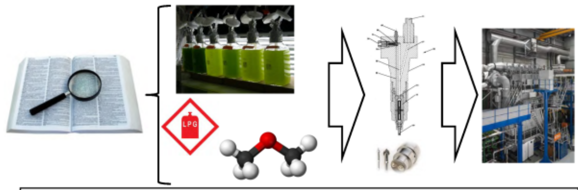
WP 1

Fuel Flexible Engine

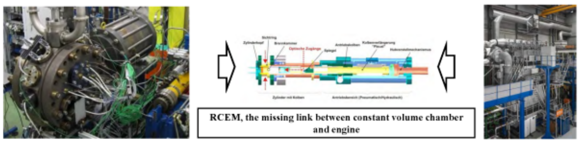
WP OBJECTIVES

To develop **engines able to switch between fuels**, whilst operating in the most cost effective way and complying with the regulations in all sailing regions.

- Study ignition capability of selected fuel candidates
- Develop a fuel injection system for multi fuel purposes
- Demonstrate fuel flexible engine operation
- Perform feasibility study on Rapid Compression Expansion Machine (RCEM)



Define requirements specification from fuel candidates, develop injection system and demonstrate fuel flexibility on the engine



RCEM, the missing link between constant volume chamber and engine

EXPECTED OUTCOME

Sub project 1.1:
The demonstration of a novel injection system, allowing the closed loop controlled application of alternative fuels in marine engines.

Sub project 1.2:
Feasibility study on rapid compression/expansion machine to base decisions on for further steps

PROGRESS AND PLANS

- Literature review accomplished (database)
- Fuel candidates identified
- Corresponding properties collected
- First design ideas evaluated

Definition of possible candidates
Definition of requirement specification
Development of the injection components

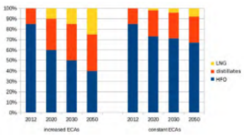


Fig. 1.1.1: Possible future fuel mix

Fig. 1.1.2: Future fuel candidates

- Literature review accomplished (database)
- Characterization and classification completed
- Requirement specifications basically defined
- Assessment applicability features (ongoing)

Elaboration of two concepts:
- crank mechanism driven
- alternative (e.g. hydraulic) driven

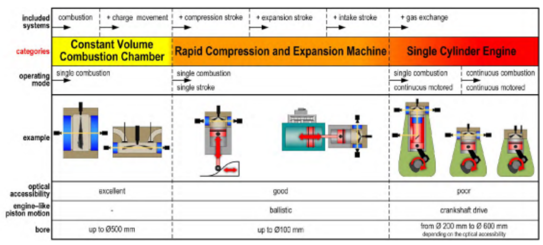


Fig. 1.2.1 : Schematic overview categories of optical accessible test rigs for combustion process investigations

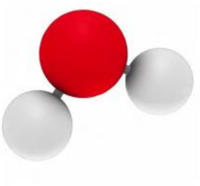
WP PARTICIPANTS

WP1 - 4 stroke
Wärtsilä Finland Ltd.
University of Vaasa
Aalto University

WP1 - 2 stroke
Paul Scherrer Institute
University of Applied Science and Arts Northwestern Switzerland
OMT Torino
Winterthur Gas & Diesel Ltd.

WÄRTSILÄ Vaasan yliopisto UNIVERSITY OF VAASA A! Aalto-yliopisto PAUL SCHERRER INSTITUT PSI n|w OMT WIN GD

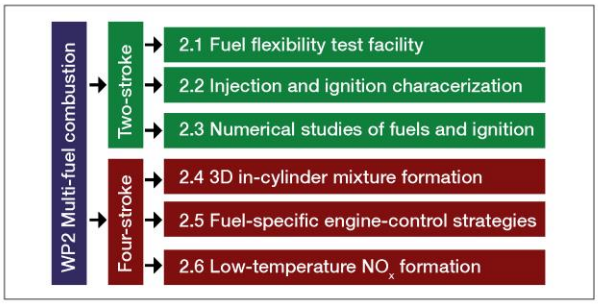
WP Contact Information: Andreas Schmid, Winterthur Gas & Diesel Ltd. (Andreas.Schmid@wingd.com)



WP2 Multi-fuel Combustion

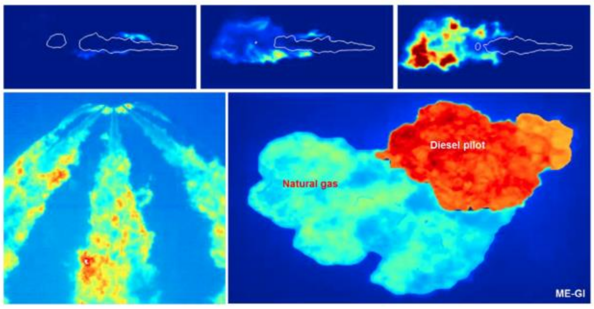
WP OBJECTIVES

The overall objective is to improve fuel flexibility of marine engines. In order to efficiently exploit a larger variety of fuels, an increased understanding of injection, combustion and emissions formation is required. For this purpose we propose to develop experimental facilities with optical access for tests under conditions relevant for marine engines. For furthering understanding of ignition and emission formation numerical tools will also be developed and applied. Finally, novel engine control strategies will be developed to fully exploit potential benefits of such fuels.



EXPECTED OUTCOME

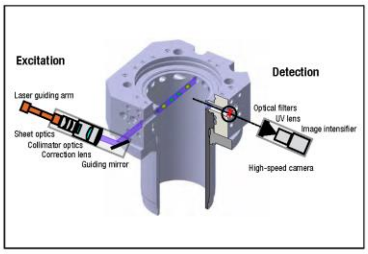
- Further improved fuel flexibility of marine engines
- Increased understanding of injection, ignition, combustion and emissions formation for novel and mixed fuels
- Experimental and numerical tools to enable exploitation of alternative fuels in marine engines:
  - Test-rigs and engines for optical studies
  - Improved CFD capabilities for multi-fuel operation
  - Improved engine control strategies.



Optical engine diagnostics in Hercules B/C and Helios

PROGRESS AND PLANS

1st year milestones	Status	Month
Multi-fuel test facility specifications	Preliminary specifications established	6
Multi-fuel test facility design	Design process has started	12
Optical engine access	Preparations in progress	12
Development of skeletal models	Work has started on LNG, LPG and methanol	12
Concept design for optical engine	Concept study ongoing	6
Concept design for 3D fuel-distribution measurement	Literature study finished, integration to engine ongoing	6
Spray chamber measurements	Ongoing	7
Study of potential of existing NO_x models finished	First calculations show promising results	8
Fuel-specific control strategy	First basic engine tests finished	-



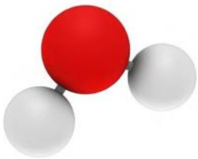
Schematic overview of set-up for 3-D mixture formation studies (Technical University of Munich)

WP PARTICIPANTS

MAN Diesel & Turbo: Copenhagen (two-stroke), Augsburg (four-stroke) • Technical University of Denmark: Department of Chemical Engineering (Prof. Glarborg) • Lund University: Division of Combustion Physics (Dr. Mattias Richter) • Technical University of Munich: - Institute of Internal Combustion Engines (Prof. Wachtmeister) - Lehrstuhl für Thermodynamik (Prof. Sattelmayer)

MAN Technische Universität München DTU Lund University

WP Leader: Dr. Johan Hult (Johan.Hult@man.eu) Deputy WP Leader: Dr. Fridolin Unfug (Fridolin.Unfug@man.eu)



WP 3 Intermetallics and adv. materials for marine engines

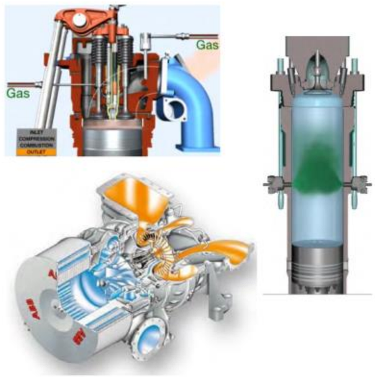
WP OBJECTIVES

Subproject 3.1: Novel materials for engine applications

Examine possibilities of using novel materials in engines to facilitate the development of components that enable higher engine loads, hereby increasing efficiency and lower emissions. Ensure proper lifetime performance and durability.

Subproject 3.2: Novel materials for turbine casing

Material of turbine casing is reviewed in respect of material and design in order to meet requirements needed for higher exhaust gas temperatures.



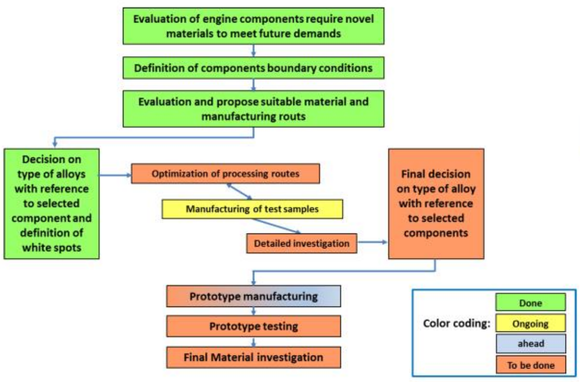
EXPECTED OUTCOME

Subproject 3.1: Suitable new materials can be identified for at least two components for higher load operations and longer life time.

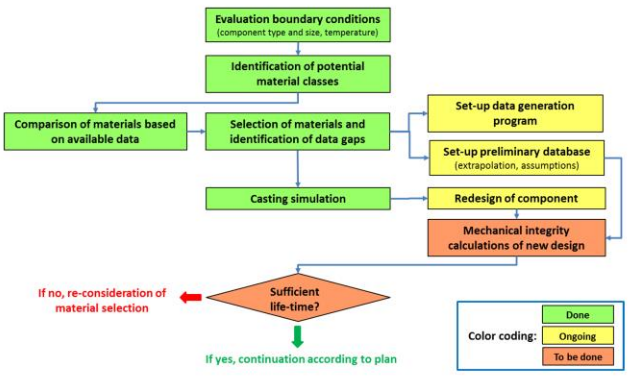
Subproject 3.2: Performance is improved through material / design optimization.

PROGRESS AND PLANS

Subproject 3.1



Subproject 3.2



WP PARTICIPANTS

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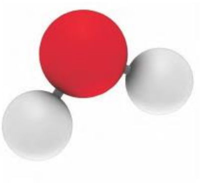


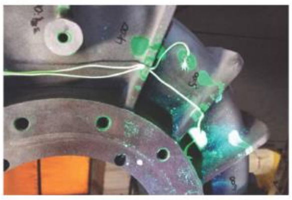
WP4 New Materials

WP OBJECTIVES

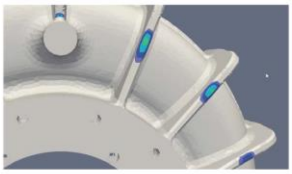
- The majority of concepts for emission reduction in internal combustion engines is followed by higher component temperatures and mechanical loads. Thus, the thermo mechanic fatigue (TMF) of engine components comes more into focus. The objective of this Work Package is to develop the use of appropriate material for optimized combustion engines focusing on the cylinder head and the turbocharger turbine casting
- Improvement of thermo mechanical cycle resistance of factor 2 under increased temperature of 50 K
- Decreased weight of cylinder head of 20%
- Improvement of thermo mechanical cycle resistance under increased temperature of 70 K under corrosion environment.

EXPECTED OUTCOME

- Quantification of the TMF characteristics of cylinder head and the turbocharger turbine casting materials
- TMF material model for the lifetime computation of turbine casting and of cylinder head
- Design and construction of test rig for cylinder head equivalent specimen component and simulation of thermal boundary condition
- Verification of TMF material model with test results.



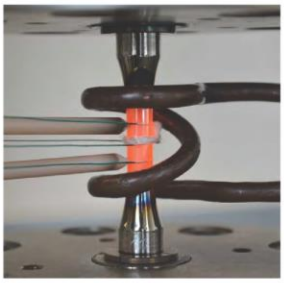
Cracks after initiating at burner rig test of turbocharger turbine casing



Computed crack locations of turbocharger turbine casing

PROGRESS AND PLANS

- Technological material tests
- Thermo Mechanic Fatigue test rig for component
- Material model for turbine casting assessment
- Thermo Mechanic Fatigue model for new cylinder head
- Cylinder head optimization.



TMF material test

WP PARTICIPANTS

MAN Diesel & Turbo SE, Augsburg • FG Fraunhofer IWM and ICT • Hochschule Offenburg University • Bundesanstalt für Materialforschung und -prüfung

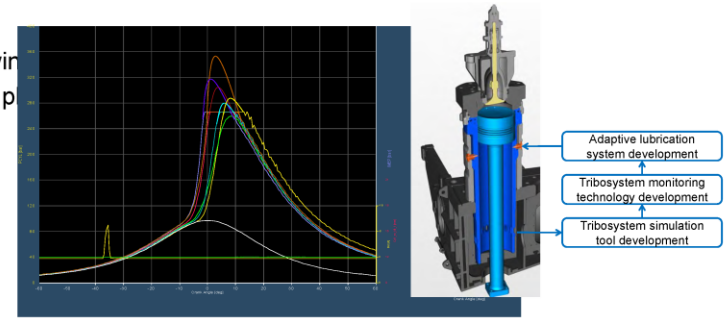
WP leader: Rayk Thumser (Rayk.Thumser@man.eu)

WP 5

Lifetime Performance Control

WP OBJECTIVES

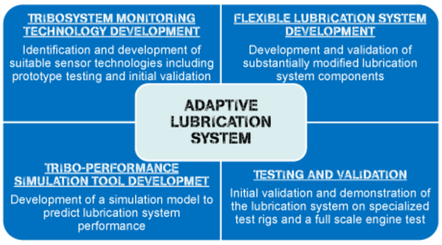
Develop methods, systems and processes allowing continuous optimized performance of the power plant throughout its lifetime

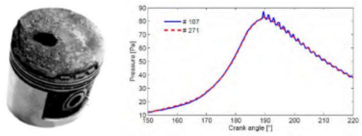


Cylinder pressure curves Adaptive lubrication system

EXPECTED OUTCOME

- Advanved lubrication control system
- Optimized lube oil feed rates
- Optimized control & parametrization algorithms
- Technology demonstrators at TRL 6
- <5% divergence of performance parameters from “as-new” state
- 10% lube oil consumption reduction





5.1: Knocking phenomena

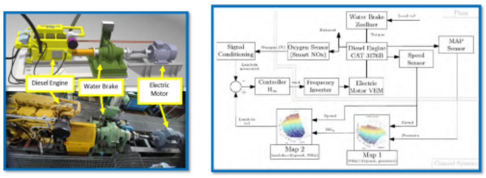
PROGRESS AND PLANS

Sub-project 5.1:
- Knock control development & testing on engine.
- Plant modelling of hybrid system & controller design

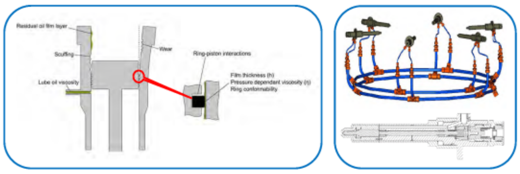
Sub-project 5.2:
- Engine parametrization conceptualization and modelling

Sub-project 5.3:
- Definition of requirements and design of experiments
- Development of a 1D simulation model to predict injection system performance

Sub-project 5.4:
- Definition of requirements and design of experiments
- Definition of suitable sensor approach



Sub-project 5.1: Engine control optimization – hybrid electric controller



Sub-project 5.3 and 5.4: Keysteps towards the development of an adaptive lubrication system

WP PARTICIPANTS

WP lead: *Wärtsilä*, WP Deputy: *WinGD*

Research partners: WÄRTSILÄ, WIN GD, The University Of Sheffield, ETH, Aalto-yliopisto, Vaasan yliopisto, UNIVERSITÀ DEL SALENTO

WP leader: Jonatan Rösgren, jonatan.rosgren@wartsila.com | WP deputy: Mattias Stark, mattias.stark@wingd.com

WP6 Model-based Control and Operation Optimization

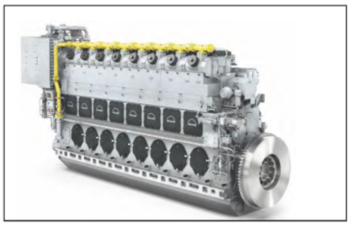
WP OBJECTIVES

Cut operating, maintenance and deployment costs: Develop systems, methods and processes for improved engine lifetime performance

Reduction of emission: NO_x - expanding operation range emission reduction technologies; Particle - novel lubrication injection system

Enhance dynamic performance: Model-based control

Increased part load efficiency: Cylinder cut-out



EXPECTED OUTCOME

WP 6.1: Evaluation of different multiple-in, multiple-out controllers

WP 6.2: Cylinder cut-out implemented in the engine control and tested

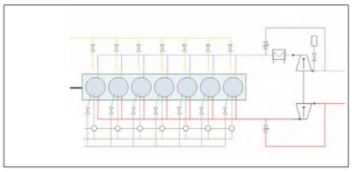
WP 6.3: Tailored outlier- and subspace search methods for compressed data

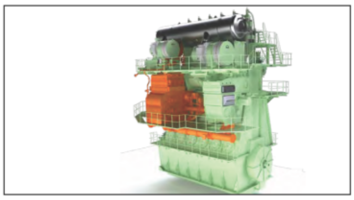
WP 6.4: Component models, full simulations and EGR-control for non-normative engine operation

WP 6.5: Retrofit solution for continuous engine performance optimization

WP 6.6: Fleet solution for unattended and secure engine software management

WP 6.7: Novel lube oil injection strategy to improve engine lifetime performance





PROGRESS AND PLANS

WP 6.1: Build-up of mathematical engine model in progress, next step: Validation

WP 6.2: Match thermodynamic model, next step: Predictive combustion model

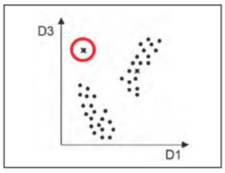
WP 6.3: Subspace search with HiCS, next step: Validation of detection quality

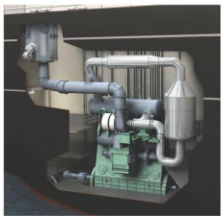
WP 6.4: Data collection and SCR model, next step: Establish transient cycle

WP 6.5: Actuator development, next step: Integration with online control

WP 6.6: Single source configuration, next step: Safe data distribution mechanisms

WP 6.7: Initial mathematical modelling of lube oil distribution system, next step: Experimental investigation of simple system

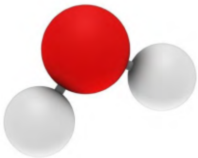




WP PARTICIPANTS

MAN Diesel & Turbo SE National • University of Bremen: Prof. BüskensVienna • University of Technology: Prof. Lauer • Karlsruher Institute of Technology: Prof. Böhm • Linköping University: Prof. Eriksson • Aventics GmbH: Mr. Rüther • Technical University of Denmark: Prof. Glarborg • National Technical University of Athens: Prof. Kyrtatos

WP Leader: Dr. Mathias Moser (Mathias.Moser@man.eu) Deputy WP Leader: Torbjoern Moeller (Torbjoern.Moeller@man.eu)



WP 7 On-engine aftertreatment systems

WP OBJECTIVES

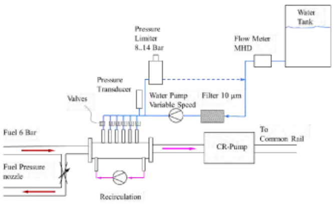
- Integration of SCR (Selective Catalytic Reduction) with the existing strong Miller cycle 4-stroke diesel engine and combining it with particulate emission (PM) abatement technology would enable to achieve more than 80% NOx emission reduction and 25% reduction in PM. Also a combination of integrated SCR and EGR (Exhaust Gas Recirculation) is to be developed. Feasible solutions of combining the above mentioned technologies having as a target the near zero emission engine are also studied.

- Integrating methane and ethane abatement technology into lean burn 4-stroke gas engines will enable compact solutions to reduce methane and ethane slip. The objective is a catalytic system working with the engine and optimization of the engine performance. Also the knowledge on deactivation & regeneration strategies for integrated catalyst solutions and methane formation and location in the engine exhaust system should increase. Target is a greenhouse gas emission decrease up to 15% and fuel savings up to 5%.

- Development of key technology for integration of the currently separated SCR after treatment into existing 2-stroke engine structure, which enables widespread installation of SCR systems on all ship types and additionally increase overall NOx removal efficiency above 80%, reduce overall hydrocarbon emissions (HCs) by 50% or more, reduce PM emissions and lead to potential fuel savings of up to 5%.

EXPECTED OUTCOME

- Literature review regarding SCR engine integration and particulate abatement.
- Emission measurement systems for SO3, NH3 and PM emissions to support integrated after-treatment technologies
- Experimental assessment of integration of methane abatement technology into gas engine structure
- Concept about catalyst aging from in-field monitoring and laboratory experiments
- Experimental assessment of SCR reduction agent injection systems with sensors for feedback control
- Experimental assessment of selected combined on-engine emission reduction system for strong Miller cycle 4-stroke diesel engines with tests on rig/engine
- Robust SCR catalysts for 2-stroke Diesel engines



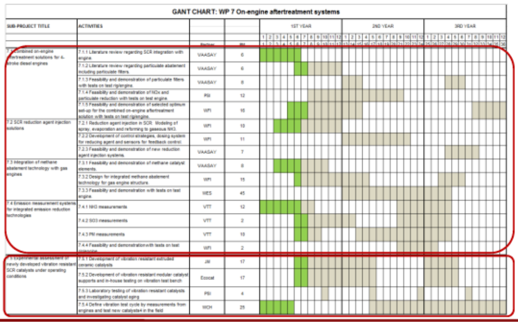
Scheme of fuel emulsion system

Emulsion mixer

PROGRESS AND PLANS

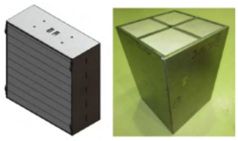
Wärtsilä

WINGD



Measurement of vibrations on engines

Vibration test setup for SCR catalysts

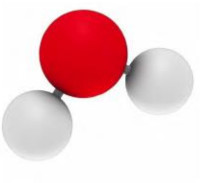


Metallic supported and extruded SCR catalyst

WP PARTICIPANTS

Wärtsilä Finland Oy, Wärtsilä Iberica, Winterthur Gas & Diesel, VTT, Unversity of Vaasa, Dinex Ecocat, Johnson Matthey, Paul Scherrer Institut

WP Contact Information: WP Leader Mr. Jukka Leinonen, jukka.Leinonen@wartsila.com / WP deputy Dr. Daniel Peitz, daniel.peitz@wingd.com

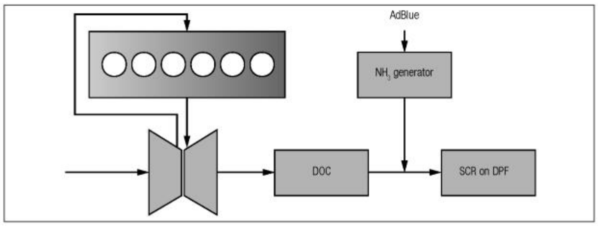


WP8 Engine Integrated SCR and Combined DPF and SCR

WP OBJECTIVES

Two-stroke objectives are to investigate the various HP SCR processes with the aim of designing compact SCR system for improved engine integration and reduced footprint.

Four-stroke objectives are to investigate LP SCR processes when combined with DPF, with the aim of reducing the total necessary installation space for a combined use of compliant DPF and SCR systems.



Schemativs of 4-stroke engine with combined SCR and DPF

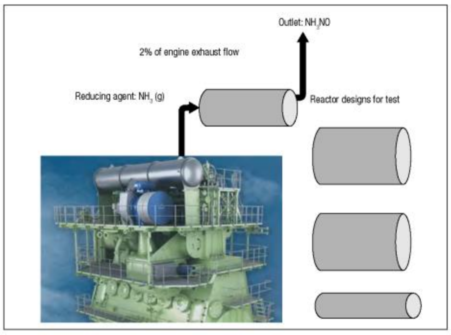
EXPECTED OUTCOME

- Engine integrated SCR design and test on 4T50ME-X test engine in Copenhagen
- High performing sub-processes (injection, mixing, decomposition etc…)
- High performing NH_3-slip control and measurement techniques
- Combined DPF and SCR with low engine room footprint
- Evaluation of optimal SCR catalyst and filter material/coating for combined DPF and SCR technology

Hot exhaust gas flow rig for invetigstion of urea injection, evaporation and mixing

PROGRESS AND PLANS

- NH_3 measurement equipment tested for basic functionality, to be used to mature engine control system for NH_3-slip (MDT-CPH)
- Concept for mini-SCR reactor for test of compact SCR performance established. To be designed, build and tested at 4T50ME-X within Q3-2016 (MDT-CPH)
- Basic comparisons between trace component flow profile and CFD calculations performed, to be expanded (MDT-CPH + DTU)
- Design of synthetic gas test bed in progress for build-up (MDT-AUG)
- Procurement of first DPF substrates and measurement equipment performed (MDT-AUG)
- Set-up of the hot exhaust gas flow test rig in progress (MDT-AUG + LUH)
- Development and verification of the measurement equipment for hot exhaust gas flow rig on track (MDT-AUG + LUH)



Concept for mini-SCR reactor for testing of compact SCR, aimed at testing at 4T50ME-X Test Engine in Q3 2016

WP PARTICIPANTS

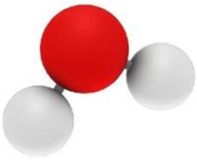
MAN Diesel & Turbo: Hanne Hostrup Poulsen • DTU: Technical University of Denmark (Ass. Prof. A. Ivarsson) • MDT-AUG: Manuel Kleinhenz • LUH: Leibniz Universität Hannover (Prof. F. Dinkelacker)

Leibniz Universität Hannover

DTU

WP Leader: Hanne Hostrup Poulsen (HanneH.Poulsen@man.eu) Deputy WP Leader: Manuel Kleinhenz (Manuel.Kleinhenz@man.eu)

9.4 *Posters from Helsinki Partners' Forum, October 2016*



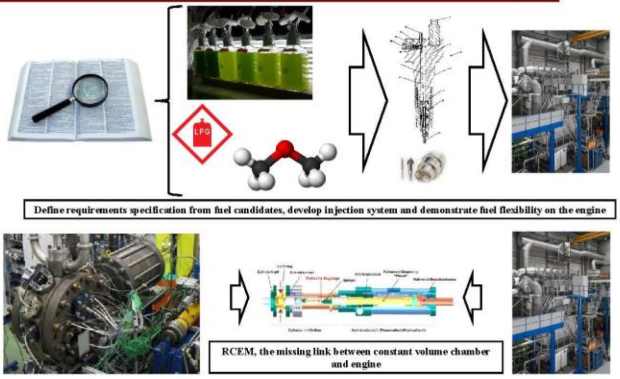
WP 1

Fuel Flexible Engine

WP OBJECTIVES

To develop **engines able to switch between fuels**, whilst operating in the most cost effective way and complying with the regulations in all sailing regions.

- Study ignition capability of selected fuel candidates
- Develop a fuel injection system for multi fuel purposes
- Demonstrate fuel flexible engine operation
- Perform feasibility study on Rapid Compression Expansion Machine (RCEM)



EXPECTED OUTCOME

Sub project 1.1:
The demonstration of a novel injection system, allowing the closed loop controlled application of alternative fuels in marine engines.

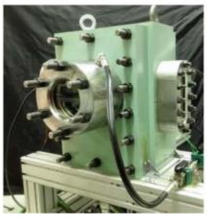
Sub project 1.2:
Feasibility study on rapid compression/expansion machine to base decisions on for further steps

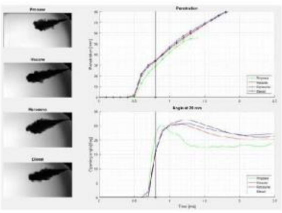
PROGRESS AND PLANS

SP: 1.1: 4-stroke

Fuel injection measurements in spray chamber with high speed camera

- The objective is to determine the opening angle and penetration with different fuels.
- Kerosene, Hexane, and Propane. Diesel used as reference fuel
- Injection pressures used: 550 bar and 1000 bar
- Chamber density: 1,2 kg/m3, 35 kg/m3 and 100 kg/m3



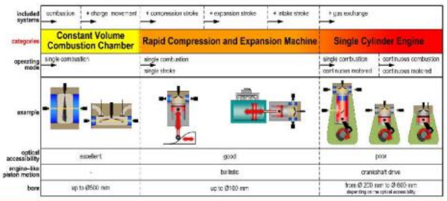


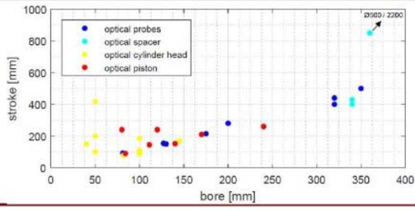
SP: 1.1: 2-stroke

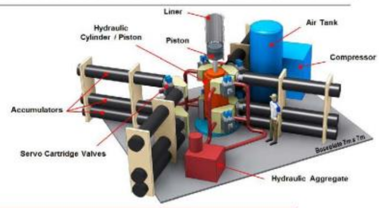
Progress:
- New cover directly derived from RTX-6, same injector position
- Injector adapters installed
- New heating system installed
- New illumination system installed

Next steps:
- First measurements with reference injection system (RTX-6)
- Commissioning multi fuel injection system
- Spray tests with alternative fuels
- Reactive tests with alternative fuels

SP: 1.2







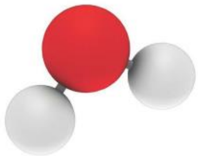
WP PARTICIPANTS

WP1 - 4 stroke
Wärtsilä Finland Ltd.
University of Vaasa
Aalto University

WP1 - 2 stroke
Paul Scherrer Institute
University of Applied Science and Arts Northwestern Switzerland
OMT Torino
Winterthur Gas & Diesel Ltd.

WÄRTSILÄ | Vaasan yliopisto UNIVERSITY OF VAASA | A! Aalto-yliopisto | PAUL SCHERRER INSTITUT PSI | n|w | OMT | WIN GD

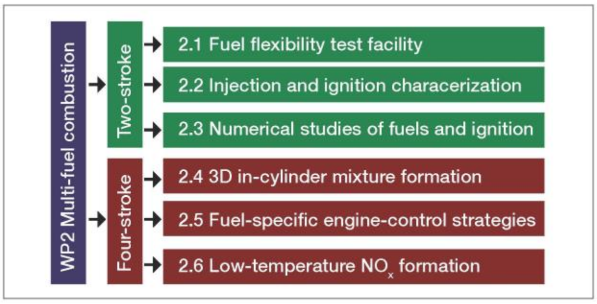
WP Contact Information: Andreas Schmid, Winterthur Gas & Diesel Ltd. (Andreas.Schmid@wingd.com)



WP2 Multi-fuel Combustion

WP OBJECTIVES

The overall objective is to improve fuel flexibility of marine engines. In order to efficiently exploit a larger variety of fuels, an increased understanding of injection, combustion and emissions formation is required. For this purpose we propose to develop experimental facilities with optical access for tests under conditions relevant for marine engines. For improving the understanding of ignition and emission formation numerical tools will also be developed and applied. Finally, novel engine control strategies will be developed to fully exploit potential benefits of such fuels.

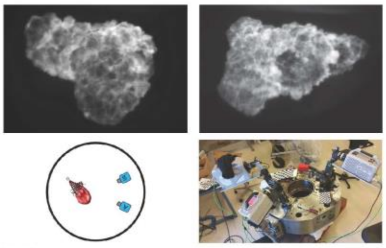


EXPECTED OUTCOME

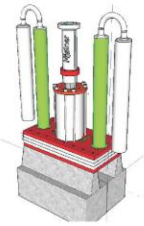
- Further improved fuel flexibility of marine engines
- Increased understanding of injection, ignition, combustion and emissions formation for novel and mixed fuels
- Experimental and numerical tools to enable exploitation of alternative fuels in marine engines:
  - o Test-rigs and engines for optical studies
  - o Improved CFD capabilities for multi-fuel operation
  - o Improved engine control strategies

PROGRESS AND PLANS

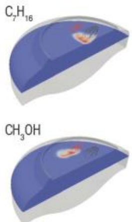
Partner	Activities
MAN CPH	TCC concept design and specifications, multi-camera tests, tabulated chemistry for CFD
Lund	High-speed Schlieren set-up, multi-view imaging, lubrication oil tracers
DTU	Detailed natural gas mechanism, propane experiments and model
MAN AUG	Design of optical accessible cylinder head, engine control tests
TUM LVK	Design of optical accessible cylinder head, fluorescent tracer validation
TUM TD	Low temperature NO_X formation, kinetic studies



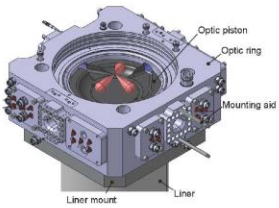
Multi-camera flame imaging (MAN CPH + Lund)



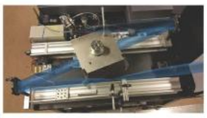
Proposed design for test combustion chamber (MAN CPH)



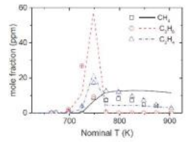
Multi-fuel CFD test (MAN CPH)



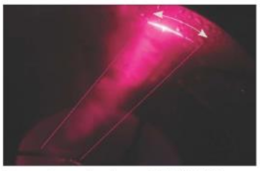
Optical engine access (MAN AUG + TUM-LVK)



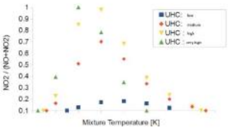
High-speed Schlieren (Lund)



Propane oxidation (DTU)



Tracer investigations (TUM-LVK)



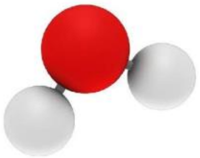
Conversion of NO to NO_2 (TUM-TD)

WP PARTICIPANTS

MAN Diesel & Turbo: Copenhagen (two-stroke), Augsburg (four-stroke) • Technical University of Denmark: Department of Chemical Engineering (Prof. Glarborg) • Lund University: Division of Combustion Physics (Dr. Mattias Richter) • Technical University of Munich: IC Engines (Prof. Wachtmeister), Thermodynamik (Prof. Sattelmayer)

MAN Technische Universität München DTU LUND UNIVERSITY

WP Leader: Dr. Johan Hult (Johan.Hult@man.eu) Deputy WP Leader: Dr. Fridolin Unfug (Fridolin.Unfug@man.eu)



WP 3 Intermetallics and adv. materials for marine engines

WP OBJECTIVES

Subproject 3.1: Novel materials for engine applications

Examine possibilities of using novel materials in engines to facilitate the development of components that enable higher engine loads, hereby increasing efficiency and lower emissions. Ensure proper lifetime performance and durability.

Subproject 3.2: Novel materials for turbine casing

Material of turbine casing is reviewed in respect of material and design in order to meet requirements needed for higher exhaust gas temperatures.

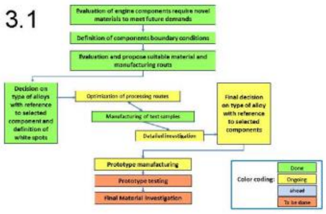
EXPECTED OUTCOME

Subproject 3.1: Suitable new materials can be identified for at least two components for higher load operations and longer life time.

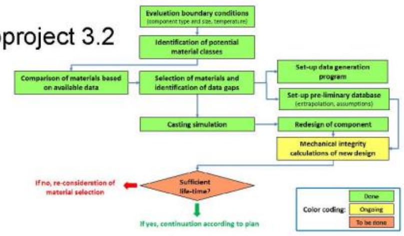
Subproject 3.2: Performance is improved through material / design optimization.

PROGRESS AND PLANS

Subproject 3.1



Subproject 3.2



Subproject 3.1 Progress of material characterisation / testing activities up to date and planned next:

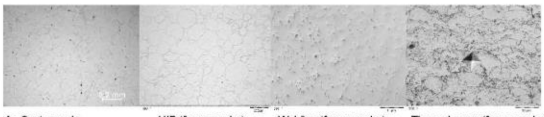
DONE

- Microstructure from different manufacturing routes & materials
- Mechanical properties (mostly done)

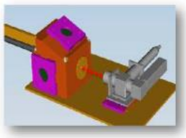
Pending...

- Corrosion testing (cold & hot corrosion) partially done, evaluation pending
- Thermal shock testing - pending (laser for test rig under repair)
- Tribo testing – samples ready / testing pending

Microstructures resulting from different manufacturing routes:



As-Cast sample HIP (from powder) Welding (from powder) Thermal spray (from powder)



Thermal cycling test rig

Tribo tester CPT

Testing of advanced bearing materials

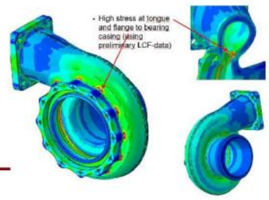
Subproject 3.2 Progress up to date and activities planned next:

DONE

- Decision on casting type & manufacturing method
- Preliminary material database setup
- Casting simulation & parametrisation of CAD-model
- Defintion of load profile
- Elimination of stress hot-spots

Pending...

- Completion of experimental material characterisation
- Production of prototype casings
- Qualification tests



WP PARTICIPANTS

WP lead: WinGD WP deputy: Wärtsilä.

Max-Planck-Institut für Eisenforschung GmbH | Deloro Wear Solutions | ABB | WÄRTSILÄ | WIN GD Winterthur Gas & Diesel

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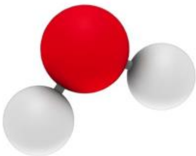


WP Group II - New Materials

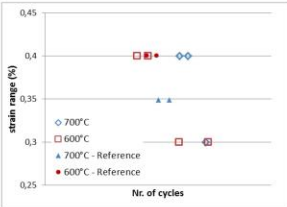
WP4 - New Materials for Higher Engine Efficiency

WP OBJECTIVES

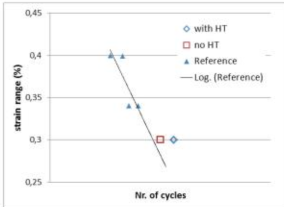
The majority of concepts for emission reduction in internal combustion engines go along with higher component temperatures and mechanical loads. Thus, the thermo-mechanic fatigue (TMF) of engine components comes more into focus. The objective of this Work Package is to develop the use of appropriate material for optimized combustion engines focusing on the cylinder head and the turbocharger turbine casting.

- Improvement of thermo-mechanical cycle resistance of factor 2 under increased temperature of 50 K
- Decreased weight of cylinder head of 20%
- Improvement of thermo-mechanical cycle resistance under increased temperature of 70 K under corrosion environment

EXPECTED OUTCOME



LCF Results

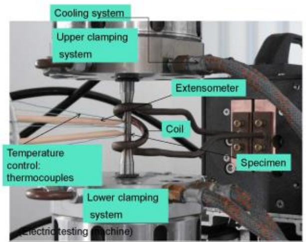


TMF Results (300°C -600°C)

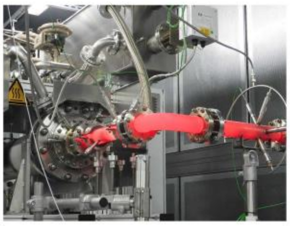
- Quantification of the TMF characteristics of cylinder head and the turbocharger turbine casting materials.
- TMF material model for the lifetime computation of turbine casting and of cylinder head.
- Design and construction of test rig for cylinder head equivalent specimen component and simulation of thermal boundary condition.
- Verification of TMF material model with test results.

PROGRESS AND PLANS

- Technological material tests
- Thermo-mechanical fatigue test rig for component
- Material model for turbine casing assessment
- Thermo-mechanical fatigue model for new cylinder head
- Cylinder head optimization



TMF material test equipment


Hot Gas Test Rig

WP PARTICIPANTS

MAN Diesel & Turbo SE is a leading supplier of diesel and gas engines for maritime and stationary applications

BAM is the Federal Institute for Materials Research and Testing of the Federal Republic of Germany.

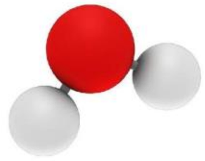
FG Fraunhofer is Europe's largest application-oriented research organization.

HSO The cornerstones of Offenburg University are applied research, innovation and technology transfer sciences.

MAN | Fraunhofer IWM | Hochschule Offenburg offenburg.university | Fraunhofer ICT | BAM

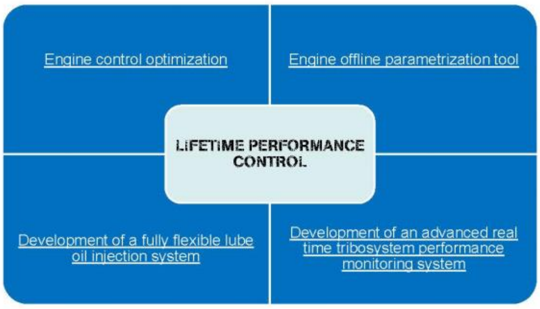
WP Leader: Dr. Rayk Thumser, rayk.thumser@man.eu, Deputy: Santiago Uhlenbrock, santiago.uhlenbrock@man.eu

WP 5
Lifetime Performance Control



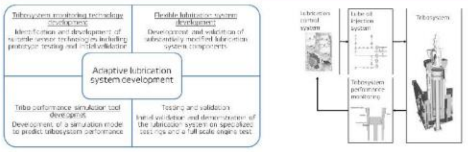
WP OBJECTIVES

Develop methods, systems and processes allowing a continuous optimized performance of the power plant throughout its lifetime

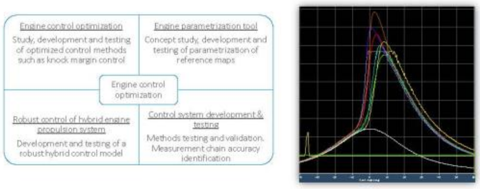


EXPECTED OUTCOME

- Advanced lubrication control system
- Optimized lube oil feed rates
- Optimized control & parametrization algorithms
- Technology demonstrators at TRL 6
- Max 5% divergence of any performance parameter from "as-new" state
- 10% lube oil consumption reduction



5.3, 5.4: Development of an adaptive lubrication system



5.1, 5.2: Engine control optimization

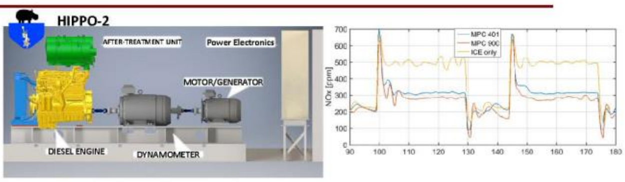
PROGRESS AND PLANS

Sub-project 5.1:
- Knock control development & testing on engine.
- Plant modelling of hybrid system & controller design

Sub-project 5.2:
- Engine parametrization conceptualization and modelling

Sub-project 5.3:
- Lube oil injector prototype optimization and testing
- Optimization of injection parameters

Sub-project 5.4:
- Viscosity and scuffing indicator prototype testing
- Investigation on alternative approaches to measure specific tribosystem performance parameters



Sub-project 5.1: Engine control optimization – hybrid electric controller

Sub-project 5.4: Tribosystem monitoring prototype testing

WP PARTICIPANTS

WP lead: *Wärtsilä*, WP Deputy: *WinGD*

Research partners: WÄRTSILÄ, WinGD, The University Of Sheffield, ETH, Aalto-yliopisto, Vaasan yliopisto, UNIVERSITÀ DEL SALENTO

WP leader: Jonatan Rösgren, jonatan.rosgren@wartsila.com | WP deputy: Matthias Stark, matthias.stark@wingd.com

WP6 Model-based Control and Operation Optimization

WP OBJECTIVES

- Reducing operating, maintenance and deployment costs
- Enhance dynamic performance
- Reduction of emission in low load operation
- Increased part load efficiency

WG calculation

$$\dot{m}_W(t) = c_d \cdot A_{geo}(t) \cdot \rho_2(t) \cdot v_2(t) = c_d \cdot A_{geo}(t) \cdot \frac{p_2(t)}{\sqrt{R \cdot \vartheta_2(t)}} \cdot \psi(\Pi_2(t))$$

Parameter identification

$$\dot{m}_C(t) = g_1(n_{TC}(t), \Pi_1(t), \vartheta_1(t))$$
$$\eta_C(t) = g_2(n_{TC}(t), \Pi_1(t), \vartheta_1(t))$$
$$\dot{m}_T(t) = g_3(n_{TC}(t), \Pi_2(t), \vartheta_2(t))$$
$$\eta_T(t) = g_4(n_{TC}(t), \Pi_2(t), \vartheta_2(t))$$

EXPECTED OUTCOME

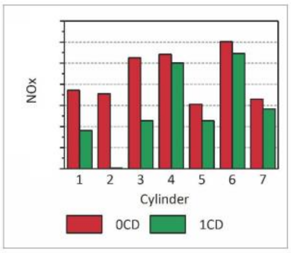
Engine control and optimization

- Model-based engine control
- Part load optimization due Cylinder cut out and expanding the operating range of EGR and SCR systems
- Continuous combustion control of mechanically controlled engines
- Novel lubrication injection system

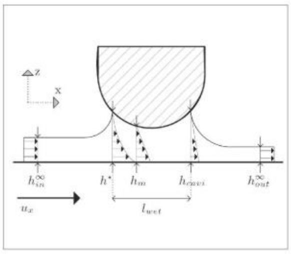
Remote monitoring & software distribution

- Algorithms for failure detection and plant analysis
- Lifetime managed engine software deployment

NO_x reduction

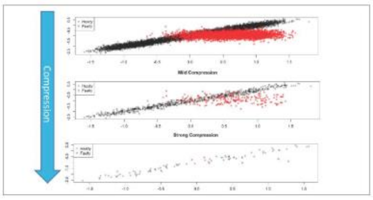


Hydrodynamic lubrication



PROGRESS AND PLANS

- Numerical problems with the engine models could be solved by implementing a new solver for the differential equations. Nest step will be the validation of the models and the development of first MB-controllers
- Combustion model for cylinder cut out was optimized and promising simulation results could be achieved in terms of emission reduction at part load. Implementation of EGR and SCR models are on track. After finishing the integration the models will be fitted with the help of measurement data
- Prototype part by Aventics available. Concept evaluation in progress
- A proposal for a theoretical model to investigate the hydrodynamic lubrication of the top compression piston ring has been made. Further investigations concerning the squeeze term and the effect on the model ongoing
- Investigation of detection quality depending on compression ratio was done
- Model for secure remote connectivity including management of access authentication between multiple partners ready to be validated



Data compression vs. accuracy

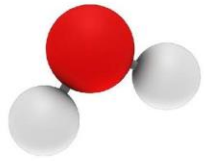
Emission reduction system

WP PARTICIPANTS

MAN Diesel & Turbo SE • University of Bremen: Prof. Büskens • Vienna University of Technology: Prof. Lauer • Karlsruher Institute of Technology: Prof. Böhm • Linköping University: Prof. Eriksson • Aventics GmbH: A. Rüther • Technical University of Denmark: Prof. Glarborg • National Technical University of Athens: Prof. Kyrtatos

MAN | Universität Bremen | TU Wien Technische Universität Wien Vienna University of Technology | KIT Karlsruher Institut für Technologie | Linköpings Universitet | AVENTICS | DTU | National Technical University of Athens

WP Leader: Dr. Mathias Moser (Mathias.Moser@man.eu) Deputy WP Leader: Torbjoern Moeller (Torbjoern.Moeller@man.eu)

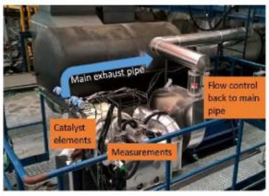


WP 7 On-engine aftertreatment systems.

50% Load, 23% EGR

WP OBJECTIVES

- Integration of SCR (Selective Catalytic Reduction) with the existing strong Miller cycle 4-stroke diesel engine and combining it with particulate emission (PM) abatement technology would enable to achieve more than 80% NOx emission reduction and 25% reduction in PM. Also a combination of integrated SCR and EGR (Exhaust Gas Recirculation) is to be developed. Feasible solutions of combining the above mentioned technologies having as a target the near zero emission engine are also studied.
- Integrating methane and ethane abatement technology into lean burn 4-stroke gas engines will enable compact solutions to reduce methane and ethane slip. The objective is a catalytic system working with the engine and optimization of the engine performance. Also the knowledge on deactivation & regeneration strategies for integrated catalyst solutions and methane formation and location in the engine exhaust system should increase. Target is a greenhouse gas emission decrease up to 15% and fuel savings up to 5%.
- Development of key technology for integration of the currently separated SCR after treatment into existing 2-stroke engine structure, which enables widespread installation of SCR systems on all ship types and additionally increase overall NOx removal efficiency above 80%, reduce overall hydrocarbon emissions (HCs) by 50% or more, reduce PM emissions and lead to potential fuel savings of up to 5%.

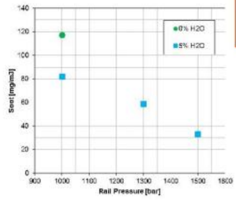


Test equipment for methane and ethane abatement tests

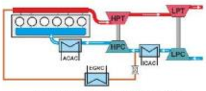
NH_3 sensor installed in stack

EXPECTED OUTCOME

- Literature review regarding SCR engine integration and particulate abatement.
- Emission measurement systems for SO3, NH3 and PM emissions to support integrated after-treatment technologies
- Experimental assessment of integration of methane abatement technology into gas engine structure
- Concept about catalyst aging from in-field monitoring and laboratory experiments
- Experimental assessment of SCR reduction agent injection systems with sensors for feedback control
- Experimental assessment of selected combined on-engine emission reduction system for strong Miller cycle 4-stroke diesel engines with tests on rig/engine



Preliminary results from EGR tests



Semi-short route EGR setup

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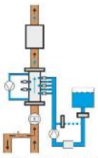
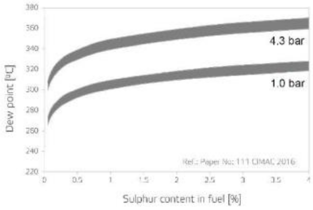


In-line Water-Fuel Emulsifier

PROGRESS AND PLANS



Robust catalysts for high sulphur HFO operation with safe operating temperatures thanks to slip stream SCR testing on test bed engine.

Hot gas vibration test bed for testing catalyst prototypes for future on-engine SCR systems

WP PARTICIPANTS

Wärtsilä Finland Oy, Wärtsilä Iberica, Winterthur Gas & Diesel, VTT, Unversity of Vaasa, Dinex Ecocat, Johnson Matthey, Paul Scherrer Institut

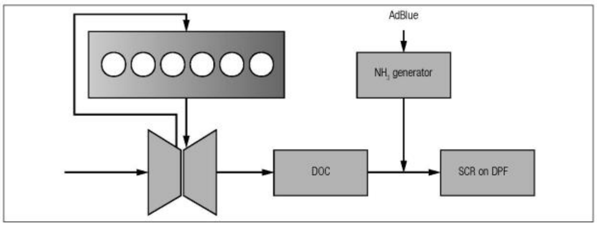
WP Contact Information: WP Leader Mr. Jukka Leinonen, jukka.Leinonen@wartsila.com

WP8 Engine Integrated SCR and Combined DPF and SCR

WP OBJECTIVES

Two-stroke objectives are to investigate the various HP SCR processes with the aim of designing compact SCR system for improved engine integration and reduced footprint.

Four-stroke objectives are to investigate LP SCR processes when combined with DPF, with the aim of reducing the total necessary installation space for a combined use of compliant DPF and SCR systems.



Concept of four-stroke high speed engine with SCR on DPF after-treatment system

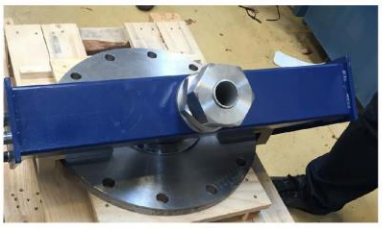
EXPECTED OUTCOME

- Engine integrated SCR design and test on 4T50ME-X test engine in Copenhagen
- High performing sub-processes (mixing, decomposition etc…)
- High performing NH_3 control and measurement techniques
- Combined DPF and SCR with low engine room footprint
- Evaluation of optimal SCR catalyst and filter material/coating for combined DPF and SCR technology


Hot exhaust gas flow rig for invetigstion of urea injection, evaporation and mixing

PROGRESS AND PLANS

- Emission control set-up for NH_3 slip completed
- Measurement device for traverse NH_3 measurements on track
- Mini-SCR test facility completed and first test performed
- Comparisons between trace component flow profile and CFD calculations performed
- Build-up of synthetic gas test bed in progress
- Investigation of SCR coated DPF samples ongoing
- Set-up of the hot exhaust gas flow test rig completed
- Validation measurements of pressure influence completed
- Measurements of mixer influence under development
- Development and verification of the measurement equipment for hot exhaust gas flow rig on track


Mechanism for NH_3 measurements


High pressure mini SCR

WP PARTICIPANTS

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MAN Leibniz Universität Hannover DTU

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10 Conclusions

The Dissemination Activities presented in this Report cover the first 18 months of the Project. Through the Dissemination Activities, the results and applications of the Projects that receive funding from the European Commission can be made known to a wider public.

The HERCULES-2 Project Dissemination Activities have taken various forms such as scientific papers, publications, presentations in Conferences, Congresses and meetings, poster exhibitions and press releases. The main Dissemination gateway is the Public Section of the HERCULES-2 website, which is operational since Month 6 of the Project.