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Quo Vadis Großmotor – Auslaufmodell oder Langläufer?

The worldwide transport of goods and people is – except in aviation – without large-bore engines as power source unimaginable. In future, the transport needs are expected to grow further – for which clear improvements regarding environmental amenity as well as public and political acceptance must be achieved.

- Can large-bore engines fulfil these requirements?
- Which development trends and technology topics will come up for large-bore engines – considering a quite moderate emission limit pressure?
- Will high-speed engines take over the market of small medium-speeds?
- Will large-bore engines be replaced partly or in total by pure electrical propulsion in future?
- Will e. g. large container vessels be propelled pure electric and operate autonomous?
- Which sustainable energy sources can provide a suitable energy density?
- Will be the direct coupled 2-stroke engines replaced by gensets with 4-stroke engines?

On the example of maritime application several scenarios and technologies will be discussed. This includes electrified and hybridized propulsion systems with batteries, clean fuels and/or exhaust gas aftertreatment, engine technology like e. g. extended peak pressure potential, flexible and decoupled valve timings, variable compression ratio, multi-stage charging systems, intelligent engine control, monitoring and maintenance. Additionally, to be considered engine components with improved material for friction reduction and extended life times as well as optimized lubricants.

Porf. Dr-Ing. Bert Buchholz

Clean Fuels for Ships - Prerequisite for an efficient On-Board Emission Reduction

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Fuels from fossil sources are still dominating the transport sector and especially the bunker market for commercial shipping fuels. The current bunker fuel market will gradually change, driven, for instance, by changes in the legislation such as the global Sulphur cap of 0.5% in 2020. On the one hand, this will improve marine fuel quality quite significantly compared to the current status, primarily in terms of Sulphur content. On the other hand, marine fuel quality will still be significantly poorer than on-road fuel qualities, even after successful implementation of the 2020 Sulphur cap. And, the dominance of fossil fuels will continue in the marine market for probably even longer than the next decade.
Against this background, the commercial shipping industry is facing two huge challenges simultaneously: the significant reduction of harmful emissions such as NOX, PM and SOX, and the reduction of green-house-gases, particularly CO2.
The first challenge requires huge progress within very short periods of time. The current discussion regarding harmful emissions of passenger car diesel engines is sending a very strong signal. The newest generation of on-road diesel engines is showing extremely low emissions under all operation conditions. As this new technology is rolled out, the focus will turn to emissions from ship engines, especially in port towns and coastal areas.
The second challenge is more long-term but first steps in the direction of decarbonisation need to be taken now. Clear GHG-reduction targets have been defined by the EU and Germany and the necessity to fulfill these requirements also in the transport sector is becoming increasingly obvious.

All this results in the need of clean and progressively CO2-neutral fuels for a sustainable shipping business in the future.
In the field of gaseous fuels, natural gas has obviously a huge future potential. As a very clean fuel it allows a significant reduction of harmful emissions. NOX, SOX and PM can be reduced well below current and future marine emission limits. In combination with SCR catalysts, end-of-pipe emission levels similar to those of modern on-road diesel engines can be reached in the future. Regarding GHG emissions natural gas has the benefit of an advantageous H/C ratio, which allows CO2 reductions of approx. 20%. This advantage can be expanded by using renewable bio-methane and synthetic methane (PtG) as drop-in-fuels in the future. The main challenge for gas or dual-fuel engines will be the reduction of the methane slip to ensure a positive overall GHG balance. Methane oxidation catalysts with low light-off temperatures and sufficient stability against deactivation are required for methane slip reduction in addition to engine internal measures.
For liquid fuels the situation is more complex. Large ship units and ocean-going transport will continue to need fuels with very high energy density, i.e. liquid fuels. To obtain emission levels as low as for on-road transport, the application of complex exhaust gas treatment systems will be unavoidable. These systems require clean fuels for an optimum conversion efficiency and reliability. Sulphur- and ash-free fuels are necessary for the highly efficient exhaust gas treatment of modern diesel engines for passenger cars and trucks. Future carbon-neutral fuels are much-discussed and subject of many research projects, but their availability is still extremely limited. It is still unclear, which synthetic fuel will be the most efficient solution for mobility and transport. Different transport modes are likely to require different synthetic fuels. Obviously, synthetic fuels should be Sulphur- and ash-free. But for marine applications, additional requirements need to be considered, such as a high flash point (safe on-board storage and handling) and a good ignitability. Paraffinic fuels fulfill these requirements and

can be produced from biomass or via synthesis (PtL). Their compatibility to current liquid fossil fuels is very high.
Reducing harmful emissions and starting the transition to carbon-neutral transport are the major challenges for shipping in the future. Clean and carbon-neutral fuels will be prerequisite for mastering both challenges.

Porf. Dr-Ing. Gunnar Stiesch, Dr. Matthias Auer, Dr. Christoph Rohbogner, Dr. Stefan Mayer, Dr. Alexander Knafl; MAN Diesel & Turbo SE

Fuel Flexibility with MAN Engines in View of 2020 0.50% Sulfur Regulations

The global limit for sulfur in fuel oil used on board ships of 0.50% m/m (mass by mass) enters into effect from 1 January 2020. This will significantly reduce the amount of sulfur oxide emanating from ships and should have major health and environmental benefits for the world, particularly for populations living close to ports and coasts [1].

Meeting the new sulfur limit will require to either use fuel at or below the 0.50% m/m sulfur limit or to employ exhaust gas abatement technologies that reduce the excess oxides of sulfur (SOx) from the exhaust stream for the case of conventional marine residual fuels containing sulfur levels in the vicinity of 3.5%. While scrubber technologies are considered mature, the investments are substantial and only a fraction of vessels will be fitted with scrubbers by 2020. Marine gas oil (MGO/DMA) presents itself as a readily available sulfur compliant solution; this, however, comes at an OPEX premium of approximately 50% at 2017 fuel prices. Additional sulfur compliant fuels include liquid natural gas (LNG), liquid petroleum gas (LPG), methanol and ethane. Over the past years, MAN Diesel & Turbo SE has developed a product portfolio of highly efficient 2- and 4-stroke engines capable of meeting the new regulations when operating on these fuels.

With the introduction of the 0.50% global sulfur limit, refineries and blenders will start to produce- and blend fuels that comply with the sulfur limit. This will require different refining processes and utilization of oil streams not currently used for marine fuels. The future fuel pool for 0.50% sulfur fuel will include heavily cracked streams, paraffinic fuels, distillates, desulfurized oil, HFO originating from sweet crudes already meeting the sulfur limit, and other types. While these fuels must comply with the current ISO 8217 specifications, it is anticipated that challenges such as instability, compatibility, high cat fines or unfavorable combustion characteristics will arise with some of the fuels.

To prepare for the new 0.50% sulfur fuels, MAN Diesel & Turbo SE is in close discussion with fuel suppliers and refineries to evaluate the impact of the new fuel product on the engines, particularly the fuel handling system, injection equipment, combustion chamber, combustion process, and the exhaust gas treatment system. A first set of 0.50% sulfur fuels have been analyzed at MAN and the results from these tests are presented.

Porf. Koji Takasaki, Dr. Daisuke Tsuru; Kyushu University, Dr. Chiori Takahashi; National Maritime Research Institute NMRI Japan, Dr. Tatsuo Takaishi; Oshima Shipbuilding Co., Ltd., Japan

Combustion Quality of low-sulfur Marine Fuels after 2020 – will be better or worse?

The author presented at the first (2010), second (2012) and third Tagung (2014), studies on the diesel spray combustion including some low-grade fuel cases using a visual test engine and a large-sized visual RCEM (Rapid Compression and Expansion Machine). In the gas engine area, the author also presented a fundamental study on the GI (high pressure gas injection) combustion at the fourth Tagung (2016).
At the fifth Tagung (2018), the following contents will be demonstrated.
In the former half of the paper, a long-term research work on the combustion quality of marine heavy fuels by the above-mentioned authors group is introduced. The group has carried out the analysis of actual fuel samples that caused severe troubles for marine engines, by using many research tools like constant volume combustion chambers and test engines to visualize the spray combustion.
Considering the modern process to reduce sulfur in the refineries side and reviewing the above-mentioned data, it is estimated that both ignition and combustion quality will surely become worse after the global sulfur cap from 2020 than now.
As the origin of troubles is different between the case of medium-speed four-stroke engine and low-speed two-stroke one, the measures to avoid the troubles are proposed for each case.
In the latter half of the paper, as a promising topic, spray combustion of methanol and LPG is introduced. For both sulfur-free fuels, also lower CO2 emission (EEDI) than the conventional fuel is guaranteed. Though a small amount of diesel fuel pilot injection is necessary to ignite them, after the ignition the both fuels show excellent combustion state rather better than gas oil. Compared to the natural gas, the both fuels have a merit that the liquid phase injection at a high pressure is possible.
In the last part of the paper, natural gas GI combustion is reviewed. Image of air-fuel mixture formation by high pressure gas jet is fundamentally near to that of liquid spray. Effect of gas injection pressure improving the air entrainment into gas jet that leads to faster diffusive combustion is confirmed by the visual data.

Jens Scharner; ROSTOCK PORT GmbH

Options to reduce vessels emissions seen from the perspective of port of Rostock

ECA-regulations in the Baltic Sea, EU-regulations on air pollution control and an ever-rising interest concerning a healthy environment in the wider public force vessel and port operators to consider all possible options to minimise the emission of exhaust gases.

During the recent years several options has been discussed and tested by ship owners, among these are Scrubbers, several fuel options such as MGO, Methanol or LNG as well as electrified operation. Each of such alternatives comes with considerable effects for ports. The presentation compares the environmental characteristics of some emission reduction technologies and shows their requirements regarding port infrastructure and services such as provision of specific supplies or disposal of certain waste streams.

The second part of the presentation focusses on LNG as one of the most promising fuels in shipping for the medium term. The presenter will give an insight into expected demand segments and volumes in port of Rostock such as ferry and roro- or cruise shipping as well as what has been done in the port to enable the use of LNG. Due to its physical properties a port specific set of regulations is needed to enable the use as bunker fuel. In the port of Rostock these regulations are derived from legislation on the level of the federal state Mecklenburg – Vorpommern and a risk analysis which uses a probabilistic approach. Meanwhile shipping and bunkering companies as well as the port authority made first experiences with this set of rules during some truck to ship bunker operations in the port. These confirm that the permit procedures are easily manageable and allow a flexible and fast bunkering procedure.

Dr. Udo Schlemmer-Kelling; FEV Europe GmbH

Technology Evaluation to Comply with Future Challenges in the Marine Buisiness

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During the 2015/16 time frame IMO has defined more stringent future emission regulations for the maritime business. Emission species like NO_X, SO_X and CO_2 will have to be reduced at decided introduction dates. To cope with these challenges, R&D efforts from several parties have been already started.
In short words the current situation can be characterized as follows:

- Technologies for NOX reduction are more or less trouble-free in operation.
- Bigger improvement of CO2 Emission is limited to physical sonic walls.
- SOX emission technologies are operating in prototypes on board of ships and are not the favorite of the ship operators.
- Gas operation (LNG) is relatively new in marine business but seems to be a green but very expensive solution.
- Mineral oils will become cleaner in near future and is the established fuel today.

Because there are so many aspects to be taken in consideration, the situation in the maritime business is not very clear. Based on a FEV developed road map, which was shown on the last GMTR in Rostock, all technical options for emission reduction are analyzed in detail and evaluated with respect to readiness of technology and financial aspects. In detail these technology blocks are:

- CO2 reduction via 2- stage charging, peak cylinder increase or waste heat recovery
- SOX reduction via scrubber or low sulfur fuel
- NOX reduction via Miller cycle, EGR or SCR catalyst
- Soot reduction via PM filter or Common Rail
- Fuel type: LNG or oil

Due to the fact that maritime applications are varying in a wide range advices are given how technology modules should be combined for the best owner related compromise. All technical solutions have pro’s and con’s and a solution like “one fits all” will not exist.

Jari Hyvönen, Tom Kaas; Wärtsilä Marin Power Solutions

Cylinder pressure based closed loop Combustion Controls, the Enabler for good Performance in medium-speed lean burn Gas Engines

The fast development of digital solutions applied in all possible technical areas and the awareness of the challenge with pollution and global warming, the comparably old reciprocating internal combustion engine technology have also reached new highlights thanks to digitalization in the form of improved engine controls.

The medium speed lean burn gas engine performance, regarding Break Mean Effective Pressure [BMEP] and engine brake efficiency, at about 1 g/kWh exhaust gas Nitrogen Oxides [NOx] emissions levels, have improved to unforeseen levels during the past 25 years. Engine power density have doubled at the same time as engine brake efficiency has improved 25%. Starting from BMEP levels of about 14bar and brake efficiencies about 40% in the early nineteen's, the BMEP of the latest two-stage turbo charged gas engines using advanced Miller valve timings, reach up to 30 bar BMEP and brake efficiencies in the best cases above 50%. The lean burn gas engines are today widely used as power source in both the very safety and reliability minded marine industry and in the power density and operating cost focused stationary power generation applications. In both cases the enabler for improved engine performance, additionally to new technical solutions on the mechanical side, have been ever improving engine controls. The operating profile of the engines has gone from slow transfers from one operating point to another to fast transient load control supporting electrical grid stability or the operation of main and auxiliary engines in marine vessels, while all the time maintaining optimal combustion in all cylinders.

The combustion process in a pre-mixed lean burn gas engine is inherently unstable. While burning the gas at high air-fuel ratios to reach low NOx levels and at the same time maximizing BMEP, the combustion control is a balance between end-gas auto-ignition, i.e. knocking, and quenching of the propagating flame, i.e. misfiring. Taking into account that the operating condition in all the different cylinders are unique in the sense that the span of cylinder wise operating conditions in all the cylinders are larger than the operating window in each cylinder. This means that each cylinder have to be operated according to its specific conditions to maintain combustion in the optimal window. Without cylinder wise closed loop combustion control this is not possible at the high engine load levels in use today. In the early days of closed loop controls the main combustion feedback signal was knock, i.e. via vibration sensors, in combination with exhaust gas temperature after the cylinder. Today the key enabler for the faster and more accurate controls is the cylinder pressure sensor. By analysing the combustion initiation and progress in each cylinder with a pressure sensor, both avoiding uncontrolled combustion, as knock, misfiring, or too high cylinder pressures, and optimizing the position of the heat release, optimal combustion performance for the cylinder specific conditions can be achieved.

Abstract

Analysing the combustion by cylinder pressure sensor data has been a standard and well established engine combustion development tool for decades. Analysis methodology starting from cylinder pressure trace statistics to more or less advanced heat release analysis has been developed for engine testing during the years. The most advanced cylinder pressure analytics have been done off-line at the office. However, the transfer from the in engine testing performed cylinder pressure analytics to implemented real-time engine controls have been and are still limited by the capability of the available sensors and engine control hardware. Step-by-step the combustion controls have become more advance and the development will continue still for a long time. Today additionally to the safety functionality against high cylinder pressure, knocking, and misfiring, new controls for combustion phasing and cylinder loading are used. Closed Loop Combustion Controls based on the Crank Angle of 50% burned [CA50] and Indicated Mean Effective Pressure [IMEP] are two key variables for optimal combustion performance.

This article reviews the combustion control development during the past 25 years at Wärtsilä and especially the latest cylinder pressure based controls that enables BMEP and brake efficiencies levels of 30bar and 50% respectively.

Markus Aberle, Alexander Kremser, Dr. Michael Willmann; L'Orange GmbH Stuttgart
L'ONOX - Urea dosing system for large engines

Due to increasing restrictions for exhaust gas emission of combustion engines (e. g. IMO Tier III and EPA Tier IV for large engines) new technologies of exhaust gas after treatment need to be introduced to the large engine market. One focus is on the reduction of nitrogen monoxide and nitrogen dioxide emission. One of the preferred systems to reach the tight restriction in the automobile industry as well as in the large engine business is the Selective Reduction System (SCR). This system uses an aqueous urea solution, which gets injected into the exhaust pipe in front of an catalytic reactor.
The most systems available on the market are based on automotive components where several dosing units are used in parallel to reach the requested quantity of aqueous urea solution. On the other hand there are expensive air assisted systems available for big power plants and large facilities.
The urea dosing system from L'Orange (L'ONOx) is explicit developed for large engines in stationary and non-stationary applications. Compared to other air-assisted and airless systems the overall layout is simplified, so less components are necessary to reach the same dosing quantity and quality. The dosing units are connected similar to a Common-Rail-System which is approved and well known in diesel injection systems. The L'ONOx urea dosing system can handle up to four dosing units with only one supply unit (pump). In this configuration it is possible to serve several exhaust gas pipes or SCR-Reactors within a single system.
The integration of a L'ONOx system is quite simple: The communication between the engine ECU and the L'ONOx Master Control Unit is set up via CAN-Bus protocol J1939. Depending on the engine ECU integrated NOx measurement and NOx calculation the needed quantity of aqueous urea solution is sent to the L'ONOx Master Control Unit and the injection gets started. The L'ONOx Master Control Unit monitors the dosing sequences and shares the information about the success of every injection event with the engine ECU.
The dosing unit can be customized to different applications (e.g. different mass flow or spray angle). Due to the architecture used and the flexible concept it is possible to apply L'ONOx systems for OEM application as well as for retrofit solutions.

Dr. Daniel Chatterjee; Rolls-Royce Power Systems AG, Mathias Bauknecht, Michael Engelhardt, Klaus Rusch; MTU Friedrichshafen GmbH

The New Generation of MTU High-Speed Genset Engines with Exhaust Aftertreatment - Challenges and Solutions

Large high speed engines in off highway applications cover today a power range from a few kW up to 10 MW DC. They are used in various applications like propulsion systems for trains, agriculture machines or ships. Compared to medium speed engines they provide a better power to weight ratio and better transient response. Historically high speed engines are typically used for emergency or backup power or temporary power solutions. Due to the increased volatility in the power grid, imposed by the increased share of renewable energy, decentralized power generation with high speed engines has become a relevant option. Similar to mobile applications emission legislations for power generation engines have and will become stricter. Besides emission legislation, local standards require the application of exhaust gas aftertreatment.

Compared to well-known systems with base load engines – mostly medium speed engines – the available space, the necessary dynamics and the variability of fuels used for the same engine put very high demands on systems for peak shaving, control energy and emergency power. The new generation of MTU high speed diesel engines is designed towards the use and integration of high performance exhaust aftertreatment systems e.g. with high backpressure capability.

In order to comply with current and future more stringent legislation and with the demand for small, cost effective and efficient systems, a close interaction between engine and SCR control algorithms is necessary. Traditional control strategies for stationary engines using a simple feed forward control logic based on a load or speed signal can only control a SCR system with low dynamic requirements in a narrow operating window. New control algorithms for SCR and DPF systems will be discussed fulfilling the demands for high performance, fast dynamic and operation with different fuel qualities. Strategies originally developed for on-road use have been adapted and expanded to more complex models including feedback control from exhaust quality sensors.

Whereas on-road engines and after treatment systems normally are designed for only limited operation at full load, diesel gensets have much higher share of full load operation which leads to exhaust aftertreatment systems capable for operation at or even above 500 °C at constant operation, putting new demands on thermal stability and the operational window.

Compact system for exhaust gas after treatment with simultaneous high durability and high performance regarding the reduction of harmful exhaust components requires a very precise design of each component. A modular system architecture allows to optimize the engine and aftertreatment system as a whole. The talk will discuss how far technologies from on-road use can be used for genset exhaust aftertreatment. Starting from catalysts and DPF technologies via exhaust sensors and urea mixers up to canning technologies for fast exchange of aftertreatment components.

The presentation further discusses simulation and modelling technologies from the level of the entire system down to components and reports on testing and field ageing experience. Additionally an outlook to gas engines, which will also be affected by stricter emission legislations, will be presented. Due to the fact that maritime applications are varying in a wide range advices are given how technology modules should be combined for the best owner related compromise. All technical solutions have pro’s and con’s and a solution like “one fits all” will not exist.

Lothar Meinders; Briese Schiffahrts GmbH & Co. KG

Experiences from the construction, supervision and operation of the installation of new engines with exhaust gas treatment on RV “Heincke”

In 2015 research vessel "HEINCKE" has been equipped with modern Diesel-engines and exhaust gas after-treatment. The aim is to reduce the nitrogen oxide and sooty particle emissions of the vessel as much as possible. The engines shall continue to be operated with Marine Gas Oil (Grade DMA) and a sulphur content of max 10 mg/kg, which is a challenge in regards to the operation of particulate filters.

The research vessel "HEINCKE" is operated by the Alfred Wegner Institute in Bremerhaven on behalf of the Federal Ministry of Education and Research (BMBF) in order to conduct multidisciplinary research. Its main operational areas are the North and Baltic Sea as well as the North Polar Region in the area of Spitsbergen. As a state-owned research vessel, it has a pioneering role in fullfilling environmental requirements beyond the law regulations. In particular, the topic of black carbon is seen very critically in the context of the melting ice in the artic region by the researchers themselves and also by the environmental associations.

In addition to the demand for the highest possible purity of the exhaust gas, however, the permanent operational safety of the ocean-going research vessel had to be considered. Technical experiments should never be done at the expense of the operational safety of the ship.

With the presentation we would like to give an impression from the point of view of the operator, what had to be considered during the project planning, which problems occurred during the installation and which experiences could be collected in the first three years of operation.

With regard to the construction of further research vessels and the further legal requirements in relation of black carbon, we want to encourage and motivate engine manufacturers of medium-speed engines for further developments in this area.

Prof. Konstantinos Boulouchos, Christophe Barro, Sushant Pandurangi, Ales Srna, Hyunchun Park, Panagiotis Kyrtatos, Yuri Wright (LAV, ETH Zürich)

Physicochemical Effects and Understanding of Ignition and Combustion in Dual-Fuel Engines

The use of natural gas in internal combustion engines is becoming ever more popular. Compressed natural gas (CNG), which contains methane as its main component, offers a CO2 reduction potential compared to liquid fossil fuels due to its reduced carbon to hydrogen ratio. In recent years, engine manufacturers have developed and introduced dual fuel engines using production diesel engines as a basis. These dual fuel engines use a pilot diesel spray to ignite a premixed gas mixture, and can now reach the power density and efficiency of equivalent diesel engines.

The combustion process in such dual fuel engines is very complex. The interaction between the liquid fuel injection and subsequent autoignition process, as well as the flame front establishment and development in the air/natural gas substrate are difficult to understand and to describe. This work presents state of the art modelling approaches for the dual fuel ignition process and the understanding that is obtained through their use. On the one hand, a Flamelet Generated Manifold (FGM) combustion model in the 3D-CFD context is used to study the impact of equivalence ratio of the base charge on ignition delay and location; validation is performed by means of data from an optically accessible Rapid Compression Expansion Machine (RCEM). In addition, phenomenological models capturing the most important effects have been developed and are used to show the process limitations.

It is well established that the ignition process in a diesel engine shows two main time scales: a kinetic (dominated by the cetane number of the fuel as well as the charge temperature and composition) and a fluid mechanic, which is a function of the mixing of the fuel with the charge. In comparison, the current investigations show that the dual fuel ignition process shows an additional kinetic component dependent on the charge composition, as well as more complex mixing processes, since the ignition occurs usually after the end of injection. The effects have been found to show strong cross sensitivity and thus should be included in any modelling as well as any engine design and optimisation consideration. In a further complication, different ignition delays also lead to different ignition locations due to the momentum of the spray. The change in ignition location affects the initial flame area and thus the flame-propagation dominated combustion process thereafter. In this work the abovementioned effects are studied using the two modelling frameworks.

Prof. Hiroshi Tashima, Prof. Daisuke Tsuru (Kyushu University), Ryosuke Ishibashi (Mitsui Engineering & Shipbuilding Co., ltd.

Consideration of Engine Size Effects on Heat Loss Focusing Large Low - Speed Marine Diesels

Large low-speed marine diesels outperform any other combustion engines working on a single heat cycle with their ultimate thermal efficiency up to 55% even on the lower calorific value of the fuel. The main reason has been considered to lie in their less heat-loss nature, and they actually lose only about 10% of the fuel energy through the chamber wall. Although their smaller surface-to-volume (SV) ratio or a “Square-cube law” is apt to be pointed as the theoretical ground, the law is not good enough to explain the nature because efficiencies and losses of piston engines should be discussed not per unittime (ex. hour or day) but per one engine cycle. This means the lower revolution of larger engines may offset the merit of their smaller SV ratio.

As for heat transfer aspects, many heat transfer models have been proposed to give reasonable estimation of the heat transfer between in-cylinder gas and chamber walls. Those models have been developed and validated in smaller engines. However, small high-speed diesels and large low-speed diesels differ entirely both in wall configuration and spray layout over the combustion chamber. To make matters worse, model parameters are usually optimized from engine to engine. All in all, it has to be said the less heat-loss nature of large diesels is only an empirical fact that has not been made theoretically clear. In this study, backgrounds of the heat loss issues of piston engines were investigated in detail thorough two approaches.

At first, a comprehensive survey was done to check the adaptability of asimilarity law from high-speed small diesels to low-speed large diesels. The survey revealed that marine low-speed engines rotatemuch more slowly than the others, and therefore they have longer cycle time than expected on their bore size. The SV ratio and other indexes were also sampled and discussed.

Second, heat transfer models were equally adopted to a small high-speed engine (100 mm bore, 2000 rpm) and a large low-speed engine (400 mm bore, 140 rpm) with keeping model parameters exactly the same. In the first stage, a 1D engine simulator with a macro heat transfer model; Woschni model was adopted. Although the heat transfer model includes the engine size effect as minus two tenth power of the bore size, the simulatoroverestimatedthe heat loss of the large engine especially in the late expansion stroke. In the second stage, a combination of a 3D CFD code witha boundary-layer-based heat transfer model;Hang-Reitz model was adopted to reflect the real chamber configuration and the spray specifications. The results finally showed good agreement with the expectation of the heat losses for the both engines and succeeded to clarify the background of the difference between them.

Dr. Martin Reißig (FVTR GmbH)

eta-up - Reduction of parasitic Losses of medium-speed Diesel Engines

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During the last decades, the overall efficiency of two-stroke and four-stroke large bore diesel engine were unreached by any other engine application. Besides fuel consumption, durability and robustness were the major development targets. Simultaneously, smaller engine categories like heavy-duty truck engines achieved significant progress not only regarding indicated efficiency but also regarding mechanical efficiency. Efforts to improve the combustion process itself increases exponentially with new technologies. As such, the large bore engine community has to unlock new potentials from other efficiency influencing engine parameters. One of them is the improvement of the mechanical efficiency. Bearing dimensions, engine oil and cooling water temperatures, engine oil supply flow levels and friction between partners like piston and liner are just a few points were a large bore engine is some kind of a victim of its own conservative design.

Within the public founded eta-up project, a consortium formed with the aim to decrease the parasitic losses of medium speed diesel engines almost by half. This reduction would lead to an improvement in fuel consumption of up to 5 %. Therefore, the engine out emissions will decrease as well by up to 5 %.

To investigate the friction behaviour of a modern medium speed diesel engine the cooling and lubricating systems of an existing test bed with a MaK 6M20 was upgraded on different levels: . All media circuits are now separated from the engine and can operated electrically. Flow rates and temperature levels can be regulated individually. Furthermore, one of the six cylinders is equipped with a specially machined piston that features surface thermocouples at the top side and bottom of the piston crown. Additionally to the test bed, measurements the project partners utilize new and self-developed simulation approaches to analyse all major friction partners like shafts, bearings, piston and liner regarding their potential to minimize losses by a right-sized design. A demand-actuated oil flow supply, as it is state of the art at smaller engines, will help lowering the primary energy consumption. In extension, coolant and lubricating oil temperatures as known from heavy-duty engines will be investigated with the aim to lower the friction losses any further. As another effect, the capability of waste heat utilization on basis of the higher temperature levels is one point of the system considerations. To make a significant contribution to the energy transition large bore engines will have to take different fields of development, like gaseous fuels, synthetic CO2-neutral fuels and waste heat recovery into account. This paper gives an overview on selected experimental results in the field of friction loss avoidance and highlights the chosen simulation approaches and development targets.

Marco Coppo, Klaus M. Heim (OMT S.p.A.)

From Biggest to Smallest Injection Quantities - OMT Common Rail Technology for Low- and Medium-Speed Engines

OMT's common rail injector family, which includes designs suitable for medium speed and low speed engines of various bore sizes, was presented at the 4th Rostock Large Engine Symposium in 2016.

Since then, the low speed version completed a 10'000 hrs field service test on an MAN S50ME-C engine installed on a shuttle tanker with very good results in terms of performance stability and reliability. This led MAN Diesel & Turbo to adopt this technology and launch its first S35ME-C common rail engine. The engine was successfully type-approved in January 2018 and the first vessel equipped with this new type of common rail engine is scheduled to operate from June 2018.

As well as presenting the evolution of the low speed version and engine test results, the paper outlines the latest developments of the medium speed injector version , which were particularly focussed on the design optimisation needed to achieve very small injected quantities suitable for gas pilot ignition, as well as reliable full power operation in liquid fuel mode.

A significant part of this work was dedicated to improving the nozzle design. Hydraulic and CFD analyses were carried out to optimise seat and sac geometry with the aim of minimising vortexes and flow separation from the walls to reduce erosion wear on the needle seat passages, as well as ensuring uniform flow distribution to all the spray holes and minimising the occurrence of cavitation.

Numerical analysis and injection rig tests in OMT were complemented with a detailed spray analysis performed by FVTR to study the effect of nozzle geometry on spray formation. This was particularly useful for assessing injector performance in operation conditions typical of a dual fuel engine running in gas mode.

The paper presents the results of such investigations as well as the most recent injection system implementations OMT is providing for its medium speed engine customers.

Dr. Bernhard Pemp, Dr. Christoph Kendlbacher, Martin Bernhaupt (Robert Bosch AG)
Injection systems for China marine emissions and measures to improve the fuel consumption

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In August 2016 the Ministry of Environmental Protection of the People's Republic of China, MEP legislated the first national emission standards for inland shipping. Those standards are similar to US EPA TIER 2/3 and are valid from 37 kW up to a cylinder swept volume of 30 dm3. Phase 1, valid from July 2018 on, leads to a reduction of 30 percent of the emitted NOx – and 60 percent of PM – emissions compared to unregulated engines. With the introduction of Phase 2 the allowed emitted NOx – emissions are further reduced by 20 percent, the emitted PM, depending on category, 40 to 48 percent.

The present paper point out the technologies and components which are favored by BOSCH for fulfillment of CN Phase 1 and 2. For conformance of mentioned emission regulations a well-balanced, and therefore a future-proof overall system, which includes a state of the art common rail injection, is needed. If the injection system is somehow restricted, other subsystems, e.g. the charging group, have to be optimized above the ordinary. That circumstance can lead to limitations regarding the use of the engine in different applications.

A further essential building block for performance and emission optimization is the control of the combustion. High engine speeds and a cylinder number up to 24 are very demanding for the used ECU. All components which are described are intended to be used in an overall system, but single us of them is also possible.

In the last part of the paper the optimization potential with the MCRS injection system is shown. A comparison to conventional ones is made and the advantages of a common rail systems are highlighted.

Dr. Silvio Risse, Klaus Buchmann (Kompressorenbau Bannewitz GmbH)

Single-stage exhaust-gas turbocharging for the highest pressure ratios - challenges and solutions

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Single-stage turbocharged, dual-fuel engines can run on both diesel to keep costs low and on gas to keep emissions low. This flexibility places high demands on the engine and exhaust-gas turbocharging. The key requirements include achieving a good performance for the different operating lines in the diesel and gas operating modes as well as proving this in the compressor map and, of course, meeting the higher boost pressure requirements in the diesel operating mode. KBB has further developed its ST27 series with single-stage turbocharging up to a pressure ratio of 6.0:1 to fulfill these requirements. The development of the new ST27-EP series essentially focussed on aims such as optimising the thermodynamics, rotor dynamics and heat balance of the exhaust-gas turbocharger. A further increase in pressure, however, is a great challenge for single-stage turbocharging not only in terms of thermodynamics but also the market-relevant lifetime expectations.

The continuous monitoring of exhaust-gas turbochargers and evaluation of the measured results are of great assistance in the development and optimisation of exhaust-gas turbochargers. The specific monitoring of exhaust-gas turbochargers can also contribute to reducing life-cycle costs by targeted, condition-based turbocharger maintenance. This primarily applies to applications with changing load profiles or widely varying intake temperatures. The paper addresses this potential and also presents approaches on how to integrate exhaust-gas turbocharger monitoring on an engine.

M. Sc. Karsten Stenzel (WTZ Roßlau)

Research on the influence of various water supply procedures to the combustion process of dual-fuel engines

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The worldwide trade without the application of highly efficient diesel engines is inconceivable. At the same time this leads to high nitrogen oxide emissions due to the relatively low engine speed and high combustion temperatures. The latest developments in the field of marine diesel engines are marked by compliance of emission regulations, maintaining high levels of efficiency. The efforts to find an ideal solution for this complex challenge had to be stepped up with the introduction of the IMO Tier III nitrogen oxide limit within acknowledged emission control areas in 2016. Set against this background, WTZ Roßlau conducted large-scale examinations on a single-cylinder research engine with a dual-fuel combustion process. Researches were conducted on how the use of a water-in-fuel emulsion, a suction pipe and a direct water injection influence the pollutant emission, the efficiency and the combustion stability, whilst the highest water contents were at 60%.

Depending on the water supply procedure the nitrogen oxide emission in diesel operation could be reduced by 40% to 50%. At the same time the filter smoke number could only be improved when using the water-in-fuel emulsion. The use of the suction pipe and the direct water injection leads to a reduction of nitrogen oxide emission by 40% in dual-fuel engines, whereas the IMO Tier III NOX limit can be undercut starting from a water content of 30% to 40%. On the contrary, the use of water-in-fuel emulsion in conjunction with an energetic pilot fuel quantity under 40% leads to a prolonged ignition delay which causes rising nitrogen oxide emissions. However, at the same nitrogen oxide emission, the combustion stability and the filter smoke number can be improved by combining the suction pipe or the direct water injection with a water-in-fuel emulsion. The use of a water-in-fuel emulsion in heavy oil operation carries a high operational risk. However, this risk can be considerably reduced with the use of the suction pipe and the direct water injection. An alternative solution is to shift the emulsification process into the injector body.

Johannes Konrad (IFA, TU Wien)

Skip Firing in Medium Speed Dual-Fuel Engines: Detailed Assessment and Engine Performance Optimization in Compliance with IMO Tier III

Globally, a rising number of maritime emission control areas - determined by the International Maritime Council - are in force or will become applicable in the near future, like the NOx emission control areas in North America and in the Baltic & North Sea from 2021. Therefore, the demand for mostly environmental neutral and also efficient propulsion systems that meet the maritime emission legislations and minimize the cargo costs is immense. Medium speed dual fuel engines are a good match. They are in accordance with the strict maritime NOx emissions legislation Tier III, are economically competitive, do not require any exhaust gas aftertreatment, and allow fuel flexibility.

The cylinder deactivation is applied for a medium speed dual fuel engine based on a predictive 1D GT-Power simulation model that is validated against test bench data, NO emission, and knock onset. Static cylinder deactivation and skip firing sequences are simulated, compared and assessed according to the resulting load depending efficiency, methane slip, and NO emission. Based on the found effects, an optimization workflow is set up in the commercial optimization software Optimus. The selected evolutionary optimization algorithm varies the static cylinder deactivation and skip firing sequence as well as the relative air/fuel equivalence ratio to optimize the load-specific engine efficiency under consideration of IMO Tier III and knock onset. The optimization is executed for discrete engine operation points in a load range from 10% to more than 50%.

The optimization predicts a significant increase of the brake efficiency and reduced methane slip at low and part load operation. This depends on an increased turbocharger efficiency, reduced pumping work, richer combustion, and higher indicated mean effective pressures of the fired cylinders. The skip firing sequences show an increased efficiency compared to the static cylinder deactivation, mostly due to improved scavenging effects and a reduced remaining unburned gas fraction. The increased indicated mean effective pressure of the fired cylinders leads to an improved combustion (shifted from diesel diffusion to natural gas premix) and engine efficiency without exceeding the IMO Tier III NOx emission and knock limits.

Horst Brünnet (SCHALLER Automation Industrielle Automationstechnik GmbH & Co. KG)

Formation and Avoidance of Crankcase Explosions in large Oil, Dual-Fuel and Gas Engines

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Crankcase explosions have always been and still are a serious threat for the operation of large 2- and 4-stroke engines. The investigations into the phenomenon started in 1947 when a dramatic crankcase explosion caused by oil mist led to the death of 28 people. Since then, SOLAS regulations and classification society rules have been established for the monitoring of dangerous oil mist levels within the crankcase as well as the corresponding type approval procedures for monitoring devices such as the oil mist detector. However, the detection of thermally generated oil mist due to severe mechanical failures or lack of lubrication can only avoid severe explosions but no damage to the mechanical components as source of the oil mist. Furthermore, the increasing population of LNG gas-fueled engines leads to another possible source for explosions within the crankcase: methane. Caused by blow-by effects in 4-stroke engines, unburned methane enters the crankcase and may accumulate to levels close to the LEL. Even though the severity of methane induced explosions compared to oil mist explosions is still scope of current discussions within the technical community, it should be avoided either way.

This paper gives an overview about the formation and avoidance of crankcase explosions in large oil, dual-fuel and gas engines. Results of crankcase atmosphere analyses are presented with respect to methane, volatile organic compounds (VOC), inert gas but also oxygen levels for different engine operating modes such as load variations but also fuel alterations. Further, a future condition monitoring approach is presented to detect the oil mist formation mechanisms. Finally, a concept is proposed to combine oil mist detection, methane (gas) detection and condition monitoring sensors to act as an early warning system for the risk of crankcase explosions.

Dr. Sturm, Michael; Banck, Andreas; Rickert, Carsten; Hoff, Marius (Caterpillar Motoren GmbH & Co. KG)

CHP - market demand and optimized solutions with the Caterpillar G20CM34 10 MW gas engine

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Natural gas constantly expands its percentage share of the worldwide total energy consumption. This trend is expected to continue during upcoming decades. Facing varying emission regulations and individual customer requirements, flexibility of modern gas engines for electric power generation gains in importance. To meet these requirements, different applications of the G20CM34 lean burn Otto-gas engine were developed. The goal is to provide the nominal engine power output of 10 MW (720rpm) respectively 10.5 MW (750rpm) at high engine efficiency and low NOx emissions within a wide range of changing boundary conditions (altitude, ambient temperature, fuel composition, plant operation mode). As a result, customized engine setups can be provided, serving customer individual needs at specific sites. In addition to these requirements, today's power plants must meet complex requirements regarding their operation mode and strategy. Consequently, cogeneration is becoming more and more important. In general, the use of waste heat reduces the primary energy demand. This is a desirable objective from an ecological as well as from an economic point of view. So, in addition to "pure power generator", various CHP applications were considered for the Caterpillar G20CM34. These include a "Combined Cycle", in which additional electrical energy is produced by a Bottoming-Cycle as well as a "Combined Heat and Power" mode in which the waste heat is used for heating purposes. Depending on the geographic location of the power plant, combinations of both technologies are conceivable to optimally serve the customer needs and thus to ensure a financial benefit for the customer. The key markets are used to assess each application and thus to derive the technical solution for the system. These solutions are exemplarily discussed and presented in this paper. In this context, the importance of highly flexible CHP power plants becomes clearer as a supporter to the future with higher portions of renewables.

Maximilian Malin; Mayr, Philipp; Pirker, Gerhard; Wimmer, Andreas; Zelenka, Jan (LEC Graz)

Development of Highly Flexible Large Gas Engines for the Power Plants of the Future

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Flexible power generation units are becoming increasingly important due to the growing share of renewable energy sources (wind, sun) and their greatly fluctuating availability. Each installed wind and solar power unit requires nearly the same amount of installed backup power. Modern gas engines are already capable of providing electrical power at high efficiency and with only minor environmental impacts within a short space of time. However, the requirements for transient characteristics will continue to increase so that future power plants can be efficiently operated (Prime Power). Improving transient operation of gas engines has thus become one of the most important development tasks. This encompasses combustion concepts as well as effective engine control, whereby compliance with emission limits in transient operation must also be guaranteed.
This paper starts with a comprehensive overview of the requirements for flexible power generation. The regulations for various applications (primary reserves, secondary reserves, emergency) are compared and then examined for their implications for engine development. The methodology must be enhanced in both simulation and experiments in order to meet these requirements during the development process. Due to the enormous number of free parameters in transient applications, it is imperative that simulation methods are increasingly used in the predesign of combustion and control concepts. Detailed transient 0D and 1D gas exchange calculations serve as the basis. Testing of concepts developed using simulation is conducted on a single cylinder test bed that allows transient operation. Multicylinder engine behavior is simulated on the SCE test bed using a hardware-in-the-loop approach. In addition to describing the methods for simulation and experiments, the paper also explains which technological components are required for highly transient gas engine operation.