Dual fuel four stroke lean burn engine supercharging system operational features

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***Abstract**: In the present publication are considered the features of the dual fuel four stroke lean burn engines supercharging system operational features. The supercharging system control means are analysed and performance data is collected from an engine in operation on an offshore vessel. The data obtained from the engine in operation is analysed, processed and figures of related parameters are obtained. The latter are analysed in relation to the importance of the supercharging technical condition. Conclusions and recommendations are stated as a final outcome.*

***Keywords**: DUAL FUEL LEAN BURN FOUR STROKE MARINE ENGINE, SUPERCHARGING SYSTEM CONTROL, WASTE GATE, MARINE TURBOCHARGER SPEED CONTROL*

1. Introduction

With the present energy transition forced changes in the marine industry there are new dual fuel engines introduced in the ship power plants, which have different behavior on gas mode operation, compared with the conventional diesel engines. As a matter of fact, these engines operate on Diesel cycle while operating on liquid fuel and change to Otto cycle while on gas.

There are specifics in the operation of the subsystems of the Lean burn Otto cycle engines such as the gas supply and the supercharging system. The operation of the supercharging system on gas mode is critical for the ability of the engine to run safe and in case of system deteriorated condition it could be even impossible to run on gas.

The information related to the specifics of the supercharging systems on the dual fuel four stroke engines are well known to the engine manufacturers but mainly remain in their envelope. The general knowledge for the supercharging systems of the dual fuel engines on gas mode should be populated and better disseminated.

In this publication the aim is to be presented the features of the supercharging system control components and the logic of the control system dealing with the air-fuel ratio on gas mode of operation. The tasks linked to the aim stated are to be collected data for the charge air system operation on dual fuel engine Wärtsilä 34DF and the data to be analyzed in respect to the features of the charge air pressure control.

2. The dual fuel four stroke engine type Wärtsilä 34DF

The object in the publication is a four-stroke dual fuel engine Wärtsilä 34DF operating in the medium speed range has the characteristics as shown in Table 1 [1].

***Table 1:** Engine 34DF characteristics*

Wärtsilä 34DF	
Cylinder bore	340 mm
Speed	650 - 720 RPM
Power output	5760 kW
Turbocharger maximum RPM	32500

The engine is part of the ship power plant of an offshore supply vessel and operates in the range of 650 – 720 RPM depending on the mode of operation. There are two turbochargers Napier NT 1-10 co-operating with the engine with specific control system components – bypass valve and waste gate system, dealing with the pressure control in two different modes – nominal and low load operation.

A sectional view of the V-type engine is shown on a figure 1 [2]. It is trunk engine, twin bank with scavenge manifold positioned between the two engine blocks.

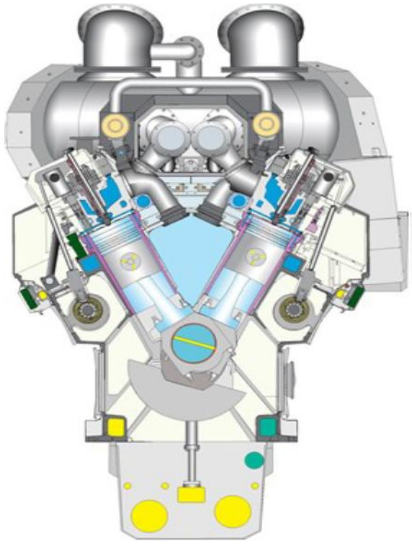

***Fig. 1** Sectional view of V34DF [2]*

2.1 Engine turbocharging control system

The function of the bypass valve is to increase the pressure of the air charge, supporting the operation of the turbocharger turbine at low engine load. It is positioned before the air cooler of the engine in order to recirculate part of the air flow. By a command from the engine control system to open it, it diverts part of the still uncooled portion of air directly to the inlet of the turbine side of the turbocharger, thereby helping to increase the turbine speed, followed by an increase of the charge air pressure in the receiver. This distinctive feature of the engine improves its performance at low loads by reducing the thermal load and avoids unwanted additional smoke creation.

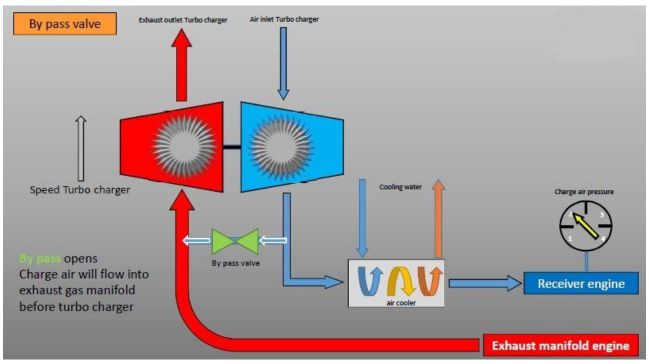

***Fig. 2 Charge air bypass valve** [2]*

The waste gate valve is installed in the exhaust gas flow path before the turbine side of the turbocharger. One of its functions is a safe activation in a high engine load mode [2]. Its function is to be opened for bypassing part of the flow of exhaust gases off the turbine upon reaching the critical values in terms of revolutions per minute for the turbocharger shaft and charge air pressure in the receiver

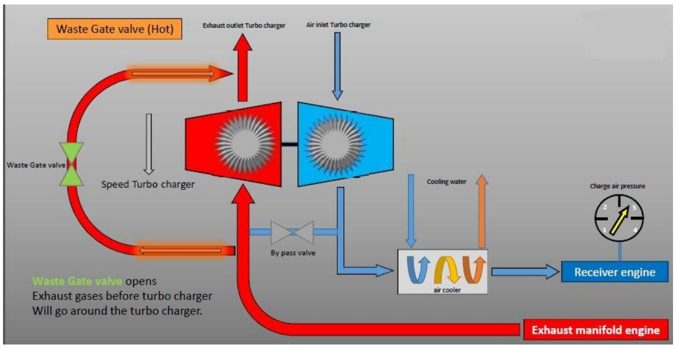

Fig. 3 *Waste gate valve [2]*

In addition, the main distinguishing feature of the waste gate is the control of the charge air pressure and thus the stability of the fuel ignition. By precisely adjusting its opening, the flow of exhaust gases entering the turbine side of the turbocharger unit is bypassed, by routing them directly to the funnel. In this way, regulation/reduction of the revolutions developed by the turbocharger is achieved, in a large range of the rotation speed and wide range of the engine power. This function determines the waste gate valve as a regulator of the maximum values of λ within the limits of a lean fuel-air mixture, preventing it from exceeding its upper limit, which would lead to problems in the combustion process, increasing the NOx formation and tending to engine knocking.

The waste gate valve control is carried out by the engine control system which monitors the value of the air pressure in the receiver and if the pressure of the charge air is higher than the set value it sends a command to gradually open the waste gate valve, until the correct pressure value set in the engine map is reached. In the event that the pressure drops below this value, the engine control system commands to gradually close the waste gate valve until the correct value of the charge air pressure is reached again. The control logic is implemented in the engine control system and no external regulators are needed [2].

3. Performance results of the turbocharging system

For the purpose of the task execution in this publication, there are collected the results of the performance of the supercharging system in variable modes from 25% to 100% load modes of the engine with liquid and gas fuel in use in actual operation of the engine, by using the engine monitoring system for data acquisition of the parameters. The condition of the engine could be evaluated as optimal as the data was attained on a mode of sea trials of the ship power plant. Due to the different control approach on both modes, there can be seen the significant differences in the supercharging system behavior. There are differences in the turbocharger performance due to the control action of the charge air bypass valve and the waste gate valve operation by the engine control system.

In table 2 are presented the results of the turbocharger RPM in the variety of the loads of the engine. It could be noticed that the revolutions of the turbocharger are higher on low load mode at gas fuel mode and tend to decrease at higher loads compared to the liquid fuel mode.

Table 2. *Turbocharger RPM*

Turbocharger RPM					
Load %	25	50	75	90	100
LNG	12315	20290	24340	25855	27045
MDO	8370	21560	25844	27845	29140

In the table 3 are presented the values of the charge air pressure in the scavenge air manifold in the both modes – liquid and gas fuel operation as the gas fuel supply pressure on gas mode of the engine.

Table 3. *Charge air and gas pressure*

Charge Air Pressure and fuel gas supply pressure (bar)					
LNG	0.4	1.39	2.46	2.93	3.35
MDO	0.15	1.61	2.88	3.64	4.12
GVU	**1.4**	**2.53**	**3.76**	**3.94**	**4.27**

The control positions of the waste gate valve and the charge air bypass valve for the liquid and gas fuel mode are shown on table 4 and table 5. It noticeable that the waste gate is utilized mostly on gas fuel mode and the charge air bypass valve is used on both modes mostly to facilitate the smokeless operation in low load operation.

Table 4 *Waste gate and charge air bypass valves control positions - gas*

Gas fuel mode operation					
Load %	25	50	75	90	100
Waste gate [%]	12	5	6	6	14
CA by-pass [%]	69	33	10	4	0

Table 5 *Waste gate and charge air bypass valves control positions - liquid*

Liquid fuel mode					
Load %	25	50	75	90	100
Waste gate [%]	0	0	0	0	8
CA by-pass [%]	31	37	20	8	0

3.1 Performance results analysis

A comparison of the RPM's of the turbocharger in both modes – liquid and gas fuel mode are shown on figure 4.

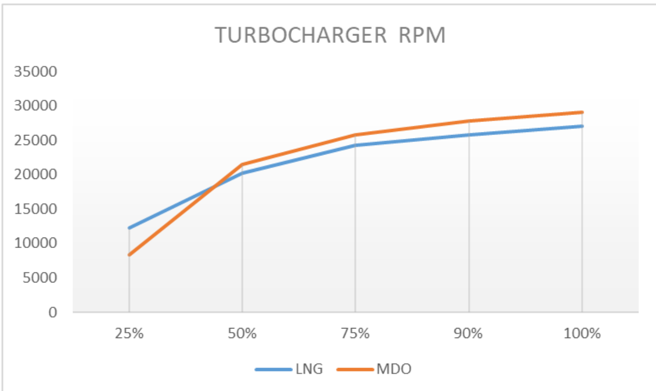

Fig. 4 *Turbocharger RPM comparison on gas and liquid fuel mode*

As it can be seen, there is a difference in the revolutions in low load of operation and the turbocharger is supported by the charge air bypass with intention to increase the turbine RPM. On the high load range, although the charge air bypass is still opened the waste gate allows part of the gases to go directly to the funnel thus controlling the turbocharger performance with relation to the charge air pressure control for the lean burn concept combustion execution.

On the figure 5 it can be seen the pressure developed by the turbocharger in both modes, compared to the fuel gas pressure supplied in the gas mode.

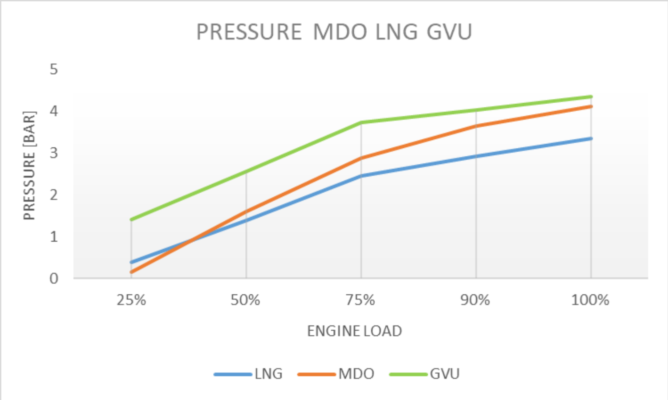

Fig. 5 *Charge air and gas pressure development*

The comparison of both lines with the orange and blue color on figure 5 shows the influence of the charge air control system on the performance of the system. The orange line representing the pressure development in liquid mode shows the simplified operation of the Diesel cycle engine compared to the gas fueled Otto engine with lean burn concept. Although there is surplus air in the combustion chamber of the engine it is not critical is it precisely metered to the fuel amount, so to obtain proper fuel-air ratio. Due to the non-homogeneous combustion of the Diesel cycle engines, there would be always rich fuel-air ratio areas in the combustion chamber which cannot be controlled due to the manner of fuel injection. It is the most significant difference with the presented subject engine in the publication. On gas mode the engine operates on homogeneous combustion which requires precise adjustment of the fuel-air ratio.

On figure 5 it could be seen another special feature of the gas fueled engine, the difference in the pressure of the charge air and gas fuel shown with blue and green color lines. There is strong dependence of the pressure difference between both fluids in the entire engine load range. The gas fuel pressure is kept higher with approximately one bar above the charge air pressure. In this relation the charge air pressure is controlled by the waste gate of the exhaust gases around the turbocharger turbine and the gas valve unit of the gas fuel system controls the supply pressure of the gas. Due to the specific mixing approach of the gas fuel and the air on gas mode it is necessary to have positive difference in the gas pressure compared to the air pressure in order to achieve proper routing of the flow of the mixture to the direction of the combustion chamber. The gas fuel is fed to the inlet charge air branch of the air manifold next to the inlet valve of the specific cylinder unit and to be sure that the gas will approach the combustion chamber the dosing gas valve has specific position and additionally the pressure must be kept with the difference described to not change the direction of the gas fuel aside from the combustion chamber to the scavenge manifold. If for any reason this pressure difference cannot be maintained there is direct safe issue with the gas operation of the engine.

On a figure 6 it is shown the opening value of the charge air bypass valve on gas mode of the engine. In an alignment with the intended use of the charge air bypass system the bypass valve is opened mostly in the low range load modes for the purpose of the smokeless combustion of the engine supported by the reverted flow of the hot charge air directly to the turbine side of the turbocharger. The bypass valve is fully closed at high load modes and supports the turbine in the mid and low range mode. It could be concluded that the by pass valve ability to support the turbine operation is similar to the control margin of the turbocharging system. If there is no sufficient air amount to be supplied to the turbine it would lead to smoke operation of the engine, especially in the low load ranges where the turbocharger operates with poor efficiency by default.

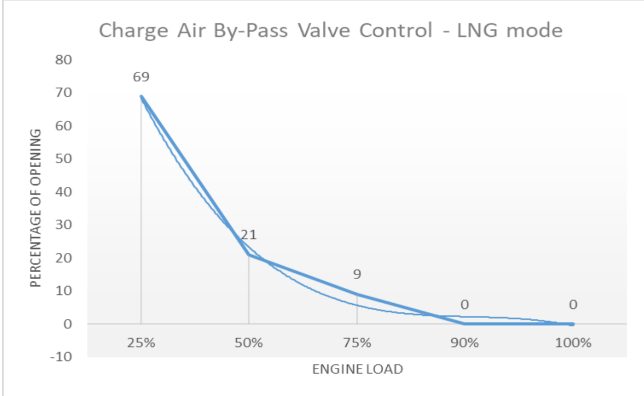

Fig. 6 *Charge air bypass valve operation*

On figure 7 it shown the waste gate valve operation in both modes – liquid and gas fuel mode.

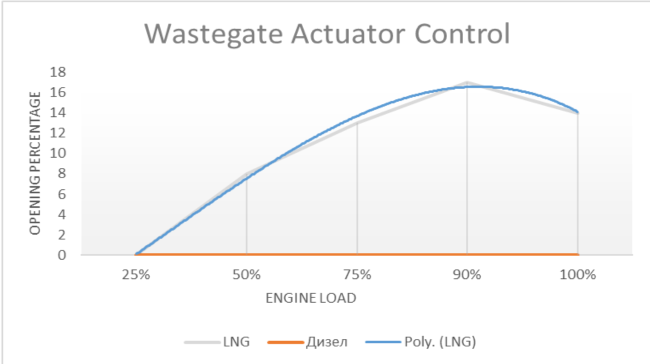

Fig. 7 *Waste gate valve operation on liquid and gas fuel mode*

The waste gate valve is used exclusively in gas fuel mode by the engine control system. As it was underlined its function is to keep the proper charge air pressure related to the engine load and the gas consumption, so to keep constant fuel-air ratio during gas mode operation. On liquid fuel mode the waste gate valve is closed, and the full capacity of the turbocharger is used to supply the engine with air. There is a possibility to use the waste gate as a safety device to redirect part of the gases on full load on liquid fuel mode in case of specific matching approach of the engine and the turbocharger by choosing smaller turbocharger for better performance in lower range of operation.

The core function of the waste gate is to act as pressure controlling device on gas mode, but it has strong dependence of the turbocharging system technical condition. The turbocharger must be able to keep its operation with control margin determined by the excessive efficiency for the waste gate opening. If there is no margin for opening the waste gate while the engine is operating on gas mode it could be impossible to keep the intended charge air pressure and respectively the fuel-air ratio in the specific mode, so the gas operation would become impossible.

The optimal condition figure of the waste gate valve position could be utilized as a reference condition for the turbocharging system deterioration. If there is excess fouling or there is marginal wear of the turbocharger components and the scavenge air system components it could be impossible to achieve the desired control of the turbocharger performance by opening the waste gate valve. The turbocharger must be kept in optimal condition for the smooth operation of the scavenge air control system. There must be considered variable factors which could influence the turbocharging system operation in different way than the considered in this publication. The margin for control is a must after all considerations.

4. Conclusions

In the publication are stated the special features of the turbocharging system of a dual fuel lean burn four stroke engine. The functions of the waste gate and the bypass valves are described in their critical minimum.

It could be considered that the dual fuel engines operate in two fundamentally different modes. On liquid fuel they are pure diesel engines and on gas fuel they are different engines. While operating on liquid fuel and not only there can be considered significant process of fouling of the turbocharger components. These components need to be in optimal condition for normal operation on gas mode. If there is a contradiction in this direction it must be expected that there will be deviation in the gas operation of the engine. It must be considered the proper maintenance of the engines and their subsystems as a critical requirement for the safe gas operation.

The experience with the diesel engines supercharging system could lead to poor results in the case of gas used as fuel [3]. The diesel engine could run in most of the cases even with turbocharging system in poor condition with some smoke and heat tensioning, but the gas fuelled engine cannot run in that way, just because of the engine control concept. The operation of relatively new engines is non problematic, but with the running hours stored there will be deviations of the technical condition which must be handled with the required attention from the engine operators.

5. Acknowledgements

The tasks in the publication to show the specifics of the turbocharging control system of the lean burn dual fuel engine is accomplished. There are shown the differences of the turbocharging system of the Diesel and the Lean burn concept engine with the potential weak points to be considered during the operation of such engines. The data analysis in the publication could be considered as a reference for the expected performance of the newly introduced dual fuel engines.

The data acquired from real ship power plant is the most realistic figure which could be seen in the real practice of the marine engineers working on natural gas fuelled ships.

The outcome of the publication could be beneficial to the marine engineers to better understand, clarify and explain the differences in the operation of the dual fuel and the Diesel four stroke engines in relation with the charge air system.

6. References

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