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Improved system of the water level controling in the smoke-tube exhaust gas boiler

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Abstract

There were many changes of ways of operation of low-speed long-stroke marine Diesel engines powering ships introduced last years. Their range of continuous low load operation has been significantly extended. That changes exerted a great influence on operating condition of equipment connected with engines, particularly waste heat boilers. The bellow paper deals with adjustment of water level in smoke – tube exhaust gas boiler depending on real operating condition of the ship powered by the marine slow-speed long-stroke Diesel engine operated under the "Super Slow Steaming" program.

Introduction

The more and more rigorous systems of cutting the costs introduced by many ship owners lead to creation of new patterns of operation of marine main engines. The pattern of the long period operation of the slow-speed long-stroke marine diesel engines rated under the level of 60% of nominal power has been defined as the "Slow Steaming". The next, more advanced version of this pattern was so called "Super Slow Steaming" [1]. In this case, the economy improvement as a consequence of the lowering of costs of consumed fuel extorts long operation of main engines loaded with just 30% of the nominal power.

On the merchant marine ships, exhaust gas boilers have been installed to increase the level of waste heat recovery from the exhaust gases produced by main engines. Their basic parameters of work are nominal working pressure steam output. The amount, length and diameter of tubes which determine the heat exchange area, are selected to obtain nominal level of the steam production under the nominal parameters of the main engine operation and standard ambient conditions stated in norm ISO[1] 3046/1. For such a condition, the nominal parameters of the main engines exhaust gases – mass flow and temperature are calculated during the design stage of the ship's engine room.

Introduction of the presented above new patterns of marine Diesel engines operation requires taking into consideration change of exhaust gas boilers working conditions during ship operation. With significantly lower ship's speed resulting from operation under the "Super Slow Steaming" conditions, the exhaust gases of marine main engines will characterize significantly lower mass flow and temperatures in comparison with designed, nominal condition. In consequence the working conditions of exhaust gas boiler will change affecting the steam production.

Feed water control systems

The nominal water level which has to be maintained in exhaust gas boiler is strictly determined during design stage of the boiler. However, it is allowed that during boiler operation this level may oscillate in range permitted by the manufacturer. Formerly, simple control systems of feed water for smoke-tube exhaust gas boilers were based on sequentially started and stopped feed pumps controlled by set of floats. Idea of such a system is being presented on figure 1.

[1] **ISO** – International Standards Organisation

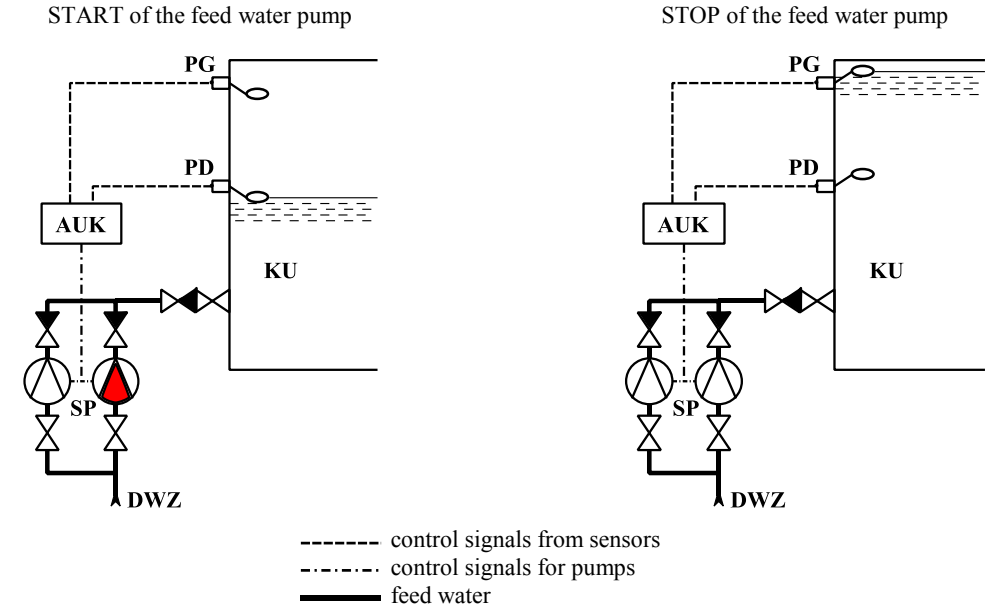

Fig. 1. Float controlled feed water system of the smoke-tube exhaust gas; AUK – automatic control system of the exhaust gas boiler, DWZ – inlet of the feed water, KU – smoke-tube exhaust gas boiler, PD – LOW float, PG – HIGH float, SP – feed water pumps

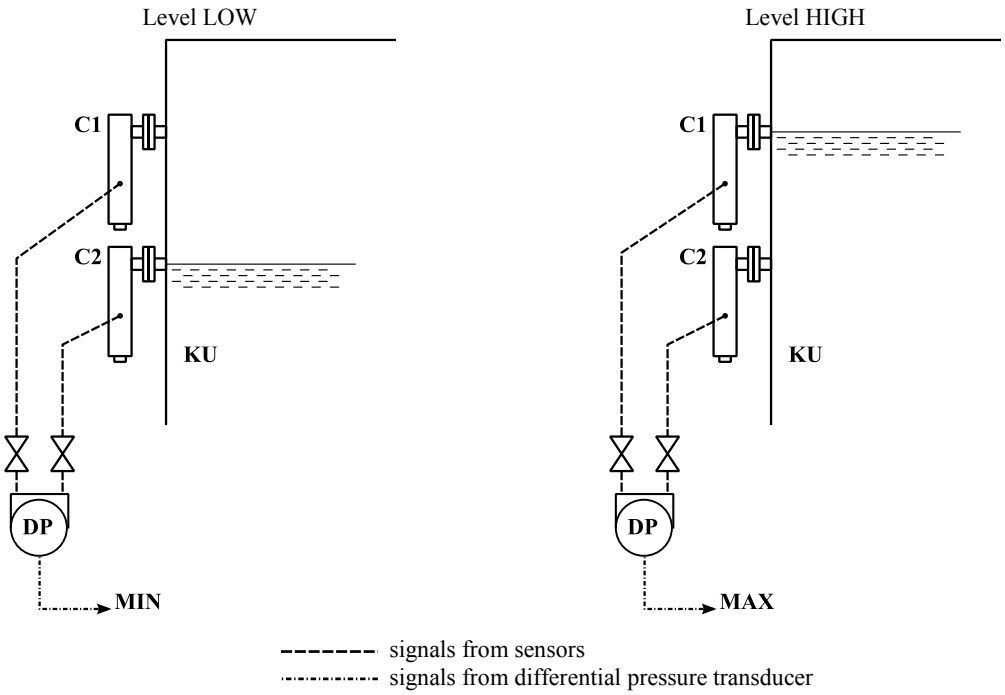

Fig. 2. Continuous read-out and control of the water level in the smoke-tube exhaust gas boiler; C1 – top water level sensor, C2 – base water level sensor, DP – differential pressure transducer, KU – smoke-tube exhaust gas boiler, MIN – current signal corresponding t the low water level, MAX – current signal corresponding *t* the high water level

Beside the simplicity, the main feature of that way of control of water level in the boiler is bound duet to possibility of accurate maintain of only two levels which are corresponding to the moments of changing of the position of floats in measuring chambers. These were so arranged that water level was kept within designed range. Additional inconvenience was lack of accurate remote information regarding the level of water if it was between "low" and "high" level. The engine room crew had to check that one only by personal observation in sight glasses. Development of this system led to improvement of functionality resulting from installing additional water level transducers. But the only purpose of that equipment was to give remote information concerning the level of the water in the

boiler for the ship's crew. Such systems are still being in use in the low costs designed engine rooms.

Modern boiler feed water control systems take advantage of continuous indication of the water level. Detection of the actual level is carried out through differential pressure transducer which is utilizing input signals from water level sensors. The output signal from the differential pressure transducer is a current with determined minimum and maximum value corresponding to the low and high level of water in boiler as presented on the figure 2. Intermediate values specify accurate level of the water surface within this range. The current signal (*MIN-VAR-MAX*) provides information for the boiler automatic control unit to workout control pneumatic signal positioning the feed water throttle valve. Such a feature will determine the mass flow of the boiler feed water supplied by continuously running feed pump. The automatic control unit of the exhaust gas boiler provides information concerning the water level to the ship safety and control systems. Additionally, it has a possibility to receive signals from those. The diagram of the simplified feed water system is being presented on figure 3.

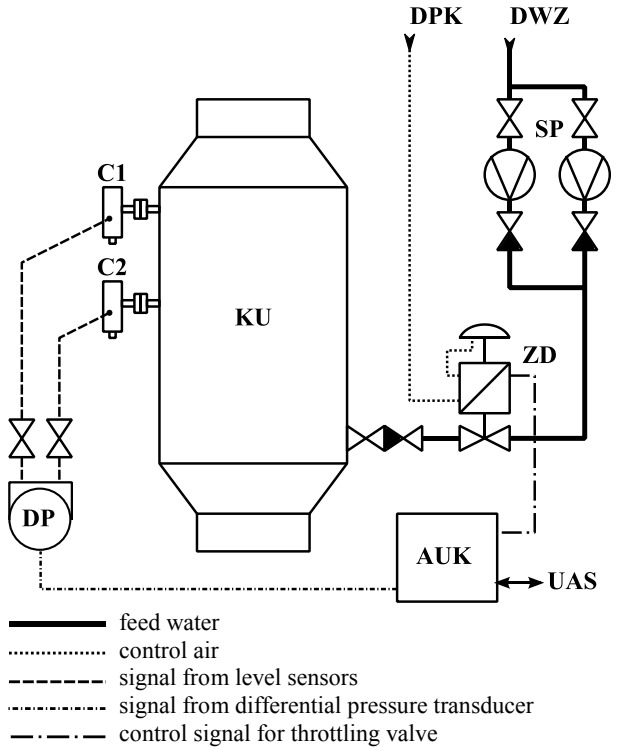

Fig. 3. Continuous read-out and control of the water level in the smoke-tube exhaust gas boiler; AUK – automatic control unit for the smoke-tube exhaust gas boiler, C1 – top level sensor, C2 – base level sensor, DP – differential pressure transducer, DPK – control air inlet, DWZ – boiler feed water inlet, KU – smoke-tube exhaust gas boiler, SP – feed water pumps, UAS – automation systems of engine-room, ZD – throttling valve

Steam production during sea passage

During sea passage the main receivers of the steam are:

- heavy fuel heating systems (*bunker, settling, and service tanks, purification and preparation for injection*);
- lubricating oil heating systems (*crankcase heaters, purification of main and auxiliary engines system oil*);
- water heating systems (*sanitary water*);
- air heating systems (*ship's air condition*);
- turbo-generators (*only in case of advanced waste heat recovery systems*).

The level of demand for steam by above listed systems mainly depends on real ambient condition and operational conditions of the particular ship. During operation of the main engine under the Slow Steaming Condition the significant drop of produced exhaust gases amount, as well as the it's temperature will have great influence on working condition of exhaust gas boiler. With unchanged steam demand by ship's systems this will lead to decrease of the steam pressure in the main supply line. However, despite significantly lowered pressure of produced steam, operation of the basic heating systems in the engine rooms will be still possible.

On the ship equipped with main engine of type 8RTflex96C (N_n = 35.1 MW, n_n = 93 rev/min), which supplied with exhaust gases the smoke-tube exhaust gas boiler of type MISSION XS-2V (p_R = 0.75 MPa, D_n = 3700 kg/h) series of tests of the steam system have been carried out. Under different ambient conditions (*tropical zone, temperate zone*) it was proved that even if the steam pressure has been lowered down to p_{KU} = 0.45 MPa it was still possible to operate the ship without putting into operation of the oil fired boiler.

Taking advantage of continuous read-out and control of the level of water, designers of the boilers and ship steam systems introduced possibility of adjustment of set point of this level during the operation of the smoke-tube exhaust gas boiler. But the issue recommended by manufacturer is not fully taking advantage of capabilities of presented system. Its main limitation results from predetermination of the only one, boundary value of the main engine load transmitted to the automatic control unit of the boiler to change the preset water level value. Usually this threshold signal is being triggered in range of 30–40% of nominal power of the engine which cowers the "Super Slow Steaming" operation. Development of that idea would be to allow adjustment of the water level in the whole

range of main engine operational load. In consequence it will require to formulate mathematical function describing relation between current boiler water level (h) in dependence of main engine load (N_{SG}):

$$h = f(N_{SG}) \text{ [mm]} \quad (1)$$

This kind of the control program for boilers will allow to keep stabile operational parameters of ship's heating systems without putting the oil fired boiler into operation.

For proper operation under described condition the very important is exact measurement of the water level in the boiler that the automatic control unit of the boiler can properly adjust position of the throttling valve controlling mass flow of the feed water. However, results of carried out calculations proved that along with drop of the working pressure in the boiler the readout signal passed from differential pressure transducer to the boiler control unit will be burdened with error. The value of this error depends on difference of nominal and actual steam pressure in the boiler.

For the boiler installed on the ship where tests were carried out, a series of simulations of changes of the water level in dependence on the different working pressures in the boiler have been carried out as well. Selected working pressures corresponded to parameters of steam production for nominal load of main engine (DP-N) and operation under "Slow Steaming" (DP-SS) and "Super Slow Steaming" (DP-SSS) as well. Obtained results were presented on figure 4. Additionally presented function of indications of the differential pressure transducer for the steam pressure $p = 0.4$ MPa (DP-4) which was the limit value for tested ship. Bellow

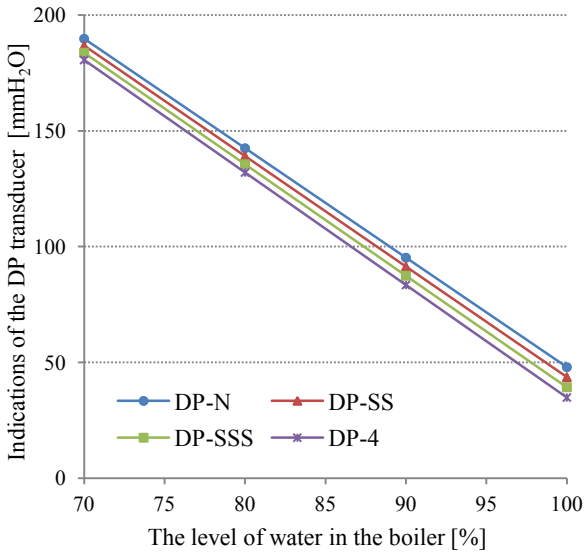

Fig. 4. Indications of transducer (*DP*) in dependence of steam pressure in the boiler

that it was not possible to operate steam system without putting into operation of the oil fired boiler even under tropical ambient conditions. Simulations of the level of the water were carried out in range of 70–100% of the nominal level.

Analysis of the obtained results pointed out that together with drop of the working pressure in the boiler the indications of the transducer (*DP*)* will be erroneous – lower than it is currently maintained in the boiler.

This fact leads to the conclusion that described before possibility of lowering of the water level in the smoke-tube exhaust gas boiler together with significant reduction of the main engine load and constant level of demand of steam by engine room systems will cause that the automatic control unit (AUK)* will maintain higher water level than designed by producer. As calculated, error of indication depends on changes of pressure and range of maintained water level. Obtained results were presented on figure 5.

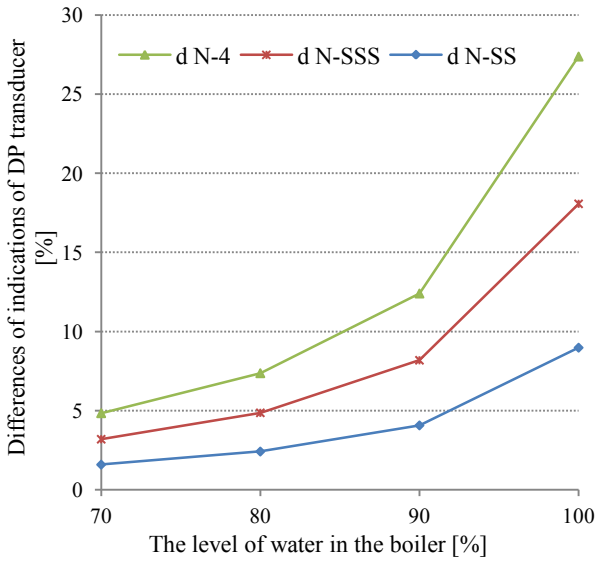

Fig. 5. Differences of indications of transducer

On the ship where tests were carried out, the automatic control unit of the boiler receiving command "ENGINE LOW LOAD" from automation systems of engine-room, automatically lowered maintained level of the water in boiler to 80% of the nominal value by readjusting pneumatic actuator of the throttling valve (ZD)*. During the real operation of the sip under the "Super Slow Steaming" condition, the difference of the water level due to incorrect indication was 5% higher than designed reducing effect of smooth operation of the exhaust gas boiler. In some special areas, like SECA (*Sulphur-oxides Emission Control Area*), where at least

* Symbols accordingly to figure 2

two types of fuel must be prepared (*heated, purified, filtered*) and ready to use, this situation may cause shortages of the produced steam. Due to dependence of the exhaust gas boiler steam output on ambient temperature [2] it may be not possible to operate steam systems in colder zones or seasons without oil fired boiler on.

Bearing in mind above information the previously described function (1) should be modified by taking into consideration additional parameter, which is actual boiler pressure (p_{KU}) to assume final form as follows:

$$h = f(N_{SG}, p_{KU}) \text{ [mm]}$$

Implementation of above function in automatic control unit of the smoke-tube exhaust gas boiler based on modern computerized components can be done by updating of software.

Conclusions

1. Continuous, long term operation of the marine low-speed long-stroke engines has become a standard practice providing a possibility to improve economy of the marine transport. This situation lead to operational disturbances of waste heat boilers, powered by exhaust gases of main engines.
2. The newest feed water systems designed for smoke-tube exhaust gas boilers allow to integrate both functions of read out and control of the water level in the boiler. Additionally that level can be freely adjusted in the range premised by manufacturer.
3. Possibility of the smooth adjustment of the water level allows to widen the range of mating of the smoke smoke-tube exhaust gas boilers with de-rated marine main engines. Unfortunately that advantage is not fully utilized.
4. Development of procedures of controlling water level in such a boilers will result in wider possibilities of the waste heat recovery. Under the real ambient and operational conditions of the ship this will allow to save additional amount of fuel, normally consumed by oil fired boilers.
5. Additional reduction of the exhausts emitted by oil fired boilers may be achieved.

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