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Disturbances of water level indication in the selected smoke--tube exhaust gas boiler under the real ambient conditions

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Abstract

New ways of the long term operation of low-speed long-stroke marine Diesel engines such as "Slow Steaming" and "Super Slow Steaming" caused disturbances in operation of waste heat recovery systems from main engines exhaust gases. The advancement of the control systems of the water level in smoke-tube exhaust gas boiler created a possibility to change that parameter during operation of the "main engine – exhaust gas boiler" system. It was made use of such a feature to develop a system of readjustment of water level in the smoke-tube boiler to main engine load. However, introduced methods were saddled with simplifications that can bring in additional disturbances in operation of the boiler feed water systems. The bellow paper deals with influence of the ambient condition of the smoke-tube waste heat boiler on the water level indication in the boiler.

Introduction

The real ambient conditions occurring during operation of the "main engine – exhaust gas boiler" system at sea have significant influence on parameters of produced steam [1]. So far, carried out researches were mainly focused on influence of changes of marine Diesel engines operating conditions causing changes of parameters of exhaust gases powering waste heat boilers. However, the type of the boiler (water-tube or smoke-tube) was not taken into consideration.

The new ways of operation of marine prime movers, introduced due to economical reasons (*Slow Steaming*, *Super Slow Steaming*), caused reduction of the temperature and mass flow of the produced exhaust gases in comparison to design conditions. Such a changes have an effect on parameters of working conditions of waste heat boilers powered by exhaust gases produced by Diesel engines, causing disturbances of steam production (*capacity*, *pressure*). Stabilisation of the steam production during the operation of the sip powered by Diesel engine accordingly to the new modes of operation requires changes in boiler's construction (*number and dimensions of tubes*, *additional elements improving efficiency of heat exchange* [2]). Such an operation is not possible to be carried out without either interfering in construction of the exhaust gas boiler or complete replacing. The option is change of parameters of the steam production system during the ship's design stage. However, this option imposes restriction on operation of the ship with significantly reduced speed only.

Alternative for above mentioned solution is an introduction of possibility of smooth adjustment of water level in the smoke tube boiler in dependence of the main engine load. For partially loaded marine prime movers to stabilize steam production without putting into operation of the oil fired boiler the reduced level in the smoke-tube exhaust gas boiler has been applied [3].

Systems of water level control in the smoke-tube boiler

Water level in smoke-tube exhaust gas boilers must be strictly maintained in range defined during designing stage. For the present, in merchant marine fleet there are two ways of control of water level in use, which are part of the boiler feed water system:

1) Float controlled (*sequential*) – the main feature of this system is simple construction and operational reliability. However, this way of control of water level in boiler enables to indicate precisely the low and high level only. This limitation disqualify of such a construction in modern, sophisticated systems of feeding of waste heat boilers with water.
2) Throttle controlled (*continuous*) – the main feature of this system is possibility of continuous indication of water level in the smoke-tube boiler. Such a solution, more advanced in respect of construction yet enables to introduce additional improvements of steam production systems by exhaust gas boilers. Symbolic representation of the throttle controlled boiler feed water system has been presented on figure 1.

Application of the level sensors and the differential pressure transducer enables to actuate the throttling valve, which opening level determines the mass flow of water continuously feeding of boiler by the feed water pump. Arrangement of the level sensors assembled on the selected smoke-tube exhaust gas boiler (MISSION XS-2V) has been presented on figure 2. Taking advantage of such way of operation, producers of the ship steam systems developed new method of feeding boiler with water, taking into consideration present load of the

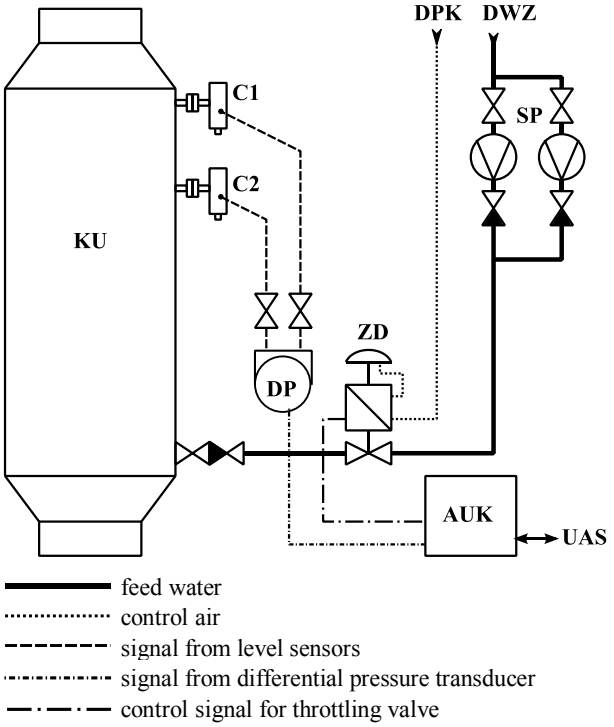

Fig. 1. The throttle controlled system and continuous read-out of the water level in the smoke-tube exhaust gas boiler: AUK – automatic control unit for the smoke-tube exhaust gas boiler, C1 – top level transmitter, C2 – base level transmitter, DP – differential pressure transducer, DPK – control air 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

Top level sensor

Base level sensor

Fig. 2. Water level sensors assembled on the selected smoke-tube exhaust gas boiler

main engine. Additional possibility to change the nominal water level maintained by automatic control unit for the smoke-tube exhaust gas boiler has been introduced. Presented solution has been based on the strict indication of the water level which is input parameter to work out proper actuating signal for the automatic control unit for the smoke-tube exhaust gas boiler throttling valve controlling flow of the feed water.

Disturbances of indication of water level in smoke-tube exhaust gas boiler

Accordingly to the boiler manufacturer publication [4], value of signal worked out by differential pressure transducer depends only on the water level in the boiler. It was proved during simulations of the boiler level indication that such simplification will lead to deviation of read outs. It was pointed out that for precise determination of water level in the boiler it is required to modify equation describing changes of value of water level in the boiler in dependence of present load of the main engine and pressure of steam inside of the smoke-tube exhaust gas boiler [3]. Determined for selected boiler function (1) should be implemented in automatic control unit:

$$l_W = f(N_{SG}, p_P) \text{ [mm]} \qquad (1)$$

where:

l_W – water level in the boiler indicated from top level;
N_{SG} – main engine load;
p_P – steam pressure in the boiler.

Further research in order to determine precise indication of water level in the boiler pointed out that ambient temperature of the smoke-tube exhaust gas boiler may have great influence on this parameter.

Both, the base and top water level sensors, assembled on the boiler (Fig. 2) are exposed to conditions which parameters depend on many ship's operational and constructional factors [5], mainly as follows:

– area of operations;
– climatic condition;
– type of ventilation system of the ship;
– arrangement of the main and auxiliary engines in engine room;
– load level of the main and auxiliary engines;
– arrangement of the exhaust gas boiler in engine room;
– construction and arrangement of the ventilation shaft in engine room.

For the selected smoke-tube exhaust gas boiler of type MISSION XS-2V (p_R = 7.5 bar, D_n = 3700 kg/h) manufactured by AALBORG, the differential pressure transducer is calibrated making assumption that ambient temperature of the boiler values 40°C [4]. Such assumption determines constant density of the water in measuring circuit "top level sensor – differential pressure transducer – base level sensor". Under the typical, real operation and ambient conditions of the ship this parameter is in range of 25–35°C but may drop even under 0°C in arctic areas. However, it may rise even more than 40°C in tropical areas. Such wide range of boiler's ambient temperature leads to additional errors in read out of the water level in the boiler. For the previously mentioned boiler, series of simulations of signals generated by differential pressure transducer have been carried out. Results of simulations showed dependence of that signal on boiler's ambient condition and level of water in the boiler in range of minimal (0%) and maximal (100%) level and have been presented as the 3D-surface on figure 3. All simulations complied with details of real system of measuring range 525 mm, which was installed on 7200 TEU (*twenty-foot equivalent unit*) container ship.

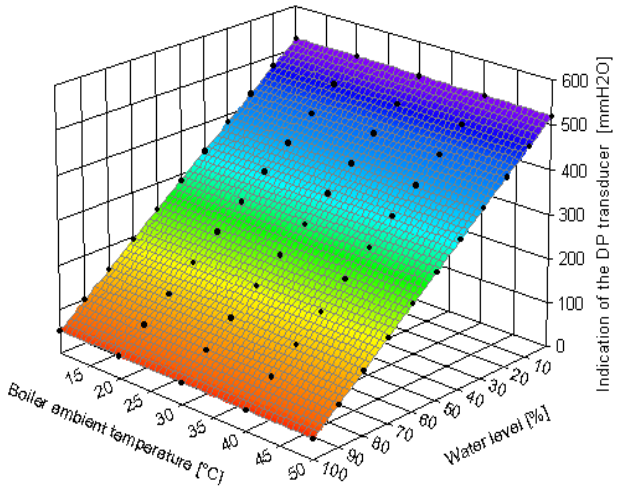

Fig. 3. Indication of the differentia pressure transducer in dependence on boiler ambient conditions and level of water

The surface presented on figure 3 describes the following empirical equation (r^2 = 0.99999979):

$$h = a - b \cdot t_B - c \cdot l_w \cdot \ln(l_w) \text{ [mm H}_2\text{O]} \qquad (2)$$

where:

h – indication of the differential pressure transducer;
t_B – boiler ambient temperature;
l_W – real water level in the boiler (percentage of nominal top);
a, b, c – coefficients of approximation equation a = 525.1068214, b = 4.729725, c = 0.02765234.

For precise determination of the water level in the smoke-tube exhaust gas boiler it is required to take into consideration above function which should be implemented in the equation (1), which will change as follows:

$$l_w = f\left(N_{SG}, p_p, t_B\right) \text{ [mm]} \tag{3}$$

where:

l_W – water level in the boiler indicated from top level;
N_{SG} – main engine load;
p_P – steam pressure in the boiler;
t_B – boiler ambient temperature.

It should be mentioned that manufacturer allows for boilers producing saturated steam applying of 700 mm and 800 mm measuring range. In consequence the lengthened signal line will increase the effect of exposure to ambient conditions of boiler.

Conclusions

1. Throttle controlled adjustment of the water level in the smoke-tube exhaust gas boiler requires applying of the more advanced feed water control systems.
2. Indications of water level measuring systems depend on many factors resulting from real conditions of the ship operation. The most affecting are main engine load, ship's engine room design and ambient air conditions.
3. Taking into consideration the influence of smoke-tube exhaust gas boiler surrounding conditions will lead to precise indication of the water level in the boiler.
4. For the selected boiler determined equation which describes changes of indications of differential pressure transducer should be implemented in the automatic control unit which adjusts level of opening of the feed water throttling valve.

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