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THE IMPORTANCE OF MEASURING MASS INTENSITY OF FLOW AIR THROUGH THE COMPRESSOR IN DIAGNOSTICS THE TURBOCHARGER SYSTEM MARINE ENGINE

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Abstract

The paper presents an analysis of the possibility of diagnosing the elements of turbocharger system marine diesel engine. Meaning of diagnostics of this system has also been discussed pointing out the most important consequences resulting from deterioration of supercharger system activity. Work evaluation of supercharger system is usually carried out on the basis of the following parameters: temperature and pressure of supercharging air in the scavenging air receiver (t_d, p_d), pressure drop in air filter and air cooler (Δp_f, Δp_{ch}), temperature exhaust gases before and after the turbine ($t_{wyl\,1}$, $t_{wyl\,2}$), temperature of overboard water before and after the air cooler ($t_{chl\,1}$ i $t_{chl\,2}$), turbocharger rotational speed (n_{TS}), pressure drop on the exhaust gas boiler (Δp_{ku}) – counterpressure of exhaust.

In exploitation practice of turbocharger system diagnostic, mass intensity of flow air through the turbocharger is not used and unfortunately measurement of this size is not realized. But in compressor diagnostics however, it is the basic exit parameter and the enter one for the rest of the elements.

Based on research results demonstrated the possibility to use to calculation the mass intensity of flow air through the compressor, measurement pressure drop on the confusor of the compressor. This calculation should be widely used in exploitation practice. This method is easy enough and sufficiently precise, in order to be used in the diagnostics the marine diesel engines.

Keywords: *marine diesel engines, operation, turbocharger system, diagnosis , air compressor diagnosis*

1. Introduction

Marine diesel engines, both main propulsion and auxiliary turbo-charged. Charging system, in addition to the injection system has a significant impact on the quality of the working process, the economics and reliability of operation.

Application turbochargers to turbocharging allows the use of energy contained in exhaust gases. Between the engine and turbocharger exists only gas-dynamics connection: stream of exhaust gases from the turbine and a stream of air from the compressor. The balance of power down through the turbine and the compressor needs shows the amount of energy used to compress air in the turbocharging system.

The structure of the mechanical-flow turbocharger and its quality is shaped at the design stage [14, 15]. This structure describes a set of values of design features, including:

- connection of a turbocharger with the engine (the foundation),
- the air collecting pipe,

- the compressor,
- the exhaust collecting pipe,
- the turbine,
- the turbocharger shaft,
- the turbocharger shaft bearings.

The deterioration of the technical condition of charging system is equivalent to the deterioration of the course working processes engine, but not necessarily directly and immediately affect the performance and parameters engine.

Due to the significant influence of the turbocharging system on the running engine, the relationship between business process flow and work of this agreement, shall be in operation in real time to diagnose his condition, including a turbocharger and air cooler. There is a close relationship and interaction (feedback) between the air charging unit (compressor, condenser), the worker process, the turbine driving the compressor and the compressor.

Complexity of the construction of the modern turbocharger and responsibility for the quality of the tasks causes the need to ensure rapid and reliable information on their current condition to the operator.

Due to the different diagnostic methods [1, 2, 3, 4, 5, 6, 7], using processes generated by the machine, parameters, and other volumes that contain diagnostic information.

The evaluation charging system work is usually carried out on the basis of the following parameters:

- temperature and pressure charge air in the scavenging air receiver (t_d, p_d),
- pressure drop across the filter and air cooler (Δp_f, Δp_{ch}),
- exhaust gas temperature before and after the turbine ($t_{wyl\ 1}$, $t_{wyl\ 2}$),
- sea water temperature before and after the cooler ($t_{chł\ 1}$ i $t_{chł\ 2}$),
- turbocharger rotational speed (n_{TS}),
- pressure drop on the exhaust gas boiler (Δp_{ku}).

In operational practice, the diagnosis of the loading system shall not use the mass flow of air through the compressor and, it is not implemented the measurement of this size. In diagnosing the compressor but it is the primary output parameter, and for other elements of the input.

2. Assessment of technical condition of the air filter

Ongoing impurity of the air filter reduces the cross section caused by the deposition of sediment on the filter cartridge. Increases resistance to flow and filtration efficiency decreases. After reaching the limit of adhesion strength of the agglomerates to the filter fibers, ends with the stable operation range of the filter. Increases aerodynamic forces and agglomerates are detached from the fibers. Increase the flow resistance in the filter is manifested to distort the flow of the intake air stream and deterioration of the compressor working.

Drops pressure at the inlet to the compressor by the pressure drop over the filter Δp_f. At the same time maintaining an unchanging compressor compression ratio π_S, air pressure decreases as the compressor p_k, a reduction in mass intensity of flow air $\dot{m}_s$ and a decrease in excess air number λ [11]. As a consequence, will among other things to supercharging pressure p_d, exhaust gas temperature T_g increases and the turbocharger rotational speed n_{TS}, and decrease the maximum combustion pressure p_{max}. This may also lead to an increase in specific fuel consumption g_e. As with the foregoing, the consequence of the impurity compressor air filter (Z_f) is:

$$Z_f \Rightarrow (\Delta p_f\uparrow;\ p_k\downarrow;\ p_d\downarrow;\ \dot{m}_s\downarrow) \Rightarrow (g_e\uparrow;\ T_g\uparrow;\ n_{TS}\uparrow;\ \lambda\downarrow;\ p_{max}\downarrow)$$

3. Assessment of technical condition of the air compressor

In the flow channels of the air compressor are deposited contaminants, despite the security air filter. It is primarily a viscous oily (sticky) mass, weakly bound to the surface elements. The compressors that consume air from the engine room cross-section of the diffuser after about 2000 hours may be from 10 to 20% reduced [16]. Deposits on the walls of the flow channels and the erosion effects of sea spray cause an increase in friction losses and change the angles of leading and trailing blades and aerodynamic flow. Deposits on the walls of the flow channels and the erosion effects of sea spray cause an increase in friction losses and change the angle of attack and angle of discharge rotor blades, and deterioration in the aerodynamic flow. As a result, there is reduction in the efficiency of the compressor η_S and the amount of air supplied to the engine. This affects the process of working in a quantity of gas flowing into the turbine, and hence a decrease in the rotational speed of the turbocharger. Decrease the amount of air supplied to the engine can cause deterioration of cylinder scavenging, increase heat loads of the components combustion chamber and increase exhaust gas temperature [12]. As the above shows, the consequence of the impurity compressor (Z_s) is:

$$Z_S \Rightarrow (\eta_S\downarrow;\ \pi_S\downarrow;\ p_k\downarrow;\ p_d\downarrow;\ \dot{m}_s\downarrow) \Rightarrow (g_e\uparrow;\ T_g\uparrow;\ \lambda\downarrow;\ p_{max}\downarrow)$$

4. Assessment of technical condition of the turbine

In the turbocharging systems of marine diesel engines, the compressor is usually driven by an axial turbine (rarely used radial turbine). During operation turbine comes to contamination. There may also be mechanical damage the blades caused by the solid materials such as, fragments of the damaged engine components and hard pieces of coke, which did not stop the turbine protection grill. Producers of marine diesel engines provide the possibility the progressive contamination the turbine. So equip turbine the special systems: water washing system, water with the addition of surfactants washing system [1] or dry-cleaning system using granulate. These activities should be performed periodically, according to the manufacturer, which allows the turbine to restore good condition (clean to keep the turbine). Deposits on the surfaces of the flow (impurity the turbine Z_T) causes a change in their profile, reducing the cross section, the increase in gas flow resistance, which has the following effect on the work of turbocharger system (increasing the values: turbine expansion ratio π_T, pressure drop on the exhaust gas boiler Δp_{ku}, specific fuel consumption g_e, exhaust gas temperature T_g; decrease the values: efficiency of the turbine η_T, mass intensity of flow air $\dot{m}_s$, excess air number λ):

$$Z_T \Rightarrow (\pi_T\uparrow;\ \eta_T\downarrow;\ \Delta p_{ku}\uparrow;\ \dot{m}_s\downarrow) \Rightarrow (g_e\uparrow;\ T_g\uparrow;\ \lambda\downarrow)$$

5. Possibility and importance of measuring delivery of a compressor in the diagnosis of turbocharger system the marine engine

The air intensity of flow through the compressor

As follows from previous considerations, as well as many other studies [8, 9, 13], the flow of air through the charging system should play a role in the diagnosis of the basic. It results from the fact that in the balance of this system one of the most important conditions is the balance of mass flow continuity, it is:

$$\dot{m}_S = \dot{m}_C \quad \text{and} \quad \beta \cdot \dot{m}_C = \dot{m}_T\,, \tag{1}$$

where:

$\dot{m}_S$ - mass intensity of flow air through the compressor [kg/s],

$\dot{m}_C$ - mass intensity of flow air through the cylinders [kg/s],

$\dot{m}_T$ - mass intensity of flow gases through the turbine [kg/s],

β - coefficient related to the increase in gas mass relative to the air mass, due to the dose delivered to the cylinders of fuel [-].

Methods of determining the air intensity of flow through the compressor

In the laboratory or in the engine test bench most often used to determine the air intensity of flow through the compressor ($\dot{m}_S$) leminiscate. Directly measured quantity is the pressure drop across the leminiscate. Then, based on appropriate mathematical relations are calculated $\dot{m}_S$. Although this method is very accurate, but in operational practice not used. Another method is to measure the air drop pressure on inlet the compressor - on the the confusor of the compressor (Δp_{konf}) [13] and use the formula (2):

$$\dot{m}_S = k \cdot \sqrt{\Delta p_{konf}} \quad , \tag{2}$$

were:

$\dot{m}_S$ – mass intensity of flow air through the compressor [kg/s],

k – constant, characteristic of the charging system [-],

Δp_{konf} – pressure drop on the confusor of the compressor [mmH_2O].

Due to the simplicity of the method indicated it should be generally applied. The author is not a known case of the practical utilization of this method. Therefore, decided to see if it is effective and sufficiently accurate. Therefore were performed laboratory tests on the marine engine, in order to determine the constant *k* turbocharging system and verify that the *k* does not change when you change the engine operating conditions.

Laboratory tests

The research was conducted on a four-stroke marine engine SULZER 3AL25/30, supercharged turbocharger VTR160N. Their goal was to test the effectiveness of the methods of determining the mass intensity of flow air through the compressor, based on the measurement of pressure drop on its confusor (Δp_{konf}). Using the possibility of imposing a $\dot{m}_S$ using leminiscate and measuring Δp_{konf}, determination of the factor *k* appearing in equation (2). Measurements were made repeatedly - for different engine loads and air temperatures at the inlet to the engine. Research was carried out in the range of loads from 200 to 280 kW, and charge air temperatures 45, 50, 55, 60 and 65 ^{0}C. V For each of the states were determined mass intensity of flow air through the compressor using an leminiscate, and measured the pressure drop across the confuzor compressor. This allowed to calculate each value of factor *k*. The results are summarized in Tab.1. Regardless of the load engine and charge air temperature, the coefficient k, in each case calculated on the basis of defined $\dot{m}_S$ and measured Δp_{konf}, has a constant value approximately equal to 0.18. The average value of *k* for the whole measurement cycle, i.e., with 75 measurements (25 states, in each of three parallel measurements) is 0.179.

Tab. 1. The results of measurements

t_k [°C]	N_e [kW]	Δp_{konf} [mmH_2O]	$\dot{m}_s$ [kg/h]	k [-]
45	200	9	0,5452	0,1868
	220	10	0,5853	
	240	10	0,6169	
	260	12	0,6519	
	280	14	0,6885	
50	200	9	0,5445	0,1804
	220	10	0,5776	
	240	12	0,6152	
	260	12	0,6404	
	280	15	0,6809	
55	200	10	0,5446	0,1752
	220	11	0,5534	
	240	12	0,6179	
	260	13	0,6092	
	280	15	0,6769	
60	200	9	0,5404	0,1761
	220	11	0,5718	
	240	12	0,6092	
	260	13	0,6408	
	280	15	0,6769	
65	200	8	0,5376	0,1805
	220	10	0,5676	
	240	11	0,6052	
	260	13	0,6399	
	280	15	0,6708	
The average value of *k*:				**0,179**

6. Conclusions

Among the many volumes of great significance in the diagnosis of the turbocharger system, a very important parameter is the - mass intensity of flow air through the compressor.

The diagnosis is the primary compressor output parameter, and for other elements of the input.

Determination of this parameter in the operational practice should be universal, and a method based on drop air pressure compressor on confusor is so simple, yet accurate enough to seriously take it into consideration in the application of operational marine engines.

Establishment of a fixed k, specific charging system, should do the engine manufacturer, after completion of procedures for the selection of turbochargers and enter the value of *k* to the documentation of the turbocharger.

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