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CHANGES OF TOXIC COMPOUNS OF EXHAUSTES DURING THE RUNNING-IN OF ENGINE

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Abstract

Reliability and durability are the most important features of the combustion engines. The significant influence on these features has construction, production technology, and proper selection of materials. Regardless of precise producing the cooperative elements of the engine should undergo the running-in process. This process has great influence on durability of elements and normal time of exploitation. If it is properly selected and conducted, it will extend the time of future engine operation by decreasing initial value of wear of its friction pairs and giving proper values to the outer layers.

During the running-in process, beside giving proper shape to the outer layers of individual elements of engine, parameters of the toxic compounds emission changes. The paper presents results of researches, which were aimed at describing the values of toxic compounds emission changes during the running-in process of engine.

1. Introduction

The main factor, which determinate reliability and durability of the engines, beside the common applied modern technologies of production using the most recent materials, still remains the running-in process, understood as a process of conscious forming the outer layers of elements by the technological transformation of outer layers (which appeared at the stage of production) into exploitative outer layer. It occurs under influence of forces such as: pressure, temperature, engine rotational speed at presence of the active compounds of lubricating factor.

As it was mentioned, the period of normal exploitation is strictly determined by the conditions and the course of running-in process at the beginning of associated friction pair. When this process will be correctly conducted, surfaces will reciprocally form and also changes of the outer layer properties occur, in comparison to the initial properties, given during obtaining the elements. These changes will result in the increase of resistance of associated friction pair on wear.

Along with this change of properties of outer layers of running-in engine elements, also broad understood working parameters of the combustion engine will change, including parameters describing the combustion process, among them parameters of the toxic compounds emission.

The information on the subject of exhausts toxicity changes during the running-in process in the available professional literature are poor, yet using obvious relation between structure parameters and directly related to them parameters of the combustion process could be make an attempt of conclusion the correctness of running-in process. It seems that suggested solution could be used with success to observe and conclude the correctness of running-in process course of engine in the place, where it is installed, which means the shipping power station, but very often service do not have specialist laboratory devices to register the parameters of running-in process.

2. The running-in process of marine combustion engine

There are great discrepancies in the running-in process worked out by producers of engines. Often these programs have been worked out on the basis of existing, verified in practice programs of the running-in process for other engines. Additionally, significant standards of similarity of the engines have not been taken under consideration, what is a condition of such action. Therefore, with high probability can be concluded that in many cases running-in process was not correctly performed.

Running-in is performed depending on the engine types, its repair and test place. Running-in program should assure realization of the typical engine load characteristic, in case of the marine engine of main propulsion it is a propeller characteristic. The optimal running-in program and related technology should be such worked out to obtain the lowest values of wear required durability of the elements – properties of outer layers – at the minimal time of the engine operation.

General conditions of optimal running-in, which enables obtaining best condition of outer layer, amounts to such engine load during the running-in process, where unit pressure on these surfaces will approach to the plasticity limit of material, but it will not be exceeded and when slide speed will assure good condition of forming lubricating wedge and its upper limit will not evoke the increase of temperature, which violate durability of the protective layers, absorbed on the friction surfaces [1,16].

To assess the quality of the running-in are applied factors of different type such as: temperature of associated elements, friction coefficient, mechanical vibrations, tightness of the cylinders, noise etc. The most convenient quality factor of the running-in process of engine is its internal resistance, which change during the running-in process. The thing is about resistance, which includes: friction resistance, hydraulic resistance, load compression resistance and spring resistance. As a result of the running-in process the friction resistance decreases while load compression resistance increases as an effect of the increase of tightness of the piston rings and cylinder set. Changes and then stabilization of the friction resistance could be used as a quality index. Friction coefficient intensively changes at the beginning of the running-in process till its stabilization, which in the further stage of running-in remains invariable. These changes depend not only on speed applied at the time of running-in, but unit and lubrication pressure.

What concerns the temperature, the increase of crankshaft rotational speed and also load are caused by the stroke temperature increase of the elements. When running-in conditions change, every time the change of temperature occurs stabilizes after some time till the next change of engine operating conditions.

Among others running-in quality indexes could be numbered: effective power and torque, unit fuel consumption, tightness of the cylinders, which is assessed by the measurement of compression pressure, vibrations, which are measured as acoustic pressure.

As it was mentioned before, the running-in of marine engine occurs according to the propeller characteristic and it could be performed during the tests in engine test stand or on the marine ship. In all tests the control parameters of the running-in process have been engine rotational speed and power reached by the engine. Because of the fact, that the running-in process occurs in terms of the resilient deformations of mircoirregular protrusions, the initial engine load should be such selected to fulfill the conditions.

In practice, the first stage of load responds to the engine operating at the idling run [1]. Then the optimal conditions for unit pressure are not fulfilled. If engine can not work at the idling run, the running-in process begins at the possibly lowest load, when engine operation is the most stable. Then this condition would be the first stage of the running-in. The second stage is realized at the load, which is a result of the minimal performance according to the propeller characteristic. Course of the running-in occurs at the load increase index within 1,2 – 1,3

Above is presented the methodology of working out the running-in program according to [1,2]:

1. Initial data:

N_z –nominated engine power;

n_z – nominated engine rotational speed;

n_{min} – the lowest engine rotational speed, when the loaded engine works stable;

n_l – engine rotational speed at idling run;

$\varphi = 1,3$ – power increase coefficient at the consecutive stages of load.

2. Initial, lowest running-in power of the test engine, which the lowest running-in power is equal to the minimal engine rotational speed, calculated from the general propeller characteristic of power.

$$N_1^* = 0,634 \cdot (n_{\min}^*)^3 + 0,0213 + 0,343 \cdot (n_{\min}^*)^4 \tag{1}$$

3. Number of running-in stages at load

$$k = \frac{\ln\left(\frac{N_2^*}{N_1^*} \cdot \varphi\right)}{\ln \varphi} \tag{2}$$

4. Number of running-in stages, considering the engine operation without load (at the laid-back run)

$$k' = k + 1 \tag{3}$$

5. Conditions of the engine load at the first stage of running-in

$$N^* = 0 \tag{4}$$

$$n^* = n_1^* \tag{5}$$

$$M_o^* = 0 \tag{6}$$

6. Values of power, engine rotational speed and torque at consecutive stages of running-in

$$N_i^* = N_1^* \cdot \varphi^{i-1} \,, \tag{7}$$

$$n_i^* = [1020\sqrt[3]{N_i^*} - 19,5 \cdot (N_i^*)^3 - 0,013 \cdot (N_i^*)^{-3}] \cdot 10^{-3}, \tag{8}$$

$$M^{*}_{0i} = \frac{N^{*}_{i}}{n^{*}_{i}}, \qquad \text{i=1,2,3…,k.} \tag{9}$$

7. General running-in time, depending on the value of nominated engine rotational speed n_n

$$\Sigma t = 200(1366 \cdot \frac{1}{n^{n}} + 1{,}177 - 0{,}0655 \cdot \sqrt[3]{n_n}) \tag{10}$$

8. Running-in time at particular stages of load

$$t = \frac{\Sigma t}{k+1} \tag{11}$$

The running-in process of cooperating surfaces of engine elements is always accompanied by the friction phenomenon and wear, which is evoked by friction. The influence on the intensity of wear of friction pair in the time of normal exploitation have properties of outer layer, which are given to the surfaces, cooperating in the running-in process. So running-in process should be proceeded in conditions possibly the closest to the real exploitation conditions. Applied programs in many cases do not take under consideration these requirements, in particular the manners of realization loads. If it concerns the marine engines of main propulsion, running-in should be bared on the progressively increase of loads according to the propeller characteristic.

The running-in process should be a continual process, which means if halt time of engine does not exceed the time, necessary to conduct the survey, remove the hitches and improve the regulation condition of working continual is not fulfilled, running-in should be conducted again. The surveys should be conducted again as well. The first should be conducted after the realization I stage and next after the realization 1/3 of working time on particular stages of the running-in process. After the end of running-in process the final survey is performed.

Oil filters should be checked and cleaned, also temperature of the crankshaft-bearing and the smooth surfaces of cylinder sleeve should be checked after every survey. During the surveys the location of friction surfaces must not be violated.

Engine load during the transitions from one stage of the running-in to another and after the working break caused by survey should be fluent. Transitions time to the other stages should be determined by the thermal condition of the engine. It is recommended, that the time of increasing load was 1 min for the engine of main propulsion and 0,5 min for the engines of current generating and auxiliary set [1].

The control of the running-in process lies in the analysis of the measured parameters, which characterize engine operation and the comparison of its values, given by the producer of engine.

Running-in is assumed as correct if:

- the running-in process is fluently realized
- engine reaches nominated value of effective power at nominated values of fuel setting and engine rotational speed

3. Engine tests

At one stage of the research project 4T12D 05 529 were performed tests, which were aimed to carry out analysis of process, which occurs in the piston-ring-cylinder set of combustion engine ZS during the running-in process and also assessment of the influence of

P-R-C set tightness on energy parameters of engine and toxic compounds emission in exhausts [5,6].

Tests have been conducted in the laboratory stand of 1SB test engine in the Exploitation Laboratory of Shipping Power Stations in the Naval Academy of Gdynia.

The running-in program of 1SB engine has been worked out according to the above presented methodology.

Comparison of particular parameters of the plan is included in table 1 and graphic is presented in Fig. 1.

Table 1. Table of parameters of the running-in program on the test engine

The running-in stage	Efficient power [kW]	Engine rotatonal speed [rpm]	Torque [kN·m]	Running-in time at the particular stage [min]	General running-in time [min]
I	3,489	796	41	46	46
II	4,535	869	49	46	92
III	5,896	948	59	46	138
IV	7,665	1032	71	46	184
V	9,964	1120	85	46	230

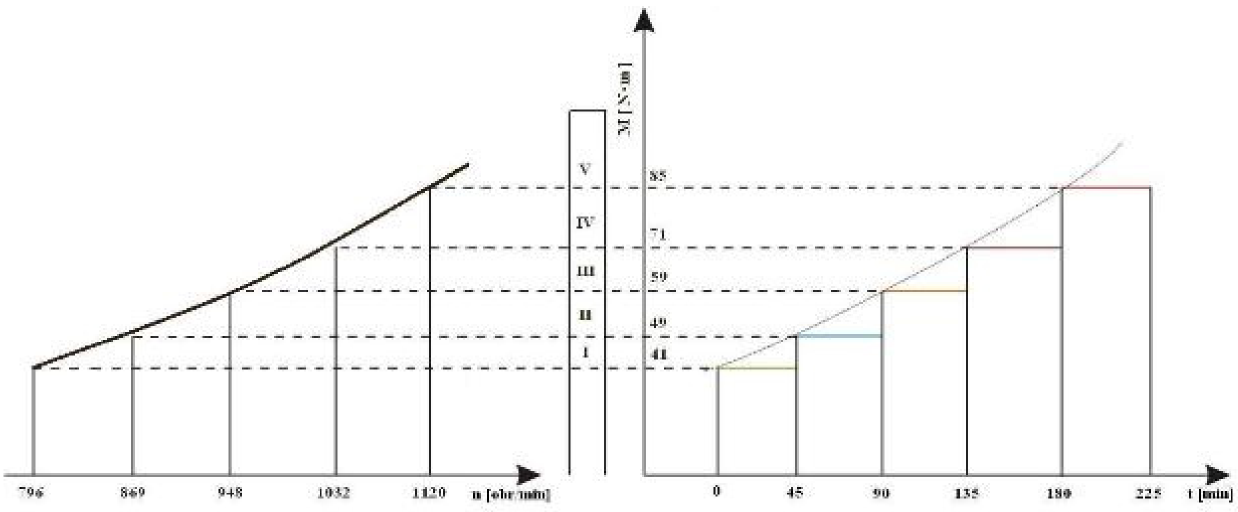

Fig.1. Graphic of the measured running-in process according to [2]

To interchangeably describe the parameters of running-in process, engine has been loaded by torque. It was possible thanks to/because of applying the electrowhirl break AMX type of Automex Company, which is characterized by great precision in the maintenance of given load. Additionally, according to the program, after establishing load and engine rotational speed the fuel stick was blocked to establish the dose of fuel. Applied engine load system has allowed to interchangeably determining the end of running-in at particular stages of approved running-in program. As is such combination should be expected, the engine rotational speed changes in case of mechanic efficiency improvement.

During the running-in process on the measure stand were registered and then analyzed above others such indexes/factors of engine as: engine rotational speed n [rpm], torque M_o [N·m], unit fuel consumption g_e [g/kW·h], exhausts temperature in the exhaust pipe T_{g2} [^oC], mean indicated pressure p_i [MPa], mean effective pressure p_e [MPa].

As it is given in the literature, first and foremost influence on the toxic compounds concentration has the course of combustion process. Significant influence on this process have unstable conditions and accompanying transitional process, which among others thing/inter alia brings into power changes i.e. change of coefficient λ. It results in throwing the cylinder off the thermodynamic equilibrium. Return to the relative equilibrium takes relatively long time (in case of CO it is the longest among/of all analyzed compounds, but its character is the same for every ZT).

The return process of cylinder to the thermodynamic equilibrium could be divided into 2 periods. The first period is relatively short, when after bringing into new load the changes of the CO concentration are greatest and the second period, when changes are relatively stabilized and they asymptotically decrease. For the reason, that participation of the first period in the time of whole process is little and in the considered case we have to deal with comparatively long period of registration the stage of running-in (i.e. 45 min) it was decided to pass over/omit this stage in the subsequent analysis. According to Fig. 2 registered course of CO changes were divided into 5 periods, which correspond to the consecutive stages of running-in.

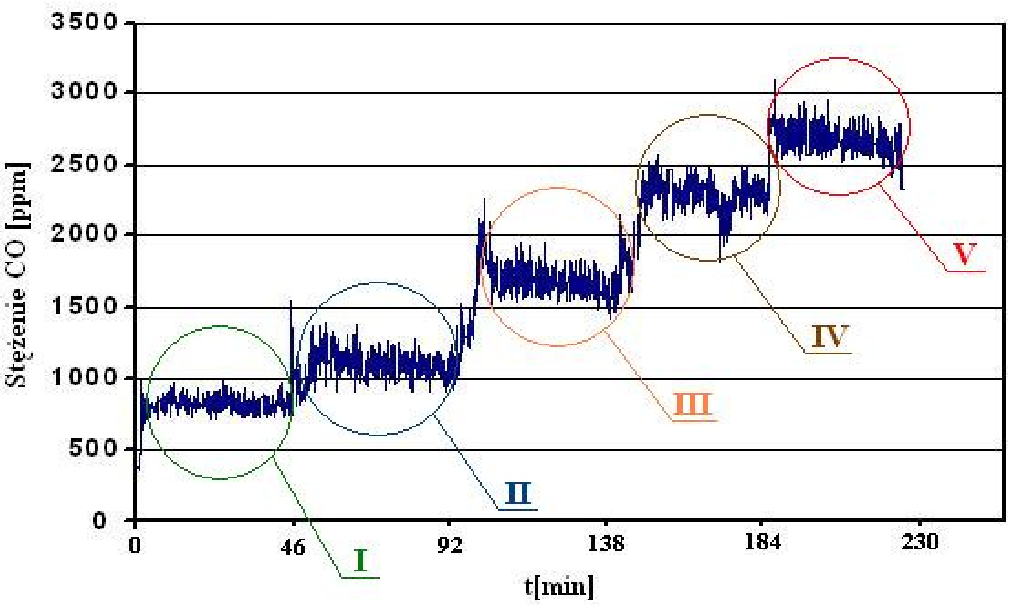

Fig. 2. Change of the CO concentration in exhausts during the running-in process, where: I-V – stages of the running-in process

As it could be noticed, along with the load increase, CO concentration increases. It is connected with the decreasing air-exceed coefficient λ. Above course is typical for the unsupercharged engine. Difference of the Co concentration between I and II stages is 300 ppm, between II and III – 50 ppm, between III and IV – 700 ppm. However, in case of transition from IV to V, this difference is 400 ppm. Probably it is connected with the insignificant change of air-exceed coefficient λ (in comparison to previous stages). Similar character has the course of change of NO_x concentration

Somewhat differently forms the course of NO_x concentration change. Analyzing this course in the context of λ change it is noticeable, that the NO_x concentration increases, despite the decrease of air-exceed coefficient λ. increase at the consecutive stages of running-in is admittedly low, but significant. It occurs, probably because of the fact, that despite the smaller amount of oxygen, which is necessary to form the NO_x, the change of combustion temperature occurs, which is the second factor responsible for the NO_x appearance [22,23]. Time of nitrogen oxides' stabilization after introducing the unstable condition, caused by the changeable extend of running-in process, is definitely shorter than in case of CO and HC. As in case of CO, which change of running-in extend ex. from 2 to 3 is 15 min, so the same change of load causes shorten reaction for NO_x, which is about 7 min.

In order to generalize the changes of particular toxic compounds' concentration observed during the process of running-in, the initial and final concentrations of different stages were compared. The time of process was also registered, considering the moment of the engine's rotation speed stabilisation as the end of running-in (on the given stage). The results of the analysis are presented with relative values (Fig. 3 and 4).

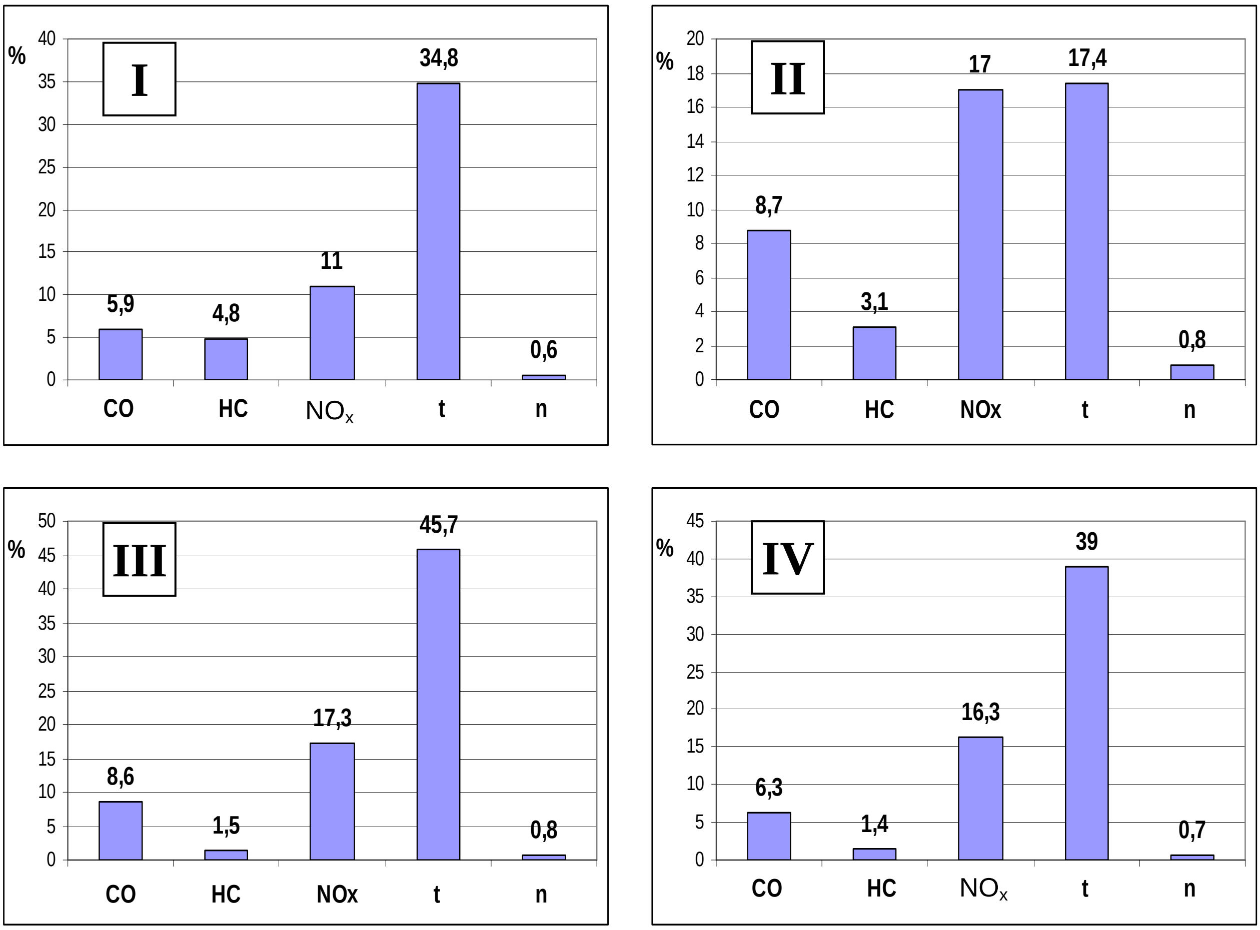

Fig. 3. Changes of the parameters of running-in process, where: I, II,…, IV – extend of the running-in process, t – time of the running-in process realization, n – engine rotational speed

V

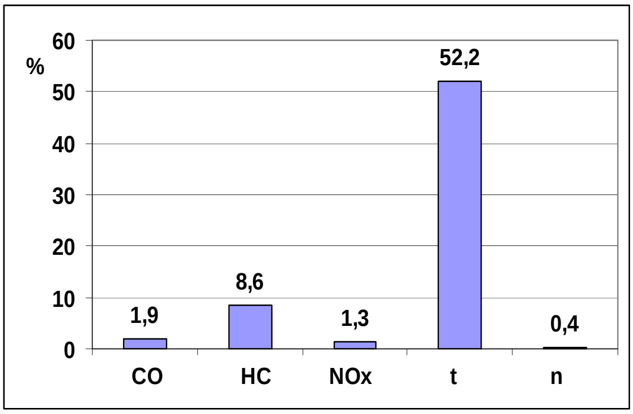

Fig. 4. Changes of the parameters of running-in process, where: V – extend of the running-in process, t – time of the running-in process realization, n – engine rotational speed

4. Conclusions

Presented above material does not fully extend considered subject, this presented experiment has confirmed obvious relation between the running-in process and processes, which occur in the engine cylinder, despite the values of parameters of structure of piston-ring-cylinder set, used in the experiment, were not significant.

The greatest changes of exhausts concentration indexes during the running-in process can be remarked for the HC and, in lower extend, for CO. Changes of index values in the HC and CO concentration are the more significant at comparison their values to changes of the basic index, which described the correctness of the running-in process course, namely engine rotational speed. Changes of this index is an order of 0,4 – 0,8% at11 – 17% of change of the HC concentration.

Considering the fact that most of the running-in programs have general character (do not consider the specificity of individual engines, as well as the differences, which come out of the tolerance of particular copies assembly).It is apparently in Fig. 3 and 4, where only at the second running-in stage time decreased for 8 min, which results in 17,4% economy of time at II running-in stage. In other cases economies are definitely greater and adequately are: I – 34,8%, III – 45,7%, IV – 39% i V – 52,2%. In this situation, when we have to deal with appreciable costs of fuel, such economy is not indifferent

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