Materials properties containing the energy grids forced internal combustion engines application

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Abstract. The efficiency improving relevance of the energy grids based on internal combustion engines is presented. Consequently, the application possibility of the internal combustion engine high temperature cooling system in the power plant by using its positive effect was considered and analysed. The analysis of the experimental data, namely of the cylinder cover fire bottom temperatures and materials parameters measurement depending on the operating temperature is presented. The obtained experimental data of the cylinder cover fore bottom temperatures level made it possible to predict the forced ICE aggregate capacity increasing limitations.

Key-words: power plant, internal combustion engine, thermometry results

1. Introduction

Energy efficiency improving issues receive worldwide as well as the European Union attention. The European Union has prepared the reference document on best available techniques for energy efficiency [1]. It was developed for information as well as implementation and monitoring in this field which is carried out in accordance with article 17 (2) of the EU Directive 2008/1. It states in paragraph 2.15.1. [1] that «energy models, databases and balance sheets are integrated and detailed energy analysis useful tools being frequently used as part of the analytic energy audits, including comprehensive ones. A model is a scheme or description comprising the energy use within the plant, unit or system.»

These provisions fully apply to power plants providing the energy and heat supply to various facilities, including oil and gas industry. The given branch can be considered as a special one as it has its own specificity. This is due to conducting the hydrocarbon fuel exploration and extraction works in small compact and remote areas where there is no power supply. Therefore, provision these remote facilities with heat and energy becomes possible by means of small power utilities. Alternatively, the energy grids can be based on the internal combustion engines.

Solving the efficiency improving issues of the energy grids based on the internal combustion engines will also make some contribution to the energy resources saving and by 2020 reduce the fuel consumption in the country by 40–48 %, equivalent to 360–430 mln tons of reference fuel per year.

Energy and resource saving is one of the most urgent priorities of this century. Russian Federation’s economy place among economically developed foreign countries, as well as our citizens living standards improvement depend on solving the mentioned problems.

Russian machine building complex has the necessary intellectual potential for the given urgent problems comprehensive solution.

2. Problem statement
As previously noted, the effective autonomous energy grids implementation including for the oil and gas industry, on the basis of the reciprocating internal combustion engines (ICE) requires their aggregate capacity enhancing. This results in the radiator units overall dimensions increase which leads to the installing on the site problems and especially in the container unit or on vehicles.

Applying the high temperature cooling (HTC) system of cooling the ICE in which the cooling fluid outlet temperature exceeds 373 K (100 °C) can contribute solutions to address the mentioned issue. The advantages include: ICE indicator values increase at partial loads due to the combustion chamber parts temperature level increase and unreasonably high excess air coefficients decrease, ICE mechanical efficiency increase in the entire load range by reducing the engine oil viscosity, changing the heat balance components of ICE in which the heat removal increases with the exhaust gases and, simultaneously it causes reducing the heat removal amount with the cooling fluid which makes it possible to reduce the dimensions and correspondingly weight and cost of radiators, the engines cylinder-piston group (CPG) parts wear and acid corrosion reduction which in turn allows to use more sulfur fuel for combustion and a number of other advantages [2, 4].

However, CPG system using has disadvantages hampering their application. Some of them include: ICE volumetric coefficient decrease at the nominal power due to the CPG walls temperature growing resulting in the indicator values decrease particularly in the high-forced diesel engines, the cooling system chambers pressure increase necessity. The ICE outlet cooling fluid temperature increase impact of more than 373 K on the CPG parts temperature status, in particular the cylinder cover should be noted.

3. Theory
For assessing the reliability of the cylinder cover and the whole energy grid, the fire bottom temperature level and change are required to be primarily defined.

Experimental studies, in particular determining the cylinder cover fire bottom temperatures were carried out on the stand with the mounted full-sized engine 6CHN 21/21 in different operating modes and at the different engine output cooling fluid temperatures.

In addition to the cylinder piston and bush, the cylinder cover is one of the most heat-stressed and critical engine parts, especially of high-performance diesel engines. Cylinder covers operation reliability improvement is primarily connected to its temperature level decrease and the fire bottom temperature change which refer to the most stressed and critical parts or more heat resistant materials application during manufacturing.

The thermocouples installation diagram with their coordinates in the cylinder cover on the fire bottom side is represented in figure 1.

![Figure 1. Thermocouples installation scheme of the cylinder cover.](image-url)
Table 1 shows the cylinder cover points temperature values (in degrees Celsius) in two power modes of 852 kW (1160 h.p.) and 883 kW (1200 h.p.) at the crankshaft speed of \( n = 25 \, \text{s}^{-1} \) and engine output cooling fluid (CF) temperature variation to 390 K (117 °C) and oil change to 369 K (96 °C).

### Table 1. Cylinder cover temperature values in two power modes.

| Point number | 852 kW (1160 h.p.) | 883 kW (1200 h.p.) |
|--------------|---------------------|---------------------|
| 1            | 269                 | 277                 |
|              | 283                 | 286                 |
|              | 292                 | 294                 |
|              | 289                 | 287                 |
|              | 292                 | 294                 |
|              | 278                 | 279                 |
|              | 287                 | 293                 |
| 2            | 380                 | 385                 |
|              | 390                 | 396                 |
|              | 400                 | 383                 |
|              | 399                 | 394                 |
|              | 397                 | 408                 |
| 3            | 250                 | 250                 |
|              | 254                 | 260                 |
|              | 264                 | 243                 |
|              | 250                 | 256                 |
|              | 260                 | 266                 |
| 4            | 292                 | 302                 |
|              | 309                 | 317                 |
|              | 317                 | 310                 |
|              | 315                 | 326                 |
| 5            | 361                 | 362                 |
|              | 364                 | 365                 |
|              | 365                 | 368                 |
|              | 373                 | 378                 |
|              | 378                 | 382                 |
| 6            | 352                 | 352                 |
|              | 354                 | 364                 |
|              | 365                 | 367                 |
|              | 364                 | 371                 |
|              | 371                 | 373                 |
| 7            | 357                 | 357                 |
|              | 365                 | 370                 |
|              | 374                 | 371                 |
|              | 370                 | 379                 |
|              | 379                 | 394                 |
| 8            | 83                  | 90                  |
| Temperature C.F., °C | 98                  | 105                 |
|              | 117                 | 105                 |
|              | 117                 | 117                 |

Subsequently, the engine output cooling fluid temperature and forcing level influence on the cylinder cover temperature was analysed on the basis of the experimental data. Moreover, an attempt to estimate the cylinder cover temperature expected values if the ICE forcing level increases taking into consideration the relevance of the problem was made.

Engine 6CHN21/21 cylinder cover temperature condition obtained studies analysis results make it possible to conclude that at the temperature of the cooling fluid of 378 K (105°C) and oil of 363 K (90°C) at the ICE power of 883 kW, the temperature is up to 667 K (394°C) and does not exceed the maximum value of 673-683 K (400-410°C) for cast iron, which the cover is made of.

### 5. Results discussion

For providing the engine life predetermined value, simultaneously forcing the engine, the mechanical strength dependence on the various materials (cast irons) temperature value was analysed. The conducted analysis results represented in table 2 suggest that at the temperatures above 673 K (400°C), the cast iron strength characteristics are sharply reduced, therefore temperatures about 788 K (415°C) are limiting for the cylinder cover with long service life. At the same time, even at 773 K (500 °C), CGI cast iron (perlite) has the mechanical strength is 30 % higher compared to gray cast iron at 673 K (400 °C).

On the basis of the conducted analysis, the preliminary conclusion can be made that stronger cast iron applying at the cylinder cover higher temperature with the engine forcing level increasing and engine output cooling fluid temperature growing is appropriate.

Gray cast iron SCH18 and SCH20 alloyed with chrome to 0.4 %, nickel to 0.9 %, molybdenum to 0.5%, copper to 0.6 % and titanium to 0.1 %; ductile cast iron, aluminum alloys of AL9 and AL30 grades with silicon content from 7 to 13 %, aluminum and magnesium alloys with magnesium content of up to 5 % in the presence of silicon up to 1 % are used as one of the cylinder covers manufacture materials. The cylinder covers material should possess the necessary creep strength, mechanical and thermal fatigue resistance in addition to the high strength characteristics under the dynamic loading conditions.

Subsequently, the processing properties and the different materials application effectiveness should be analyzed.

The parameters analysis results of table 2 show that at the temperature above 673 K (400°C), the strength characteristics of virtually all cast irons are reduced. Thus, the temperature in the range from 783 to 788 K (from 410 to 415 °C) is assumed to be the limit one for the cylinder cover given applied material.

### Table 2. Strength properties of some cast irons.

| Temperature T (t) | Cast iron strength E (kgf/mm²) |
|-------------------|-------------------------------|
|                   |                               |
As mentioned above, if diesel power is increased to 957 kW (1300 h.p.), the cylinder cover temperature was predicted. The temperature amounts to 706 K (433°C) which is above the recommended value by more than 8 % for the given material. Therefore, when choosing the cylinder cover material, particular attention should be paid to its strength characteristics taking into account the temperature during operation.

This suggests that heat-resistant cast iron applying, for example, ChVG grade at the cylinder cover higher temperature with ICE aggregate capacity increasing is appropriate.

As an example, table 3 presents the ductile cast irons mechanical properties and metal matrix structure.

| Cast iron | σt, MPa | δ, % | HB | Metal matrix structure |
|-----------|---------|------|----|------------------------|
| VCh 38-17 | 380     | 17   | 1400-1700 | Ferrite with a small amount of perlite |
| VCh 42-12 | 420     | 12   | 1400-2000 |                               |
| VCh 50-7  | 500     | 7    | 1710-2410 |                               |
| VCh 60-2  | 600     | 2    | 2000-2800 | Perlite with a small amount of ferrite |
| VCh 80-2  | 800     | 2    | 2500-3300 |                               |
| VCh 120-2 | 1200    | 2    | 3020-3800 |                               |

The chemical composition after modifying these cast irons has the following values: 3.0-3.6 % C; 1.1-2.9 % Si; 0.3-0.7 % Mn; up to 0.02 % S and up to 0.1 % P. The ductile cast iron matrix is the metal structure consisting of ferrite or perlite. The ferritic cast iron mainly consists of ferrite and spheroidal graphite, besides perlite up to 20 % is allowed. Perlitic cast iron structure is sorbitic or lamellar perlite and spheroidal graphite, and ferrite up to 20 % is also allowed.

Lamellar graphite possesses the metal matrix smaller mechanical parameters and at the same time have increased strength and low ductility. High-strength cast irons are marked for the ultimate strength and relative elongation.

The given cast irons have been widely used in various branches of industry and in some cases by replacing steel in many products and structures. The rolling mills equipment (rolls having a weight of up to 12 tons), press-forging equipment (the crosshead, anvil block), guide vane blades, in turbine construction the steam turbine housing and parts, in diesel engine and automotive manufacturing the crankshafts, pistons and many other parts being the main ones which operating parameters have high cyclic loads including under the wear conditions are made of the mentioned above materials.

In some cases, castings heat treatment is used for improving the mechanical properties of products made of these materials: quenching and tempering in the range from 773 to 873 K (500-600 °C) are applied for improving the strength, and annealing contributing to perlite spheroidizing is used for improving the ductility.

6. Conclusions

Thus, it can be concluded that when improving the efficiency of the autonomous energy grids based on the reciprocating internal combustion engines, special attention should be paid to the particularly critical parts applied materials properties. This primarily refers to the cylinder cover operating under the cooling fluid high temperature conditions for various power plants including oil and gas industry.
Besides, the obtained experimental data of the cylinder cover fire bottom temperature level by using the engine installed on the test bench, made it possible to predict the high performance ICE aggregate capacity increase limitations taking into consideration the operational conditions.

7. References

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