Assessing the forcing level of air cooled diesel engine considering parameter spread of boosting system

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Abstract. Spread of parameter values of piston internal combustion engine boosting parts is normally due to extreme deviations (spread, error margin) of original parts and quality of assembly. Spread of relation of boosting pressure to counter pressure at outlet of turbo compressors $P_k/P_t$ of the same type affects not only the engine parameters, but also thermal expansion of cylinder-piston group parts and cylinder head. At stable relation value of $P_k/P_t$, boosting pressure and maximal air flow, turbo compressor allows us to reduce the thermal factor of combustion chamber and cylinder head due to higher values of air excess ratios. This is very important, first of all for air cooled engine as in case of dramatic surge of its thermal factor we face a risk of cracks occurring in inter valve and inter valve- nozzle connectors of cylinder head fire bottom, cracking of setting bevels at valves of gas distribution mechanism. We analyzed the impact of technological spread of boosting details parameter on the value of achieved forcing limit. Impact analysis of technological spread of turbo compressor parameters on diesel engine performance was done on the basis of test results of ten $В-400$ engines, fitted with randomly selected pairs of ТКР8,5-С7 turbo compressors out of a lot of 20 pieces. For each turbo compressor we determined preliminarily characteristics and efficiency factors $\eta_k$, of turbine $\eta_t$, and of a unit as a whole $\eta_{tk}$.

1. Introduction
Power forcing of air cooled diesel engines is limited by maximum allowed thermal condition of parts in cylinder-piston group and cylinder head. Analysis of cylinder temperature fields, piston and cylinder head of air cooled engine at various levels of forcing showed that [1 - 8] maximal temperature gradients of cylinder head are almost three times as high as maximal temperature gradients of cylinder or piston. Based on calculations and test results of $B$-$400$ diesel engines it was established that with sufficient reserve of rigidity and hardess of framework and bearing capacity of crankshaft, the factor, limiting permitted forcing level of air cooled engine is thermal condition of cylinder head, having most non-uniform temperature field and levels of thermal stress as compared to parts of cylinder-piston group.

As shown by experience, thermo-cyclic destruction of cylinder head begins either in the point of maximal temperature or close to it as long as the maximal temperature exceeds for a long time the permitted one for the material used. Spread of thermo-cyclic crack is due to spread of material microstructure of cylinder head. Thermometering results of the surface of cylinder head fire bottom of $B$-$400$ diesel engine prove that the maximal temperature on the cylinder head bottom seriously affects the maximal temperature gradient. Based on the above, the maximal temperature of cylinder head fire bottom of air cooled diesel engine can be a criteria for finding a forcing limit of such engine.
Higher size of air cooled diesel engine aggravates the problem of maintaining permitted thermal factor of the structure, as the cooling area of cylinder head, limiting heat removal is rising in proportion to a cube of the cylinder diameter, whereas as heat release increases in proportion to the diameter cube.

For each particular structure of diesel engine, establishing limits of possible forcing is an important practical task, which, if not solved, prevents creation of a feasible engine with maximal high running parameters. Especially acute is the problem of availability and so determining permitted forcing levels for air cooled diesel engines, operating in harsh climatic conditions becomes a critical issue.

We proposed methods of determining the ultimate forcing level of air cooled diesel engine of certain design by boosting. The methods were verified at В400 engine, having the largest size of all serially produced and being produced now air cooled diesel engines.

2. Object of research
The object of research is a diesel air cooled engine В-400. Other technical characteristics of engine В-400 are given in table 1.

Table 1. Key technical characteristics of engine В-400.

| Description of parameter               | Parameter value |
|----------------------------------------|-----------------|
| Stroke                                 | 4 strokes       |
| Number and position of cylinders       | 8, V-90°       |
| Diameter of cylinder, mm               | 150             |
| Piston stroke, mm                      | 160             |
| Liter capacity, l                      | 22.6            |
| Power, kW                              | 307+15          |
| Rotation frequency, min-1              | 1700±20         |
| Specific fuel consumption g/kW*h, not more than | 210            |
| Boosting pressure, MPa                 | 0.19-0.22       |

3. Ensuring reliable operation of air cooled engine at forcing limit
When determining limits of possible forcing by boosting of the diesel engine we note high sensitivity of thermal condition of the parts of cylinder- piston group and cylinder head to relation of boosting pressure Pk and pressure Pt of off-gases upstream of turbine [9]. With the increase in relation Pk/Pt at preset forcing level, the excess air factor goes up, the mean integral temperature of the working medium goes down and so does accordingly the temperature of combustion chamber surfaces.

In serial production there is always some spread of indices in a lot of boosting parts, installed in an engine. As an example you can see on Figure 1 an experimentally produced spread of values of relation Pk/Pt for the right and left rows of cylinders in В-400 diesel engine with installed on it a ten pairs of 8,5C-7 turbo compressor, selected randomly from a lot of this type turbo compressors.

It can be assumed that to ensure reliable operation, the limit of air cooled diesel engine forcing should be determined based on smallest values of relation Pk/Pt. As you can see, the maximal deviation of relation Pk/Pt from the relative mean value towards an adverse side, i.e. towards reduction of the relation is 3.5%.
Figure 1. Spread of relation \( \frac{P_k}{P_t} \) of diesel engine B-400. N of pair TKP – No. of turbo compressor pair, installed on the engine.

Figure 2-5 below show processing results of experimental data on testing B-400 diesel engine, equipped with ten different pairs of turbo compressors TKP8,5C-7.

Figure 2. Spread of excess air factor \( \alpha \).

Figure 3. Efficiency factor of used compressors TKP8,5C-7.
We have determined that air cooled [9], diesel engines are especially sensitive to relation $P_k/P_t$. This means that the engine is at the limit of forcing by thermal condition, technological tolerance of this relation towards an adverse side may have a serious impact on increasing the chance of engine failure due to thermo- cyclic destruction of the cylinder head. In view of the above we made a calculated assessment of technological spread of influence $P_k/P_t$ on thermal condition of the cylinder head. Results of calculations are given in table 2 and in Figure 6.

**Table 2.** Calculation results of diesel engine B-400 at different relations of value $P_k/P_t$.

| $N_e$ (kW) | $N_b$ (min⁻¹) | $P_k/P_t$ | $G_a$ (kg/hour) | $P_z$ (MPa) | $T_{wch}$ (K) | $T_{max}$ (K) |
|-----------|--------------|-----------|----------------|------------|--------------|--------------|
| 275       | 1700         | 0.950     | 1.74           | 1609       | 9.29         | 488          | 590          |
| 275       | 1700         | 1.162     | 1.86           | 1693       | 9.47         | 479          | 576          |

*aEffective power of engine.*

*bRated rotation frequency of crankshaft.*

*cMaximal pressure of burning.*

*dWeighted average temperature of cylinder head fire bottom.*

*eMaximal temperature of cylinder head fire bottom.*
Figure 6. Temperature of cylinder neck bottom at variation of relation $P_k/P_t$.

4. Conclusion
When using turbo compressors of the same model we can witness due to technological spread of parameters an obvious variation of cylinder head temperature field. Technological spread of parameters TKP8.5C-7 shows as an example significant (within 6\%) effect of relation $P_k/P_t$ on maximal temperature of cylinder head fire bottom.

If an air cooled engine is at the ultimate level of forcing, we should consider it and for reliable operation the forcing limit must be established based on minimal values of relation $P_k/P_t$.

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