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A computer calculation method for thermal load control of ship diesel engine combustion chamber

SUMMARY

In the paper strong emphasis is placed on importance of thermal load control of combustion chamber of ship diesel engine in exploitation. To this end a computer software was elaborated suitable for determination of thermal load index values when the basic, easy measurable, operational parameters of the engine are known. Example results of application of the software are attached.

INTRODUCTION

One of the basic conditions for correct operation of ship diesel engine, i.e. obtaining its demanded power output, is effective work of the engine's fuel injectors.This depends not only on quality of the fuel delivered to the injectors, choice of spray nozzles and the course of the entire fuel spraying process, but also - and to very large extent - on thermal load of combustion chamber of the engine.Therefore the author's intention was to elaborate a computer calculation method suitable for investigating thermal load of diesel engine combustion chamber, hence also its elements, inclusive of injectors.

CHOICE OF THERMAL LOAD INDEX

In the literature of the subject in question many calculation criteria can be found considered as synthetic indices of thermal load of the engine, or indices of its power output per cylinder. An example of the first kind is the formula (1) :

$$K = \frac{N_i}{D}\ [\mathrm{kW/m}] \qquad (1)$$

and (2) and (3) - of the second kind :

$$N_c = \frac{z}{2} \cdot C_m \cdot P_{me}\ [\mathrm{MW/m^2}] \qquad (2)$$

$$N_{cc} = \frac{N_{re}}{i \cdot F_p \cdot \sqrt{\frac{S_p}{D}}} = \frac{N_c}{\sqrt{\frac{S_p}{D}}} \qquad (3)$$

where:

- C_m – mean piston speed [m/s]
- D – cylinder diameter [m]
- F_p – piston area [m^2]
- i – number of cylinders
- K – synthetic thermal load index
- N_c – cylinder power index
- N_{cc} – corrected cylinder power index
- N_i – indicated power [kW]
- N_{re} – rated effective power [kW]
- p_{me} – mean effective pressure [MPa]
- S_p – piston stroke [m]
- z – coefficient dependent on type of engine.

Values of such indices can be easily calculated, but they provide only a general assessment of thermal load of the engine (combustion chamber) and do not show in which way the load is dependent on the main operational parameters of the engine.

Such relationships are reflected to some degree by the temperature indices described in the publications [1÷15]. Their practical application onboard the ships in service is very difficult as they demand to make complicated measurements by means of special instruments.

Having all that in mind this author focused his attention on the thermal load index given by the formula (4) defined by Kostin [15] on the basis of a relationship between the density of wall-penetrating thermal flux and the engine operational parameters :

$$K_K = BC_m^{0.5}\left(p_{me}\cdot f_e\cdot\frac{T_{sa}}{T_a}\right)^{0.88}\cdot\left(\frac{D}{\lambda_{ae}p_{sa}}\right)^{0.38} \quad (4)$$

where :

- B – constant value (for 4 - stroke engine : B = 5.73, for 2 - stroke engine : B = 10.20)
- C_m – mean piston speed [m/s]
- D – cylinder diameter [m]
- f_e – specific fuel oil consumption [g/kWh]
- K_K – Kostin's thermal load index
- p_{me} – mean effective pressure [MPa]
- p_{sa} – supercharging air pressure [MPa]
- T_a – ambient temperature [K]
- T_{sa} – supercharging air temperature (behind the turbocharger) [K]
- λ_{ae} – air excess ratio.

It is important that all magnitudes introduced to the Kostin's index, can be easily measured at diesel engine exploitation conditions [14]. It means that by using the formula (4) it is possible to monitor changes of combustion chamber's thermal load, effected due to changing values of the important engine operational parameters. Hence it could be used as a basis for elaboration of a computerized simulative control means.

SERVICE INVESTIGATIONS

To collect necessary empirical data on operation of ship diesel engine in service, investigations of operation parameters of 7RND 90M SULZER diesel engine installed - as its main engine - onboard one of the ships of Polish Steamship Company, Szczecin. Results of measurements of the parameters which decide – in line with the formula (4) – upon magnitude of thermal load of the engine combustion chamber, are given in Tab.1 together with values of K_K index calculated on this basis. The calculations were performed with the use of the computer software OBCIAZENIE (Load) developed by the author.

Tab.1. *Measurement results of the selected operational parameters of 7RND 90M Sulzer diesel engine, which influence thermal load of its combustion chamber, together with K_K index values calculated by means of OBCIAZENIE software*

p_{sa} [MPa]	f_e [g/kWh]	λ_{ae} [–]	p_{me} [MPa]	T_a [K]	T_{sa} [K]	K_K
0.055	225	0.4	7.6	298	293.8	3050438
0.066	224	0.5	8.0	299	293.9	2362310
0.068	223	0.6	8.2	301	295.4	2209100
0.07	222	0.7	8.5	303	295.5	2001434
0.078	221	0.8	8.5	303	296.2	1868224
0.08	220	0.9	8.5	304	296.7	1744605
0.085	219	1.0	8.7	304.5	297.7	1702672
0.086	218	1.05	8.7	304.8	299.7	1760086
0.087	217	1.1	8.7	305	304.2	1955787
0.089	216	1.15	8.7	305	307.1	2053228
0.089	215	1.2	8.8	305	307.7	2063830
0.09	214	1.25	8.8	305.5	307.8	1992901
0.09	213	1.3	8.9	306	308	1958379
0.09	211	1.35	9.0	306.5	359.3	1970262

Tab.2. *Input data selected for 7RND 90M Sulzer engine*

Cylinder diameter	D	[m]	0.90
Value of the constant	B	–	10.2
Mean piston speed	C_m	[m/s]	6.3

The results of the service investigations made it possible to describe functionally influence of particular operational parameters of the engine on the thermal load of its combustion chamber.

FUNCTIONAL APPROXIMATION OF THE MEASUREMENT RESULTS

The functional approximation of the relationships in question, based on the measurement results, was made by means of the least squares method. Relevant calculations were carried out with the use of EXCEL 97 program, a component of OFFICE 97 package. Graphical representation of the relationships is given in Fig.1÷5 together with their approximate functional expressions.

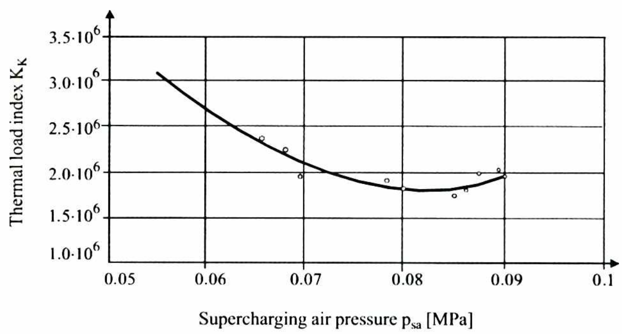

Fig.1. *Thermal load index K_K in function of supercharging air pressure p_{sa}*
ooooo - points calculated from measured values
—— - approximating function diagram

$$K_K = 5\cdot10^{10}p_{sa}^3 - 8\cdot10^9 p_{sa}^2 + 4\cdot10^8 p_{sa} - 3\cdot10^6$$

Correlation coefficient $R^2 = 0.9562$

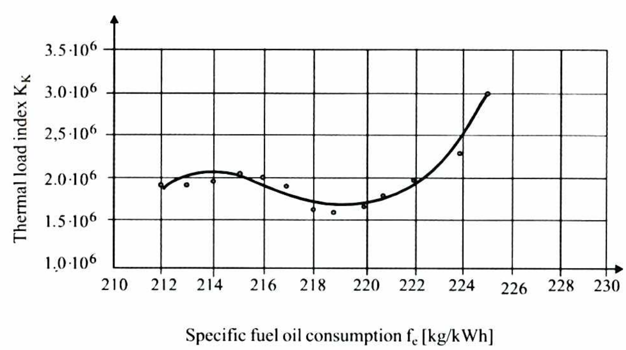

Fig.2. *Thermal load index K_K in function of specific fuel oil consumption f_e*
ooooo - points calculated from measured values
—— - approximating function diagram

$$K_K = 3151.3f_e^3 - 2\cdot10^6 f_e^2 + 4\cdot10^8 f_e - 3\cdot10^{10}$$

Correlation coefficient $R^2 = 0.956$

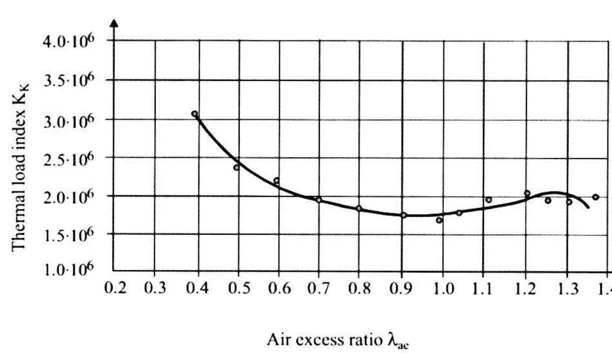

Fig.3. *Thermal load index K_K in function of air excess ratio λ_{ae}*
ooooo - points calculated from measured values
—— - approximating function diagram

$$K_K = (-2\lambda_{ae}^5 + 1)\cdot2\cdot10^7 + (2\lambda_{ae}^4 - 3\lambda_{ae}^3 + 3\lambda_{ae}^2 - \lambda_{ae})\cdot10^8$$

Correlation coefficient $R^2 = 0.9642$

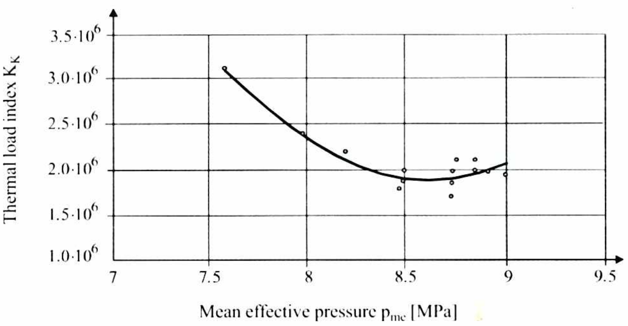

***Fig.4.** Thermal load index K_K in function of mean effective pressure p_{me}*
ooooo - points calculated from measured values
——— - approximating function diagram

$$K_K = 167893 \cdot p_{me}^3 - 3 \cdot 10^6 p_{me}^2 + 2 \cdot 10^7 p_{me} - 2 \cdot 10^7$$

Correlation coefficient $R^2 = 0.8904$

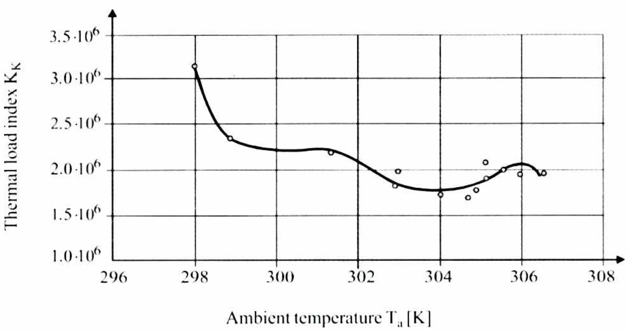

***Fig.5.** Thermal load index K_K in function of ambient temperature T_a*
ooooo - points calculated from measured values
——— - approximating function diagram

$$K_K = -1371.5 \cdot T_a^5 + 2 \cdot 10^6 T_a^4 - 10^9 T_a^3 +$$
$$+ 4 \cdot 10^{11} T_a^2 - 6 \cdot 10^{13} T_a + 3 \cdot 10^{15}$$

Correlation coefficient $R^2 = 0.9313$

COMMENTS ON THE CALCULATION RESULTS

First of all it can be stated that the applied approximation process is characterized by the satisfactorily high values of the correlation coefficients, contained within the range of 0.89÷0.96. Therefore the obtained functional relationships can be deemed well describing the thermal processes which occur in the combustion chamber of the investigated diesel engine.

It can be clearly observed from the diagrams of K_K functions that the thermal load of the engine's combustion chamber is strongly influenced by the following engine operational parameters :

- supercharging air pressure p_{sa}
- air excess ratio λ_{ae}
- mean effective pressure p_{me}
- ambient temperature T_a

At lower values of the specific fuel oil consumption f_e, the combustion chamber thermal load at lower values of the above mentioned operational parameters of the engine is much higher, which makes operational conditions of the injectors more difficult.

Worth mentioning, that at the temperature of the nozzles of about 453 K sediments and carbon deposits build up around them, which reduces their operational effectiveness.

Hence necessity of controlling the combustion chamber thermal load seems to be justified, and the presented method could be helpful for that.

However it should be also remembered that design variety of the diesel engines and their operational characteristics is so large that it makes it impossible to apply the results obtained from one engine, to another one.

CONCLUSIONS

- The continuous trend of increasing unit power of highly supercharged ship diesel engines makes it necessary to pay particular attention to their thermal load. The engine producers determine the permissible limits of that load for each type of the engines, depending on a.o. cooling system design of cylinders, pistons and combustion chambers. The limiting values are published in catalogues of the engines.
- For this reason it is very important to have at one's disposal an instrument making it possible to control thermal load of the combustion chamber during exploitation of the engine.
- In the light of the presented investigation results, such role could be fulfilled by the software OBCIAZENIE based on the thermal load index K_K given by the formula (4).
- This is a universal computer program applicable to different ship diesel engines provided that at this end current values of their basic operational parameters are measured in service, and the obtained values of K_K index are then compared with the permissible limiting values given by the engine producer.
- The simulative character of the software makes it possible to predict changes of thermal load due to change of any of the engine operational parameters accounted for in the software.

Appraised by Stefan Żmudzki, Prof.,D.Sc.

BIBLIOGRAPHY

1. Drozdowski J.: *Research on thermal load of injectors by means of electric analogy method* (in Polish) Silniki Spalinowe, 1984, No 3
2. Drozdowski J.: *Research on injector body materials of 6ZL 40/48 ship diesel engines with particular account for their thermal load* (in Polish). Zeszyty Naukowe. Maritime University of Szczecin No 25/85
3. Drozdowski J.: *A calculation method for determination of temperature of B 7855 engine injector* (in Polish). Zeszyty Naukowe. Maritime University of Szczecin, No 25/85
4. Drozdowski J.: *Determination of temperature fields of injectors of RD 68 SULZER ship diesel engine by means of electric analogy method* (in Polish). Zeszyty Naukowe. Maritime University of Szczecin, No 25/85
5. Drozdowski J.: *Research on temperature field of ship diesel engine injector by using a calculation program* (in Polish). Silniki Spalinowe, 1986, No 4
6. Drozdowski J.: *Thermal loads of ship diesel engine injectors* (in Polish). Silniki Spalinowe, 1984, No 1
7. Dziubek A.: *Notion and criteria of thermal load of piston combustion engines* (in Polish). Silniki Spalinowe, 1971, No 1
8. Dziubek A.: *On possible comparative assessment of thermal load of diesel engines* (in Polish). Silniki Spalinowe, 1972, No 1
9. Niewiarowski K.: *Piston combustion engines* (in Polish). WKiŁ. Warszawa, 1983
10. Piotrowski I.: *Ship diesel engines* (in Polish). WM. Gdańsk, 1983
11. Wajand J.A., Wajand J.T.: *Piston combustion engines* (in Polish).WKiŁ. Warszawa, 1993
12. Wiśniewski S.: *Thermal loads of piston combustion engines* (in Polish).WKiŁ. Warszawa, 1972
13. Wiśniewski S.: *Determination of steady and transient temperature fields in walls surrounding working space of piston engine cylinder* (in Polish). Silniki Spalinowe, 1972, No 2
14. Włodarski J.K.: *Ship diesel engines. Service loads* (in Polish). Gdynia Maritime Academy. Gdynia 1995
15. Włodarski J.K.: *Service states of ship diesel engines*. Gdynia Maritime Academy. Gdynia, 1998