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Contributions to the Study of Energy Flow at Supercharger Groups for Marine Engine

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Abstract—**The paper was developed using data from literature but also my experience in the operation of machines and installations on board as chief engineer. In this paper we defined key functional parameters that define and influence the energy flows of supercharging groups at ships engines which have to ensure safe operation for all operating regimes.**

Keywords- **Marine engine,supercharges, fluid flow, air temprature, ait compressorr**

I. INTRODUCTION

Supercharging unit is freely rotatable; the gas turbines convert the energy flow in mechanical power that is transmitted to a compressor supplying air energy flow necessary for gas exchange in thermal cylinders engine.

II. DEFINITIONS AND OPERATING PARAMETERS DETERMINATION

A. Hourly fuel consumption

Functional characteristics of the engine can be presented in table view or graphical representations. With the processing of the specific fuel consumption $C_e = f(P_e)$, figure 1 [B2] we obtain the hourly fuel consumption of the engine, which can be verified by direct experimental determination.

$$C_h = C_e \cdot P_e \left[\frac{Kg\ Cb}{h}\right] \qquad (1)$$

Where:

$C_e \left[\frac{Kg\ Cb}{h}\right]$ - actual specific fuel consumption

$P_{e_{cyl}}[KW]$ - effective power corresponding to a cylinder

$P_e[KW]$ - actual engine power

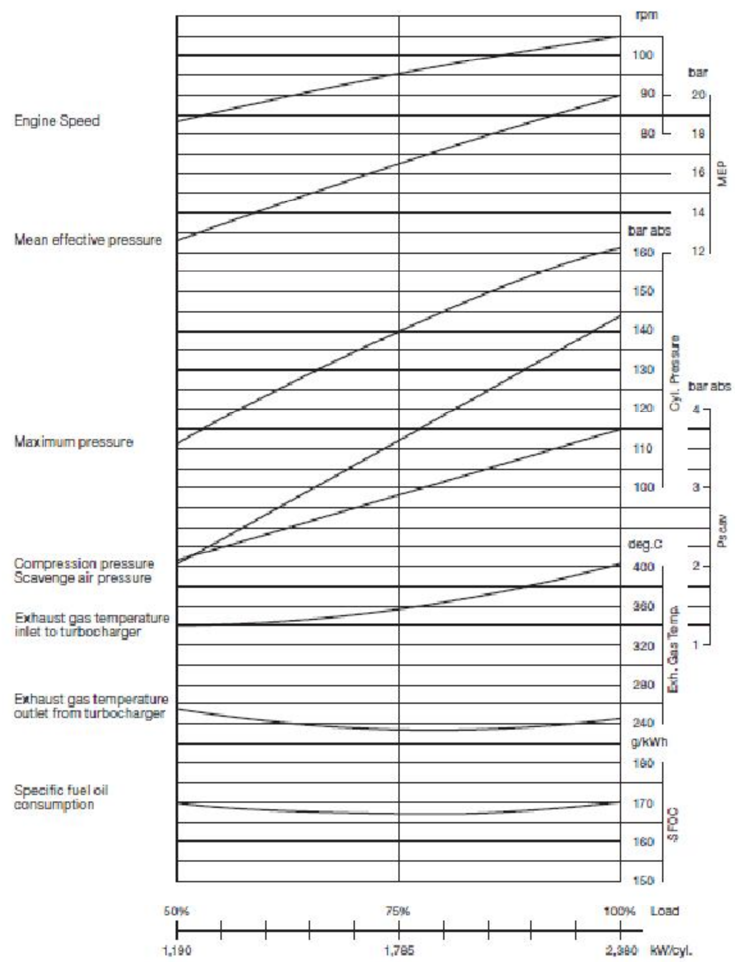

Fig.1: Performance curves for marine engine MAN B&W [B2]

B. Power flow available

Energy flow obtained by burning the fuel named energy flow available:

$$\dot{Q}_d = \frac{C_h Q_i}{3600}[KW] \qquad (2)$$

$C_h \left[\frac{Kg\ Cb}{h}\right]$ - hourly fuel consumption

$Q_i \left[\frac{KJ}{KgCb}\right]$ - lower calorific power of fuel

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C. Actual engine power

Actual engine power is determined by the relation:

$$P_e = \eta_e \cdot \dot{Q}_d [KW] \quad (3)$$

Or else

$$P_e = \eta_e \cdot \frac{C_h Q_i}{3600} [KW] \quad (4)$$

Or else

$$\frac{1}{C_e} = \eta_e \cdot \frac{Q_i}{3600}$$

D. Specific fuel consumption:

$$C_e = \frac{1}{\eta_e} \cdot \frac{3600}{Q_e} \left[\frac{Kg\ Cb}{KWh}\right] \quad (5)$$

E. Effective yield:

$$\eta_e = \frac{1}{C_e} \cdot \frac{1}{Q_i} [\ -\ ] \quad (6)$$

For reference conditions ISO 3046/2002 from [B2], lower calorific power Q_i = 42700 $\left[\frac{KJ}{Kg\ Cb}\right]$

Table 1. Functional features

$P_{e_{cil}}$ $[KW\}$	n [rpm]	$C_e \left[\frac{Kg\ .\ Cb}{KWh}\right]$	$Q_i \left[\frac{KJ}{Kg\ .\ Cb}\right]$	K_P	K_n
1190	78	0.170	42700	0.5	0.743
1785	95	0.167	42700	0.75	0.91
2380	105	0.170	42700	1	1

Where:

$K_P = \frac{P_{e_{exp}}}{P_{e_n}}$ - load factor or power ratio

$K_n = \frac{n_{exp}}{n_n}$ - revs report

$P_{e_{exp}}$ - effective operating power

P_{e_n} - nominal effective power

n_{exp} - operating revs

n_n - nominal revs

III. FLUID FLOW

A. Specific air flow

It determines for the conditions:

a) Burning specific air flow
b) Gas exchange specific air flow

a) $d_{a_{ard}} = m_{aer_t} \cdot \alpha_{ard} \cdot C_e \left[\frac{Kg\ air}{KWh}\right]$

b) $d_{a_{asg}} = m_{aer_t} \cdot \alpha_{sg} \cdot C_e \left[\frac{Kg\ air}{KWh}\right]$

Where:

$m_{aer_t} \left[\frac{Kg\ air}{kg\ cb}\right]$ - theoretical air mass needed to burn 1 Kg of fuel; it's determined according to elemental analysis of the fuel

For liquid fuel:

m_{aer_t} =13,5 ÷14$\left[\frac{Kg\ air}{Kg\ cb}\right]$;

α_{ard} =1.4 ÷ 3 - excess air ratio for burning;

α_{sg} =2.2 ÷ 4.6 - excess air ratio for gas exchange;

B. Specific gas flow

$$d_g = d_{asg} + C_e \left[\frac{Kg\ gas}{KWh}\right] \quad (9)$$

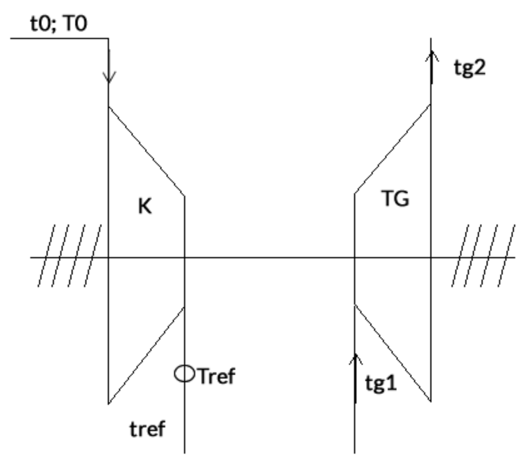
Or else:

$$d_g = (m_{aer_t} \cdot \alpha_{sg} + 1) \cdot C_e \left[\frac{Kg\ gas}{KWh}\right] \quad (10)$$

IV. ENGINE SUPERCHARGING

Engine supercharging is done with supercharging groups consisting of gas turbine an air compressor. From figure 1. [B2] we determine the temperature drop of the gas in the gas turbine.

A. The fall of temperature turbine



$P_{e_{cil}}$ [KW]	k_p	Δ tan TG [°C]
1190	0.5	85
1785	0.75	120
2380	1.00	155

Δ tg TG = $tg_1 - tg_2$ [°C];

B. Temperature rise in the compressor

Air temperature increase in the air compressor

$$\Delta \mathrm{t_{aK}} = \Delta \mathrm{T_{aK}} \ ; \ \Delta \mathrm{t_{aK}} = \mathrm{t_{ref}} - \mathrm{t_0}[°C]$$
$$\Delta \mathrm{T_{aK}} = \mathrm{T_{ref}} - \mathrm{T_0}[K]$$

C. Boost energy flows on supercharging aggregate

Supercharger group in free rotation requires energy balance between drive powers of compressor whit the effective power of the gas turbine.

a) The power required to drive the compressor

$$P_{ant_R} = \frac{1}{\eta_k} \cdot \frac{d_{asg} \cdot P_e}{3600} \cdot ca \cdot \Delta \mathrm{t_{aK}}[\mathrm{KW}] \qquad (11)$$

b) Effective power turbine

$$P_{e_{TG}} = \eta_{TG} \cdot \frac{d_g \cdot P_e}{3600} \cdot cg \cdot \Delta \mathrm{t_{gTG}}[\mathrm{KW}] \qquad (12)$$

And

$$P_{ant_K} = P_{e_{TG}}[\mathrm{KW}] \qquad (13)$$

Ca $\left[\frac{KJ}{KG \cdot grd}\right]$ - air specific heat; Cg $\left[\frac{KJ}{KG \cdot grd}\right]$ - gas specific heat;

η_k - effective yield of the compressor; η_{TG} - effective yield of the gas turbine;

According to the relation (13) we obtain:

$$\frac{1}{\eta_k} \cdot d_{asg} \cdot Ca \cdot \Delta \mathrm{t_{aK}} = \eta_{TG} \cdot \mathrm{dg} \cdot \mathrm{Cg} \cdot \Delta \mathrm{t_{gTG}} \qquad (14)$$

And results are:

$$\Delta \mathrm{t_{gTG}} = \frac{1}{\eta_k \cdot \eta_{TG}} \cdot \frac{d_{asg}}{d_{gTG}} \cdot \frac{Ca}{Cg} \cdot \Delta \mathrm{t_{aK}}[°C] \qquad (15)$$

And

$$\Delta \mathrm{t_{aK}} = \eta_k \cdot \eta_{TG} \cdot \frac{d_{gTG}}{d_{asg}} \cdot \frac{Cg}{Ca} \cdot \Delta \mathrm{t_{gTG}}[°C] \qquad (16)$$

Yield of the supercharging group:

$$\eta_{GSA} = \eta_k \cdot \eta_{e_{TG}} \qquad (17)$$

Discharge temperature from the supercharging air compressor:

$$T_{ref_k} = T_0 \cdot \left(\frac{P_{ref}}{P_0}\right)^{\frac{n_S - 1}{n_S}} [K] \qquad (18)$$

Where:

$T_0[K]$ - ambient air temperature

$P_0[bar]$ - ambient air pressure

n_S - polytrophic compression exponent of the air inside the compressor

Relation (15) becomes:

$$\Delta \mathrm{t_{gTG}} = \frac{1}{\eta_{GSA}} \left(\frac{m_{air_t} \cdot \alpha_{sg}}{m_{air_t} \cdot \alpha_{sg} + 1}\right) \cdot \left(\frac{Ca}{Cg}\right) \cdot \Delta \mathrm{t_{aK}}[°C] \qquad (19)$$

Relation (16) becomes:

$$\Delta \mathrm{t_{aK}} = \eta_{GSA} \cdot \left(\frac{m_{air_t} \cdot \alpha_{sg} + 1}{m_{air_t} \cdot \alpha_{sg}}\right) \cdot \left(\frac{Cg}{Ca}\right) \cdot \Delta \mathrm{t_{gTG}}[°C] \qquad (20)$$

The discharge pressure of the air is determined from Fig 1 [B2]

The yield η_{GSA} is determined from Fig 2 [B1]

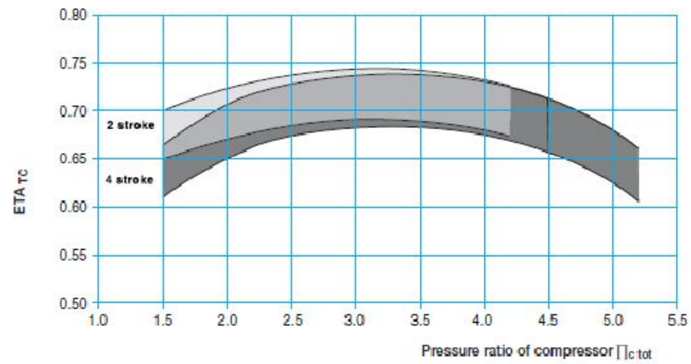


Fig. 2: Range of turbocharger efficiency [B1]

Table 2 – Functional characteristics for the supercharging group

K_p	T_0 [K]	n_S	P_{ref} [bar]	T_{ref} [K]	$\Delta \mathrm{t_{aK}}$ [°C]	η_{GSA}	$\Delta \mathrm{t_{gTG}}$ [°C]
0.5	318	1.35	2.00	381	63	0.62	83
0.75	318	1.35	2.80	415	97	0.65	121
1.00	318	1.35	3.80	449	131	0.68	157

V. DETERMINATION OF AIR EXCESS

A. Mass of fuel injected per cycle

For the cyclic functioning of the engine is determined

The number of cycles per minute $N_{C_m} = \frac{2n}{\tau}\left(\frac{cycles}{min}\right)$

The number of cycles per second $N_{C_S} = \frac{2n}{\tau} \cdot \frac{1}{60}\left(\frac{cycles}{s}\right)$

The number of cycles per hour $N_{C_h} = \frac{2n}{\tau} \cdot 60\left(\frac{cycles}{h}\right)$

Where:

$n\left(\frac{rot}{min}\right)$ - RPM of the engine;

τ - number of races the piston perform for one engine cycle

$\tau = 2$ - for M2T engines – the piston performs 2 races per cycle;

$\tau = 4$ - for M4T engines – the piston performs 4 races per cycle;

$m_c = \left[\frac{Kg\ cb}{cycle}\right]$ - fuel mass injected per cycle

$$m_c = \frac{c_e \cdot P_{e_{cil}}}{\frac{2n}{\tau} \cdot 60}\left[\frac{Kg\ cb}{cycle}\right] \qquad (21)$$

Table 3 – Fuel mass injected per cycle

K_p	K_p	$C_e\left[\frac{kg\ cb}{KWh}\right]$	$n\left[\frac{rot}{min}\right]$	τ	$m_c\left[\frac{Kg\ cb}{cycle}\right]$	$L.I = \frac{m_{c\ exp}}{m_{c\ n}}$
0.5	0.5	0.170	78	2	0.04323	0.660
0.75	0.75	0.167	95	2	0.0523	0.815
1.00	1.00	0.170	105	2	0.0642	1.00

Where:

L . I – load indicator; $m_{c\,exp}$ - fuel mass injected into operation; $m_{c\,n}$ - fuel mass injected into nominal conditions

B. Air mass needed per cycle for burning

$$m_{air_{cycle}} = m_{air_t} \cdot \alpha_{ard} \cdot m_c \left[\frac{kg\ air}{cycle}\right] \qquad (22)$$

Table 4 – Air mass needed per cycle for burning

$m_a \left[\frac{kg\ air}{cycle}\right]$	$m_{aer_t} \left[\frac{kg\ air}{kg\ cb}\right]$	$m_{air_{cycle}}\left[\frac{kg\ air}{cycle}\right] = f(\alpha)$						
		1.4	1.6	1.8	2	2.2	2.5	2.8
0.04323	13.6	0.823	0.941	1.058	1.18	1.29	1.47	1.65
0.0523	13.6	0.996	1.14	1.28	1.42	1.56	1.78	1.99
0.0642	13.6	1.222	1.397	1.5716	1.75	1.92	2.183	2.444

C. Determination of air excess for the reference engine

For the reference engine from [B1]

D = 0.6 [m] – cylinder diameter; S = 2.4 [m] –piston stroke

The volume of the piston race is determined by:

$V_S = \frac{\pi\ .\ D^2}{4}\ .S\ [m^3]$; $V_S = 0.6786\ [m^3]$

ε= 14.45 – the compression ratio

Combustion chamber volume - the minimum volume of engine fluid

$V_{CA} = V_{min_f} = \frac{V_S}{\epsilon - 1}$; $V_{CA} = 0.0504\ [m^3]$

The volume of the piston race affected by the presence of window strea**k**

$\Psi_{FB} = 0.09 \div 0.12$; $\Psi_{FB} = \frac{h_{FB}}{S}$;

$h_{FB}[m]$ - the height of window streak

$V_{FB} = V_S . \Psi_{FB}$; $V_{FB} = 0.06786\ [m^3]$

At the end of the gas exchange, the covering of the window streak, the air needed for burning is retained in the volume:

$$V_{aer_{cil}} = V_S + V_{CA} - V_{FB}[m^3] \qquad (23)$$

$V_{aer_{cil}} = 0.66114 \left[m^3/_{cycle}\right]$

For this volume is calculated the air mass needed for one cycle:

$$m_{aer_{ciclu}} = \frac{p_{aer_{cil}} \cdot V_{aer_{cil}}}{R\ T_S} \left[\frac{kg\ air}{cycle}\right] \qquad (24)$$

$R = 0.286 \left[\frac{KJ}{Kg\ grd}\right]$; $T_S = 360\ [K]$

Results:

$m_{aer_{ciclu}} = 2.44 \left[\frac{kg\ air}{cycle}\right]$ for which corresponds the air excess coefficient $\alpha_{ard} = 2.795$ correspondent to the nominal operating system for which was projected and planed the engine.

VI. CONCLUSION

1. Monitoring functional parameters allow correlation with geometric engine parameters for safe operation by preventing thermal and mechanical overloads;

2. Mass and energy flows of the supercharging unit depend on the engine load, ambient parameters but also fuel quality;

3. Using calculation and experimental determinations permit correct interpretation of the functional interactions between the combustion engine and supercharger unit;

4. The reference values of functional parameters can be presented in tabular or graphic, by the designer and manufacturer and must be used for comparison in various situations of exploitation;

5. Correlation boost energy flows on supercharging aggregate can be done by comparing the functional parameters of the flue gas flow.

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