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THE CHARGE AIR ENERGY LOSSES OF A PARTIALLY LOADED LOW SPEED ENGINE

Key words

Low speed engine, partial load, charge air, energy loss, waste heat recovery.

Summary

The structure of the low speed ship engines energy balance has changed during the last 30 years of engine development. The significant rise of the charge air waste heat is noticeable. The presented article describes changes of this kind of energy loss for partially loaded low speed engines. Calculations are based on the mathematical analysis of engine data and parameters recorded during ship operation under real conditions.

Introduction

The consequence of improvements introduced to low speed ship engines are great changes in the balance of the waste heat energy produced by this kind of diesel engines [1, 2]. Taking advantage of data of the currently produced low speed engine analysis, research was carried out concerning the changes of the structure of the mentioned above waste heat balance. The charge air temperature grow is noticeable, and it reaches 170 to 180°C for engines operated under an ambient condition following reference ISO 3046/1 conditions (air temperature before blower t_A = 25°C; barometric pressure p_A = 1000 mbar; charge air coolant (*fresh water*) temperature t_{FW} = 29°C). This significant change results from a much higher charge ratio of the currently produced engines. It is essential that, for low speed engines with a high charge ratio, the amount of this kind of energy loss is higher than energy loss caused by water cooling of the cylinders, covers, exhaust valves, and elements of turbochargers. As an example, three of the low speed engines charged by a constant-pressure turbocharger have been compared to emphasise the mentioned changes (Table 1).

Table 1. Engine parameters comparison

Engine type	6L80GFCA	4S80MC	12RTflex96C
Year of delivery	1975	2000	2006
Nominal rating [kW]	30400	30720	68640
Overall efficiency [%]	44.4	49.6	49.3
Charge air energy loss [kW]	3160	4424	19632
Charge air energy loss [%]	10.4	14.4	14.1
Turbocharger air temp. [°C]	130	170	170

All of the above values are valid for engines loaded at the nominal Maximum Continuous Rating point (P_{MCR}) [3, 4]. To calculate the charge air energy resources that can be recovered during ship operation under real conditions, it is important to determine its quantity under the engine partial load too. Such a determination requires data as charge air cooler inlet (t_{CAC1}) and outlet temperature (t_{CAC2}) as well as the quantity of the air ‘consumed’ by engine ($\dot{m}_{CA}$). All temperatures may be recorded by either the automatic data logging system of the ship or the additionally assembled data acquisition unit. To determine the charge air mass flow, a new calculation method may be introduced.

1. The charge air mass flow

It is possible to estimate charge air amount that is necessary to carry out a combustion process inside an engine cylinder by means of the following equation [5]:

$$\dot{V}_{CA} = 0{,}0354 \cdot Vn\eta\varphi \frac{1}{\rho_{CA}} \left(\frac{p_{CA}}{p_A} \right)^{\frac{1}{m}} \tag{1}$$

where:

$\dot{V}_{CA}$ – air consumption [m^3/min],
V – engine displacement [m^3],
n – engine revolutions [1/min],
ρ_{CA} – charge air density [kg/m^3],

m – polytrophic compression exponent,
φ – scavenging coefficient,
η – displacement coefficient,
p_{CA} – charge air pressure [bar],
p_A – ambient air pressure [bar].

But the above equation is not applicable to carrying out an analysis of charge air consumption changes by engines operated under real conditions. Available information concerning the parameters of charge air are valid for the nominal maximum continuous rating (*MCR*) of the diesel engine operated under ambient conditions following reference conditions. A former analytical research, carried out by the author, revealed a great dependence of the charge air mass flow on the engine rating and the turbocharger inlet air temperature. Taking advantage of the mathematical software allowing a mathematical analysis of gathered data of low speed engines produced by MAN DIESEL (*MAN B&W*) and WARTSILA (*SULZER*) [3, 4], an empirical equation has been formulated describing a progress of charging air mass flow function $\dot{m}_{CA} = f(P_{\%}, t_{TCin})$. An influence of the real operating conditions of the ship is represented by various engine ratings. Real, ambient conditions are represented by various air temperatures delivered by engine room blowers to the turbochargers.

$$\dot{m}_{CA} = \dot{m}_{CAn} \cdot \mathrm{e}^{3{,}2433 + 0{,}0307 \cdot \sqrt{\left(\frac{P}{P_n}\right)} \cdot \ln\left(\frac{P}{P_n}\right) - 0{,}0017 \cdot t_{TCin}} \tag{2}$$

where:

P – actual engine load [kW],
P_n – nominal engine load (*at MCR*) [kW],
t_{TCin} – turbocharger inlet air temperature,
$\dot{m}_{CAn}$ – nominal air consumption (*at MCR*) [kg/h].

Based on diesel engines manufacturer's publications [6, 7], a simplification has been applied assuming that turbocharger inlet air temperature (t_{TCin}) is equal to the main engine room blower inlet temperature (*ambient air temperature*). During the charge air parameters recording session, the temperature of air delivered through air ducts from the main engine room blower to turbochargers kept stable and no changes of this parameter have been recorded. Thus, such a simplification was applicable.

2. The charge air temperature

Recording of the charge air temperature has been carried out on the 3740 TEU container ship powered by the low speed engine WARTSILA 7RTA84CU.

To record required parameters, the TESTO T177-T4 electronic data logger has been used. The histogram of recorded parameters on the charge air coolers inlet (*turbocharger outlet*) is presented in Fig. 1. Air temperatures on the charge air coolers outlets has been controlled by the engine room automation system and kept stable at the level of 44°C. Temperatures have been measured by the K type thermocouples with measuring accuracy of 0.1°C on range –200 to 400°C.

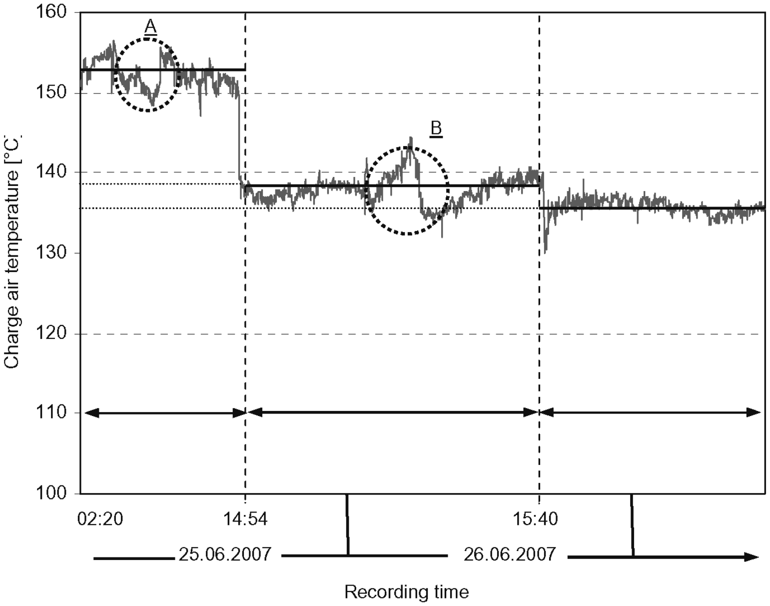

Fig. 1. The charge air cooler air inlet temperature

The main engine turbochargers have been supplied with air by the main blower of the engine room with a capacity of 96 000 m^3/h, afterwards 40 000 m^3/h of air has been delivered through separated air ducts to each turbocharger [7]. The technical condition of the main engine followed standard operating conditions during the parameter recording session. Both turbochargers of type TPL-80 B12 SGA04 have been cleaned accordingly to the manufacturer’s (*ABB TURBO SYSTEMS Ltd*) recommendations:

– The turbine side was cleaned with an organic material (*nut shells*) and
– The compressor side with water.

Prior recording, an initial chemical cleaning of both charge air coolers was carried out to preclude the influence of the high flow resistance on air parameters on the “blower-turbocharger-engine” way. Continuous control of air pressure drop across charge air coolers and their final inspection revealed that the fouling level did not increase during measuring and data acquisition time.

Areas ‘A’ and ‘B’ (Fig. 1), showing sudden temperature changes at both of the air cooler inlets, have been highlighted. Such a situation is a result of the necessity of manoeuvring the ship. Out of both marked areas, recorded temperature kept stabile. Its mean values, depending on engine load and mean ambient air temperature, are presented in Table 2.

Table 2. Engine parameters comparison

Range	I	II	III
Engine load [kW]	21690	19880	19120
Engine load [% of MCR / % of CMCR]	76.5 / 86.3	70.2 / 79.1	67.5 / 76.1
Ambient air temperature [ºC]	29	28	29
Turbocharger outlet air temperature [ºC]	153	139	135

3. The charge air waste heat

The specific heat of air c_{CA} [kJ/kgK] was calculated accordingly to the procedure described in [8].

$$c_{CA}\Big|_{t_{CAC2}}^{t_{CAC1}} = f\left(t_{CAC1}, t_{CAC2}, p_B, p_{CA}, p_S, X\right) \tag{3}$$

where:

p_B – ambient air pressure [Pa],
p_{CA} – charge air pressure [Pa],
p_S – saturation pressure [Pa],
X – ambient air absolute humidity,
t_{CAC1} – charge air cooler: air inlet temperature [°C],
t_{CAC2} – charge air cooler: air outlet temperature [°C].

Calculated and recorded parameters of the charge air allowed us to estimate changes of the low speed ship engine energy loss resulting from the necessity of the charge air cooling (Fig. 2). All relative values refer to the total energy delivered to the engine, calculated accordingly to recorded fuel consumption and its analysis carried out by the USA DNVPS (*Det Norske Veritas Petroleum Services*) laboratory located in Houston. An additionally calculated value of the energy loss for investigated engine loaded at contracted MCR (*CMCR*) and its tabular values applying to the nominal MCR are shown.

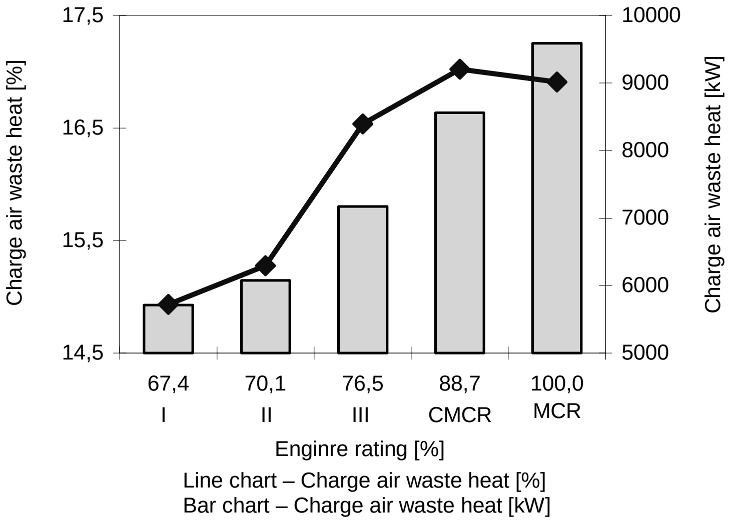

Fig. 2. The charge air waste heat

Conclusions

The determined values indicate that a high level of the charge air energy loss takes place even in a partially loaded low speed engine. For the engine loaded at 67.4% of its nominal MCR power, the charge air energy loss exceeds 14% of the total energy delivered to the engine, which is about 7% of the energy delivered by the engine to the propeller.

The 21.3% engine output power drop from contracted MCR (*88.7% of MCR power*) to 67.4% of MCR power cause only a 12.3% reduction of the charge air waste heat. However, such a high level of energy accumulated in the charge air leads to the conclusion that there is still a possibility to utilise waste heat energy during the sea passages carried out with the reduced speed of the ship.

To describe all changes of the structure of the partially loaded low speed ship engine energy balance, it is necessary to determine of all energy losses of this kind of engine.

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Reviewer:
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Straty energetyczne powietrza doładowującego silników wolnoobrotowych obciążonych częściowo

Słowa kluczowe

Silnik wolnoobrotowy, obciążenie częściowe, powietrze doładowujące, strata energetyczna, odzysk strat ciepła.

Streszczenie

Struktura bilansu energetycznego okrętowych wolnoobrotowych silników spalinowych uległa zmianie wraz z rozwojem w ciągu ostatnich 30 lat. Zauważalny jest znaczący wzrost strat energii cieplnej zawartej w powietrzu doładowującym. Prezentowany artykuł przedstawia zmiany tego typu rodzaju strat dla częściowo obciążonych silników wolnoobrotowych. Obliczenia zostały oparte na analizach danych silników oraz na zarejestrowanych parametrach podczas eksploatacji statku w warunkach rzeczywistych.