OPTIMISATION OF 798-05 DIESEL ENGINE PERFORMANCE USING WASTE-GATED TURBOCHARGER

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Abstract: *The engine which is the object of the research work is used on commercial and military vehicles such as DAC 8.120-FPEG and DAC 11.154-DFAE for transport of cargo, being known as 798-05. The paper studies the increase of performance for heavy duty turbocharged diesel engines when the series type turbocharger is replaced with a waste-gated turbocharger. There were presented dynamometric tests performed on the facilities of Road Vehicle Institute Brasov - Romania, being evaluated engine performance parameters such as rated power, torque, specific consumption and smoke level on the speed characteristic at total load. It is emphasized the influence of intake manifold pressure variation which changes the profile of torque curve, improving the dynamic behavior and the environmental impact.*

Key words: *diesel engine, waste-gated turbocharger, visible pollutant emissions.*

1. INTRODUCTION

A classic method of energy harvesting in internal combustion engines is the turbocharging which turns a part of exhaust gas energy into mechanical work in the air charge compressor.

The mass of air intake in each cycle is increased and a higher fuel mass can be injected, thus producing a higher power at the same displacement, in other words, a higher power per unit of displacement.

The most compact and efficient turbocharger solution is made of a centripetal rotor gas turbine and a centrifugal compressor.

The turbocharger operation is, in a certain extent, self-adjustable as the lowering of speed or load reduces the energy of exhaust gas and, consequently, the compressor work and air flow rate.

In spite of energy benefits, there are also some drawbacks as turbocharger operation is not satisfactory along all the range of speeds.

The paper presents a research work performed to improve engine-turbocharger compatibility for the diesel engine 798-05 manufactured by Roman Truck Company of Brasov – Romania.

The engines of the series, with different ratings, were used on commercial and military vehicles (DAC 8.120-FPEG and DAC 11.154-DFAE, medium all-terrain unarmored cabovers for transport of cargo [4]).

The practical objectives of the work were to improve dynamic engine performance at low speeds and to meet the visible pollutant standards.

2. THEORETICAL APPROACH

For turbocharged engines operating at low speeds, the air flow rate delivered by the compressor is lower than the engine requirement and fuel combustion is incomplete, producing high emission of visible pollutants which, in lay terms, are called black smoke.

A partial solution to heavy smoke is the use of a device mounted on the mechanical in-line injection pump which limits the quantity of injected fuel in function of available air flow rate.

The device, known as LDA (abbre-viation of German term Ladedruck-abhängigkeit) regulates the injected fuel flow rate according to the charge air pressure [1, 3].

The design of diesel engines for vehicle propulsion should take into account two dynamic indicators [2]. The adaptability indicator, σ_M , measures the variation of engine torque with speed, expressing the engine capacity to overcome rolling resistance and aerodynamic drag:

$$\sigma_M = \frac{M_{\max}}{M_P} \tag{1}$$

with - $M_{\max}$ - maximum effective torque;

- M_P - rated effective torque.

The higher the values of σ_M , the higher is the engine capacity to overcome vehicle propulsion resistances.

The elasticity indicator, σ_n , measures the vehicle maneuverability in terms of gear shifting:

$$\sigma_n = \frac{n_P}{n_{M_{\max}}} \tag{2}$$

with n_P - rated speed;

$n_{M_{\max}}$ - maximum torque speed.

The higher the values of σ_n , the lower is the need for gear shifting.

The use of the LDA device is not favorable for the two indicators, as it reduces the engine torque at low speeds and rises the speed at which maximum torque is reached.

The balance between engine and turbocharger was studied, one of the most acceptable solution for heavy duty engines being the use of waste-gate turbocharger.

The engine-turbocharger operation can be explained according to figure 1, using the charge air pressure (p_s) variation reported to atmospheric pressure (p_0) versus engine speed. When the engine speed decreases, turbine speed decreases too, lowering the charge air pressure and air flow rate (curve no.2 in fig.1).

In this case, the fuel combustion is incomplete and engine exhaust emissions are increased.

Another solution can be a turbine having a higher ratio of expansion which can transmit more energy to the compressor and rise its speed, pressure and air flow rate (curve no.1 in fig.1).

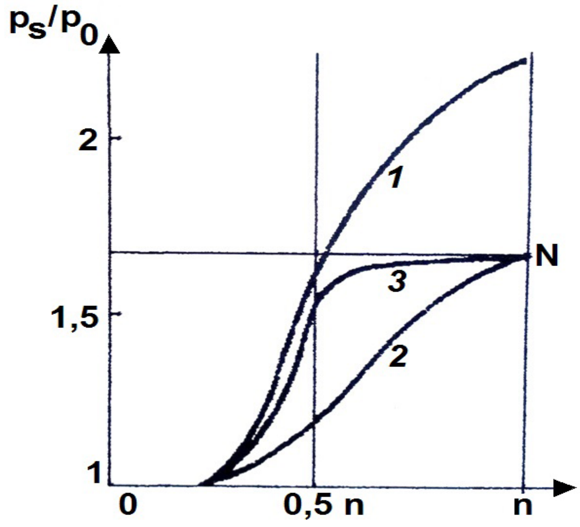

Fig.1 Profiles of pressure rise versus speed

The drawback in this situation is that at rated engine speed, the turbine speed is exceeding the reliability limit, the risk of failure being huge.

The optimum behavior is represented by curve no.3 which can be obtained using a by-pass system (waste-gate) which deviates a share of exhaust gas flow rate outside the turbine.

The exhaust gas deviation is done using a by-pass valve which is controlled by the charge air pressure in compressor which is proportional to the turbine speed.

The static pressure is taken over from the compressor casing which is transmitted pneumatically to the by-pass valve, which deviates more or less exhaust gas.

3. ENGINE TESTING

The engine subjected to testing was of the type 798-05, having the serial number 3702, with the main characteristics described in table 1. Preliminary measurement of charge air pressure indicated that the series turbocharger has a curve no. 2 characteristic, explaining the unsatisfactory results in terms of smoke emissions.

The following testing indicates the comparative behavior of the same engine, fitted with the series turbocharger (H1S-6780G H15A5) and waste-gated turbocharger (HB1C 6780G H07A5), both manufactured at Hidromecanica Brasov.

Table 1. Engine characteristics [7]

Engine type	4-stroke, direct injection
Cylinder configuration	6-cylinder, in line
Bore x Stroke [mm]	102 x112
Displacement [L]	5.5
Compression ratio	17:1
Rated power [kW]	88
Rated speed [rpm]	2500
Max. torque [N·m]	364
Max. torque speed [rpm]	1800

The engine was mounted on a dynamometric test bench of 300 kW, type MEZ-VSETIN at Road Vehicle Institute Brasov (INAR) [7], being instrumented with specific sensors of temperature (air, cooling liquid, oil and exhaust gas), pressure (atmospheric, oil and charge air), mass flow rates (air, fuel) and speeds. During testing the ambient temperature was 15°C and the atmospheric pressure was 720 mm Hg. The tests were performed according to Romanian engine testing standard [5].

The engine had the following auxiliaries:

- 6 blade cooling fan Φ 530x80 mm;
- no compressor and unloaded alternator.

The smoke emission was measured with a Hartridge MK3 opacimeter which has the effective length of measurement tube of 430 mm, the smoke indicator displayed being either HSU (Hartridge Smoke Units) or the coefficient of light extinction (m^{-1}).

At rated power, the air intake system indicated 170 mm column H_2O pressure loss and at the exhaust system 470 mm column H_2O , meeting the product specification. The engine tests included the plotting of engine speed characteristics at total load (power, torque, specific fuel consumption, smoke emission and charge air pressure).

4. INTERPRETATION OF RESULTS

The quality of the turbocharging can be evaluated using air charge pressure as illustrated in fig.2.

It can be noticed a constant increase of pressure for the waste-gated turbocharger.

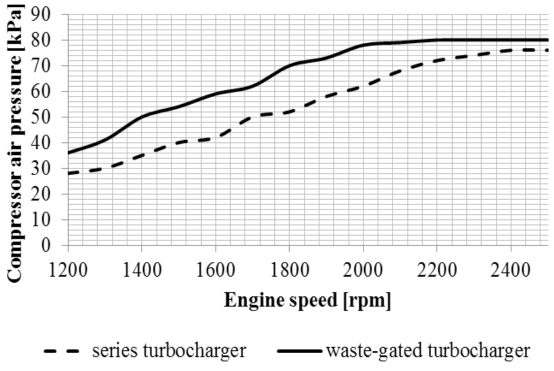

Fig.2 Air charge pressure versus speed

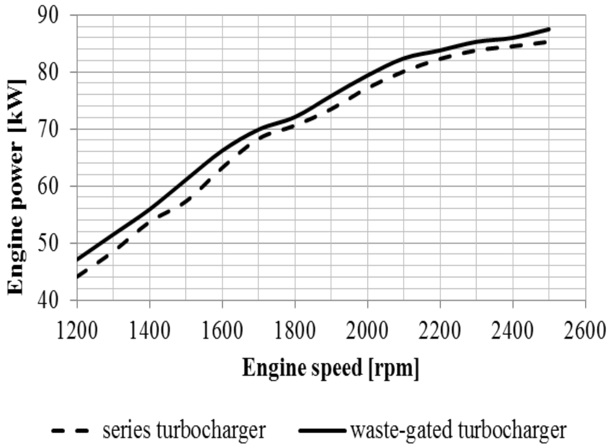

Fig.3 Rated power versus speed

Waste-gate turbocharging increases constantly the power with 2.5-5 kW on the whole range of speeds as can be seen in fig.3.

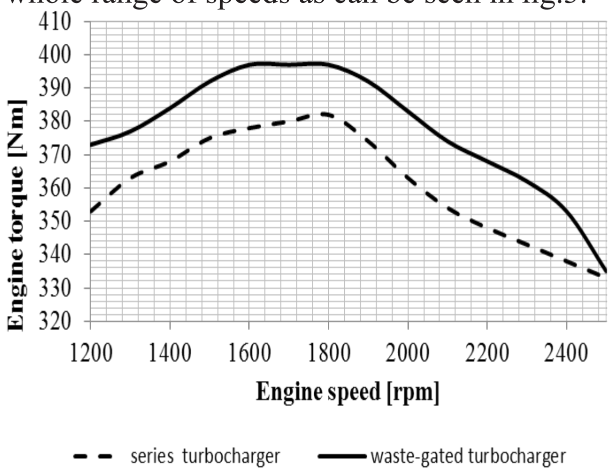

Fig.4 Engine torque versus speed

In figure 4 it can be observed a shift of $n_{M_{\max}}$ from 1800 rpm to 1600 rpm which improves the dynamic indicators: the adaptability coefficient, σ_M , rises from 1.14 (series) to 1.18 (waste-gated), proving that the vehicle fitted with waste-gated turbocharger will overcome better the propulsion resistances; the elasticity coefficient, σ_n, rises from 1.39 (series) to 1.56 (waste-gated), showing a lower need for gear shifting.

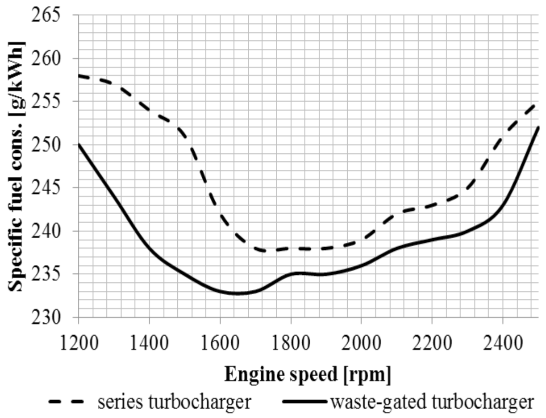

Fig.5 Specific fuel consumptions

In terms of energy economy, figure 5 illustrates that waste-gated solution is more advantageous, the energy contained in the fuel is better used resulting lower specific fuel consumption along the speed range.

The visible pollutants, as limited in ECE R 24.03 regulation [6], can be seen in fig.6, in red line.

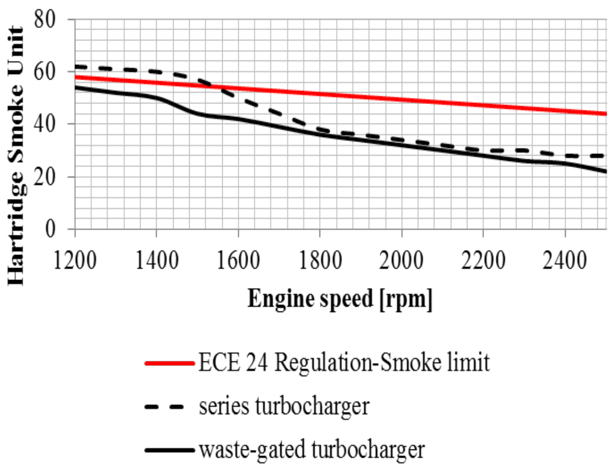

Fig.6 Smoke emissions versus speed

At lower speeds, the smoke is higher than the limit for the series turbocharger, but it lowers under the limit for the waste-gated version.

CONCLUSIONS

The waste-gated turbocharger demonstrated in average 3.5 kW higher rated power (3.3%), 16.3 N·m higher maximum torque (4.5%) and 7.1 g/kWh (2.9%) specific fuel consumption lower than series turbocharged version. It also revealed improved dynamic indicators, as well as the compliance with visible emission standard ECE R24.03 on the whole range of speeds.

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