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SOME EXPERIMENTS IN DIESEL ENGINE NET POWER RATING

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Abstract: *The paper presents an analysis of the measurement of combustion engine net power in the process of certification according to requirements of the UN ECE 85 Regulation. The influence of some factors affecting power declaration such as atmospheric conditions and admitted auxiliaries are discussed. A road vehicle diesel engine is experimented on the dynamometric bench at dissimilar atmospheric factors (barometric pressure, atmospheric temperature and humidity). Some comments were made on the relation between gross and net power as well as on error analysis.*

Key words: *engine net power, certification, power correction factors.*

1. Introduction

The performance of an internal combustion engine depends on two independent set of factors which are atmospheric conditions and installed auxiliaries.

Atmospheric pressure, temperature and humidity were reported to influence the engine performance parameters such as power output, torque and specific fuel consumption. In order to compare performance of different engines operating in dissimilar atmospheric conditions, some correction factors were adopted both in technical literature and in power standards. According to [1], the correction factor is based on the unidimensional steady compressible flow through a flow restriction which, for full load mode of an engine, will generate a proportionality, (k), between mass flow rate of dry air $\dot{m}_a$ and total pressure p and temperature T, upstream of the restriction. Equation (1) expresses the result of this correlation:

$$\dot{m}_a = k \frac{p}{T^{0.5}} . \quad (1)$$

As the mass flow rate of dry air $\dot{m}_a$ is proportional to the indicated power P_i measured at any p or T, then the indicated power reported to standard atmospheric conditions P_{is} (at standard pressure p_s and standard temperature T_s) would equate:

$$P_{is} = C_f \cdot P_i \quad (2)$$

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with the correction factor:

$$C_f = \frac{p_s}{p}\left(\frac{T}{T_s}\right)^{0.5}. \tag{3}$$

For a better accuracy, the correction factor evolved including the contribution of the humidity in the air on total pressure, ambient water vapor partial pressure, P_v and standard water vapor partial pressure, P_{vs}:

$$C_f = \frac{p_s - p_{vs}}{p - p_v}\left(\frac{T}{T_s}\right)^{0.5}. \tag{4}$$

Apart from using correction factors for certification purposes, the work described in [3] used them to assess the power variation with atmospheric pressure and temperature of a vehicle in a road test.

2. Legislation Analysis

In the field of internal combustion engines used for propulsion of passenger cars, trucks and other motor vehicles, the first correction factors included in power standards were dependent only on pressure and temperature, neglecting humidity.

Since 1970s Equation (3) represented the fundamental correction formula included in some European power rating standards [4]; humidity was considered as in Equation (4) firstly in American standards [7], then it was admitted worldwide [5, 8, 9]. Later on, the correction factors adopted other exponents in Equation (4) and corrected the fuel flow with a motor factor.

The auxiliaries have had a significant contribution in the power rating of the engines; some parts, such as fans or water pumps, were driven by the crankshaft and decreased the power output at the flywheel, while others, such as silencers or filters, increased the fluid flow resistance.

In 1960’s commercial pressure on the automotive manufactures made them declare engine power with the minimum number of accessories. In the same time legislators introduced the terms of gross power and net power. According to [2], in older literature, net power meant the output of an engine with all the components required for its operation, while gross power meant the output of the engine with minimum components; gross power was seen as the maximum power of an engine on a test stand without fan, alternator, silencers or emission after-treatment devices, corrected to standard atmospheric conditions.

For the same engine, the gross power is higher than net power. In many cases the gross power was advertised, but net power was what a customer could get on a specific application.

Nowadays, the power rating of an internal combustion is defined as the power obtained on a test bench at the end of the crankshaft at the corresponding engine speed determined under reference atmospheric condition, the difference between gross and net power being given by the accessories imposed by the standards. For international ISO standards [5, 6] the accessories in discussion are included in Table 1.

Options for engine auxiliaries for net and gross power test Table 1

<table>
<tr><th>Auxiliaries</th><th>Fitted for net power test
(Reg. UNECE 85 [9], ISO 1585 [5])</th><th>Fitted for gross power test
(ISO 2534) [6]</th></tr>
<tr><td>Crankcase emission control system and air filter</td><td rowspan="7">Yes, standard production equipment</td><td>Optional</td></tr>
<tr><td>Speed limiting device</td><td>No</td></tr>
<tr><td>Silencer and tail pipe</td><td>Optional</td></tr>
<tr><td>Exhaust brake</td><td>No</td></tr>
<tr><td>Fuel prefilter/filter</td><td>Optional</td></tr>
<tr><td>Liquid cooling fan/radiator</td><td>No</td></tr>
<tr><td>Air cooling fan and regulating device</td><td>No</td></tr>
</table>

The objective of this paper is to assess the variables in the process of net power rating using experiments for the same given engine, finding the influence of the dissimilar atmospheric conditions and evaluating the difference between gross and net power.

3. Engine Testing

The tested engine was manufactured at Motoare AB Company (Brașov, Romania) being provided to power commercial vehicles such as trucks and buses. The six-cylinder, turbocharged and intercooled diesel engine codification is 550-L6-DTI with series number S154 and the engine specifications from engine standard presented in Table 2.

Engine characteristics Table 2

Engine type	**Diesel**
Bore x Stroke [mm]	102 x 112
Total displacement [L]	5.491
Compression ratio	17.5 : 1
Rated power [kW]	117 +/- 5%
Rated speed [rpm]	2600
Maximum torque [N·m]	585 +/- 5%
Maximum torque speed [rpm]	1600 +/- 100

The tests were performed on a dc-300 kW dynamometric test bench at the Road Vehicle Institute - INAR Brașov. As engine cooling agent it was used the distilled water from the cooling system of the test bench. For the engine operation it was used diesel fuel according to the standard EN 590 and a lubricant with the viscosity class SAE 15W30. The pressure loss on the test bench air intake was 290 mm H_2O column and 1020 mm H_2O column on the exhaust duct, measured at the rated power. The engine was instrumented with temperature sensors (for the cooling liquid, oil, and exhaust gas), pressure sensors (for oil, air, and exhaust gas), flowmeters (air and fuel), being running-in before the tests.

The testing program aimed to measure the net power according to UNECE Regulation 85, for three types of tests [10]:

V1, V2 - Test according to Reg. 85 in different ambient conditions from Table 3.

V3 - Test to evaluate the difference between gross and net power, in the ambient conditions from Table 3.

Atmospheric conditions during tests Table 3

Test version	Barometric pressure [mm Hg]	Atmospheric temperature [K]	Relative humidity [%]
V1	706	295	63
V2	715	299	65
V3	712	292	75

The lower values of atmospheric pressure during the study are explained by the altitude of 650 m of the place of experiments.

The engine was delivered by the producer with a fixed injection timing of 9° rotation of crankshaft, being equipped with:

- in-line injection pump, fitted with timing and speed regulator;
- fuel correction device;
- unloaded alternator;
- no compressor;
- six blade fan Φ 530 x 79 on the crankshaft, for V1 and V2 / (without fan for V3) ;
- Holset type H1C turbocharger;
- air filter and exhaust duct of the test bench.

Previous injection pump tests revealed the maximum injector pressures at maximum torque speed and at rated power speed, of $p_{Mmax} = 700$ bar and, respectively, $p_{Pmax} = 867$ bar.

The engine performance was corrected according to pressure and temperature with the correction coefficient α (notation specific to Reg. 85, α equivalent to *Cf*), with f_a atmospheric factor and f_m engine factor, with the formulas:

$$\alpha = f_a^{fm}, \tag{5}$$

$$f_a = \left(\frac{99}{p}\right)^{0.7} \left(\frac{T}{298}\right)^{1.5}, \tag{6}$$

where p - measured atmospheric dry pressure [kiloPascal], T - measured atmospheric temperature [Kelvin], 99 kPa - standard reference pressure for dry air, calculated as difference of total reference pressure and water vapor part pressure at 298 K (100 – 1 = 99) and 298 K-standard reference temperature. Equation (6) is valid for turbocharged diesel engines with or without cooling of inlet air. The Engine factor depends by the corrected fuel flow q_c according to Equation (7):

$$f_m = 0.036 \cdot q_c - 1.14, \quad (7)$$

$$q_c = \frac{q}{r}, \quad (8)$$

with q - fuel flow in milligram per cycle and per liter of total swept volume [mg/(L · cycle)] and r - air pressure ratio of compressor outlet and compressor inlet:

$$q = \frac{Z \cdot \dot{m}_f}{V_d \cdot n} = \frac{120000 \cdot \dot{m}_f}{V_d \cdot n}, \quad (9)$$

where Z – 120000 for four stroke engine, $\dot{m}_f$ - fuel flow rate [g/s], V_d - total swept volume in litres and n - engine speed [min^{-1}]. The formula (7) is valid only when q_c is between 40 mg/(L · cycle) and 65 mg/(L · cycle). For lower values f_m = 0.3 and for higher values f_m = 1.2.

For the three tests, the calculated values of α ranged in the interval 1.00-1.025, which was included in the standard range of acceptability which is 0.9-1.1.

The experimental tests consisted in plotting engine power- speed characteristic at full load. The certification of the engine according to Reg. 85 is approved if the corrected net power is +/-5% from rated power declared in Table 2. The accuracy of torque measurement was 1% and for speed 0.5%. The measured values of effective power, torque and fuel consumption were corrected using the following formula, written for effective power:

$$P_{corr,ef} = \alpha \cdot P_{m,ef}, \quad (10)$$

with $P_{corr,ef}$ - corrected effective power and $P_{m,ef}$ - measured effective power.

4. Interpretation of Results

In order to assess the influence of the ambient factors on engine power, there were considered the same full load test in function of engine speed, on the same engine, but at dissimilar ambient factors, as specified in Table 3. The test versions assigned V1 and V2 were compared on the same graphic in Figure 1. The correction factor for V1 was constant at all the speeds, 1.008. The correction factor for V2 was variable due to engine factor, between 1.0133-1.0248, with a mean of 1.0157. By taking into account the corrected power values in V1 and V2, the mean relative error reported to V1 was 2.04%.

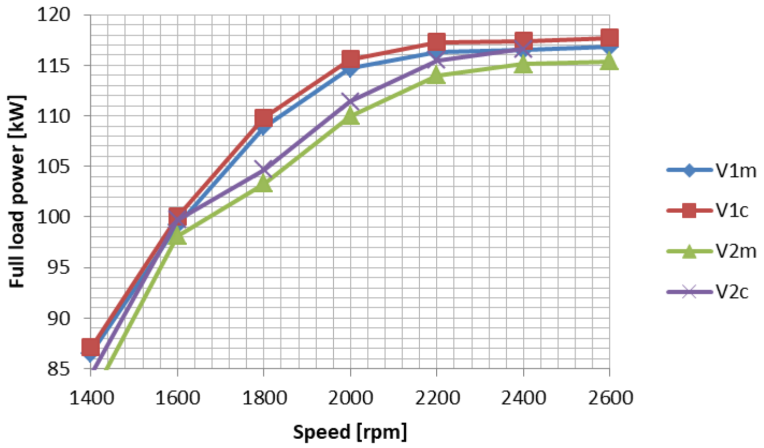

Fig. 1. *Measured (m) and corrected (c) net power in dissimilar atmospheric conditions*

By taking into account the corrected power values in V1 and V2, the mean relative error reported to V1 was 2.04%.

In the atmospheric conditions given in Table 3, the same engine was operated without fan, in other words the corrected power being the gross power. From the corrected engine power in operation without fan it was subtracted the driving fan power which was measured on a dedicated fan test bench; its value ranged with speed in 0.8-3.2 kW.

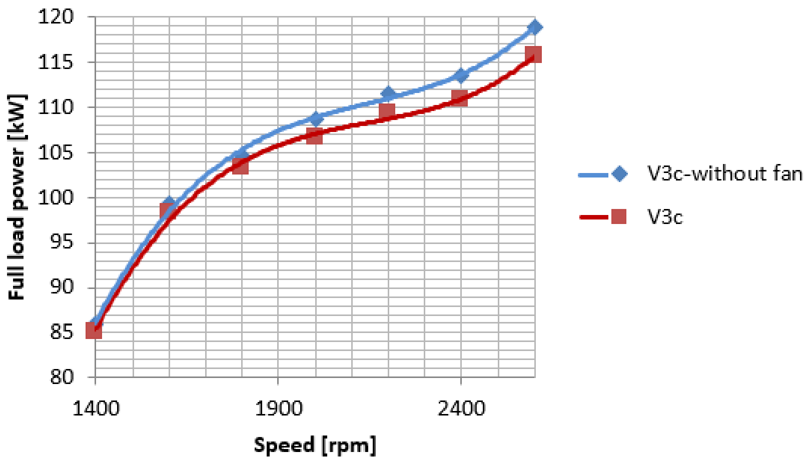

Fig. 2. *Estimation of difference gross-net power*

From Figures 1 and 2 it may be concluded that all three type of tests succeeded to meet the requirements of Reg. 85, the corrected values being in the 5% range around 117kW, namely 117.7 for V1, 117.0 for V2 and 115.6 for V3.

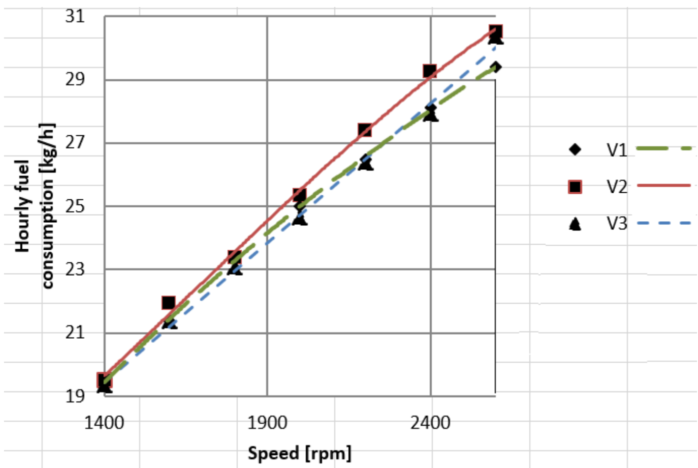

Fig. 3. *Hourly fuel consumption versus engine speed*

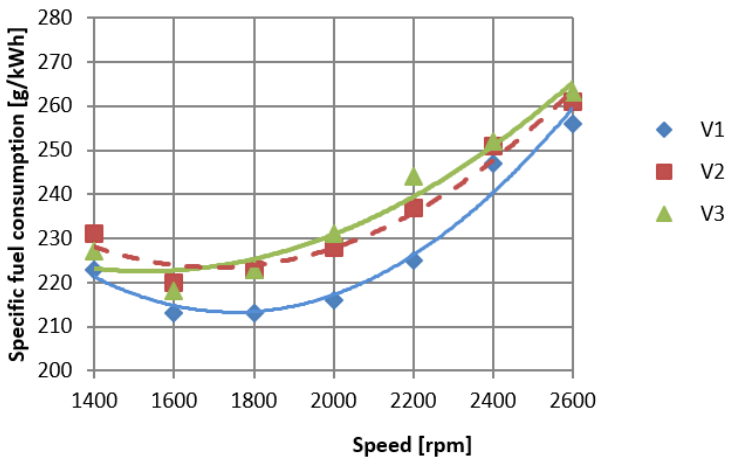

Fig. 4. *Corrected specific fuel consumption versus speed*

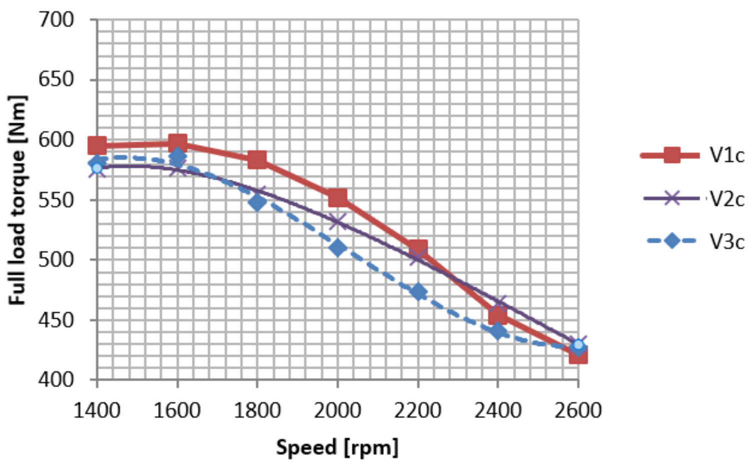

Fig. 5. *Corrected torque versus speed*

The specific fuel consumption was calculated using the hourly fuel consumption which was reported to the corrected power, so the values represented in Figure 4 are also corrected. It can be noticed that the lowest values are found at the speed of the maximum torque (1600 rpm) being in accordance with engine literature [1]. The comparison between corrected specific fuel consumption in V1 and V2 which can be explained mainly on atmospheric condition variation showed a mean relative error of 3.75%. For corrected torque the similar value was 2.48%. The calculation of corrected specific fuel consumption involves the division of the hourly fuel consumption to corrected power which was dependent both on speed and torque so it explains the fact that its mean relative error was higher than the torque error.

5. Conclusions

The power rating tests performed in the same conditions excepting the atmospheric ones show small differences after applying correction factors. The influence of the fan drive on the engine performance was around 3%. The differences between corrected values can be explained by cyclic dispersion whose physical explanations are not totally understood.

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