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EXPERIMENTAL MEASURES FOR MEETING STANDARDS OF DIESEL ENGINE VISIBLE EMISSIONS

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Abstract: *The paper presents research work done on a turbocharged inter-cooled direct injection diesel engine for the reduction of smoke emission. The engine type D2156MTN8R having a rated power of 280 HP at 2100 rpm, manufactured by Roman Truck Company, was tested on the dynamometric bench being measured performances and emissions. According to standards there were measured performance parameters such as corrected power (P_{ec}), corrected torque (M_{ec}), hourly fuel consumption (C_h), specific fuel consumption (c) as well as emissions –in terms of smoke number (N_s)expressed in Hartridge smoke units (HSU). The opacity of exhaust gas was compared to limits imposed by European Regulation ECE 24.Further experimental adjustments were done to correct smoke emissions at lower speeds,in four steps: variation of the injection timing, variation of fuel flow rate injected in the combustion chamber, axial rotation of the injector nozzles and variation of the injected fuel flow rate according to charged air pressure.*
Keywords: *diesel engine, visible emissions, experimental adjustments*

1. INTRODUCTION

Diesel engine applications are dominant in freight and passenger transportation due to fuel economy and reliability, being also redesigned to reduce exhaust gas emissions. Although major abatements were done, visible exhaust gas can cause air pollution and health problems. Heavy duty diesel engines must meet simultaneously severe requirements both on performance and emissions, regulated by European standards. Among the most spread emission standards, ECE R 24 [1] defines provisions for approval with regard to "visible pollutants" which is called, in lay terms, smoke. The regulation defines smoke limits which must be checked by testing engine on the dynamometric bench. If the engine smoke emissions are lower than imposed limits, the engine type is considered certified according to Regulation 24.

2. ENGINE REQUIREMENTS

The D2156MTN8R engine having the block series no.1226 was tested on the dynamometric test bench at Road Vehicle Institute (INAR). The engine performance depends on atmospheric conditions and fitted equipment. During the tests the atmospheric conditions were as follows [2]:

- Pressure : 710 - 721 mm Hg;
- Air temperature : 9-15 º C;

The engine performance is corrected according to pressure and temperature with coefficient α, with f_a atmospheric factor and f_m engine factor, with the formula:

$$\alpha = f_a^{fm} \quad (1)$$

$$f_a = \left(\frac{99}{p_s}\right)^{0.7}\left(\frac{T}{298}\right)^{1.5} \quad (2)$$

p_s - atmospheric dry pressure expressed in kilopascals, T - atmospheric temperature in Kelvin.
The air temperature in absolute Kelvin scale is measured at the engine inlet at 0.15 m upstream the air filter.

$$f_m = 0.036 \cdot q_c - 1.14 \quad (3)$$

$$q_c = \frac{q}{r} \quad (4)$$

with q - fuel flow in milligramme per cycle per liter of total swept volume (mg/(l.cycle) and r - pressure ratio of compressor outlet and compressor inlet. The calculated values of α range in 1.04-1.06 the interval being included in the requirement of 0.9-1.1.
As a cooling agent it was used the dedurised water from the cooling system of the test bench, the temperature being kept in 75-80°C. For the engine operation it was used diesel fuel according to standard EN 590.
The engine was fit with a 6 blade Φ680 fan, an aluminum made charge air cooler, an (unloaded) alternator and without air compressor.

3. ECE 24 REQUIREMENTS AND TEST RESULTS

There are two dissimilar tests when are determined the emission of visible pollutants, the measurements at steady speeds (A) and at free acceleration (B)[1].
The measurements were performed with opacimeter AVL 465 in which the gas is measured in a confined enclosure with a non-reflecting internal surface; the effective length of light path is determined avoiding the influence of the protective devices of light source and photoelectric cell. The opacimeter has two scales, a linear scale ranging from 0 to 100 and a logarithmic scale in absolute units of light absorbtion ranging from 0 to 4 unit m^{-1}.

(A) Test at steady speeds over the full-load curve

The test is carried out on an engine being measured the opacity of the exhaust gases running under full-load and at steady speed, between minimum and maximum rated speed, in this case 1000 - 2100 rpm.
For each of the engine speeds at which the absorption coefficient is measured, the nominal gas flow shall be calculated by means of the following formula, for four-stroke engines:

$$G = \frac{V \cdot n}{120} \quad (5)$$

in which:
G - nominal gas flow, in liters per second (l/s), V - cylinder capacity of the engine, in liters (1), n - engine speed, in revolutions per minute (rpm).
In all the tests which were represented below, there were calculated corrected power (P_{ec}), corrected torque (M_{ec}), hourly fuel consumption (C_h), specific fuel consumption (c) as well as emissions –in terms of smoke number (N_s) expressed in Hartridge Smoke Units (HSU).
The initial tests were performed with injection timing at 25°CR (Crankshaft Rotation), illustrated in figure 1, with continuous line. The measured engine performance in terms of power, torque and specific fuel consumption complies with the engine type declaration, as stated in Romanian standard STAS 6635. The allure of performance curves is typical for heavy duty diesel engine, having the lowest specific fuel consumption in the range of speeds corresponding to the highest torque.
As it can be noticed, the smoke number expressed in Hartridge units exceeds the limit required by Regulation 24 for lower speeds,in this case lower than 1200 rpm.
The first step to meet the limits was done by variation of injection timing around the value of 25°CR which is imposed by engine standard. So injection timing was modified with ±2° at 27° and 23°.The higher injection timing corresponding to 27° is represented in figure 1 with dashed line and the smaller injection timing corresponding to 23° with dotted line.
It was noticed that from the three measurements, the one performed for injection timing of 27°CR has the power, torque and specific fuel consumption improved; the hourly fuel consumption was even and the smoke number was the best only until the speed of maximum torque of 1400 rpm. At lower speeds the measured smoke was higher than admitted limit.
When the engine run with 23° injection timing the performances were worse at speeds higher than 1400 rpm, but at at lower speeds, critical from the point of view of meeting regulation, the smoke number was a little bit better.Also the specific fuel consumption increased, the lowest pole being deviated in the area of smaller speeds, which are not so frequently operated during engine life span.
The influence of injection timing of only ±2° is significant in terms of power difference (around 20 kW) and specific fuel consumption difference (around 15 g/kWh) while the hourly fuel consumption was not sensitive at all.

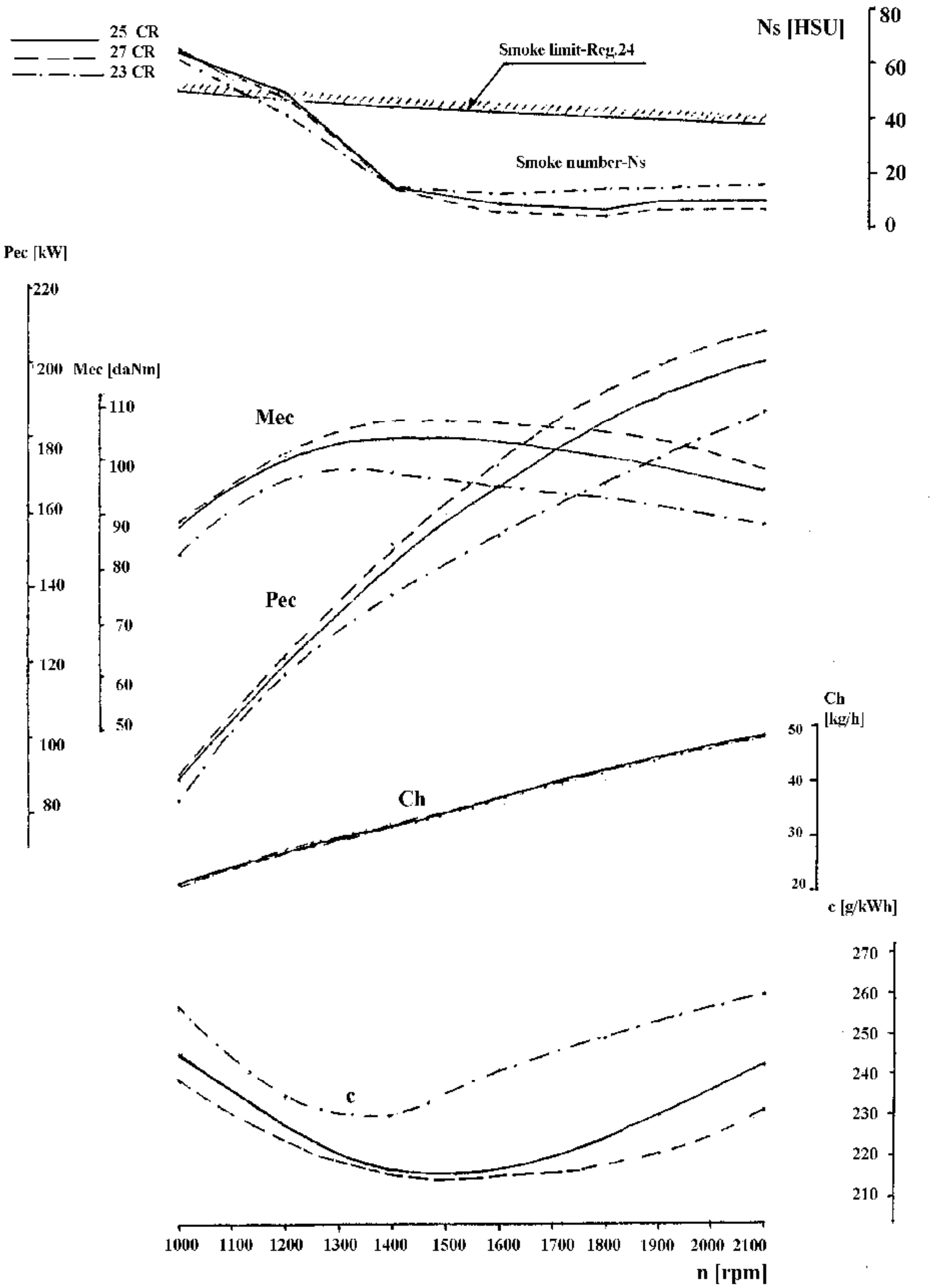

Figure 1: Engine performance versus injection timing (crankshaft rotation - CR) in degrees

The second step was to study the influence of fuel flow rate in the injection pump being represented in figure 2. The injection pump was adjusted for maximum rated power at 280 HP and for a lower power of 240 HP. For the fuel flow rate adjusted for 240 HP the smoke number was higher than for 280 HP on the whole range of speeds.

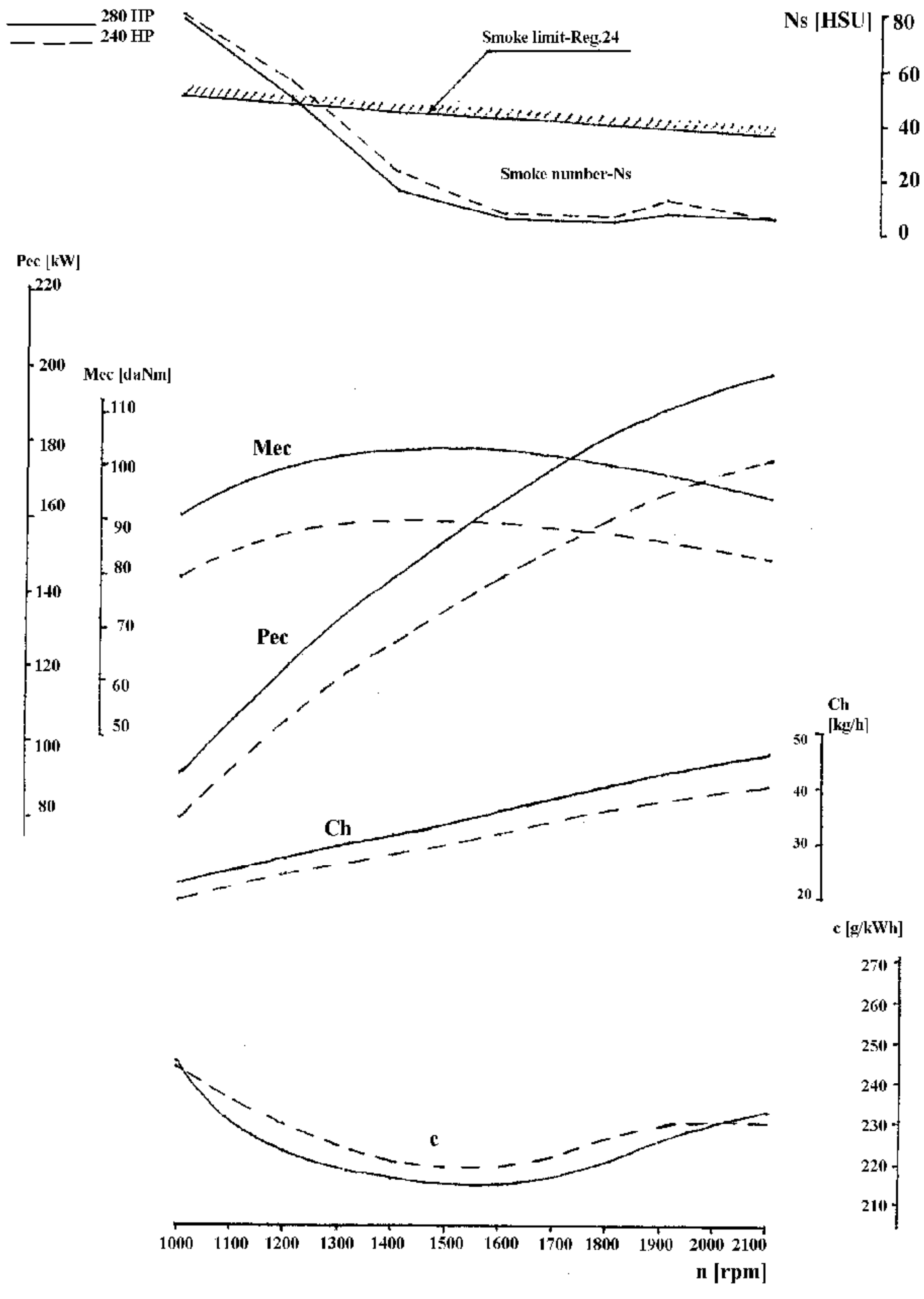

Figure 2: Engine performance versus fuel flow rate

The third step investigated the influence of the axial position of the fuel sprays in the combustion chamber. The engine combustion chamber is a sperical Meurer type, being very sensitive to the position of injectors in the combustion chamber, due to the asymmetrical shape of the walls which influences the air-fuel mixture evolution. From the reference position indicated on the documentation the injector nozzles were rotated with ±5° (forward rotation -counter clockwise and backward rotation –clockwise).The performances are presented in figure 3. It can be observed that the backward rotation produced an increase of power, torque and a smoke reduction; even so, the smoke limit was exceeded for speeds lower than 1100 rpm. This new position of the injector nozzles was mantained in the next tests.

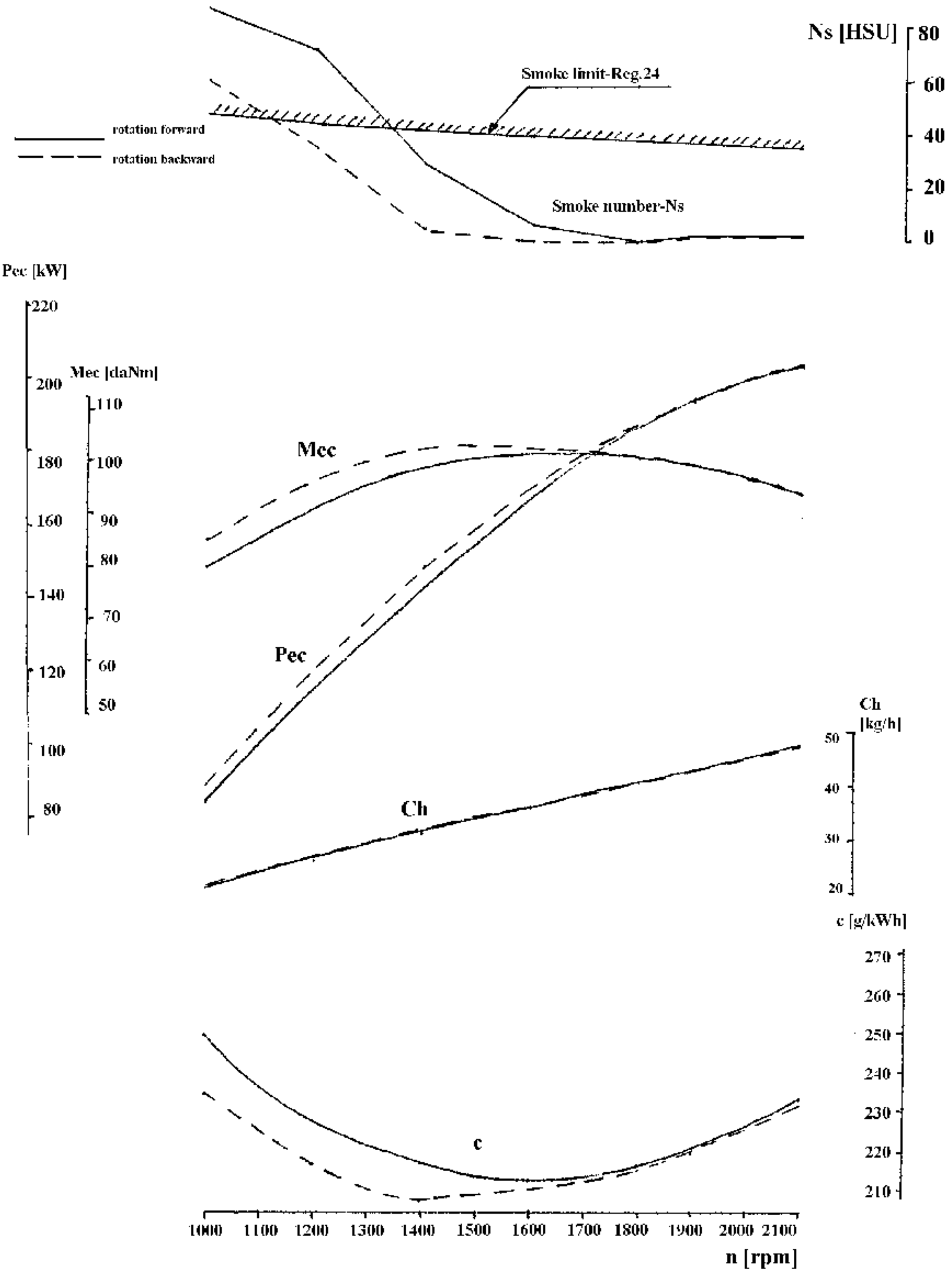

Figure 3: Engine performance versus injector rotation 5°CR forward and backward

The fourth step was to reduce the smoke number under the limits in the range of 1000-1100 rpm by means of adjusting the injection pump fuel flow rate by means of a device called LDA (abbreviation from German term Ladedruckabhängigkeit*)*. That device, specific to in-line pumps, can correct the injected fuel flow rate according to charged air pressure. The law of variation of the measures aforementioned can be simply adjusted passing from the „series value" to a lower value by modifying the charge air pressure corresponding to that speed and reducing the fuel flow rate.The effect of the modification can be seen in figure 4, the smoke number was decreased under the limit as the fuel flow rate was reduced from 140 mm^3/cycle to 110 mm^3/cycle. At 1000 rpm the smoke value was 50 HSU and the imposed limit was 50.4 HSU.

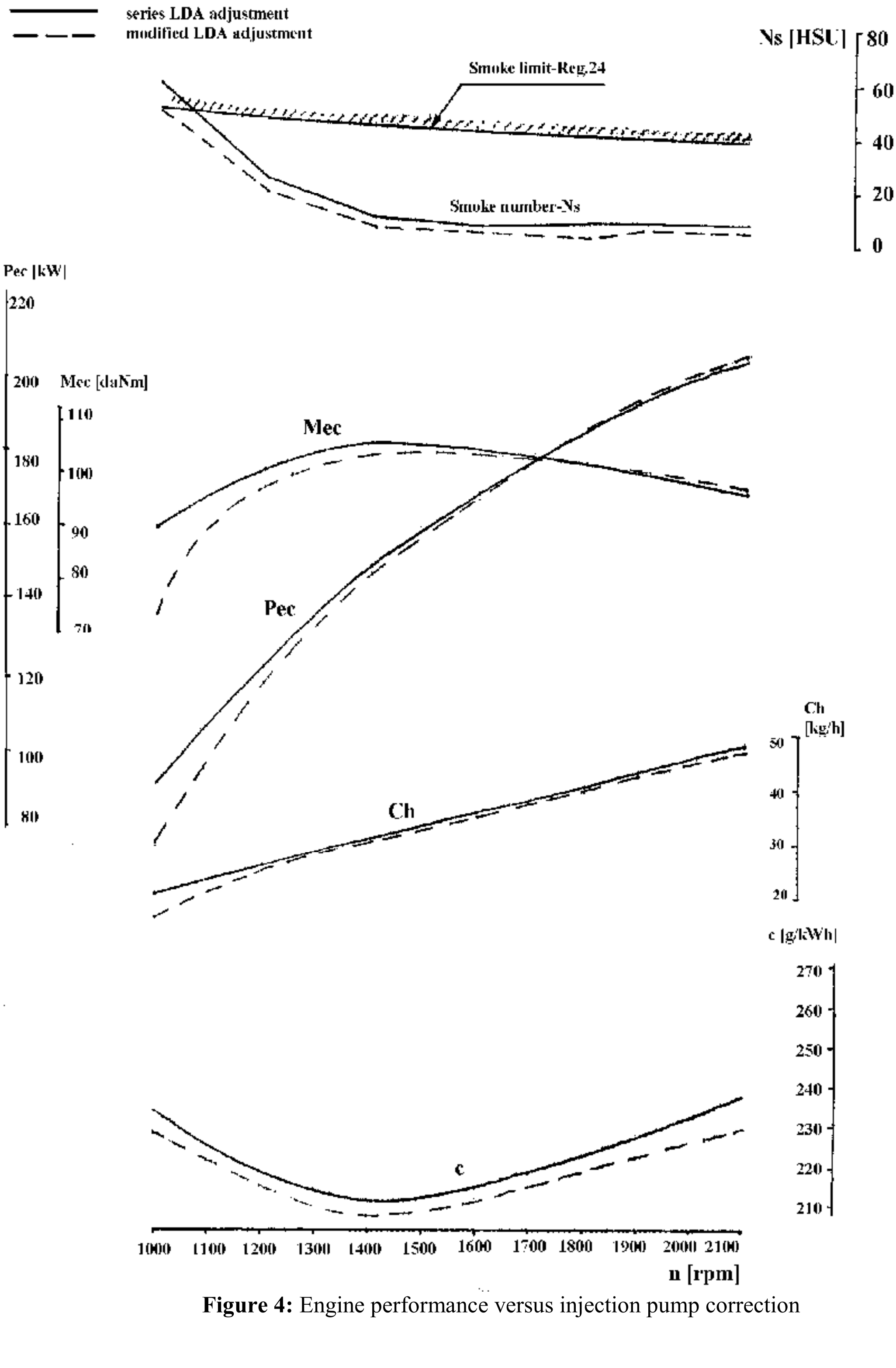

Figure 4: Engine performance versus injection pump correction

In order to verify the engine operation there were measured the mechanical efficiency through the method of power loss in motoring operation, the values ranging from 0.79 to 0.86. It was verified the compression ratio by means of measuring combustion chamber volume being calculated the value of 15.3:1.

(B) Free acceleration test

The visible pollutants are measured in free acceleration on the engine running in the maximum rated speed and maximum power. The absorption coefficient X_M is the mean value of four readings which should not differ with more than 0.15 m^{-1}.

For turbocharged engines the absorption coefficient measured under free acceleration shall not exceed a limit depending on the nominal flow rate corresponding to the maximum absorption coefficient measured during the tests at steady speeds, plus 0.5 m^{-1}.

For the present test, free acceleration smoke measurement were performed according to requirement from Appendix no. 5 of 24 ECE Regulation. The measured value of opacity index in free acceleration is X_M = 2.0 m^{-1}.The corrected value X_C of opacity index in free acceleration is: X_C = 2.5 m^{-1}.Being the smallest value calculated from: $X_C = X_M (S_L / S_M)$ and $X_C = X_M + 0.5$,in which S_M = 0.796 m^{-1} – the measured opacity in stabilised operation mode which is the closest to the prescribed limit and S_L =1.90 m^{-1} – the limited value of opacity corresponding to the speed at which S_M is measured.

4. CONCLUSIONS

The paper summarizes research work performed in four steps in order to obtain the approval on the engine type on visible emissions. The procedure was done step by step proving that experimental adjustments may lead to the meeting of the requirements.

The test results of the engine D2156MTN8R indicated that the engine complies with the values of smoke limits according to ECE 24 Regulation in the following conditions:

- the injection timing is 27° crankshaft rotation;
-injector nozzle position is rotated with 5° backwards (clockwise) from the initial position prescribed in documentation;
-injection pump correction device should allow a fuel flow reduction at 1000 rpm of 20% (30 mm^3/cycle).

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