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INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2013
Brasov, 23-25 May 2013

EXPERIMENTAL RESEARCH ON THE SUPERCHARGING OF THE COMPRESSION IGNITION ENGINES WITH PRESSURE WAVE COMPRESSOR DRIVEN BY ELECTRIC MOTOR

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Abstract: *The compression ignition engine (CIE), as an important propulsion source must be developed in a fast rate so that the highest requirements regarding to power and economy energetic performances to be satisfied. These performances, can be ameliorated if the efficiency of the combustion process improves, by using supercharging compressors which provide in each operation regime of the engine, the optimal quantity of the intake air. A powerful supercharging compressor, characterized by an efficiency comparable to the turbocharger's one, is the pressure wave compressor (PWC). This, still has a great development potential because in our days it is driven by the crankshaft, which involves limited running performance. The solution proposed in this article, to improve the PWC performances and also the one of the CIE, is to drive this compressor through a DC electric motor, with revolutions not depending on the supercharged engine's one. Applying this new driving solution is possible because driving the PWC requires in average, relatively low power consumption (300-400 W). As result of the experimental researches carried out on the engine testing bench, in this article is presented the degree of energetic performance improvement of a CIE, due to supercharging it, with PWC driven by an electric motor.*

Keywords: *pressure wave compressor, driven, energetic performances*

1. INTRODUCTION

Between the main imposed requirements for the vehicle's propulsion systems are found the ones related to power and economy energetic performances improvement of compression ignition engines (CIE).

These performances can be improved if the quantity of heat, released in the engine's cylinders increases due to burning the fuel injected per cycle (Q_0). According to the thermal balance equation (Equation 1), the heat Q_0 is equivalent to the sum of heat converted into effective mechanical work Q_1 , the heat released to the exterior through the

cooling system Q_2 , the heat released through the exhaust gases Q_3 , heat lost due to incomplete combustion Q_4 , heat transferred to the oil through the lubrication system Q_5 and residual heat that we do not take in account through the other components of the thermal balance Q_6 . [2]

$$Q_0 = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \quad (1)$$

Analyzing this formula it can be affirmed that the power and economy energetic performances can be improved if CIEs are equipped with supercharging compressor which use the energy stored in the exhaust gases (Q_3) for intake air compression. In this way, through improving the filling process the

heat quantity Q_4 caused by the better efficiency of the burning process will be reduced, thus maintaining the same fuel quantity, the heat Q_0 will be increased. [3]

A powerful supercharging compressor, characterized by an efficiency comparable to the turbocharger's one, is the *pressure wave compressor (PWC)*. But this presents the disadvantage of difficult synchronization with the supercharged engine, at all speed and load range. This disadvantage is exclusively caused by the way the compressor is driven nowadays, driven by the crankshaft of the engine through a belt. [5, 6]

Due to these considerations this article proposes to highlight the benefits of a new driving system that permits this compressor to provide the proper air quantity for the supercharged engine, regardless to the engine speed and load regimes at which it operates.

2. THEORETICAL ASPECTS

The CWP (figure 1) compresses the fresh air at a pressure that depends mainly on the pressure of the burned, exhausted gasses. This is possible because the exhaust gases and the fresh air enter in each channel of the rotor of the PWC and after the pressures are equalized the gasses leave the compressor on different paths.

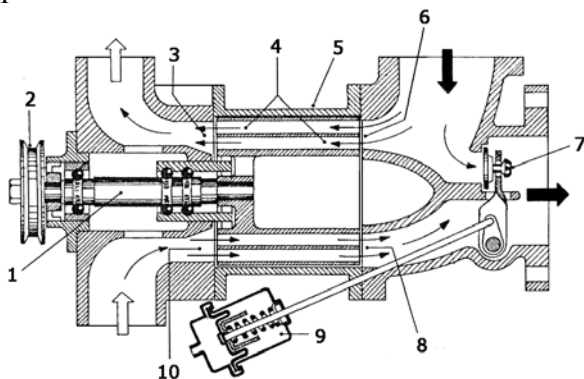


Fig. 1. The components of the PWC [1, 4]: 1-drive shaft; 2-drive pulley; 3-compressed air exit port; 4-rotor channels; 5-rotor case; 6-exhaust gas intake port; 7-wastegate valve; 8-exhaust gas exit port; 9-wastegate valve actuator; 10-air intake port.

Therefore, the compressed air leaving the PWC, enters in the CIE often at a pressure close to that of the exhaust gasses. This, having a high pressure even at low engine

loads and speeds of the CIE, enables in optimal conditions the supercharging process in all operating regimes of the engine.

Besides the geometric dimensions of PWC, a parameter that essentially influences the quality of supercharging process is represented by the speed with which the compressor is driven. The period while the exhaust gases are in contact with the fresh air are depending directly to the value of this speed. This time through which the process of pressure equalization of the two fluids in the rotor of the PWC, decisively influences the value of the: intake air pressure, flow of the compressed air for the engine and the degree of compressed air contamination with exhaust gasses. [5]

Of course, a high quality supercharging process involves a good correlation between geometric dimensions and speed of the PWC on one hand and the operating regime of the CIE on the other hand. But, in our days, it is difficult to realize this optimal correlation, because the PWC being driven by the crankshaft, (with a speed dependent on the CIE's one) it can't be driven at speeds that allow it to compress the intake air at the needed level for each operating regime of the supercharged engine.

All these aspects lead us, taking in account the maximal exploitation of the PWC performances, to a new driving system, which ensures a rotational speed that is not dependent on the rotational speed regimes of the CIE.

3. EXPERIMENTAL RECONFIGURATION AND VALIDATION OF THE PWC'S DRIVING SYSTEM

3.1 Electrical driving of the PWC. The proposed solution, in order to make the PWC more efficient, is that to drive it with a DC electric motor, having an electronically modified speed, according to the speed and load regimes of the CIE.

Taking in account the role of the PWC's rotor which is the working fluid's distribution, it implies a reduced driving power, the electric motor will have smaller dimensions, fact that



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doesn't present difficulties mounting it on the supercharged engine.

It will be also facilitated the positioning of the PWC on the CIE, because the compressor is no longer driven by the crankshaft.

Considering the acceleration response time of the engine, supercharged by the PWC driven by the electric motor, due to the electronic control, this time will remain comparable with the time had in case of driving it with the crankshaft.

3.2 Experimental research of a CIE supercharged with a PWC. To prove that the driving solution of the PWC with an electric motor improves the performances of the supercharging process, experimental researches were done on a supercharged CIE engine. [5]

The experimental researches were performed in two stages. During the first stage of the experimental researches, the CIE was supercharged with a turbocharger type compressor (version, offered by the manufacturer) and in the second stage of the research, the CIE was equipped with a PWC of Complex type driven with variable speed by an electric motor (modified version).

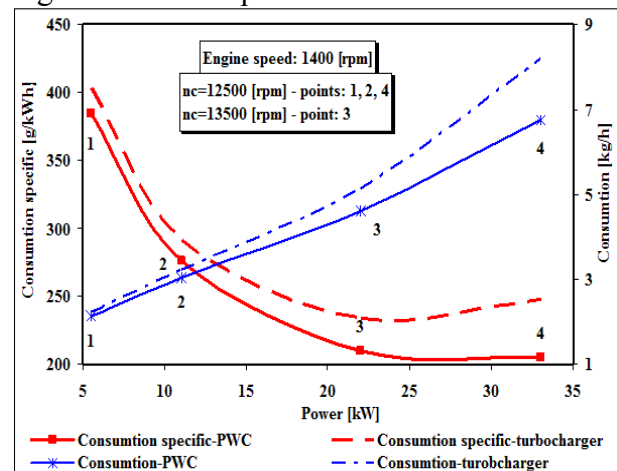
This PWC model is capable to supercharge engines having effective power in the range of 40-80 [kW] and support driving speeds up to 8000 [rpm].

Going through these two stages it made possible the energetic performance's comparison of the experimentally researched CIE, obtained during the two supercharging variants.

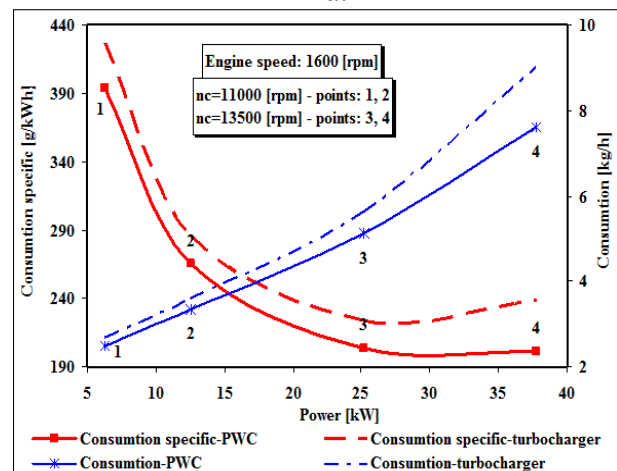
Because the CIEs work mostly in regimes, characterized by partial loads, below are presented the load characteristics of the experimentally researched engine.

In this way there are highlighted the changings of economy energetic performance as function of the supercharging version.

When the load characteristics are obtained (figure 2) for the CIE supercharged in modified version, the PWC was driven in each operating regime, with speed (n_c) giving the highest intake air pressures.

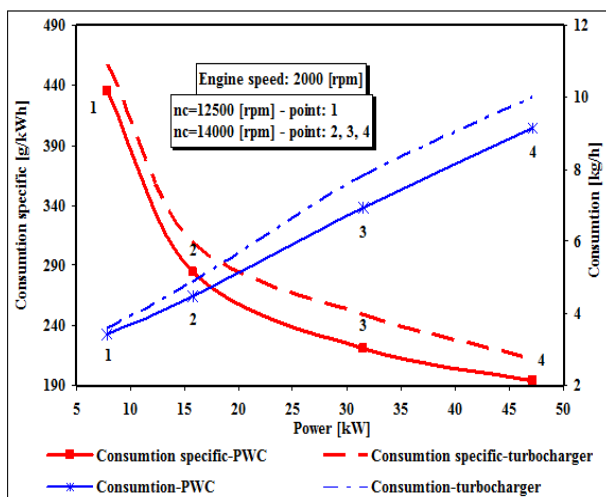


a.

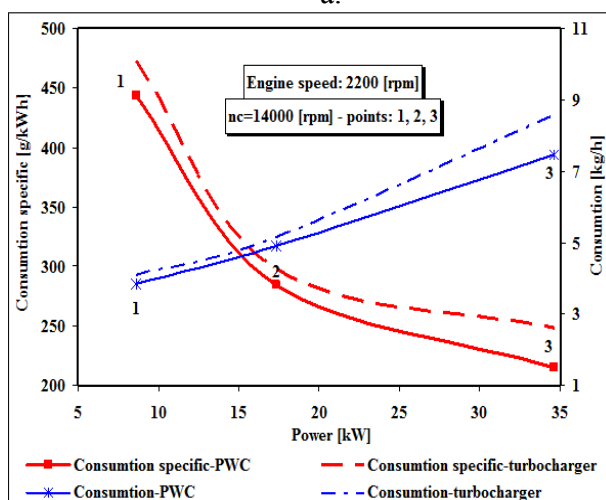


b.

Fig. 2. Load characteristics of a CIE supercharged with a PWC driven by an electric motor (continuous line) and with a turbocharger (discontinuous line) at low engine speeds of: a. 1400 [rpm]; b. 1600 [rpm].



a.



b.

Fig. 3. Load characteristics of a CIE supercharged with a PWC driven by an electric motor (continuous line) and with a turbocharger (discontinuous line) at medium engine speeds of: a. 2000 [rpm]; b. 2200 [rpm].

Analysing the overall load characteristics of the experimentally researched CIE it can be stated that the obtained energetic performances in case of supercharging with PWC of Complex type driven by electric motor, are sensitively improved in comparison to those obtained in the case of supercharging with turbocharger.

It should be mentioned that in all regimes presented in Figure 2, the intake air pressure at the output of the Complex type PWC was permanently higher than the intake air pressure at the output of the turbocharger.

Taking into account the flexibility of the new driving system of the PWC, capable to offer for each operating regime of the supercharged engine optimal values for the

intake air pressure, it can be stated that the increase the energetic performances of CIE, mounted on the testing bench, is due mainly because of the more efficient air-fuel mixing process and hence combustion process.

3. CONCLUSIONS

The PWC can provide for the CIE's intake air a high pressure even at low speeds and loads. This is due to its operating principle, which involves a dependence of the intake air pressure to burned gas pressure and not to the flow of them, how it happens in the case of the turbocharger.

Driving the PWC with the help of a DC electric motor whose speed can be electronically modified according to the speed and load regimes of the CIE, represents a viable solution which confers the CIEs increased energetic performances.

Also, because the PWC is not anymore driven by the crankshaft, it will be facilitated the positioning of the compressor on the supercharged CIE.

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