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RESEARCHES ON THE INFLUENCE OF PRESSURE WAVE COMPRESSOR ON THE INTAKE AIR TEMPERATURE AT THE SUPERCHARGED ENGINES

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Abstract: *In this paper, the way how the working principle of pressure wave compressor influences the temperature field of intake air is presented. The research on a supercharged Diesel engine with successive configurations, one with turbocharger and another with pressure wave compressor, showed that there are different temperature fields of the intake air at the exit of the two supercharging compressors. The paper also presents the causes for this increase in temperature for each of the two compressors, these causes being very different from one compressor to other.*

Key words: *intake air, temperature, pressure wave compressor, engine.*

1. Introduction

The intake air temperature at the internal combustion engines has a great influence on the necessary air quantity for combustion.

High temperatures of the intake air reduces the air mass trapped inside the cylinder, thus the mass of fuel involved in combustion must be reduced.

Significant rise of intake air temperature takes place especially in the case of supercharged internal combustion engines.

However, by supercharging or turbocharging the intake air pressure is raised. In this way, by increasing the air consumption, the contributing mass of fuel can be increased too, as in the principle of downsizing. This leads to a favorable situation for improving the energetic and ecological performances of engines.

The intake air can be compressed with supercharging compressors like: *compressors of turbochargers* or *the pressure wave compressors*. In both cases, the side effect of the pressure rise of the intake air is actually the temperature rise, which reduces the action of the supercharging.

Both supercharging *compressors* use the energy of the exhaust gases for compressing the intake air. However, there is a significant difference between these two, which consists in the way the energy from the exhaust gases to the intake air is transmitted.

In the case of the turbocharger, the energy of the exhaust gases is transmitted to the intake air through two rotors mounted on a common shaft, while the flow paths of the two gases are well bounded [2].

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In the case of the pressure wave compressor, the exhaust gas energy is transmitted directly to the intake air since the two gases are in contact to each other. Another difference is that the air and exhaust gases are travelling successively through the channels [5].

Due to these functional characteristics, in pressure wave compressors there is a supplementary heating source of the intake air, comparing to turbocharges, and that is the direct contact of the air both with the exhaust gases and with the channel walls of the rotor, which took a part of the heat from the exhaust gases.

Under these assumptions, this paper emphases the rate of temperature rise of the intake air due to the supplementary heat sources present in the pressure wave compressors.

2. Aspects on the Influence of the Intake Air Temperature on Engine Performances

Nowadays, the fuel injection systems are working at high efficiency being able to assure the entire necessary fuel quantity for the burning process in optimum conditions. In order to burn a larger amount of injected fuel there is necessary to bring the corresponding amount of air into the cylinders. So, the air mass trapped inside the cylinders at the end of the intake stroke is an important parameter, of which the quality of the burning process and thus, the power and fuel consumption of internal combustion engines depend [5], [6].

The mass of air trapped inside a volume depends on the air density, according to Equation (1):

$$m = \rho_a \cdot V_s, \tag{1}$$

where: m - the mass of air used in one cycle; ρ_a - intake air density; V_s - cylinder volume.

The intake air density depends on its pressure and temperature:

$$\rho_a = \frac{P_a}{R \cdot T_a}, \tag{2}$$

where: P_a - intake air pressure; T_a - intake air temperature; R - ideal gas constant.

So, Equation (1) can be written as:

$$m = \frac{P_a}{R \cdot T_a} \cdot V_s. \tag{3}$$

Since the ratio V_s/R is constant, Equation (3) can be written as:

$$m = \text{const} \cdot \frac{P_a}{T_a}. \tag{4}$$

Equation (4) emphases the influence that the intake air temperature has on the amount of air trapped inside the cylinders.

The power produced by a four stroke internal combustion engine, described by Equation (5), is proportional to the mean effective pressure (p_{me}) and to the engine speed (n):

$$P_e = \text{const} \cdot p_{me} \cdot n. \tag{5}$$

The mean effective pressure can be estimated by Equation:

$$p_{me} = \text{const} \cdot \rho_a \cdot \eta_v \cdot \eta_e \cdot \frac{1}{\lambda}, \tag{6}$$

where: η_v - volumetric efficiency; η_e - effective efficiency; λ - excess air factor.

By replacing Equation (2) and (6) into Equation (5), we obtain [1]:

$$P_e = \text{const} \cdot \frac{P_a}{T_a} \cdot \eta_v \cdot \eta_e \cdot \frac{1}{\lambda} \cdot n. \tag{7}$$

According to [3], it is estimated that each increase in T_a by 10 ^{o}C, P_e is reduced by

3%. Also, according to [7], [8], by cooling the intake air at a supercharged engine, the fuel consumption can be reduced by almost 6%, followed by an increase in P_e by 15%. In this way, by reducing the aspired air temperature by 25 °C, one obtained smaller fuel consumption by 20 g/kWh and a higher P_e with 4 kW.

3. Air Compression inside Supercharging Compressors

The link between pressure and temperature makes the cooling of the intake air necessary especially when the air is compressed in a compressor. The increase in intake air density (π_ρ) at a supercharged engine can be estimated by Equation [3]:

$$\pi_\rho = \frac{\rho_{a2}}{\rho_{a1}} = \frac{\dfrac{p_{a2}}{R \cdot T_{a2}}}{\dfrac{p_{a1}}{R \cdot T_{a1}}} = \frac{p_{a2} \cdot T_{a1}}{p_{a1} \cdot T_{a2}}, \qquad (8)$$

where: with 1 - air parameters before entering into compressor, with 2 - compressed air parameters.

So, the rise of temperature T_{a2} has a negative influence on the supercharging compressor. Considering an adiabatic compression of the intake air, then the temperature T_{a2} may be found as follows:

$$T_{a2} = T_{a1} \cdot \left(\frac{p_{a2}}{p_{a1}} \right)^{\frac{k-1}{k}}, \qquad (9)$$

where: k - adiabatic exponent.

In reality, the rise of T_{a2} is higher due to the turbulent flow of air in compressor and the heat exchange between intake air and compressor's component walls.

For this reason, the increase in T_{a2} depends on the construction of each supercharging compressor.

4. Functional Particularities of Compressors That Use the Energy of the Exhaust Gases

4.1. Turbocharger

One of the most used compressors for supercharging internal combustion engines is the turbocharger (Figure 1).

Here, the compressor is connected to the driving turbine through a common shaft.

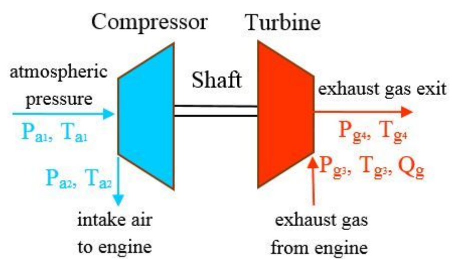

Fig. 1. *The working principle of the turbocharger*

The turbine turns when the hot burned gases are entering into it radially and are exhausted axially. A part of the kinetic energy of the exhaust gases are transformed into mechanical energy by driving the rotor of the turbine. For this reason $P_{g4} < P_{g3}$ and $T_{g4} < T_{g3}$.

The compressor aspire the air which enters axially and is exhausted radially.

The compression inside the rotor changes the air parameters, such that: $P_{a2} > P_{a1}$ and $T_{a2} > T_{a1}$.

For the construction of this type of supercharger, the flowing paths for the exhaust gases and fresh air charge are entirely different and separate. That is the reason why the temperature rise of the fresh charge is mainly due to the compression process.

Between compressor and turbine there are thermal insulations installed, which decreases the conduction heat transfer from turbine to compressor.

For this type of supercharging, P_{a2} and T_{a2} depends on the speed of the turbocharger rotor. This speed depends directly on the exhaust gas flow (Qg).

4.2. Pressure Wave Compressor

The pressure wave compressor is made out of a rotor, which is bounded at the ends by two stators. Through one stator exhaust gases flow and through the other one, the intake air flows. Longitudinal channels on two rows are passing through the rotor (Figure 2).

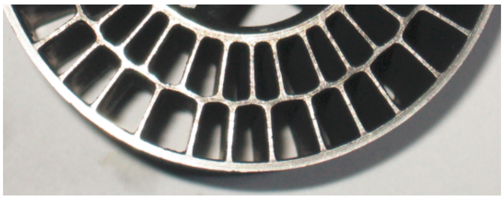

Fig. 2. *The channels of the rotor contained in a pressure wave compressor*

In the case of the pressure wave compressor, the intake air is compressed by the exhaust gases too. However, P_{a2} and T_{a2} depend directly on P_{g3} and T_{g3} and not on Qg, as for the turbocharger.

To realize the air compression process, the rotor of the compressor must be turned.

The pressure wave compressor can be driven by the crank shaft or by an electric motor with variable speed.

A functional cycle of the compressor (Figure 3) begins by introducing the exhaust gases inside one channel of the rotor, in which fresh air exists. The high pressure of the exhaust gases is compressing the existing air inside the channel. The compressed fresh air is exhausted towards the cylinders of the engine, while the rotor turns.

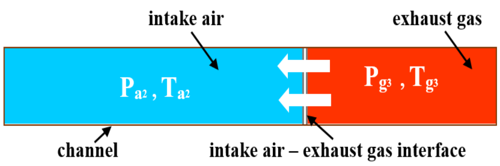

Fig. 3. *The compression of intake air inside a channel of the compressor*

So, it can be observed that during the rotation of the rotor of the pressure wave compressor, the volume of a channel is occupied alternatively by the exhaust gases and the intake air. Thus, heat is transferred from one fluid to other both through convection and conduction.

5. Experiments and Discussions

One way to highlight the influence on intake air temperature using pressure wave compressor comparing to turbocharger is to supercharge an internal combustion engine both with a turbocharger and with a pressure wave compressor.

Such experimental researches have been realized on a four-cylinder compression ignition engine. The original version of the engine is using turbocharging.

The modified version of the engine is equipped with a pressure wave compressor. This compressor was driven by an electric motor with variable speed. By varying the speed of the electric motor, the efficiency of the compressor could be modified. For each speed of the compressor, the pressure and temperature of the intake air was different.

At certain working regimes of the internal combustion engine, the same values for intake air pressures as in the case for turbocharging were obtained by modifying the efficiency of the compressor. On the other hand, the temperature of the intake air differed. This difference in temperature may due to the heat transfer (from the pressure wave compressor) from the exhaust gases to the intake air. This heat transfer are: direct transfer *exhaust gases - intake air* and indirect transfer *exhaust gases - walls of the channels inside the rotor - intake air*.

In Figure 4 there are presented the values for T_{a2} of the intake air, which is compressed at the same pressure both in turbocharger and in pressure wave compressor.

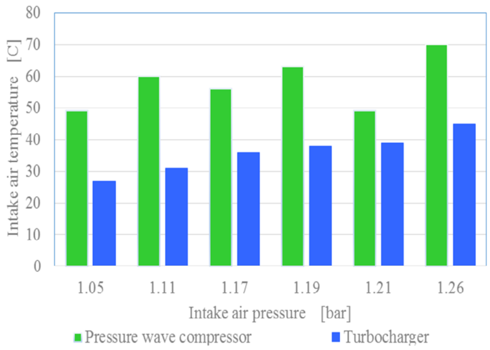

Fig. 4. *The temperature of the compressed intake air in turbocharger and pressure wave compressor*

It can be observed that the temperature of the compressed air in the turbocharger rises with the rise of P_{a2}.

In the case of the pressure wave compressor, the evolution of T_{a2} is not as ascending as in the case of the turbocharger. This can be explained by the fact that T_{a2} is significantly influenced by the time spent by the intake air in contact with the exhaust gases and the walls of the channels (exposure to heat transfer), but also is influenced by the exhaust gases temperature.

If the exposure depends mainly on the rotational speed of the compressor, the exhaust gas parameters depends mainly on the speed and load internal combustion engine [4], [9].

However, according to [4] and the Table 1, the dependency between the speed of the pressure wave compressor and intake air pressure is nonlinear.

Table 1

The compressor speeds to which were obtained the intake air pressure

Intake air pressure [bar]	**Speed pressure wave compressor [rpm]**
1.05	7000
1.11	8500
1.17	11.000
1.19	10.000
1.21	12.500
1.26	8500

In Figure 5 there is presented the influence that the working principle of the pressure wave compressor has on the intake air temperature.

The difference between the temperatures of the intake air exiting the two compressors lies within the interval 10-29 ^{o}C, on condition the same degree of compression.

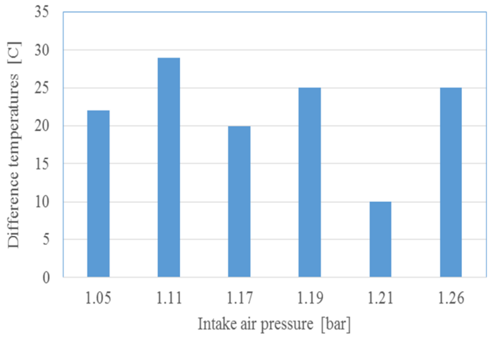

Fig. 5. *The temperature rise of the intake air at pressure wave compressor comparing to turbocharger*

6. Conclusions

At pressure wave compressors, there is a certain heat transfer from the exhaust gases to intake air.

The amount of heat transferred can be estimated through the perspective of temperature rise of the intake air at pressure wave compressors, comparing to turbocharger.

For the choice of the driving speeds of the pressure wave compressor must be taken into consideration both the pressure and temperature of the intake air.

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