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THEORETICAL AND EXPERIMENTAL RESEARCHES AS REGARDS RAISING THE EFFICIENCY OF THE SUPERCHARGING PROCESS ACHIEVED BY THE PRESSURE WAVE COMPRESSORS

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Abstract: *Raising the efficiency of the supercharging process, as intermediate stage in the endeavour to improve the overall performances of the internal combustion engines, may be obtained if this process is achieved by the pressure wave compressor driven with an independent rotative speed from the supercharged engine. To this end, the paper herein presents, through an analysis model in virtual environment, the evolution of the parameters that determine the success of the supercharging process, when a good correlation exists between the driving rotative speed of the pressure wave compressor and the pressure of the exhaust gases. This evolution inside the compressor is experimentally validated through experimental tests conducted on an engine mounted on the test stand.*

Key words: *pressure wave compressor, intake air, simulation.*

1. Introduction

The overall performances of the internal combustion engines decisively depend on the quality of the combustion process that takes place within the cylinders. The combustion process depends in its turn, to an overwhelming extent, on the perfection degree of the cylinder air filling and fuel injection. The air filling process (especially considering supercharging compressors), versus the injection process that has reached a high quality degree, further displays an important development potential for the internal combustion engines. Therefore new solutions must be identified for raising the efficiency of the supercharging compressors, so that they should provide the internal combustion engines with fresh air at pressures adequate to every operating regime of the supercharged engine [1], [5].

A high-performance supercharging compressor that is capable, due to its operating principle, to provide high pressures of the intake air, even at low rotative speeds and loads of the internal combustion engine, is the pressure wave compressor. Despite its performances, this compressor is likely to be improved, through better adjustment of its joint functioning with the supercharged engine, along the entire range of rotative speeds and loads [4].

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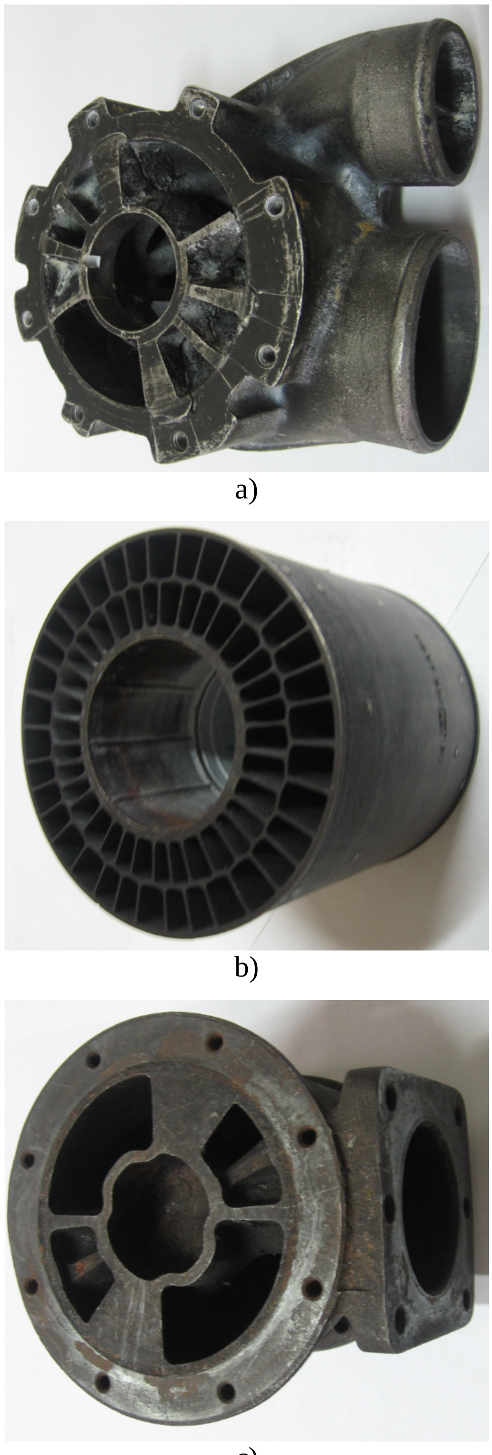
With a view to developing the compressor in accordance with the aforementioned, the processes occurring inside the pressure wave compressor were analyzed in virtual environment, mainly pursuing the evolution of the parameters that determine the success of the supercharging process. In the present paper, the emphasis is laid both on submitting the simulations performed with Fluent software, and on experimentally validating them.

2. Analysis Model in the Virtual Environment

The amelioration of the performances of the pressure wave compressors supposes improving the conditions for achieving the compression and expansion processes developed within the compressor. In order to identify the probable solutions to raise the perfection degree of these processes, through an analysis model in virtual environment, the movement of the pressure waves in a rotor channel of the pressure wave compressor was simulated.

The geometrical parameters used for achieving the analysis model are sized according to an existing model (Figure 1) of the pressure wave compressor. This figure shows the two stators that frame the rotor. The warm stator is made up of the intake windows for the exhaust gases (IWG) and of the outlet windows for the mixture of exhaust gases and air (OWG), whereas in the cold stator there have been placed the outlet windows for the compressed air (OWA) and the intake windows for the environmental air (IWA), as well as the bearings whereby the rotor leans on the driving shaft. The existence of the double number of windows allows for two full operating cycles to be completed during a rotation of the rotor, which has as advantages both the symmetrical distribution of the thermal strains and the reduction of the geometrical dimensions and rotative speed of the pressure wave compressor.



a)

b)

c)

Fig. 1. *The main components of the pressure wave compressor: a - cold stator; b - rotor; c - warm stator*

The geometrical model, as partially exemplified in Figure 2, mainly supposed sizing: 1 - the channel and rotor, 2 - the windows in the stators, 3 - the distances between the stator windows and the reference line (where a new functional cycle of the compressor is reckoned to start), 4 - the inclination angle of the windows.

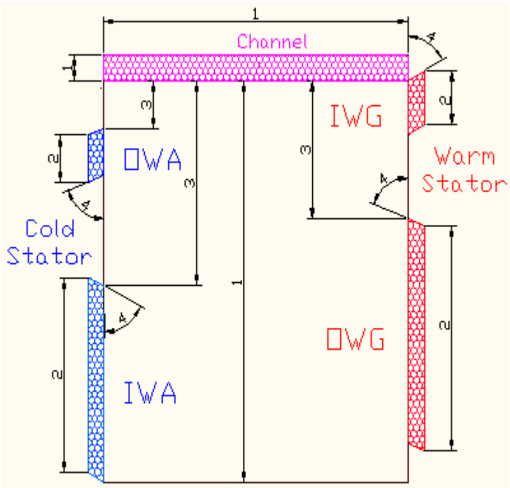


Fig. 2. *Geometrical model of the analysis model*

The mathematical model of the simulation mainly consists of the differential equations of the well-known method of the finite volumes. The application of these equations requires the replacement of the geometrical model with a set of finite volumes (control volumes) that geometrically approximate the studied domain. By associating each finite volume to a node placed inside the volume, a discretization network of the analyzed geometrical volume will be formed. Subsequent to this discretization, by calculating the equations associated to every created control volume, with the matrix calculation methods, the unknown values of the discretization network nodes will result. Achieving a virtual analysis model of higher accuracy mainly depends on the efficiency by which the geometrical space was discretized.

3. Simulation of the Ideal Operating Cycle of the Pressure Wave Compressor

The evolution of the pressure waves was simulated during an operation cycle achieved in ideal conditions, resorting to Fluent 6.0 software - CFD model.

The intake with pressure of the gases exhausted by the internal combustion engine, within the channels practiced in the compressor rotor (wherein there is fresh air penetrated at the end of the previous cycle), produces a primary compression wave that propagates towards the cold stator. So that the pressure wave compressor should attain maximum operating efficiency, the primary compression wave must reach the cold end of the channel before the latter reaches OWA (Figure 3). This way, the primary wave will be reflected by the cold stator wall as secondary compression wave, which will cross the channel from the cold to the warm side. This new wave must reach the warm end after the channel passes past IWG (Figure 4), so that it should be reflected by the warm stator wall, compressing thus, the second time, the air in the channel [2], [6]. Therefore the compressed air leaving the rotor through the OWA window will have higher pressure than the exhaust gases entering it.

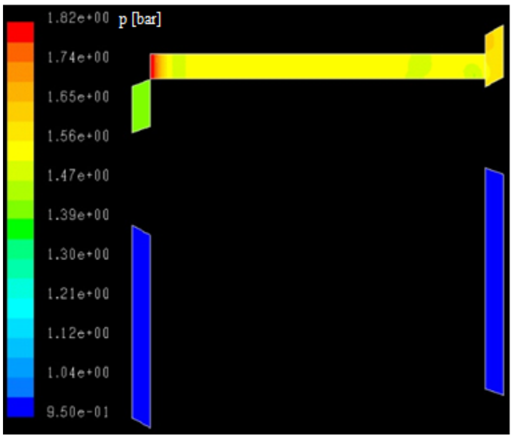


Fig. 3. *Reflection of the compression wave by the cold stator*

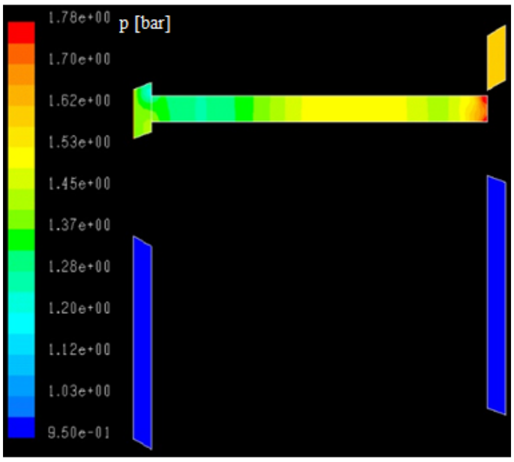


Fig. 4. *Reflection of the compression wave by the warm stator*

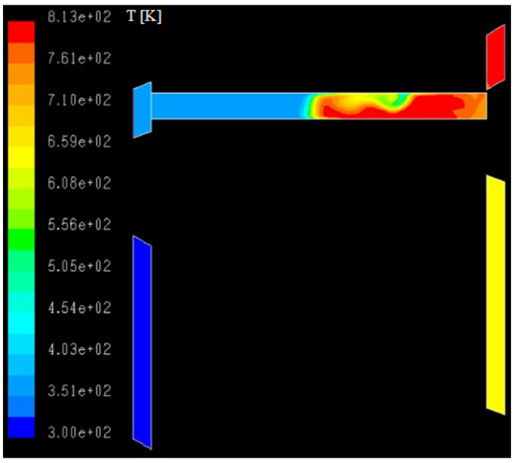


Fig. 6. *Evolution of the working fluid temperature at the moment of IWG closing*

Due to the fact that the compression waves travel at greater speed then the contact area between the exhaust gases and the fresh air, Figures 3 and 4 does not clearly show the volume of the channel occupied by the exhaust gases. Therefore, considering the great difference between the temperature of the fresh air and the one of the exhaust gases in the channel, Figures 5 and 6 shows simulation captures that allow distinguishing the areas occupied by the two working fluids.

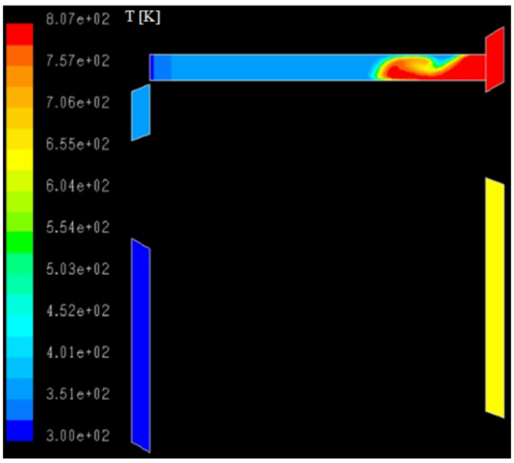


Fig. 5. *Evolution of the working fluid temperature at the moment of OWA opening*

Consequently, the pressure wave compressor operates with high efficiency when the pressure wave reaches the channel ends at adequate times. The high efficiency of the compressor, which mainly supposes obtaining a high value of the intake air pressure, decisively depends on the exhaust gas pressure and on the rotative speed of the pressure wave compressor.

Due to the direct dependence between the pressure level of the exhaust gases and the operating regime of the supercharged engine, it can be inferred that the driving rotative speed of the compressor remains the one important parameter that decisively influences the performances of the supercharging process, at a certain operating regime of the internal combustion engine.

In this context, the need arises for driving the pressure wave compressor with a rotative speed directly conditioned on obtaining a high pressure of the intake air.

However, because the pressure wave compressor is currently driven by the crankshaft via a belt, the driving rotative speed of the compressor depends on the rotative speed of the supercharged engine, which limits the efficiency of this compressor.

A solution therefore arises to improve the performances of the pressure wave compressors; namely to drive this supercharging compressor with a variable rotative speed, independent from the rotative speed of the internal combustion engine. This solution can be implemented if we resort to direct-current motors aided by electronic systems managing the rotative speed.

Due to all these reasons, the simulations aimed, at a certain value of the exhaust gas pressure and temperature, at determining the optimal rotative speed for driving the pressure wave compressor, so as to obtain the most favourable evolution of the intake air pressure and temperature.

4. Experimental Validation of the Simulations

Simultaneously with the achievement of the analysis model, experimental tests were conducted on the test stand, on a compression ignition engine supercharged with a pressure wave compressor, driven by an electric motor with variable rotative speed [3].

These experimental tests made it possible, according to Table 1, for the values of the start parameters (columns 1 - 4) used for performing the virtual analysis model to be similar to the real values.

Following this table, we may state that at a pressure of 1.5 bar and a temperature of 800 K of the exhaust gases, through the simulation of an operating cycle conducted in a rotor channel, the rotative speed of 12500 rpm was obtained, in which case the pressure wave compressor conferred a pressure of 1.51 bar and a temperature of 359 K upon the intake air.

Likewise, comparing the values obtained by simulation with the experimental values, one can notice (columns 1-4) that at a percentage difference between the input values in the model and the experimental values ranging between (–1.3) - (+4.1) %, a percentage variation was obtained (columns 5-7) of the results determined by simulation compared to the experimental values ranging between (–4.7) - (+1.32) %.

The fact that the values obtained by simulation are comparable to those obtained within the experimental tests indicates a close resemblance between the evolution of the pressure and temperature waves obtained through the virtual analysis model, and the real evolutions occurring in the rotor channels.

Table 1

Comparison between the values obtained by simulation and the experimentally obtained values

Method of determination	**Environmental Air**		**Exhaust Gases**		**Compressor Speed**	**Intake Air**	
	Pressure	**Temp.**	**Pressure**	**Temp.**		**Pressure**	**Temp.**
	[bar]	**[K]**	**[bar]**	**[K]**	**[rpm]**	**[bar]**	**[K]**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Simulation	0.95	300	1.5	800	12500	1.51	359
Experimental Tests	0.95	300	1.52	767	12500	1.49	376
Values Ranging	0%	0%	- 1.3%	+ 4.1%	0%	+ 1.32	- 4.7%

5. Conclusions

Following the simulations, validated by experimental tests, we can state that raising the efficiency of the supercharging process performed by the pressure wave compressor is conditioned by the correlation degree between the driving rotative speed of the compressor and the pressure of the exhaust gases entering the rotor and implicitly the load and rotative speed regime of the supercharged engine.

A qualitatively higher adjustment of the internal combustion engine to the pressure wave compressor may be obtained if the latter is driven with variable rotative speed by a direct-current motor. There are thereby eliminated the restrictions imposed on the driving rotative speed of the pressure wave compressor by the current driving system, which permanently ensures the proportionality between the rotative speed of the compressor and of the crankshaft.

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