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# MESH BASED MODELING OF A PRESSURE WAVE SUPERCHARGER

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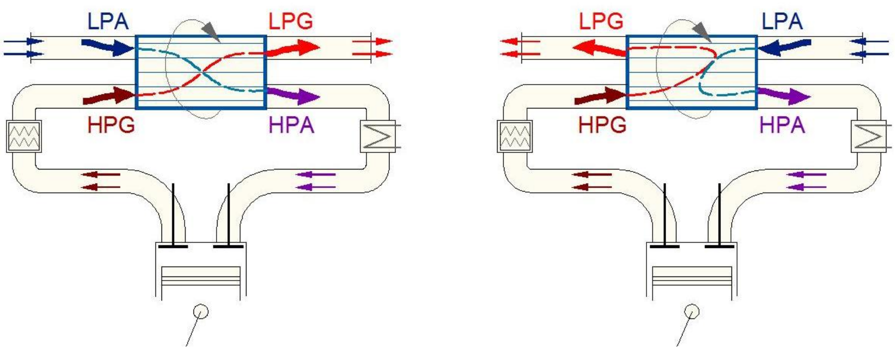
***Abstract:*** *This paper presents a mesh based analysis of the evolution of the velocity and pressure along the wave rotor channels. The simulation was modeled using 3D k-ε model to reproduce data such as pressures, mass flows usually measured in real engine pressure wave supercharging. Results were obtained at different range of operating conditions.*
***Keywords:*** *Wave rotors, pressure wave supercharging, shock waves, rotor channels.*

## 1. INTRODUCTION

A priority for the European Union (EU) and other world-wide nations is preventing the climate change by reducing substantially the greenhouse gas emissions, the main cause of the increase in global temperature [1] and the level of pollution. One EU target for 2020 is cutting off 20% in greenhouse gas emissions compared with 1990, as well as 40% cut for 2030 [1]. The long-term consequences of the climate change have led to legislative measures meant to reduce the high levels of pollution, mainly caused by its primary factor: burning fossil fuels. As the propulsion systems are the main consumers of fossil fuels, it is stated that the road transport sector is responsible for about a fifth of greenhouse gas emissions in Europe [2]. Therefore, the internal combustion engines (ICE) became the primary object for energy conservation and emission reduction in the world [3, 4].
Pressure wave devices use shockwaves to transfer energy directly between fluids without additional mechanical components, thus having the potential for increased efficiency [5-7]. In a Pressure wave supercharger (PWS) the interaction between the exhaust high pressure and high temperature gas and the low pressure and low temperature air produce a boost. The hot gases produce a shock wave that expands through the PWS channels and compresses the fresh air.

## 2. PWS OPERATING PRINCIPLE

The PWS principle of operation is based on the fact that if two flowing fluids having different pressures are brought into direct contact in narrow channels, equalization of pressure occurs faster than mixing of fluids [8, 9]. In Figure 1 is shown the interaction between the components of a four port PWS [10]. Since the end cold and hot plates that include the ports have fixed positions, the rotor channel ends are exposed alternatively to the ports.




a) *passing-through flow* b) *reverse flow*

**Figure 1:** PWS configurations

Thus, the compression and expansion waves are initiated within the channels and the gas generates shock waves that evolve along the channel and compress the fresh air.

PWS can be designed for different fluid passage in two configurations, as shown in Figure 1: a) *passing-through flow* - when all flows travel in the same direction and b) *reverse flow* - when each flow (gas or air) exits on the same side [10]. This paper presents a theoretical analysis of the evolution of the pressures along the channels of a PWS for the exhaust gases and for the fresh air.

## 2. NUMERICAL MODEL

In the present work the geometry was created in three-dimensional model using AutoCad and was imported in Comsol [11] (see Figure 3). The model uses baseline dimensions for CX-93 four port reverse flow pressure wave supercharger. The mesh resulted after some geometry repair operations are presented in Fig.4 consisting in 2836822 tetrahedral elements.

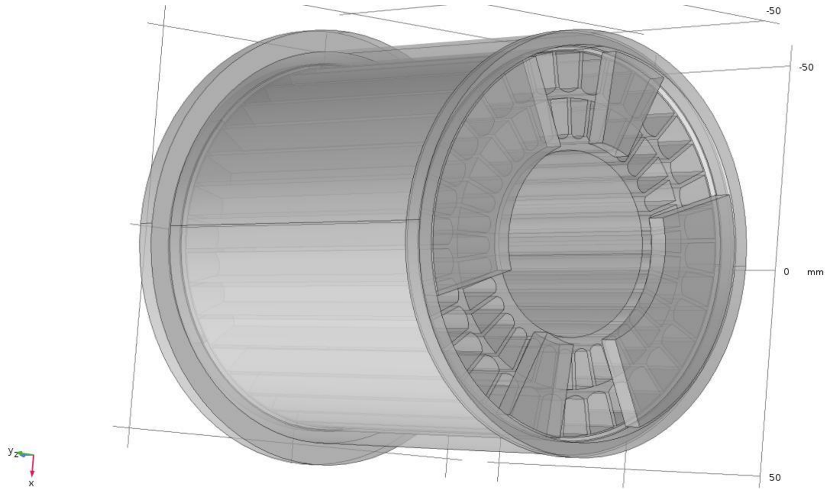



**Figure 3:** PWS geometry

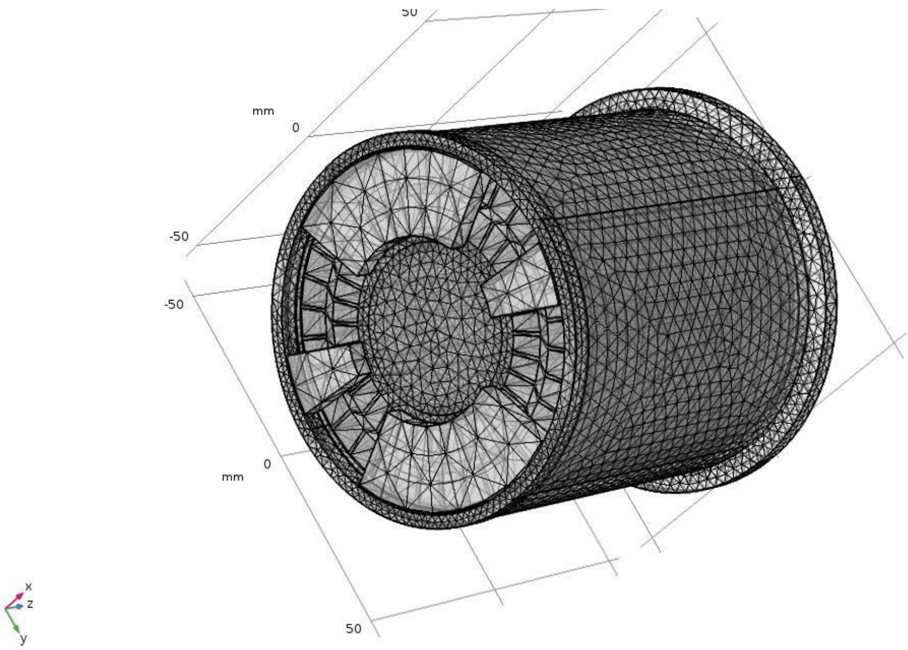



**Figure 4:** PWS mesh

The rotor material was considered steel and the fluid used is the air. Air was considered as compressible gas. The specific heat, thermal conductivity and the viscosity were considered as temperature dependent.

The model uses the Reynolds-averaged Navier-Stokes (RANS) equations in the air domain. The properties for the fluid are the air at atmospheric pressure, and for the solid those of steel. The air properties are considered as temperature dependent. The equations for air domain, which includes equations for turbulent kinetic energy k and for dissipation ε, are used for rotating domain model. To simulate the PWS time dependent behavior a rotating domain model was used. First step was the frozen rotor study to provide an initial guess for velocity field and pressure in 3D domain. In the second step the flow was treated as turbulent and time dependent using coupling of the conservation and momentum equations with the energy equation.
The boundary conditions at inlet and outlet ports were set up as: a velocity and pressure inlet on the gas ports, and a pressure inlet on fresh air ports. To the entire rotating domain, rotor domain containing fluid, an axial motion was set up with the rotational speed *n*. The boundary conditions are presented in Table 1.

**Table 1 Entry data for the analytical model**

| Property | Value |
|---|---|
| Exhaust gas inlet pressure | $1.80 \cdot 10^5$ Pa |
| Exhaust gas inlet temperature | 1465 K |
| Exhaust gas inlet velocity | 60 m/s |
| Air inlet pressure | $0.98\ 10^5$ Pa |
| Air inlet temperature | 293 K |
| Air specific heat ratio | 1.4 |
| Air specific gas constant | 287 J/kg K |
| Channel length | 93 mm |
| Rotor diameter | 92 mm |
| Revolutions per time | 12600 1/min |

## 3. RESULTS

The results obtained with the 3D model described above are presented below. The pressure distribution in PWS channels in contour plot is presented in Fig.4. The velocity field is presented in Fig. 5. The pressure distribution for a single PWS channel in the case of flow that is moving from right to left is presented in Fig. 6.

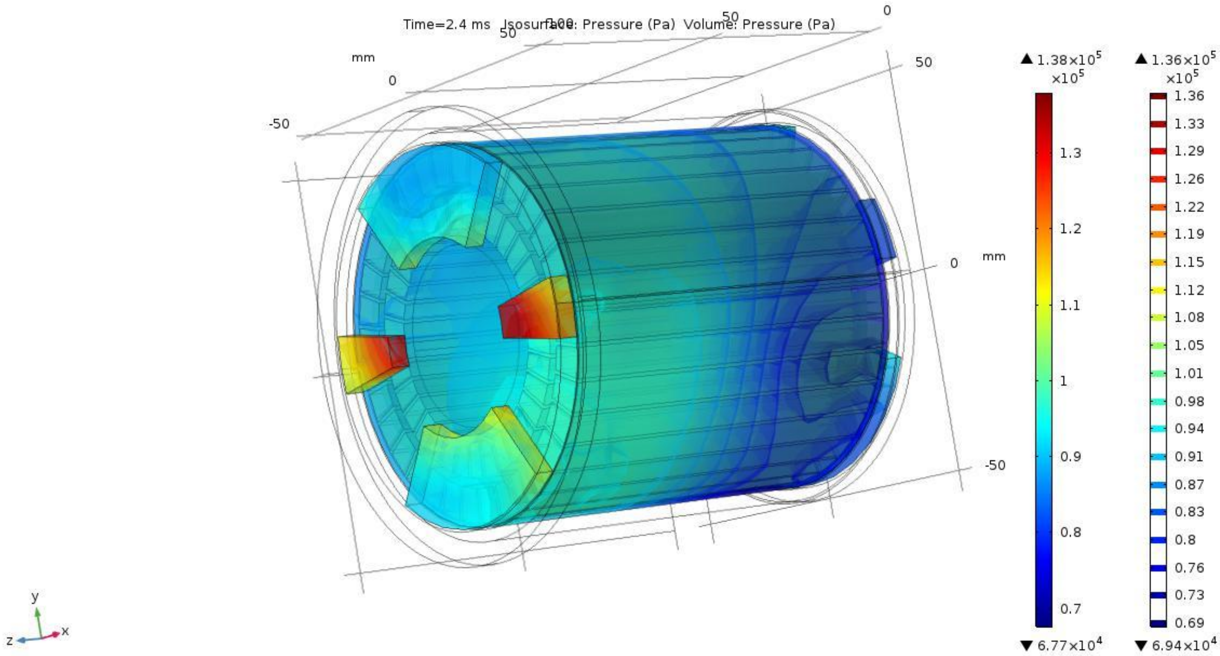



**Figure 5:** PWS Pressure field @2.4ms time for 12600 rot/s

The results obtained for the pressure on PWS air ports on the left side of the Figure 5 shows that the compressed air at the moment of 2.4 msec. of time reaches the value of 1.36 bar on exit air ports. In the Figure 5 also are shown the resulting pressure field inside channels from exhaust gas inlets, the right side of the figure, to air side on the left.

For the velocity field the results obtained are presented in Figure 6. The PWS air ports are on the right side of the Figure 6 that shows that the exhaust gas enters with a maximum value of 75 m/s through inlet ports and travels to air side. Because of rotating domain of the CX rotor the velocity field is deflected from exhaust gas inlets to air ports. In the Figure 6 was shown the resulting velocity field inside channels from exhaust gas inlets, from the left side of the figure, to air side on the right side.

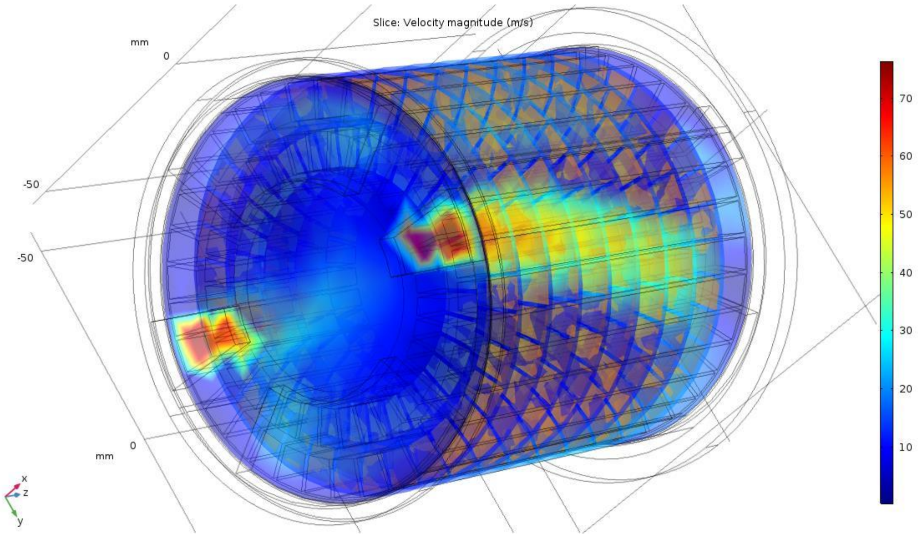



**Figure 6:** PWS velocity field

## 3. CONCLUSION

Utilizing a wave rotor to improve the performance of an internal combustion engine appears to be a promising solution since the exhaust gas generates an increase of air pressure on the aspired air which is a benefic effect on internal combustion engine cycle. Even if pressure ratio of the baseline engine is already optimized, the wave rotor can still enhance both the overall thermal efficiency and cycle specific work output if the wave rotor compression efficiency is higher than that of the baseline engine compressor. Adding a wave rotor also reduces the baseline compressor pressure ratio of the compressor. All theoretical and numerical results presented here encourage the idea that at microscale compression by compression waves may be more efficient than by conventional centrifugal compressors.

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