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The use of computational fluid dynamics (CFD) method in the analysis of the operation of an engine turbocharger

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1. INTRODUCTION

The downsizing trend caused by increasingly stringent emission standards is resulting in the very frequent use of supercharging in internal combustion engines. Turbocharging increases the unit power output of an engine by increasing the density of the supply air, lowering exhaust emissions and reducing fuel consumption. A turbocharger is a device in which the kinetic energy of the exhaust gas drives a turbine, which drives a pump through a shaft so that the air supplied to the cylinder is concentrated, resulting in increased engine efficiency.

The basic parameters describing a turbocharger are boost pressure and discharge. The values of the discharge and boost pressure largely depend on the pump rotor speed and may vary even several times depending on the engine speed.

The aim of the was to analyse the influence of the turbocharger pump rotor speed on its operating parameters, such as discharge and boost pressure. The study was carried out on a virtual model using SolidWorks Flow Simulation software.

2. SUBJECT OF RESEARCH

The object of the analysis was a virtual model of an IHI VB10 17201-27050 turbocharger from a 1CD-FYV Toyota engine (displacement 2000 cm^3, power 90 PS). The engine was found in Toyota Corolla and Toyota Verso cars.

Fig. 1 Photo of IHI VB10 turbocharger

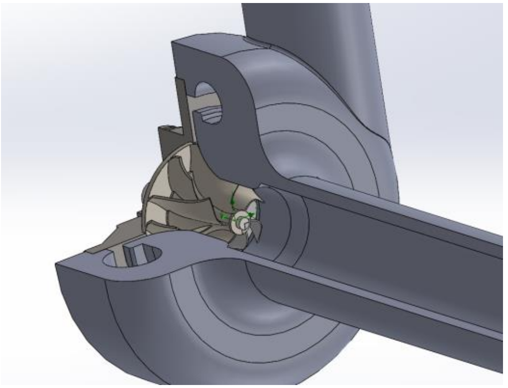

Fig. 2 CAD model of IHI VB10

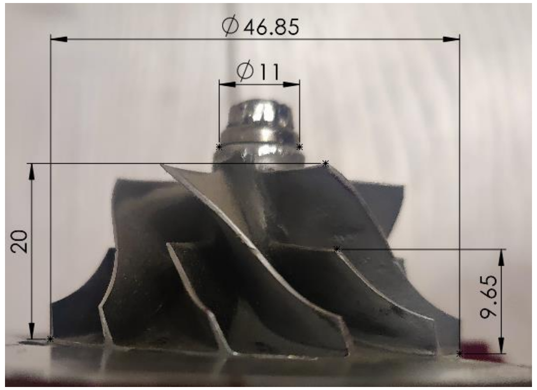

Fig. 3 View of pump impeller with main dimensions marked

Fig. 4 CAD model of pump impeller

3. *METHODOLOGY OF CALCULATIONS*

The analysis of the turbocharger pump parameters was carried out in SolidWorks Flow Simulation software. The solution was obtained using the conservation of momentum principle for a moving fluid according to the Navier-Stokes equations and the conservation of mass principle. The solution of these equations allowed the velocity and pressure to be determined at any section or point of the model for each geometry. As flows could occur in the laminar and turbulent range, Favre's mass averaging was added to the Navier-Stokes equations. Boundary conditions at the inlet and outlet were defined as atmospheric pressure. In the pump rotor area, a rotational area with definable speed was set. Pressure and density results were determined at point *A* at the turbocharger exit, while mass flow rate was determined at the wall of the exit boundary codition.

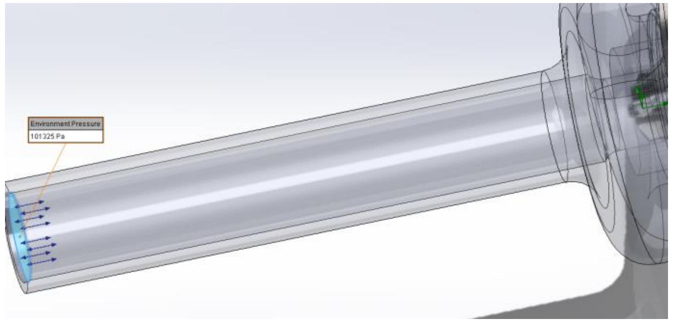

Fig. 5 Inlet boundary condition

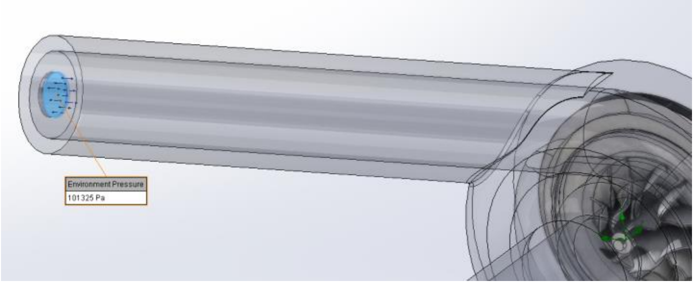

Fig. 6 Outlet boundary condition

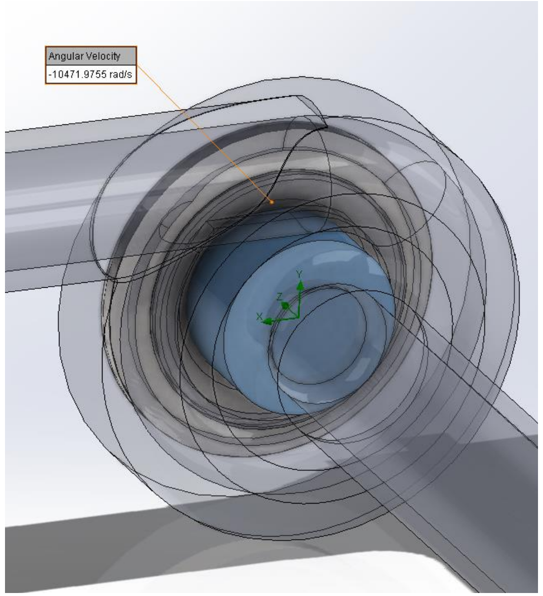

Fig. 7 Rotation of the pump impeller

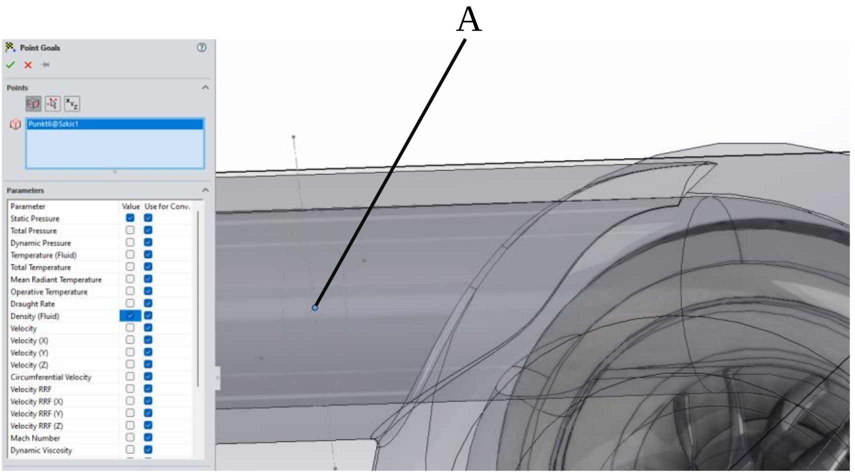

Fig. 8 Result parameters

ASSESSMENT OF THE CONVERGENCE OF MESH

An important step before starting the analysis was to test the convergence of the mesh. The test consisted of globally compacting the grid in the area under consideration and observing the changes in the result values. The parameters calculated were the mass flow at the outlet (*G*) and the pressure value before the turbocharger (*p*).

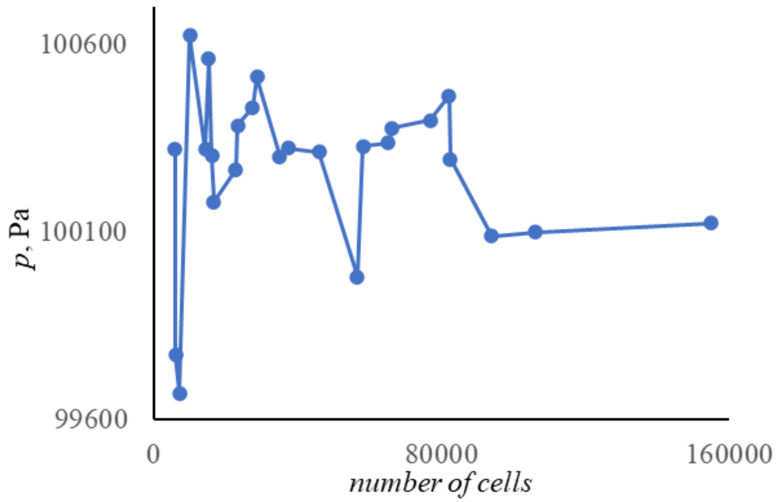

Fig. 9 Dependence of number of cells on inlet pressure value

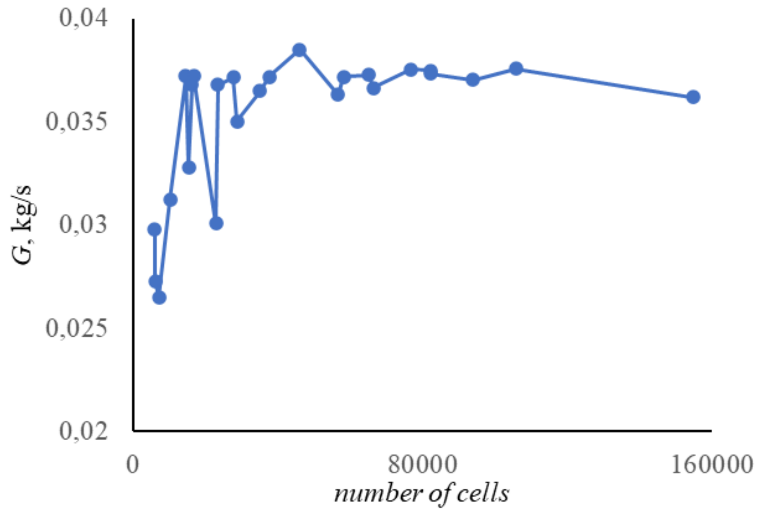

Fig. 10 Dependence of number of cells on outlet mass flow rate

ADOPTED MESH

Based on the mesh convergence study, a mesh of 105899 cells was adopted, i.e. with a main setting of 5 and a minimum gap size of 2 mm.

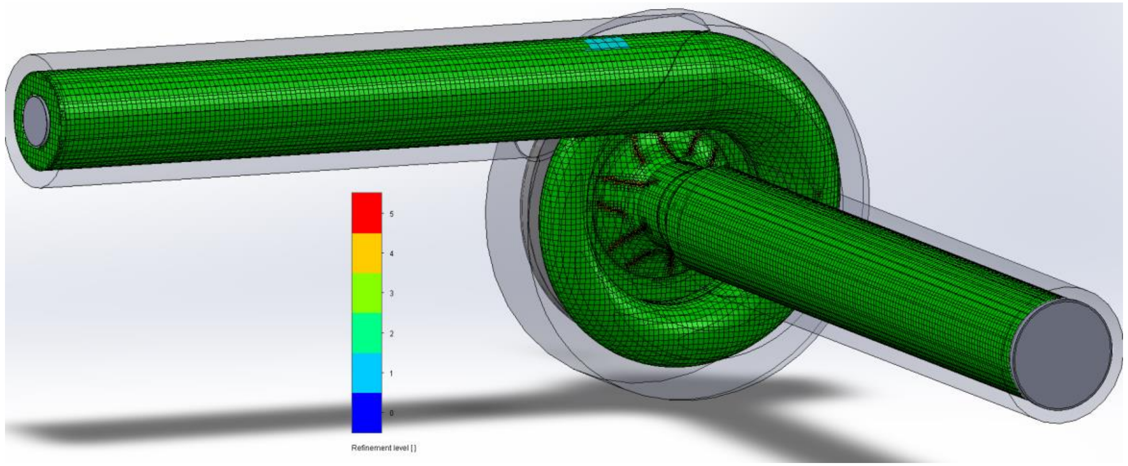

Fig. 11 General view of mesh of the model

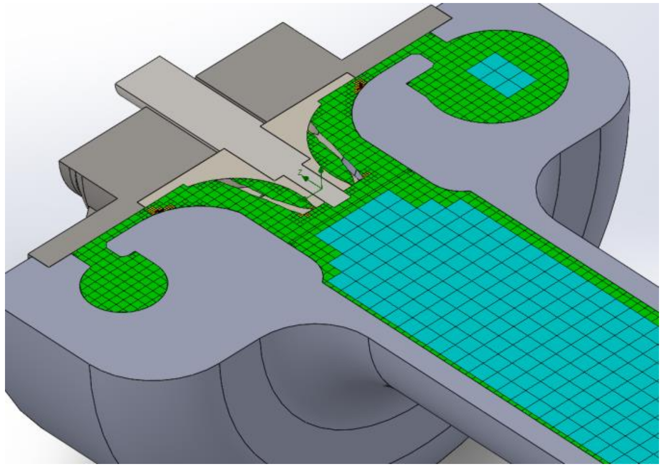

Fig. 12 View of mesh at cross-section through the impeller axis

RESULTS

As part of the analyses, the following turbocharger pump parameters were calculated: mass flow (G), density (ρ) and pressure (p) at the outlet as described earlier. The calculations were carried out for different pump rotor speeds of: 40.000; 60.000; 80.000; 100.000; 120.000 and 140.000 min^{-1}. Nature of the airflow trajectories through the turbocharger pump showed no significant differences.

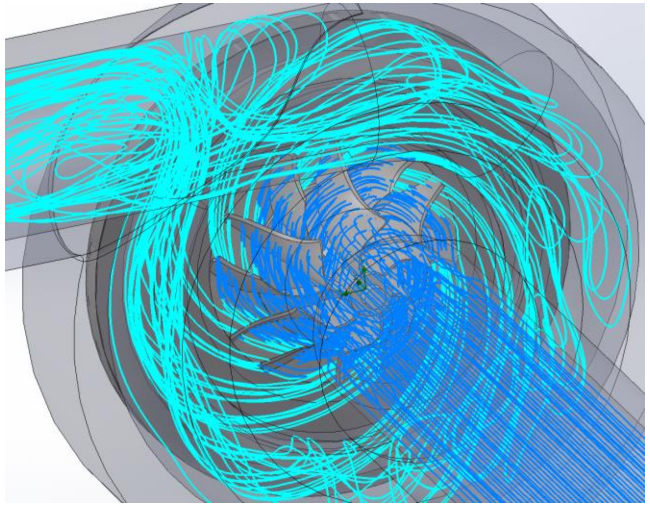

Fig. 13 Airflow trajectories through the compressor at 40.000 min^{-1}

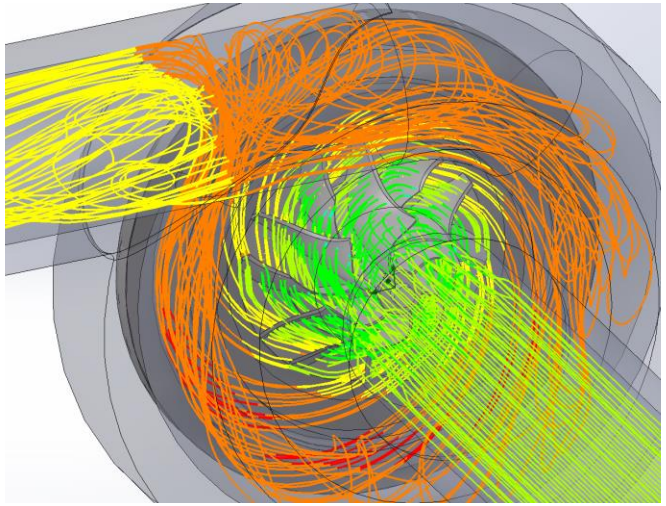

Fig. 14 Airflow trajectories through the compressor at 100.000 min^{-1}

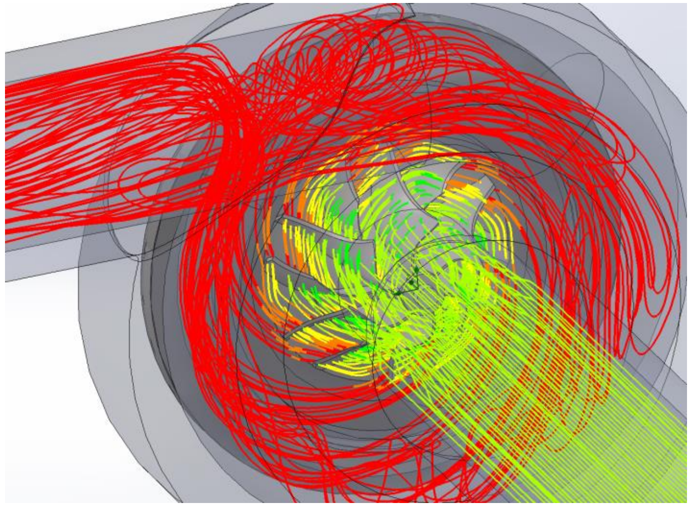

Fig. 15 Airflow trajectories through the compressor at 140.000 min^{-1}

Each time the results were approximated by a trend line in the form of a 2nd-degree polynomial, obtaining high values of the determination coefficient.

Increasing the turbocharger rotor speed resulted in higher values of its characteristic parameters, such as boost pressure, density and mass flow rate. The air mass flow rate increases almost linearly, while density and pressure increase in a way that can be described by a quadratic function. This indicates that the rotational speed of the turbocharger rotor has a significant effect on the turbocharger parameters. Thus, the aim of the study was achieved.

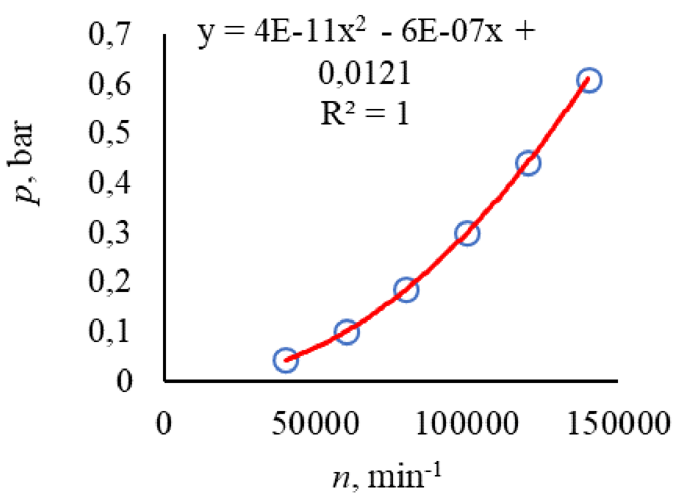

Fig. 16 Boost pressure dependency on impeller rotation speed

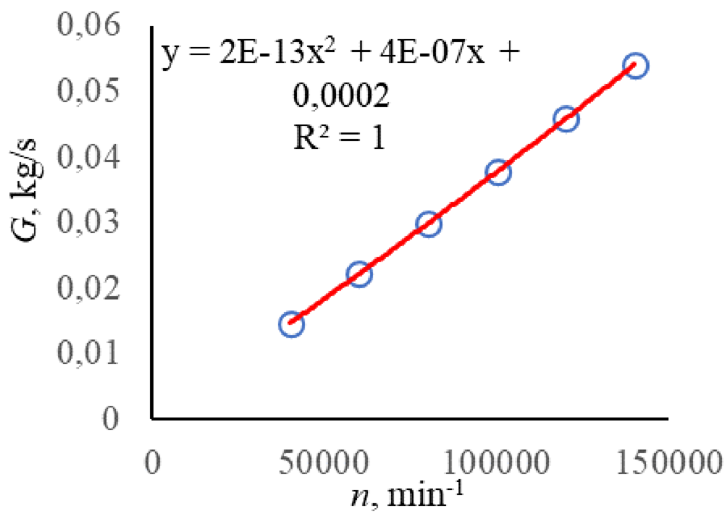

Fig. 17 Mass flow rate dependency on impeller rotation speed

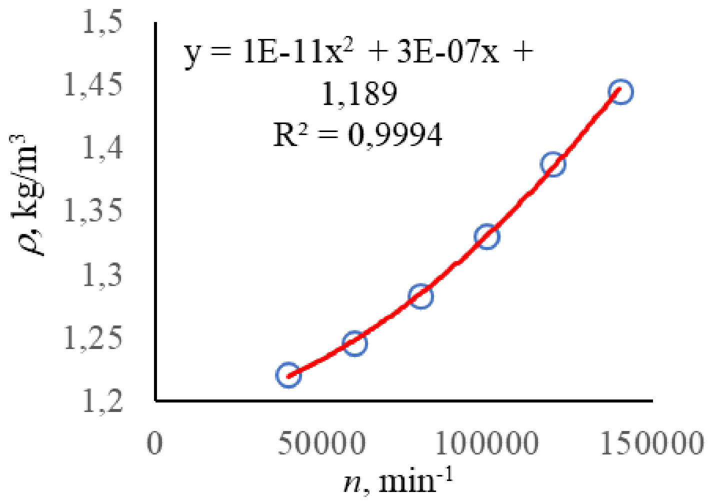

Fig. 18 Density dependency on impeller rotation speed

5. *CONCLUSIONS*

Based on the calculations and analyses carried out in the study, the following conclusions were drawn:

1. Numerical fluid mechanics (CFD) was successfully used to determine the characteristic parameters of a turbocharger as a function of pump rotor speed.
2. SolidWorks Flow Simulation software was used for the simulation, where a simplified model of an IHI VB10 turbocharger was used as a base.
3. The analyses determined the effect of rotational speed on boost pressure, mass flow rate and density, and the results were approximated by a trend line in the form of a 2nd-degree polynomial obtaining high values for the coefficient of determination.
4. The mass output increased almost linearly with increasing speed, and the pressure and density increased in a way that could be described by a quadratic function.
5. The result will be applicable to the turbocharger configuration for the selected engine type.

6. *Further research*

The calculation and inference proposed in this paper are applicable to the determination of turbocharger characteristics. Ultimately, the effect of the number and shape of the turbocharger's pump blades on its functional parameters will be determined in further analyses. The results obtained in this way will be helpful in assessing the feasibility of modifying the turbocharger for applications in various internal combustion engines, while leaving its external dimensions and mountings unchanged.

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Thanks for your attention