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# A METHOD OF ROTARY ENGINE PERFORMANCE PREDICTION

**Summary**. The rotary engine mainly developed for the automotive industry by the NSU corporation is currently used in unmanned aircraft, transportable generators and small watercraft. In the early stage of the engine development, the simulation of the performance characteristics is advisable. The 3D CFD engine simulation is highly expensive in terms of CPU time demand and requires a high level of optimisation to provide adequate data. This method can be used later in the development and fine engine tuning. For the design of the prototype 1D, simulation is being used as a tool to compare various designs of the engine. While the current commercially available software (GT-suite, Ricardo Wave, etc.) is being improved marginally, the functionality of the software is being tested on the piston reciprocating engines. This paper explores the possibility of the algorithms of such a software to be used on the rotary engine thermodynamic simulation and provides an approach to design a simulation model that can be solved by the software to predict the performance characteristics of the engine prototype.

**Keywords:** internal combustion engine, rotary engine, 1D simulation

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## 1. INTRODUCTION

The commercially available performance prediction software (GT-power, Ricardo Wave, etc.) for combustion engines currently does not include support for rotary engines. The main reason is the significantly lower market demand for these engines. For the time-efficient prediction of the performance parameters during the early stage of the development of the rotary power unit, it is advisable to use a one – dimensional software. Unfortunately, the direct use of the available software for the piston engines is not possible because of the following differences between the two engine designs [3, 16-18, 21, 23, 24, 26]:

- the ratio of the main shaft rotation to the 4-stroke cycles of the rotary engine is equal to 3. Single-cylinder 4-stroke piston engine crankshaft rotates twice for the same quantity of cycles,
- the difference of the surface to displacement ratio during the main-shaft rotation,
- the difference in the heat-transfer proprieties coming from the differences in the geometric shape of the combustion chamber,
- the length of the combustion chamber increases the time of the combustion process, which reduces the overall efficiency of the combustion,
- the movement of the working chamber across the whole loop of the main housing influences the difference in the temperature distribution of the engine. The speed of this process also influences the speed of the flame propagation through the working chamber as the leading apex seal of the rotor is constantly moving forward from the flame front.

The main objective of this paper is the creation of the virtual piston engine (VPE) with modified parameters that correspond to the designed rotary engine. The VPE will then be used as a model for the 1-D solver to provide the required data for the development process.

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## 2. COMPUTATIONAL MODEL

The initial condition in the simulation model setup must be the equity of the volume of the operating chambers in relation to the crankshaft rotation.

As the input, the piston position of the virtual piston engine (VPE) in relation to the crankshaft angle α is used in the algorithm, the equation used for the virtual piston position [14]:

$$x = \frac{e^2\left[\pi+\left(\frac{\pi}{3}-\frac{\sqrt{3}}{4}\right)\lambda^2-\frac{3\sqrt{3}}{2}\lambda\cos\left[\frac{2}{3}\left(\alpha-\frac{\pi}{2}\right)\right]\right]h_p-S_4h_p+V_p}{B} \tag{1}$$

where $e$ is the eccentricity of the rotary mechanism, $\lambda$ is the trochoid constant, $\alpha$ is the relative angle of the rotor, $S_4$ is the area between the outer shell of the trochoid and the line between 2 apexes of the rotor, $h_p$ is the rotor width and $V_p$ is the rotor hollow volume.

The bore of the VPE is taken as the diameter of the circle with equal area to the area of the rotor exposed to the working chamber. The head area of the cylinder of the piston reciprocating engine remains constant during the engine operation, however, in the rotary engine from its principle the area changes with the main shaft rotation. This difference is not accounted for in the algorithms for the 1D simulation solver. The virtual area of the head equivalent surfaces is therefore calculated as the weighted average with the heat flux to the head area as the weight of the calculation. The rotary engine of the Wankel type works with four-stroke cycle and each rotor and housing pair creates 3 working chambers. For these reasons, using the four-stroke template with 3 cylinders configuration is advisable. To maintain the equity of the volumetric flow through the VPE and the rotary engine, the ratio of the main shaft rotation to the rotation of the crankshaft of the VPE is 3/2. The cylinders are interconnected with the piping of the negotiable length simulating the overflow of the exhaust and the intake during the port openings to the adjacent chambers. Both intake and exhaust port openings were simulated with a kinematic simulation to determine the active areas of the ports in relation to the main shaft rotation. The calibration of the flow coefficient of the ports was done using the CFD approach (Fig. 2), then further calibrated in the GT-Power software via volumetric flow measured on the test engine.

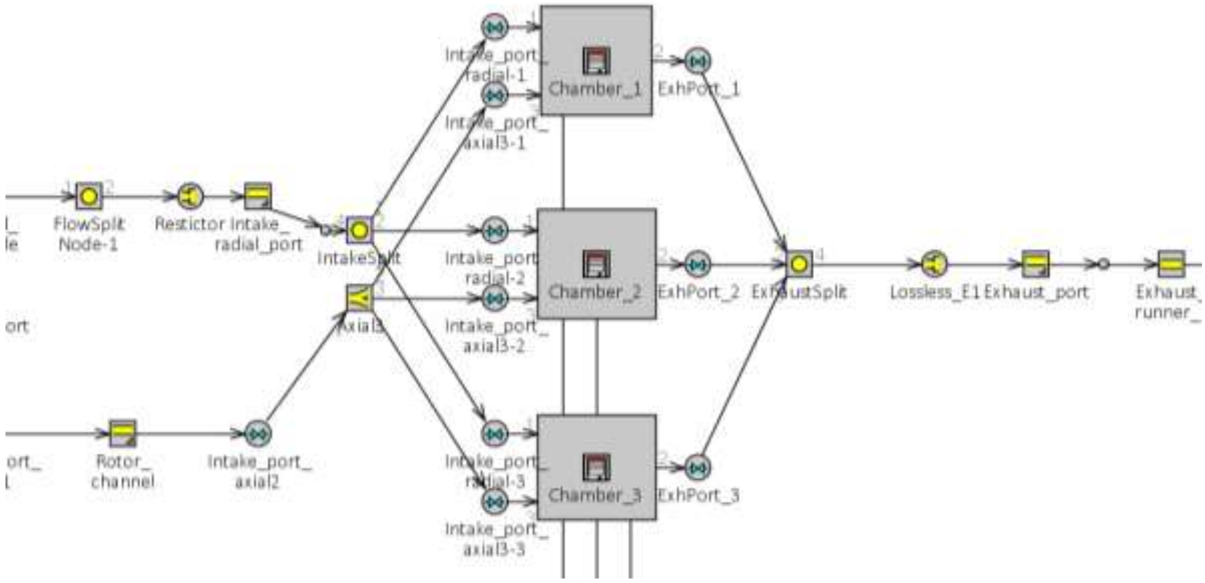


Fig. 1. Base structure of the mathematical model

## 3. SIMULATION RESULTS

For the first iteration of the port flow coefficients calculation, the 3D CFD method was used [13]. As the experimental method of using the blow through mass-flow measuring station cannot be executed in the early stages of the development due to the lack of the physical engine model, using the commercial computational software is the only option to determine these parameters. The discharge coefficients of the intake and exhaust system were computed at the major points of the system. Intake and exhaust port opening and closing discharge coefficients were approximated by the linear function as this approach reduces the time needed for the 3D CFD method and can be used without large error as presented in the [2]. Due to the complexity of the axial intake system on the simulated engine, two simulations were carried out [4, 5]. The results of the simulations were then used to calibrate the 1D model of the virtual piston engine.

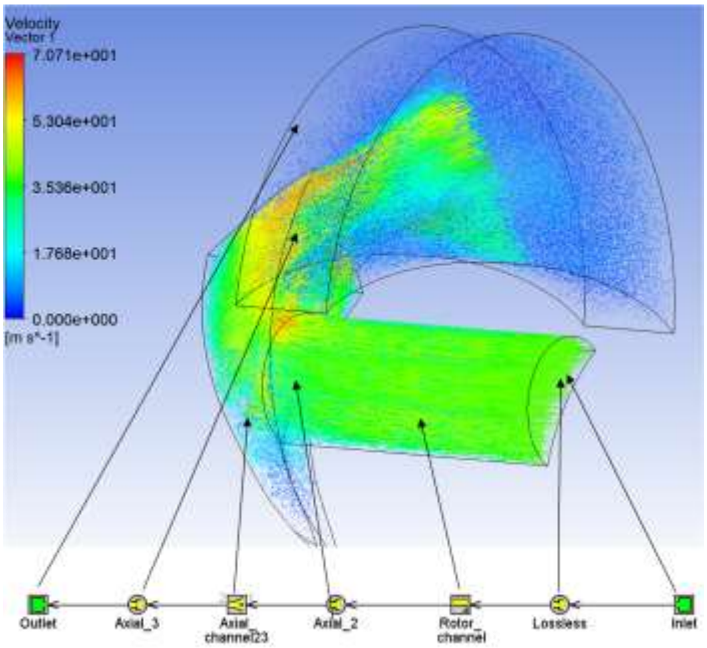


Fig. 2. Axial intake port 3D calibration

Using the previous input data calibrations from the known engine, the simulation was run to evaluate the concept of the virtual piston engine creation. For the engine performance, the average difference of the simulated and measured values was 3.08% (Fig. 3). Torque and power are the overall engine characteristics, which determine the quality of the method used in the simulation, however, for the previously mentioned discharge coefficient calibration validation of the 1D model, engine air mass flow is used.

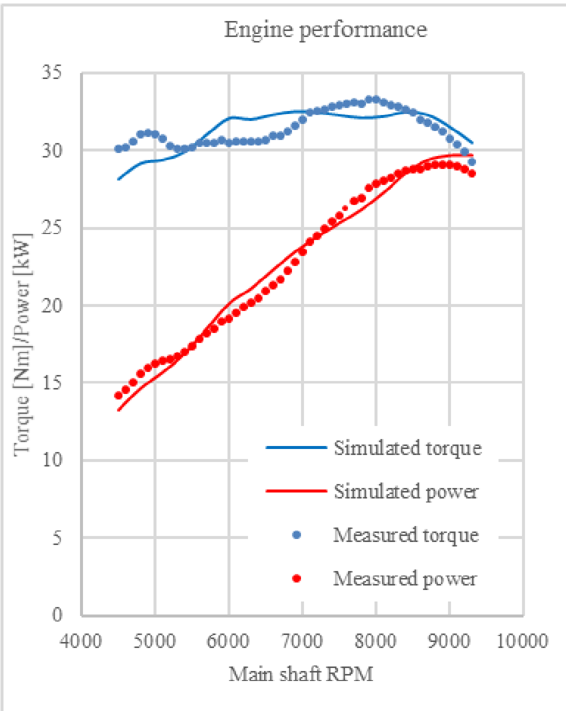


Fig. 3. Engine prediction correlation with measured data

## 4. CONCLUSION

As the commercially available software for thermodynamic simulation of the rotary engine is not available due to the comparably low market demand to the reciprocating-piston engine type, the available software input can be modified to provide accurate simulation results. The method of creating the virtual piston engine is shown using the calculated bore, stroke and piston position data to provide the equivalent surface area and volume of the working chamber. The calculation method using the 3D CFD software was applied for the complicated axial intake of the engine. Using the outcome of the 3D simulation, the 1D simulation model was calibrated to provide the comparable mass air flow results. The heat transfer coefficients were calculated using the forced convection over the flat plane analogy. These results are then used as weight for the average calculation of the head surface area, which remains constant in the reciprocating-piston engine but changes with the angle of the main shaft in the rotary engine. For future work, testing is required to measure the in-cylinder pressure data and temperature and pressure data from the engine intake and exhaust system as these are to be used for the model calibration. Additionally, further development of the rotary engine needs to solve NVH problems using the methods described in [10, 11, 19, 20, 22] and further modify using prototyping methods [8, 9], the control units for its specific applications. Using this advanced simulation and experimental methods, the new rotary engine unit parameters can be designed, optimised and performance predicted. Modern production technologies [1, 6, 7, 12, 15, 25] will be used to produce optimised rotary engine components.

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