FLOW SIMULATION THROUGH WANKEL ENGINE THROTTLE USING COMPUTATIONAL FLUID DYNAMICS

Mirosław Wendeker, Łukasz Grabowski
Konrad Pietrykowski, Paweł Magryta

Lublin University of Technology
Nadbystrzycka St. 36/605A, 20-618 Lublin, Poland
tel.: +48 81 5384764, fax: +48 81 5384749
email: p.magryta@pollub.pl

Abstract

The paper focuses on the airflow through the throttle in the Wankel engine (Aixro XR50). The author's main challenge was to adapt a Wankel engine for hydrogen injection system, which required a very new full electronic throttle to be installed. Thus, an injector adapter and flow meter were mounted in this engine. The engine will be used as a stationary power unit to generate electricity for small households. Using hydrogen instead of hydrocarbon fuel will reduce the emission of green house gases. The simulation was in the AVL Fire using Computational Fluid Dynamic for 9 different throttle opening angles, i.e. ranging from 20° to 90°, i.e. 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°. The boundary conditions being as the pressure at the inlet and outlet of the throttle module correspond to the real values in the engine. The data on the properties of the flowing medium (air) were selected by default from the AVL Fire library. The authors use the k-zeta-ef model of turbulence to simulate flow through a Wankel engine throttle. The simulation results include the distributions of pressure, velocity and stream lines. The dependence of the mass flow rate as a function of the throttle position angle was presented. The turbulence disappears when the throttle opening angle of 60° is crossed. For full throttle the velocity at the pipe walls decreases to about 12 m/s. The highest velocity throughout the model occurs just where the throttle is mounted.

Keywords: *flow simulation, CFD, a Wankel engine, a throttle*

1. Introduction

The simulation tests of the airflow through the throttle of a Wankel engine will be to assess the state of the dynamic phenomena in the throttle module and to determine the relationship of a mass flow rate as a function of a throttle opening angle. These simulations are prior to the actual modification of a Wankel engine to be hydrogen powered. The engine inlet system whose part is the throttle module will be also equipped with an injector adapter. The measurements of the electronic throttle module and the geometry of the injector adapter were used to build the research model.

2. Wankel engine throttle geometric model

The geometric model for the throttle module is made in Catia v5. The geometry of the model includes a throttle module throat, a throttle and an injector adapter (Fig. 1).

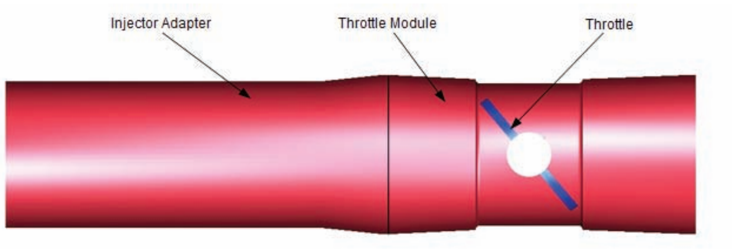

Fig. 1. Throttle module made in Catia v5

3. Boundary conditions and course of throttle airflow

The throttle airflow simulation was performed for nine different cases having a varied throttle opening angle. Table 1 shows some cases that fall into the range of 20 - 90º and correspond to the proportional range of 15.66 - 100%.

Tab. 1. The angles and proportional throttle opening

Model	-	1	2	3	4	5	6	7	8	9
Angle	[º]	20.00	30.00	40.00	50.00	60.00	70.00	75.00	80.00	90.00
Proportional opening	[%]	15.66	27.71	39.76	51.81	63.86	75.90	81.93	87.95	100.00

Due to the complex geometry, the number of elements in a mesh varies according to a throttle position. The adopted computing mesh has 150 – 75.000 elements (Table 2). To demonstrate varying computational conditions with respect to different cases, the elements have a fixed maximum size of 2.5 mm. The mesh mainly consists of tetrahedral elements. Figure 2 shows the mesh for one of the nine cases.

Tab. 2. The number of elements

Model	1	2	3	4	5	6	7	8	9
Elements	150574	106068	76640	91150	79642	80371	78641	79916	75441

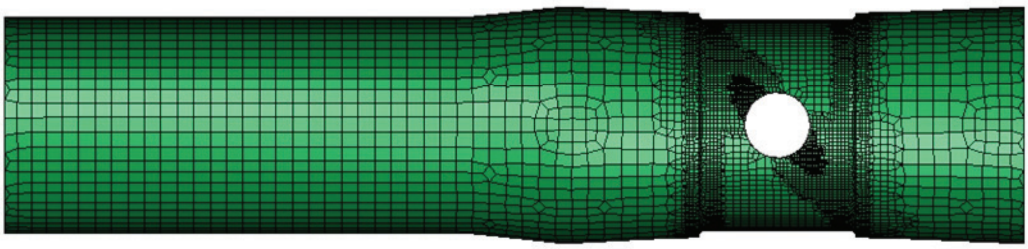

Fig. 2. Mesh view

The same boundary conditions and assumptions about the model have been adopted for all of the cases:

- adiabatic walls (no heat exchange with the medium)
- compressible flow,
- k-zeta-f turbulence model,
- the air in the model is of the following properties:

• density under NTP conditions	1.18415	kg/m^3,
• dynamic viscosity	1.81 e-05	kg/ms,
• specific heat	100362	J/kg K,
• thermal conductivity	0.02637	W/m K,
• molecular weight	28.96	kg/kmol.

The simulation was carried out using the option *steady*, which means that the temperature and airflow did not change during the simulation. To map the actual conditions precisely, the following boundary conditions have been adopted:

- pressure at the model inlet	100	kPa,
- inlet-outlet pressure	99.7	kPa.

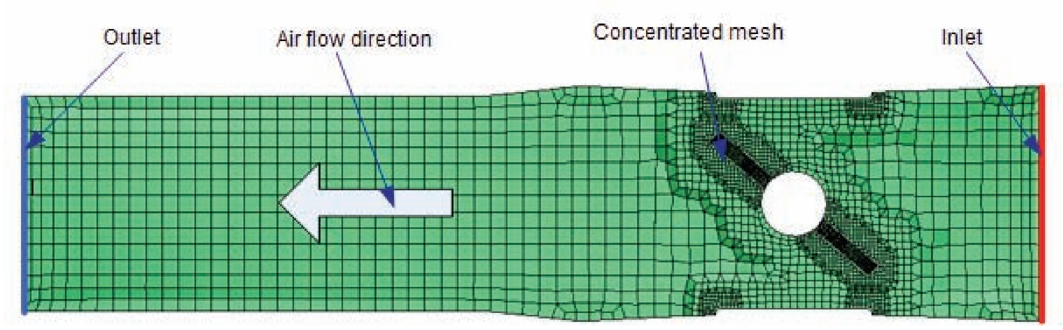

Fig. 3. Mesh cross-sectional view with the boundary conditions marked

All of the calculations for each model were carried out not later than the mass flow rate in the inlet settled. Due to the different positions of the throttle, the number of iterations in the various cases ranged from 600 to 4000. Figure 4 shows the course of the mass flow rate as a function of the number of iterations (refers to the 50° throttle opening).

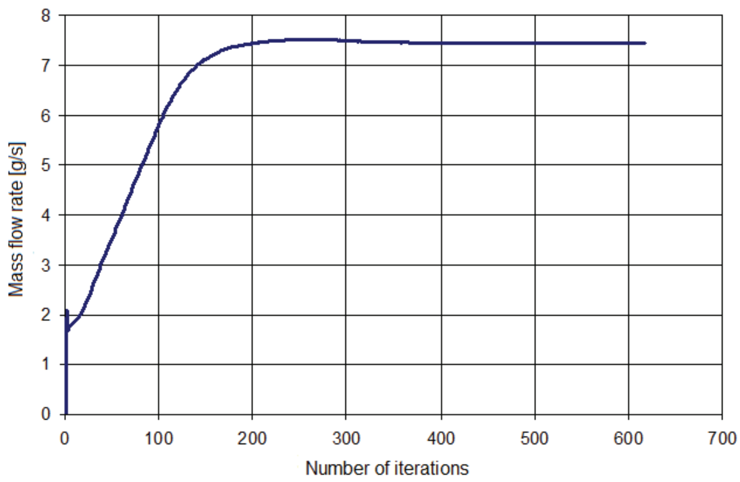

Fig. 4. The inlet system mass flow rate

3. Flow simulation results

The airflow simulation has provided the distributions of pressure, velocity and stream lines in the model geometry. Figures 5, 6, 7, 8, 9 present the pressure distribution in the longitudinal section for the five successive throttle positions, i.e. 20º, 40º, 60º, 80º and 90º. As noted, the significant pressure levelling at the outlet and inlet is noted not before a certain value of a throttle opening angle is crossed. This relationship is best noticed for Figures 6 and 7 that show the opening angles of 20º and 40º. As you can see, for the opening angle of 20° the pressure at the throttle module inlet is higher than for the opening of 40°. For full throttle, i.e. 90º the pressure at the inlet throttle module remains constant up to the outlet as soon as it goes through the throttle.

Fig. 5. Pressure distribution in the throttle cross- section for the angle of 20º

Fig. 6. Pressure distribution in the throttle cross- section for the angle of 40º

Fig. 7. Pressure distribution in the throttle cross-section for the angle of 60º

Fig. 8. Pressure distribution in the throttle cross-section for the angle of 80º

Fig. 9. Pressure distribution in the throttle cross- section for the angle of 90º

Figures 10, 11, 12, 13, 14 present the velocity distribution for a longitudinal section for several successive throttle positions. As for the pressure distribution, the same throttle opening angles, i.e. 20º, 40º, 60º, 80º and 90º were analyzed. The maximum velocity value in the throttle module is 36 m/s, which is given in Figure 14. It should be noted that a small change in a cross section where the throttle is mounted limits the higher velocity airflow area. Smaller throttle opening angles cause the uneven distribution of velocity areas, which is connected with some turbulence in the model.

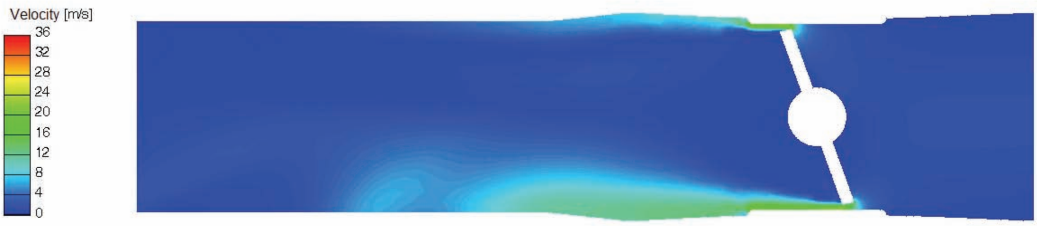

Fig. 10. Velocity distribution in the throttle cross-section for the angle of 20º

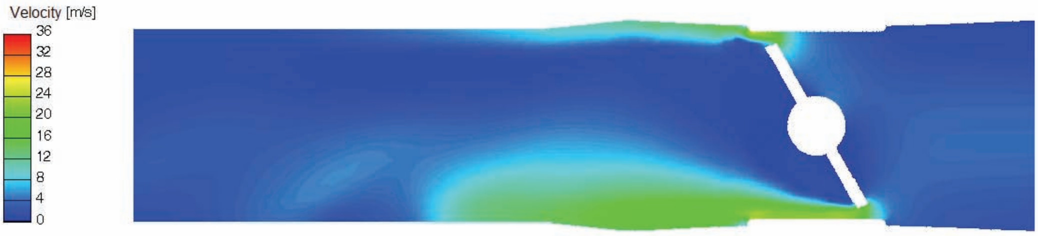

Fig. 11. Velocity distribution in the throttle cross-section for the angle of 40º

Fig. 12. Velocity distribution in the throttle cross-section for the angle of 60º

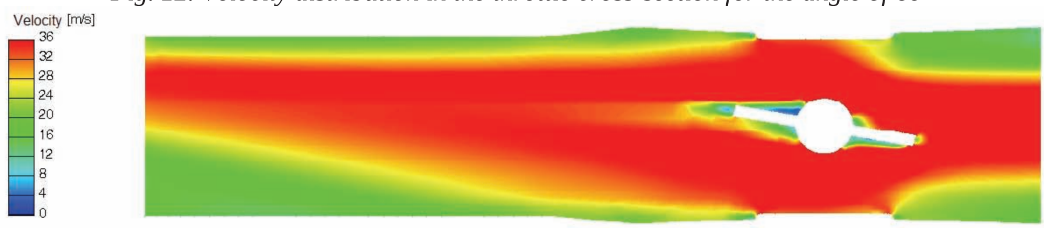

Fig. 13. Velocity distribution in the throttle cross-section for the angle of 80°

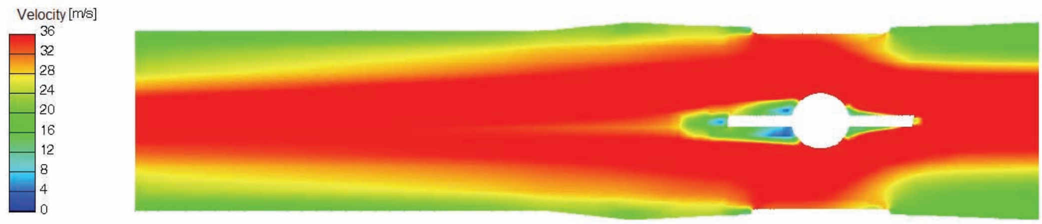

Fig. 14. Velocity distribution in the throttle cross-section for the angle of 90º

Figures 15 and 16 present the distribution of stream lines for a longitudinal section for the two throttle positions, i.e. 50º and 60º. The authors have chosen these throttle angles on purpose because the airflow stabilizes just at the change from 50º to 60º. The turbulence (see Figure 15) occurs for smaller throttle opening angles. This phenomenon is useful since the fuel-air mixture can be pre-mixed before it reaches the cylinder. However, if a throttle is much loaded and maximally opened, a lot of mixture needs to be supplied where turbulence is not so necessary and exist no longer.

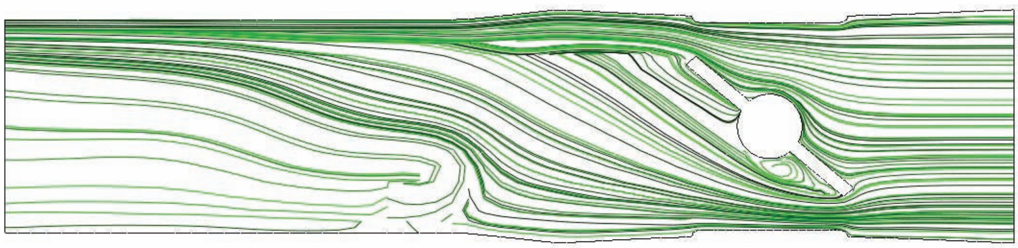

Fig. 15. Stream line distribution in the throttle cross-section for the angle 50 º

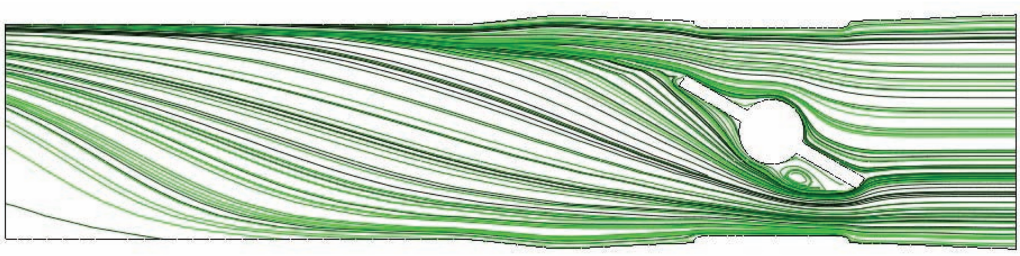

Fig. 16. Stream line distribution in the throttle cross-section for the angle 60 °

Based on the calculations, the relationship between the inlet pipe mass flow rate and the throttle opening angle was determined (Fig. 17). At a given pressure difference between the inlet and outlet, the maximum value of 24.66 g/s was obtained.

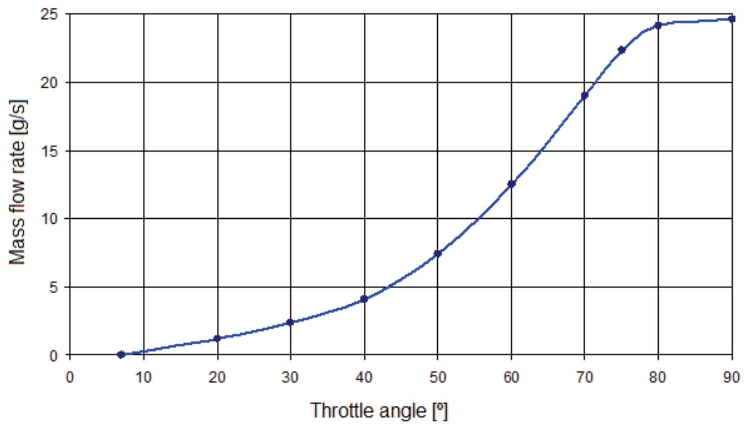

Fig. 17. Dependence of the mass flow rate on the angle of the throttle position

4. Conclusion

Based on the simulations, the maximum airflow velocity was 36 m/s. Based on the generated stream lines, it was found that the turbulence disappears when the throttle opening angle of 60° is crossed. Another conclusion is that for full throttle the velocity at the pipe walls decreases to about 12 m/s. The highest velocity throughout the model occurs just where the throttle is mounted.

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