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Optimized Design of Motors Gas Intake System in FSAE Racers

Xiaolong Cheng, Bo Wu*, Zhi Li, Bangzhen Huang, Leilei Hao

Harbin University of Science and Technology, School of Mechanical & Power Engineering, Harbin, China
ChengXiaoLong658@163.com

ABSTRACT. In order to enhance the performance of engine on FSAE racing, we analyze the gas intake system and optimize it. First, we study the relation among intake manifold, stabilizing cavity and volumetric efficiency by using GT-Power. Then, based on the results. We obtain the length of intake manifold and the volume of volumetric efficiency. Then, we build the 3D model of Gas Intake System by using UG. Finally, we use ANSYS to analyze the unevenness of gas intake to further optimize the gas intake system.

KEYWORDS: *FSAE, air intake system, optimized design*

1. Introduction

The formula car race of Chinese college students is called FSAE, a car design and manufacturing competition participated by groups of automotive engineering majors or students specializing in automobile-related majors of institutions of higher learning. All teams participating in the race will design and manufacture small formula racers independently within a year according to the rules and standards of the race. The main component affecting the performance of racers is the engine. The main role of the gas intake system of engines is to provide enough fresh air according to the different work conditions of engines to be mixed with the fuels gushed into the intake manifold for the combustion of engines. Wonderfully designed gas intake systems can maintain high gas intake efficiency under more working conditions and within wider scope of revolving speed of engines.[1]

The car team of our university will select Honda CBR 600 engine for the racer, and design the gas intake system according to the rules of the competition.

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2. Confirmation of gas intake system plans

2.1. Basic structure of gas intake system

A gas intake system, as the supply system of motors, generally includes the following parts: air filter, air damper, flow-limiting valve, intake manifold, pressure stabilizing cavity and intake manifold.

2.2. Confirmation of gas intake forms

By the way of gas intake, the gas intake system can be divided into two categories, respectively natural gas intake and pressurized gas intake. The latter way to pressurize and induce gas is not only complicated in structure, but also would keep the engine working under high load for a long time, exposing the spare parts to damage more easily, besides, the pressurized turbine will become sluggish with low revolving speed, making it difficult to control. The structure of natural gas intake is simple. Although the existence of metering valve would reduce the volume of gas intake, the efficiency of inflation can be improved through changing the length of gas feeders. In the end, natural gas intake is confirmed as the way of gas intake by combining the characteristics of our university.

2.3. Confirmation of the form of intake manifold

The layout forms of intake manifolds mainly include symmetric and offset types. The former type is beneficial for the balance of gas intake in all cylinders, capable of improving the dynamic property and stability of engines at high revolving speed. As to the latter type, as the gas flows into the engine from the side of pressure stabilizing cavity with dramatically curved path of gas current, while such a structure of pressure stabilizing cavity adds to the unevenness of gas intake, and the work condition of various cylinders differs after all, severely affecting the life service of the engine and the performance of gas intake.[2]

Above all, this paper selects symmetric layout form of intake manifolds as follows:

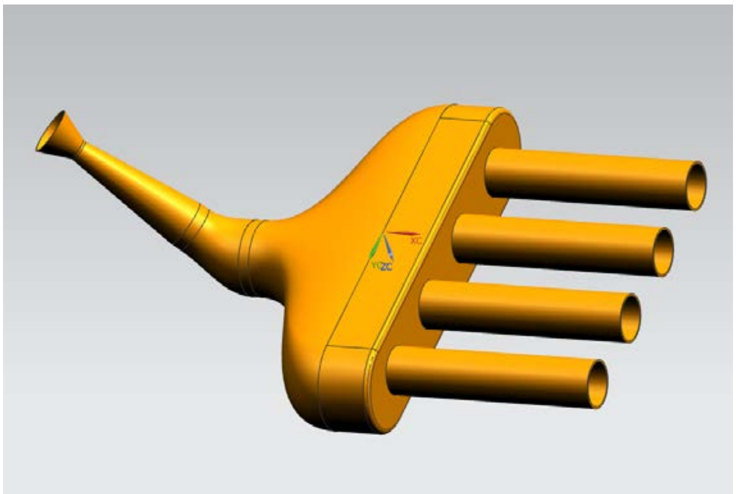

Figure. 1 The Layout Form of Gas Intake System

3. Basic parameters of all parts of gas intake system

For gasoline engines, the amount of gas intake determines the performance of engines directly.[3] There is resonance effect in the gas inflow tubes of gasoline engines, and either the dynamic effect can be made use of reasonably is key to the improvement of the charging efficiency, while the main factors influencing dynamic effect are the length of the intake manifold and the volume of pressure stabilizing cavity.

3.1. The length of common intake manifold

According to Rule 1.6.1, in order to limit the power of the engine, a flow-limiting valve with round-shaped internal section must be installed between air intake system, gas damper and engine, and the gas intake flow of all engines shall pass through this flow-limiting valve.[4] Therefore, the structure of the header pipe is Venturi, and the length of the header is fixed at 150mm according to the requirements of the race.

3.2. Intake manifold

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The Intake Manifold should fit together with the gas damper on the engine. The caliber of gas dampers on CBR600 engines is 45mm. Therefore, the preliminary size is fixed to be 45mm, and the preliminary length of the Intake Manifold is fixed at 200mm according to the design data of various institutions of higher education.

3.3. Volume of pressure stabilizing cavity

Volume is a factor in the design of pressure stabilizing cavity, directly influencing the sensitivity of the accelerator pedal. When the volume is too small, the engine will be too sensitive to operate.[1] When the volume is too large, the accelerator will be too slow in reaction. For CBR 600 engines with a displacement of 599ml, the volume of its pressure stabilizing cavity is fixed at 3L preliminarily.

4. Simulation of gas intake system

4.1. Establishment of the model

The model established with GT-power mainly includes gas intake system, gas cylinder, crank case and exhaust system. All components have corresponding simulation modules. The logical relationship between them is connected with line segments and a complete engine model is established as follows:

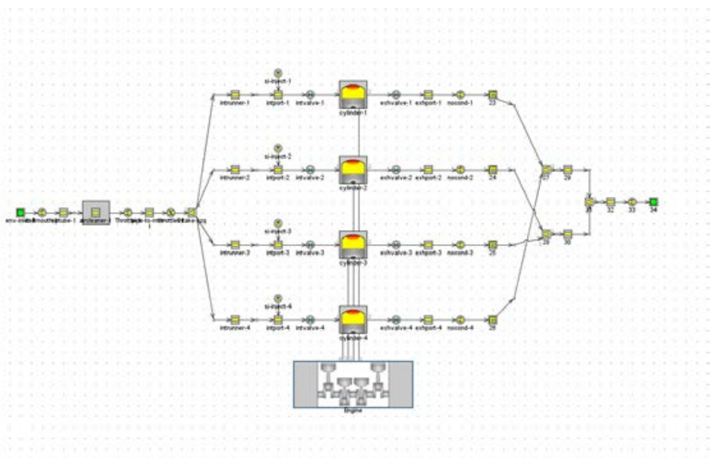

Figure. 2 Simulation Model of the Working Process of CBR600 Engine

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4.2. Research and analysis on the length of intake manifold

The length of Intake Manifold has great influence on charging efficiency. In the process of optimizing gas intake system, the length of Intake Manifold is set as the goal of optimization. Increase the length of Intake Manifold by 10% and 20%, or reduce it by 10% and 20% to get the curve showing the change of inflation efficiency, torque and power with the revolving speed of engines through simulation in the following diagram.

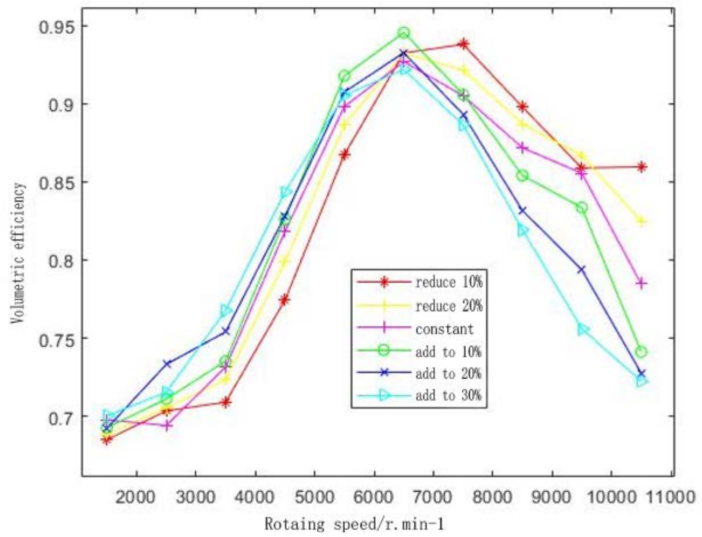

Figure. 3 The Influence of the Length of Intake Manifold on the Charging Efficiency

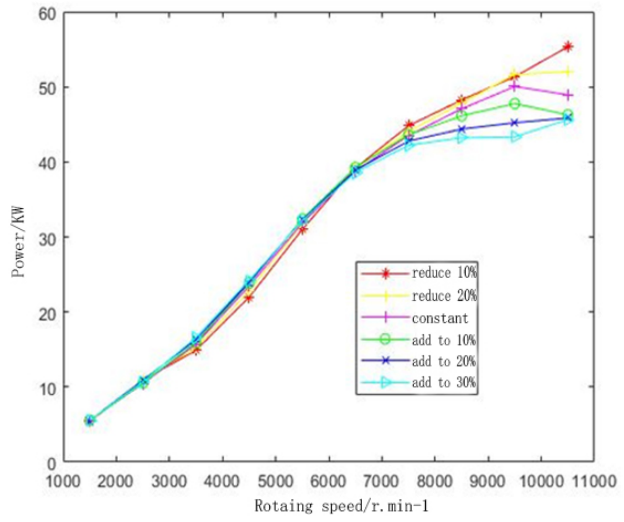

Figure. 4 The Influence of Changes in the Length of Intake Manifold on Power

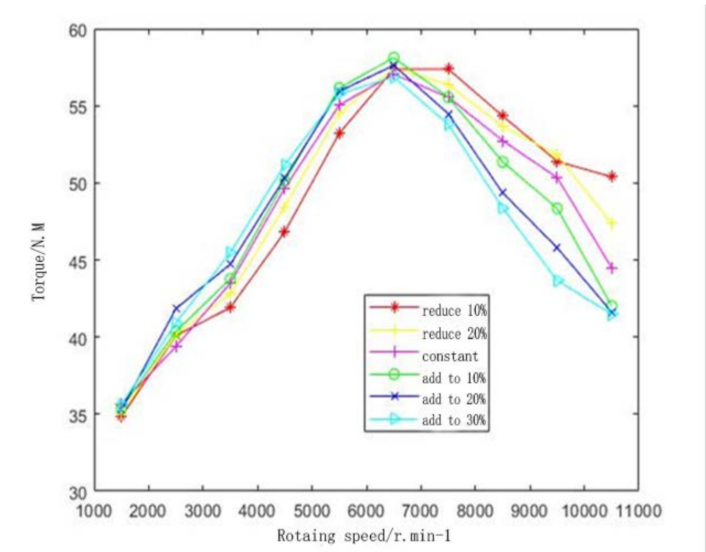

Figure. 5 The Influence of Changes in the Length of Intake Manifold on Torque

Within the range of low revolving speed, 1500r/min-6500r/min, the charging

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efficiency and torque of engines will both reduce with shortened Intake Manifold, and the range of descending will increase with the widened range of shortened Intake Manifold. When the Intake Manifold increases, both the charging efficiency and torque will go up and then go down with the length of Intake Manifold. When the length is increased by 20%, there is a peak value. The length of Intake Manifold has small influence on the power of engines within this range of revolving speed.

Within the medium-high revolving speed range between 6,500r/min and 11,000r/min, when the length of Intake Manifold is reduced, the charging efficiency, power and torque of the engine will all increase, and the rising range will increase with the shortening of Intake Manifold. When the Intake Manifold is lengthened, the charging efficiency, owner and torque decrease and the descending range will increase with the lengthening range of gas intake divided manifold.

Above all, the length of Intake Manifold has great influence on the revolving speed of engines at medium-high range, and small influence on engines within low revolving speed range. According to the above-mentioned analysis, the length of Intake Manifold is increased by 20% in the end.

4.3. Research and Analysis on the Volume of Pressure Stabilizing Cavity

The volume of pressure stabilizing cavity is closely related to the sensitivity of accelerator pedals. When the volume is too small, the pedals will be too sensitive. If the volume is too large, the pedals will be slow in reaction. Therefore, generally speaking, the volume would be set around 3L [1]. This paper chooses to study the volume of 2.5L, 3L, 3.5L, 4L, 4.5L and 5L so as to conclude the curve of changes of inflation efficiency, torque and power with the revolving speed of motors of different volumes.

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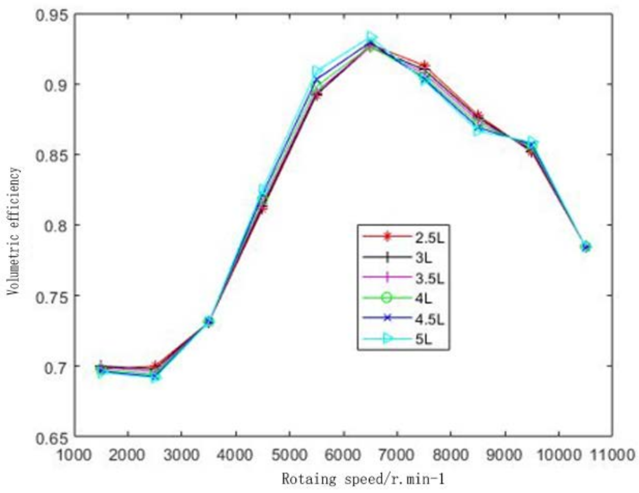

Figure. 6 Influence of Changes in the Volume of Pressure Stabilizing Cavity on Charging Efficiency

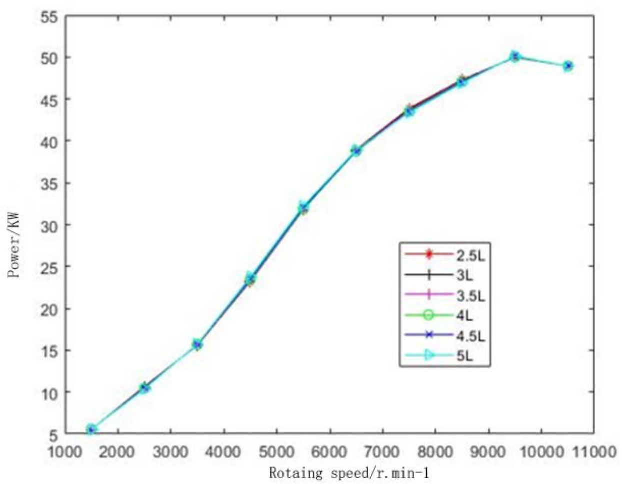

Figure. 7 6 Influence of Changes in the Volume of Pressure Stabilizing Cavity on Power

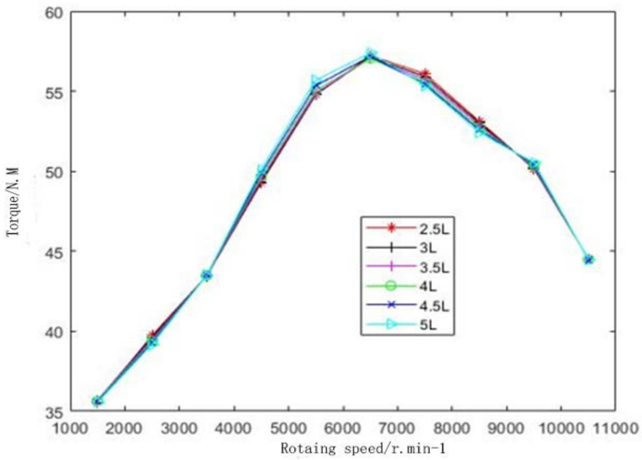

Figure. 8 Influence of Volume of Pressure Stabilizing Cavity on Torque

As for charging efficiency, it will increase with the reduction of the volume of pressure stabilizing cavity either with low or high revolving speed. The charging efficiency would increase with the volume of pressure stabilizing cavity within the scope of medium revolving speed. From Fig.7 it can been seen that the influence of changes in the volume of pressure stabilizing cavity on the power of engines is small. As to torque, at medium revolving speed, the torque would increase with the volume of pressure stabilizing cavity. By combining the analysis results and items in

5. Analysis on the characteristics of gas intake flow field

5.1. Establishment of 3D model and gird division of gas intake system

In order to better simulate the fluid dynamics of gas intake system when FSAE racers are working and further optimize the gas intake system, 3D modeling software UG is made use of to set up a simplified 3D model of gas intake system according to previous simulation results. The model includes gas feeder, flow-limiting valve, pressure stabilizing cavity and intake manifold. The model of gas intake system is introduced to MECH module of FLUENT software for meshing. Non-structural meshing is adopted for the meshes of gas intake system.

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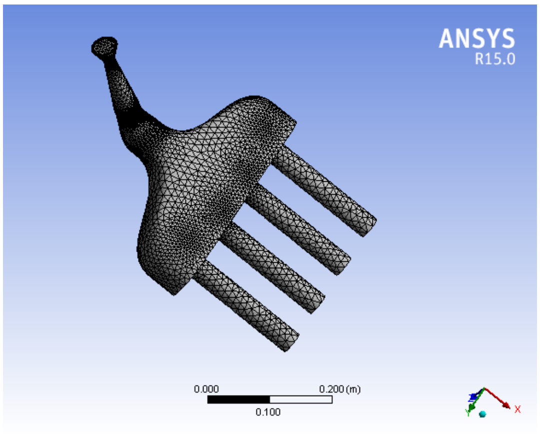

Figure. 9 Girds of Gas Intake System

As the fluidity analyzed is air, and the compressibility of gas is much larger than that of liquid, it can be treated as compressible fluid, and the motion form of fluid is turbulent flow, so the standard k-epsilon model is adopted. The boundary conditions are set as follows:

- Inlet boundary: Boundary conditions for mass flow rate inlet are adopted. As the engine takes in gas naturally, and the air temperature at the entrance is set at room temperature, the inlet temperature is set as 300K, the inlet boundary is 0.0862kg/s, involving no process of heat transfer, therefore, only its flowing performance will be simulated.
- Outlet Boundary: Boundary conditions of outlet pressure are adopted. Set the outlet pressure as one bar pressure, or 101325 Pa, and set the temperature at the outlet as 300K
- Wall Boundary: Non-slipping conditions are adopted, and the temperature is set as 300K.

5.2. Unevenness analysis

When there is air intake in FSAE engine, the velocity contour at the cross-section of gas intake system is visible, and the gas intake in all cylinders is quite uneven.

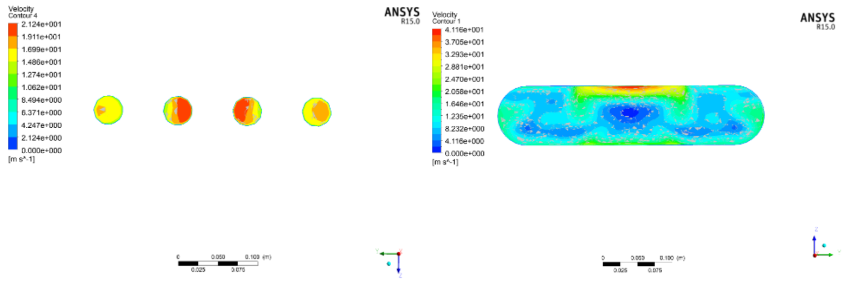

Figure. 10 Velocity Contours

The streamline of the whole gas intake system is as shown in Fig.11, from which one can see many eddies, causing great flow losses.

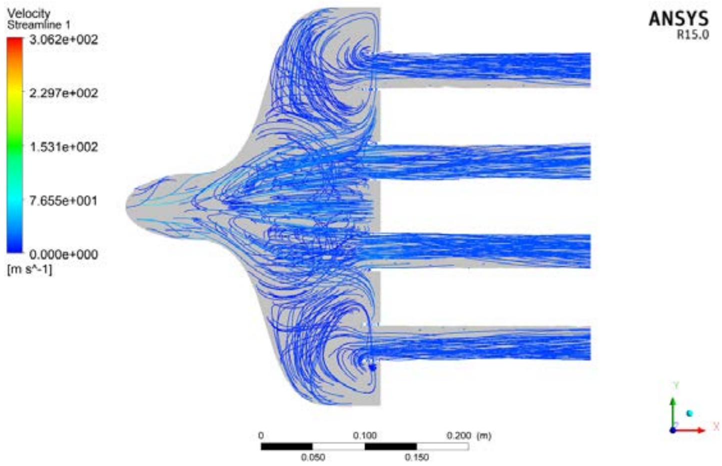

Figure. 11 streamlines of Gas Intake System

The generated analysis report on boundary flow rate is shown in the following graph.

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Mass Flow Rate	(kg/s)
inlet	0.086200006
outlet1	-0.019803828
outlet2	-0.022822035
outlet3	-0.02281172
outlet4	-0.02075918
Net	3.2428652e-06

Figure. 12 Graph of Boundary Flow Rate Report

From the graph of boundary flow rate report, it can be concluded that the mass flow rate of the inlet is 0.086200006kg/s, and the mass flow rate of four outlets of Intake Manifold (Outlet 1,2,3 and 4) is respectively -0.019803828kg/s, -0.022822035kg/s, -0.02281172kg/s and -0.02075918kg/s. FLUENT tacitly approves of setting the numerical value when the fluidity flows in from outside as positive and the numerical value when the fluidity flows outside from inside as negative. The unevenness of engines, E, is shown in the following formula.[2]

$$E=\frac{\phi_{\max}-\phi_{\min}}{\phi_{me}} \tag{1}$$

$\phi_{\max}$ represents the maximum value of the mass flow rate of Intake Manifold;

$\phi_{\min}$ represents the minimum value of the mass flow rate of Intake Manifold;

ϕ_{me} represents the average mass flow rate.

According to Formula (1), the unevenness of gas intake system can be calculated as 0.139642154.

5.3. Optimization of intake manifold

The unevenness of gas cylinder is closely related to the structural parameters of

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wind pipes. On the basis of the original model, this paper designs wind cups with four heights for flow field analysis.

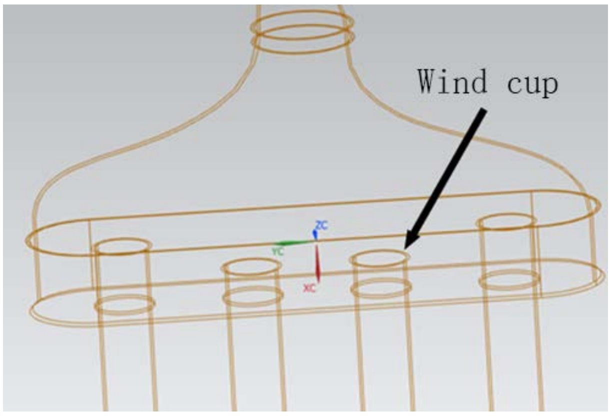
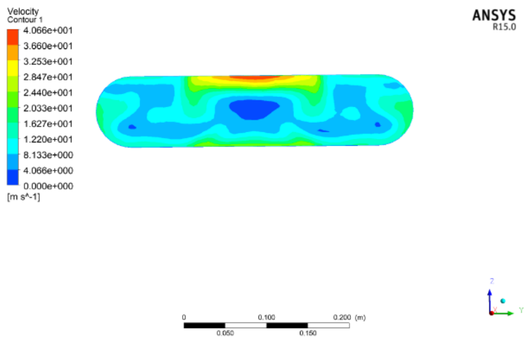


Figure. 13 3D Diagram of Wind Cups

The velocity contours corresponding to various wind cups are shown below. It can be seen that when the wind cups of the first and fourth cylinders are 40mm tall, and the second and third cylinders are 20mm tall, the gas intake of all cylinders is comparatively even.



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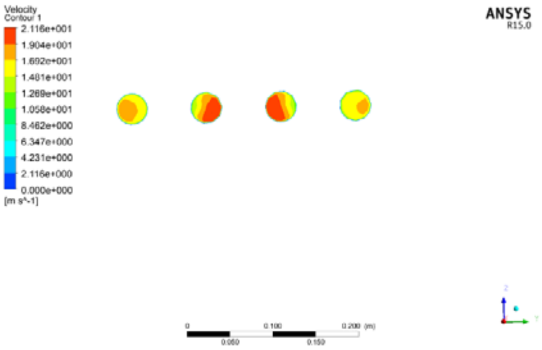
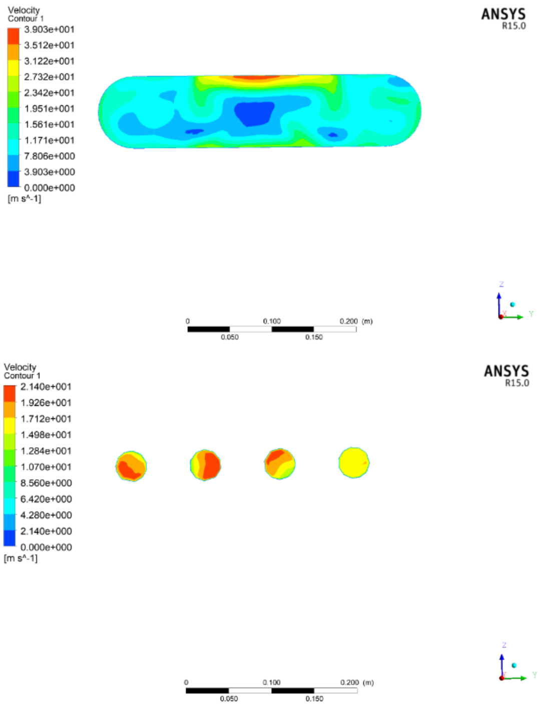


a) The wind cups of the forest, second, third and fourth cylinders are 20mm tall



b) The height of wind cups in the first and fourth cylinders is 30mm, and the height of wind cups in the second and third cylinders is 20mm

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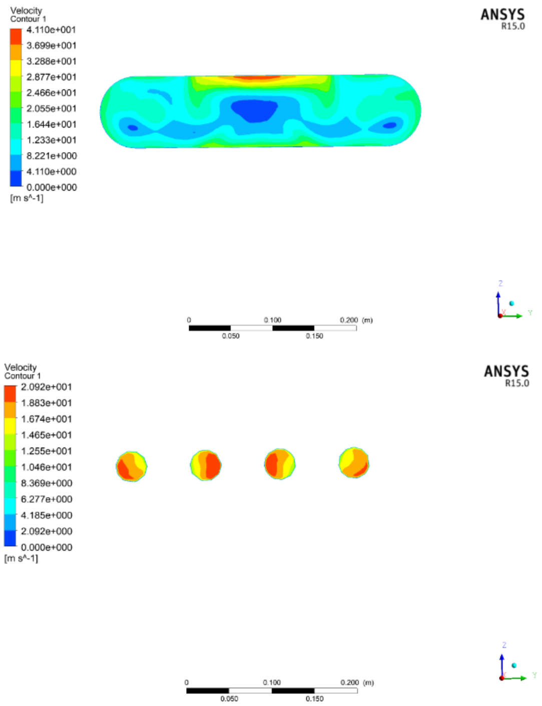
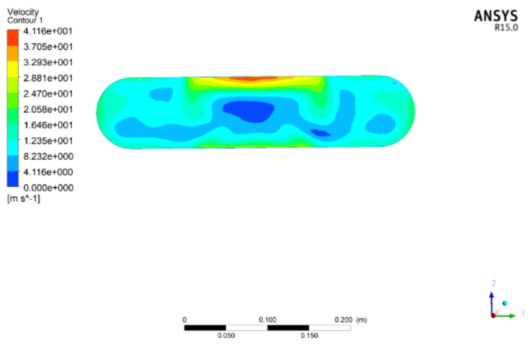
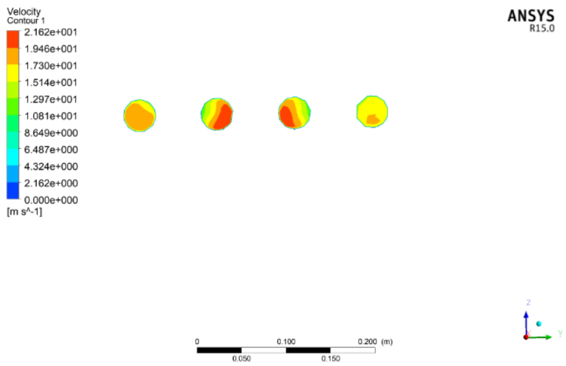


c) The height of wind cups in the first and fourth cylinders is 40 mm, and the height of wind cups in the second and third cylinders is 20mm

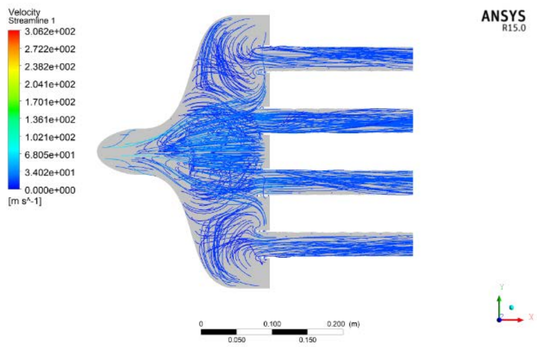




d) The height of wind cups in the first and fourth cylinders is 30mm, and the height of wind cups in the second and third cylinders is 15 mm

Figure. 14 Velocity Contours

From the streamline of the gas intake system, it can be seen that when the height of the first and fourth wind cups is 40mm, and the height of the second and third wind cups is 20mm, there will be the fewest eddies in the pressure stabilizing cavity and the smallest flow losses.



a) The height of the first, second, third and fourth wind cups is 20mm

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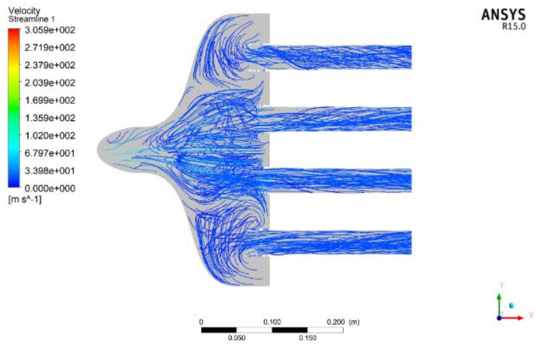
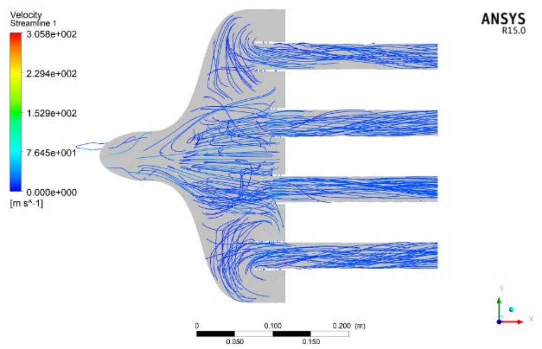


b) The height of the first nans fourth wind cups is 30mm, and the height of the second and third wind cups is 20mm



c) The height of the first and fourth wind cups is 40mm, and the height of the second and third wind cups is 20mm

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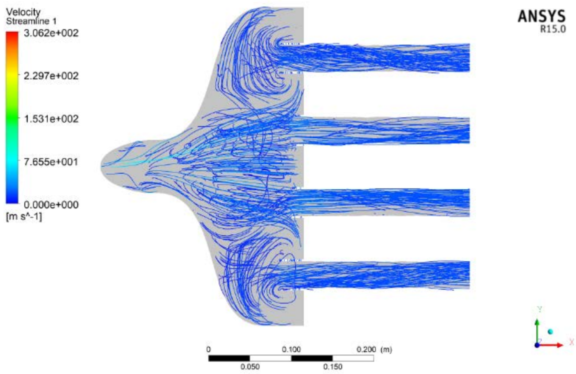

d) The height of the first and fourth wind cups is 30mm and the height of the second and third wind cups is 15mm

Figure. 15 Streamlines of Gas Intake System

In the end, the unevenness of various wind cups concluded from Formula (1) is shown below.

Table 1 Unevenness Corresponding to Wind Cups

Height of Wind Cups in the First and Fourth Cylinders	Height of Wind Cups in the Second and Third Wind Cups (mm)	The total flow of gas intake (kg/s)	Unevenness (%)
20	20	0.0862	13.9
30	20	0.0862	18.6
40	20	0.0862	6.98
30	15	0.0862	12.5

From Table 1 it can be seen that when the height of wind cups in the first and fourth cylinders is 40mm, and that in the second and third cylinders is 20mm, the minimum unevenness of gas intake in all cylinders is 6.98%. Above all, the design of wind cups in Intake Manifold is that the wind cups in the first and fourth cylinders are 40mm tall, and those in the second and third cylinders is 20mm tall.

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6. Conclusion

First of all, this paper makes use of GT-Power, an engine-simulation software, to set up an engine model, analyze the influence of changes in the overall length of main pipes in the air intake system and volume of pressure-stabilizing cavity on the inflation efficiency of engines, and optimize their parameters. In the end, ANSYS, a fluid simulation software is utilized to optimize the unevenness of all cylinders during gas intake and reduce the flowing losses.

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