Structural Design and CFD Analysis of Engine Plastic Intake Manifold

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Abstract. The quality of the intake manifold has a direct impact on the performance of the engine. Based on the characteristics of the cavity structure of the intake manifold, this paper designs a new three-dimensional cavity model of the intake manifolds. Then the author analyzes the flow field of intake manifold, the flow velocity and pressure distribution and local pressure loss in the airway by using CFD fluid analysis software. The results show that the flow field inside the intake manifold is stable without obvious pressure loss area and no airflow wall separation phenomenon. Hence the resulting design could meet initial design requirements with improvement of power and economy of the engine.

1. Introduction
The ever-expanding scale of the car and the improvement of the performance requirements have led to the development of lightweight components. The lightweight of the automobile is one of the directions of the automobile industry. The feature of easy modeling of the plastic makes it more and more used for manufacturing engine intake manifold and other complex components[1]. The design of the plastic intake manifold is a vital part of the development process of the plastic intake manifold. The design of the structure has a crucial influence on the engine power, fuel consumption, torque and other related parameters[2-4]. Combined with the actual production and business requirements, this paper needs to develop a new type of plastic intake manifold, so as to achieve the vehicle's lightweight requirements and to meet the current national energy-saving emission reduction targets. It needs a comprehensive balance between the downstream assembly production and related factors in the design process. At the same time, we need analyze mechanics of the intake manifold, improve the irrational structure of the intake manifold design to improve the work reliability of the tube.

2. Structural design of plastic intake manifold

2.1 Selection of basic structural parameters for intake manifold
In the condition of other parameters no changed and the basic length parameters the host factory given, the paper determines that the optimization parameters are the intake manifold length and regulator chamber volume by experience value and reference value. The increment of the intake manifold is no more than 300mm. The initial parameters required for the design of the intake manifold are the equivalent axis length of 400 mm for the intake manifold and Ø40 mm near the flange side. The flange diameter is Ø57mm and needs to be the same as the given throttle flange diameter; the diameter of the regulator chamber side is Ø58mm; the volume of the regulator chamber is 1.3L. The engine intake
manifold cavity structure will be designed based on the above structural parameters.

2.2 Structural design of intake manifold

The air intake design of the intake manifold should take into account the inertial fluctuation effect and energy loss of the intake manifold to increase the filling efficiency. Its installation space in the engine and the vehicle, the modelling process of the plastic parts and friction welding process should all be considered at the same time. In our design process, the length of the manifold is given by the factory, the axis can be adjusted appropriately in the design, but the length of the axis should be avoided as much as possible. The structural design scheme of the intake manifolds is as follows.

As shown in Figure 1, we added two guide ribs to the intake manifold cavity. Adding appropriate guide ribs can make the flow of each branch uniform, and the flow field has good fluidity. After the design scheme is determined, we design the structure of the intake manifold. Figure 2 is a panoramic view and figure 3 is an exploded view of the designed intake manifold.

In the process of airway design, we must pay attention to the designed airway to meet the technological requirements of plastic parts, and ensure that the implementation of the segmentation scheme is conducive to the subsequent design and production of the mold. In addition, it is necessary
to consider the determination of the welding direction when doing the slicing. Generally, the welding direction is consistent with the product demolding direction.

3. CFD analysis of the intake Manifold

Combined with the characteristics of the complex structure of the intake manifold and closely related to the performance of the engine, we have produced four different design schemes through the three-dimensional parametric design in the early stage of the design. The CFD analysis of the scheme 4 is carried out to verify that it is the best solution, so as to help improve the overall performance of the engine[5-6].

3.1 Pro-surf import geometry data

Firstly, the paper imports IGES-formatted CAD files into Pro-surf. As the point and line of CAD model exists errors, it is not necessarily suitable for the generation of the grid. The original CAD model performs surface geometry cleaning by using pro-surf automatic repair function. In the pro-surf the wrong line can be automatically patched. Based on the model after repair, the surface mesh is divided. Because the tetrahedral mesh calculates faster and is better than the other grid, we choose the tetrahedral mesh. The grid map after meshing is shown in Figure 4.

![Figure 4. The grid map after meshing](image)

After the grid is divided, we need to set the boundary conditions, the physical properties, the calculation content and the control parameters in the calculation before the calculation.

1. Import pressure boundary conditions

Boundary conditions take the pressure boundary: the inlet total pressure is 1 atmosphere, and the outlet static pressure is 0.75 atmospheres.

The pressure conditions at the inlet boundary require the estimation of $k$ and $\varepsilon$. The distribution of $k$ and $\varepsilon$ can be estimated from the turbulence intensity $T_i$ and the characteristic length $L$.

$$ k = \frac{3}{2} \left( \overline{u_{ref}} T_i \right)^2 $$

$$ \varepsilon = C_{\mu} \frac{k^{3/2}}{l} $$

$$ l = 0.77L $$

$\overline{u_{ref}}$ is the average speed at the inlet, the characteristic length $L$ can be calculated according to the equivalent diameter.

2. Import flow boundary conditions

The entry is defined as the specified flow, and each manifold outlet defines the specified pressure.

3. Turbulence model

Use the high Reynolds number standard $k-\varepsilon$ model [7].

4. Wall boundary conditions

Wall temperature uses adiabatic boundary conditions, the wall speed uses no slip boundary conditions. In the wall area, in order to avoid the use of fine computing grid in the near wall to reduce
the calculation time, the wall function method is used to relate the physical quantity on the wall to the corresponding physical quantity in the core region of the turbulence.

4. CFD analysis results

The post-processing is carried out after the calculation completed. In the post-processing stage, we can determine the deviation of the air intake performance of the intake manifold by analyzing the velocity field and pressure field and the result of the pressure loss and the uniformity of the cylinder in the same working condition. This can be used to determine the effective cross section of the manifold and the intake balance of each tube [8]. The velocity field distribution of each tube is shown in Figure 5.

![Velocity field distribution of manifold](image)

**Figure 5.** Velocity field distribution of manifold

From the velocity field profile, it can be seen that there is no air separation in the inner wall of the intake manifold, and the flow field is relatively stable. The pressure field distribution of each tube is shown in Figure 6.

![Pressure field distribution](image)

(a) pressure field of the first pipe
(b) pressure field of the second pipe

**Figure 6.** Pressure field distribution of manifold
From the pressure distribution map, it can be seen that there is no significant pressure loss area within the manifold. From the inlet to the outlet, the pressure value gradually decreases, and the pressure in the stabilizing chamber does not change much and is evenly distributed.

From the analysis above, we can see that the equilibrium of the gas has been greatly improved after the addition of two diversion ribs. According to the itself state of the intake manifold and the distribution of the flow field and the pressure field in the CFD analysis result, the increase of the appropriate diversion ribs for the intake manifold can make the flow of the branch pipes uniform. The flow field is good and the air flow is smooth. No large vortex is formed, so that the airflow noise is also small, the effective flow of fluid flow changes better, the tube gas balance is better. These can achieve the required performance of the engine. In addition, CFD analysis provides clear internal flow and pressure field information that can provide a reliable theoretical basis for designers to design intake manifolds [9-10].

5. Summary
The article mainly designs the structure of the plastic intake manifold. In order to improve the gas flow in the intake manifold, the structure design increases diversion ribs in the regulator chamber, which can greatly improve the flow balance of the airway. The design of three-dimensional cavity structure of the intake manifold is reasonable. In order to meet the plastic molding process and vibration friction welding process requirements, the intake manifold assembly adopts a four-slice welding type. Compared to a three-piece, four-piece structure, the single-piece mold is relatively simple, and the processing is relatively easy, which has certain cost advantages. From the velocity field diagram, it can be seen that there is no airflow separation phenomenon in the inner wall of the intake manifold, and the flow field is relatively stable. From the pressure distribution diagram, it can be seen that there is no obvious pressure loss area inside the manifold. The flow resistance and air flow coefficient of the manifold after modification are better than those of the original model. But CFD simulations can’t completely replace the actual test measurements. To ensure the rationality and results of the design, the final determination of the plastic intake manifold must be verified by the gas flow test, the engine assembly test, and the engine bench test. We will determine the final model structure of the intake manifold verify according to the external characteristics of the engine.

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