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Analysis of Air Pump Flow Field Based on Fluent

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Abstract **– The research object of this paper is the cylinder of the air pump. Firstly, the working principle of the air pump is analyzed, and then the cylinder model is established, and the model is divided into grids. By setting a reasonable turbulence model and solving method, the cylinder pressure changes of a stroke are obtained. The simulation results can provide theoretical guidance for the reasonable design of air pump parameters and improving the structure, so as to improve the operation efficiency of air pump.**

Keywords **– Air Pump, Flow Field Analysis, Dynamic Grid, Fluent.**

I. Introduction

Suspension is a device connecting body and wheel, the main function is to realize the transfer of force between body and wheel [1]. Suspension can be divided into passive suspension, semi-active suspension, active suspension [2-3]. With the improvement of people's requirements for vehicle riding comfort, the development of automobile suspension is inclined to active suspension [4]. As a kind of active suspension, the air suspension can control the air spring filling according to the change of the external environment, so as to realize the adaptive adjustment of the height of the body [5-6].

The air pump is the supply device of the air path system of the air suspension. Its main function is to compress the air, and the compressed air is stored in the high pressure gas storage tank through the drying tank. The cylinder is the main component of air pump to produce high pressure gas, and its internal flow field characteristics have a key influence on the performance of air pump. Zuyao Xu et al. established a mathematical model of the high-pressure cylinder of a natural gas compressor, and used Ansys software to analyze the temperature and thermal stress changes of the cylinder [7]. Dong Zhu et al. used a two-dimensional model to analyze the cylinder flow field in the air compressor and studied the pressure variation in the cylinder [8]. Fanzong Zeng et al. established a physical model and a dynamic grid model for the cylinder of a four-stroke engine, and obtained the dynamic changes of the temperature field and pressure field in the cylinder [9].

Based on the above research, in this paper, the three-dimensional model of the cylinder is established, and the Fluent software is used to conduct transient simulation analysis of the gas flow process of the air pump cylinder, and the change of the flow field of the cylinder in one stroke during the operation of the air pump is obtained.

II. The Working Principle of Air Pump

Air pump mainly includes brush DC motor, piston, cylinder, drying pipe. The working principle is that after the motor is energized, the rotation of the motor shaft drives the piston for reciprocating motion to realize the compression of gas. The high-pressure gas is filtered through the drying tank and input into the high-pressure gas storage tank. The working principle of the air pump is shown in Figure 2.1.

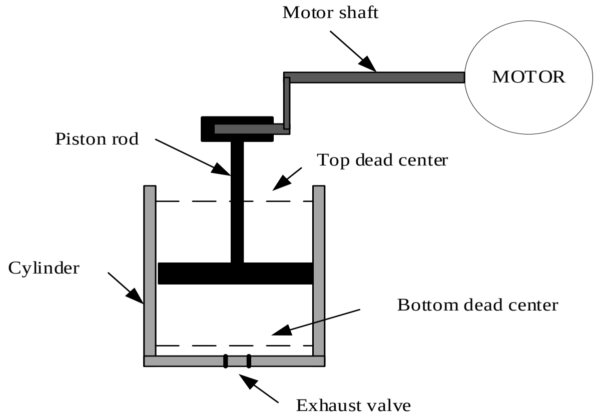

Fig. 2.1. Working principle diagram of air pump.

The reciprocating motion of the piston in the cylinder can be divided into four processes: compression process, exhaust process, expansion process and intake process. The inlet and exhaust port is closed, the piston moves from top dead center to bottom dead center, and the gas in the cylinder is compressed; When the pressure of compressed gas in the cylinder is greater than the gas pressure in the gas storage tank, the exhaust valve opens, the high pressure gas from the cylinder to the gas storage tank, the piston moves to the bottom dead center, the exhaust process ends; The piston moves from bottom dead center to top dead center, the exhaust valve closes, and the remaining high-pressure gas in the cylinder expands; When the gas pressure in the cylinder is less than atmospheric pressure, the intake valve is opened, the air enters the cylinder, the piston moves to the top dead center, the intake valve is closed, and the intake process is over.

III. Numerical Simulation Method

3.1. *Fluent Software Overview*

Fluent is a simulation software widely used at present, which can realize the simulation and analysis of two-dimensional and three-dimensional models [10]. It has a variety of mesh division methods and a variety of built-in solution methods, which can achieve the best solution accuracy. In addition, Fluent has dynamic grid technology, which can realize the flow simulation of compressible gas. The solution steps of Fluent software are shown in Figure 3.1.

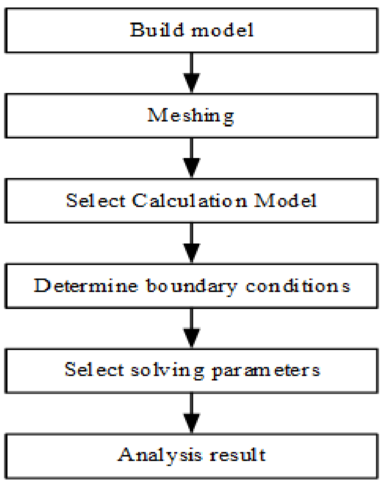

Fig. 3.1. Fluent solution procedure.

3.1. *Continuity Equation*

Continuity equation is also known as mass conservation equation, that is, the net mass flowing into the cell at the same time is equal to the increase rate of fluid flow in the cell in unit time. The continuity equation is shown below.

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

Where u, v and w are velocity components in directions X, Y and Z, t is time, ρ is the density.

3.3. *Turbulence Model*

The main flow form of the gas in the cylinder is turbulence, which is a very complex irregular movement. Fluent provides a variety of turbulence models. In this paper, standard $k-\varepsilon$ model is selected, so the transport equation of standard $k-\varepsilon$ model is shown below.

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{2}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\frac{\partial(\rho \varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \tag{3}$$

Where, the turbulence viscosity coefficient is,

$$\mu_t=\rho C_\mu \frac{k^2}{\varepsilon} \tag{4}$$

Where, k is turbulence kinetic energy, ε is the turbulent dissipation rate, G_k, G_b, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ is an empirical constant, ρ is the density.

IV. SIMULATION ANALYSIS OF AIR PUMP CYLINDER FLOW FIELD

4.1. *Build Model*

The research object of this paper is the first stage compressed air pump, and the specific parameters of its cylinder model are shown in the following table. The specific image is shown in 4.1.

Table 4.1. Cylinder Parameter Table.

Cylinder Diameter	Piston Stroke	Clearance Stroke	Inlet Valve Diameter	Exhaust Valve Diameter
25mm	17mm	0.6mm	3.5mm	3.5mm

Fig. 4.1. Cylinder model.

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4.2. *Meshing and Dynamic Meshing Setup*

Because the piston inside the cylinder of the air pump is reciprocating circular motion, it is necessary to use the dynamic mesh to simulate the gas flow in the cylinder. Dynamic mesh is used to simulate the time change of fluid motion region caused by the deformation of moving boundary. Fluent provides three dynamic mesh partitioning methods: smoothing method, layering method, and re-meshing method [11]. The layering method can realize the generation and disappearance of grids according to the changes of fluid motion region. When the fluid motion region increases, the grids will be generated; when the fluid motion region decreases, the grids will disappear. It is suitable for the problem that the mesh deformation amplitude is small and the fluid motion boundary is linear and rotating, so this paper chooses the layered dynamic mesh.

As the layering method has a high requirement on grid quality, the cylinder dynamic grid part is divided into global hexahedral grids. In order to improve the solving speed, the rest parts are divided into tetrahedral grids, and the cell grid size is set to 1mm. The meshed model is shown in Figure 4.2.

Fig. 4.2. The grid model of the cylinder.

Set the air pump speed, piston stroke, piston diameter and other parameters in the dynamic mesh, set the moving area of the dynamic mesh, and set the opening and closing time of intake valve and exhaust valve through Event.

4.3. *Boundary Condition*

The air inlet is set as the pressure inlet, and his pressure is set as 0 MPa, the exhaust is set as the pressure outlet, and his pressure is set as 1.5MPa. The fluid in the cylinder is set as an ideal gas, the wall is set to adiabatic without slip.

V. Simulation Result Analysis

In order to clearly reflect the change of pressure in the cylinder, the longitudinal plane of the cylinder is intercepted for pressure analysis. The specific results are shown in Figure 5.1 to 5.4.

In the compression process, the intake valve and exhaust valve are closed, the piston moves from top dead center to bottom dead center, the volume of gas in the cylinder decreases, the pressure increases, and the pressure on the cylinder wall is higher than that inside the cylinder. When the gas pressure in the cylinder reaches the set outlet pressure, the exhaust valve opens and the compression process ends.

During the exhaust process, the exhaust valve is opened, and the gas in the cylinder is quickly discharged from the cylinder. At this time, the pressure of the exhaust valve port is less than the pressure inside the cylinder, which is because the volume of the gas is compressed is greater than the volume of the gas discharged.

The gas pressure in the cylinder will gradually recover to the set pressure value after a short rise.

In the expansion process, at this time the exhaust valve is closed, the piston moves from bottom dead center to top dead center, the remaining gas in the cylinder will expand rapidly, the volume of the gas in the cylinder increases, and the pressure decreases gradually, at this time the pressure distribution in the cylinder is uniform. When the pressure of the gas in the cylinder is less than the external atmospheric pressure, the intake valve opens.

In the intake process, the intake valve opens, the gas pressure in the cylinder is less than the external atmospheric pressure, and the gas enters the cylinder under the action of pressure difference. At this time, the pressure in the cylinder will gradually increase until it is balanced with the external atmospheric pressure, and the piston moves to the top dead center. At this time, the intake process is over.

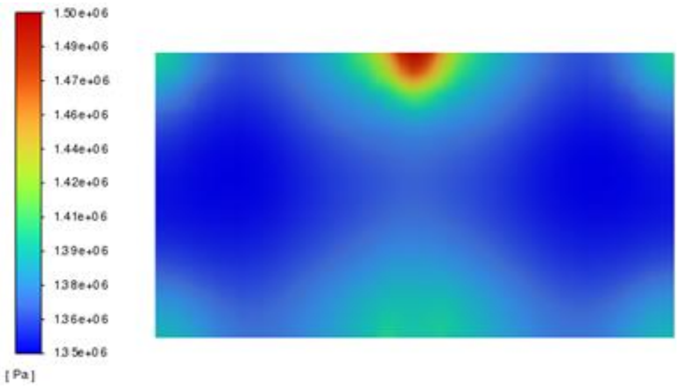

Fig. 5.1. Pressure cloud image of compression process.

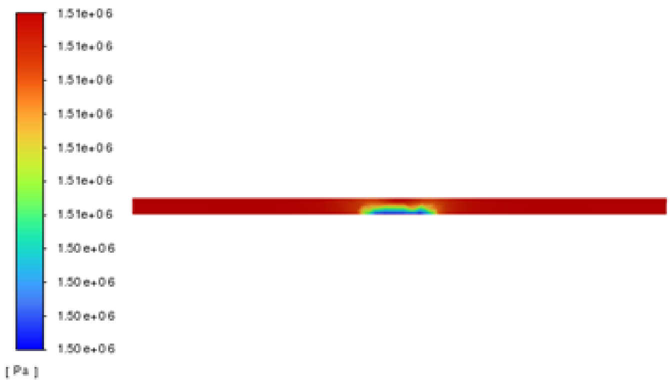

Fig. 5.2. Pressure cloud diagram of the exhaust process.

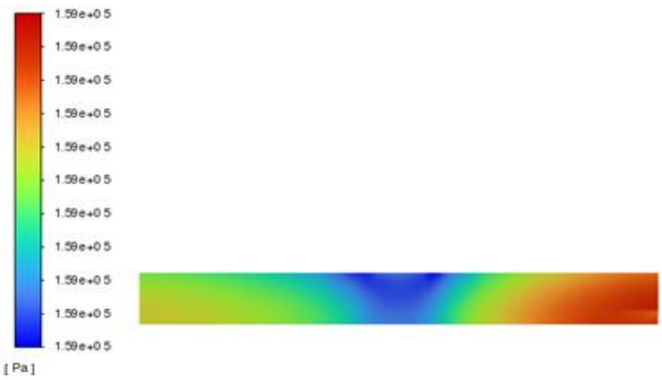

Fig. 5.3. Pressure cloud image of the expansion process.

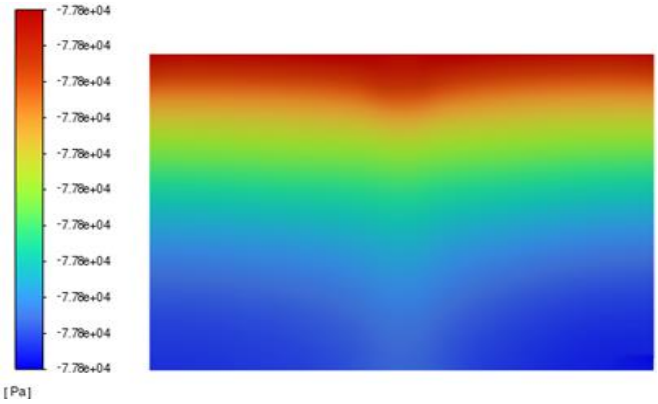

Fig. 5.4. Pressure cloud image of the intake process.

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