Research on optimization of dust measurement pipeline based on Bernoulli Effect

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Abstract. According to the principle of Bernoulli Effect in fluid mechanics, a dust measurement pipeline with Bernoulli Effect is designed. According to the previous research of the project, this paper simulates by CFD software, obtains the particle motion velocity and electrostatic induction under different pipe diameter ratio, and finds out the maximum electrostatic induction under the better tube diameter ratio. The annular electrostatic sensor is used to find a better diameter ratio for Bernoulli Effect tube. The improved device model with different pipe diameter ratio was established in Gambit2.4, and 2D stereo model was used for experimental simulation. The velocity cloud map of particle motion is obtained by using FLUENT6.3 to solve the problem, and the corresponding velocity value is obtained according to the cloud image. The electrostatic induction calculation by MATLAB shows that when the diameter ratio d/D is 0.4 and the velocity is 9.76m/s, the electrostatic induced charge of dust particles is the largest at this time. It has certain guiding significance for the design of dust measurement pipeline.

1. Introduction

In recent years, the research on hydrodynamics has been applied to various fields, and it has become particularly important in daily life for the rational use of the related effects of hydrodynamics.1 Bernoulli Effect [1-5]. Scholars at home and abroad have done a lot of research in this field. In the 1980s, scholars all over the world began to use the Bernoulli Effect in fluid mechanics to study the flow velocity of the valve, and so on. There are many researches in China, such as the effects of Zhu Xuping on the negative pressure of the airflow, and the effect of Lu Qianqian on the spool force of the slide valve [6-9].

Based on the Bernoulli Effect in fluid mechanics, a Bernoulli Effect tube with measurable dust concentration is designed. In the pneumatic conveying process in the pipeline, the dust particles are in the state of rapid flow or vibration, and friction, collision and separation with the air and the pipe wall make the particles carry a considerable amount of static electricity. Alternating signals are produced on the electrode due to electrostatic induction. By collecting the random noise signal of this flow, processing and analyzing it, the conveying speed of powder and the concentration of dust are obtained [10-16]. By establishing an improved device model in Gambit2.4 and setting up the solution parameters in Fluent6.3, The effectiveness of Bernoulli Effect in pipeline is obtained. At the same time, the
movement speed of dust particles is much faster under this effect, and the electrostatic induction of particles is increased, thus improving the accuracy of dust concentration measurement.

In this paper, we will continue to simulate through CFD software, through obtaining different diameter ratio of pipe, the velocity of particle motion and electrostatic induction are used to find a better ratio of pipe diameter to diameter and to provide certain data support for the design of measuring device.

2. Bernoulli Effect

2.1. Principle

Neil Bernoulli proposed the Bernoulli principle in 1726. This is the basic principle of hydraulics before the establishment of continuum theory equation of fluid mechanics, which is essentially the conservation of mechanical energy of fluid, also called boundary layer surface effect. It is suitable for all fluids, including gases, is one of the basic phenomena of steady flow, reflecting the relationship between fluid pressure and velocity, following is the relationship between velocity and pressure [6-9]:

\[ p + \frac{1}{2} \rho v^2 + \rho gh = c \]  

In formula (1), \( p \) is the pressure of a certain point in the fluid, \( \text{Pa} \); \( \rho \) is the density of the fluid, \( \text{kg/m}^3 \); \( v \) is the velocity of the fluid at this point, \( \text{m/s} \); \( g \) is the acceleration of gravity, \( \text{m/s}^2 \); \( h \) is the height of the point, \( \text{m} \); \( c \) is a constant. The above expressions represent the pressure energy, kinetic energy and gravity potential energy of the unit volume fluid respectively. The sum of the total energy remains unchanged in the course of moving along the streamline, that is, the total energy conservation.

The Bernoulli effect is very common in life, such as sailing against the current, banana ball principle, boat suction and so on [6-9].

2.2. Improvement Devices

According to Bernoulli principle, figure 1 is an improved device diagram based on Bernoulli Effect, where the detector is a ring electrostatic sensor. When the dust particles enter the measuring pipe, there will be frictional collisions in the course of motion. By increasing the speed, the energy of the particle is increased, and the sensor will get the charge of the particle as it passes through the effect section. Then the dust concentration is obtained under the processing of the operation circuit. The diameter of the pipe is 6 cm, the length of the inlet segment is 4 cm, the length of the effect segment is 8 cm, the length of the outlet section is 4 cm and the minimum spacing of the effect segment is 3 cm.

![Figure 1. Improved device diagram](image)

The advantage of this design is that the fan pulls the dust particles into the air inlet, which causes the particles to collide and extrude. When the particles pass through the effect section, the velocity direction moves with the pipe wall. Because of the Bernoulli Effect, the pressure difference in the tube is increased, the particles collide with each other, the moving speed of the particles is increased, and the particles move more fully, thus increasing the charge quantity of the particles. It is also proved that the charge amount of dust particles in the tube is related to the above factors. The charged particles pass through
the annular electrostatic sensor and the dust concentration is obtained from the magnitude of the charge amount.

3. Ring Electrostatic Sensor

Fig. 2 is a mathematical model of a circular electrostatic sensor, the outermost layer of which is a shielding layer, an insulating layer, a ring electrode, nesting in the middle of a dust particle channel. The insulating layer of the ring electrostatic sensor is level with the outer wall of the dust particle channel, the ring electrode is close to the inner wall of the dust channel, the shielding layer is outside the insulation layer, and the external electromagnetic interference is isolated. Reduce the measurement error caused by mechanical vibration on the wall of probe and prevent the influence of temperature and humidity on the measuring circuit, sensor probe, particle electrostatic characteristic [12-14].

The calculation and analysis of inductive charge are as follows:

\[
Q = -\frac{Dq}{4\pi} \int_{0}^{\pi/2} \left( \frac{0.5D \cos \theta}{F^2(x, \theta)} \right) \frac{z + 0.5w}{[(z + 0.5w)^2 + F^2(x, \theta)]^{1/2}} - \frac{z - 0.5w}{[(z - 0.5w)^2 + F^2(x, \theta)]^{1/2}} d\theta
\]

\[
F(x, \theta) = [(0.5D)^2 + x^2 - D \cos \theta]^{1/2}
\]

Where \( z \) is the product of particle velocity \( v \) and time, \( w \) is the width of the polar plate, \( q \) is the point charge passing through the plate at a certain speed, \( D \) is the diameter of the annular plate, \( Q \) is the amount of the induced charge on the plate. \( X \) is the distance between the inductive charge and the axis of the polar plate, and \( \theta \) is the angle between the integral block and the axis.

![Mathematical model of ring electrostatic sensor](image)

4. Hydrodynamic Simulation

4.1. Modeling and Meshing

Figure 3 device model, in order to analyze the problem more clearly, an improved device model is established in Gambit2.4, and 2D stereo model is used for experimental simulation. Create a boundary layer and mesh it with Elements: Tet/Hybrid and Type: TGrid types in the mesh face dialog box, with the mesh spacing (Interval size) as 0.1, and the other parameters remain default. In the Specify Boundary Types dialog box, the in, type is defined as the speed entry boundary (VELOCITY_INLET) on the left. Define right side as out, type for free flow boundary (OUTFLOW), others default to pipe wall (WALL).
4.2. Solving Operations
The starting FLUENT6.3, uses 2D single precision solver. Read the Mesh file of the model. After checking the grid and displaying the grid correctly, calibrate the grid and select "cm" in the Scale Grid dialog box.

The solver is defined as a pressure-based implicit solution. The Eulerian model is chosen and the viscosity is the k-epsilon two-equation model. The physical properties define the air phase as the main phase and the dust as the second phase. The CP (Specific Heat) of the dust particles is 1 200 j/kg, Density is 2 600 kg/m 3, thermal Conductivity is 0.3 w/m-k, Viscosity is 1. 8e-0. 5 kg/m-s, and the particle size is 1 μm. The operating environment is standard atmospheric pressure and the working fluid density is 1.225 kg/m3.The inlet hydraulic diameter of the channel is calculated according to the hydraulic diameter of the model and the inlet size of the model unit. The turbulence intensity of mixture is 5, the hydraulic diameter is 0.5, the air velocity is 4m/s, and the dust velocity is 3m/s. The particle volume fraction is 0.015. Volume relaxation factor 0.5, other default. The convergence accuracy is set to 0.001.

4.3. Simulation Results and Analysis
Because the diameter ratio of the pipe is different, the velocity of the particle passing through the device is different, and the charge of the particle will also be different. So the model is simulated under the same experimental parameters and different diameter ratio. The set d is reduced by 0.4cm from 4.0cm to obtain the velocity value of different diameter ratio.

The dust particle velocity cloud in figure 4, the velocity cloud maps with d = 1.6 ~ 2.4 ~ 3.2 ~ 4.0cm were taken respectively. Under the action of Bernoulli Effect, it can be clearly seen that the particle...
motion velocity is very different under different pipe diameter ratio. At the same time, because of the effect of the fan, the particle will be pulled by the drag force. In the middle of the effect section of the optimized device, the velocity change is the most obvious, and the charge quantity of the corresponding particle is the largest here. It is very important to measure the dust concentration accurately. Therefore, the setting of measuring points is helpful to improve the accuracy of measurement.

In order to obtain the charge quantity of the maximum electrostatic induction, the velocity value under the optimal diameter ratio of the tube is selected, the maximum diameter d of the spoon-shaped tube is reduced in turn by 0.4 cm, and the other conditions are all unchanged, and the modeling and simulation are carried out. The velocity of dust particles at different diameter ratios is obtained, and the inductive charge at different diameter ratios is obtained from the formula of electrostatic induction, as shown in Table 1.

Table 1. Velocity values at different diameter ratios

| d/cm | d/U | v/(m/s) | Q/c |
|------|-----|---------|-----|
| 4.0  | 0.67| 6.16    | 0.0930 |
| 3.6  | 0.60| 6.78    | 0.1622 |
| 3.2  | 0.53| 7.65    | 0.2291 |
| 2.8  | 0.47| 8.60    | 0.2726 |
| 2.4  | 0.40| 9.76    | 0.2989 |
| 2.0  | 0.33| 11.7    | 0.2973 |
| 1.6  | 0.27| 13.9    | 0.2740 |
| 1.2  | 0.20| 17.0    | 0.2280 |
| 1.0  | 0.17| 18.9    | 0.2014 |

Through the modeling and simulation of CFD software, it can be seen in Table 1 that the velocity value increases gradually with the decrease of the diameter ratio of the tube in turn, but the electrostatic induction shows the peak state after the correlation calculation by MATLAB. Therefore, the better diameter ratio of Bernoulli Effect tube will appear before and after the peak value.

The electrostatic induction at different diameter ratios in Table 1 is compared, as shown in Fig. 5.

![Fig 5. Induction charge of different diameter ratio](image)

By unifying treatment, from fig. 5, the inductive charge amount under different diameter ratio is obtained. Finally, when the tube diameter ratio is 0.4 and the velocity is 9.76m/s, the electrostatic inductive charge of dust particles is the largest at this time. It has certain guiding significance for designing the pipe of dust concentration measurement.
5. Conclusion
Firstly, the principle of Bernoulli effect in fluid mechanics is introduced, and a dust concentration measuring device with Bernoulli effect is designed. According to the previous study of the project team, this paper will continue to use CFD software to model and simulate, through the different pipe diameter ratio, the particle motion speed and electrostatic induction, to find a better tube diameter ratio under the maximum electrostatic induction.

By studying the related structure mechanism of the sensor and its placement in the pipeline, the mathematical model of the sensor is analyzed, and the better pipe diameter ratio is found for the Bernoulli effect tube.

The improved device model with different pipe diameter ratio was established in Gambit2.4. 2D stereo model was used to carry out experimental simulation and FLUENT6.3 was used to solve the problem. The velocity cloud map of particle motion was obtained, and the corresponding velocity value was obtained according to the cloud image. The electrostatic induction calculation by MATLAB shows that when the diameter ratio is 0.4 and the velocity is 9.76m/s, the electrostatic inductive charge of dust particles is the largest at this time, which has certain practical significance for the design of dust measurement pipeline.

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