Optimization of dust concentration measuring device

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Abstract: The existing equipment for measuring dust concentration has the problem of imprecise measurement of low concentration and small particle size dust. In this paper, the measuring device is optimized to solve this problem, and the spiral channel is added to the existing vertical pipe dust concentration measuring device, which makes the dust rotate in the pipeline. As a result, the velocity of the dust particles and the friction between the dust particles and the pipe wall are increased. A three-dimensional model is established in Gambit2.4, and the gas-solid two-phase flow is simulated by Fluent6.3. The velocity distribution cloud and pressure distribution cloud of dust were obtained. Through the comparison and analysis of the experimental data, the optimized measuring devices are as follows: The effect can improve the pressure difference and velocity of dust particles in the pipeline, so that the amount of induced charge measured by electrostatic sensor is greatly increased, so the accuracy of measuring low concentration and small particle size dust is improved.

1. Introduction

With the development of energy industry in China, especially coal and electric power, the detection and control of dust concentration has become one of the important contents in the production process. Dust not only pollutes the environment, but also does great harm to people's health. It is one of the most important causes of occupational diseases, and it may lead to a disaster[1-3].

At present, the main methods to measure dust concentration are capacitance method, piezoelectric crystal induction method, β-ray method, laser scattering method, oscillatory balance method and so on. All kinds of methods have molded products in the market and are used in flue. Measurement of dust particle concentration in air and coal mine underground[4-6].

Charge-sensitive method is a kind of on-line measurement method for particle mass concentration which has been paid more and more attention in recent ten years. The method of measuring gas-solid two-phase flow parameters based on electrostatic induction technology has long been applied[7-8]. At present, the application of electrostatic induction principle in the study of particle flow parameters is in a leading position and some achievements are made by Professor Yan Yong of the University of Kent in the United Kingdom, Chen Jiange and others have established a charge-sensing model between dust particles and rod-shaped electrodes. Zhao Enbiao and others have experimentally studied the relationship between the charge produced by electrostatic sensors at different dust concentrations[9-11].

In order to solve the problem of low concentration and small particle size dust measurement accuracy of the existing device[12], the dust concentration measurement device designed by me is based on the existing device, and four spiral channels are added in the inner part of the device. Due to the
action of the spiral channel, the dust can rotate along the spiral channel after entering the device, so that the dust particle pressure will increase and the speed will be increased. At the same time, the friction between dust particles and pipe wall will be increased, and the electric capacity of dust particles will be increased, and the measurement of electrostatic sensors will be more accurate.

2. Analysis of dust concentration measurement devices based on electrostatic induction

2.1. Circular electrostatic sensor

The first mathematical model of the induced charge on the ring electrostatic sensor is Professor YAN Yong of the University of England. The calculation formula of the induced charge of the ring electrostatic sensor is (1), (2). The mathematical model is shown in figure 1.

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

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

Of which, \( z \) is the product of particle velocity \( V \) and time, \( w \) is the plate width, \( q \) is the point charge through the plate at a certain speed, \( D \) is the diameter of the annular plate, \( Q \) is the amount of induced charge on the plate, \( x \) is the distance between the induced charge and the central axis of the plate, \( \theta \) is the angle between the integral block and the axis. The mathematical model is shown in figure 1.

![Figure 1. Mathematical Model of Annular Electrostatic Sensor](image)

2.2. Structure analysis of existing dust concentration measuring device

The existing dust concentration measurement devices based on electrostatic induction include air inlet, outlet, straight pipe, ring electrostatic sensor and pumping equipment. Its structure is shown in figure 2.

In the process of gas movement, there will be friction and collision between the dust particles and the wall of the pipe and between the particles and the particles, and then the dust particles will produce electrostatic charge after the suction equipment of the outlet pumps the dust particles from the air intake port and into the air inlet, and after that, the dust particles will be subjected to electrostatic charge during the process of gas movement. The annular electrostatic sensor is embedded in the middle section of the pipeline, and its ring electrode is close to the inner wall of the pipeline. When the generated electrostatic charge passes through the annular electrostatic sensor, the corresponding induction signal will be generated. The parameters of dust concentration can be obtained by amplifying the induced signal [13-15].

The device has the advantages of simple structure and easy operation, but under the condition of low concentration and small particle size, the dust particles can not fully collide and friction in a
limited space, so the electric capacity is extremely weak. The induced electrical signal is very weak, which leads to the inaccurate measurement of dust concentration. In view of this shortcoming, the existing electrostatic induction dust measuring device has been improved, so that the dust particles can be fully collided and rubbed in a limited space, so that the amount of charge of dust particles greatly increased, in the case of low concentration, small particle size of the measurement accuracy has been improved.

![Figure 2. existing device straight tube structure diagram](image)

3. Improved dust concentration measuring device

3.1. Design principle and advantage analysis

The improved dust concentration measuring device adds four spiral channels on the basis of the original straight tube measuring device. The dust particles are rotated along the channel after entering the channel, the structure of which is shown in figure 3. Then the electric charge measuring device in the existing device is used to detect the dust concentration and finally the dust particles leave the pipe along the spiral channel outlet according to the measured electric quantity.

![Figure 3. improved device structure](image)

In this improved device, the length of spiral channel is 16 cm, the radius of cylinder is 3 cm, the length of spiral channel is 4, the axial length of single spiral channel is 2 cm and the pitch length is 8 cm. Compared with the straight tube, the improved device can produce more contact with the pipe wall, friction, friction between dust particles and dust particles, and the movement of dust particles will also become faster. Therefore, the improved dust measurement device can make dust particles produce more static electricity.

3.2. The establishment of geometric model

The experiment will establish a 3D stereoscopic model of the pipeline, which consists of a cylindrical tube and a spiral channel, dividing it into grids, each mesh area is 0.5mm² set the left side of the pipeline as the entrance, its type is VELOCITY_INLEN, the right side of the pipe for the exit, its type is OUTFLOW, The other default is Tube wall. Other parameters are default.

3.3. Simulation and analysis of model

The design will be simulated in Fluent6.3, and Eulerian model will be used to simulate the movement of dust particles in the pipeline. The k-epsilon model is used in the relevant numerical calculation, and
the relevant data of dust parameters are set. The thermal conductivity is 0.3, the density is 2600, the specific heat capacity is 1200 and the viscosity is 1.8e-05. The unit and other values are default. The hydraulic diameter of the inlet of the pipe is calculated according to the size of the inlet of the unit. The hydraulic diameter of the pipe inlet with mixture is 0.5, the turbulence intensity is 5, and the velocity of air flowing into the inlet is 4m/s, dust speed 3m/s, the volume fraction of particles is 0.01, the other values are default, and the convergence accuracy in iterative calculation is 0.001. In the course of motion, dust particles will be subjected to the action of gas drag force, lift force and inertia force. The formula (3) of the force to which the dust particle will be subjected will be as follows:

\[
\frac{du_p}{dt} = F_d(u - u_p) + \frac{g_i(\rho_p - \bar{\rho})}{\rho_p} + F_s
\]

\[\rho\] is the density of gas, kg/m^3; \[u_p\] is the velocity of particles, m/s; \[g_i\] is the physical force in the \[i\] direction of the fluid element, \[N\]; \[F_d(u - u_p)\] is the drag force per unit mass of particles, \[N\]; \[\rho_p\] is the bulk density of particles, kg/m^3; \[F_s\] is the interphase force, \[N\]; \[u\] is the velocity of the airflow, m/s.

The momentum formula for particle variation (4) is as follows:

\[
P = \sum \frac{18\mu C_p Re}{24\rho_p d_p^2} (u_p - u) + F \bar{m}_p \Delta t
\]

In the equation, \[\mu\] is the gas dynamic viscosity, Pa.s; \[\Delta t\] is the time step, s; \[\bar{m}_p\] is the particle mass flow rate, kg/s; \[d_p\] is the particle diameter, m; \[F\] is the interphase force other than drag force, \[N\].

The dust concentration is set to 5 mg/m^3; figure 4, figure 5, shows a cloud image of the speed of the existing device and the optimized device. The particle size of 10 μm is taken as an example.

![Figure 4. Straight tube velocity cloud](image)

![Figure 5. Spiral channel velocity cloud](image)

According to the velocity cloud diagram, it can be clearly seen that the speed of dust particles in the pipeline is much higher than that of the straight pipe, which means that the dust particles are moving more fully in the improved pipe than in the straight pipe. The friction collision between particles is also more intense, the amount of charge generated is increased, and the measurement accuracy is greatly improved.

4. Experimental results and analysis
Through the experiment simulation and calculation analysis, the data comparison between the existing device and the optimized device is shown in Table 1.

**Table 1. Velocity data for different pipelines**

| Grain size (µm) | 30   | 20   | 10   | 9    | 7    | 5    | 3    | 1    |
|-----------------|------|------|------|------|------|------|------|------|
| **Canal of spiral** | 5.84 | 6.07 | 6.78 | 7.01 | 7.21 | 7.53 | 7.95 | 8.56 |
| **Straight tube**   | 3.88 | 3.93 | 3.98 | 4.04 | 4.05 | 4.08 | 4.09 | 4.14 |

According to the data in Table 1, the spiral tubes of the optimized device with different particle sizes are compared with the straight tube velocities of the existing devices, as shown in figure 6. The charge is calculated by the induction charge formula (1), (2), and the results are also normalized as shown in figure 7.

![Figure 6. Velocity contrast chart](image)

![Figure 7. Charge normalization treatment diagram](image)

Compared with the straight tube device, the speed of the dust particles in the spiral tube is obviously higher than that in the straight tube, which makes the dust particles move more fully in the channel. At the same time, the pressure difference in the pipeline is larger, which makes the dust particles move towards the pipe wall, and greatly increases the charge of the particles. According to the figures 6 and 7, the improved measuring device can effectively increase the dust concentration in the low concentration. The accuracy of measurement in the case of small particle size.

5. Conclusions

After comparing and analyzing the existing straight pipe dust concentration measuring device and the improved one, it can be seen that the existing straight pipe dust measuring device is not accurate under the condition of low concentration and small particle diameter. In order to improve the accuracy of dust measuring device under the condition of low concentration and small particle diameter, this paper increases the velocity of dust particle movement and friction with pipe wall by adding spiral channel on the basis of the existing device. As a result, the charge is increased and the measurement precision is improved.

The pipeline model of the optimized device is established by Gambit2.4 and simulated in Fluent6.3 to keep the other experimental data unchanged. The velocity cloud and pressure cloud of straight tube...
and spiral tube are obtained by changing the size of particle size of dust, and the velocity cloud and pressure cloud of straight tube and spiral tube are obtained by changing the size of dust particle size. According to the experimental data, the induced charge is calculated according to the formula of induction charge.

After the analysis of the experimental data of the improved measuring device and the existing measuring device, it can be seen that the improved measuring device is much more inductive charge than the existing measuring device, so the improved dust concentration measuring device has higher accuracy in the case of low concentration and small particle size.

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