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Design and Numerical Simulation of Dust Removal System for Sutomotive Iongitudinal Beam Plasma Cutting

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Abstract

To improve the poor efficiency of the dust removal system in the plasma cutting station of automotive longitudinal beams, and reduce the cutting surface quality degradation due to dust, a bottom-side suction dust removal system is designed, and the dust removal effect is optimized through the setting of the following dampers and diversion plates. The result of numerical simulation indicates that the particle collection rate can reach 99.44%, and the field test also proves the effectiveness of the dust removal system, which is of guiding significance for the transformation of other similar dust removal systems.

Keywords: *plasma cutting; dust removal equipment; simulation*

1 Introduction

Plasma cutting is a commonly used cutting method, the main principle of which is to heat the machine part through a high-temperature plasma arc, so that the material locally melts under the high temperatures, evaporates or goes out with the high speed plasma, and finally forms the processing method of cutting [1]. Because of the high cutting speed, high efficiency, good cutting surface, accurate size and flexibility with various working gases, plasma cutting is widely used in aerospace, machining, electrical and electronic areas, and can be use for cutting aluminum, copper, titanium, galvanized steel and other materials which are difficult to cut by oxygen cutting. However, in the cutting process, a large amount of dust is generated when metal materials and plasma are encountered, mainly containing metal dust and smoke, with the primary soot consisting of spherical particles with a diameter of about 3 micrometers, and the secondary aggregated soot with larger size. The soot can easily enter the human lungs, harming health and polluting the environment. Therefore, dust removal devices must be installed in plasma cutting to protect on-site personnel and the environment while improving product quality [2].

In order to analyze the movement principle of dust in the cutting process and optimize the dust removal effect, scholars in China and other countries have carried out detailed studies. Based on the principle of fluid dynamics, Jiang Huarui [3] simulated the flow direction of dust particles in laser precision cutting, and studied the distribution and trend of smooth and turbulent flow of dust particles in the cavity. Hoover [4] analyzed the cutting materials and found that the processing of brittle materials has a larger median diameter of the mass of dust particles produced than the processing of ductile materials and that the stronger the fracture toughness, the more the material produces the more dust. D. Dekeyser et al. [5] obtained the effect of different airflows on the dust removal effect by setting different flow rates, flow velocities, and fan powers. Ma Yubao [6] focused on optimizing the host airflow of the dust removal system in plasma cutting. Chen Chao [7] discussed the influence of host power and suction port area on the dust removal effect. It can be seen that the influence of the dust removal effect includes the characteristics of material and the process parameters of the exhaust system, and the use of process parameters for optimization is relatively simple and feasible. On the other hand, scholars actively improving the structure of the dust removal device to enhance the dust removal effect. Yingchuang Lv [8] shortened the air duct by setting welded partitions and improved the dust removal speed.Ligui Jiang [9] improved dedusting efficiency by designing a partitioned dedusting system for a large-envelope laser cutting machine with two dampers working simultaneously in the same partition and an axial fan installed on the top cover of the machine guard, which greatly inhibits the diffusion of metal fume into the upper space of the working table. Yanjun Chen [10] combining high-pressure water spraying and dry cartridges, the dust removal system has been modified, which greatly facilitates the cleaning of dust at a later stage.

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Danyang Feng [11] The dust removal of fine plasma cutting is improved by increasing the dust removal air volume, adding a side-blowing device, modifying air ducts, and strengthening maintenance. Aiwei Liu [12] optimized the dust removal pipe of the machine tool, the clearance between the workbench and the blanking plate, and the damper control.Guangming Hu [13] et al. designed a special cutting air outlet capturing a vertical table, but the structure occupies a large site area and is not conducive to the automation improvement of the workstation, etc. Zhongwei Wu [14] based on the principle of plasma discharge adsorption to purify welding fume, has developed a dust removal device, which can track the source of welding fumes in real time but is not suitable for cutting large parts such as longitudinal beams. Although it is feasible to improve the dust removal efficiency by increasing the device, it is not suitable for all enterprises that have already installed the completed dust removal system due to the high coefficient of structural difficulty and high modification costs.

This paper optimizes the dust removal system for the cutting longitudinal beam station of an enterprise, proposes a more cost-effective structure improvement scheme, and confirms a better effect of dust removal through simulation and on-site testing, which not only improves product quality and productivity, reduces manpower costs, but also provides a reference to solve the related problems in the industry, which has greater value for market application.

2 Basic Principle of Plasma Dust Removal System

At present, most of Chinese enterprise use wet dust removal methods and dry dust removal methods.

2.1 Method of wet de-dusting

The method of wet de-dusting is to set up a water storage pool under the workstation,the cutting and sparks generated during cutting can automatically fall into the pool, due to the light density of soot，the dust removal efficiency is low.Cutting in water, although the dust removal efficiency of this method is higher, it affects the cutting efficiency and also prolongs the time of auxiliary processes such as loading and unloading, and at the same time, it is easy to cause water pollution.

2.2 Method of dry dusting

Dry dust removal processes typically require the design of a collection system to capture the fumes and dust in the system, which is then transported to the purification equipment and discharged after the treatment is completed. Commonly used collection systems are negative pressure de-dusting systems，also called direct suction systems， and blowing suction de-dusting systems.The negative pressure type dust removal system has more applications, and according to the suction, position can be divided into top suction type and side suction type [15]. Top suction in the cutting table above the negative pressure device, side suction in the table below the negative pressure device, and the opening of the air door around the table, according to the direction of the air door can be subdivided into a single side, double-side, four-side suction system [16], respectively, for with 3 meters or less, 3 meters to 5.5 meters, 2.5 meters or less, and the table is wider.

3 Overall Structural Design of the Dust Removal System

The automotive longitudinal beam is an important supporting structure of the car, and usually needs to be cut by laser or plasma cutting, etc. to obtain the corresponding shape, to meet the appearance and functional requirements of the product. In the traditional dust removal method adopts, the air is sucked out from the top of the room, but the soot easily adsorbs to the lower surface of the longitudinal beam during the rising process, which on one hand affects the quality of the cutting surface, and on the other hand, affects the subsequent painting process, so it is necessary to add a special process to remove the soot.

Now we design a side suction dust removal system located under the table, which is modeled by mechanical software，Siemens NX12. The main structure is shown in Figure 1. One of the dust removal boxes is divided into two layers, the inner box is used to hold the cutting waste inner box, the sandwich between the inner and outer layers of the fume collection channel and along the direction of the main guide rail of the cutting machine is divided into several uniformly closed small areas, the side of the open air outlet, the air outlet is equipped with a horizontal diversion plate above, and the bottom of the upward tilting of the diversion plate, as shown in Figure 2. Each extraction chamber is designed to install a mechanism to open the dampers. By moving the table to trigger the switch, the resulting fumes and dust will be sucked into the air ducts promptly, and directly into the main body of the dust collector for purification. The original ordinary switch model is converted into into a conical damper.

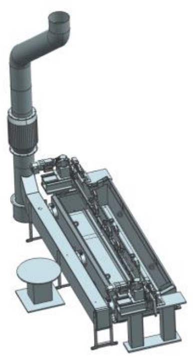

Figure 1 Overall structure of dust removal system

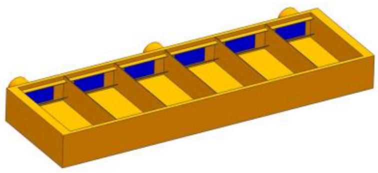

Figure 2 Structure of dust removal box

4 Mathematical Modelling

The process of absorbing dust is a typical turbulent gas-solid two-phase flow composed of moving airflow and ejected dust particles, which is a typical two-phase flow model, Commonly used two-phase flow models include the Volume of Fluid Model, the Mixture Model, and the Eulerian Model. In these models, the Eulerian Model regards each phase as a continuous medium that fills the entire flow field, writes the mass, momentum, and energy conservation equations for the two phases respectively, and couples the two sets of equations together through the interaction between phase interfaces, providing a more comprehensive and widespread method.

Modeling of fluids starts by following the continuity and momentum conservation equations. Due to the anisotropic vortex flow of the gas in the dust removal system, the Reynolds stress model with the assumption of turbulent isotropy is used, and the coupling between the gas and particle phases is solved using the Lagrangian multiphase flow model.

The continuity equation:

$$\frac{\partial(\rho u_x)}{\partial x}+\frac{\partial(\rho u_y)}{\partial y}+\frac{\partial(\rho u_z)}{\partial z}+\frac{\partial \rho}{\partial t}=0 \tag{1}$$

In the formula, u_x, u_y, u_z is the fluid velocity; ρ is the fluid density.

Conservation of momentum equation:

$$\frac{d\vec{V}}{\partial t}=\vec{F}+\frac{1}{\rho}(\frac{\partial \vec{P_x}}{\partial x}+\frac{\partial \vec{P_y}}{\partial y}+\frac{\partial \vec{P_z}}{\partial z}) \tag{2}$$

In the formula, $\vec{P}$ is the fluid stress vector, and $\vec{F}$ is the mass force distribution density.

Reynolds stress equation:

$$\frac{\partial}{\partial t}(\rho\overline{u_\iota u_J})+\frac{\partial}{\partial x_k}(\rho U_k\overline{u_\iota u_J})=D_{ij}+\varphi_{ij}+G_{ij}-\varepsilon_{ij} \tag{3}$$

In the formula, $\frac{\partial}{\partial t}(\rho\overline{u_\iota u_J})$ is the time rate of change of the Reynolds stress, $\frac{\partial}{\partial x_k}(\rho U_k\overline{u_\iota u_J})$ is the convection term, D_{ij} is the diffusion term, and φ_{ij} is the pressure strain term, G_{ij} is the generation term, and ε_{ij} is the dissipation term.

Particle equations of motion:

$$\frac{du_p}{\partial t}=F_d(U_I-u_p)+g\frac{(\rho_p-\rho)}{\rho_p} \tag{4}$$

$$\frac{dx_p}{\partial t}=u_p \tag{5}$$

In the formula, x_p is the particle position, ρ_p is the particle density, u_p is the particle velocity

5 Simulation and Experimental Verification

5.1 Model building and meshing

In the dust duct, each small enclosed area is isolated from one another and the dampers are controlled independently. During the cutting process, the nozzle moves at an approximately constant speed, and when the nozzle moves to the corresponding area, the damper in the area opens, so a closed area is modeled as a simulation object, and it is modeled using Siemens NX12 as shown in Figure 3. The damper is set as a pressure outlet, the upper surface is set as the velocity inlet, and all others are walls. The meshing is carried out in ANSYS MESHING in the form of tetrahedral mesh with the number of meshes 330639, as shown in Figure 4.

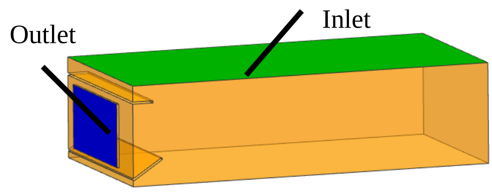

Figure 3 Physical model

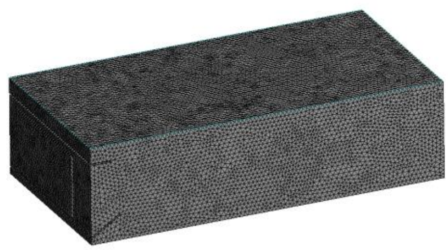

Figure 4 Mesh division

5.2 Model solving

The dust removal process was simulated using FLUENT. The transient simulation is used, the gravitational acceleration is set, the time step of the transient simulation is set to 0.001s, the number of inner iteration steps is set to 20, and the maximum solution time of the transient is 5 s. The gas inlet boundary condition is the velocity inlet with a velocity value of 10m/s, the material is air and the exit velocity is the pressure outlet with a pressure value of -1000 Pa. The particle incidence method is the planar incidence source. and the incident plane is the gas-phase Inlet plane, the material is steel, the incident direction is the dierection normal to the plane, the incident length is 1s, the size of the particles is 3 microns, the incident velocity is 5m/s, and a total of 8248 particles injected. The particles at the inlet were set to escape and the outlet was set to capture, i.e., the particles were considered to be absorbed when they reached the outlet.

5.3 Simulation results and analysis

The simulated particle movement trajectory is shown in Figure 5. The number of particles captured at the pressure outlet surface is 8202, and the particle collection rate is 99.44%, dividing by the number of captured particles by the number of incident particles. The effectiveness of the dust removal system is proven. The results of the pressure simulation are shown in Figure 6, which shows that the application of the diversion plate effectively reduces the pressure loss, so that the dust removal suction can have a more effective effect on the inlet surface. Meanwhile, as shown in Figure 7, the velocity vector diagram shows that the underlying particles can also be effectively absorbed .

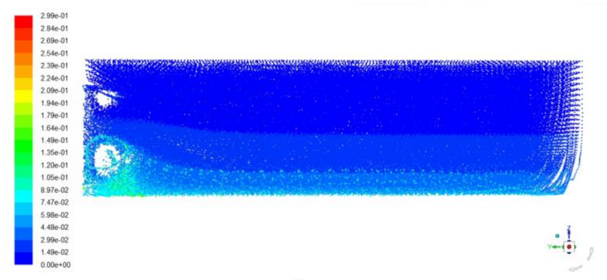

Figure 5 Particle trajectories diagram

Figure 6 Pressure cloud diagram

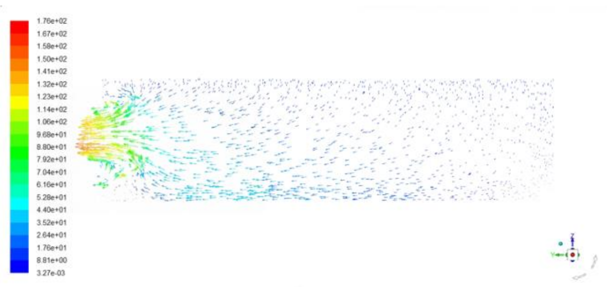

Figure 7 Velocity vector diagram

5.4 Experimental verification

Based on the simulation results, the original upper suction dust removal system was converted into the lower side (Figure 8). The height of the workstation from the ground is 420mm, the thickness is 50mm, the cutting stroke is 2.7m, the track spacing is setted to 1.5m, the height above the ground is 820mm, the waste box dimensions are 2900×800×350mm and the height above the ground is 770mm, the length of the waste box in the middle of the length is 3.3m. After the transformation to carry out the actual test was completed, it was found that the test had a better effect on dust removal.

(a)Before modification (b) After modification

Figure 8 The dust removal system

6 Conclusion

Automotive longitudinal beams are key structural components of automobiles and need to be processed using plasma and other cutting processes. The dust generated during the plasma-cutting process needs to be collected effectively to prevent polluting the environment and damaging the health of employees. This paper A bottom-side suction dust removal system is proposed, using a follower damper with a diversion plate to achieve dust collection. And it is verified that the dust removal rate is higher than traditional method by simulation and field tests, which is of some significance as a guide for similar production modifications. The dust removal method can also explore the blowing and suction combination, the overall pressure adjustment of the workshop and other technologies can also be studied to make further improvement on the dust removal rate.

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