

Numerical Simulation of Airflow Organization in Paint Spraying System of car Lampshade

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Abstract. According to the design requirements of the airflow organization of the car lampshade paint spraying system, the corresponding physical model is established, and the flow state of the air organization in the entire paint spraying system was simulated using Fluent software. On this basis, the wind speed of all mechanical air supply and air exhaust in the paint spraying system are adjusted to find the optimization and improvement direction of the airflow organization, so that the air pressure and wind direction in the system meet the environmental requirements of the car lampshade painting process, economically reducing the harm of paint, and providing reference for the ventilation design of the paint spraying system.

Keywords: Automotive lamp shades, paint spraying systems, airflow organization.

1. Introduction

The lampshade is the most direct visible surface of the car lamp and the surface treatment effect of the lampshade will directly affect the appearance performance of the whole car lamp. The surface treatment process of the car lampshade is mainly the paint spraying process, by coating a wear-resistant, high-temperature resistant, corrosion-resistant and anti-fogging film layer on the surface of the car lampshade to improve the service life of the car lamp. The spraying process of the lamp is carried out in the paint spraying system, and airflow organization in the system will affect the spraying effect of the car lampshade. Moreover, paint mist particles and volatile components of organic solvents such as benzene series and non-methane total hydrocarbon will be produced in the lampshade paint spraying room. If these pollutants cannot be reasonably treated, not only the environment will be polluted, but also the health of on-site workers will be seriously endangered. The unreasonable setting of the air supply and exhaust system of the whole paint spraying system will lead to the unstable air volume and pressure difference in each room, resulting in the paint diffusion in the spraying room.

CFD (Computational Fluid Dynamics) technology, as a new discipline of simulating fluid movement, was first used in air conditioning engineering to simulate indoor air flow. Nowadays, it has been widely used in many fields [1-6], such as building engineering, food engineering, environmental chemical engineering, mechanical engineering, and building engineering. In this paper, the CFD software Fluent is used to simulate the air flow in the car lampshade painting workshop, and a reasonable ventilation scheme is designed to meet the requirements of the car lamp painting process, and reduce the harm of toxic and harmful substances economically and reasonably.

2. Lampshade paint spraying process

The paint spraying process of car lampshade mainly includes three processes: dust removal, painting and curing. The purpose of dust removal is to remove the static electricity and adsorbed dust on the surface of the lampshade, to prevent the uneven film thickness and impurities of the sprayed film layer caused by the uncleanness of the lampshade surface. Painting is mainly carried out on the surface of the lampshade by a robot with a spray gun according to the pre-designed path and angle. The purpose of curing is to make the sprayed paint evaporate some water and solidify under certain light intensity and temperature, which can greatly shorten its curing time compared with the natural

cooling and curing of the paint. In order to achieve the best process purpose, there are strict environmental requirements in the entire spraying system. The cleanliness of the entire spraying system needs to reach Class 10000, and each area has its own air pressure and wind direction requirements. Figure 1 shows the air pressure and wind direction requirements of the spraying system, and the direction of the dotted arrow is the wind direction requirements.

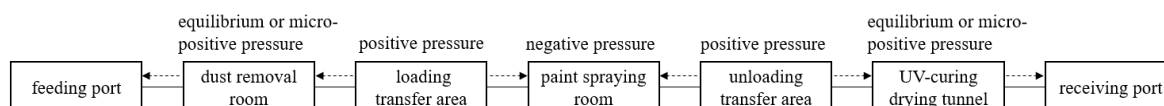


Figure 1. Requirements for air pressure and wind direction of paint spraying system.

The main process of paint spraying the lampshade is shown in Figure 1. Workers feed the unpainted lampshade into the dust removal room through a feeding port, where a robot cleans the surface of the lampshade with a dust removal air gun. After the dust removal, a robot in the loading transfer area transports the lampshade to the turntable in the paint spraying room, where the lampshade is transported to the spraying operation area. The spraying robot then sprays the surface of the lampshade. After spraying, the turntable carries the lampshade to the exit of the paint spraying room, where another robot in the unloading transfer area transfers the painted lampshade to the UV-curing drying tunnel. The paint on the lampshade will be cured after being irradiated by ultraviolet light in the UV-curing drying tunnel, and finally will be transported to the receiving port for inspection and acceptance by workers. In order to prevent paint from spreading into other work areas, the painting room must maintain negative pressure, while adjacent transfer areas must maintain positive pressure. The dust removal room and UV-curing drying tunnel must maintain an equilibrium or micro-positive pressure to prevent unpurified gases from entering through the feeding and receiving ports.

3. Simulation

3.1 Simulation model

The main purpose of the simulation study is to analyze the changes in air flow, wind speed, air pressure within the entire paint spraying system under different ventilation parameters, in order to design a reasonable ventilation scheme to meet the environmental requirements of the painting system. Using CFD software to numerically simulate different ventilation parameters, the indicator cloud diagram obtained can intuitively show the advantages and disadvantages of different parameters. This paper mainly considers the airflow state in the paint spraying room and the pressure difference relationship between each room. The rest of the objects in the system have little impact on the simulation results. Therefore, in order to facilitate the calculation and rational allocation of computer resources, the model is simplified by simplifying the structures such as robots and baskets that have little impact on the simulation calculation results. The specific physical model is shown in Figure 2.

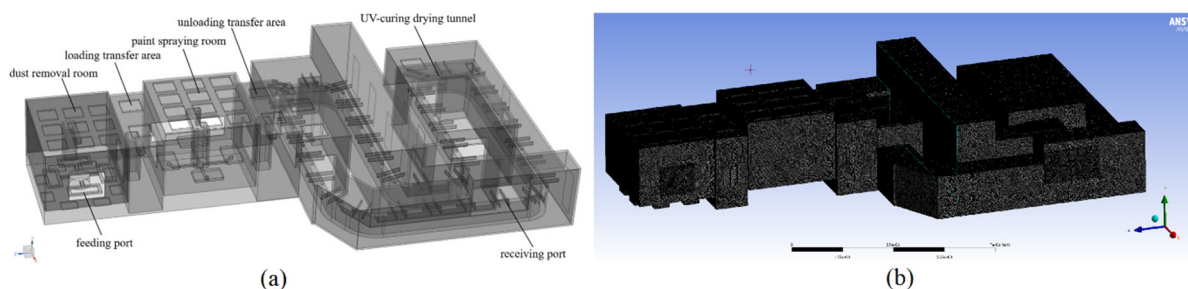


Figure 2. (a) Simulation model and (b) mesh division of paint spraying system.

The entire model area mainly includes a dust removal room, a paint spraying room and an UV-curing drying tunnel. The lampshade enters the dust removal room first, and after the surface is subjected to the process of electrostatic removal and dust removal, it enters the paint spraying room for paint spraying. After spraying, it enters the UV-curing drying tunnel, where the paint rapidly solidifies under the irradiation of ultraviolet light and high temperature. The main source of pollution in the entire process is the paint produced during spraying. If the paint enters the UV-curing drying tunnel and dust removal room, it will pollute the surface of the lampshade, resulting in poor coating effect, uneven film thickness, impurities on the surface, and other problems. In addition, if the paint flows out of the UV-curing drying tunnel with the air flow and is inhaled by the workers, it can also pose a health hazard.

In this simulation, SST (shear-stress transport) $k-\omega$ model is used as the turbulence model, and SIMPLEC algorithm is used as the algorithm. As shown in Figure 2, the mesh is partitioned using the built-in mesh module in Fluent, with a uniform cell size of 40mm throughout the model. The mesh is refined at the air inlet and outlet, with a cell size of 30mm, and the total number of mesh elements is 11,523,049.

3.2 Boundary conditions

There are two main factors that affect the magnitude and stability of the spatial pressure: one is the dynamic changes in the indoor supply and exhaust air, and the other is the airtightness and opening conditions of the room doors and windows. All processes in the paint spraying system are completed by robots, and no workers enter, and the entire painting system is closed. Therefore, the impact of room airtightness is ignored. The main ventilation modes in the entire painting system are mechanical air supply and mechanical exhaust. By adjusting the wind speed of the air supply and exhaust fans, the negative pressure requirements in the paint spraying room can be achieved, and the positive pressure in other rooms can also be met.

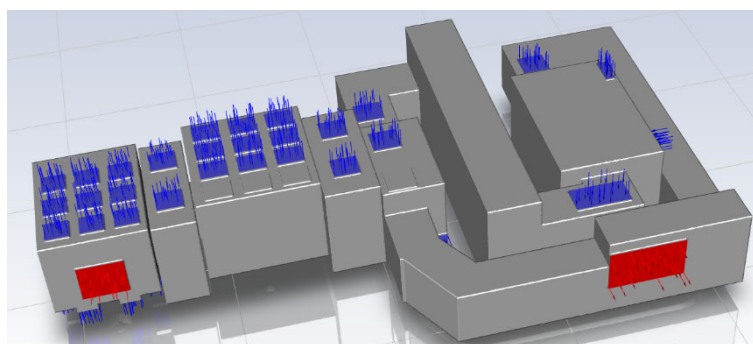


Figure 3. Schematic diagram of inlet and outlet wind speed setting.

Based on actual wind speed measurements on site and simulated adjustments of relevant parameters, the feeding and receiving ports are set as zero-pressure outlets, and all other air outlets are set as air inlets, with positive and negative signs indicating direction. Figure 3 shows the inlet and outlet wind speed setting in simulation model, and the specific wind speed parameters are shown in Table 1.

Table 1. Wind speed for air inlets and outlets.

	inlet of dust removal room	outlet of dust removal room	inlet of loading transfer area	inlet of paint spraying room	outlet of paint spraying room	inlet of unloading transfer area	inlet of UV-curing drying tunnel	outlet of UV-curing drying tunnel
Wind speed (m/s)	1	-1.5	4	0.5	-3	4	0.5	-2

4. Simulation results

4.1 Pressure field analysis

Figure 4 shows the simulation results of the entire system pressure, which indicate that the pressure difference between the various rooms in the entire production line meets the process requirements. The paint spraying room is under negative pressure, and the dust removal room, transfer areas and the UV-curing drying tunnel are under slightly positive pressure. The pressure in the loading transfer area is the largest, about 8Pa, and the pressure in the paint spraying room is the smallest, about -2 Pa. The lampshade is about 1.2 meters high from the ground in the entire system, so the simulation results of the pressure at the 1.2 meter height plane are shown in Figure 4. The results show that the minimum pressure area is at the exhaust of the Paint Spraying room, and the maximum pressure area is in the transfer area. From the perspective of pressure difference, the pressure in the loading transfer area is greater than the pressure in the dust removal room, and the pressure in the unloading transfer area is slightly greater than the pressure in the UV-curing drying tunnel.

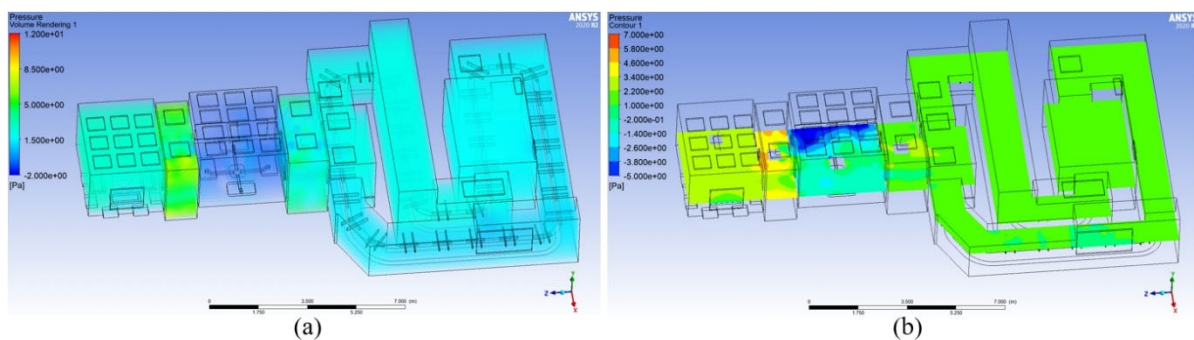


Figure 4. Pressure simulation results of (a) the whole system and (b) X-Z plane section.

4.2 Velocity field analysis

Figure 5 shows the velocity simulation results of the whole paint spraying system. The results indicate that the average wind speed in the transfer areas is the largest, followed by the paint spraying room and dust removal room. The average wind speed in the curing tunnel is the lowest and relatively stable, but the wind speed in some areas near the transfer areas is higher than the rest of the area. Similarly, the wind speed simulation results at the 1.2 meter height plane are shown in Figure 5. The results indicate that the wind speed inside the paint spraying room varies the most, and the maximum wind speed is at the exhaust port and located on one side near the loading transfer area, about 4m/s. The average wind speed in the dust removal room is lower than in the paint spraying room, and the wind speed of the area near the loading transfer area and the loading port is higher than that of the area on the other side. The wind speed in UV-curing drying tunnel is the lowest, averaging about 0.4m/s.

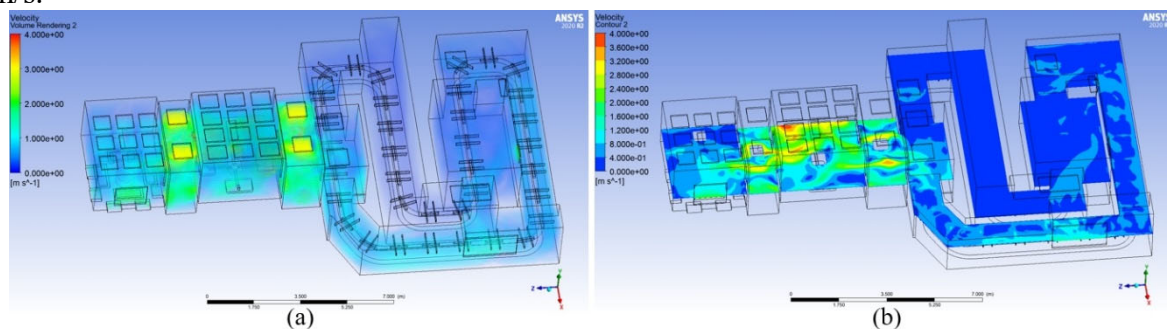


Figure 5. Velocity simulation results of (a) the whole system and (b) X-Z plane section.

In order to see the airflow direction of the entire system, half of the position of the entire paint spraying system in the X direction is selected as the section. The Y-Z section contains the passage

connecting the entire system. The airflow direction of the two adjacent areas can be simply determined by the airflow direction of the passage. Figure 6 shows the velocity simulation results of the Y-Z section. The direction of the red dotted arrow in the figure indicates the air flow direction between adjacent areas. The airflow directions of the transfer areas are outward, while the airflow directions of the paint spraying room are inward, and there is no polluted gas flowing outward, which meets the expected process requirements.

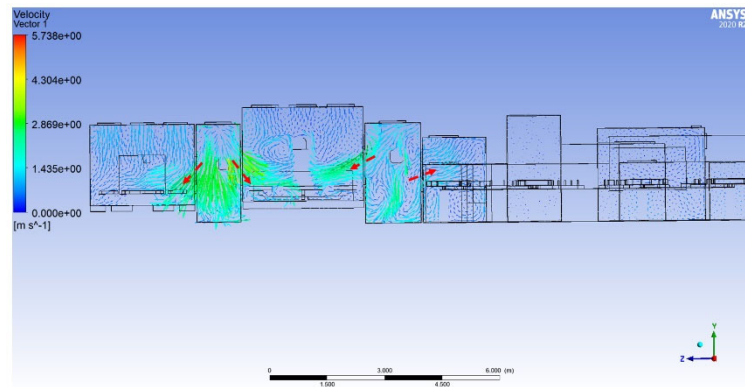


Figure 6. Simulation results of Y-Z section velocity.

Figure 7 shows the velocity simulation results of the X-Y section at the feeding port and the receiving port. The results indicate that the airflow direction at both the feeding port and the receiving port meet the process requirements, with the wind direction flowing outwards, effectively avoiding the entry of unclean air from outside into the paint system.

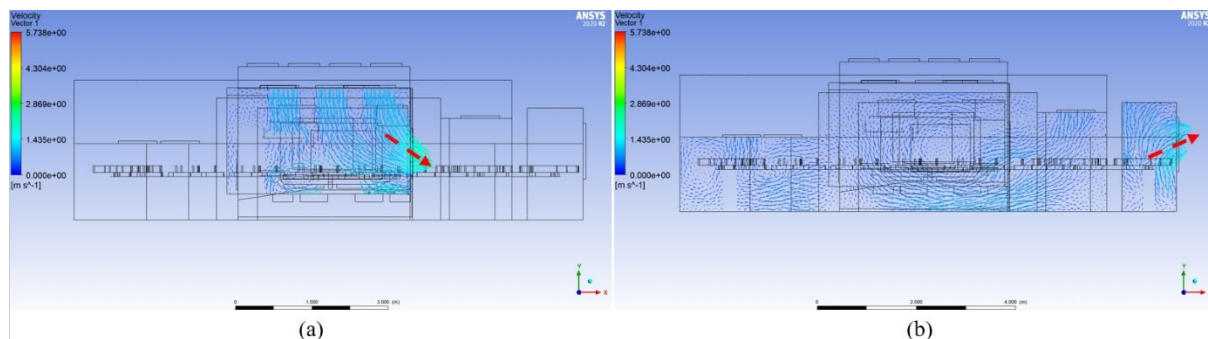


Figure 7. Simulation results of X-Y section velocity at the feeding port (a) and receiving port (b).

5. Conclusion

In this paper, the CFD software Fluent is used to simulate the airflow organization and movement in car lampshade paint spraying system. The simulation results show that under the reasonable inlet and outlet wind speed settings, it is possible to achieve pressure and wind direction control in each room of the paint spraying system, and to obtain an optimized solution that meets the requirements of the painting process environment. This paper also provides a reference for the ventilation scheme design of the painting system.

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