Study on the distribution characteristics of "Characteristic Ring" in irregular cross-section ventilation roadway

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Abstract. In order to study the airflow distribution in irregular cross-section roadway, the numerical simulation method were carried out to simulate the influence of hemispheres with radius of 100mm, 200mm, 300mm, and 400mm placed in different positions in the roadway on the distribution of “characteristic rings”. The results showed that concave body is not the key factor influencing the distribution of “characteristic ring” in ventilation roadway. Convex body is the key factor influencing the distribution of “characteristic ring”, the greater the ventilation velocity, the smaller the velocity gradient in the stable zone and the velocities in the stable area are more closely to the average velocity. As the increase of ventilation velocity, the velocity gradient is larger in transition zone. The size and position of the convex and concave bodies are not the key factors influencing the velocity distribution on the central axis of cross-section.

1. Introduction
The purpose of mine ventilation is mainly to provide fresh air to the workers and to dilute toxic and harmful gases. The actual cross-sections of roadway in the underground mine are mostly irregular shapes. Study on the influence of irregularity on the “characteristic ring” in the roadway is very meaningful to further determine the average velocity distribution and to guide the accurate monitoring of the velocity and air volume in the roadway and to realize the effective management of ventilation system.

At present, there are relevant achievements on the airflow distribution in the roadway, mainly focusing on the study of the airflow distribution in the regularly shaped roadway[1-5] and the study of the average velocity distribution[5-7], and some papers have studied the influence of supporting methods and personnel on airflow distribution and velocity measurement[8-10]. However, due to over-excavation and under-excavation, the actual cross-section of the underground roadway is irregular. While the influence of irregularity on the velocity distribution in roadway are rare studied. Therefore, this paper aim to analyse the influence of the irregularity of the three-centre arch section roadway at fully developed cross-section on the distribution of the "characteristic ring" by using simulation methods.

2. Numerical simulation method

2.1 Physical and mathematical model of irregular roadway
The 3D numerical analysis model is established according to the underground ventilation roadway. The roadway section is three-centres arch section, the roadway length is 100 meters, the cross-section width is 4.6 meters, wall height is 2 meters, arch height is 1.5 meters. In the underground roadway, the
roadway walls have certain irregularities. Therefore, in order to analyse the influence of irregularity on the "characteristic ring" of the roadway, the irregularity model were quantified and idealized, and hemispherical convex and concave bodies with radius 100mm, 200mm, 300mm and 400mm were selected to reflect irregularity of the wall. The convex and concave bodies are located at X=88m where the turbulence is fully developed in the roadway. The convex and concave bodies are respectively located at the top, middle and bottom of the wall of the three centres arch cross-section (called position 1, position 2 and position 3 respectively). The irregular roadway model and cross-sections with convex and concave bodies are shown in Figures 1 and 2 respectively.

As the concentration of gas and coal dust in the main horizontal roadway have been diluted for a certain time and distance, the mutual diffusion and heat exchange among gas and coal dust and airflow are ignored in the calculation process, and the physical model can be simply described as the flow of air along the roadway. In the numerical calculation, standard $\kappa$-$\varepsilon$ equation was adopted to calculate the turbulent flow of the fluid.
2.2 Boundary conditions and assumptions
The entrance of the roadway adopts the boundary condition of velocity inlet, and the exit of the roadway adopts the boundary condition of pressure outlet. The assumptions are as following: the air is incompressible; there are no workers, debris stacking and vehicles in the roadway; the wall of the roadway are insulated, and no mass flux and heat flux pass; and gas, coal dust and blasting smoke are ignored.

2.3 Parameters
According to the literatures [5-7], the distribution of average velocity on the cross section has no relation with the ventilation velocity in the roadway. Therefore, this paper selects three representative velocities in the simulation: 0.15m/s, 2m/s and 8m/s. The velocity inlet is 0.15m/s, 2m/s, 8m/s respectively, and the relative pressure is 0Pa. So the airflow distribution on the irregular cross-section in the fully developed turbulent roadway are simulated and calculated.

In order to compare the airflow distribution on irregular cross-section with regular cross-section, the airflow distribution in regular three-centres arch section roadway is also simulated in this paper. The calculation method and boundary conditions and physic model are consistent with the above-mentioned parameters, the differences are that the convex and concave bodies are removed.

3. The distribution of "characteristic ring" in the roadway with irregular cross-section

3.1 The influence of the location of the convex and concave bodies on the distribution of "characteristic ring"
When the roadway is irregularly shaped, convex and concave bodies will have a certain disturbance to the airflow in the roadway, and the distribution of "characteristic rings" on its cross-section would be affected to some extent. According to the literature [5], the distribution of "characteristic rings" on the cross section is related to shape of cross-section. The influences of the location of convex and concave bodies on “characteristic rings” were analysed firstly. Since the velocity in the underground roadway is generally between 1.5m/s~5m/s, the simulation conditions that the velocity is 2m/s and the radius of convex and concave bodies is 200mm are chosen. The velocity distribution at fully developed turbulence cross-section (X=88m) are shown in Figure 3.

![Position 1](image1.png)

![Position 2](image2.png)

position 1

position 2
It can be seen from Figure 3 that the velocity value in the concave body is very small, and the distribution of the "characteristic ring" is nearly not destroyed, so it can be considered that the concave body are not key factor to affect the distribution of "characteristic ring". When the convex body exists, the overall ring shape of the "characteristic ring" on the cross section hardly changes, but the velocity gradient of the "characteristic ring" changes from the centre of the cross section to the wall of the roadway. The "characteristic ring" near the convex body are deformed, and the deformation of the "characteristic ring" change with the position of the convex body change: the position of the convex body at position 1 and position 2 has a greater impact on the airflow than at position 3. The phenomenon can be explained as following: the distance between the convex body at position 3 and the centre of the "characteristic ring" is greater than the distance between the convex body at position 1 and position 2 and the centre of the ring. Meanwhile the highest velocity in the entire cross-section appears on the wall of the convex body, which is similar to the principle of the aircraft wing generating lift. Therefore, the velocity distribution around convex body’s surface can be explained by the velocity distribution characteristics of the upper surface of the aircraft wing section.

3.2 The effect of convex and concave bodies on the velocity gradient of "characteristic ring"

From the above analysis, we can see that the convex body has a certain effect on the velocity gradient of the "characteristic ring". The velocity gradient of the "characteristic ring" on the cross section under different convex body sizes and ventilation velocities were further quantitatively analysed. Through the above analysis, the distribution of "characteristic ring" at irregular cross-section is still a ring similar to the shape of the three-centres arch section. Therefore, the change of the velocity gradient on the central axis can be approximated as representative of the "characteristic ring" velocity gradient changes. The velocity distribution on the central axis of the three-centres arch section under different ventilation velocities and different convex and concave body sizes and positions are analysed, as shown in Figure 4.
convex body with radius 100mm

velocity distribution on the central axis (velocity = 0.15 m/s)

convex body with radius 200mm

velocity distribution on the central axis (velocity = 0.15 m/s)

convex body with radius 300mm

velocity distribution on the central axis (velocity = 2 m/s)

convex body with radius 400mm

velocity distribution on the central axis (velocity = 2 m/s)
In order to analyse the velocity gradient clearly, the velocity distribution on the central axis is divided into two areas, and the intersection points of the velocity distribution curve on the central axis when there is no convex body and a convex body are considered as the boundary points, and the velocity distribution on the central axis is divided into "stable zone" and "transition zone", as shown in Figure 5.

![Velocity distribution on the central axis](image)

Fig 4. Velocity distribution of the central axis at different velocities and radii (X=88m)

It can be seen from Figure 5 that the size and position of the convex and concave bodies have little effect on the velocity distribution on the central axis among 0.15m/s and 8m/s, but the airflow distribution on the cross section are affected by convex body. The velocity values in the "stable zone" on the central axis of the irregular cross-section are all smaller than the velocity value on regular cross-section. As the ventilation velocity increases, the distribution on “stable zone” is more smoother and the velocity is more closer to the average velocity. While the velocity value in "transition area" of...
the irregular cross-section is greater than or equal to the velocity value on regular cross-section, and as the ventilation velocity increases, the velocity distribution curve of the "transition area" is more steeper.

4. Conclusion
This paper aims to analyse the influence of irregularity and ventilation parameters on the distribution characteristics of "characteristic ring" in the roadway according to the characteristics of the underground roadway, and the distribution of "characteristic ring" in the irregular roadway were acquired. The results show that:

(1) The velocity in the concave body is very small, and it can be considered that it has almost no effect on the distribution of "characteristic rings".

(2) The "characteristic ring" near the convex body is deformed, and the deformation of the "characteristic ring" changes with the change of the position of the convex body. Meanwhile, the convex body will increase the velocity of its surface, and the highest velocity in the entire section appears on the surface of the convex body, which is similar to the higher velocity value of the upper surface of the aircraft wing section.

(3) The size and position of the convex and concave bodies are not the key factors to affect the velocity distribution on the central axis; The velocity in the "stable zone" of the irregular cross-section is less than the velocity on regular cross-section. As the ventilation velocity increases, the distribution on "stable zone" is more closer to the average velocity. While the velocity in "transition area" of the irregular cross-section is greater than or equal to the velocity on regular cross-section.

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