Falloff Angle of Wet spraying Machinery Nozzle and Shotcrete Quality Control

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Abstract. During the construction process, a lot of dust in wet spraying machinery threatens the health and safety of workers. This paper combines numerical calculation with experimental research to investigate the effect of the nozzle angle on the performance of the wet spraying machinery. The results show that when the falloff angle of the convergent section is less than 3°, the falloff angle has little effect on the spray of the concrete mass. However, with the increase of the falloff angle, the spraying velocity of material flow decreases and wear of the nozzle increases; when the convergent section falloff angle is greater than 6°, the outlet velocity of concrete is very small and the nozzle is easily blocked. When the falloff angle of convergent section is between 3°-6°, the nozzle has a better performance.

1. Introduction
In recent years, with the wide application of shotcrete support, concrete wet spraying machinery have been widely used in the construction of mine tunnels, railway or highway tunnels, water conservancy culverts, various underground projects, and military projects. Improper nozzle structural parameters will result in uneven discharging of nozzle, nozzle blockage and large amounts of dust, which will seriously affect construction safety and progress. At present, the range of nozzle falloff angles in engineering is relatively large and lacks certainty, which has a great influence on the performance of wet spraying machinery. In view of this, the research value of the nozzle falloff angle is prominent. In this paper, the numerical calculation and experimental research is used to study the effect of the nozzle's falloff angle on concrete spray performance. According to the results of numerical calculations, the structure of the nozzle will be fabricated, and then the correctness of the numerical simulation results will be verified by experiments. Finally, it will be applied to engineering practice [1-3].

2. The theoretical model of the numerical calculation of the internal flow field in nozzle

2.1. Characteristics of Shotcrete
The concrete is sprayed with compressed air from the nozzle. In the nozzle flow field, the mixed fluid has its own phase concentration, and the Euler standard phase is used to describe the air phase and the
particle phase [4]. Select any one of the microelements in the nozzle flow field, the size of which is small enough for the size of the entire flow field, yet sufficiently large for the size of the individual particles. There are sufficient number of particles within the microelements. Particle phase concentrations can be introduced in the calculation of continuous distribution of velocity, pressure, and volume fractions.

2.2. Selection of Multiphase Flow Models
The VOF model is suitable for free surface flow, while the mixed model and Euler model are suitable for phase mixing and separation in flow, or when the volume fraction of dispersed phase exceeds 10%. When the volume fraction of dispersed phase in the flow is less than or equal to 10%, Euler-Lagrange method analysis should be used. It is clear that the phase volume fraction of the mixed flow in this study exceeds 10%. Since the Euler model is more complex and its computational stability is worse than that of the hybrid model, convergence problems may arise, while the mixed model has a small amount of calculation (less equation than that of Euler model) and the calculation stability is better. Therefore, this study selects the mixed model for numerical calculation in FLUENT software [5-6].

3. Modeling of the internal flow field in the nozzle of wet spraying machinery

3.1. Boundary Condition Processing
Based on the nozzle of a certain type of wet spraying machinery, the 3D modeling software Solid works is used to establish the 3D internal flow field model of the nozzle and ANSYS ICEM for meshing. According to the characteristics of the flow field model in the nozzle, in order to determine the optimal number of mesh, six groups of models with a mesh number of 650,000 to 2 million were Selected for numerical calculation. Comparing the numerical results, it is found that after the number of the mesh reaches 1.5 million, the efficiency fluctuation is stable within 0.5%. Therefore, considering the computer performance comprehensively, the optimal number of mesh for the final calculation model is 1.5 million [7].

Figure 1. Diagrams of meshing.
4. Influence of the Falloff Angle on the Performance of Wet Spraying Machinery Nozzle

4.1. Numerical Calculation

In this study, falloff angles of the convergent sections were setting as 3°, 4°, 5°, 6°, and 7°, respectively in modeling, and the numerical calculation was carried out.

Figure 2. Velocity nephograms of different falloff angle nozzle horizontal section.
4.2. Analysis of resultant velocity field of the outlet section

When the pressure of the wet sprayer and the pumping pressure of the concrete are constant, the greater the outlet velocity of the concrete jet flow is, the more energy-saving the nozzle structure would be; the less contact between the concrete mass and the inner wall surface of the nozzle is, the less wear of the nozzle would be. The mean velocity of the outlet section $\bar{U}$ (1) is regarded as an assessment index for the analysis of the outlet section velocity field to analyze the mean velocity of the outlet section.

$$\bar{U} = \frac{1}{N} \sum_{i=1}^{N} U_i$$

(1)

Where $U_i$ stands for sampling point velocity of the outlet section (m/s); $\bar{U}$ stands for the average sampling point velocity of the outlet section (m/s).

Then extract velocity values of the sampling points of the nozzle outlet section with different falloff angles, and select the average value as shown in Table 1.

**Table 1.** Mean velocity of individual structure of outlet section.

| Falloff 3°  | Falloff 4°  | Falloff 5°  | Falloff 6°  | Falloff 7°  |
|------------|------------|------------|------------|------------|
| Mean value | 40.64      | 37.70      | 36.47      | 35.40      | 19.66      |

After that, import the data of even value into Origin and obtain the data fitting curve. As shown in Fig 3. From Fig3, it can be seen that when the falloff angle of the convergent section is less than 3°, the concrete group is considered to be transported in an approximately equal-diameter straight pipe, and the outlet velocity of the concrete does not change much; when the convergent section falloff angle is greater than 6°, the concrete transport velocity is very small and the nozzles are easily blocked.

**Figure 3.** Mean velocity fitting curve of different outlet section.
4.3. Analysis of Split Velocity Field at Exit Section

Due to the characteristic of the structure of wet spraying machinery nozzle, the air concrete mixture has a velocity along the x direction in the flow field, and a velocity component deviating from the main velocity, i.e., the y and z directions. The resultant velocity in y-z direction characterize the amount of drag force that deviates the air-concrete mixture from the main motion direction. Reducing the y-z direction velocity component at the nozzle is conducive to the reduce of the divergence at the outlet. And it can reduce the dust generation, if it is impossible to avoid the shot Crete coil sucking air. The ratio of the y-z direction resultant velocity of the outlet section of the nozzle model with different falloff angles to the velocity of the point x direction is regarded as the assessment index of the outlet section velocity field analysis:

$$U' = \frac{\sqrt{u_y^2 + u_z^2}}{u_x} \times 100\%$$ (2)

$$\overline{U'} = \frac{1}{N} \sum_{i=1}^{N} U'_i$$ (3)

Where $u_x$ stands for x direction velocity of sampling point of outlet section (m/s); $u_y$, y direction velocity of sampling point of outlet section (m/s); $u_z$, z direction velocity of sampling point of outlet section (m/s).

| Table 2. $U'$ Mean velocity of outlet section of different structures. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Falloff Angle 3°| Falloff Angle 4°| Falloff Angle 5°| Falloff Angle 6°| Falloff Angle 7°|
| Mean Velocity   | 0.03            | 0.05            | 0.05            | 0.06            | 0.08            |

From the analysis above, it is known that the velocity of YZ direction is related to the dust generation of the nozzle. From Fig. 5, it can be seen that with the increase of the falloff angle of convergent section, the amount of dust on the shot Crete site increases.
4.4. Nozzle Making and Testing

According to the previous analysis, nozzle structures with falloff angles of 4°, 5°, and 6° were fabricated as shown in Fig 5, and the on-site dust test was performed. The analysis of test results data is based on the Article 740 of the Coal Mine Safety Regulations for Coal Mine Enterprise's regulations for monitoring downhole dust production. The measured dust concentration is compared with the dust concentration specified in the Coal Safety Standard to check whether the total dust concentration and the respiratory dust concentration in the sprayed concrete work area are qualified. The total dust amount of the 4°-falloff angle nozzle structure is 7.8 mg/m³, and the respiratory dust is 2.5 mg/m³; the total dust amount of the 5°-falloff angle nozzle structure is 8.2 mg/m³, and the respiratory dust is 2.7 mg/m³; the total dust amount of the 6°-falloff angle nozzle structure is 9.0 mg/m³, and the respiratory dust is 3.3 mg/m³. The dust generated with the 4°-falloff angle nozzle structure is less. The comparison between the experimental results and the numerical simulation results shows that there is a good correspondence between the numerical simulation results and the test results.

5. Conclusion

In this study, the combination of numerical calculation and experimental research was employed to study the effect of the nozzle's falloff angle on spraying performance of concrete. According to the numerical calculation results, the nozzle structure was produced. The correctness of the numerical simulation results was verified by experimental research, and finally applied to engineering practice. The results show that when the falloff angle of the convergent section is less than 3°, the falloff angle has little effect on the spray of the concrete mass. However, with the increase of the falloff angle, the spraying velocity of material flow decreases and wear of the nozzle increases; when the convergent section falloff angle is greater than 6°, the outlet velocity of concrete is very small and the nozzle is easily blocked. When the falloff angle of convergent section is between 3°-6°, the nozzle has a better performance.

Acknowledgments

This work was financially supported by Natural Science Foundation of Anhui Provincial Education Department (No. 2016A828).

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