Simulation Research of Airflow in the Prefabricated Large Duct Elbow with Different Deflectors

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Abstract: For the large air duct with inner and outer arc elbows commonly used in engineering, the forms of setting internal deflector will led to different diversion effects, which will affect the airflow uniformity, energy and pressure loss as well as noise in the elbow. In this paper, the comparison of different diversion forms, spacing and number of pieces in large air duct with inner and outer arc elbow are carried out. This paper aims to provide reference for engineering construction by using visualization technology.

1. Preface
The definition of large air ducts is an air duct that has a long side or a diameter greater than 2m and can be commonly found in the interior of large buildings. In order to save building space or meet the needs of system layout, such air ducts are often used as the medium of air flow. According to the requirements of national standard "Code for Acceptance of Construction Quality of Ventilation and Air Conditioning Engineering" GB50243-2016[1], except for the elbows that both inside and outside bends are curved, other elbows with side length greater than 0.5m shall be equipped with deflectors. However, In the national standard "Code for Construction of Ventilation and Air Conditioning Engineering" GB50738-2011[2], it is further defined that the setting form of deflectors is monolithic form and crescent form, the number of deflectors should be determined by the result of side length divided by the multiple of 500, the maximum of the number of deflectors should not be more than 4 and the deflector spacing can be equal or change gradually. In the subsequent publication of the industry standard "Technical Specification for Ventilation Ducts" JGJ141-2017[3], the setting position and number of deflectors for rectangular duct with elbows that both inside and outside bends are curved commonly used in engineering are also recommended accordingly.

In the large air duct elbow, because the air distribution cannot be obtained by traditional visualization means, and different types of deflector led to different Diversion effect, which directly affects the energy loss and noise level of the air flow in the elbow. For extra-large air ducts, when the number of deflectors is set to exceed 4, the interference degree of deflector spacing on the diversion effect also needs to be further explored. This paper is supported by funds of "Development of Integrated Platform and Key Technology of Equipment for Industrial Construction on Construction Engineering Site" (No.: 2018YFC0705800) and "Research on Industrial Construction Technology of Electromechanical Installation" (Annual Scientific Research Plan of Shanghai Construction Engineering Group: 17 JCSF - 30). Taking The large air supply pipe in the electromechanical engineering of Shanghai Xinzhuang Metro Comprehensive Development Project as the simulation object and using the Computational Fluid Dynamics, Computational Fluid Dynamics, hereinafter
referred to as "CFD") method to reveal the influence of different diversion forms on the air flow inside elbows with both inside and outside bends are curved in large duct, so as to obtain the optimal diversion method.

2. Introduction of CFD and establishment of simulation model

2.1 Introduction of CFD
As a branch of fluid mechanics, CFD technology was first used in the aerospace field and in the end of last century, the technology has been widely available to the ventilation and air conditioning, health care and nuclear industry. The biggest advantage of CFD is visually predicting the flow experiments that can be unable or difficult to realize traditionally, such as water flow, the flow of air flow or current, thereby reducing some experiments in high cost, high risk and harsh environment. Through prediction, problems can be found in the early stage in time and deepened modification can be made in time. In the field of engineering construction, a large number of modifications and rework can be avoided in the later stage. Therefore, this technology has been widely used in structural construction, mechanical and electrical installation and decoration engineering.

2.2 Establishment of the model
According to the design drawings of Xinzhuang Metro Engineering of Shanghai, the size of the largest ground-based rectangular supply air duct in the project is 4m×1.2m. In the simulation software, a section of air duct is set as the basic research objection according to the layout of the drawings, and the upper and lower sections of the elbow are respectively equipped with 1m straight pipe sections. Referring to the requirements of the above specifications, the radius of curvature of the elbows that both inside and outside bends are curved is the side length of a plane. The plane is smooth, the inner arc of the deflector is concentric with the elbow and the chord length is equal to the inner arc of the air duct.

By conducting the simulation, following issues will be discussed and resolved:

(1) The large elbows that both inside and outside bends are curved itself has a good flow diversion effect. Will a deflector being set inside it further optimize the air flow? In this paper, a comparison was made between the non-diversion model and the 4-piece monolithic deflector with gradual spacing model.

(2) It is stipulated in the specification that the number of deflectors should not be more than 4. Can the diversion effect be enhanced by increasing the number of deflectors in extra-large air ducts? In this paper, a comparison was made between 4-piece monolithic deflector with same spacing model and 6-piece monolithic deflector with same spacing model.

(3) The specification emphasizes the optional form and spacing of the deflector, but there is no strict limitation. In this simulation, 4-piece monolithic model and 4-piece crescent model are set; A comparison of prediction effect was made between 4-piece monolithic deflector with same spacing model and 4-piece monolithic deflector with gradual spacing model.

Fig.1. 4-piece monolithic deflector with gradual spacing elbow and air duct model
2.3 **Boundary conditions and calculation Settings**

In this simulation model, the inlet air velocity of the duct is set as 4m/s, and the parameters of the air duct (density, conductivity coefficient, roughness, etc.) are set according to the thin steel plate. The parameters of the airflow in the air duct are set according to the air. As the simulation studied the flow of the airflow in the elbow, the influence of temperature on it is ignored and the temperature is set to normal condition. When modeling in the early stage, the unstructured grid is selected in order to better match the complex models such as arc elbow, crescent deflector and rectangular straight air duct.

| Name               | Boundary type     | Note                                                |
|--------------------|-------------------|-----------------------------------------------------|
| The wall of air duct | Wall              | Parameters are set according to the steel plate     |
| Air inlet          | Velocity-inlet    | Wind speed is set as 4m/s                           |
| Air outlet          | Outflow           | /                                                   |
| Deflector          | Wall              | Parameters are set according to the steel plate     |

The number of grids of different computing models are between 600000 and 800000. At the same time, under relaxation technology is introduced to effectively prevent the divergence in the calculation process, such that to improve the convergence of calculation and make the simulation more suitable for the actual working conditions. In order to improve the accuracy of the flow field with high Reynolds number, the k-ε equation is used and the non-equilibrium wall function is introduced to modify the equation.

3. **Calculation result analysis**

3.1 **Influence of deflector setting on airflow in the elbow**

Fig.2 is the comparison between the effect of non-diversion and the 4-piece monolithic deflector with gradual spacing model in large elbow. The center surface of the air duct is selected in the calculated model for visual analysis. It can be seen from the figure that setting monolithic deflectors with gradual spacing according to the recommended distance in “Technical Specification of Ventilation Ducts “JGJ141-2017 helps to uniform the airflow in the elbow. The specification performances are represented by the velocity difference in the elbow and the reduction of the area of high-speed flow. The high-speed flow area without diversion form is concentrated in the inner arc of the elbow, where the airflow is pushed by the subsequent airflow. Compared with the outer arc area, the inner arc part is unable to diffuse outward due to the limitation of the flow area, so the flow velocity is increased compared with the initial condition. The maximum flow velocity is greater than 6m/s. When the deflectors are set, the high-speed airflow in the inner arc is blocked and the high-speed flow area expands outward. The maximum flow velocity is about 5m/s.

![Fig.2. Comparison of velocity field between non-diversion model and 4-piece monolithic deflector with gradual spacing model](image-url)
There is obvious stratification in the velocity field at the non-diversion elbow, indicating uneven airflow. However, the stratification in the velocity field is well inhibited after the diversion. Except for the external high-speed area, the velocity near the deflectors is about 3.5m/s. Only the inner arc area of the deflector is affected by the structure and the flow velocity drops to about 2.5m/s. Fig. 2 reveals that the setting of the deflector with gradual spacing has a certain optimization on the air distribution in the elbows that both inside and outside bends are curved. After stabilization, the outlet wind speed of the air duct without diversion is about 3.8~3.9m/s, while the outlet wind speed after diversion loses about 0.3m/s and the flow velocity are about 3.5m/s due to the influence of the structure of deflector. The above structure reveals that the deflector plays a certain role in improving the uniformity of the air flow in the air duct system, but it will affect the air speed. Therefore, it is recommended to use the deflector to reduce the noise when the noise reduction requirements are stringent. However, it is recommended not to use the deflectors to increase the energy saving effect for the inner and outer arc elbow, especially in the exhaust duct or smoke exhaust duct in general occasion.

3.2 Influence of the number of deflectors on airflow in the elbow

Fig. 3 is the comparison of the influence of the number of deflectors on the airflow in the elbow. It can be seen from the figure that after the deflectors are set, the limitation of the flow area in the outer arc has a great influence on the airflow velocity. The increase of the deflectors can further increase the flow uniformity in the inward arc region of the deflectors. But it also leads to the further enhancement of the high-speed flow due to the reduction of the flow area behind the deflectors. The increase of the deflectors does not make an overall improvement on the flow uniformity in the elbow because the velocity difference is enlarged. The huge impact of force caused by high-speed airflow in large elbows will increase the vibration of the wind pipe wall, so the external arc cracking is easy to occur. It is suggested that this place should be reinforced in engineering construction.

According to the comparison between Fig.3 (a) and Fig.2 (b), it can be seen that the setting of the gradual space-increasing deflector is better than the isometry deflector. The specification performance is represented by the reduction of the airflow velocity difference inside the elbow, which is also caused by the influence of the flow area at the outer arc of the elbow. Comparing with Fig.2 (a), the flow velocity at the outlet section of the air duct is not uniform due to the use of isometry deflector, although the overall flow velocity loss is small. In general, isometry deflector is not recommended for elbows that both inside and outside bends are curved.

3.3 Influence of the type of deflector on airflow in elbow

Fig.4 is the diversion effect of crescent deflector in the elbow. The maximum velocity of the outer arc area is about 5.5 m/s, which is basically similar to monolithic deflector. However, the uniformity of the air flow in the deflector and the overall airflow is slightly worse than that of the monolithic deflector, but obviously better than the form without diversion. Compared with Fig.4 (a) and Fig.2 (b), the specification performances are represented by the increasing area of outer arc high-speed flow field and the great velocity difference between the both sides and the middle of the deflector. As
shown in Fig. 4, the flow direction of the airflow reveals that the flow direction of the high-speed flow field in the outer arc region is chaotic and there is a small shunt phenomenon, which has also been confirmed in the simulation of other setting form of deflector. In the comparison of the outlet speed of the air duct, the crescent deflector can improve the wind speed about 0.2m/s compared with the monolithic deflector and the uniformity of the outlet section is similar to that of the monolithic deflector. The simulation results show that when considering the production process and cost, it is recommended to use monolithic deflector in the inner and outer arc elbow. When considering the comprehensive effect of energy saving and noise reduction, it is recommended to use crescent deflector.

![Distribution of flow field](image1.png)  ![Analysis of flow direction](image2.png)

**Fig.4. the diversion effect of crescent deflector**

4. **Conclusions**

In this paper, the influence of different forms of deflector, deflector spacing and the number of deflectors on duct elbow airflow is compared. The following conclusions are drawn:

1. When the deflector is set, the flow area of the outer arc field is the key factor to determine the high-speed flow in the elbow. It can be concluded from the simulation results that the diversion effect of gradual-change spacing form is better than the isometry form.

2. The setting of deflector can solve the phenomenon of velocity stratification in the elbow and the setting of different deflector will lead to different diversion effect. According to the requirements of the specification, the number of deflectors is recommended to be set no more than 4 pieces.

3. The shape of the deflector has minor influence on the overall flow channel. The monolithic diversion and crescent diversion have their own advantages. The flow field uniformity in the elbow of monolithic diversion is slightly better than that of crescent diversion, while the pressure loss of the latter is less than that of the former.

4. The stratification of flow velocity in the large non-diversion elbow is serious, which may lead to the vibration of the air duct after long-term use. Therefore, for places with strict acoustic control, it is recommended to set a certain number of deflectors in the elbow.

**Reference**

[1] Code for Acceptance of Construction Quality of Ventilation and Air Conditioning Engineering GB50243-2016[S], Beijing.

[2] Code for Construction of Ventilation and Air Conditioning Engineering GB50738-2011[S], Beijing.

[3] Technical Specification for Ventilation Ducts JGJ141-2017[S], Beijing.