Study on the characters of control valve for ammonia injection in selective catalytic reduction (SCR) system of coal-fired power plant

Che Yao1,2*, Tao Li1, Zhang Hong1, Zhou Yanming1,2
1-State Grid Hunan Electric Power Corporation Research Institute, Hunan Changsha, 410007
2-Hunan Xiangdian Test & Research Institute. CO. LTD. Hunan Changsha, 410004
syww1986@163.com

Abstract. In this paper, the characters of two control valves used for ammonia injection in SCR system are discussed. The linear/quadratic character between pressure drop/outlet flow rate and valve opening/dynamic pressure inlet are investigated using computational fluid dynamic (CFD) and response surface analysis (RSA) methods. The results show that the linear character of brake valve is significantly better than butterfly valve, which means that the brake valve is more suitable for ammonia injection adjustment than the butterfly valve.

1. Introduction
With the proposed low-emission technology of coal-fired power plants, the NOX emission limit for coal-fired boilers is reduced from 50mg/m³ (100mg/m³ in key areas) from <GB 13223-2011 Thermal Pollutant Air Pollutant Discharge Standard>, which means a new challenge to the control precision and regulation sensitivity of existing coal flue gas de-NOX technology[1,2]. The problem of uneven injection of ammonia in SCR system is becoming more and more important, and it is necessary to ensure the rapid response and linear regulation of spray ammonia control valve[3,4]. In this paper, the use of Computational fluid dynamics technology and Response surface analysis method investigate the response characteristics of typical butterfly valve and gate valve pressure drop and outlet flow rate to different valve opening and inlet flow velocity, analysis of the type of control valve for ultra low emission sprinkler adjustment and its regulation of linear correlation.

2. Models and methods
In this paper, the response surface test is designed by the center and the CFD technique is used to simulate the test of the group, and the response of the valve pressure loss and the outlet flow velocity to the valve opening and inlet flow velocity are obtained.

2.1. Response surface analysis method
In response surface analysis, a Box-Wilson central composite design, commonly called a central composite design, contains an imbedded factorial or fractional factorial design with center points that is augmented with a group of 'star points' that allow estimation of curvature. If the distance from the center of the design space to a factorial point is ±1 unit for each factor, the distance from the center of the design space to a star point is |α| > 1. The precise value of α depends on certain properties desired for the design and on the number of factors involved[5].
Similarly, the number of center-point runs the design is to contain also depends on certain properties required for the design.

![Central Composite Design](image)

**Figure 1. Generation of a Central Composite Design for Two Factors**

A central composite design always contains twice as many star points as there are factors in the design. The star points represent new extreme values (low and high) for each factor in the design. Figure 1 illustrates the relationships among these varieties.

2.2. **Theory of CFD method**

The theoretical basis of CFD is similar to the theoretical basis of fluid mechanics, the mass conservation equation, the momentum conservation equation (Newton's law of motion) and the energy conservation equation (the first law of thermodynamics) are the cornerstones and cores of CFD theory.

3. **Results and discussion**

3.1. **Fluid characteristic of typical butterfly valve**

Firstly we discuss the response of pressure drop (ΔP) and outlet Z-velocity (ZV) to the valve opening (VO) and inlet dynamic pressure (P_d). The analysis range of VO (°) and P_d (Pa) are set at (30, 60) and (50, 100). The result of CFD modelling is shown as Figure 2&3 and RSA result is shown as Figure 4&5.

![Pressure Distribution](image)

**Figure 2** Impact of butterfly valve opening and P_d inlet on total pressure distribution of outlet surface

As can be seen from the results, VO has negative effect on ΔP and positive effect on ZV, meanwhile, P_d has positive effect on ΔP and negative effect on ZV. In the inspection interval of
VO&ΔP, all effects are significant due to the RSA results. With the increase of VO and P_d, the difference between max&min value of outlet total pressure became smaller, and the distribution of outlet total pressure tend to be more uniform as shown in figure 2. Larger outlet total pressure means less ΔP in the injection pipeline.

Figure 3 Impact of butterfly valve opening and P_d inlet on ZV distribution of outlet surface
At the meantime, the increase of VO and P_d indicate the smaller difference between max&min value of outlet ZV, and the distribution of outlet ZV tend to be more uniform as shown in figure 3. Larger outlet ZV means less fluid loss for the ammonia injection.

Figure 4 Response of pressure drop to the variation of VO and P_d inlet
As we insert the data into RSA test sheet, the 2D&3D features of response surface of ΔP are shown in figure 4. The response of ΔP to the variation of VO and P_d inlet appear to be quadratic relation, and the quick response zone is at the relative high value zone of VO and relative low value zone of P_d, which means the adjustments of VO and P_d are only significant in the quick response zone, at the lower value zone of VO and high value zone of P_d, the response of ΔP is more relatively retardant.
At the meanwhile, the 2D&3D features of response surface of ZV are shown in figure 5. The response of ZV to the variation of VO and $P_d$ inlet appear to be quadratic relation too, and the influence of $P_d$ is more significant than VO, and the quadratic relation means the adjustments of VO has no significant impact on ZV compared to the $P_d$ effect, and the response of ZV is more relatively retardant to the change of VO.

3.2. Fluid characteristic of typical brake valve

Then we discuss about the response of pressure drop ($\Delta P$) and outlet Z-velocity (ZV) to the valve opening (VO) and inlet dynamic pressure ($P_d$). In case that the opening of brake valve can not be set too low, so the analysis range of VO (%) is set at (40, 80) and $P_d$ (Pa) are set at (50, 100). The result of CFD modeling is shown as Figure 6&7 and RSA result is shown as Figure 8&9.

As can be seen from the results, similar as the butterfly valve, VO of brake valve has negative effect on $\Delta P$ and positive effect on ZV, meanwhile, $P_d$ of brake valve has positive effect on $\Delta P$ and negative effect on ZV. With the increase of VO and $P_d$, the difference between max&min value of
outlet total pressure became smaller, and the distribution of outlet total pressure tend to be more uniform as shown in figure 6, and the uniformity is better than butterfly valve as shown in figure 2.

Figure 7 Impact of brake valve opening and P_d inlet on P_d distribution of outlet surface
At the meantime, the increase of brake valve’s VO and P_d result in a smaller difference between max&min value of outlet ZV, and the distribution of outlet ZV tend to be uniform as shown in figure 7, and the uniformity is much better than butterfly valve as shown in figure 3.

Figure 8 Response of ΔP to the variation of VO and P_d inlet
As we insert the data into RSA test sheet of brake valve, the 2D&3D features of response surface of ΔP are shown in figure 8. The response of ΔP to the variation of VO and P_d inlet appear to be linear relation, which means the adjustments of brake valve’s VO and P_d are significant in the whole response zone, and the impact of VO is far more significant than P_d as shown in the 3D response surface.

Meanwhile, the 2D&3D features of response surface of ZV are shown in figure 9. The response of ZV to the variation of brake valve’s VO and P_d inlet show a prominent linear relation, and the influence of VO is far more significant than P_d, which means that the VO control of brake valve is
extraordinary suited for ammonia injection adjustment, and this control effect can follow the unit load change quickly and precisely.

Figure 9 Response of ZV to the variation of VO and \( P_d \) inlet

4. Conclusion
Above all, after the CFD&RSA analysis of adjustment characters comparison between butterfly valve and brake valve, several conclusions can be summarized as follow:

1) The brake valve has better regulation performance than the butterfly valve due to its significant linear adjusting character;
2) The brake valve can quickly and precisely response to the variation of unit load by changing VO value, which results in the high-efficiency operation of SCR system.

Consequently, the brake valve is more suitable for ammonia injection adjustment in SCR system than the butterfly valve.

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