Experimental and Numerical Study on the Tee Resistance Reduction in Ventilation and Air Conditioning

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Abstract. Energy consumption due to duct resistance accounts for approximately 30–50% of the total energy consumption in central air conditioning systems. Three resistance reduction methods of dividing flow tees in a ventilation and air-conditioning duct are studied. A reasonable position for installing the guide vane is proposed. The form of the guide vane and the cambered surface are optimized. The resistance characteristics of the tee are analyzed. The implementation effect of optimizing a tee is verified through a full-scale experiment. The results show that the resistance reduction rate of the proposed guide vane is 18.3% to 65.1% under different resistance reduction methods. The calculated results are verified by a full-scale experiment and by previous studies, ensuring the accuracy of the present study.

1. Introduction
The energy consumption of fans in central air conditioning systems account for approximately 30% of the total energy consumption and can reach 50% in partial central air conditioning systems with greater duct resistance. Therefore, reducing duct system resistance, especially the resistance of the local components in duct systems, is important [1-2].

The guide vane is a common and easily applied method to reduce the resistance of local components. Lorenzini (2015) studied the enhancement of the heat transfer of a curved guide groove, showing that the minimum pressure loss can only be obtained with a reasonable guide vane setting[3]. Rashidian (2016) studied the influence of guide vanes at different axial positions on the temperature distribution and emission of a biomass combustor, showing that the ability of the guide vane at different axial positions to reduce the emissions of CO and CO2 differs[4]. The aforementioned studies show that guide vanes can indeed optimize the flow field and reduce resistance, but further research is necessary.

The components(such as tee) were firstly studied by Miller and Gilman[5-6]. And those structure have remained unchanged for half a century. We can optimize the form of the guide vane in the tee and the tee’s cambered surface.This study focuses on the resistance and consumption reduction of local components represented by the split-flow tee, which not only saves energy considerably, but also provides ideas for the resistance reduction of other Ventilation and air conditioning ducts.

2. Assumptions in this study
The study assumes that the reduction of the local resistance of the tee duct consider the unfavorable circuit. The two typical layout types of the air duct used in actual practice are shown in Figure 1.

Several studies have shown that the resistance problem of local residence components is the energy dissipation under the action of fluid deformation [7-8]. The \( \varphi \) is the portion of the mechanical energy converted to heat energy due to the viscous effect, and is calculated as follows:
\[ \phi = \mu \left\{ 2 \left[ \left( \frac{\partial u}{\partial x} \right)^2 + \left( \frac{\partial u}{\partial y} \right)^2 + \left( \frac{\partial u}{\partial z} \right)^2 \right] + \left( \frac{\partial u}{\partial y} + \frac{\partial u}{\partial z} \right)^2 + \left( \frac{\partial u}{\partial z} + \frac{\partial u}{\partial x} \right)^2 + \left( \frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} \right)^2 \right\} \] (1)

Where \( \mu \) refers to the viscosity coefficient; \( u \) denotes the flow velocity; \( x, y \) and \( z \) represent the \( x \) coordinate, \( y \) coordinate and \( z \) coordinate, respectively.

3. Methods
To determine the proper effect of tee resistance reduction, we here use a combination of numerical simulation and experimental verification. The RSM model was chosen in this numerical simulation. An unstructured grid is used in the tee and the structured grid is used in outside the tee (all straight ducts). The experimental system is composed of a fan, a flexible joint, a plenum chamber, a turbulent plate, a rectangular air duct, a circular arc standard tee, a reducer and valves.

4. Results and discussion
4.1. A reasonable position for installing the guide vane

The branch duct direction is the aim resistance reduction direction. \( a/L3 \) refers to the position of the guide vane. The optimal guide vane position of these five tees under the same velocity ratio \((V_3/V_1=0.1)\) is the same at \( a/L3=0.3 \); The range of resistance reduction rate is 18.3% to 39.1%.
4.2. Form optimization of a tee guide vane

The form of the traditional guide vane is rectangular, and we try to change the form of the guide vane. The resistance reduction direction is the direction of the straight pipe. Through research we found that L1 is the optimized form. Although the resistance reduction rate of K123 is the highest in theory, the actual value is low using current technology and investment ratios. The optimization of form and size with respect to the resistance reduction rate is shown in Figure 4.

![Fig. 3. Schematic for form Optimization](image1)

![Fig. 4. Resistance Reduction Rate of Different Forms of the Guide Van](image2)

4.3. Cambered surface optimization

The study assumes that the reduction of the local resistance of the tee main duct does not need to consider the one-way resistance of the tee branch duct. The optimization process was shown in Figure 6. A final resistance reduction ratio of 42.59% is obtained.

![Fig. 5. Schematic for surface optimization](image3)

![Fig. 6. Resistance reduction rate of different cambered surface curves](image4)

4.4. Analysis of turbulent dissipation rate

Taking cambered surface optimization as an example to analyze turbulent dissipation rate. With the protrusion of the Arc A cambered surface, the energy dissipation intensity of the cambered surface decreases, see Figure 7. The Arc B cambered surface of TN cut down the energy dissipation intensity.

![Fig. 7. Energy Dissipation Field in the Tee: (a) Longitudinal Section; (b) Cross Section](image5)
of the duct’s side wall. The Arc C cambered surface with a certain tilt angle allows the boundary layer above it to be thin, and energy dissipation decreases.

4.5. Experimental verification analysis

![Fig. 8. Experimental Verification: (a) A reasonable position; (b) Form optimization of a tee guide vane; (c) Cambered surface optimization](image)

To verify the tee’s resistance reduction effect, the full-scale experiments are carried out to measure the resistance. With an increased horizontal ordinate, the simulation results are consistent with the experimental values as well as the results of previous studies. The simulation result is closest to the experimental data, because the tee structure sizes are the same under the simulation and experiment.

5. Conclusions

To improve the traditional tee used in the field of ventilation and air-conditioning, the following third methods were performed in this study. The study conclusions are summarized as follows:

- The rule of the optimal guide vane position of a T-shaped tee composed of different sizes is basically similar: if V3/V1=0.1, the optimal guide vane position is recommended at a/L3=0.3;
- According to the form optimization of the tee guide vane, the optimal resistance reduction rate is 65.1%;
- A total of six sets of curves were optimized for the four cambered surface of the tee. The resistance reduction rate of the optimized cambered surface structure tee is 42.6%;
- The three resistance reduction methods reduced the amount of mechanical energy convert to internal energy, and appreciably reduced the turbulence energy dissipation;
- A consistent trend was observed and good agreement was achieved between the experimental and simulated numerical results.

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