EXPERIMENT AND ANALYSIS OF INDUCTION AIR-CONDITIONING SYSTEM IN TRAIN

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ABSTRACT
With the rapid development of the train, people pay attention to air quality. The study on the airflow behavior in the air-conditioning passenger car is one important part of the modern air-conditioning passenger car technology, which is the base of further studies on air behavior, thermal comfort, and air quantity. The induction unit (IDU)——the terminal equipment of induced draft system is studied in this paper. Aiming at this IDU, some experiments was done to investigate its characteristic, including fluid field of return air inlet and supply air outlet, velocity decrease of supply air outlet resistance characteristic and induction ratio. Moreover, considering the thermal comfort of passenger, the noise of IDU is measured. By analyzing three kinds of IDU and each capability, the last optimized scheme is brought forward in the end. The result is instrumental and of guidance significance for the design, construction and program similar system; What’s more, it has established the foundation for the research in the future.

INDEX TERMS
Air-condition in passenger train, IDU, Induction ratio, Optimization scheme

INTRODUCTION
All air induction air-conditioning system is not only suitable to in ordinary train, but also in high-speed train. Compared to the special demand of air-conditioning system in high-speed train, all air induced draft system has some advantages as follows: 1) The pipe room is saved. 2) Air quality and comfort in train is improved. 3) The stabilization and dependability of system is high. 4) The location of set is low. 5) The system can be controlled independently. 6) Because the IDUS are installed under the windows, hot air touches the glass firstly in winter. Correspondingly condensation and dewfall are eliminated (Shi X. 2000.3).

PRINCIPLES OF INDUCTION SYSTEM AND EXPERIMENTAL DEVICES
Work principle of induction system
In the induction air-conditioning system, the primary air handled centrally is induced into the IDU in the air-condition room by fan, and then comes into plenum chamber of IDU, finally is shot in high speed by nozzle. Because of the negative pressure in the IDU made by induction of the high-speed jet, the secondary air is sucked in IDU, and mixed with primary air, lastly enters the room through supply air outlet. The primary air is usually fresh air, but some return air is adopted when it is necessary. The IDU is the air terminal unit which is set up in each room, including plenum chamber, nozzle and coil. Induction ratio is an important performance of IDU. The Formula of induction ratio can be described as follows:

\[ n = \frac{G_2}{G_1} \]  \hspace{1cm} (1)

Where, \( G_1 \) is the primary air volume. \( G_2 \) is the secondary air volume.

Experimental devices
Variable-speed fan is adopted in the supply air system. Considering economy and practicability, Model I IDU is designed for the coach in train. After testing it, such as induction ratio, noise air volume and so on, the Model II and Model III IDU are designed to compare (W.P.Janes. 1997).

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Table 1: dimension of Model I  II  III IDU

<table>
<thead>
<tr>
<th>Name</th>
<th>Size of Model I IDU (mm)</th>
<th>Size of Model II IDU (mm)</th>
<th>Size of Model III IDU (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDU</td>
<td>520×80×550</td>
<td>410×90×500</td>
<td>510×80×500</td>
</tr>
<tr>
<td>Supply pipe diameter</td>
<td>130×70</td>
<td>130×60</td>
<td>130×63</td>
</tr>
<tr>
<td>Plenum chamber</td>
<td>520×80×250</td>
<td>410×90×200</td>
<td>510×80×200</td>
</tr>
<tr>
<td>nozzle</td>
<td>14×D15</td>
<td>15×D20</td>
<td>19×D20</td>
</tr>
<tr>
<td>Return air inlet</td>
<td>450×70</td>
<td>360×90</td>
<td>450×90</td>
</tr>
<tr>
<td>Supply air outlet</td>
<td>500×60</td>
<td>400×80</td>
<td>500×70</td>
</tr>
<tr>
<td>Mixing box</td>
<td>520×80×300</td>
<td>410×90×300</td>
<td>510×80×300</td>
</tr>
</tbody>
</table>

EXPERIMENTS AND ANALYSIS OF IDU PERFORMANCE

Through the comparison of three kinds of IDU, final optimization schemes are presented.

Study on velocity uniformity of nozzle

Experiments are carried out in two different conditions. Multi-channel thermal anemometers are used in the tests.

There are fourteen jets in Model I IDU. The seven test points are located two point five centimeters above the nozzles and are in the center of the nozzle in level. In the condition I, primary air is brought into plenum chamber in which has splitter. The velocity profile of nozzle is uniform in the common role of plenum chamber and splitter. In the condition II, the primary air is also brought into plenum chamber in which the velocity pressure is turned into static pressure. Then the air passes through splitter, and effuses form nozzles. In the latter, for simplifying the test, only four test points are located. The diversity factor is taken to evaluate the non-uniformity. It can be describe as follows:

\[ n = \frac{v_{\text{max(min)}} - v}{v} \]  \hspace{1cm} (2-2)

Where, \( v_{\text{max(min)}} \) —— maximum or minimum velocity of nozzle, m/s;
\( v \) —— mean velocity of nozzle, m/s;
\( n \) —— diversity factor.

The diversity factor can be got from the data according to formula 2-2. Table 2 describes it in details.

Table 2: velocity table of nozzle in two conditions (Unit: m/s)

<table>
<thead>
<tr>
<th>Test points</th>
<th>Condition 1</th>
<th>Condition 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>14.3</td>
<td>12.0</td>
</tr>
<tr>
<td>Average</td>
<td>14.1</td>
<td>11.6</td>
</tr>
<tr>
<td>n (%)</td>
<td>4%</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

From the table 2, the velocity profile of nozzles is uniform when the splitter is installed in front of nozzle. Diversity factor is so small that the non-uniformity of nozzle velocity can be neglected.

Analysis of induction ratio

Induction ratio is an important characteristic of IDU. In the same condition, the IDU with larger induction ratio should be chosen. Firstly, when the total air volume is same, the primary air requirement is smaller than the ones with smaller induction ratio. As a result, air volume handled by air-conditioning unit is reduced heavily, so the energy is saved. On the other hand, the duct size of primary air is reduced and occupied space is saved accordingly. Secondly, fresh air requirement probably meets the need of primary air volume. Secondary air system can be
avoidable. Therefore, the system is simplified and capital expenditure decreases. But too little fresh air can low the comfort, when too large induction ratio is designed.

Induction ratio is a quantity associated with structure of IDU. There are many factors effecting induction ratio, such as size of return and supply air grille, fan head, duct resistance, mode and arrangement of nozzle, etc. There are many ways of raising induction ratio. It can be concluded as follows:

1. Changing the structure of IDU is. In general, the available way is that changing the arrangement of nozzles, turning the single row grilles into doubles, and using jets instead of spouts.

2. Fan with small head is adopted in the condition of same primary air volume.

3. Raising the dimension of return and supply air grille in order to raise induction ratio.

The tests show that the induction ratio of IDU with nozzle won’t be too large to lack enough fresh air. So how to raise the induction ratio is the only question needed to consider (Mats Sandherg 1998).

**Noise test of Model III IDU**

The noise of air-conditioning plays an important part in affecting people’s comfort in train. So in the test (The size of supply air grille is 500mm×60mm, and that of return air grille is 450mm×50mm.), the noise is measured. Taking Model III IDU for example, table 3 discusses it in details.

<table>
<thead>
<tr>
<th>Fan frequency (Hz)</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle velocity (m/s)</td>
<td>10.67</td>
<td>12.58</td>
<td>14.65</td>
<td>16.52</td>
<td>18.41</td>
<td>20.34</td>
</tr>
<tr>
<td>Total air volume (m³/h)</td>
<td>182.5</td>
<td>221.4</td>
<td>259.2</td>
<td>297.0</td>
<td>334.8</td>
<td>371.5</td>
</tr>
<tr>
<td>Total noise (dB)</td>
<td>40</td>
<td>43</td>
<td>46</td>
<td>49</td>
<td>52.5</td>
<td>55</td>
</tr>
<tr>
<td>Background noise (dB)</td>
<td>39.3</td>
<td>41.1</td>
<td>43.6</td>
<td>45.3</td>
<td>48.4</td>
<td>50</td>
</tr>
<tr>
<td>Noise of IDU (dB)</td>
<td>31.7</td>
<td>38.5</td>
<td>42.3</td>
<td>46.6</td>
<td>51.6</td>
<td>53.3</td>
</tr>
</tbody>
</table>

The noise of IDU in Table 3 is one without background noise which is produced mainly by fan. The higher the Fan frequency is, the larger background noise is. Table 3 shows that the system noise increases with air volume. The noise of IDU is caused by primary air in high-speed jet. When jet velocity is 10.67 m/s, the noise of IDU is 31.7 dB. At this time, it is much quieter. While it is 20.34 m/s, the noise of IDU reaches 53.3 dB, and then the passengers will feel fidgety. So decreasing jet velocity is the main way of diminishing system noise (Z.H.Li, J.S.Zhang 1998).

**Analysis of IDU resistance**

If the resistance of IDU is so large that the head of fan is too high, moreover it will make operating expense increase. It is necessary to analyze resistance of IDU. In hydromechanics, resistance is in direct proportion to the square of air volume. Moreover, resistance coefficient is relevant to the size of return and supply air grille.

**OPTIMIZATION SCHEME OF IDU**

In sum, performances of IDU are quietly affected by its structure. Though IDU is equipped with same nozzle, its induction ratio and resistance head are closely related with the size of return air and air supply grilles, arrangement of nozzles, and also numbers and size of nozzles. So the reasonable IDU plays an important role in energy conservation, reducing space occupation and making a comfortable environment. In addition, considering economy, IDUS of train should be optimized.

**Optimization principium**

From the experiments of three different IDUS, some factors in optimization design of IDUS should be considered as follows:

1. Induction ratio should be increased. Fresh air usually acts as the primary air in the condition of smaller air
requirement;

(2) System noise should be decreased;

(3) System resistance and fan head should be reduced. At the same time, the installation cost and operating expense can dramatically fall down. So the resistance lost should be decreased as soon as possible;

(4) Pipe space should be saved. Due to compact space in train coach, the size of IDU should be reasonably designed in order to save space;

(5) The system should be economical.

**Optimization scheme**

The optimization can be concluded as follows:

1. Integral size optimization of IDU is fixed. On the one hand, the smaller air conditioning system is needed in the train. On the other hand, smaller size of IDU will make induction ratio reduce. As a result, the final integral size of IDU is chosen as 500mm × 80mm × 500mm. The air supply grille and return air grille should be long slot grille to attain larger induction ratio. Meanwhile, the width of return air grille should not be too large in case of the short-circuit phenomenon of primary air. So the air supply grille is 480mm × 60mm, and the return grille is 460mm × 80mm.

2. The structure of jet is adopted to reduce the cost. The jet is fixed on the separator between the first mixing box and plenum box. ① The single line of jets are adopted here. ② Nozzle is optimized. Air velocity of nozzle has nothing to do with induction ratio when the structure of IDU is fixed. That is to say, for a certain IDU, the induction ratio is constant despite air velocity of nozzle is rising. So nozzle with larger area could be chosen in the design. There are three advantages as follows:

   (1) The resistance loss is reducing with air velocity of nozzle reduction. As a result, the head of fan decreases, and energy conservation is realized at the same time.

   (2) The system noise could be effectively reduced by raising the area of nozzle.

   (3) The induction scope is enlarged with increase in area of nozzle. So fourteen nozzles are arranged in single row, each diameter is 22.5mm. The final optimization scheme is described as Table 4.

<table>
<thead>
<tr>
<th>IDU</th>
<th>Pipe diameter of supply air</th>
<th>Plenum chamber</th>
<th>Nozzle</th>
<th>Return air inlet</th>
<th>Supply air outlet</th>
<th>Mixing box</th>
</tr>
</thead>
<tbody>
<tr>
<td>500×80×</td>
<td>130×70</td>
<td>500×80×2</td>
<td>14×D22.5</td>
<td>460×80</td>
<td>480×60</td>
<td>500×80×2</td>
</tr>
<tr>
<td>500×80×</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONCLUSION**

With the advantages others don’t have, induction air-conditioning system can be used in ordinary and high-speed train. Through analysis and experiment of IDUS, the optimization scheme of IDU is submitted. The size of IDU should be small as far as possible on the premise of large induction ratio. For saving capital expenditure, nozzle is chosen and arranged in single line. To enlarge induction ratio, area of nozzle should be increase.

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