Applied Mechanics and Materials *Online: 2010-12-06*
ISSN: 1662-7482, Vols. 44-47, pp 1724-1728
doi:10.4028/www.scientific.net/AMM.44-47.1724

Comparison on Simulation and Experiment of Supply air through Metro Vehicle Air Conditioning Duct

Hongge Tao[1,a], Huanxin Chen[1,b], Junlong Xie[1,c] and Junzhi Jiang[1,d]

[1]Department of Refrigeration and Cryogenics, Huazhong University of Science & Technology, Wuhan, 430074,China

[a] thg0218@163.com, [b] chenhuanxin@tsinghua.org.cn, [c] hustxjl@163.com, [d] jiangjunzhi2005@126.com

Keywords: supply air, air duct, simulation, experiment, metro vehicle.

Abstract. CFD technique is often employed to simulate and optimize air duct design, but the corresponding experiment validation in metro vehicle is rare. By taking an independent metro vehicle duct as research object in this paper, supply air through air duct is simulated and compared with the actual test results from the angle of supply air velocity at each outlet and supply air volume through several outlets of air duct. The results show that the relative deviation of simulation and test value of air velocity at most of the outlets are within or near ±20%, which is acceptable for the engineering applications. Moreover, the ratio of supply air volume through several outlets to the corresponding total supply air volume through main air duct or flat duct in the case of simulation is consistent with that in the case of experiment. It can be concluded that numerical simulation method is effective and reliable in air duct optimization design of metro vehicle.

Introduction

At present, there are some 174 cities in China each with a population of more than 1 million, of which 33 cities have more than 2 million population each [1], Huge population has posed a serious challenge for the urban transport system. Considering large transit volume, low pollution, punctuality and swiftness of subway traffic, Governments have declared subway construction and would like it to ease the traffic pressure on major cities. As of August 2009, the State Council had approved 22 cities' subway construction plan, and by 2015, 79 new rail lines will have been built, the total length of rail line will reach 2259.84 km [2].

With the extending of rail lines, the demand for metro vehicles will increase. At the same time, as the improvement of passenger's requirements on environment inside the subway car, air conditioning units must be configured and passenger comfort must be guaranteed for newly manufactured metro vehicles. Supply air uniformity along the length of air duct directly affects passenger comfort, while the air duct structure directly affects supply air uniformity, therefore, the optimization of air duct structure is an important factor to ensure comfort. Traditional metro vehicle air duct optimization design is mainly based on experience and experiment, however, only experience and experiment often require high cost and long cycle. When the demand for metro vehicles is less, long air duct design cycle can be guaranteed. But now, domestic metro vehicles are basically in short supply, and the various regions' requirements for metro vehicle are very different, such as the structure and decorations inside subway car, so air supply system must be adjusted to maintain passenger comfort. Because of the adjustment, the traditional air duct design can not keep up with the overall vehicle production schedules. In order to reduce air duct design cycle as much as possible, the preliminary numerical simulation and optimization on air duct will be expected. At present, numerical simulation has been used in the air duct optimization design in air-conditioned trains and cars [3-6], for air duct design in metro vehicle, L Wang [7] and L Yang [8] made a preliminary study by numerical simulation. CFD technique is often employed to simulate and optimize air duct design, but the corresponding experiment validation in metro vehicle is rare.

The present work of the paper is firstly to optimize the most commonly used air duct in the current metro vehicles by numerical simulation, then test optimized air duct and compare with the simulation results, and finally verify whether the simulation results are reasonable for air duct design in metro vehicle.

Metro Vehicle Air Supply System

Currently, the schematic of the whole air supply system most commonly used in domestic metro vehicle is shown in Fig.1, a carriage is equipped with two air conditioning units on its roof, conditioned air is sent out from both ends of air conditioning units, then sent into air distribution box through soft air duct, and then sent into main air duct and flat duct, respectively, ultimately sent into the carriage through air supply outlets on main air duct and flat duct.

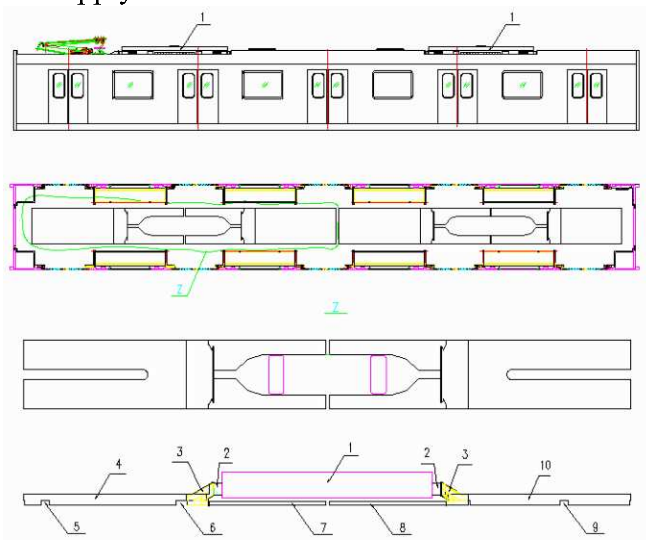


Fig. 1 The schematic of the whole air supply system of metro vehicle
1- air conditioning unit; 2- soft air duct; 3- air distribution box; 4,10- main air duct ;
5, 6, 9- the position reserved for the cross girder; 7,8- flat duct

It can be seen from Fig.1 that air supply system of a carriage is composed of four independent main air ducts and flat ducts. For the same model metro vehicles, the flat ducts structure is identical, while the the main air ducts structure is affected by the position reserved for other installation above the carriage's ceiling, which makes the length of main air ducts and the position reserved for the cross girder not exactly the same in one carriage, then this leads to the differences in internal structure of each main air duct. Therefore, If we simply rely on experience and experiment to determine the duct structure, it will inevitably increase the workload of air duct experiment and extend air duct optimization design cycle. Consequently, it is necessary to adopt small-cost and efficient numerical simulation tool to aid air duct optimization design in metro vehicle. But, the reliability of simulation results need to test to verify.

Metro Vehicle Air Duct Simulation and Optimization

An independent air duct structure is symmetrical along the width direction of air duct and air flow parameters at air inlet are the same, therefore, to simplify the calculation, we take an unilateral structure of an independent air duct as research object shown in Fig.2. Air supply outlets are interval distribution along the length direction of air duct, such as outlets 1-9 on main air duct and outlets 1-11 on flat duct.

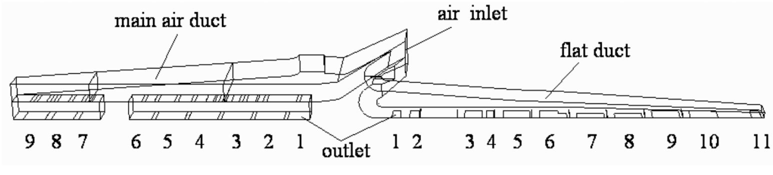


Fig. 2 The schematic of an unilateral structure of an independent air duct

Supply air volume in one carriage is 9600m^3/h, so supply air volume through unilateral duct of an independent air duct is 1200 m^3/h. As the good heat insulation measures are taken at the outside of air duct, the airflow temperature variation within air duct is ignored. Widely used standard k-ε turbulence model [9] is adopted to solve gas flow within air duct.

Velocity-inlet is set at air inlet, pressure-outlet is set at air supply outlets. Finite volume method and second-order upwind scheme are used to discretize the governing equations, pressure and velocity are coupled with SIMPLE algorithm, a standard wall function is adopted near wall region.

The objective of metro vehicle air duct optimization is to make supply air through each outlet uniform. By numerical simulation, we can understand intuitively gas flow within air duct and obtain average supply air velocity at each outlet. The simulation results can provide the basis for air duct restructuring and setting and adjustment of the baffle plate and orifice plate within air duct. Through several adjustments and simulations, the scheme shown in Fig. 2 is finalized. Under the scheme, supply air velocity at each outlet on air duct are obtained shown in Table 1 and Table 2, supply air volume through the outlets are also acquired shown in Table 3 and Table 4.

Metro Vehicle Air Duct Experiment

The experiment is performed in a specialized rail vehicles Ventilation Lab in a company shown in Fig.3. The structure of tested duct and simulated duct is the same. Matched air conditioning unit provides supply air to air duct. The rated supply air volume is 2400 m^3/h through single end of air conditioning unit, namely, the rated supply air volume sent into the unilateral duct is 1200 m^3/h.

The experiment consists of two parts, that is, air velocity and air volume test at the outlets on air duct. Impeller anemometer VELOCICALC 5725 of TSI Inc. is used to test air velocity, its range is 0.25~30m/s, test accuracy is ± 1% or ± 0.02m/s of reading, and operating temperature is 5~ 45 ℃. Air volume hood ACCUBALANCE® 8375 of TSI Inc. is used to test air volume, its range is 50~3500m^3/h, test accuracy is ±5% or ±8.5m^3/h of reading, and operating temperature is 0 ~ 60℃.

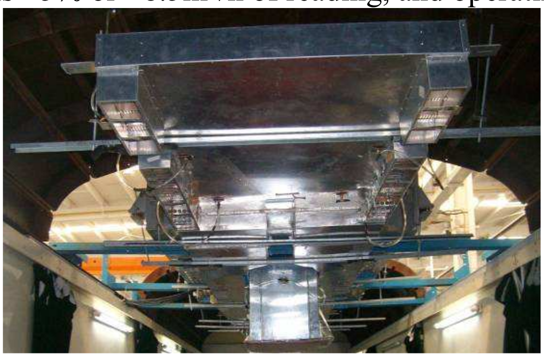


Fig. 3 Rail vehicles Ventilation Lab

Air Velocity Test. Test air velocity at each outlet on air duct is shown in Table 1 and Table 2.

Table 1 The test and simulation value of air velocity at each outlet on main air duct [m/s]

outlets	1	2	3	4	5	6	7	8	9
experiment	1.67	1.46	1.46	1.48	1.37	1.39	1.62	1.42	1.32
simulation	1.25	1.03	1.69	1.24	1.45	1.96	0.89	1.03	1.23

Table 2 The test and simulation value of air velocity at each outlet on flat duct [m/s]

outlets	1	2	3	4	5	6	7	8	9	10	11
experiment	0	1.72	0.78	1.49	1.58	1.69	1.55	1.96	2.10	1.73	2.11
simulation	0.27	2.18	0.73	1.22	1.07	1.48	1.82	1.81	1.08	1.36	2.02

Air Volume Test. When testing air volume, main air duct and flat duct are divided into two sections, respectively. The cross girder position is used as a boundary line of main air duct, namely, supply air volume through the outlets 1-6 is measured together and supply air volume through the outlets 7-9 is measured together. A boundary line of flat duct is approximatively located in the middle of flat duct, that is, supply air volume through the outlets 1-6 is measured together and supply air volume through the outlets 7-11 is measured together. Test results are shown in Table 3.

Table 3 The simulation and test value of supply air volume through the outlets on air duct [m^3/h]

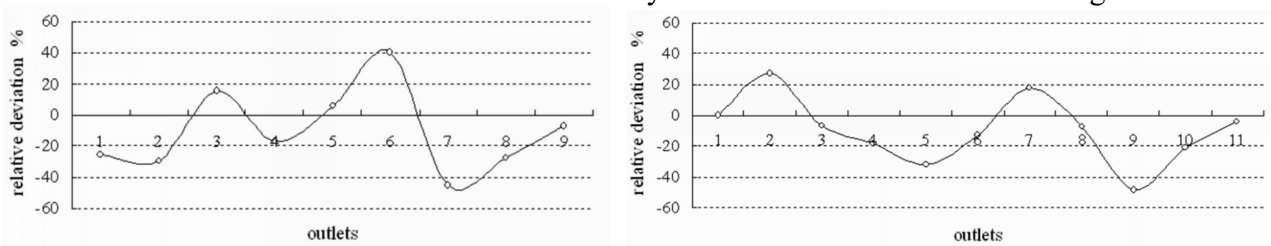
outlets	$V_{main-1-6}$	$V_{main-7-9}$	$V_{main-1-9}$	$V_{flat-1-6}$	$V_{flat-7-11}$	$V_{flat-1-11}$
simulation	498	152	650	246	303	549
experiment	467	198	665	289	275	564

Where, $V_{main-1-6}$ and $V_{flat-1-6}$ indicate the total air volume through the outlets 1-6 on main air duct and flat duct, respectively, $V_{main-7-9}$ and $V_{flat-7-11}$ indicate the total air volume through the outlets 7-9 on main air duct and the outlets 7-11 on flat duct , respectively, $V_{main-1-9}$ and $V_{flat-1-11}$ indicate the total air volume through all outlets on main air duct and flat duct, respectively.

Discussion

Comparison on the Simulation and Test Value of Air Velocity. It can be seen from Table 1 and Table 2 that the simulation and test value of air velocity at each outlet are consistent on the whole. The outlet 1 at the front of flat duct is taken as an example, flat duct is very short and only 63mm, moreover, flow velocity of gas sent into flat duct from air distribution box is higher, so there is obvious jet phenomenon at the front of flat duct. The jet phenomenon makes the static pressure at the outlet 1 smaller, thus affects supply air at the outlet 1. For above phenomenon, simulation result agrees with test result.

Because air velocity tested at the outlet 1 on flat duct is zero, the relative deviation of the simulation and test value of air velocity is assumed to be zero at the outlet 1 on flat duct. The relative deviation of the simulation and test velocity at all other outlets is shown in Fig. 4.



(1) main air duct (2) flat duct

Fig. 4 The relative deviation of the simulation and test velocity at each outlet on air duct

It is found from Fig. 4 that the relative deviation of the simulation and test value of air velocity is within ±20% or near ±20% at most of the outlets on main air duct and flat duct, the relative deviation is acceptable for the engineering applications.

Comparison on the Simulation and Test Value of Air Volume. It can be seen from Table 3 that the total air volume tested through main air duct and flat duct is larger than that designed through the main air duct and flat duct, their difference is 15 m^3/h, respectively. The difference value is the superposition of two measurement error for main air duct and flat duct, respectively. that is, average measurement error is within the measurement error of air volume hood in the experiment.Therefore, measurement data for air volume are considered credible.

To analyze the difference between the simulation and test value of air volume through the outlets on air duct, the formula (1) is given as follows:

$$\alpha_i = \frac{V_i}{V_{total}}. \quad (1)$$

Where, α_i indicates the ratio of supply air volume through several outlets to the corresponding total supply air volume through main air duct or flat duct, V_{total} is $V_{main-1-9}$ when V_i is $V_{main-1-6}$ or $V_{main-7-9}$, V_{total} is $V_{flat-1-11}$ when V_i is $V_{flat-1-6}$ or $V_{flat-7-11}$.

That the data in Table 3 are substituted into the formula (1) can compute the ratio of supply air volume through several outlets to the corresponding total supply air volume through main air duct or flat duct in the case of simulation and test, the results are shown in Fig. 5.

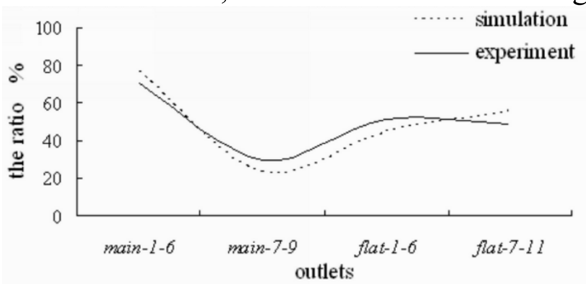


Fig. 5 Comparison on the ratio of supply air volume through several outlets to the corresponding total supply air volume in the case of simulation and test

From figure 5, it is found that the ratio of supply air volume through several outlets to the corresponding total supply air volume through main air duct or flat duct in the case of simulation is consistent with that in the case of test, which shows that the simulation results are credible from the perspective of supply air volume.

Conclusions

Numerical simulation is a useful tool which effectively shorten the air duct design cycle, however, the reliability of simulation results need to be verified through testing. For this reason, by taking an independent metro vehicle duct as research object in this paper, the supply air through air duct is simulated and compared with the actual test results from the angle of supply air velocity at each outlet and supply air volume through several outlets on air duct. The results show that the relative deviation of simulation and test velocity at most of the outlets is within or near ±20%, which is acceptable for the engineering applications. Moreover, the ratio of supply air volume through several outlets to the corresponding total supply air volume through main air duct or flat duct in the case of simulation is consistent with that in the case of experiment.

Acknowledgement

The research work is financially supported by CSR Zhuzhou Electric Locomotive Co., Ltd.

References

[1] Maohua Zhong, Congling Shi, Xuwei Tu et.al: Journal of Loss Prevention in the Process Industries Vol.21 (2008), p. 287-298.
[2] Lan Lan: China Instrumentation Vol.10(2009), p. 28-31, in Chinese.
[3] Jiangqiang Deng, Yiyong Jin, Zaoxiao Zhang et.al: Journal of Refrigeration Vol.1(2001), p. 30-34,in Chinese.
[4] Jiangping Chen, Yongming Chen, Jingyang Mu et.al: Automotive Engineering Vol.24 (2002), p. 134-136, in Chinese.
[5] Xianmin Wang, Xiaomei Wang: Journal of Hefei University of Technology (Natural Science) Vol. 30(2007), p. 357-360, in Chinese.
[6] Zhaogang Qi, Jiangping Chen, Wei Hu: Automotive Engineering Vol.27(2005), p.103-106, in Chinese.
[7] Liu Wang: Huazhong University of Science & Technology(2008), in Chinese.
[8] Liu Yang: Huazhong University of Science & Technology(2008), in Chinese.
[9] Wenquan Tao: Numerical Heat Transfer (Xi'an Jiaotong University Press, Xi'an 2001), in Chinese.