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Research Article

The Experimental Study of Reducing Cooling Fan Noise Using Test Bench

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Abstract

The blade pass frequency (BPF) noise for axial flow cooling fans in Electrical Vehicles (EV) is much obvious in some of rotational speeds. The root cause of this BPF noise is due to the cooling fan loading which is caused by the pressure difference between inlet and outlet of the fan. The pressure difference is defined as the resistance value of the fan. The resistance value of fan in EVs is much higher than the value of internal-combustion engine (ICE) vehicles. It is very difficult to obtain the resistance value in full vehicle condition. A new method to estimate the vehicle resistance value is developed using bench tests. By assuming, on the same operating parameters of the same fan both in vehicle and in test bench, such as inlet voltage, current and rotational speed, the resistance value of the fan in vehicle is the same as in test bench, thus, the operating parameters are used in the bench testing to simulate the resistance value of the fan in vehicle. Once the resistance value is achieved, the noise values of the fan can be measured in the test bench under different rotational speeds. Several testing results of different fans show that the BPF noises in bench with the defined resistance value align with those in vehicle. Using this method, the cooling fan noise can be studied in bench, earlier fan prototypes can be evaluated before finalizing design parameters. From this study it is found that the deformation of blades under the operation is the main factor to affect BPF noise levels. During operation the blade deformation changes the gap between the blade and the shroud in axial direction. The gap is related to the initial gap and the strengthen of the fan blade. This gap can be designed and optimized to balance the BPF noise in the total rotational range. The guidelines for designing low noise fan are outlined in this paper also.

Keywords

Cooling Fan, Blade Pass Frequency Noise, Test Bench, Resistance Value, Blade Deformation

1. Introduction

Axial flow fans are widely used in most industrial conditions, such as air conditioning, vehicle cooling system, computer rooms, and so on. Axial fan has high flow rate and low cost. Most of the cooling fans in the electrical vehicle are axial fans and made of plastic material also because of its low cost and easy manufacturing. The aerodynamic performance and noise performance are the top two performance parameters of the cooling fan. So many researchers study on the improvement for aerodynamic performance and noise performance of axial fan. Author's primary paper studies on the BPF noise in vehicle with CAE methods [1].

There are two performance requirements of the cooling

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fan in EV. They are air flow rate and noise. The two performances usually conflict in design if the boundary conditions are limited. The air flow rate of the cooling fan becomes larger and larger due to the battery capacities quickly increasing. Bigger air flow rates usually led to higher noise. There is no engine in EV, the customer needs lower noise inside vehicle cockpit. It is important to design a quiet fan or high sound quality fan for EV.

CFD methods and experimental methods are used to analysis the aerodynamic noise of the cooling fan. The BPF noise is the top factor which influences the fan sound quality in aerodynamic noises. The general researches are mostly depending on the experimental methods.

The former researches focus on experimental woks. D. A. Quinlan invest the small axicial fan noise [2]. Ouyang H [3] and Bianchi S. [4] did the experimental study on low blades. Bianchi S. [5] and Jin G. Y. [6], Shuliff D. L. [7], Woodward R. [8] work on the blade edge to reduce noise. Increasing the diameter of the fan is a directly solution, but limited by the installation conditions in most vehicles. Optimizing the number of blades is also a useful proposal, 6 to 7 blades fan is studied and its angle effect the noise spectrum significantly [9]. And some studies focus on the total noise of the installation of FAN arrangement [10].

Two typical noise resources are observed in the cooling fan. The first one is vortex noise which is related to the fan blade, inlet and outlet of the fan. The vortex noise is hard to be estimated. It is not researched in this paper. The other noise is the rotational noise, it generated from the rotation and output power of the fan and related to the number of the blade [11]. BPF noise is the principal one in the rotational noises.

The main research method to reduce the noise of the fan is experimental method. The direct solution to improve the sound quality is to reduce the BPF noise. It is very difficult to exactly estimate the BPF noise in vehicle conditions by CAE and CFD methods. Experimental researching in whole vehicle to reduce BPF noise is difficult too and cost huge. Test bench developing method is needed to simple the developing process and achieve cost reduction.

The boundary conditions can change the overall noise and BPF noise of the cooling fan. The boundary conditions in EV change greatly with those in ICE vehicle. The profile of EV is much unique with ICE ones. To obtain the air flow rate controlling capacity, the inlet accessory components and AGS are common used. The full packaged engine room and luggage box utility led to the outlet of fan changes. All the above increase the resistance of the fan. The fan becomes different with the one in ICE vehicle. The fan in EV becomes near a ventilator, and its sound quality cut down significantly than before.

General fan noise test bench hasn't loading supply equipment, the resistance of the fan is limited to be very small. The fan noise results in bench don't align with the results in vehicle. A new fan noise test bench is set up with that the resistance can be adjusted as specifications. Assuming on the same operating parameters of the same fan both in vehicle and in test bench, the resistance value of the fan in vehicle is the same as the one in test bench. Repeat the same operating conditions in test bench as those in whole vehicle, the pressure difference and air flow rate are obtained. Then the resistance value is drawn.

The resistance value of the cooling fan in the vehicle is nearly stable, thus the fan test bench can easy simulate the vehicle cooling fan oprational conditions. During operation the blade deformation changes, then the gap between the blade and the shroud in axial direction changes. Design and optimize the gap can improve the BPF noise significantly. The above works can be carried out in test bench. And the optimized solutions are proved in vehicle. Thus, developing a low noise cooling fan in test bench is possible. The guidelines for designing low noise fan are outlined.

2. Cooling Fan BPF Noise in Vehicle and Unit Test

In recent years, the market share of EV is increasing much quickly. The initial quality survey (IQS) of the cooling fan increase significantly. Some customers complain the cooling fan noise inside and outside the vehicle. A low noise cooling is need to match the marketing requirements.

The followings show the noise results of a cooling fan with 7 blades in EV. The interior noise position is in the driver's right ear, the noise waterfall diagram is shown in Figure 1. It is shown that the 7th order is obvious and changes with different rotational speeds. There is a significant brilliant increase of the 7th order when the cooling fan rotational speed is 1800-2100rpm.

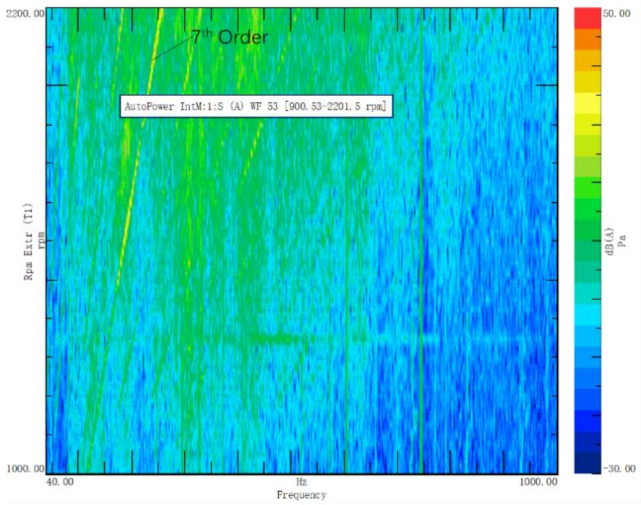

Figure 1. *Inside Noise waterfall diagram at driver's right ear location inside an EV.*

The outside noise position is 1m in front of the vehicle and 1.65m high. The noise waterfall diagram at outside of the vehicle is shown in Figure 2. There is the same phenomena as theos in the inside noise results.

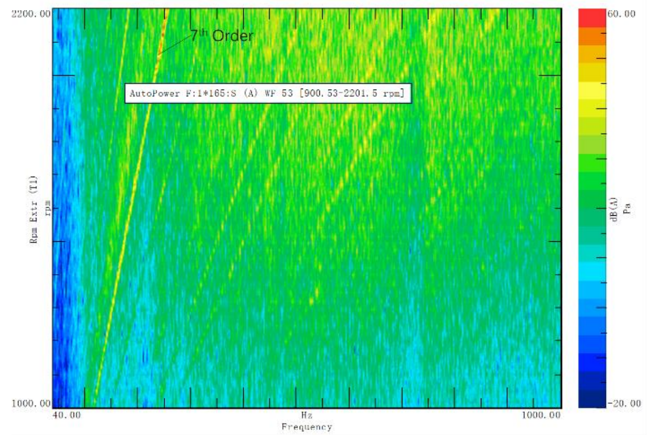

Figure 2. *Outside Noise waterfall diagram at 1.65m high & 1m in front and of an EV.*

The BPF order vs rotational speed is calculated as follows,

$$\mathrm{OA} = \sqrt{\int_{\omega=20}^{16000} (f(\omega))^2 d\omega} \quad (1)$$

$$\mathrm{Order(N)} = \sqrt{\int_{\omega=\omega_L}^{\omega_H} (f(\omega))^2 d\omega} \quad (2)$$

Where

$$\omega_H = \frac{n}{60} \cdot (N + \frac{B}{2})$$

$$\omega_L = \frac{n}{60} \cdot (N - \frac{B}{2})$$

N is the defined order.
n is the fan rotational speed, rev/min.
B is the order width, generally is 0.5.

The noise results of the overall level and BPF order vs the rotational speed are shown in Figure 3. The inside BPF order noise is above the target (40dB (A)), and the outside BPF is above 52dB (A). The sound quality is poor both inside and outside the EV. The cooling fan must be modified to catch the noise performance specifications.

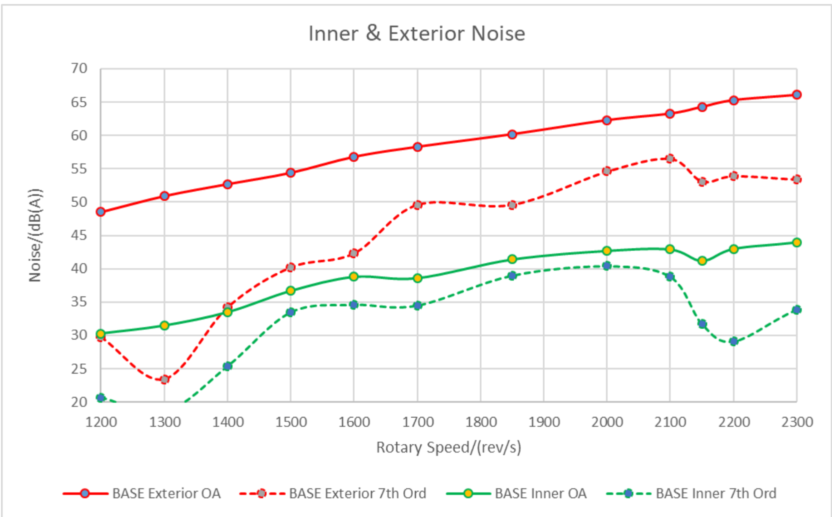

Figure 3. *Noise Level Comparison between inside & outside an EV.*

Red solid line – EV outside noise overall level
Red dotted line – EV outside noise BPF order
Green solid line – Inside EV noise overall level
Green dotted line – Inside EV noise BPF order

The cooling fan is also measured in general noise bench without loading. The microphone position (named CRFM: FC) is 1m distance to the fan center. Refer to Figure 4. The microphone noise in bench is much near than the one in EV, the overall level is bigger. In order to comparing in the same base line, the overall level in general bench is adjusted to the same as that in EV. The comparisons of noise test results between in vehicle and in bench are shown in Figure 5.

There is an obvious peak in 1800-2000rpm in the BPF noise in vehicle. But there is no significant peak in general bench test results. The general noise test bench can't simulate the operating conditions of those in vehicle.

Compare the fan operational conditions, the pressure difference in vehicle is much bigger than that in general bench.

The pressure difference influences the BPF noise greatly. General noise test bench for cooling fan can't simulate the operating conditions in vehicle, developing a low noise cooling fan in bench is impossible. New noise test bench is required.

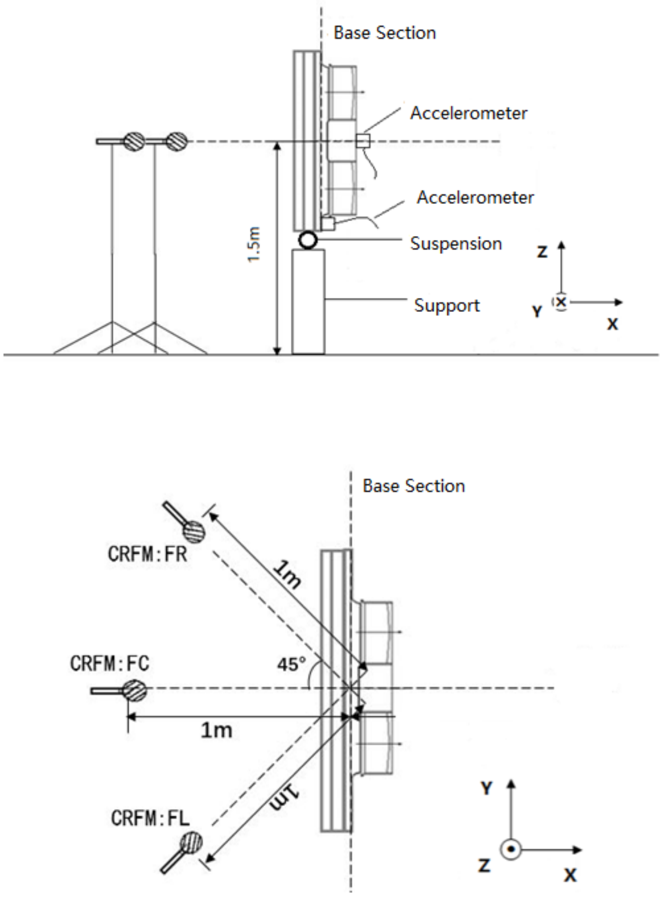

Figure 4. Schematic Diagram of FAN noise test setup.

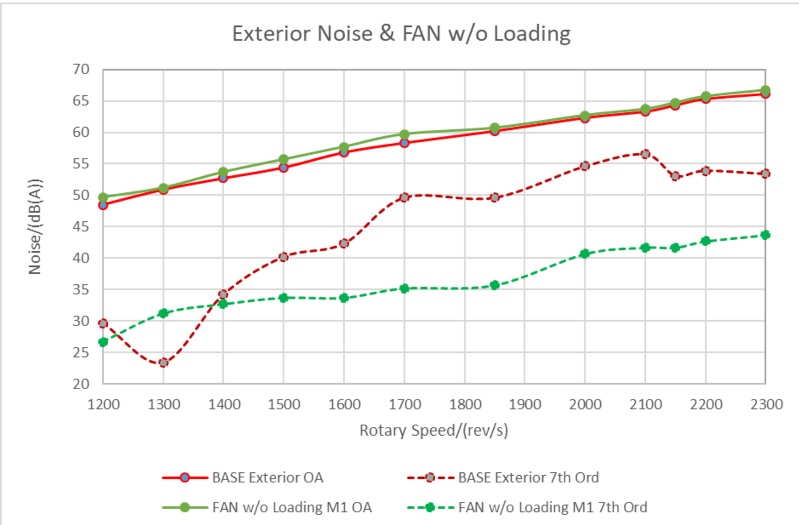

Figure 5. Noise Level Comparison between in EV & in General Bench.

Red solid line – EV outside noise - overall level
Red dotted line – EV outside noise - BPF order
Green solid line – General bench noise - overall level
Green dotted line – General bench noise- BPF order

3. New Test Bench

To simulate the pressure difference of the fan in bench, a new noise test bench is set up.

3.1. New Test Bench Setup

A new noise test bench is built in the semi-anechoic chamber. One side of the bench is designed as a plane to install the cooling fan, the other side assemble an air flow duct which connected with the air survey equipment. The pressure difference between inside and outside the box can be adjusted with the air flow rate changing. Refer to Figure 6.

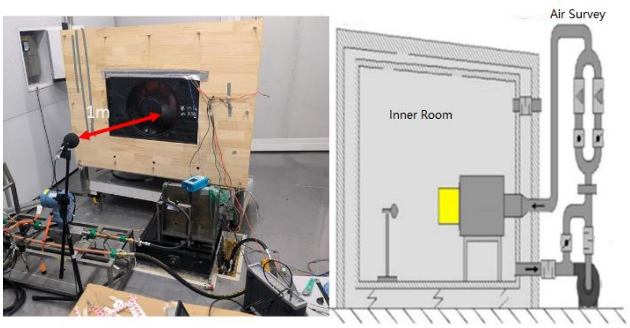

Figure 6. *The picture of New Noise Test Bench.*

The air survey equipment adjusts the air flow rate to match the defined pressure difference between inside and outside the box. The resistance value is defined with equation 3.

$$R = \frac{\Delta P}{Q^2} \quad (3)$$

Where,

R is resistance value, Pa/(L/s)^2

ΔP is the pressure increase while FAN test, Pa

Q is the air flow rate, L/s

The fan can be applied defined resistance value while noise test.

Estimate the Resistance Value in Vehicle

The new test bench can be used to measure the resistance value of the fan in vehicle.

Assuming on the same operating parameters of the same fan both in vehicle and in test bench, the resistance value and air flow rate of the vehicle is the same as that in test bench. The parameters include inlet voltage, current and rotational speed. The process to measure the resistance value is shown as follows.

Step 1, In vehicle, fixed the input voltage and adjust the rotational speed from low to high, measure the current of the fan motor in each rotational speed.

Step 2, Disassemble the cooling fan of the vehicle, and install it in the new test bench. Fix the input voltage and the rotational speed, adjust the outlet pressure to achieve the same current in vehicle. Record the air flow rate and the pressure.

Step 3, Calculate the resistance value.

The results of the parameters for above fan are shown in Table 1 and the calculated resistance values are shown in Figure 7. The resistance values under different rotational speeds are nearly the same. Thus, the resistance value of the fan in vehicle is obtained. The new noise test bench can simulate the vehicle resistance using a defined statistic value.

Table 1. *FAN test parameters.*

No	RPM	Voltage (V)	Vehicle Current (A)	Pressure (Pa)	Air Flow Rate (L/s)	R (10^-3 Pa/(L/s)^2)
1	1200	14.5	3.9	50	306	0.54
2	1300	14.5	5.1	58.5	319	0.57
3	1400	14.5	6.4	62.5	311	0.65
4	1500	14.5	8	73	350	0.60
5	1600	14.5	10	82	372	0.59
6	1700	14.5	12.2	92	387	0.61
7	1850	14.5	14.7	120	458	0.57
8	2000	14.5	17.8	145	500	0.58
9	2100	14.5	21.4	158	540	0.54
10	2150	14.5	25.5	170	589	0.49
11	2200	14.5	30.3	189	617	0.50

No	RPM	Voltage (V)	Vehicle Current (A)	Pressure (Pa)	Air Flow Rate (L/s)	R (10^-3 Pa/(L/s)^2)
12	2300	14.5	35.7	208	653	0.49
13	2450	14.5	40.2	224	675	0.49

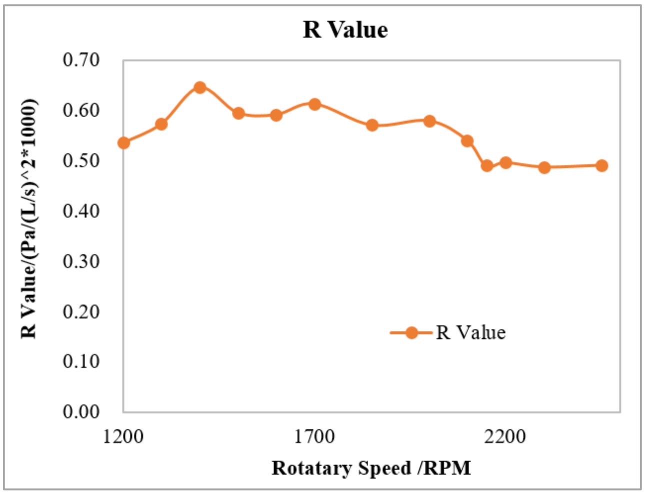

Figure 7. Resistance value in EV.

3.2. Comparisons BPF Noise in Vehicle and Bench

The statistic resistance value (in this case is 0.0006Pa/(L/s)^2)) is applied under different cooling fan rotational speeds in the new noise test bench. As before, the overall level in bench is adjusted to align with that in EV. The comparisons of the noise results between in EV and in new test bench are shown in Figure 8.

It is shown that there is a peak in 1800-2100rpm both in bench and vehicle. There is a valley in 1400rpm in EV but not in bench. The reasons are that the FAN support resonance frequency is 23Hz. When the cooling fan runs in 1400 rpm, the resistance of vibration led to the noise differences.

The new noise test bench can simulate the fan conditions in vehicle. The noise performance in bench meets well with that in vehicle. The method to obtain vehicle resistance value is acceptable. Using the above method, the cooling fan noise can be studied in the new test bench.

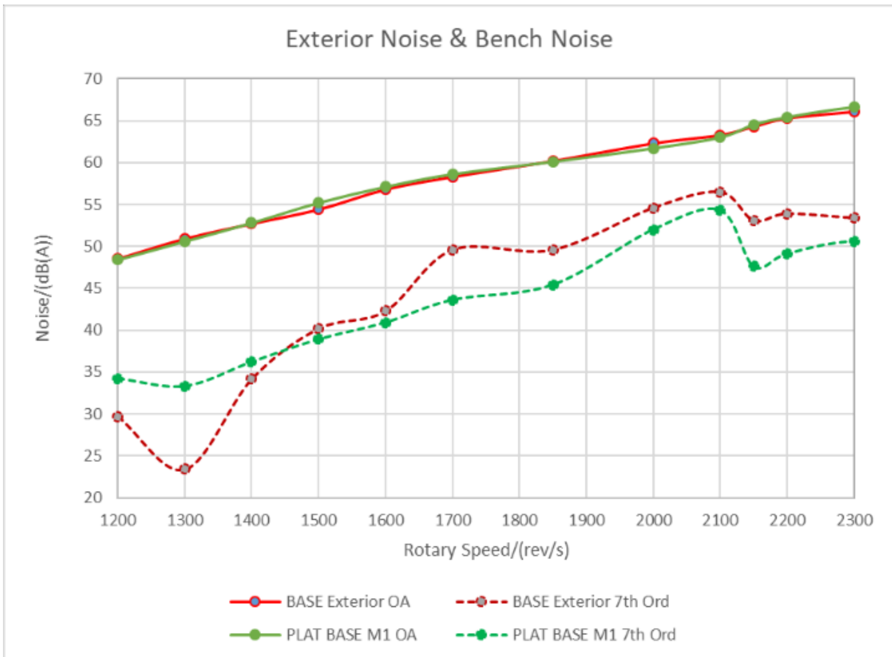

Figure 8. Noise Comparison between in EV and Test Bench.

Red solid line – EV outside noise overall level
Red dotted line – EV outside noise BPF order
Green solid line – New Bench overall level
Green dotted line – New Bench BPF order

4. Case Solutions

Since there are BPF noise issues of the cooling fan in EV. The fan is studied in new noise test bench. The noise in the test bench with fixed resistance value repeats the BPF noise phenomena. During operation the blade deformation changes, the gap between the blade and the shroud in axial direction changes too. The gaps in low speed and in high speed are shown in Figure 9. The higher the rotational speed, the bigger the gap.

The gap between the fan blade and shroud affect the BPF noise greatly. The gap cannot be reduce due to the design limitation to avoid fan blade and shroud confliction. The biggest gap is limited to avoid fan blade and water exchanger confliction. Several fans are modified with the different gaps (+1mm, +2 mm, +3mm) and tested in bench. The comparisons of the BPF results are shown in Figure 10.

The noise results for +3mm modified fan have been improved greatly compared with the base one. The peak of BPF cure cut down 8dB (A) and the peak position is lower than before.

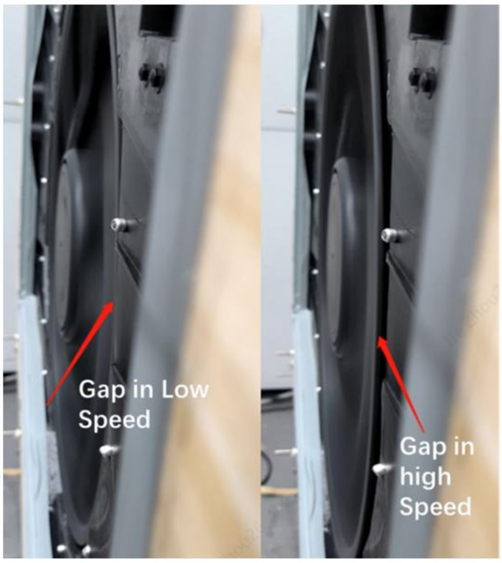

Figure 9. *Deformation of the FAN blade during operations, obtained using new test Bench.*

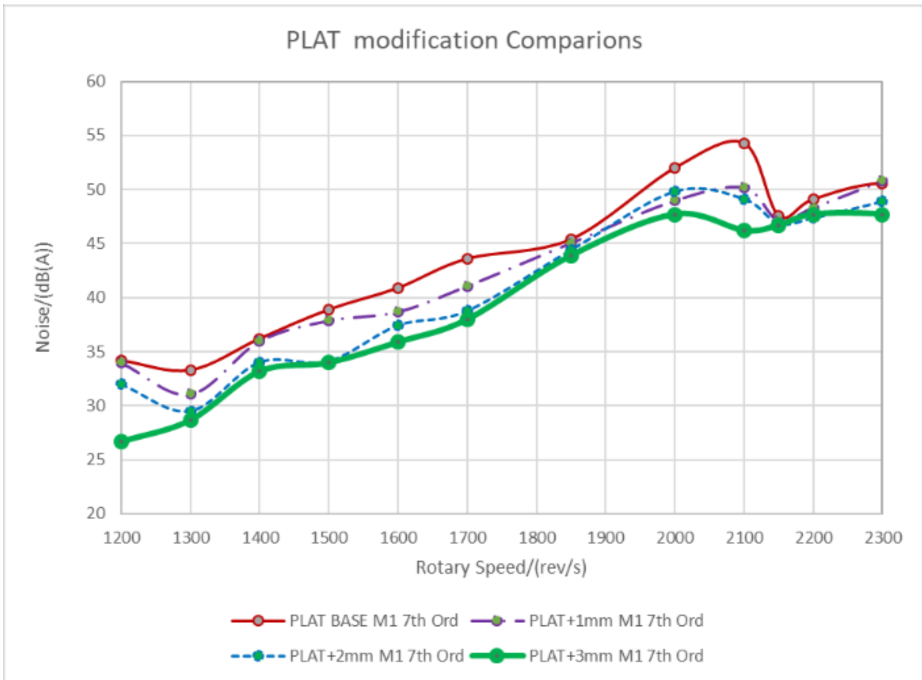

Figure 10. *Noise comparison between +1mm/+2mm/+3mm Fan & Base in test bench.*

Red solid line – BASE fan
Purple Center line – +1mm modified fan
Blue dotted line – +2mm modified fan
Green solid line – +3mm modified fan

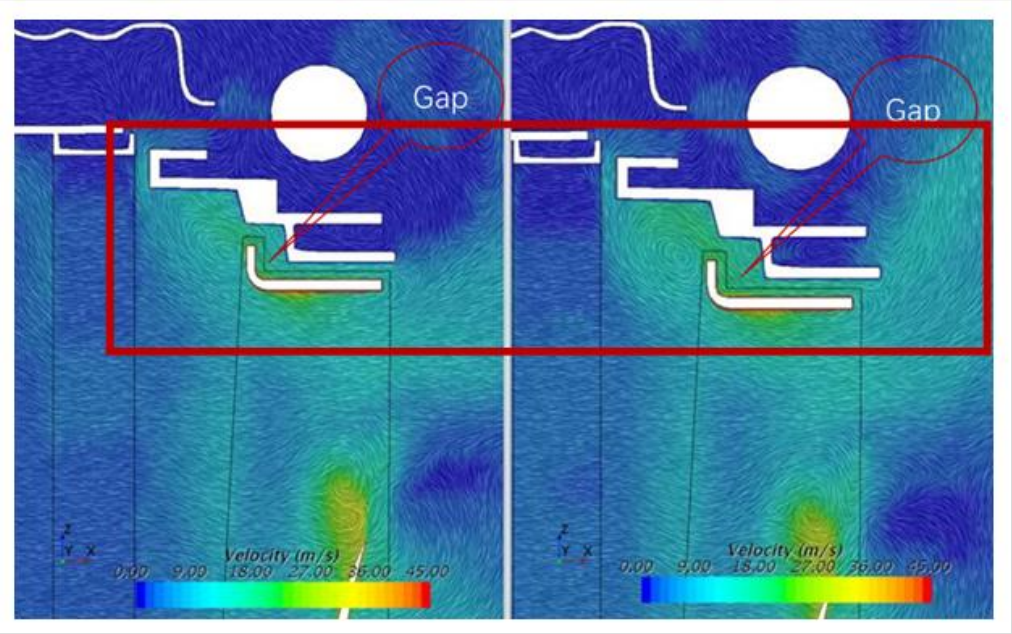

Figure 11. CFD velocicty Diagram comparison between +3mm FAN and Base.

Left – Base fan
Right – +3mm Modified fan

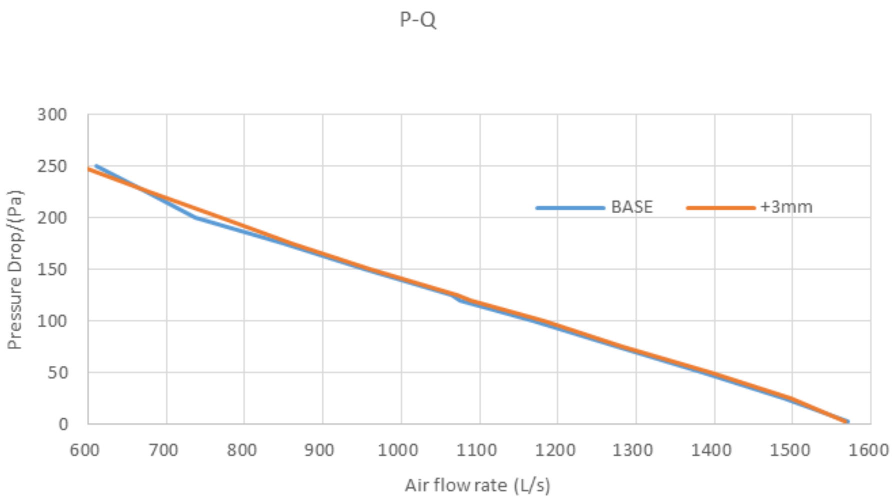

Figure 12. P-Q Diagram for +3mm modified fan in 2200rpm.

The CFD results of Base and +3mm modified fan are shown in Figure 11. There are differences of the air flow velocity distribution after the gap, but it can't help to identify the noise. It is difficult to find noise solution based on CFD results. There are no efficient rules to identify the noise affection of the CFD results.

The air flow rate Q is also validated in the new bench. It is similar with the base one, only less than 2% differences, refer to Figure 12. The +3mm modified fan has good noise performance and keep the air survey performance.

The +3mm modified fan is assembled in the same vehicle. The inside and outside noise test results are shown in Figures 13 &14. It is shown that the outside BPF noise decreases 5dB (A) and overall level decreases 3 dB (A). The noise results of modified fan in vehicle aligns with those in bench. The overall level of inside noise decreases 3-4 dB (A). The inside BPF noise changes significantly. The sound quality improved so much in most rotational speed range.

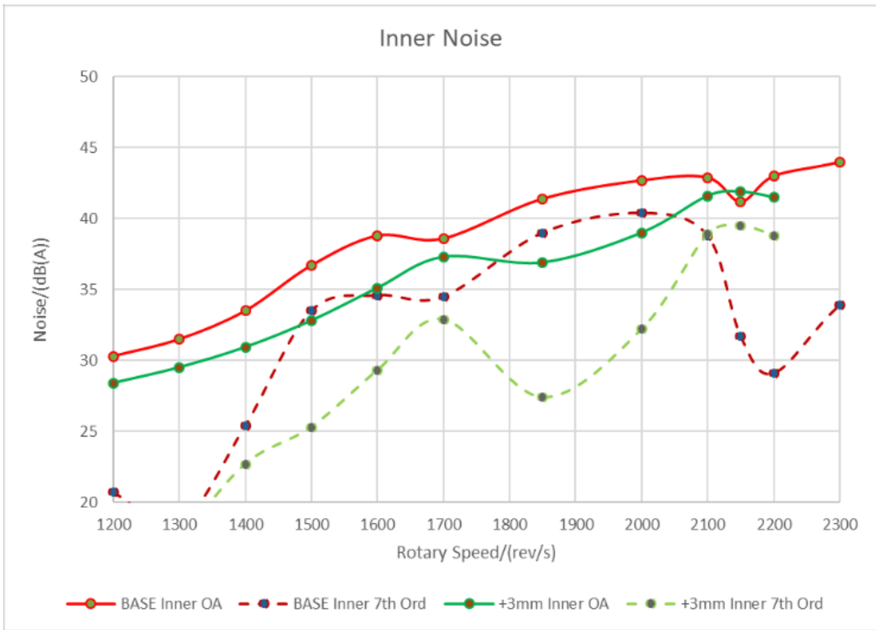

Figure 13. Outside Noise comparison between Modified fan and Base fan.

Red solid line – Base fan outside noise overall level
Red dotted line – Base fan outside noise BPF order
Green solid line – +3mm Modified fan outside noise overall level
Green dotted line – +3mm Modified fan outside noise BPF order

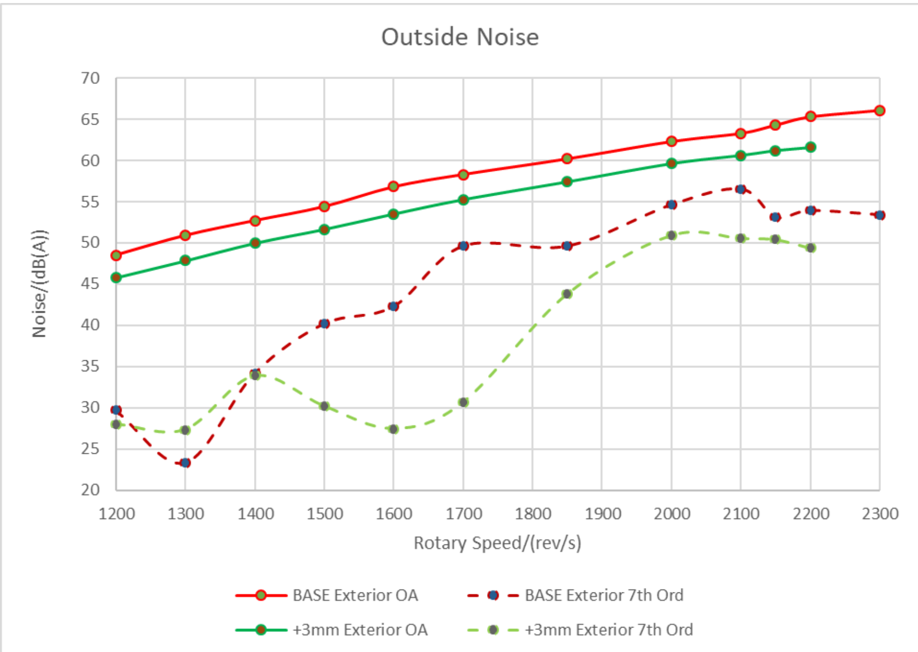

Figure 14. Inside noise comparison between Modified fan and Base.

Red solid line – Base fan inside noise overall level
Red dotted line – Base fan inside noise BPF order
Green solid line – +3mm Modified fan inside noise overall level
Green dotted line – +3mm Modified fan inside noise BPF order

Developing the cooling fan noise designing in bench is possible and useful. The method to measure the resistance value of the fan in vehicle and apply it to the new noise test bench is acceptable.

5. Conclusions

It is difficult to obtain the resistance value in full vehicle operational condition. A new method to estimate the resistance value under vehicle operational condition is developed using a newly developed bench testing. By assuming on the same operating parameters of the same fan both in vehicle and in test bench, the resistance value of the fan in vehicle is the same as in test bench. The operating parameters include inlet voltage, current and rotational speed. The operating parameters are used in the bench test to simulate the resistance value in the vehicle. Thus, the resistance value of fans in vehicle is obtained. It is found that the resistance value in vehicle is nearly stable.

Once the resistance value under vehicle operational conditions is determined and simulated in the bench testing, the noise value can be developed in the test bench under different rotational speeds. It is found that the resistance value affects the cooling fan noise greatly, especially for the BPF noise. The noise test results show that the BPF noise in bench shows a good correlation relationship with those in EV. It becomes feasible to study the cooling fan noise performance using bench testing.

It is found from this study that the deformation of the fan blade under the operation is the main factor of affecting BPF noises. During operation, the blade deformation changes the gap between the blade and the shroud in axial direction. The gap is related to the initial gap and the strengthen of the fan blade. Therefore, this gap can be designed and optimized to balance the BPF noise in the total rotational range. For the base designed cooling fan, several modifications are applied with different gaps. Finally, it is found that the +3mm modified fan has the better noise performance. Both CFD analysis and testing results show that the air flow rate of the +3mm modified fan still meets the heat performance specification.

The results of modified fan in test bench show that the BPF noise is reduced 3-5 dB (A). The outside noise of the same fan in vehicle also decreases 5 dB (A). The sound quality of vehicle inside noise improves greatly in most of the rotational speeds. The guidelines for designing low noise fan are also developed.

Abbreviations

AGS	Auto Grill System
BPF	Blade Pass Frequency
CAE	Computer Aid Engineering
CFD	Computational Fluid Dynamics
CRFM	Cooling Radiator and Fan System
EV	Electrical Vehicle
DOI	Digital Objective Unique Identify
ICE	Internal-combustion Engine
IQS	Initial Quality Survey

Acknowledgments

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The New Test bench is claimed as the part of the GEELY Company Standard.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Chuanxue Duan, Wei Qian. Reduce the Cooling FAN Blade Pass Frequency Noise in Electrical Vehicle, International Journal of Mechanical Engineering and Applications. Volume 11, Issue 2, April 2023, pp. 54-59. https://doi.org/10.11648/j.ijmea.20231102.13

[2] Quinlan D. A., Bent P. H.: High Frequency Noise Generation in Small Axial Flow Fans, Journal of Sound and Vibration, No. 02, 1998, 177-204.

[3] Ouyang. H., Li Y., Du Z. H., et al.: Experimental Study on Aerodynamic and Aero Acoustic Performance of Low Blades, Journal of Aerospace Power, vol. 21, No. 04, 2006, 668-674.

[4] Bianchi S., Corsini A., and Sheard A. G.: Experimental Characterisation of the Far-Field Noise in Axial Fans Fitted with Shaped Tip End-Plates, ISRN Mechanical Engineering, Vol. 102, 2012, 01-09.

[5] Jin G. Y., Ouyang. H., et al.: Research of Aerodynamic Noise Source in Tip Region of Axial Fans with Circumferential Skewed Blades at Off-Design Conditions, Journal of Shanghai Jiaotong University, vol. 45, No. 06, 2011, 345-349.

[6] Sutliff D. L., Tweedt D. L., and Fite B. E.: Low Speed Fan Noise Reduction with Trailing Edge Blowing, Glenn Research Center, Cleverland, Ohio, 2002.

[7] Woodward R. P., Fite E. B., and Podboy G. G.: Noise Benefits of Rotor Trailing Edge Blowing for a Model Turbofan, Glenn Research Center, Cleverland, Ohio, 2007.

[8] Avinash, D., Shankar, M., Maller, R., and Ravindran, V., “Reduction of Aero-Acoustics Tonal Noise for a Tractor Cooling Fan,” SAE Technical Paper 2021-26-0299, 2021, https://doi.org/10.4271/2021-26-0299

[9] Teymourpour, Sh., Mahdavi-Vala, A., Yadegari, M., Kia, S. et al., “Engineering Approach for Noise Reduction for Automotive Radiator Cooling Fan: A Case Study,” SAE Technical Paper 2020-01-5085, 2020, https://doi.org/10.4271/2020-01-5085

[10] Karlsson, M. and Etemad, S., “Installation Effects on the Flow Generated Noise from Automotive Electrical Cooling Fans,” SAE Technical Paper 2020-01-1516, 2020, https://doi.org/10.4271/2020-01-1516

[11] Zhou, Z., Lin, H., Shangguan, W., Wang, X. et al., “Calculation of Cooling Fan Blade Deformation and Aerodynamic Performance Based on Fluid-Structure Model,” SAE Technical Paper 2023-01-0815, 2023, https://doi.org/10.4271/2023-01-0815