Fan noise reduction to improve comfort inside cabin of Grader Vehicle

Author: Mr. SHINDE NIKHIL | Mahindra
, co-author (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)
Affiliation (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

Abstract:

Earthmoving industry in India is growing at rapid rate so the competition and stringent government norms. To keep up with the competition, major OEMs are working on improving the product quality and customer feel. one such focus is given on cabin comfort in terms of operator ear level noise and vibration. Inline to this at Mahindra, grader vehicle taken to improve comfort level by reducing driver ear noise and improving in cabin sound quality. Different NVH measurements on Grader vehicle for source identification revels that fan was one of the major contributors. This paper focuses on fan noise in grader vehicle, by working on different fan designs to arrive at good aerodynamic design thus by reducing source noise levels. Also, worked around fan environment to reduce noise radiation at vehicle level. Contrary to noise radiation, fan noise has a stringent flow requirement to be met as these machines work at remote location in the extreme conditions. Component level trials helped to understand and achieve best design which will meet the flow requirement with low noise at source. Vehicle level confirmatory trials were carried out to confirm the importance in product. Finally, it was noticed that working on source as well as path is important for fan noise reduction. Combine effect shows good amount of reduction in noise levels which interns improves cabin comfort.

Introduction:

There are now wide variety of applications used in earthmoving industry such as Backhoes, Excavators, Graders, Bulldozers & Dump trucks. Due to ongoing vast road developments & infra developments, this sector is witnessing very high growth in terms of sales & revenue. More companies are entering into this market with some having strong product development background & some are having little experience. Due to this variability, the Ministry of Road Transport and Highways (MoRTH) has come out with some Industry standards to improve the driver safety & comfort who works for long hours in tough terrains. These norms are well designed after considering each machine with its architecture & application.

NVH, one of the major factors under the operator comfort, has gained a lot of attention which not only important to driver but also to the vehicle surrounding. Keeping this in mind, in phase I, ISO 6393 & 6394 for stationary evaluation were designed & in phase II, ISO 6395 & 6396 were designed considering the operation cycle of the machine. ISO 6394 & 6396 takes care for operator level noise while ISO 6393 & 6395 evaluates vehicle exterior noise. The limits of which are set by the Ministry of Road Transport and Highways in the year 2020 for different applications. Primarily, the limits are based on the power of the vehicle. More the power, more noise levels are permitted.

This paper describes the methodology adopted to address the issue of fan noise which was found to be major contributor for interior as well as exterior noise for motor Grader vehicle. In said grader vehicle, the fan is connected to engine by a pulley. As per the general NVH development method for ISO norms, base proto will be evaluated first & based on the noise source ranking, the development is prioritized for high ranked noise sources. One by one the noise level of each source is reduced & final measurement is done for verification of meeting the ISO norms.

During the development phase, effect of one change needs to be evaluated for effect on other systems also. In case of Fan system, there is contradictory requirement between cooling & NVH. If the cut-off temperature to be reduced, then cooling requires higher fan RPM whereas NVH recommends low fan RPM. Due to this scenario, there is always tradeoff between NVH & cooling which lead to draw a golden line for win-win situation.

Methodology:

The Grader NVH development work started from the proto vehicle baseline ISO measurement. The typical test set up consist of 2 in-cab microphones & 6 exterior microphones under the hemisphere whose radius is defined by the basic length of the machine. The in-cab microphones are termed as driver/operator ear LH & RH (refer figure 1). Their position is 200 mm ± 20 mm from the median plane of the head of the operator within line of the eyes, as mentioned in the ISO 6394 & 6396. The maximum value of the two positions is considered as the final measurement. For the exterior microphones, microphone 1 & 4 will be the first approaching during vehicle forward travel to the right & left side of the vehicle. Microphone 2 & 3 will be at the end, in line with microphones 1 & 4. Microphones 5 & 6 will be at the highest points. The exact microphone location can be referred from ISO 6393 & 6395 as shown in figure 2.

Figure 1. In-cab noise measurement microphone set-up.

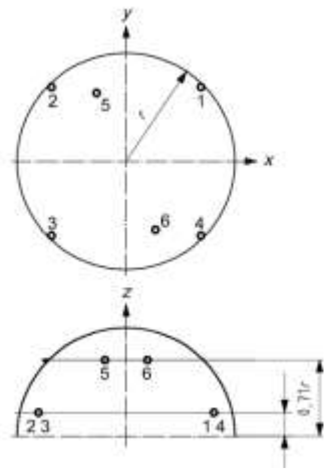

Figure 2. Exterior noise measurement microphone set-up.

For Grader vehicle, for phase I, the measurements must be done in engine rated RPM & vehicle stationary. For phase II, measurement must be done in vehicle forward movement at engine maximum fly up RPM but not exceeding 8 kmph speed. The results for in-cab noise will be measured as Sound Pressure Level (dB(A)) & exterior noise will be measured as Sound Power Level (dB(A)). As per the standards, the measurements were done & the results were checked. They were differing 2-7% from the acceptance criteria. The in-cab noise level was very high & it was very harsh primarily due to fan engagement. This condition was very uncomfortable for the driver which called for detail analysis for noise source identification. Once the contribution from each noise source was evaluated, it will be easier to prioritize the development for high ranked noise sources. These sources consist of Engine, Fan, Exhaust, Intake, hydraulic system & engine accessory noises. Then, the noise was captured from each source was captured & ranked against the target. (Refer figure 3). There was major contribution found from cooling fan apart from engine & hydraulic system. Exhaust, Intake & engine accessories have lower contribution to the in-cab noise.

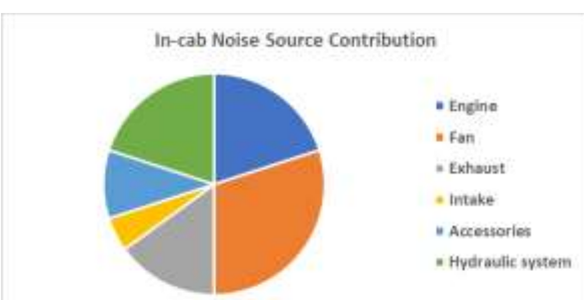

Figure 3. Contribution of different noise sources in In-cabin Noise.

Now, the development trials were focused on the fan noise. In general, there are 2 aspect of fan noise, one is Blade pass frequency (BPF) & second is air flow noise. Each of them has different system dependencies & different frequency content. The blade pass frequency is a function of fan speed & number of fan blades as per equation 1,

$$BPF = \frac{\text{Fan RPM} * \text{N.of fan blades}}{60} \quad (1)$$

Whereas, the flow noise depends on fan speed, fan geometry, tip clearance & shroud geometry. Higher the fan speed, higher will be the air flow noise. For this vehicle, due to cooling requirement, fan speed was more, hence overall fan noise was more. The detail analysis was done to get the problematic frequencies. It was observed that the fan BPF has high contribution as can be seen in below image. As per engine RPM & no. of blades, the BPF came to be 339 Hz. There was a frequency band of 339 Hz to 373 Hz observed from the microphone that captured noise near the fan. These frequencies are due to air flow dynamics between fan & shroud. One measurement was also tried after removing the fan, there was a difference of around 5-6 dB(A) in in-cab as well as exterior noise with & without fan trial. This analysis gave more insights to work on the required area. (Refer figure 4)

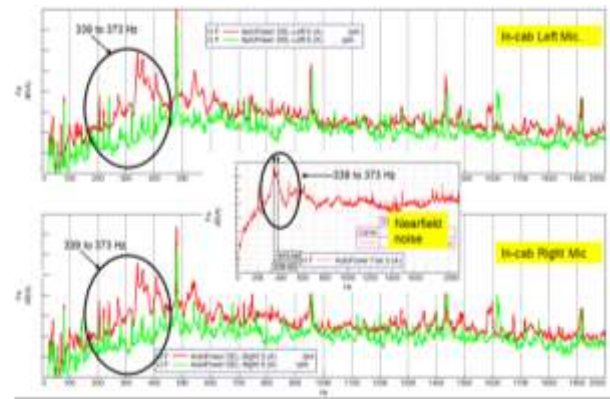

Figure 4. Noise spectrum analysis for fan contribution with & without fan.

Next phase of the development was the standalone fan noise measurement on test rig & comparison with benchmark. There were 2 fans benchmarked. Baseline fan had 7 blades, benchmark 1 had 11 blades & benchmark 2 had 7 blades. The materials for all fans were different. The rated fan speed required was also different due to flow requirement for cooling. One thing to notice for Mahindra fan was that unequal distant fan blades which theoretically helps to reduce the BPF contribution. (Refer figure 5)

Figure 5. Geometry of different fans used for comparison.

Figure 6 shows the test set up used for stand-alone fan noise measurement inside the semi-anechoic chamber. The drive to the fan given from external motor which was isolated from test set up. Total 5 mics were used at a location 1m. from fan in front, LH, RH, Rear side & 2m in the front side (fan flow direction).

Figure 6. Test set for Rig level fan noise measurement.

After analyzing the results, it was observed that standalone Mahindra fan has lowest fan noise levels than benchmark fans at same constant speed. (Refer figure 7)

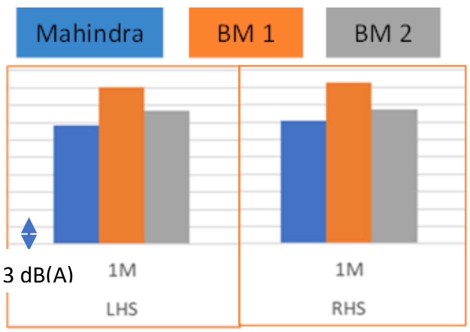

Figure 7. Rig level fan noise measurement results.

The BPF contribution was also found to be lower in Mahindra fan. Only difference came when it was driven at the rated fan RPM. Benchmark fan had lower rated fan RPM as per their cooling requirement. Hence, higher fan noise was observed for Mahindra fan at fan rated RPM. It was decided to add radiator assembly & vehicle hood to get some sense as per actual vehicle condition without engine. (Refer figure 8). Same measurements were carried out & the results revealed that fan noise in these measurements increases from standalone fan noise (Refer figure 9). This was primarily due to air flow interaction between the tip of the fan blade & radiator shroud. Below plot shows the results of this trial.

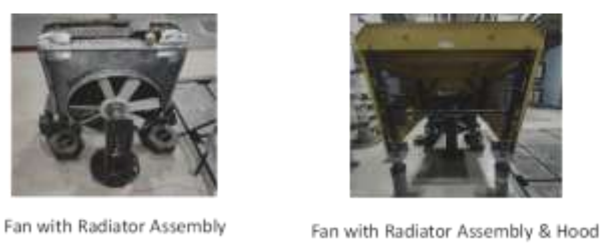

Figure 8. Rig level fan noise measurement results.

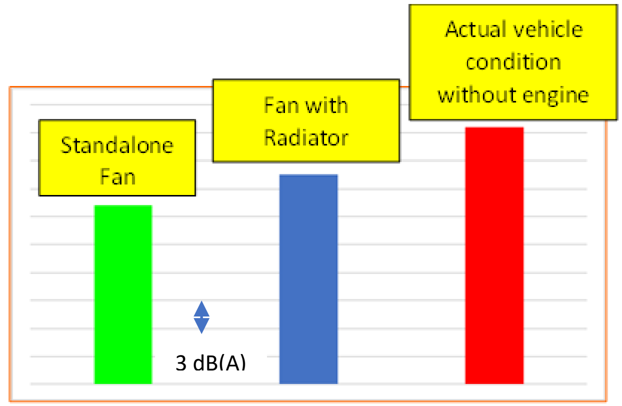

Figure 9. Rig level fan noise measurement results with Radiator assembly & hood.

Some quick trials were done with respect to the radiator shroud geometry, notch on geometry, tip clearance & fan shroud gap in longitudinal direction. These trials were meant for a solution without major change in the system. Some of the trials did not give any improvement & in some cases modifications were not feasible in production. With current fan, reducing the RPM was not feasible due to cooling challenges.

All the constraints led to a new fan design. Target was set to reduce noise by 3 dB(A) at the source in the vehicle level from the baseline & meeting the cooling the requirement. Different suppliers were approached for on the shelf part which might fulfill the requirement. Idea behind of It to reduce development time considerably. 3 proposals were made available considering the system requirement & packaging constraints. Out of which 1 fan sample stand apart which met NVH & Cooling requirements. The fan diameter was same as baseline, no. of blades was more, blade width also increased & blade angle was reduced. This geometry was ideal for more flow at same speed. One special treatment from NVH perspective was addition of blex to the tip of the fan blade This is for reducing the tip clearance & ultimately noise creating from air flow from blade cutting the shroud. (Refer figure 10).

Figure 10. New fan geometry.

Figure 11 shows the testing results of fan noise at the vehicle level. It is very clear that the improvement is observed at the required frequency zone.

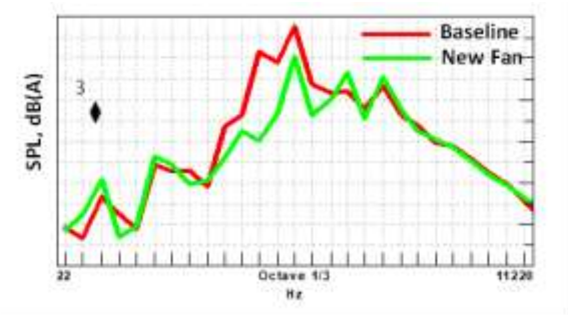

Figure 11. Noise comparison between baseline fan & new fan.

In-cab noise was reduced considerably & harshness produced by fan engagement was also reduced. This was also reflected in ISO measurements. The vehicle which was failing earlier was now passing with values on the edge of the acceptance criteria, but this was not sufficient considering vehicle & measurement variability. As expected, cooling also improved with new fan giving space for further fan RPM reduction. This was further taken to reduce the engine RPM by 4% which indeed resulted in 4% fan RPM reduction. In this case also, cooling requirement was met & NVH had given considerable margin with respect to ISO acceptance criteria. Apart from this, side grill of vehicle hood was optimized for opening. Some trials were done to reduce noise emitting outside without affecting cooling requirement. As per the concluding measurement, in-cab noise was reduced 8% from baseline & sound quality was also improved. All the development finally improved the driver comfort inside the cabin.

Conclusion:

The fan noise development journey shows the step-by-step approach to solve the NVH issue in any vehicle. The noise source ranking & data analysis are very promising tools that led to narrow down the problem & focus on major concerned areas. The correct target setting & fan selection was very important. One thing stands apart in NVH-Cooling trade off was, more efficient fan aids in reducing fan RPM which in turn helps NVH reducing the noise. In the end, the goal of improving the driver comfort by reducing fan noise was achieved. ISO target is also achieved with flying colors, improving the air flow resulting better cooling.

Reference:

1. ISO 6393, “Earth moving machinery – Determination of sound power level – Stationary Test Conditions”, Third edition, 2008.
2. ISO 6394, “Earth moving machinery – Determination of emission sound pressure level at operator’s position – Stationary Test Conditions”, Third edition, 2008.
3. ISO 6395, “Earth moving machinery – Determination of sound power level – Dynamic Test Conditions”, Second edition, 2008.
4. ISO 6396, “Earth moving machinery – Determination of emission sound pressure level at operator’s position – Dynamic Test Conditions”, Second edition, 2008.
5. The Gazette of India, PART II - Section 3 - Sub-section (i), Ministry of Road Transport and Highways Notification, 2020.