NOISE SOURCE IDENTIFICATION METHODOLOGY FOR BRAKE AIR COMPRESSOR ASSEMBLY NOISE IN COMMERCIAL VEHICLE BY TEST BASED RESULTS

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With advancement of technology, methods to restrict concerns at source in automobiles at early stage has become standard. With certain knowledge base industry has been saturated with standard processes to be followed to achieve the required targets. The field of noise and vibration is dynamic and depends on perception of customer. Noise source annoying to one customer might not be same to other. Once we suppress predominant noise in the vehicle secondary noise source can be perceived and becomes irritant. Even with low level of these intermittent noises, annoyance level of customer can change and create bad perception about product. In current study, based on subjective analysis irritant noise source identification using test based measurements of noise and vibration has been performed to find the critical component of brake air compressor assembly in commercial vehicle with diesel engine. With diagnostic tools and angle domain analysis the cyclic behaviours of main source had been identified, which in turn used for noise reduction methodology.

Keywords: Air compressor, Commercial Vehicle, Source Identification, Torsional fluctuation

1. Introduction

In commercial vehicles, engines with high power and torque ratings are used to cater the needs of customer. With increase in demand for quieter product, standards has been set for refinement of vehicle. Refinement for noise, vibration, sound quality has been included in the product development process. With standard process to reduce noise and vibration for engine, driveline, vehicle structure as routine, vehicle cabin has become quieter and comfortable. Mohanty and Pierre [1] studied standard noise sources in commercial vehicle and how driveline components and structural components contributes to overall noise. With enhancement of technological advancement, computer aided simulation for noise and vibration diagnostic has reduced the cost and selection of component based on numerical data has become feasible. Soundatte and Shah [2] described standard process for driveline simulation for finalizing the
clutch in a commercial vehicle. As the field of noise and vibration highly dynamic depends on the customer, customer perceived quality has become an important assessment factor. With suppression of major noise sources, intermittent noise with shorter duration comes into picture. With increase in customer knowledge base and saturated market for commercial vehicle, these abnormal noise creates bad perception of product.

Noise source identification and diagnostic for irritant and intermittent noise is complex as these noises do not generate a profile in frequency domain but can be visualised in time domain. Sound pressure level or acceleration at surface alone cannot be used to define the characteristic of such noises. Mahale and Kalsule [3] described the methodology for noise source identification and benchmarking the vehicle, they described the major noise sources in automobile and identification for a new vehicle. Fatima and Mohanty [4] has used noise source identification methodology for defining the contributing noise source for domestic refrigerator. Lane and Timour [5] have used structural vibration analysis methodology in which different excitations to the engine structures are provided and responses are tracked in frequency domain for noise source identification for diesel engine.

Brake assembly is a continuous loading pneumatic circuit which works based on the brakes application requirement. It consist of Pneumatic compressor for delivering pressurized air to tank, pneumatic air routing to deliver the dry and pressured air to tank and the while using to brake, pneumatic tank for air storage and brake assembly. Pneumatic compressor is usually receive its driving power from engine. It can be a belt drive or gear drive based on the compressor location. Compressor gets loaded while filling the tank, once the pressure inside the tank reaches the required pressure specification, it cuts off the compressor output to atmosphere. This loads at compressor reflects the load on engine and also becomes sources of noise in the general systems. Yang & He [6] studied the abnormal noise source identification by taking case of front end accessories driven heating and ventilation system. It had discussed the TPA methodology for noise source identification. Karaca [7] has discussed the effect of loading of front end accessories, it has been widely explained how the fluctuation in input torque to accessories lead to noise and vibration in the output to the system.

In the current work, keeping customer perceived quality as primary focus, source identification of the intermittent and irritant noise issue had been performed using test based measurement. The diagnostic process involved use of cause and effect tool to differentiate the contributing source by eliminating the probable cause and keeping possible root cause. With use of different techniques time data has been evaluated to find the final root cause.

2. Problem Statement

2.1 Problem Description

During vehicle proto level measurement and component optimization phase, target based on benchmark noise level had been achieved. To achieve the same predominant noise source as engine, transmission, driveline and transfer path as chassis and body had been diagnosed and vehicle level modification had been performed. With reduction in vehicle level noise, certain irritant noise had been observed. The nature of the observed noise had been categorised as repetitive and cyclic. It had been directed from engine run brake pneumatic compressor assembly. Noise level rises with increase in storage tank pressure and reduces as compressor cuts off outlet and directs the output to atmospheric pressure on reaching the pneumatic tank pressure to desired pressure. Figure 1 shows the noise level at 1m from the compressor in time domain. As compressor outlet pressure shifts from tank pressure to atmospheric pressure, overall noise level reduces by 5 dBA as shown in the graph and peak value goes down.
2.2 Construction Layout and Input

Drive from the engine is transferred to the pneumatic compressor for brake assembly by gear train. The pneumatic compressor pumps atmospheric air to a reservoir tank via pneumatic routing and pressure inside the tank increases, once tank pressure reaches certain limit valves at reservoir cuts off the compressor output and direct it to the atmosphere. Once the air inside the tank is used for braking the valves redirects the air to tank. Figure 2 shows the schematic diagram of airflow layout from the compressor in on and off condition.

Figure 3(a) shows drive arrangement from engine to compressor where crankshaft has been directly coupled through gear train with 1:1 ratio and Figure 3(b) shows compressor at other end coupled with fuel injection pump (FIP) and driven by the shaft and keyway.
3. Root Cause Analysis

Root cause analysis or cause effect analysis is a quality control tool to find the root cause of a problem. In the process of root cause identification probable cause for the issue is assembled with the help of brainstorming with subject experts. These probable causes are validated based on test based measurement and root cause for the issue been identified. Fishbone diagram shown in figure 4 shows the probable cause of the issue. Major identified root cause are as per the table 1.

![Fishbone diagram](image)

Figure 4: Fishbone diagram for finding the probable causes for brake air compressor noise.

Table 1: Probable cause table

<table>
<thead>
<tr>
<th>Issue</th>
<th>Probable causes</th>
<th>Root causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake air Compressor Noise issue</td>
<td>Brake air Tank</td>
<td>Tank Cut off pressure</td>
</tr>
<tr>
<td></td>
<td>Tank volume</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fluctuations from engine</td>
<td>Engine excitation</td>
</tr>
<tr>
<td></td>
<td>Brake Assembly</td>
<td>Brake excitation</td>
</tr>
<tr>
<td></td>
<td>Compressor Drive</td>
<td>Gear Rattle</td>
</tr>
<tr>
<td></td>
<td>Gear Alignment</td>
<td>Gear Alignment</td>
</tr>
<tr>
<td></td>
<td>Compressor Valve system</td>
<td>Valve opening and closing mechanism</td>
</tr>
<tr>
<td></td>
<td>Compressor Crank train</td>
<td>Conrod Misalignment</td>
</tr>
<tr>
<td></td>
<td>Compressor Routing</td>
<td>Crankshaft Unbalance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pipe Length</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pipe Diameter</td>
</tr>
</tbody>
</table>

4. Root Cause Identification

Brainstorming with subject matter experts lead to probable causes and main component that can lead the noise generation. With the given vehicle iterations were performed to validate the probable root causes.

4.1 Brake Air Tank system

In brake air tank, possible root cause can be loading done on compressor to fill the reservoir tank. Filling is governed by two parameters, tank pressure and tank volume. Iterations were performed with different tank pressure and different tank volume to find effect of loading of compressor in sound pressure level near compressor as shown in table 2 & 3 respectively.
Table 2: Effect of change in tank pressure in noise level

<table>
<thead>
<tr>
<th>Reservoir tank cut off pressure (bar)</th>
<th>Noise at compressor unit dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>89.77</td>
</tr>
<tr>
<td>8</td>
<td>89.87</td>
</tr>
<tr>
<td>6</td>
<td>89.95</td>
</tr>
</tbody>
</table>

Table 3: Effect of change in tank volume in noise level

<table>
<thead>
<tr>
<th>Tank capacity (litres)</th>
<th>Noise at compressor unit dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>89.95</td>
</tr>
<tr>
<td>60</td>
<td>89.29</td>
</tr>
</tbody>
</table>

Overall noise level showed, there is no effect of tank pressure and volume on noise levels is ruled out from the root cause.

4.2 Engine Excitations

Excitations from engine were measured and results showed plausible second order torsional fluctuation, which seems comparable with benchmark vehicle. To confirm the effect of engine excitations, compressor had been driven by dyno motored engine. The overall noise level near compressor remained same as shown in table 4.

Table 4: Effect of change in Engine excitations

<table>
<thead>
<tr>
<th>Excitations</th>
<th>Noise at compressor unit dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With engine excitations</td>
<td>89.9</td>
</tr>
<tr>
<td>Engine driven with Dyno</td>
<td>89.4</td>
</tr>
</tbody>
</table>

4.3 Compressor Valve Mechanism

With different opening and closing valve mechanism, it has been diagnosed that opening and closing mechanism had not effect in overall noise.

Table 5: Effect of change in Valve mechanism

<table>
<thead>
<tr>
<th>Valve mechanism</th>
<th>Noise at compressor unit dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reed type</td>
<td>89.96</td>
</tr>
<tr>
<td>Ring type</td>
<td>89.94</td>
</tr>
</tbody>
</table>

4.4 Compressor Body and Routing

Modifications had been performed to find effect of stiffening the compressor body and routing and change in the pipe length on overall noise. Measured result showed no difference due the table 6 mentioned modification on overall noise levels.

Table 6: Effect of change in Compressor body and routing

<table>
<thead>
<tr>
<th>Excitations</th>
<th>Noise at compressor unit dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>89.1</td>
</tr>
</tbody>
</table>
Compressor outlet pipe isolated by butyl pad & 89.4
Compressor body and outlet pipe isolated by butyl pad. & 90.0
Compressor body stiffened by M-Seal and outlet pipe isolated by butyl pad. & 89.9
Compressor body stiffened by M-Seal and intake & outlet pipe isolated by butyl pad. & 90.4
Length of outlet pipe to 4 meters. & 90
Length of outlet pipe to 5.5 meters. & 90.45

4.5 Compressor Crank-train

Compressor cranktrain analysis showed no variation in terms of misalignment and unbalance in crantrain components. Running compressor separately showed no abnormal noise. With validated the noise originate after integration of compressor with engine.

4.6 Brake Assembly

With subjective assessment, brake excitations were very low to influence the compressor assembly. It was ruled out to check the excitations from brake.

4.7 Compressor Drive

Compressor had been driven by engine via gear train mechanism. Drive mechanism includes crank gear mounted on engine crankshaft, compressor gear mounted on compressor shaft and idler gear. To check the effect of gear drive, gear train had been replace with belt drive to run the engine. By replacing the drive overall noise level near compressor reduced by 5dBA. With deeper analysis of data in color-map plot as shown in figure 5 with change in drive abnormal noise got eliminated in the high frequency zone. Analysis validated the root cause of compressor noise had been rattle of gear drive.

Figure 5: Color-map plot of compressor noise with and without gear drive.

5. Source Validation

Based on the root cause identification, gear train drive had been diagnosed as root cause of the noise source from compressor. To find the exact reason of noise, extensive noise, linear vibration and angular vibration data had been captured and angle domain processing of measured data been performed.
5.1 Measurement Setup

Measurement had been performed at vehicle level. Noise had been measured at near compressor location, 1m from compressor, driver and co-driver ear. Vibration had been measured at compressor head, body, FIP connected to compressor, engine head, and oil sump. Angular torsional vibration had been measured at crank gear, idler gear and compressor gear. All the data had been measured while tank filling and 30 sec after tank filled with monitoring the pressure inside the tank. As shown in figures 6 time domain data has been converted into angle domain with crank gear rotation as reference.

![Time domain to Angle domain conversion](image)

Figure 6: Time domain to Angle domain conversion.

5.2 Result and discussion

Figure 7 shows angle domain processed result of torsional vibration at compressor gear. Data had been processed for low tank pressure condition, max tank pressure before compressor cut off and after compressor cut-off.

![Angle domain results of compressor gear torsional vibration](image)

Figure 7: Angle domain results of compressor gear torsional vibration.

Results shows peak in gear RPM which eliminates when compressor cuts off the output to atmospheric pressure. On overlapping the vibration and noise data with the compressor gear RPM in angle domain, as shown in figure 8 & 9 respectively, source of vibration and noise had been identified as peak in torsional vibration of compressor gear which originates by hitting of compressor gear tooth at idler gear.

![Compressor gear torsional vibration overlapped with compressor body vibration](image)

Figure 8: Compressor gear torsional vibration overlapped with compressor body vibration.
Figure 9: Compressor gear torsional vibration overlapped with compressor noise.

This validates the source of compressor noise and vibration is rattle hit by compressor gear on idle gear due to load on compressor gear.

6. Conclusion

In this paper, test based measurements were performed to find the root cause of the noise from brake air compressor assembly. Intermittent noise generated by compressor assembly was identified during subjective evaluation. Based on test data and use of quality control tool as cause and effect analysis was done extensively to diagnose the source and find the root cause. Probable causes were validated to check the effect of cause on noise levels. Test results showed the compressor driving gear train as root cause. These results will be further used for solving the noise generation problem. There is scope of performing simulation to predict the main parameters of gear train that affect the noise and optimization to be done based on these simulation results.

REFERENCES