CHARACTERIZATION OF SQUEAKS AND RATTLES OF VEHICLE SEATS

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A systematic study on vehicle seat related squeak and rattle noise problems are presented. The design and its position adjustment of a seat and their relationship with squeak and rattle are presented in details. A FEA seat model was developed and the correlation between seat modes and the vehicle body modes are presented. The root causes of squeak and rattle and their countermeasures that are commonly applied to various types of vehicle are discussed. The correlation between the road test results and shaker evaluations are presented in the paper. Finally, four case studies such as comparison between loaded and unloaded seats, head rest shaking analysis, road input vs. shaker input, and natural frequency matching analysis are included.

1. Introduction

Noise, Vibration and Harshness (NVH) as it pertains to automotive vehicles and is generically divided into three categories; felt (tactile), heard (audible), or seen (visual). These observations are witnessed from the vehicle during various modes of operations. While an audible response could be witnessed to come from any component of an automobile during operation and can be interpreted as a buzz, squeak, rattle, or boom, a tactile response would only come from a vibration in the floor, seat, steering wheel, or other component in contact with a passenger. The cause for the vehicles NVH response is due to components either rubbing, vibrating / resonating or rotating [1]. Squeak and rattle from seats are two major concerns for customers and auto manufacturers because it crosses both tactile and audible NVH categories.

One of major dilemma in seat squeak and rattle issues is the large variation in NVH performance occurred across different body types and test methods while using the same seats. The objective of this study is to take systematic approaches through understanding the design, the structure, the position, modal characteristics of seats and investigating the root causes of squeak and rattle with case studies to develop a complete picture of this critical issue.

2. Seat structure and design position

The seat structure is a complex design with multiple joints and linkages for functionality. Although these functionalities offer viable solutions that satisfy customer requirements they can also inherit design problems that can cause customer dissatisfaction. For example, the seat tracks offer conformability to the front seat occupants as far as leg room; however this poses a non-rigid joint at the base of the suspended vertical cantilevered seat system. Any looseness in the seat track due to manufacturing tolerance stackups can result in an impact type rattle noise or a visual seat
shake motion. Moving the seat in either direction from nominal position offers less interaction of the upper seat track to the lower seat track potentially resulting in lowering the seat stiffness. The same thing can be said about the seat recliners and fold forward/fold-flat seat mechanisms. Also most adjustable headrests have the adjustment in the posts, which suspends the mass body of the component further away from guides located in the top of the seat. Managing the clearance between the headrest post and guide requires a fine balance between headrest lift efforts (low efforts require less interference or a gap) and having a gap that can easily cause a rattle.

2.1 Seat Structure

Automotive seat structures consist of multiple components. The main components that relate to seat squeak, rattle and shake are headrest posts to guide pins, back frame assembly, recliner, seat tracks and seat risers. Also seat trim can contribute to noise such as leather seat to center console or plastic seat back covering to seat belt buckle. Figure 1 presents a general component layout. The majority of seat structure is developed by suppliers to meet safety and reliability standards and is commonly applied to multiple manufactures, at least in part.

![Figure 1. Seat Components and Trimmed Seat](image)

A seat track consists of and upper and lower half in order to allow for the fore aft adjustment. Figure 2 shows a cut away section view. The lower half is mounted and fixed to the body through a pair of seat risers while the upper half is attached to the seat base assembly. Given a certain amount of manufacturing assembly tolerance, and part to part variations, looseness can be exhibited within the track sub-systems and can result in noise or objectionable seat back vibration.

![Figure 2. Seat Track Cut Away Section View](image)
2.2 Seat Design Positions

The design adjustments of the seat assembly allow for the accommodation of various human statures as necessary for sitting safely and comfortably during vehicle operation. The tilt angle of a recliner for the test seat specimen is $21^\circ \pm 2^\circ$, but can accommodate up to $60^\circ$ of tilt at full recline. The fore aft adjustment of the seat track is 240 mm and is typically tested at nominal; the condition where the upper track is in line with the lower track. These values are indicated in reference to the seat as shown in Figure 3.

![Figure 3. Seat Adjustment Positions](image)

The seat is mounted at an angle of $8^\circ$ up from horizontal at the front and can be adjusted to have an additional $+/-6^\circ$. As the seat base is adjusted toward its full forward or full rearward position the track halves have less interaction. This results in a lower stiffness as mentioned above. When the seat is moved rearward the location of the center of gravity also moves rearward from the mounting locations and causes the vibrational forces to be multiplied by the larger moment, (distance from force input to the center of gravity), resulting in a highly increased amount of seat back shake displacement during driving from the road load vibrations. When a seat possess any manufacturing tolerance variations or if the seat belt buckle is close to the seat back, then the seat back shake motions can cause irritating noises to the occupants and lead customers to feel the poorly about the vehicle quality.

3. Analytical modelling of a car seat

A Finite Element Analysis (FEA) model with 6205 mass elements and 7121 nodes of a car seat was developed as shown in Figure 4. It is often of interest to understand how the seat will naturally vibrate due to the application of a wide range vibration-sweep. Performing a Finite Element Analysis study is one way to determine the natural frequencies of any component with a high number of elements and nodes. Understanding the seat response through software analysis will assist in reducing costs associated with physical testing of actual parts via trial error. Performing a Finite Element Analysis study is one way to determine the natural frequencies of any component with a high number of elements and nodes. Understanding the seat response through software analysis will assist in reducing costs associated with physical testing of actual parts via trial error. While analysis of the seat component is important so too is the obtaining local responses around the seat mounts on the body due to road input in order to minimize the occurrence of seat resonance; a condition where the vehicle’s body natural frequency is in the range of the seat’s natural frequency.
In one case the FEA resulting mode shapes of a seat are shown in Table 1. It shows that for the rigidly mounted seat, the first mode is due to lateral bending and occurs at 13.2 Hz, second mode is Fore/Aft 22.6 Hz, third mode Twist 43.7 Hz, and forth mode is Base Up-Down excitation occurring from 54 Hz input.

Table 1. General Seat Mode Shapes

<table>
<thead>
<tr>
<th>Mode Shape</th>
<th>$\omega_n$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Bending</td>
<td>13.2</td>
</tr>
<tr>
<td>Fore/Aft Bending</td>
<td>22.6</td>
</tr>
<tr>
<td>Twist Bending</td>
<td>43.7</td>
</tr>
<tr>
<td>Base Up-Down</td>
<td>54</td>
</tr>
</tbody>
</table>

From the vehicle level impact it was determined that the actual resulting natural frequency will be slightly lower due to the vehicle mounting structure not being completely rigid, as defined in the FEA model’s boundary conditions and component level shaker table testing. The primary causing mechanism of lateral seat back shake will correspond to body torsional mode. This means that to control the amplitude of the natural lateral seat mode, the body torsional mode of the vehicle with this seat should not be in the range of 13 Hz, and rule of thumb includes plus or minus 20%. The primary causing mechanism of fore/aft seat back shake will correspond to the body bending mode. This means that to control the amplitude of the natural F/A seat mode, the body bending mode of the vehicle with this seat should not be in the range of 22 Hz +/- 20%, depending on the accuracy of the model. The seat back twist mode is most likely due to body second F/A mode at 44 Hz. The primary causing mechanism of the Base Up-Down seat bottom shake mode will correspond to suspension and body bending modes. This means that to control the amplitude of this fourth natural seat mode, the suspension and body bending mode of the vehicle should not be in the range of 54 Hz. If either of these is in the range of these values, the component’s frequency is said to be “In Phase” or “Aligned Modally”.

Figure 4. FEA model of a car seat
4. Root causes of seat squeak and rattle

In general squeaks and rattles are caused by different mechanisms. Both can be heard due to a high amount of vibration (frequency or amplitude), subjected to two interacting parts that are not constrained rigidly, on a very small scale. Because of the manner in which two interacting parts making a noise are not well constrained, almost all S&R can be attributed to structural deficiencies. To control squeaks and rattles means to control the contacting parts through either isolation (separating the part), integration (combining the parts), or through some type of surface treatment to make one of the contacting surfaces soft or smooth. One of the materials used to keep a long lasting low friction surface is Krytox® and can have a diverse set of applications [7]. The mechanism of a “squeak” is due to sliding motions at the component interface (like a brake pad squeal to the rotor), while a “rattle” is heard due to intermittent (periodic) particle or face (transverse) contact (similarly to a baby’s rattle). The larger the gap, the larger vibration amplitude is required to hear a noise, (part momentum is needed). It is also true that for a noise to re-occur due to parts interacting with a small gap the frequency should be high. Depending on the vibration amplitude and frequency input and the part mass and gap between the parts different noise characteristics can be observed. Through practice and training the characteristic of the noise can be identified and used to focus the root cause investigation; i.e. the noise has a high pitch so the part may have a low mass or low stiffness or high hardness. Basically, the noise emitted from a wire harness rattling to plastic sounds different from it hitting metal, and the same is true from plastic to plastic or plastic to metal etcetera.

The root cause of the large variation in seat performance (squeak & rattle noise), which occurred across different body types while using the same seats, is summarized in Table 2 below. There were three separate root causes. The first concern was with the development test method. During development of the new program, multiple years ago, the seat test method specified from the design department to the seat supplier failed to specify a criterion for unoccupied seat shake performance. Secondly, this seat test method used a single low amplitude frequency sweep to evaluate the lateral and fore aft seat shake amplitude, which was found to be less severe than on road performance. Thirdly, it was determined that a process used to confirm and plan modal targets between suspension, body and its major components such as the seats did not exist or was not followed resulting in the natural frequency of the vehicle’s body torsion and seat’s lateral shake modes were very near. From this study it was found that each of these major points contributed to the uncontrolled variation in seat performance as applied across different body styles.

<table>
<thead>
<tr>
<th>Root Causes</th>
<th>Countermeasure</th>
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<tbody>
<tr>
<td>1) No Unloaded Seat Shake Test Method</td>
<td>Add Unloaded Seat Shake Test Method and Criteria to NDS</td>
</tr>
<tr>
<td>2) Road Input Is More Severe Than NDS Shaker Table Input and Varies From Model To Model</td>
<td>Provide Road Input From Seat Mounts To Supplier For Each Body Type</td>
</tr>
<tr>
<td>3) Modal Alignment Between Seat and Body/Suspension</td>
<td>Create Standard Process To Better Phase Out Response Modes</td>
</tr>
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5. Case Studies

5.1 Case I: Loaded and Unloaded Seat Test
When it comes to loaded and unloaded seat shake test methods, previous development tests have only required the supplier to meet loaded / occupied seat shake criteria. This was primarily due to capturing the risk of providing high vibrations into the occupant’s rear torso; simulating your back falling asleep on long rides with the road input primarily being smooth highway roads and speeds. However, recent interests arose in creating an unoccupied specification due to a high amount of visual shake and audible noise resulting on a development project. When the seat is unoccupied, such as no passenger in the assistant’s seat, there is not a large amount of mass damping being added to the seat. A human’s body damps the vibration input and causes the seat back shake to be reduced due to its high mass ratio to the seat. The affect to seat shake can be seen in Figure 5. This figure shows the vibration of an unoccupied seat is on the order of 160% higher than that when tested with a real human.

![Figure 5 Loaded and Un-loaded Comparison](image)

5.2 Case II: Head Rest Shaking Analysis

One method used to calculate the dB shake level is seen in Figure 6 (a) below, which shows the seat mounted in the lateral position. In this Lateral Vibration Characteristic Test setup input force is recorded by an impact hammer. The more current method uses three accelerometers excited with sine sweep through the shaker table as shown in Figure 6 (b).

![Figure 6 Lateral Vibration Characteristic Test Method to Determine Seat Frame Resonance](image)
In the impact test set up, the input force value is used as the denominator to the shake equation Eq. 1. The accelerometer fixed to the upper seat back frame, via glue, is used to record the output vibration of the system, and its value is used as the numerator

\[ dB = 20 \log \frac{A(m/\text{sec}^2)}{F(N)} \]  

For the shaker test set up, the shake dB level is calculated by using Eq.2 as shown below:

\[ dB = 10 \log \frac{X_{out}}{X_{in}} \]  

(2)

5.3 Case III: Road inputs vs. shaker inputs

A second major contributor to the poor seat performance is due to the lower severity of response from the seatback during shaker table actuator input to the seat as compared to the effects of road input. A severely higher dB shake, up to 91% higher, was observed coming from the seat back system for each of the seats tested, as summarized below in Figure 7, when comparing to the supplier component level test to actual in-vehicle tests. This demonstrates the need to study how to improve the component level testing used by the supplier to more closely match what will actually be witnessed by customers when operating the vehicle. Benefit may be obtained by having the supplier use road profiles.

![Figure 7. Road Input Yields a Higher Seatback Shake Response for Various Seats](image)

5.4 Case IV: Natural frequency matching analysis

During the early development stages of a new program, when the seat performance criteria are being established, the seat’s natural frequency is needed to be set and established based on predicted values of the suspension and body modes. If the seat is developed without regard or well understanding of these values the seat may still be able to pass the entire set of supplier level testing. However, once the seat is coupled to a vehicle body it could be subjected to resonance due to modal alignment where the seat natural frequency is too closely matched with that of the base structure, i.e. the vehicle body, or that of the suspension. The natural frequency matching analysis condition is shown in Figure 8 below for the “A-2 Row Truck” where the “Body Nat Freq” is in the same frequency range as the “Lateral Nat Freq” and again for the “C-Sedan - Suspension” where the “Body Nat Freq” is in the same frequency range as both seat “Lateral Nat Freq” and the “Fore Aft Nat
Freq”. For this reason it is important to have an accurate CAE model or data from prior similar models to use as reference points. Once the seat and vehicle are developed it can be very costly to adopt effective countermeasure and typically results in adding a mass damper rather than modifying the body design or re-tuning the suspension.

![Figure 8 Mode Map - Natural Frequency Range of Seat / Vehicle Body / Suspension](image)

6. Conclusions

The large variation in seat performance as reported by JD Power’s did in fact occur across different body types while using the same seats. This was proven through the warranty analysis. The seat FRF test results supported the warranty in that:

1) Unoccupied seat shake is about three times more severe than occupied shake
2) The effect of the road input on seat shake can be up to six times more severe than the sinusoidal component level shake as performed by the supplier
3) The side effect to seat shake deterioration is an increase in squeak and rattle claims due to a decay in seat natural frequency, high component stresses, and an increase in mechanism looseness or gap

REFERENCES

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