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SQUEAK AND RATTLE: A COMPARATIVE STUDY USING CAE ON AUTOMOTIVE VEHICLES

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ABSTRACT: *Squeak and rattle evaluation is a common problem faced by automotive OEM"s. With increased importance to driving comfort and quality perception, squeak and rattle detection and elimination in modern automotive systems has become much more important in recent years. Many techniques involving time-frequency analysis, acoustics, digital signal processing, etc. are used to understand and control this unpredictable and undesirable vibro-acoustic phenomenon. An extensive literature survey was performed to gain understanding of the current state of the art. It is an attempt to perform a comparative analysis on experimental acoustic data collected on four, completely trimmed vehicles. These cars were tested on the four-axis, hydraulic road simulator at the Non-linear Testing Facility.*

The data was then analyzed using time-frequency techniques such as short time Fourier transform (STFT) and also with the advanced, complex Morlet wavelet technique. The objective of the analysis was to detect and localize (in time and frequency) squeaks and rattles in automobiles. Practically it is obtained from digital data recorded on the microphones when the hydraulic actuators were exciting the vehicle with certain signals. Analysis of the data resulted in the conclusion that from the frequency and displacement graph we could able to obtain peak to peak amplitude (termed as hot spots) and preventive measures were taken.

I. INTRODUCTION

Motivation:In recent years, the automotive industry has seen a gradual increase in the level of ride comfort demanded by customers. The interpretation of ride comfort has also undergone huge metamorphosis. Continuous improvements in technology coupled with increased awareness levels about safety, economic viability and clean environment have taken the design and analysis processes in the auto industry to a higher level. With this continuous improvement over the years, automobiles have become more and more user and environment friendly.

All the factors considered above have given way to fierce competition amongst the US and international automakers. Given this scenario, customer satisfaction in all fields is of utmost importance for the growth of any corporation. In this context, noise, vibration and harshness (NVH) problems like buzz, squeak and rattle are major concerns because any of these is directly related to perceived quality of the vehicle as such. This is because of the effect that car interior noise has on the perspective of the customer. In the recent past, with better engines, vehicle structures and well designed interiors, chances of any noise being generated at all and, if generated, the probability of those noises reaching the driver/passenger, has been reduced. Therefore, any sound emanating from the interior stands out. There has been considerable research and development activity concentrated around this problem by all manufacturers. NVH groups have been an integral part of all automakers ever since the inception of the automotive industry. The importance associated with the department has only increased over the years.Detection and source localization of such noises is the backbone of current research in this area. Different methods of experimentation and CAE analysis are being researched for aneffective solution. This thesis reviews and advances the state-of–the-art in squeak and rattledetection methods.

II. PROBLEM DESCRIPTION

Squeak and rattle are unexpected events, usually noises of short time duration, perceived by a listener to stand out from the background (expected) noise

Squeak is a friction induced noise caused by relative motion resulting from slip-stick phenomenon between interacting surfaces. The elastic deformation of contact surfaces stores energy that is released when static friction is overcome, producing audible squeak noise. Audible squeaks are generally in the frequency

range of 200 – 10000 Hz. The amplitude and frequency content depends on a host of complex factors such as material constituents, coefficient of friction, normal load and load history, sliding velocity, inertia and thermal effects, wear characteristics, temperature and humidity conditions, etc.

Rattle, generally is an impact induced phenomenon that occurs when there is a relative motion between components with a short loss of contact. It is generally caused by loose or overly flexible elements under forced excitation. Impacts are caused when surfaces close to each other move perpendicular to each other due to insufficient structural strength, forcing repeated separation and contact. Possibilities of these actions increase when the vibration is excessive and the tolerances are inadequate. Rattles generally occur in the frequency range of 200 – 2000 Hz. Higher frequency rattles are referred to as "Buzz".

All these sounds are audible only when the surface areas adjacent to the impact are capable of radiating audible sound power levels.The physical nature of S&R is well established because of the enormous amount of research activity both at the industry and academic level. Research is now focused on how to eradicate the problem by eliminating the root causes. Part modeling and subsequent analysis using CAE software, vibration and modal testing of substructures, property study on materials (plastics) used in the vehicle interior etc. are activities very widely performed in the industry. In spite of a sustained effort in this regard, squeaks and rattles are observed when the fully trimmed cars are tested on the proving grounds or off road testing methodologies based on multi axis shaker tables/road simulators. So, research directed towards a robust car interior noise detection scheme that can be used to test/analyze subsystems and also fully trimmed vehicles . The techniques thus evolved are meant to replace the historic "find and fix" approach which is associated with 47% of the concerns detected during vehicle launch, with subsequent cost and durability issues.

III. SOUND GENERATION MECHANISM

Driving over road irregularities generates impacts on vehicle suspension. This excitation causes free and forced vehicle vibration in the low frequency range according to suspension design, with typical resonance frequencies between 2 to 15 Hz. Besides the rigid body vibration, the whole chassis will respond to a wide frequency range, leading to deformation and relative motion between components and impacts. Almost all S&R can be attributed to structural deficiencies, incompatible material pairs or poor geometric control. Newer fastening methods are an example of poor geometrical control. Fast production has changed the older techniques of like the use of screws on the instrumentation panel with plastic fasteners which may fail occasionally. This can be a major cause of concern. S&R is generally caused due to relative motion exceeding the threshold value. Relative motion might not always cause S&R but S&R is always caused by relative motion. In the current research project, the road surface is being simulated using the MTS320 hydraulic actuator system. When the vehicle is subjected to the forces of the hydraulic actuator, gaps are filled momentarily, metal or plastic members rub nearest materials and loose parts rattle. These are the primary mechanisms that generate the annoying squeak and rattle sound its high bandwidth requirement and the fast growing video population. In recent years, it is reported that Internet traffic is already dominated by video [1].The mechanisms to distribute video content include CDN (such as Akamai [2]) and Peer-to-Peer (P2P). CDN is a traditional solution based on deploying servers at the edge of the network, near video access points. Scalability is a limitation of CDN because the server capacity becomes a bottleneck when there is a large number of concurrent peer requests. Later P2P becomes a popular solution, and is adopted by many content distribution systems such as [3]–[5]. In a P2P content distribution system, peers who create demand for videos also share their content with other peers. The service capacity thus increases automatically with increasing peer population, making scalability an advantage of the P2P solution. Usually, however, peers are not stable since they can leave and join the system at any time. Furthermore, the online peers cannot alwaysprovide stable and powerful service capacity.

IV. TIME-FREQUENCY ANALYSIS CONCEPTS

4.1.Digital Signal Processing Considerations

Analog versus Digital Data

While most of todays data acquisition starts with analog sensing, the analog signals thus acquired are almost always followed by digitization of the signal at some point. This is clearly because of the ease of data storage and computation given the capability of modern day digital computers.

Shannons Sampling Theorem

This is one of the base principles on which signal processing is built upon. The theorem explains the relation between time and frequency domains.

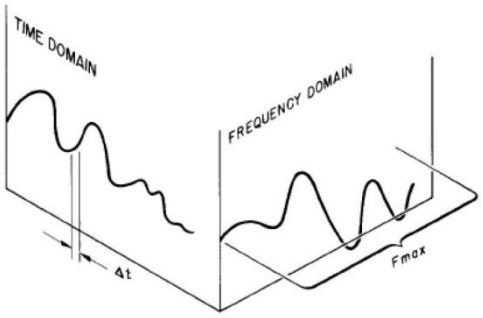

Figure: Relation between time resolution and frequency domain

Fsamp is the digital sampling frequency, Fnyq is the corresponding Nyquist frequency and Δt is the time interval between each time sample.

Rayleigh s Criterion

This states the relation between frequency resolution and time data. The relation can be enumerated as

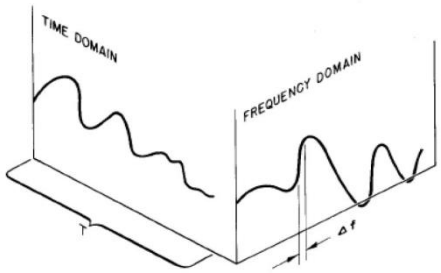

Fig 2.2 Relation between frequency resolution and time domain

Digital Signal Processing

Errors are always a part of data acquisition in any real system. These enter into the measurement invariably due to a number of reasons. These errors can be classified broadly into random and bias errors.

Random errors can be easily dealt with by averaging the data. But, bias errors need special attention. Aliasing and leakage errors are bias errors most commonly encountered in a signal processing situation.

Time - Frequency Transform

A transform is basically a conversion from one domain to another without loss of information. The time - frequency transform, therefore, is a mathematical relation between time and frequency domains.

This is possible today due to the introduction of the concept of Fourier analysis. In order to represent general physical signals, it is necessary to analyze time as well as frequency characteristics. This is known as time – frequency (T-F) representation Time - frequency analysis has become a very common analysis scheme and has gained importance in the science and engineering world ever since its inception

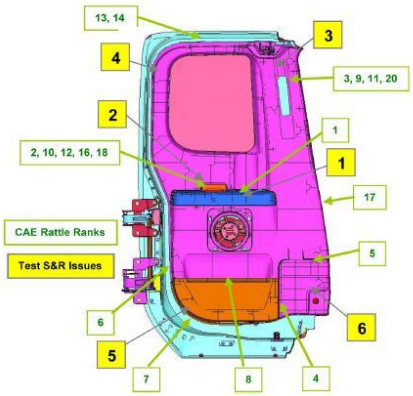

Fig 2.3 Reference Node Points Taken for Response

V. TESTING AND DATA ACQUISITION

5.1.Need for testing

Increasingly, testing of final products is becoming a validation methodology. Analysis has become the primary consideration with the extensive use of analysis software and extremely powerful computers. It is a known fact that the cost, expertise and technical manpower required to perform large scale testing is too expensive for most automotive manufacturers (OEMs). Squeak and rattle, however, is still a problem that is being handled by testing and experimental data processing due to poor predictability of S&R problems with respect to practical manufacturing issues. Moreover, the capability to reproduce actual noises during testing, as heard by customers during operation, will aid in better understanding and probable development of early corrective methodology for future projects.

5.2.Methodologies

Squeak and rattle testing and data acquisition is commonly done in two ways.

1. Operational data collection on moving cars
2. Testing of the structure full or subsystems (such as IP cutaway) on a simulation platform like the MTS 320 road simulator, multi axis shaker table or using electrodynamicshakers.

VI. CONCLUSIONS & DISCUSSIONS

The data acquisition methodology, MATLAB code and the analysis presented shows promise in the area of automotive S&R detection and quantification. Several examples have been presented of successful detections. The code developed can be used a robust analysis tool for both laboratory based road simulator data and on road operational data. Both energy and amplitude normalized complex Morlet wavelet analysis was compared to STFT analysis. Independent wavelet parameter control incorporated in the code helps in varied forms of analysis depending on the interest of the researcher and application. Though not tested, the code should be able to work in higher sampling frequencies covering full spectrum of human hearing. Similar wavelets like the Mexican hat can replace the Morlet wavelet in the existing code with relative ease.

The code thus developed has proved to be a handy tool to analyze signatures of transient events occurring in time streams. The frequency range selection, scale resolution variation, etc. can easily be used by anyone with basic understanding of wavelet analysis. The use, though, is subjected to certain constraining factors such as computer virtual memory and manual time. Processing 6 – 7 second long time streams sampled at 25 KHz itself is found to be extremely heavy on normal computer memory and MATLAB is observed to be unable to handle this amount of data. Therefore, analysis has to be repeated several times to cover the full time stream.The code does not have the capability to discern between good and bad data. Meaning, should there be discontinuities in the acquisition process for any reason, the transform will still be performed on the data available regardless of the error (gaps in data). Therefore, time domain data needs to be checked for workability manually in order to get meaningful results. The analysis is primarily quantitative. The human element is not considered inside the scope of the current project. But the possibility of application.

Though four different vehicles were tested, only one vehicle of a certain model was tested due to limited resources. Therefore, reaching a well researched conclusion on vehicle quality based on statistical number of samples is not possible.

6.1.Future Research Potential

1. Data acquisition on more vehicles belonging to same model should be performed for better comparability and all rounded conclusions on quality of particular vehicles.

2. Signature extraction of squeaks and rattles can help in creation of a new wavelet with particular application to S&R analysis. A wavelet and its dilates which are similar in character to squeak o r rattle in time domain, can be used effectively in the detection process.

3. Robust methodology for indicating existence of disturbances in long time streams aiding quicker analysis times.

4. Neural networks are commonly used in the fault detection schemes and are proven to yield good results. Coupling the existing methodology with neural networks to automate the process can be very interesting for automotive majors. Quick and reliable results can be obtained with a well trained neural network.

5. Development of a comprehensive road profile file to be run on a road simulator by making use of the signature knowledge base. This will help in reducing testing and acquisition time but, yielding good results.

Increasingly, testing of final products is becoming a validation methodology. Analysis has become the primary consideration with the extensive use of analysis software and extremely powerful computers. It is a known fact that the cost, expertise and technical manpower required to perform large scale testing is too expensive for most automotive manufacturers (OEMs). Squeak and rattle, however, is still a problem that is being handled by testing and experimental data processing due to poor predictability of S&R problems with respect to practical manufacturing issues. Moreover, the capability to reproduce actual noises during testing, as heard by customers during operation, will aid in better understanding and probable development of early corrective methodology for future projects.

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