

Ride handling and NVH ACHA6003

NVH overview

Due to its impact upon customers perceptions of quality, feel and experience, Noise vibration and harshness is a fundamental consideration within the automotive industry. NVH measurement therefore forms a fundamental part of the design process taken to ensure that optimum comfort, vibration, and noise levels are achieved during manufacture.

Harshness is the perception of sudden discomfort such as a noise, change in direction or sudden unwanted movements of the vehicle. These sudden movements interact with the human body and can be discomforting when there are unexpected changes. Harshness can significantly impact a consumers view of quality. This can be caused by overly stiff suspension, wheels which have very low-profile tires to which they don't absorb potholes very well.

Vibration can originate from unbalanced mechanically rotating parts, such as engine rotation, gearbox operation and road conditions, this motion can lead to great discomfort especially if its prolonged. These vibrations can also lead to premature failure of components and can compromise the overall structural integrity of the vehicle.

Task 1

For this project, consideration will be focused upon the engine as an excitation generator, due to the combustion process of an engine it can create unwanted vibrations, sounds and harshness that travel throughout the structure of the vehicle and can be felt by its passengers. Passenger vehicles are very complex and have many sub systems of interest within NVH studies. This is due to all these sub systems having to interact with each other, during the vehicles use.

Engine:

The engine is a key part of the vehicle producing the power to propel the vehicle forward. This item is often the source of vibrations felt through the cabin of the vehicle, especially in smaller capacity engines and in particular, in small vehicles fitted with Air conditioning. This is due to the extra load placed on the engine when operating at idle. Under the assumption that the vehicle is fitted with a four-stroke engine, with a firing order of 2-4-1-3, this means that the excitation order will be 2-4-1-3.

Suspension:

The suspension is constructed of many components such as shock absorbers, springs and bushes. These all work in harmony to try and produce a smooth and composed ride for the occupants or, based upon the vehicles purpose can equally be aggressive and harsh as in a sports car requiring firmer control arm bushes, and stiffer springs. Similarly, a luxury vehicle requiring the greatest comfort would have a softer springs and would more than likely provide a smoother ride.

Drivetrain:

This is the system that transfers all the rotational force produced from the engine to the wheels and includes the gearbox, clutch and flywheel assembly, driveshaft and the differential. This sub system consists of many rotating parts which must be manufactured to strict standards as, unbalanced rotating components within this sub structure would result in severe and damaging vibration being felt throughout the whole vehicle and would prove to be unpleasant.

Exhaust system:

The exhaust system is essential for the dispersal of exhaust gases and sound produced by an engine. Often comfort or luxury-based cars will have an optimised exhaust system to suit the use of the vehicle, this can include multiple silencers and resonators throughout the exhaust system again to minimize the amount of NVH produced by the engine. However, in high performance vehicles these can be optimised or fine tuned to produce an appealing sound to the consumer, this can attract more sales especially in the high-performance market to which the overall pleasing sound of an engine is a big selling point.

Body shell and structure:

The body structure is the full shell of the vehicle which provides the majority of its structural integrity and support, with all the components having to attach to it in one way or another. It's often found that some items such as shock absorbers will prove to be a main source of NVH felt through the chassis due to the impact of any road inconsistency travelling through the suspension system straight to the mounting which is the chassis.

Tires and wheels:

The tires and wheels are what transfer all the force absorbed from the road through the vehicle. This is due to them being the only point of contact with the road, these will transfer vibrations and noise and harshness through the cabin of the vehicle from the road surface which can change, this can give an annoying and uncomfortable vibration on certain road conditions.

Excitation Orders explanation:

Order analysis is a form of analysing the noise and vibration produced by rotating machinery such as an engine or gearbox. This is performed to identify how the vibration of one component can contribute to the overall vibration and can help when designing other components so that they can withstand the consistent vibrations that will be exerted by its powertrain etc minimising the risk of premature failure and supporting the overall quality and longevity of the components.

Below is the excitation order of a 4-cylinder engine throughout the rev range of up to 5000 RPM which is a functional day to day usable rev range.

Excitation Order	1000 RPM	2000 RPM	3000 RPM	4000 RPM	5000 RPM
1	16.7	33.3	50	66.7	83.3
2	33.3	66.7	100	133.3	166.6
3	50	100	150	200	249.9
4	66.7	133.3	200	266.7	333.2
5	83.4	166.6	250	333.4	416.5
6	100.1	199.9	300	400.1	499.8
7	116.8	233.2	350	466.8	583.1
8	133.5	266.5	400	533.5	666.4
9	150.2	299.8	450	600.2	749.7
10	166.9	333.1	500	666.9	833
11	183.6	366.4	550	733.6	916.3
12	200.3	399.7	600	800.3	999.6
13	217	433	650	867	1082.9
14	233.7	466.3	700	933.7	1166.2
15	250.4	499.6	750	1000.4	1249.5
16	267.1	532.9	800	1067.1	1332.8
17	283.8	566.2	850	1133.8	1416.1
18	300.5	599.5	900	1200.5	1499.4
19	317.2	632.8	950	1267.2	1582.7
20	333.9	666.1	1000	1333.9	1666
21	350.6	699.4	1050	1400.6	1749.3
22	367.3	732.7	1100	1467.3	1832.6
23	384	766	1150	1534	1915.9
24	400.7	799.3	1200	1600.7	1999.2
25	417.4	832.6	1250	1667.4	2082.5
26	434.1	865.9	1300	1734.1	2165.8
27	450.8	899.2	1350	1800.8	2249.1

Component harmonic resonance:

Harmonic resonance occurs when a system or component is subjected to oscillating or cyclical loading having a frequency similar or higher than the natural frequency of that component. This can result in increased vibrations, and potentially if prolonged, in component failure. Resonance can often cause stresses and strains and can often be an uncomfortable noise or vibration that can be felt throughout the cabin.

In regard to the engine, the crankshaft is susceptible to harmonic resonance issues and vibrations caused by the changing rpms. For example, if the engine isn't fitted with a harmonic damper that can absorb these vibrations it can cause premature failure of key components such as the big end and bottom end bearings when the engine is operating at high RPM's.

This is due to the way the crankshaft operates and the effect of torsional twist and vibrations.

In reference to the crankshaft where the engine operates in the 2nd order, at a high rpm of 5000, the frequency of this order is 249.9Hz which is quite high, and can often lead to premature failure of the bearings as mentioned above if the engine is operated at this RPM for prolonged times. This is where manufacturers would implement devices such as the vibration damper to reduce this.

The Piston operates at the 4th excitation order which in terms of harmonic resonance within this component, as used above this will be evaluated at 5000 RPM's, the frequency experienced by the piston is 332.2Hz, this is relatively high and this can effect the whole system not just the engines, with a frequency this high it can potentially cause engine damage, this is due to the effect of resonance, this can lead to a decrease In engine performance also, this is due to it comprising the overall performance of that system.

When components are exposed to resonance for prolonged periods of time, this is often the cause of premature failures, for example if this engine was driven by a timing chain which features a tensioner and guides that is found in many vehicles, over a long period of time, if harmonic resonance was present this would eventually wear away at the guides allowing chain slack, this can often be the cause of severe engine failure as if the engine was an interference engine and the chain snapped, this would result in a cylinder head rebuild. This is why most modern vehicles that feature this timing system include a large hydraulic damper, this is often the case on vehicles that also feature stop-start technology where they are shutting down and restarting the engine significantly more during a drive cycle.

Measurement of mechanical vibration:

Measurement of mechanical vibration throughout automotive testing is crucial to critically analyse to whether the vehicle is ready for mass production and meets the quality expectation by the manufacturer and the consumer. This is a process that cannot go unmissed during development as this provides crucial information on the dynamic behaviours of the system.

To measure the vibrations throughout the system the use of sensors comes into play, there are various types of sensors that are available and have different uses. These sensors convert a mechanical movement/vibration into an electrical signal that can be displayed in graphical terms showing the amplitude of the vibration or noise etc. This is analysed using specific audio and visual software such as Dewesoft, AVL etc, this gives the ability for engineers to produce a report to decide whether any changes are required within the design, material etc.

Piezoelectric accelerometer:

The first and most common sensor when testing a components NVH, is the Piezoelectric accelerometer. This sensor utilizes the piezoelectric effect to measure the acceleration on a components surface and when the accelerometer is subjected to an acceleration, it exerts a force on the piezoelectric material which is often found to be Crystal or Quartz, when the force is applied it causes deformation which generates a small electrical charge which can then be measured. These sensors have a wide frequency range so can be used in many different scenarios; they are highly sensitive which is ideal for picking up the smallest vibrations.

Selection Criteria for a Piezoelectric accelerometer:

When selecting a sensor to perform a NVH study, the sensor must be adequate for the range of measurements that will be take, when selecting to use a piezoelectric accelerometer, this will be to pick up very small vibrations, this will often be within the cabin of the vehicle as these are highly sensitive to changes in force, pressure and acceleration, this is in order to capture very small vibrations and acoustic sounds that may be present, another reason for selecting this form of sensor is its compact size, this can be placed in very tight areas where some other options may not be suitable, for example this could be behind a dashboard to measure the vibrations and sound emitted by a heater blower motor, this will help engineer when they are testing the overall NVH within the interior. These sensors also have a high signal to noise ratio, this will help when trying to isolate a certain vibration, this helps engineers narrow down what may well be an issue.

Micro Electromechanical System Sensor:

MEMS NVH sensors are manufactured on a micro scale, these are small, cost effective and readily available sensors. They integrate many mechanical structures and sensing elements on one single chip and are commonly used to measure linear acceleration and angular velocity. These are constructed between a suspended mass between a pair of capacitive plates, where when the tilt of the mass changes, it creates a difference in electric potential that can be measured. The difference is then measured as a change in capacitance.

Selection Criteria for a Micro Electromechanical System Sensor:

When selecting a MEMS sensor this would be because they similarly to the piezoelectric accelerometer have a wide sensitivity range which allow them to detect small vibrations and accelerations, however they cannot capture data as well as the piezoelectric accelerometer when talking about high frequency as they suffer a loss of accuracy there, they are very cost effective compared to a piezoelectric variant, they are extremely compact, the piezoelectric variant can be compact however not to the scale of a MEMS sensor so these can be placed in the smallest of spaces, this is where the MEMS sensor maybe required when compared to others due to its cost effectiveness and its small design ensuring it can fit in most places to perform a NVH study.

Measurement of acoustic air pressure:

The measurement of acoustic air pressure is particularly important when performing NVH studies when developing a vehicle, this is to analyse sound characteristics and levels of noise within various environments. This measurement helps analyse the effect upon the occupants of the vehicle and provides an insight to the acoustic air pressure waves within the vehicle.

To measure the acoustic air pressure specialist equipment and sensors are required, within the automotive industry the use of microphones and specialist sound pressure sensors are used, these sensors convert the change in air pressure caused by the sound waves into electrical signals similar to the mechanical sensors, so that this data can be processed and analysed by engineers which will decide whether any adaptations are required.

Piezoelectric Microphone:

Piezoelectric microphones are widely used in the automotive industry when performing NVH studies, these can be mounted inside and outside of vehicles and are often used similarly to the mechanical variant for testing areas of interest in the high frequency range due to their ability to capture data clearly in that range.

Condenser Microphones:

These microphones are often used also due to being cost efficient and readily available, these also can be mounted inside and outside of the vehicles, these work in the same way as listed above, however when exposed to higher frequencies they may not be as accurate, these can be mounted in many places to gather as much data as possible. These are a more general microphone however for brief studies they should provide a result that can be used however may not be as accurate as desired.

Pressure Field Microphones:

A pressure field microphone is designed to measure the true pressure within the sound field, in their design they have a small opening that allows the air to travel through to directly interact with the diaphragm within the microphone, this microphone diaphragm responds solely to the pressure its exerted with which has no direction, this makes these microphones omnidirectional, these are designed to work within small cavities, or an enclosed space.

The choice of what sensor to use varies based upon its intended purpose and what will be investigated. For brief studies where there is no high frequency sound, a standard condenser type microphone would be ample for that purpose, however, in terms of investigating high frequency sounds the piezoelectric variant would be preferred given its increased accuracy range when investigating high frequencies. However, these are more expensive than the condenser type, and finally the pressure field microphone, this would be used in enclosed spaces and small cavities to measure to true change in pressure.

Effects of NVH on occupants:

NVH can effect occupants significantly if there are issues within the quality ride and sound of a vehicle, this can cause discomfort and fatigue to both the driver and passengers making the vehicle undesirable for longer journeys, this is often found in smaller high performance budget cars where they are designed to serve one purpose, which is performance, long term exposure to uncomfortable vibrations from the drivetrain and loud exhaust sounds can be very draining to the occupants, and in some instances can cause sickness.

Long term exposure to loud exhaust or engine sounds can often result in hearing damage and which results in health issues, a loud cabin also makes it difficult for occupants to communicate with each other easily which can often elevate stress and tension in scenarios.

The result of a loud and uncomfortable vehicle can often be perceived as a poor-quality product, to which rattles may develop within the plastics of the interior due to being exposed to vibrations for extended periods. This can often result in a downfall in sales of the vehicle due to it gathering a reputation for poor quality.

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