

Vehicle Design for Robust Driveline NVH Due to Imbalance and Runout Using a Monte Carlo Process

2011-01-1546

Published
05/17/2011

Mohamad S. Qatu
Mississippi State Univ.

Roger King
Mississippi State Univ

Rachel Wheeler and Omar Shubailat
Mississippi State university

Copyright © 2011 SAE International

doi:10.4271/2011-01-1546

ABSTRACT

Variation in vehicle noise, vibration and harshness (NVH) response can be caused by variability in design (e.g. tolerance), material, manufacturing, or other sources of variation. Such variation in the vehicle response causes a higher percentage of produced vehicles with higher levels (out of specifications) of NVH leading to higher number of warranty claims and loss of customer satisfaction, which are proven costly. Measures must be taken to ensure less warranty claims and higher levels of customer satisfaction. As a result, original equipment manufacturers have implemented design for variation in the design process to secure an acceptable (or within specification) response. This paper focuses on aspects of design variations that should be considered in the design process of drivelines. Variations due to imbalance and runout in rotating components can be unavoidable or costly to control. Some of the major components in the vehicle that are known to have imbalance and traditionally cause NVH issues and concerns include the crankshaft, the drivetrain components (transmission, driveline, half shafts, etc.), and wheels. The purpose of this paper is to assess NVH as a result of driveline imbalance and runout variations and the methods that can be used to help design a more robust system to such variations.

INTRODUCTION

Variations in vehicle noise, vibration and harshness (NVH) response from one vehicle to the next can have significant

impact on the company's profile and profitability. Variation can be caused by variability in design (e.g., tolerance stack-up), material (e.g., stiffness properties), manufacturing (e.g., locations of part to part assembly, welding), customer usage, environmental conditions, or other sources of variation. Such variation in the vehicle response causes a higher percentage of produced vehicles to go out of specification in terms of their NVH response. This is found to be a major component of warranty claims. In fact, there is evidence that more than one fourth of warranty claims are first detected through excessive noise and vibration. In addition, variations in vehicle NVH response can cause a loss in customer satisfaction. Loss of customer satisfaction is proven to be even more costly than the warranty claims themselves.

Measures must be taken to ensure reduced warranty claims and higher levels of customer satisfaction. Excessive variations in vehicle response cause manufacturers to improve the target mean value (so that less number of vehicles can reach specification limits). This approach is found to be costly and does not guaranty satisfactory results if a high level of variation is encountered. Instead, research has to be performed to understand the root cause of variation in the vehicle NVH response and control it. As a result, original equipment manufacturers have implemented design for variation in the design process to secure a response that is within specification.

Variations can be due to many factors. Variations in vehicle usage and environmental conditions are often uncontrolled

factors. On the other hand, other variations can be caused by design as in tolerance stack-up, materials and manufacturing processes. For example, certain materials (e.g. rubber) are known to have variation in stiffness that is either unavoidable or proven costly if tighter control is desired. Rubber materials are used as engine mounts, sub-frame mounts, exhaust hangers, tires, as well as other components. Other variations of particular interest in the case of rotating components are due to imbalance. This paper focuses on variations due to driveline imbalance and/or runout.

Driveline NVH has been considered by many research studies. An overview of automotive noise and vibration was described that includes much work on powertrain and driveline NVH [1]. Among the recent research that shows the significant interest in the subject is the work of Iqbal et al [2,3]. They discussed optimization of frequencies of a two-span shaft system joined with a hinge. In addition, Qatu and Iqbal [4] studied the transverse vibration of a two-segment cross-ply composite shaft with a lumped mass. Iqbal et al [5] investigated transverse vibration of a three-piece shaft system joined with multiple hinges.

Robustness of powertrain systems has been the subject of various researches. Robustness of powertrain mount systems for noise, vibration and harshness at idle has been the subject of several studies [6]. Robustness of axle mount systems for driveline NVH was also considered [7]. Optimization studies on driveline systems have been the subject of other studies. Optimization of the high-frequency torsional vibration of vehicle driveline systems using genetic algorithms was carried out [8].

Driveline-induced NVH can be felt by the customer at many customer touch points (CTPs). The CTPs that are typically considered include:

- a. Vibration at the steering wheel.
- b. Vibration in the seat. To avoid complexity of adding the seat dynamics into the analysis, the vibration at the seat track will be assessed. It should be noted here that this particular assessment may require the acceleration (or velocity) to be measured in all three directions.
- c. Audible noise. This is measured either at the driver's in-board ear or driver's out-board ear or both.

Vibration in the floor pan can also be assessed. There are other CTPs. One can consider the seat track of other seats in the vehicle. One may also consider arm rest areas and the transmission lever as possible CTPs. Attention to these is less than the others.

THE TECHNICAL APPROACH

The general mindset is that noise and vibration energy is born at a source. In almost all of the cases studied, the source is a

structural or machine element. The noise and/or vibration energy is then transferred through the vehicle structure and enclosures to a receiving point. This is referred to as the path. The receiving point (a customer touch point) is often referred to as the receiver. If the path of the noise and/or vibration energy includes an energy transfer through air, the NVH energy is referred to as airborne. Examples of airborne noise include pump whine, transmission whine, alternator whine, as well as many others. It should be emphasized here that although we refer to this as airborne noise, the actual energy was born at a structure (usually the housing of the pump, transmission, or alternator that is transmitting such energy). If all the NVH energy is going through a structural path, the NVH concern is referred to as structureborne noise. In general, structureborne vibration concerns are of low frequency nature. This is the case because of two main reasons:

1. Higher frequency energy is usually dampened in the structural path through various levels of isolation
2. Customers are less sensitive (or even not sensitive) to vibration energy at higher frequencies (above 150 Hz). Higher frequency energy is usually picked up by customers as sound.

Figure 1 shows a typical diagram that relates the warranty claim that is generally referred to as “vehicle vibrates while driving” as perceived by the customer. The figure shows how this issue has to first be translated to values measured objectively at customer touch points (seat track, steering wheel and possibly others). While this seems to be a trivial step, experience shows that it may actually be a demanding one. Challenges may rise in trying to duplicate the customer complaints both at the dealer, with the actual vehicle in which the customer experienced the concern, and in a similar setting with a similar vehicle. In many cases, the concern may appear in certain conditions that are not easily reproducible even with the same vehicle. One should keep in mind that variations at this level may occur. These variations can be due to:

1. Variations in customer perception of the NVH phenomenon at hand. What is unacceptable to some customers may be fairly acceptable to others or even unperceived to the rest.
2. Variations in the customer usage conditions. This refers to variations in the habits of different drivers. For example, certain resonances may not be excited unless the vehicle accelerates slowly.
3. Variations in the environmental surrounding. This includes variations in altitude, humidity, temperature, and others.

The second challenge that is faced is to find the actual metric that can be used for measurement and their location. In the case of driveline imbalance-related NVH concerns, these are