

FWD Halfshaft Angle Optimization Using 12 Degree of Freedom Analytical Model

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ABSTRACT

This paper describes the development of an analytical method to assess and optimize halfshaft joint angles to avoid excessive 3rd halfshaft order vibrations during wide-open-throttle (WOT) and light drive-away events. The objective was to develop a test-correlated analytical model to assess and optimize driveline working angles during the virtual design phase of a vehicle program when packaging tradeoffs are decided. A twelve degree-of-freedom (12DOF) system model was constructed that comprehends halfshaft dynamic angle change, axle torque, powertrain (P/T) mount rate progression and axial forces generated by tripot type constant velocity (CV) joints. Note: "tripot" and "tripod" are alternate nomenclatures for the same type of joint. Simple lumped parameter models have historically been used for P/T mount optimization; however, this paper describes a method for using a lumped parameter model to also optimize driveline working angles. The 12DOF model results enable evidence-based decisions during the virtual vehicle phase for driveline working angles, powertrain mount rate and locations relative to P/T center of gravity. Several challenges were encountered and addressed during the 12DOF model development and correlation process, including halfshaft dynamic angle determination, P/T lateral rigid body mode frequency determination and subjective rating prediction.

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INTRODUCTION

Consumer preferences are increasingly trending toward car-based crossover sport utility vehicles (SUVs) because they are fuel efficient and practical for the typical family usage that requires transporting passengers, cargo and occasional towing. Automakers strive to maximize commonality between sedan and SUV architectures to achieve scale and profitability. Using common underpinnings for sedan and SUV also reduce complexity and enables manufacturing of multiple body styles at a single plant, improving capacity utilization. However, sub-system part commonality between sedan and SUV can have consequences that lead to customer dissatisfaction with vehicle performance if vehicle level integration is not optimized for each variant.

For example relevant to this project, a low-cost standard tripot CV joint is often preferred on sedans where halfshaft static and dynamic operating angles are sufficiently small. Using the same CV joint on SUV variants may lead to objectionable halfshaft induced vibration during a drive-away condition. SUVs generally require higher ground clearance, which results in higher operating angles of the halfshaft joints. Additionally, SUVs often have more powerful engines and different P/T mounting systems to react increased driveline torque. Several factors that differentiate SUVs and sedans also have significant influence on the system dynamics that control halfshaft induced drive-away vibration. Driveline torque, halfshaft operating angles and P/T mount characteristics are the main factors that influence both the halfshaft generated axial forces (GAF) and the

vehicle level vibration response to GAF. These critical factors must be included in virtual vehicle design analyses early in the development cycle, such that the P/T and driveline dynamic packaging can be established, and acceptable vehicle level vibration performance can be assured.

Setting aside the challenge of halfshaft commonality between sedan and SUV variants, difficulty may arise in selecting the proper halfshaft joint type to satisfy all operating conditions including curb weight, gross vehicle weight (GVW), light drive-away and WOT acceleration driving. Time-based analytical simulation of halfshaft GAF and vehicle level responses under various operating conditions has been presented by others [1]. However, high fidelity time-domain simulations with significant nonlinearities are often run-time and resource intensive. Therefore, a simple lumped-parameter frequency-based tool is useful for preliminary design studies and multi-purpose analyses. The goal of such analyses is to define the desired characteristics of the dynamic system that includes the vehicle body, P/T, mounts, halfshafts, and suspension, such that the vehicle level customer interface vibration targets are met.

The following sections of this paper will demonstrate a useful analysis method to define driveline static angle requirements for various operating conditions. Topics discussed include a description of halfshaft induced drive-away vibration, background for the 12DOF

modeling tool, test vs. 12DOF model correlation and a practical application of the method to optimize static halfshaft joint angles in the virtual vehicle development phase.

HALFSHAFT INDUCED DRIVE-AWAY VIBRATION

Front wheel drive (FWD) vehicles may exhibit a low frequency (typically 7-15 Hz) lateral vibration when accelerating from around 5-25 mph. Lateral vibration from 7-10 Hz is often subjectively described by vehicle occupants as a “wobble”, whereas lateral vibration at 10 Hz and above is often described as a “shudder”. The mechanism for both perceived disturbances is the same. This phenomenon is caused by halfshaft 3rd order GAF exciting the P/T lateral rigid body mode. Lateral vibration of the P/T is transmitted to the body via the P/T mounting system. The vehicle body vibration is transmitted to the occupants through the floor and seat, where it is perceived as wobble or shudder. Test data illustrating typical vibration responses on the P/T and seat track during a drive-away vibration event are shown in Figure 1.

In Figure 1, it is evident that the amplitude peak observed at the driver's front inboard seat track vibration is aligned in frequency with the amplitude peaks measured on the P/T at the mount locations. Thus the key responses to be analyzed and simulated are the P/T vibration and the vehicle body vibration.

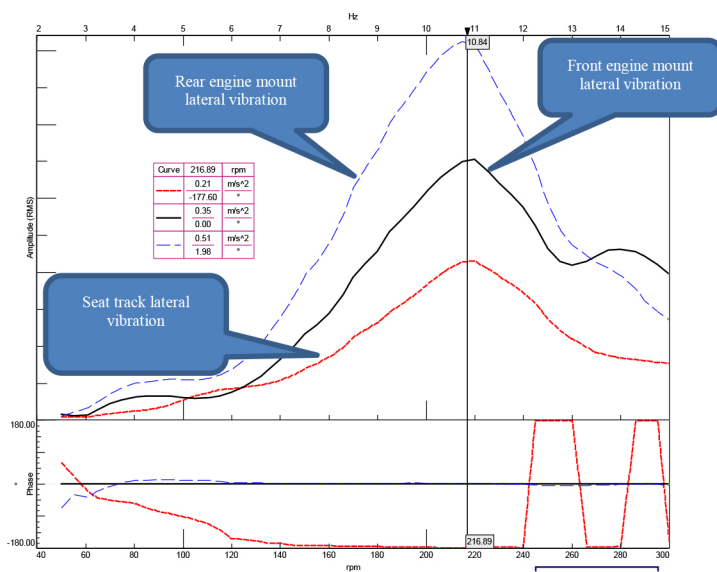


Figure 1. Halfshaft 3rd order lateral vibration measured at the seat track, front engine mount and rear engine mount locations.

TWELVE DEGREE-OF-FREEDOM ANALYTICAL MODEL

Simple lumped-parameter models have historically been used in the development of powertrain mounting systems [2],[3]. These models typically concentrate on the influence of a limited set of parameters. Modelling the powertrain mounting system this way is well-suited for the virtual phase of vehicle development, as it allows the rapid development and preliminary tuning of the system to be conducted over a wide range of alternative designs, operating loads and

conditions. The 12DOF model described in this paper accurately represents the rigid body modes of the powertrain and the response of the vehicle body at frequencies below the first body flexible modes.

The powertrain mounting system must be designed to accommodate several competing design objectives. This drives the desire for a versatile system optimization tool to find a balanced design solution. The modelling tool developed for this project was equipped with an interactive interface, which incorporates design of experiment (DOE) features for semi-automated optimization. Using the simple lumped-parameter model, the eigenvectors and eigenvalues of the system can be calculated nearly instantaneously, and therefore a large design space can be quickly and efficiently explored.

As shown in Figure 2, the model represents twelve degrees of freedom. Six degrees of freedom are assigned to the sprung mass of the trimmed vehicle structure and the other six are assigned to the P/T. The model is allowed to deflect and rotate as defined by the location and stiffness of the powertrain mounts and the suspension corners due to the forces of gravity and any applied external force or torque. The 12DOF model accurately represents the modal properties and responses of the system, but it is sensitive to the accuracy of the input properties including masses, moments of inertia, stiffnesses and damping values.

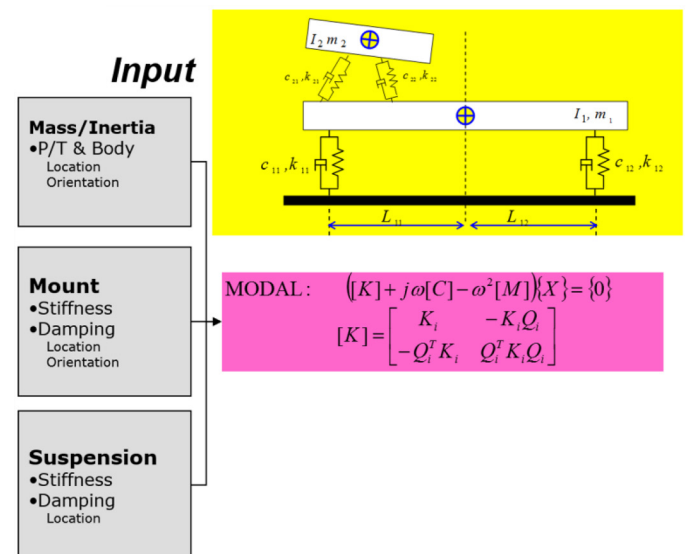


Figure 2. Graphic representation of the eigenvector problem set up by the simple lumped mass parameter model

To comprehend the study of wobble and shudder, the input parameters for the “snapshot” to be simulated in the 12DOF model must be chosen carefully to accurately represent an event that occurs over a time interval during the drive-away of the vehicle. The actual drive-away is a complex sequence of interacting factors. As the driver presses the accelerator pedal, he/she commands the powertrain to deliver an increase in axle torque. On a transverse front wheel drive vehicle the axle torque is reacted through the P/T mounts causing the top of the P/T to rotate rearward. The mounts often have a non-linear rate progression, with the stiffness increasing in response to torque. As the axle torque is reacted through the wheels and suspension on the road, it accelerates the vehicle forward and causes the front end to rise