

Combined Variation Modeling of Structural and Tuning Components for Vehicle Performance Assessment

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ABSTRACT

During the vehicle development process, dimensional variation simulation modeling has been applied extensively to estimate the effects of build variation on the final product. Traditional variation simulation methods analyze the tolerance inputs of structural components, but do not account for any compliance effects due to stiffness variation in tuning components, such as bushings, springs, isolators, etc., since both product and process variation are simulated based on rigid-body assumptions. Vehicle performance objectives such as ride and handling (R&H) often involve these compliance metrics. The objective of this paper is to present a method to concurrently simulate the tolerance from the structural parts as well as the variability of compliance from the tuning components through an integration package. The combination of these two highly influential effects will allow for a more accurate prediction and assessment of vehicle performance. Vehicle alignment modeling is used as the case study in this paper to demonstrate this developed process because the variability of alignment is a key contributor that impacts handling performance. The benefit of coupling tolerance analysis and system compliance analysis is the ability to ultimately assess static and dynamic effects of component variability on the range of ride and handling performance experienced by the customer.

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INTRODUCTION

There are several common techniques available for analyzing assembly dimensional variations, which include worst case analysis (stack method), statistical analysis (probability method) and the Monte Carlo (MC) simulation. Dimensional variation simulation modeling using the MC method has been extensively used for the robust product and process evaluation during the early phases of engineering development. During this period the largest impact can be made with the least amount of overall program cost. By instituting the dimensional analysis early in the development process, engineering and manufacturing will understand the dimensional requirements and design the product and process such that strategies to manage the variation exist before the first parts are produced. Based on the analysis, geometric dimensioning and tolerancing (GD&T), measurement strategies and process control plans can be created and implemented. Manufacturing can then monitor and maintain the requirements at each level of the build. However, there has been a lack of analytical methods capable of estimating

variability impacts from tuning components (i.e. suspension bushings) and how those impacts affect vehicle performance targets.

The objective of this paper is to present an integrated analytical approach using both traditional dimensional variation simulation modeling as well as multiple body dynamics (MBD) modeling to determine sources of variation. This integrated modeling technique would help predict the output range of the vehicle performance targets. There were some previous modeling approaches developed by the author of this paper that links dynamics modeling to dimensional variation simulation [1]. In [1], the dynamic model and dimensional variation simulation model were run separately. Then outputs of displacement for tuning components were input to the rigid body analysis either as an additional mean shift from design nominal and/or as a new geometrical location for parts to assemble in an MC simulation. The benefits in applying a combined modeling approach, demonstrated through case studies in this paper, is that the new approach accounted for the interactions between



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structural and tuning parts. The total variability would not be underestimated with rigid body based MC modeling. With this new proposed process, both types of simulations were executed simultaneously in an integration package environment (i.e. Isight [2]), which would allow the incorporation of the stochastic effects from all systems in real time.

VARIATION MODELING FOR VEHICLE PERFORMANCE

The development of dynamic performance is aimed at customer satisfaction. Dynamic performance is evaluated through driving characteristics including ride, steering, noise/vibration/harshness (known as NVH) and handling, all whilst meeting regulatory requirements. Since vehicle steering and handling characteristics are influenced by suspension and steering system kinematics and compliance (K&C) attributes, development of a robust design concept requires understanding the range of variability of K&C parameters. This further helps the engineers design and specify the components and systems that could minimize variation in vehicle performance.

One critical K&C attribute is the orientation of the wheels, which is determined by a combination of three parameters: static alignment, suspension kinematics (geometry) and suspension compliance [3]. The orientation of the wheels relative to the vehicle and road surface is critical to the directional control of the vehicle. This case study will use a modeling process for vehicle wheel alignment to illustrate the developed rigid body and multi body combined variation simulations. The common alignment measurements used in the industry are toe, camber and caster. The alignment output of toe and camber became the main interests for the study in analyzing performance of a rear suspension system. The definition of toe and camber are extracted from [4] and the illustrations are displayed at Figure 1 and Figure 2 below.

1. Toe: Angle formed by each front wheel plane and the longitudinal axis of the car.
 - a. Toe-in: Slight inward inclination of the leading edge of the front wheels to improve steering and equalizing tire wear.
 - b. Toe-out: Slight outward inclination of the leading edge of the front wheels.
2. Camber: Angle formed by the plane of the wheel to the perpendicular as viewed from the front.
 - a. Positive Camber: Wheel leaning outwards at the top.
 - b. Negative Camber: Wheel leaning inwards at the top.

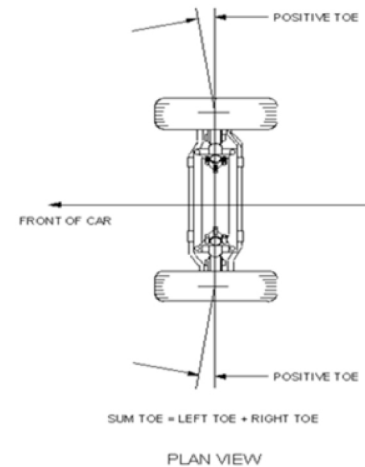


Figure 1. Illustration for Toe Measurements

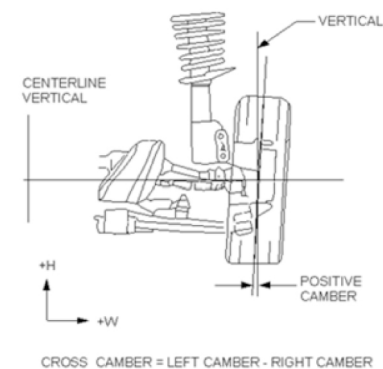


Figure 2. Illustration for Camber Measurements

Assembly Modeling for Alignment

In creating an MC dimensional simulation model, first the subassembly and assembly process and sequence are defined. Then, for wheel alignment modeling, related components of vehicle steering, suspension, and body-in-white assemblies can be put into the assembly model according to the datum structure of each part or assembly sequence. The design intent GD&T values, typically with assumed normal or other predefined distributions, were also applied to all parts in the model.

The process of creating a dimensional variation simulation model is to construct a 3D mathematical model relating the geometry of the components to the entire manufacturing process. The equation that defines 3D geometry relationships is generated first. Assuming the geometry relationship equation is based upon variables X , Y and Z , all with normal distributions, the assembly dimensional variation is as shown in equation (1):

$$T = \sqrt{\left(\frac{\partial}{\partial x} T_x\right)^2 + \left(\frac{\partial}{\partial y} T_y\right)^2 + \left(\frac{\partial}{\partial z} T_z\right)^2}$$