

Applying Virtual Statistical Modeling for Vehicle Dynamics

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ABSTRACT

Dimensional variation simulation is a computer aided engineering (CAE) method that analyzes the statistical efforts of the component variation to the quality of the final assembly. The traditional tolerance analysis method and commercial CAE software are often based on the assumptions of the rigid part assembly. However, the vehicle functional attributes, such as, ride and handling, NVH, durability and reliability, require understanding the assembly quality under various dynamic conditions while achieving vehicle dimensional clearance targets.

This paper presents the methods in evaluating and analyzing the impacts of the assembly variations for the vehicle dynamic performance. Basic linear tolerance stack method and advanced study that applies various CAE tools for the virtual quality analysis in the product and process design will be discussed.

INTRODUCTION

In order to introduce the variation analysis methods using the design tolerances, it is necessary to clarify the terms of variation and tolerance. As they were defined in [1], variation is the change that occurs in size and shape of features from one part to the next at many steps within the manufacturing cycle. Tolerances are engineering specifications that define the extremes in variation from the ideal or nominal dimensions that the quality standards will allow or accept. The objective of variation analyses is to model the effect of component variation upon assembly units. Since such variation is not known, so the design mean and tolerance values are used to represent the extreme variation that will occur if the product specifications are met.

There are several common techniques available for analyzing assembly variations, which include worse case analysis (stack method), statistical analysis (probability method), and the Monte Carlo simulation.

1. **Worse Case Analysis:** This method is also called as the stack method and it evaluates the assembly tolerance under the assumption that all part dimensions are at their extreme values. It is often used for predicting variation of a system when two variables or less are used.
2. **Statistical Analysis:** In statistical analysis, the tolerances on the individual parts are specified as statistical distributions. One special case of statistical tolerance analysis is Root Sum Square (RSS) method. This method for predicting variation is used when the study contains more than two input variables and the process averages agree with the nominal dimension. The result is produced by first summing all of the tolerances after they have been squared and then taking the square root of this amount.
3. **Monte Carlo (MC) Simulation:** Simulation is a modeling method that provides the tool to model process and makes predictions on the performance of the process under different conditions. In mass production for tolerancing purposes, MC simulation creates a statistical distribution of an assembly by randomly selecting many values from the known distributions of the parts. The process of creating a simulation model is to construct of a 3D mathematical model relating the geometry of the components to the entire manufacturing geometry. The equation that defines 3D geometry relationships is generated first. Assuming that the geometry relationship equation is based upon variables X, Y, Z, all with normal distribution, then the assembly variation:

$$T_{assembly} = \sqrt{\left(\frac{\partial}{\partial_x} T_x\right)^2 + \left(\frac{\partial}{\partial_y} T_y\right)^2 + \left(\frac{\partial}{\partial_z} T_z\right)^2} \quad (1)$$

where: $\frac{\partial}{\partial_x}$ is the partial derivative of the tolerance equation with respect to X , etc.,

T_x, T_y, T_z is the individual tolerance, and $T_{assembly}$ is the total assembly variation.

In simulation, computer runs of the model to simulate the random interaction of the component variances using their assigned tolerances T_i , probability distributions and manufacturing capability. The Monte Carlo method randomly selects many values from the known distributions of the parts to create a statistical distribution of an assembly. The results of a dimensional variation simulation are in a statistical format and are used to analyze the effects of the part and assembly variation on desired measurements.

In automotive industry, 3D variation simulation with Monte Carlo method has been used as an advanced analytical tool for engineers to virtually predict the design quality and to optimally allocate the parts geometric tolerances. Meanwhile, it provides the design team with the statistical data regarding the effects of variation on the product and process. On the other side, CAE tool as ADAMS [2] simulates the motion behavior of a mechanical system, and it is used to compute the reaction forces at each joint and attachment area in an assembly for the kinematics effects. Therefore, by bringing ADAMS analytical results to the variation model, the predicted variation results will have the factors due to assembly variations, as well as the part displacements when the assembly moves under various driving and handling conditions.

VARIATION PREDICTION UNDER DYNAMICS

Vehicle dynamics deals with forces and their relation primarily to the motions. Applying with 1D linear tolerance analysis, the displacement caused by forces can be added to the stack up using the worst case or RSS methods. Illustrated on [Figure 1](#), this example is to apply the mounts load displacement to a RSS stack-up analysis. The objective of the study is to estimate the variation range between a truck cab to the frame. The mount linear displacement was calculated and used as one worst-case range tolerance.

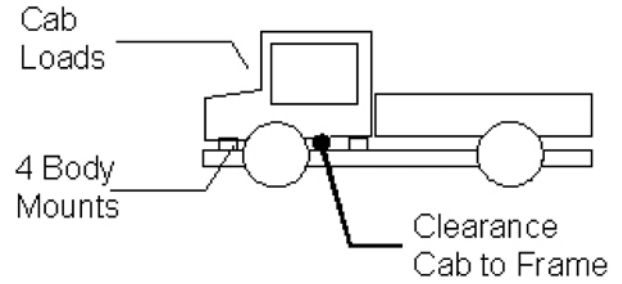


Figure 1. Study Clearance from Cab to Frame

CAE load analysis provides the body loads on each of four body mount for this design study. From the mount static load chart as displayed on [Figure 2](#), we can get each mount displacement range Di under its full load condition.

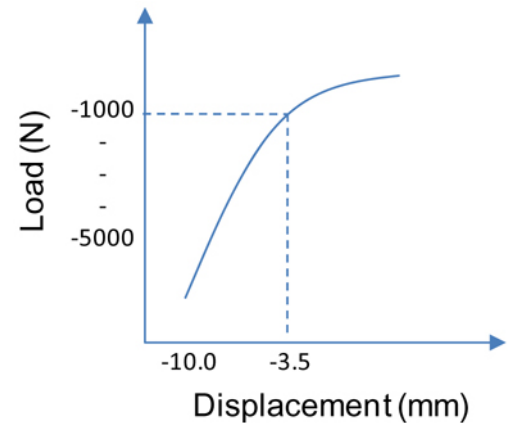


Figure 2. An Example of Mount Static Load Curve

The variability of each component T_i in [Equation 2](#) includes the frame rail Up/Down surface, the mounts length (tolerance of both free-state nominal size and **under loads**), and the cab floor surface tolerance. The maximum linear displacement $Max(Di)$ is from the highest load among four mounts, which is added as an item of a full range variable.

$$T_{total} = \sqrt{\sum_{i=1}^n T_i^2} + Max(Di) \quad (2)$$

Where: Di is the displacement on mount i (in mm), n is total number of the parts in the study.

From this study, using [Equation 2](#), if we know that certain clearance goal has to be achieved, then the tuning components, i.e., mounts, may have to be adjusted its rate without giving away any performance requirements. On the other hand, if the mount property was determined, then the study could provide the information on the estimated clearance after assembly. 1D linear stack-up provides the