

Development in the Acquisition of Vehicle Loads Integrated with a Rigid and Flexible Multi-Body Model

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ABSTRACT

As is known to all, the modeling of vehicles and durability simulation is becoming more accurate and more compatible with physical testing, resulting in shortening of the analysis process, and a lower cost. It would be more advantageous in the future to simulate the full vehicle system before the physical testing. Thus, in the analysis of vehicle durability performance, the need for more precise rigid and flexible vehicle modeling and more precise external loadings acquisition method is increasing.

In view of the typical difficulties faced in the vehicle multi-body dynamics (MBD) simulation and in the associated loading extraction, this paper proposes a method to achieve accurate external vehicle loadings by virtual simulation. This method is performed based on the physical testing and compensates for the imperfections in the MBD modeling, thus being able to improve the quality of fatigue life prediction (FLP). Key technologies to implement this approach in this study include finite element analysis (FEA), MBD simulation and virtual iteration technique (VIT).

A rigid and flexible multi-body dynamics model with less modes is constructed in order to reduce the computation time and to make a better convergence in the computing of the MBD analysis simultaneously. Integrated with the statistics of physical testing, the multi-channel vehicle loadings can be achieved through virtual iteration (VI). Meanwhile, this iteration process identifies corrections to model parameters, thus helping to get a more precise MBD model. Accounting for the nonlinear effects of some of the vehicle components, by using the corresponding precise vehicle loads to excite the dynamic model, body loading spectrums of vehicle are obtained for subsequent FLP. All these measures have been demonstrated for a commercial vehicle analysis. The result showed that a better acquisition of the loading-time history has been obtained, thus reducing the time and effort used in FLP process.

KEYWORDS: durability loads simulation, external vehicle loads, rigid and flexible modeling, virtual iteration

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INTRODUCTION

With the advances in software technology and in the MBD theory in the past decades, vehicle virtual simulation has evolved immensely to be an essential part of the vehicle development process. Integrated with the physical testing, it contributes to achieving better vehicle performance, lower cost, and shorter light-off time to real mass production. For instance, durability simulation now is able to restore the real motion characteristics and to compute damage so as to predict the

fatigue-life of vehicle component. In order to make the durability analysis more accurate and more compatible with physical testing, the key focus needs to be on rigid and flexible vehicle modeling and on the external loading extraction. Efforts in this direction have been made, such as the virtual road load data acquisition approach adopted to derive invariant loads [1]. Geunsoo Ryu and Jaewook Jeon proposed the method of optimal modes selection in flexible multi-body dynamics [2]. In current durability analysis practice, engineers usually combine the spectrum of digitized road and drive signals with

complete MBD model to compute the body loading spectrum used in the subsequent FLP process. But this method is badly considered concerning the artificiality of road spectrum and the typical imperfections of standard MBD model, because the tire mechanical characteristics and some variable properties of components such as bushings still remain unknown and can be difficult to simulate.

This paper focuses on a new methodology of simulation and analysis, with the aim to achieve the accurate external loads by virtual iteration based on the loads which can be measured with relative ease in physical road testing. In addition, performing virtual iteration obviates the need to build a model with tire modeling. What's more, it helps to correct the model during the VI process so as to compensate for the imperfections mentioned above. The proposed approach helps to ensure that the loading spectrum of vehicle component is more accurate and that the subsequent FLP also achieves a better result. The methodology is provided and a multi-channel virtual iteration example performed on a vehicle cab is presented.

EXTERNAL VEHICLE LOADS ACQUISITION

Rigid and Flexible Modeling

In the dynamic analysis for vehicle performance, the component flexibility of MBD model is an important factor related to the accuracy of simulation results. In the MBD modeling, a finite number of bodies are connected by numerous kinds of interconnections, which allow the relative motions between the bodies. Compared with the rigid multi-body dynamics, in a vehicle system, the global deformations of the flexible vehicle components under bending or torsion effects can be characterized more accurately. So usually in the MBD analysis, some of the rigid vehicle components are substituted by modal based flexible vehicle bodies. The practical deformations of the flexible bodies are expressed by modal superposition calculated from normal mode analysis using finite element model, expressed as mode shapes and eigenvalues [3].

Though increasing the number of flexible body and modes can increase the accuracy of MBD analysis, it also makes worse simulation time and convergence. So the number of modes is decided first, especially those modes with less modal participation are ignored. To take control of the convergence process and to reduce computational time without losing the accuracy in practical engineering analysis, the common criterion about modes selection is followed, namely modes with the frequency range that is two or three times the maximum frequency of interest are preserved. In addition, the nodes of FE model may add to the number of degrees of freedom which may produce useless modes. To avoid this problem, an optimal modes selection method employing modal participation factor calculated with only modal deformation shapes at the interface nodes of flexible body is used [2]. The flexible body model is built up by using HyperWorks & Nastran. The eigensolutions,

namely eigen values, normal and constraint mode shapes are firstly obtained with NASTRAN normal modes analysis (SOL 103) and then the mode shapes, eigenvalues, generalized mass, stiffness matrix and so on transformed into MNF(modal Neutral File) for interface with ADAMS/flex module [4].

Typical difficulties in building the verified MBD model still remain in this study. Though the tire models are dispensable here, some variable properties of the connection components such as the bushings and the springs are still unknown and are difficult to represent in simulation. So in the durability analysis relying on the standard MBD simulation alone to acquire internal loadings, there may be significant loss of accuracy. However, by using virtual iteration, these imperfections can be compensated to an allowable extent. Further explanation will be represented below.

Road Testing and Signal Processing

To conduct virtual iteration, achieving the virtual road load data is the first step. With the appropriate transducers and an instrumented test vehicle, the road loading spectrums for different types of durability road courses are gathered for further analysis. As iteration objective signals, the accuracy and the reliability of the loading spectrum are of great importance to the final result of VI. Original statistics obtained from the road testing may contain part of the interferential ingredients, such as the interference signals caused by the nonlinear distortion of the testing devices, and the stochastic error signals mixed in during the road testing. These interferential ingredients may have remarkably negative effects on the analysis result and should be eliminated. So the preprocessing and the identification of road loading spectrum is essential.

Road Testing

Regarding the complexity of vehicle components and limits on the operating space in road testing, only those points that can be represented as boundary conditions of durability simulation are chosen to be sampled. Signals gathered are usually the state responses of the vehicle system. These responses can be nearly every mechanical quantity such as forces, displacements, and accelerations. Some internal quantities generated in flexible components like strains and stresses can also be gathered with special transducers. In practical implementation of virtual iteration, of primary interest are accelerations since these can be measured with relative ease and lower cost compared to measuring generalized spindle forces using the wheel force transducers.

Pre-Processing and Identification of Signals

The measured signals are usually invariant and stochastic, so they may contain some transducers related errors and some other interference signals mentioned above. To eliminate the negative effects of these interferential ingredients, mathematical statistics is the indispensable tool. The

conventional pre-processing procedures of mathematical statistics usually contain four major parts:

1. Tendency term: the signals whose periods are longer than the sampling period, caused by the systematic interference and resulting in the distortion of low frequency signals. Based on the abnormal tendency and the required accuracy, there are three main methods that can be used to mitigate these errors: high-pass filtering, least squares approach and balance approach.
2. Singular points: the signals caused by occasional faults during measuring, switching, recording, and transmission. Based on the PauTa criterion (3σ criterion), these odd sites mixed in useful signals can be distinguished and eliminated.
3. Stability and normal distribution checking: these two procedures are aimed towards evaluating the stability and the normal distribution characteristics of the measured stochastic signals, ensuring the feasibility of VI based on signals.
4. Frequency domain analysis: as a signal analytic method, it can help to understand the signal composition associated with frequency angle, which is of vital importance in VI.

All these pre-processing procedures are aimed at providing a series of credible and effective objective signals for the sequent virtual iteration.

Virtual Iteration

The concept of virtual iteration is to solve an inverse nonlinear problem using a linear transfer function matrix based on a MBD model. The response of the vehicle system has been gathered through road testing. Based on the gathered response, the task of VI is to find out the external loads that deliver the known response [5]. The whole VI flow often has three main sections, namely system identification, objective signals emersion, convergence judging.

Identification of Mechanical System

The principle of virtual iteration should generate appropriate identification signals which are typically the white pink noise. Using the identification signals to drive the MBD model and to make the dynamic simulation, the corresponding responses to the drive signals can be obtained. After that the frequency response function matrix (FRF), can be obtained by the H1 Method which has the following equation:

$$H(j\omega) = \frac{G_{xy}(j\omega)}{G_{xx}(j\omega)} \quad (1)$$

In which $G_{xy}(j\omega)$ is the cross power spectral density function of the input and output signals, and $G_{xx}(j\omega)$ is the auto-power spectral density function

In [equation 1](#), $G_{xx}(j\omega)$ must not be a singular matrix in order to assure the independence between the identification signals.

One special aspect of VI is that the number of drive signals is related to that of the response signals. The number of the response signals mustn't be smaller than that of the drive signals, otherwise convergence will not be reached because the system is under-determined. Typically the amplitudes of white signals can be set higher or even approximately fit to the real ones. If so, the calculated FRF matrix represents the characteristics of the mechanical system much better and the sequent iteration reaches convergence faster.

Iteration on Objective Signals Emersion

Theoretically, the external loadings can be acquired through the back-calculation based on the desired responses and the FRF matrix. However, due to the non-linearity of the mechanical system, some deviations might exist between the desired responses and the computed ones. Thus, iteration steps are introduced to optimize the differences to a minimum. The academic approach consists of the following progressive steps in order to accomplish the iteration target:

1. Calculate the initial drive signals.
2. Use the initial drive signals to drive the MBD model and to perform a dynamic simulation.
3. Compare the computed responses of the mechanical system with the desired responses to obtain the deviations.
4. Revise the drive signals based on the deviations in each iteration step using the principle as following:

$$U_{k+1}(j\omega) = U_k(j\omega) + \alpha H^{-1}(j\omega)[Y_D(j\omega) - Y_k(j\omega)] \quad (2)$$

In which $U_{k+1}(j\omega)$: drive signals for the NO.(k+1) iteration loop

$U_k(j\omega)$: drive signals for the NO.k iteration loop

α : safety coefficient (set to control the gain of drive signals)

$H(j\omega)$: frequency response function matrix

$Y_D(j\omega)$: desired responses

$Y_k(j\omega)$: the response of system of NO.k iteration loop

Convergence Assessment

From a numerical perspective, during iteration loops, a nonlinear system has to be simulated up to a high accuracy through linear equations. How to determine the accuracy of computed responses remain to be a big practical problem. Oftentimes the statistical measure is the most proper choice, which consists of three direct comparisons: time domain, frequency spectrum density and equivalent damage. The comparison in the domain of time and frequency is intuitive and user subjective. The judging criterion is to see the overlap ratio of signals including tendency and peak value. Since the fatigue life prediction has a complex relationship to loading time