

Understanding Measured Spindle Loads Differences with Advanced Tire Model

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ABSTRACT

In this study, a full vehicle with advanced LMS comfort and durability tire (CDT) model was established with ADAMS software to predict the spindle loads of the vehicle under a severe proving ground rough road event. From a series of simulations with various design changes, the spindle loads sensitivities to those design changes were identified. The simulated results were also compared with the measured data and a good correlation was achieved.

INTRODUCTION

During a vehicle development process, various performance attributes need to be considered and balanced, including ride and handling/stability, NVH, durability and reliability, as well as crash and safety, etc. The targets for each performance attribute can be initially established, based on their design objectives and benchmarking results. It is, however, hard to balance all performances attributes within established targets without integrations of overall vehicle system performance simulations. If the sensitivities of each performance attribute to various design variables are known, it is relatively easier to realize such a balance.

Therefore, it is crucial to understand the sensitivity of various performances to various design variables. With field measurement or laboratory test alone, it is expensive, time-consuming and practically impossible to achieve the goal. Alternatively, well-correlated computer simulation is a viable approach to make an initial assessment of performance sensitivities to various design variables. In this way, it can discipline the vehicle design for data collection and management. On the other hand, it is efficient and cost-effective to make a reasonably accurate prediction of the sensitivities.

Vehicle durability development has been significantly improved with the application of advanced simulation technologies in recent years [1, 2], where the spindle loads are the major inputs to the simulations. Thus an accurate estimate of spindle loads is crucial to the success of vehicle durability development. In this process, an accurate full vehicle simulation on digitized road profiles is highly desirable with the tire model being one of the most critical sub-systems of concern. The recent study about LMS CDT [3] shows that the tire model is an effective tool to predict the spindle loads under various road profiles including severe rough road surfaces, such as Belgium Block, random potholes, and cobble stone, etc.

Due to the design changes from Phase-A to -B of a concerned vehicle program in this study, including hard-points, ride and roll rates associated with the spring and bushing stiffness, and shock damping characteristics, etc., the measured spindle loads of a light-duty pick-up truck are significantly different between the two phases. From the measurement results alone, it is hard to explain the differences. Thus, in this study, the validated advanced comfort and durability tire model integrated with a full vehicle model is applied to study the vehicle spindle loads sensitivities to those design changes. From the simulations, the reasons for the spindle loads differences can be identified.

The major process to perform this study is listed as follows:

- Document the measured data differences between Phase-A and -B;
- Document the modeling data differences between the two design phases;
- Make assumptions for the full vehicle model and simulations;
- Summarize the simulation results and make conclusions.

MEASURED DATA DIFFERENCES

There are several commonly used ways to compare two sets of time history data, such as statistics, power spectrum density (PSD), rain-flow cycle counts and/or level crossing counts, etc. The statistics usually include max/min values, root mean-squared value, standard deviation, etc. For spindle load response time histories under random road type event, the PSD and rain-flow cycle counts or level-crossing counts would be preferable, since they include more in-depth information than the statistics. More importantly, the rain-flow cycle counts method includes the information that is directly associated with the fatigue performance of the vehicle and/or components.

Furthermore, the measurement run-to-run variations, which are unavoidable in reality, may mislead if the max/min or peak-to-peak range statistics are used to compare the spindle loads under random road event, where the actual road input from run-to-run may vary. Therefore in this study, the PSD and the pseudo-damage [4] values derived from the rain-flow cycle count of spindle loads time histories are compared among different designs.

On a Belgium Block proving ground event, the PSD responses derived from the measured spindle loads time histories for Phase-A and -B designs are illustrated in [Figure 1](#), where 512 points and Hamming window are applied for PSD estimate with 50% overlap. LF, RF, LR and RR represent left-front, right-front, left-rear and right-rear corners, respectively.

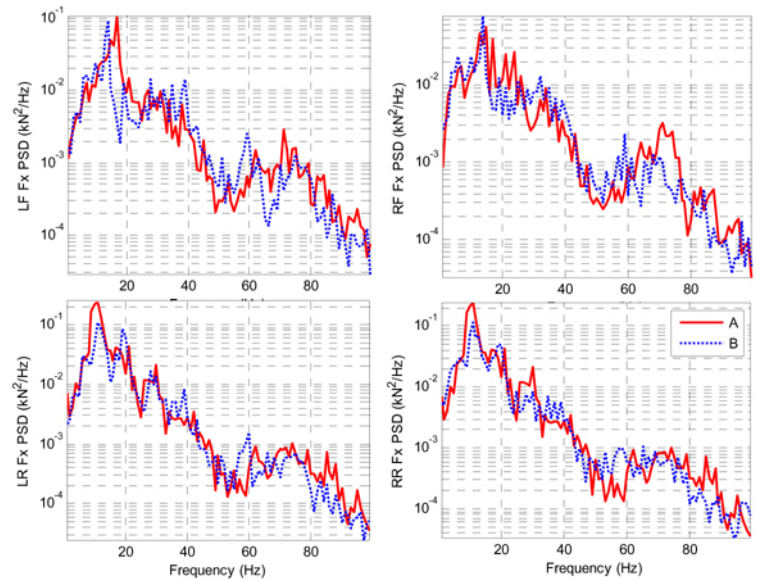


Figure 1(a). Four-corner longitudinal direction.

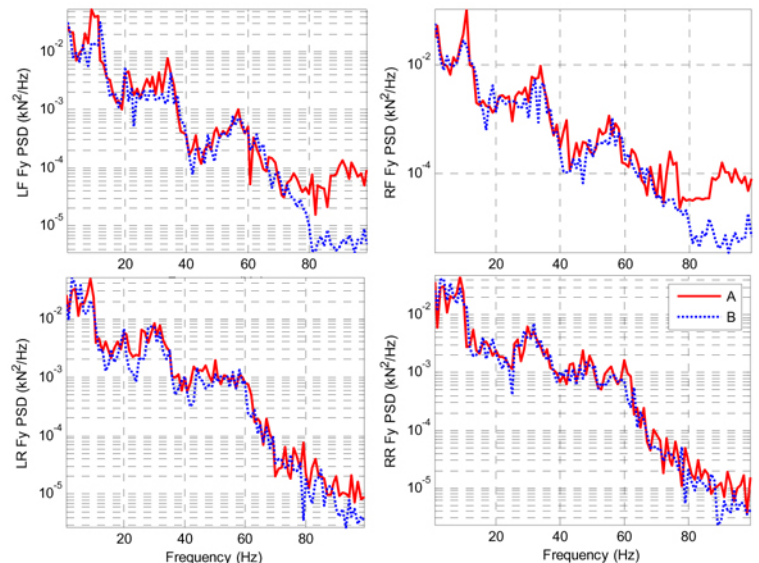


Figure 1(b). Four-corner lateral direction.

Figure 1. Measured PSD responses of spindle loads for Phase-A and -B designs.

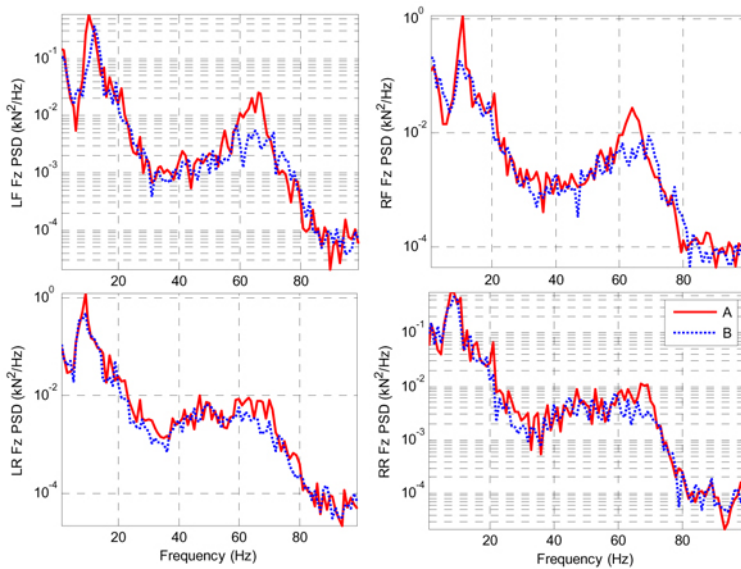


Figure 1(c). Four-corner vertical direction.

Figure 1. Measured PSD responses of spindle loads for Phase-A and -B designs.

It can be seen that the spindle loads PSD responses for both Phase-A and -B designs demonstrate similar pattern in three directions at four corners. Clearly, Phase-A design yields higher responses at frequency about 10 Hz in rear axle longitudinal direction, front axle lateral direction, and right-front spindle vertical direction, respectively, which may be associated with the design changes between the two phases, as well as the tire pressure, vehicle speed, and run-to-run variations, etc.

On the same event, the spindle loads time histories from three passes are further processed to obtain the pseudo-damage values. The average pseudo-damage ratios at each corner for Phase-A to -B design are summarized in [Figure 2](#), where X, Y and Z represent longitudinal, lateral and vertical directions, respectively. In this study, a damage value is calculated based on the rain flow-cycle count of a spindle load time history, where the intercept of loads and slope of Load-Cycle (log-log scale) curve are 20000Lbs and -5 , respectively.

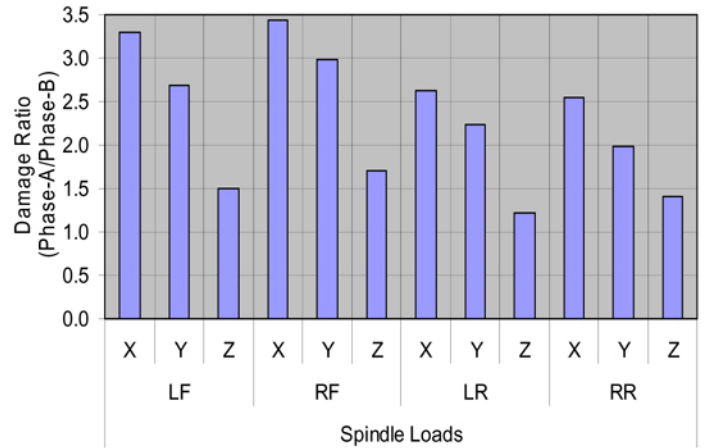


Figure 2. Spindle load damage ratio between Phase-A and Phase-B designs.

It can be seen that, in average, the longitudinal, lateral and vertical spindle loads damage of Phase-A design are about 3.0, 2.5 and 1.5 times those of Phase-B design, respectively. Such significant differences will yield very different designs of suspension components for their structures and associated costs. Thus it is vital to verify the root-cause.

It should be noted that the damage ratios illustrated in [Figure 2](#) was derived from specific Belgium Block type proving ground event with given speed. From the analyses of all measured data under various events (roads and speeds), the damage ratios for different conditions vary significantly. This indicates that the spindle loads depend heavily on the road surfaces and operating conditions. Therefore, to understand the spindle loads differences due to the design changes, the simulations should be performed on the same roads and speeds as those in field measurements.

DOCUMENTED DESIGN DIFFERENCES

In order to understand the root-cause of spindle loads difference between Phase-A and -B designs, the first thing is to investigate the design differences. The vehicle considered in this study is of SLA (Short-Long Arm) type front independent and five link solid axle rear suspensions, respectively. The major design differences between Phase-A and -B can be summarized as follows.

Suspension Hard Points

[Table 1](#) illustrates the differences of front and rear suspension hard points between Phase-A and -B designs.

Suspension Kinematics and Compliances

The front and rear suspension Kinematics and Compliances (K&C), in terms of wheel rate, roll rate, brake force stiffness,