

Advances of Virtual Testing and Hybrid Simulation in Automotive Performance and Durability Evaluation

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ABSTRACT

Virtual testing is a method that simulates lab testing using multi body dynamic analysis software. The main advantages of this approach include that the design can be evaluated before a prototype is available and virtual testing results can be easily validated by subsequent physical testing. The disadvantage is that accurate specimen models are sometimes hard to obtain since nonlinear components such as tires, bushings, dampers, and engine mounts are hard to model. Therefore, virtual testing accuracy varies significantly. The typical virtual rigs include tire and spindle coupled test rigs for full vehicle tests and multi axis shaker tables for component tests.

Hybrid simulation combines physical and virtual components, inputs and constraints to create a composite simulation system. Hybrid simulation enables the hard to model components to be tested in the lab. As a result, it greatly reduces the requirement for an accurate analysis model and increases the chance for obtaining more accurate results.

Mechanical Hardware-in-the-Loop™ (mHIL™) is one of the hybrid simulation approaches. It has been developed to enable actual physical components to replace selected components for “Real-Time” vehicle dynamic simulation. In this approach, the virtual to physical coupling is accomplished in “real-time” allowing an accurate vehicle dynamics simulation to be conducted in a hybrid environment. The disadvantage of this approach is that the “real-time” requirement poses significant constraints on the model and test rig.

To address the limitation of real-time techniques, an alternative technique, Hybrid System Response Convergence (HSRC), has been developed. The HSRC method uses an iterative approach to develop a solution that satisfies the equations of motion for the hybrid system. The iterative approach allows the physical and virtual systems to run sequentially as open-loop systems, rather than simultaneously, thus avoiding the requirement to run in real-time. The disadvantage of this method is that an iterative approach is more time consuming.

Another approach address the limitation of real-time is to use a software named OpenFresco and a predictor-corrector algorithm to connect dynamic analysis software and a test system. If the solving speed cannot meet the requirement of real time, the predictor-corrector algorithm slows down the actuator to allow more time for the model to be solved. This approach is called soft real time hybrid simulation. The disadvantage of this approach is that it still requires the hybrid simulation to be conducted at the near “real-time” speed.

INTRODUCTION

A trend towards the integration of analytical investigations and testing hardware prototypes has emerged due to the increasing pressures of shortened development cycles and the desire to save costs. The combination of physical and virtual testing can accelerate the design process due to the identification and subsequent elimination of physical and virtual prototype deficiencies, such as model parameter inaccuracies.

In the early design stage, finite element analysis (FEA) and multi body dynamic analysis has been widely used for

vehicle development. One of the most important issues for a good FEA model is to establish accurate loads and boundary conditions, but there is often no clear path for the analyst to establish these. One of the methods is to model the full vehicle together with the digital roads and obtain the load and boundary conditions by using a multi-body dynamic analysis, e.g. via software like ADAMS (MSC Software Corporation). This approach is called Virtual Proving Ground. The advantage of this method is that little or no experimental data acquisition is required. The disadvantage is that an accurate full vehicle model is needed. But accurate vehicle models are difficult to create because some of the components, such as tires, are difficult to model.

For many years, automotive companies have used laboratory simulation testing to improve the quality, durability and reliability of vehicle components. Laboratory simulation testing provides accurate durability and performance information, and reduces the product development cycle time. To further accelerate development it is believed that it would be valuable to replicate the laboratory test in the analytical world and conduct virtual testing.

Because lab testing can provide accurate information for the hard to model components, some of the components and/or sub systems are moved from the model to test lab. A virtual model and physical test rig hybrid system is formed in order to achieve more accurate result.

VIRTUAL TESTING

The virtual test approach models a physical test using multi body dynamic or FEA software. To accelerate the design process, virtual testing is executed more and more often prior to performing physical tests. The following are advantages of this method:

- Virtual tests can be conducted at a very early design stage
- The design can be evaluated before an expensive prototype is built.
- A test can be simulated before the test equipment is available.
- The simulation can provide information regarding the type of test equipment needed.
- Load and boundary conditions can be investigated.
- Virtual tests can be conducted faster, easier, and at lower cost than physical tests.
- Additional information can be obtained from a virtual model that is not readily available from a physical test. For example, virtual sensors (“requests”) can be placed in the virtual model to output displacement, velocity, acceleration and load at any point in the structure.
- A number of design alternatives can be rapidly evaluated in “what if studies. This allows optimized design with respect to cost, weight, durability, etc.

To conduct virtual or laboratory based testing, some kind of road load data is usually required. However, when the prototype is not available, it is impossible to collect road load data. Therefore, a generic method to calculate the desired road response from existing information must be used. The RPC™ iteration process can then be utilized to reproduce the road data using a virtual test rig and a vehicle model. Consequently, the load time history and fatigue life of each component can be predicted long before a prototype is available. After the initial prototype is available, real road load data can be collected and lab simulation test can be conducted. The road load data from proving ground and from Generic Road Approach can then be correlated. The virtual and physical test results can also be compared. [Figure 1](#) illustrates this virtual testing process.

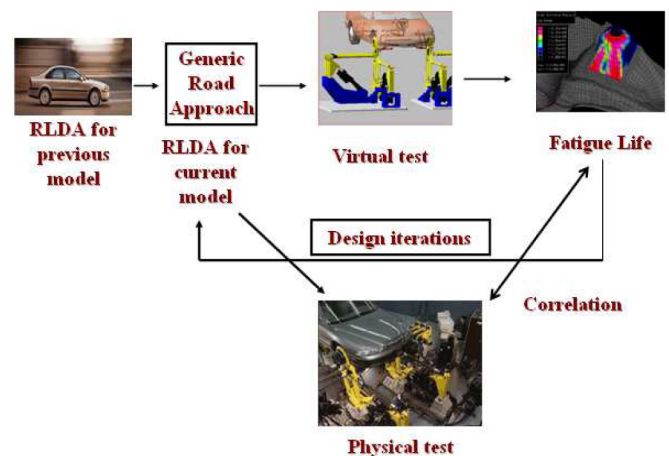


Figure 1. Virtual Testing Process

One of the virtual testing examples is to simulate spindle coupled full vehicle durability tests for the purpose of completing virtual durability evaluations on components and full vehicles before a prototype is available [1]. The reproduction of measured spindle loads was achieved on a virtual model of a passenger car coupled to 6 DOF spindle coupled test system (See [Figure 2](#)). By using techniques originally developed for physical testing, satisfactory results were achieved.

In this virtual testing activity, inaccuracies in the vehicle model and/or road load data can cause inaccurate model response if only the road loads are applied to the vehicle model. For this reason, a non-square RPC iteration method can be used to try and reproduce not only spindle loads but also expected spindle motion. During RPC iterations, weighting values can be used so that the best compatible solution for load and motion will be reached. As a result, both load and motion can be adequately reproduced using the virtual model. The ability to find a compromised solution between load and motion and produce meaningful results in

the presence of model and road data inaccuracies is another important advantage of virtual testing.

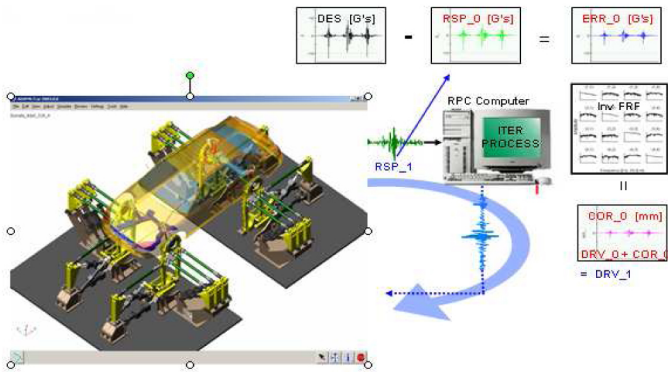


Figure 2. Spindle Coupled Virtual Test System

Another virtual testing example is to evaluate a truck trailer refrigeration unit [2]. By only modeling the component test instead of modeling a vehicle driving on the road, this virtual testing setup simplified the modeling process significantly. Figure 3 shows the ADAMS model of the virtual testing system. By combining multi-body dynamics analysis, finite element analysis, and fatigue analysis, fatigue life and failure mode of the frame of the refrigeration unit was predicted. The virtual test predicted that an engine mount location would fail first which matched the lab test observation. The fatigue life at that location predicted by the virtual test was 17,500 repeats of the test event. During the physical testing, that location failed at 10,070 repeats. The ratio between fatigue lives obtained from virtual and physical testing was 1.74, which was an excellent match. This result demonstrated that virtual component testing was able to predict the failure mode and fatigue life accurately.

Virtual testing relies heavily on an accurate specimen model, which is difficult to achieve for some nonlinear components, such as tires, bushings, dampers, and engine mounts. Therefore, the accuracy of the results is questionable especially at early stage of the design cycle when properties of the components are not fully understood.

Another requirement of virtual testing is that accurate road data is needed. At beginning stage of the vehicle development process when a prototype vehicle is not available, road data has to be calculated from the data for an existing similar vehicle. This will introduce a certain level of error, and the accuracy of the virtual testing result will be negatively impacted.

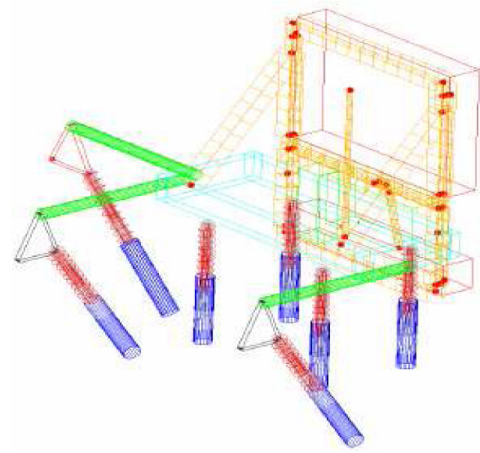


Figure 3. Virtual Testing System of a Refrigeration Unit

mHIL™

One of the methods that is aimed to overcome the limitations of virtual testing is real time hybrid simulation. The idea of this approach is to test the hard-to-model vehicle components/subsystems and model the rest of the well understood components/subsystems. The test system and the analysis model form a hybrid system that is solved in “real time”. This approach is named “mechanical Hardware In the Loop” or mHIL™.

One of the examples of mHIL™ system is the Four-Corner Damper system developed by MTS Systems Corp (See Figure 4). In this system the four physical dampers are tested using four damper test machines. In the vehicle model, the dampers are replaced with single component forces. The inputs of the test system are displacements calculated by the vehicle model. The measured damper forces are sent to the single component forces representing the dampers in the vehicle model.

The accuracy of the mHIL™ Four-Corner Damper system was verified by several handling and ride comfort events including Constant Radius Turn, Braking, Acceleration, and Ramp Steer. mHIL tests showed sufficient agreement with actual track test for all events. The accuracy of this Four-Corner Damper system was confirmed to be sufficient for modeling vehicle handling events [3].

By conducting mHIL tests, Nissan Motor was able to find an unwanted irregular behavior in vehicle motion of a vehicle design. The cause of the irregular behavior was traced to a component by conducting mHIL characterization tests. A countermeasure was successfully adopted prior to the vehicle prototype test. The Four-Corner Damper system was considered by Nissan Motor to be “beneficial to secure high performance and quality of the first vehicle prototype” [3].

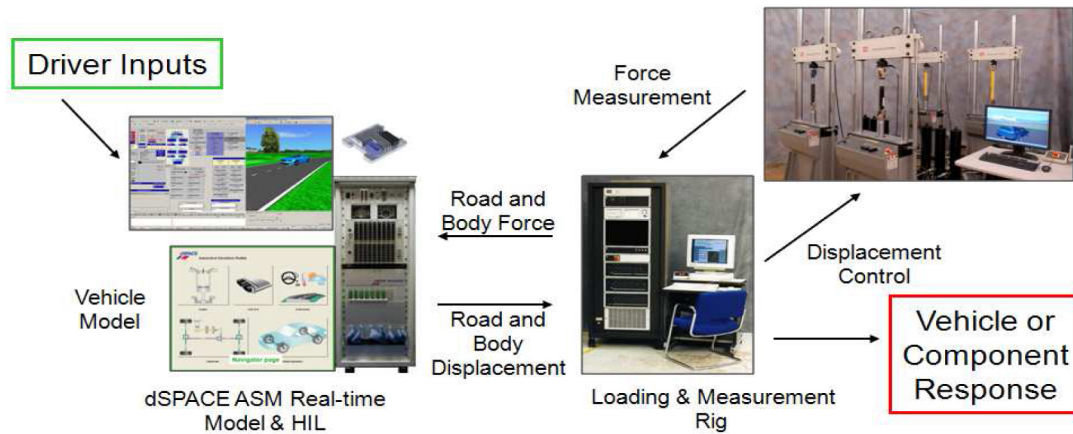


Figure 4. Diagram of Four-Corner Damper System

Another mHIL™ example is the Quarter Car System developed by MTS Systems Corp (See Figure 5). In this system, the vehicle model calculates tire vertical motion, shock tower vertical motion, and tire lateral force. These signals are used as input commands of the Quarter Car test system to excite the physical specimen that includes a tire and a suspension with an active air spring that is difficult to model. In this hybrid system, the active air spring is controlled in part by the vehicle motion that is calculated by the virtual model. The vertical shock tower force that is measured from the Quarter Car test system is applied to the vehicle model so that realistic virtual vehicle motions will be predicted.

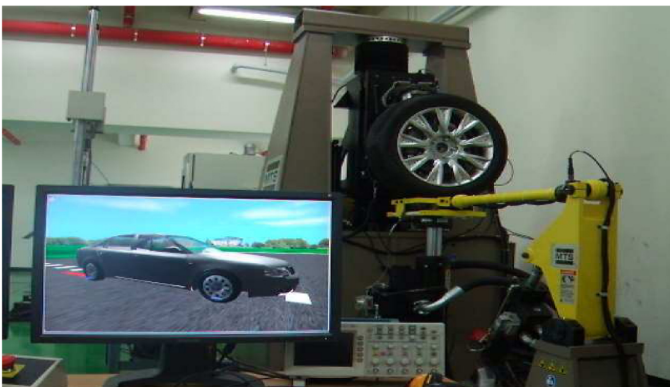


Figure 5. Quarter Car System

The mHIL Quarter Suspension System allows full subsystem evaluation with maneuver based tests, algorithm development and validation, fault & limit handling event testing, pre-tuning, durability evaluation, component and system validation on one test bed without a full vehicle prototype. It is an effective tool in developing air spring, CDC damper, plumbing, compressor, controls, wiring, ECU development and programming, etc.

The mHIL™ approach is designed to operate in “real-time”, which requires the virtual model to be solved in real time. To achieve the solving speed, the vehicle model cannot be very complicated, and some of the sophisticated tire models cannot be used. Flexible components, such as vehicle body, have to be considered as rigid. Due to these kinds of simplification, it is hard for the vehicle models to generate accurate results within the frequency band required for ride comfort and durability events.

Another characteristic to consider is that test systems required to exercise and load the physical hybrid components are often too complex to achieve the “perfect” load and motion tracking control required for real-time hybrid simulation. Multi-axis test rigs designed for high amplitude and frequency vehicle system simulation typically rely on compensated programming that has been iteratively developed to generate the desired responses within the test components.

mHIL™ has proven to be a very effective tool for vehicle performance simulation, but due to the above limitations, it is not currently a feasible method for performing most vehicle comfort and durability simulations.

HSRC

To address the limitations of real-time techniques, MTS Systems Corp. has developed an alternative approach to hybrid simulation for durability applications. The Hybrid System Response Convergence (HSRC) technique enables physical and virtual components with multi-degree-of-freedom (MDOF) dynamic behavior to be simulated as if they were a coupled, hybrid system. The various physical and virtual components of the system are operated sequentially as open-loop systems, rather than simultaneously, thus avoiding the requirement to run in real-time. The HSRC method uses an iterative approach that modifies the inputs to the physical system until the physical and virtual system responses