

Vehicle Dynamics Simulation in Extreme Driving Conditions

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ABSTRACT

The increased weight produced by measuring instruments and the limited space available for such instruments make it a challenge to measure vehicle characteristics in extreme driving conditions such as circuit driving that take the vehicle to its performance limits. The ability to conduct bench simulations of vehicle behavior, that consider a variety of factors such as changes in the form of the vehicle and the forces acting on it, across a wide range of driving conditions, from standstill to extreme driving, would enable the measurement of physical characteristics which has been unlikely to be measured to date. Additionally, this would contribute to more precise analysis of vehicle characteristics during driving. Honda's Dynamic Vehicle Simulator (DVS) was developed as a multi-axis test system with the capacity to enable simulation of vehicle behavior from standstill to extreme driving on the bench. A method of efficiently reproducing this wide range of driving conditions on the bench using the DVS has been developed. This method has enabled vehicle characteristics in the extreme driving range, which has previously been challenging to study in vehicle tests, to be analyzed on the bench.

1. Introduction

Because actual driving tests for analyzing vehicle performance under extreme conditions are straining on drivers and may cause considerable wear in engines and tires, repeated tests are more challenging to conduct than with normal driving tests. In addition, many physical quantities cannot be measured in such tests because of the measuring equipment itself, the weight of which changes vehicle performance and the mounting of which is subject to various restrictions.

Consequently, the ability to simulate on the bench vehicle attitudes, forces, and various other conditions that occur during extreme driving would offer advantages such as eliminating the need for test drivers, reducing tire and engine wear, and, consequently, greater ease of repeated testing. In addition, quantities immeasurable in actual driving tests would be measurable, enabling much more detailed analysis. In short, such a capability would be highly significant.

However, reproducing vehicle behavior from that at standstill to behavior under extreme driving conditions on the bench necessitates a multi-axis, multiple-degree-of-

freedom test system with the control capabilities to simulate a broad range of vehicle and tire behavior. Control was challenging in such test systems because of frequent tire slips and tire lifts relative to the road surface during extreme driving. Thus the need existed for a control technique.

Honda's Dynamic Vehicle Simulator (DVS) is a multi-axis, multiple-degree-of-freedom test system developed with the goal of simulating, on the bench, a wide range of vehicle behavior, from standstill to extreme driving. The system is mainly composed of four wheel pans, which contact the tires, and a center table, which connects to the vehicle body. Various vehicle behaviors during actual driving are reproduced by simultaneously operating the center table and the four wheel pans, which simulate a road surface (Fig. 1). We have developed a technique called Body-Centered Mode Simulation for using DVS to reproduce actual driving conditions, up to vehicle performance limits, on the bench. This technique enables on-the-bench measurement and property analysis of even race-circuit driving and other extreme driving conditions involving intense steering maneuvers.

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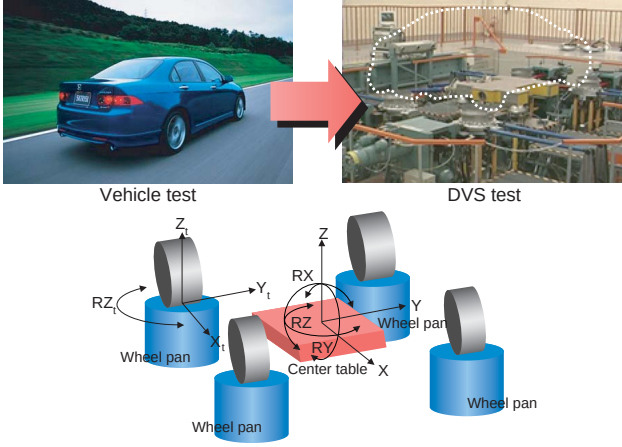


Fig. 1 Outline of DVS

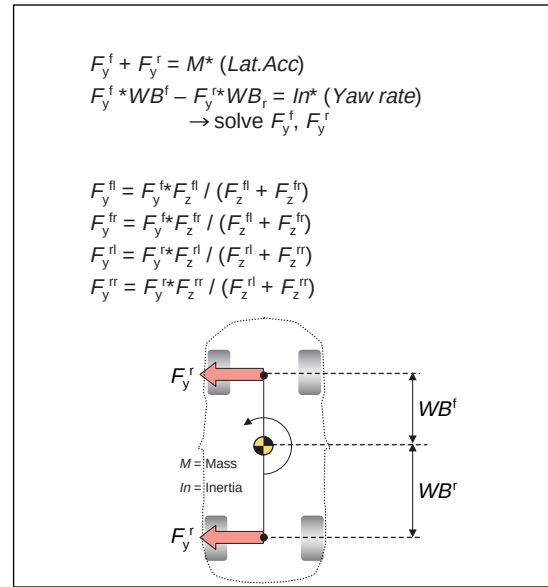
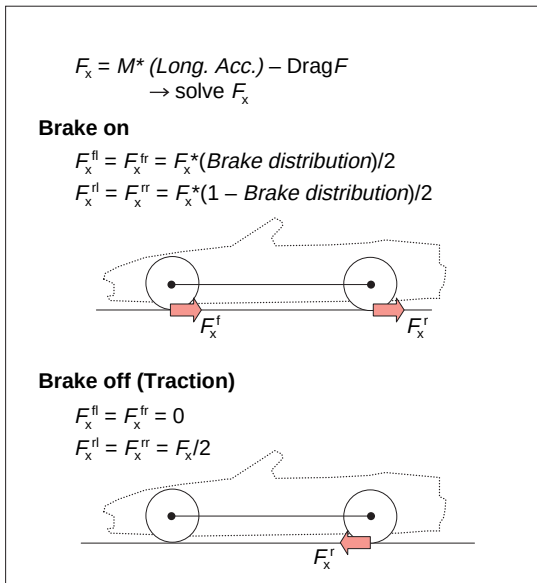
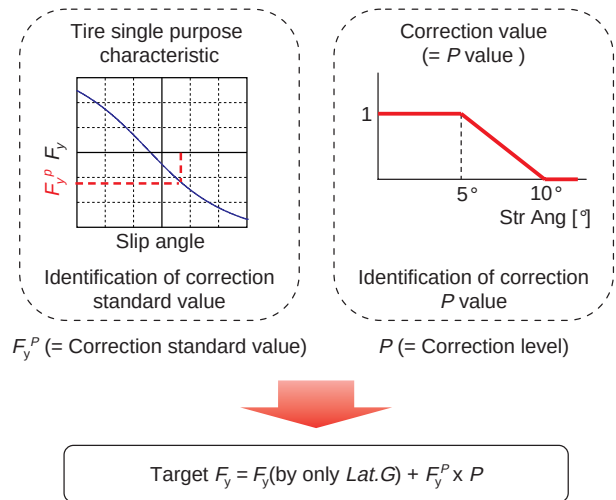
2. Road Simulation

Here, “road simulation” is broadly defined as encompassing simulation technologies for reproducing actual driving conditions on DVS. The fundamental concept of road simulation is to predefine control target quantities based on forces, displacement, and other variables occurring during actual driving and adjusting the DVS actuators to meet those targets in order to reproduce the various changes in condition that occur while actually driving.

Because measurable quantities are limited in actual driving tests at a vehicle’s performance limits, control targets should be defined based on measurable quantities. As this effort focused on the analysis of various compliance properties in suspension components, steering angle and force on the tire contact patch were chosen as

the control targets. Tire tread force was estimated from quantities measurable in actual driving tests.

Figures 2 and 3 illustrate the basic principles for estimating tire tread forces, longitudinal force F_x and lateral force F_y . The former is calculated from quantities such as longitudinal acceleration, air resistance, and brake distribution; the latter by correcting the value obtained from yaw angular rates, lateral acceleration, changes in wheel load, location of center of gravity, and other quantities, with the opposing forces that occur constantly during straight driving. Specifically, the corrected value was $F_y^P \times P$, where F_y^P is the opposing force during straight or near-straight driving, and P is a weighting factor for F_y^P according to steering angle. Adding this adjusted value yielded the final control target F_y (Fig. 4).


 Fig. 3 Identification of F_y generated in tire

 Fig. 2 Identification of F_x generated in tire

 Fig. 4 Method of correction of F_y

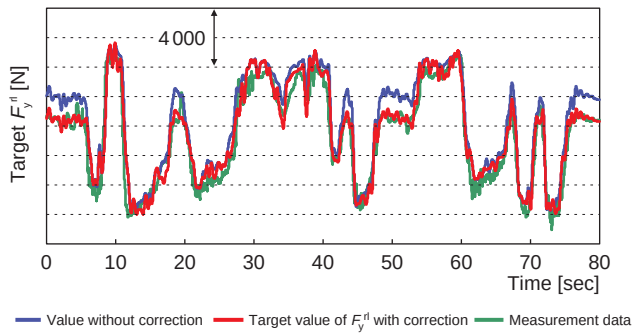


Fig. 5 Target data for F_y

Figure 5 is a graph comparing F_y values measured with a six-component transducer mounted to a tire under actual driving conditions and F_y calculated as described above, both with and without correction. This comparison shows that this correction method enables the calculation, with a high degree of accuracy, of F_y values that are consistent with those in actual driving.

3. Position Control and Load Control

Two methods for controlling vehicle and wheel movements with DVS are used, depending on the target quantity. One is position control, in which position and displacement information are controlled as the target quantities. The other is load control, in which force information is controlled as the target quantity. The advantage of position control is precise reproduction of quantitative displacement, whereas the disadvantage is that because the system is controlled so as to eliminate displacement drift, even when a slight drift away from the target quantity results in excessive force, vehicle damage can result. In contrast, load control involves accurately reproducing the forces that occur, eliminating the possibilities of vehicle damage due to excessive force, but loss of control can result when impractical force is defined as the target value, e.g., when slight lateral force is defined as the target value in a situation in which no contact load acts on tires. In road simulation that includes extreme driving conditions, a large force can occur locally,

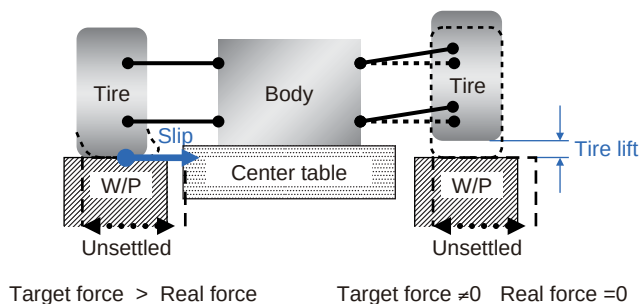


Fig. 6 “Slipping” and “floatage”

resulting in large displacement and in tire slip and tire lift relative to the contact surface as shown in Fig. 6. Consequently, relying exclusively on one control technique helps prevent accurate reproduction. An important element in road simulation is deciding which control technique to use to operate which part of the vehicle. Using both techniques for the appropriate parts enables the use of body-centered mode simulation (BCMS), described in the following section, to reproduce a wide range of driving conditions, including extreme driving ranges.

4. Body-Centered Mode Simulation (BCMS)

Depending on how changes in vehicle attitude are reproduced, road simulation can be categorized into several methods. Most broadly, there are two methods: body-fixed simulation, in which behavior of a moving vehicle is reproduced by fixing the vehicle body to the road surface and moving only the four tires; and body-moved simulation, in which the tires and vehicle body are moved simultaneously.

In body-fixed simulation, control targets are reproduced by using position control for the (immobile) vehicle body and load control for the wheels. However, despite this method’s advantage of requiring fewer actuators as only the wheel pans are moved, this method was not used in this study because of the many inherent error factors involved, such as shifting in the direction of gravity due to changes in the roll and pitch angles, and the tire–road contact angle differing from that of actual driving.

Body-moved simulation can be further divided into two methods: pin fix simulation^{(1),(2)}, in which a certain point on the vehicle body is fixed to a certain point in space and only rotational motion around the X, Y, and Z axes is reproduced; and a method in which both rotational and translational motion occur as the vehicle body is moved in all six degrees of freedom. In fact, BCMS is a type of the latter form of simulation (Fig. 7). In pin fix simulation, the center of gravity is fixed, so the vehicle body and road surface coordinate systems can be aligned with the position of the center of gravity. The advantage

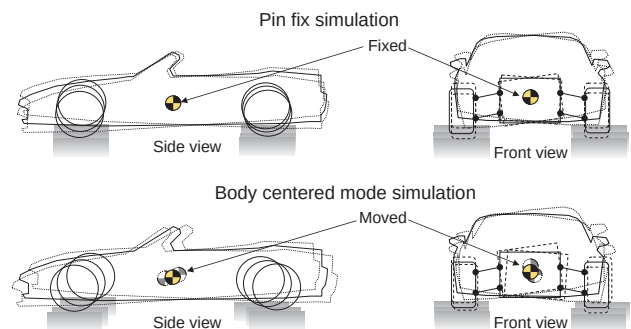


Fig. 7 Difference from pin fix simulation with BCMS

is the ease of measuring from the outside, making changes in vehicle body attitude easier to handle. However, because load control is used for the wheel pans, the occurrence of tire slip and tire lift (Fig. 6) in even a single wheel will immediately result in loss of control. Consequently, pin fix simulation is unsuited to the simulation of extreme driving conditions, in which tire slip and tire lift occur frequently.

BCMS is a method for moving the vehicle body in all six degrees of freedom. It is a road simulation method developed for on-the-bench simulation with a high degree of accuracy and robustness against tire slip and tire lift. Figure 8 shows the basic concept of the method. In BCMS, control targets are divided into high- and low-frequency components. The high-frequency component is reproduced by the wheel pans by means of load control, whereas the low-frequency component is controlled using load control for the center table and position control for the wheel pans. Position control used for the low-frequency component involves maintaining each wheel pan so that the center of rows and columns of each wheel pan pair stays aligned with a preset reference point. This makes it possible to determine the position of the vehicle body relative to the reference point at any time. With BCMS, even if slip and lift occurs in a wheel when simulating extreme driving conditions, position control of the wheel pan helps prevent any deviation from the control target. In short, BCMS is a road simulation system made possible by the multiple degrees of operational freedom that DVS provides for both the wheel pans and center table. Results validating the accuracy of BCMS are discussed below.

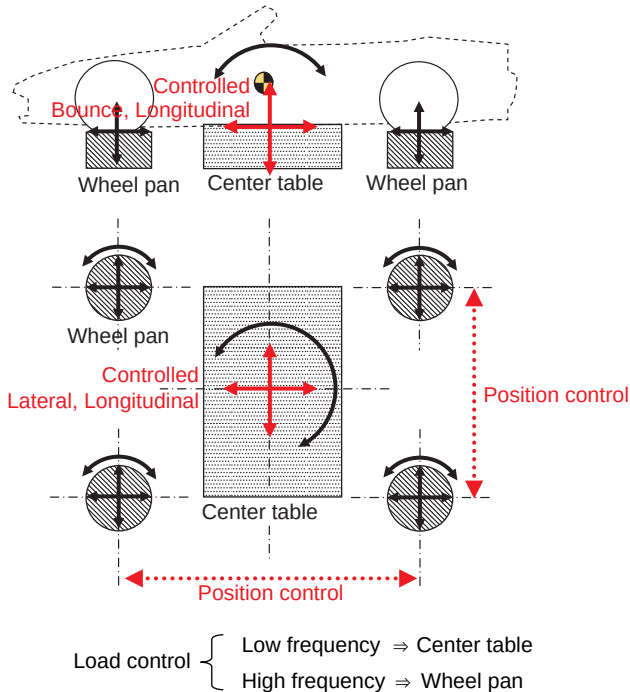


Fig. 8 Theory of BCMS

5. Validation of Simulation

Figure 9 is a graph comparing the control target (force acting on tire contact patches) with the force acting on tire contact patches in actual driving as reproduced under DVS-based BCMS. The satisfactory agreement between the two validates the ability of BCMS to accurately reproduce extreme driving conditions.

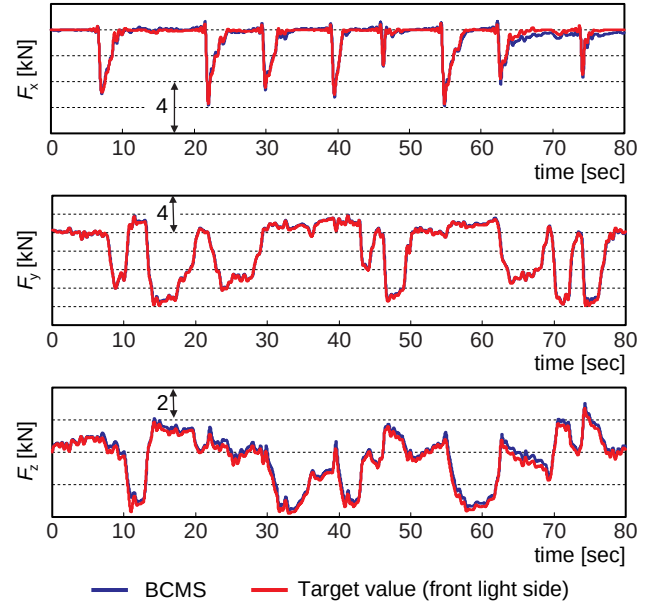


Fig. 9 Comparison between BCMS and measurement values

6. Example Analysis

The graphs in Fig. 10 illustrate the difference between measurements of changes in suspension alignment (i.e., toe changes) in actual driving as reproduced on the bench by BCMS, and toe change characteristics that occur when the forces are eliminated one by one in the following order: F_x , M_z , F_y . (Here, M_z represents alignment torque.) The top and middle graphs show toe change characteristics according to the tractive direction and alignment torque, respectively. The bottom graph shows toe change according to lateral force and indicates that various compliance characteristics relating to toe change can be determined on the basis of actual driving. Thus characteristic vehicle behavior in a certain location can be analyzed on the basis of compliance characteristics. It is also possible to analyze the effects of aerodynamic properties from changes in vehicle body attitude, for instance, and perform quantitative analysis of pitch and roll, which are challenging to measure in actual driving.

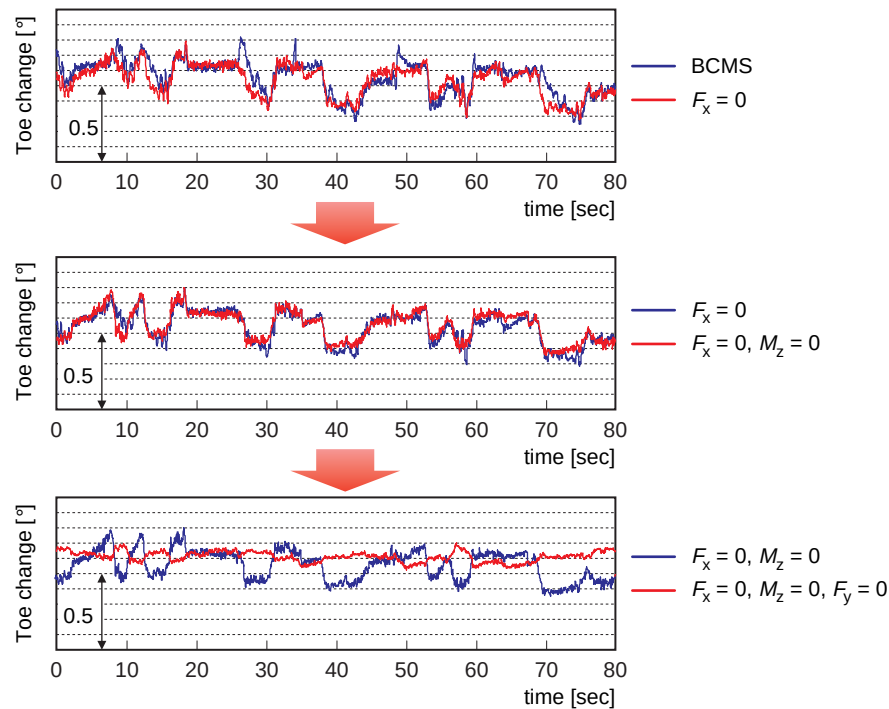


Fig. 10 Compliance characteristics of toe by F_x & M_z & F_y

7. Conclusion

This research aimed to use DVS to reproduce a wide range of driving conditions, from standstill to extreme driving, and thereby build the technology for the benchtop analysis of various vehicle properties during actual driving. The conclusions reached are as follows.

- (1) Appropriate use of both load control and position control is important, particularly when reproducing extreme driving conditions. When using BCMS, reproduction of driving (including extreme) conditions was made possible by having different control targets for the low- and high-frequency components and operating both the wheel pans and the center table according to each.
- (2) BCMS was shown to be capable of the benchtop reproduction of a wide range of driving conditions, from standstill to extreme driving at a vehicle's performance limits.
- (3) Road simulation using BCMS easily facilitates repeated testing, enables the measurement of otherwise challenging-to-measure quantities, and allows quantitative analysis of transient compliance characteristics on the basis of actual driving conditions.

References

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