

Control Strategy for the Excitation of a Complete Vehicle Test Rig with Terrain Constraints

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ABSTRACT

A unique concept for a multi-body test rig enabling the simulation of longitudinal, steering and vertical dynamics was developed at the Institute for Mechatronic Systems (IMS) at TU Darmstadt. A prototype of this IMS test rig is currently being built. In conjunction with the IMS test rig, the Vehicle Terrain Performance Laboratory (VTPL) at Virginia Tech further developed a full car, seven degree of freedom (7 DOF) simulation model capable of accurately reproducing measured displacement, pitch, and roll of the vehicle body due to terrain excitation. The results of the 7 DOF car model were used as the reference input to the multi-body IMS test rig model. The goal of the IMS/VTPL joint effort was to determine whether or not a controller for the IMS test rig vertical actuator could accurately reproduce wheel displacements due to different measured terrain constraints. This paper presents the prototype test rig, high-fidelity terrain measurement process, seven degree of freedom car model, and the vertical actuator control strategy. The results indicate that the vertical hydraulic actuator control meets the requirements needed to accurately reproduce excitations due to terrain constraints.

CITATION: Fietzek, R., Chin, P., Cheng, C., LaBrie, R. et al., "Control Strategy for the Excitation of a Complete Vehicle Test Rig with Terrain Constraints," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(1):2013, doi:10.4271/2013-01-0671.

INTRODUCTION

In recent years, mechatronic systems have developed into one of the biggest drivers of innovation in the automotive industry. This development in the research area can be illustrated by the start of production of systems like dual clutch transmission, lane departure warning systems and active suspensions. These systems have an influence on the longitudinal, steering and vertical dynamics of the vehicle. The interaction of these individual systems on the vehicle

level is crucial for an optimal result in the fields of efficiency, comfort, safety and dynamics. In this context, the final adjustments are usually performed on a test track. The downside of this method is that the results can be negatively influenced by variable and uncontrollable testing conditions. For example, even experienced test drivers cannot perform an exact repetition of a driving maneuver. Even slight changes in timing or speed of a steering movement alter the results in a negative way, which makes the isolation and removal of certain occurrences difficult. This results in higher expenses

in both time and effort. In order to circumvent these challenges, the Institute for Mechatronic Systems in Mechanical Engineering (IMS) designed a conceptual test bed which allows for the optimization of mechatronic systems at the vehicle level under laboratory conditions. The prototype configuration of the “Car-in-the-Loop” (CiL) concept test bed is illustrated below in Figure 1. This prototype is currently in the process of being set up in the IMS laboratory.

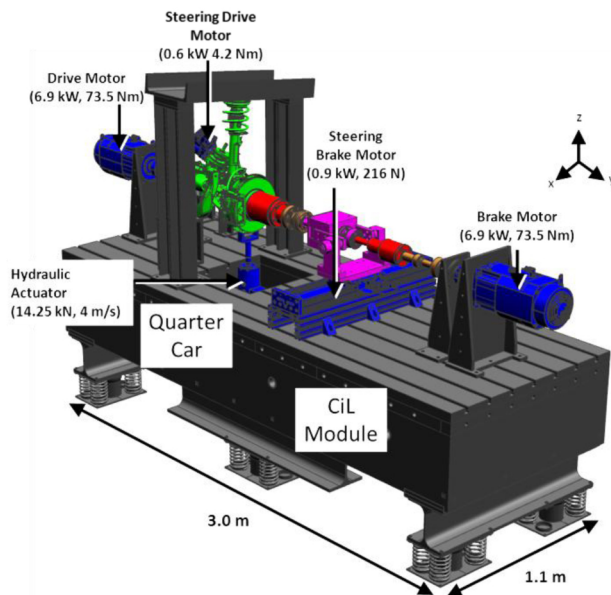


Figure 1. Prototype of the “Car-in-the-Loop” concept

In this paper, a seven degree of freedom model and the CiL test rig are parameterized using values from a BMW Mini Countryman. The seven degree of freedom model is simulated with measured terrain profile inputs, and the displacement between the sprung and unsprung mass is the output. This relative displacement is then used as the reference input into the CiL multibody model.

Typical quarter car parts are the: side shaft, suspension arm, suspension strut, steering gear, wheel bearing housing and the brake disc. The CiL accounts for the interaction of these parts in the following manner. The combustion engine is replaced by a synchronous motor, which is referred to as the drive motor. Another synchronous motor is responsible for simulating driver steering inputs. Figure 2 depicts the “CiL module” that contains the test rig shaft which is mounted on the right side of the sprung foundation along with another synchronous motor which is referred to as brake motor. The brake motor is used to simulate driving resistances like aerodynamic drag for example. The control strategy for the longitudinal degree of freedom was described in [1].

The test rig shaft shown in Figure 2 consists of three sections which are connected by constant velocity joints. The first and the third section provide length compensation. A

linear motor is mounted to the second section to simulate steering resistances, such as self-aligning torque.

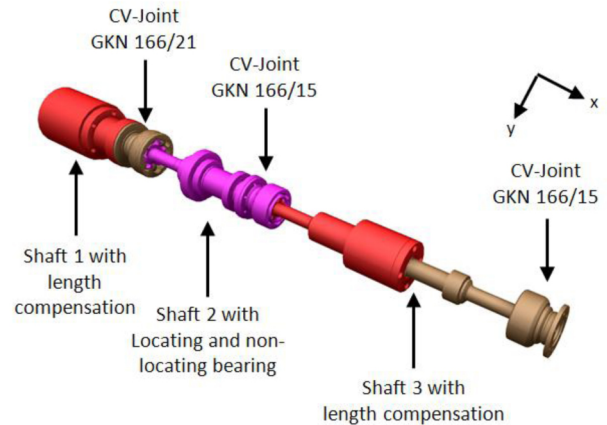


Figure 2. Test rig shaft of the CiL module

MULTI BODY MODEL

A multi body model was created using the Simulink toolbox SimMechanics in order to analyze and describe the kinematics of the prototype “Car-in-the-Loop” test rig. Figure 3 shows an x-y plane view of left and right turn steering maneuvers. During a maneuver, the second section of the test rig shaft is moved parallel to the longitudinal axis of the car while the first and third sections provide length compensation.

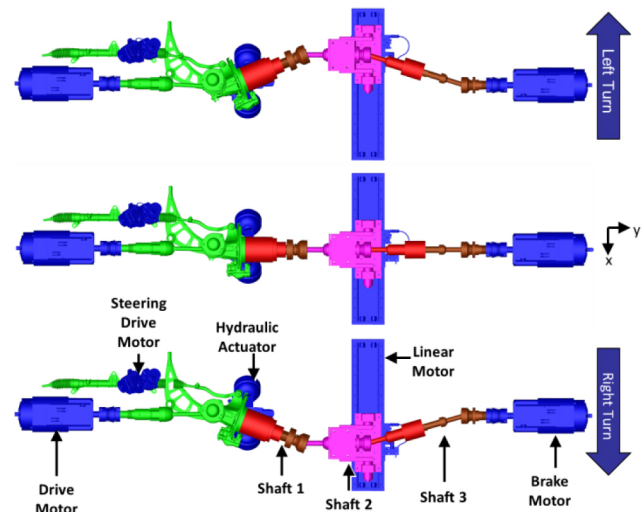


Figure 3. Kinematics of test rig shaft during steering

The movement of the test rig shaft during vertical compression and decompression of the suspension viewed in the y-z plane is shown in Figure 4. The second section of the shaft rotates around a pivotal point while the first and the third section provide length compensation. A hydraulic

actuator, which is mounted instead of a suspension strut, moves the wheel hub according to the terrain profile.

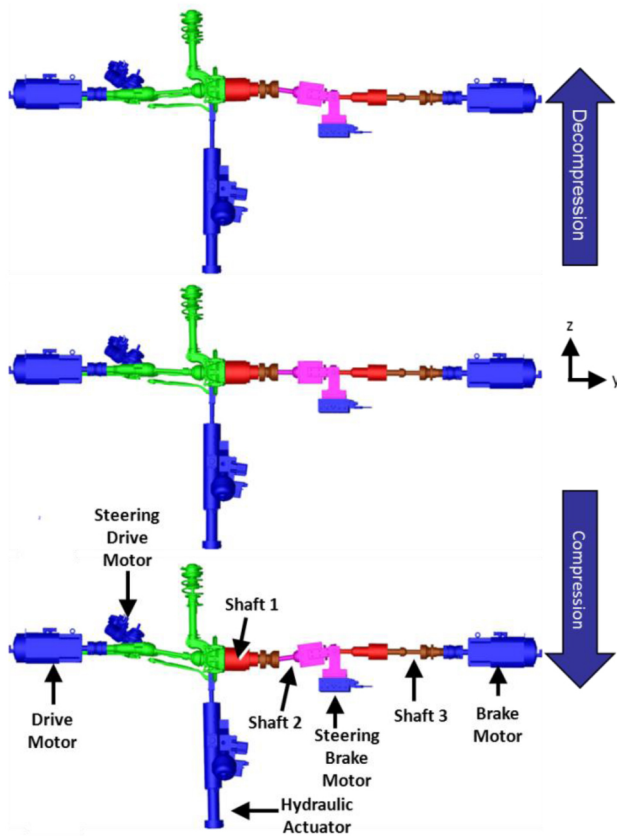


Figure 4. Kinematics of test rig shaft during compression/decompression

Previous test rig concepts in literature have been known to simulate combinations of longitudinal, steering, and vertical dynamics but not all at once [2]. The combination of all the three degrees of freedom in the “Car-in-the-Loop” concept represents a new approach [3]. The focus of this paper is the control strategy for the vertical degree of freedom, in particular, the wheel hub position. In this paper, realistic simulation is achieved by using measured terrain profiles and a 7 DOF model of the BMW Mini Countryman.

TERRAIN SCANNING



Figure 5. Terrain profiler

The Vehicle Terrain Measurement System (VTMS) shown in [Figure 5](#), developed by Virginia Tech's Vehicle

Terrain Performance Laboratory (VTPL), is a state-of-the-art test bed for comparing and validating theoretical, computational, and simulation work with experimental data [4], [5], [6]. The VTMS is designed to acquire high-fidelity, three dimensional, multi-scale terrain topology measurements and is capable of producing measurements with longitudinal (x-axis), transverse (y-axis) and vertical (z-axis) precisions of less than 1 millimeter over short distances.

The VTMS consists of six major components: two laser measurement subsystems, an Inertial Navigation System (INS), accelerometers, a data acquisition system, and a power management system. All components work in concert to measure terrain topology, the placement of the topology in world coordinates, and storage of the terrain data. The INS (a Novatel SPAN system) combines a differential GPS with an Inertial Measurement Unit (IMU). Terrain and host vehicle motion measurements are synchronized in time with the INS for post-processing, enabling the correction of the motion of the laser subsystems as they scan the terrain topology. After measuring the same surface several times, the associated drift error of a surface measurement is modeled as a random walk process and removed [7].

Once the laser data has been corrected, the measured, non-uniformly spaced, three dimensional terrain surface data is converted to a uniform grid [8]. A weighted inverse-distance gridding accounts for the error for the longitudinal and transverse position of the nodes and the probability distribution for the vertical terrain height is calculated for each node [9]. [Figure 6](#) shows a section of a 308 meters long Belgian block dataset gridded at 1 cm x and y axis increments. [Figure 7](#) shows the power spectral density (PSD) [10] of the dataset, reporting the mean, 10th and 90th percentiles, and ± 3 dB per spatial wavelength in a manner similar to [11]. The three noticeable spatial wavelengths shown in [Figure 6](#) occur at roughly 10.8, 5.5, and 3.6 cm per cycle, and confirm the strong periodic wavelength content of the Belgian block. This dataset is used in this paper as one of the real terrain inputs to the simulated seven degree of freedom car model.



Figure 6. Belgian Block Dataset: Rendered Data Overlapping a Picture