

Car-in-the-Loop Complete Vehicle Test Rig

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ABSTRACT

During the last years mechatronic systems developed into one of the biggest drivers of innovation in the automotive industry. The start of production of systems like dual clutch transmission, lane departure warning systems and active suspensions proves this statement. These systems have an influence on the longitudinal, steering and vertical dynamics of the vehicle. That is why the interaction on vehicle level is crucial for an optimal result in the fields of efficiency, comfort, safety and dynamics. To optimize the interaction of mechatronic systems, in this paper a new test rig concept for a complete vehicle is presented. The so-called Car-in-the-Loop-concept is capable of realistically reproducing the loads, which act on the powertrain, the steering and the suspension during a test drive. The resulting advantages are the possibility to exactly reproduce test procedures, the independence from weather conditions and a minimization of the risk of human injuries during testing of safety functions. A prototype of this concept, which includes parts of the powertrain, the steering and the chassis corresponding to the left front side of a BMW Mini Countryman, was built at the lab of the Institute for Mechatronic Systems in Mechanical Engineering of the TU Darmstadt. A test rig shaft connects the wheelhub of the BMW Mini Countryman to actuators, which generate realistic loads corresponding to the current driving situation. To provide the needed adaptiveness for the steering and suspension movement constant velocity joints and ball-spline supported length compensations are included in the test rig shaft. A highly dynamic test drive is being reproduced on the prototype to prove the functionality of the Car-in-the-Loop-concept.

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INTRODUCTION

Automotive mechatronic systems can be assigned to three basic degrees of freedom of the vehicle. In this paper systems belonging to the powertrain will be assigned to the longitudinal degree of freedom, steering systems will be assigned to the steering degree of freedom and systems of the chassis and particularly the suspension will be assigned to the vertical degree of freedom. As shown in [figure 1](#) these degrees of freedom interact on vehicle level.

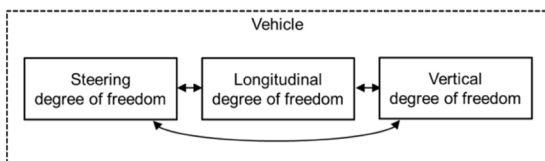


Figure 1. Basic degrees of freedom

The interaction between mechatronic systems on vehicle level will become more important in the future. Through this interaction additional functionalities can be obtained. A parking assistant is an example for a state of the art system, which uses mechatronic systems of the steering and powertrain to automatically park the vehicle. In future, systems like an emergency steer assistant will become available, whereby the long term development goal are driverless cars. This development results in increasing interaction of mechatronic systems of the powertrain, the steering and the chassis

on vehicle level. Today this interaction is optimized 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. These are reasons why more development is transferred “from road to rig”. This section shows an overview of state of the art complete vehicle test rigs.

The first example is powertrain test rigs. Like shown in [figure 2](#), a complete vehicle can also be mounted and tested on such test rigs. Electric motors, which simulate the driving resistances, are connected directly to the wheel hub. It is possible to simulate highly dynamic phenomena, like wheelspin. Because the electric motor is connected via a short rigid shaft to the wheel hub the mounted car cannot steer and the suspension cannot compress or decompress.

The “x-dynodrive” test rig, which is produced by the German company Dürr and shown in [figure 3](#), includes a test rig shaft, which is flexible because of constant velocity joints. Therefore the mounted car can steer on this test rig. On the downside highly dynamic phenomena, like wheelspin cannot be reproduced and the wheel hub cannot move vertically.



Figure 2. Powertrain test rig [1]



Figure 3. x-dynodrive [2]

Another example for a complete vehicle test rig is shown in [figure 4](#). It consists of four flat belt modules, which are mounted on steward platforms. On this test rig three basic degrees of freedom can be reproduced, that means the powertrain, the steering and the suspension can be loaded with driving resistances. Furthermore wheelspin can be reproduced on this test rig, but since the friction coefficient of the flat belt is constant, it is more challenging to reproduce driving maneuvers which include a rapidly changing coefficient of friction, for example when the vehicle drives over an icy spot. The downside of this concept are the high masses of the modules. Therefore high forces must be provided by the actuators of the steward platform to match the dynamic requirements, which results in high costs.

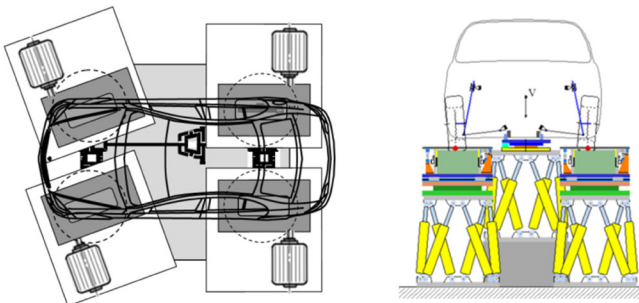


Figure 4. Flat belt test rig

In the next two sections the Car-in-the-Loop-concept and the prototype are described. The state of the art review shows, that the Car-in-the-Loop-concept is the only test rig concept, which can realistically reproduce the loads acting on the powertrain, steering and suspension during a test drive at a reasonable cost. A multibody model was used to simulate the dynamics and kinematics of the prototype. The control concept, which was used, is explained in the corresponding section. The motivation of this paper is to identify and compensate the couplings caused by the test rig shaft and to show that the prototype of the Car-in-the-Loop-concept therefore is capable of reproducing a highly dynamic test drive. This is shown in the last section before the conclusion and this also defines the current state of research.

CAR-IN-THE-LOOP-CONCEPT

In order to circumvent these challenges and combine the advantages of the test rigs shown in the section before, the Institute for Mechatronic Systems in Mechanical Engineering (IMS) designed a test rig concept, which allows for the optimization of mechatronic systems at the vehicle level under laboratory conditions. An overview of the Car-in-the-Loop test rig is shown in [figure 5](#).

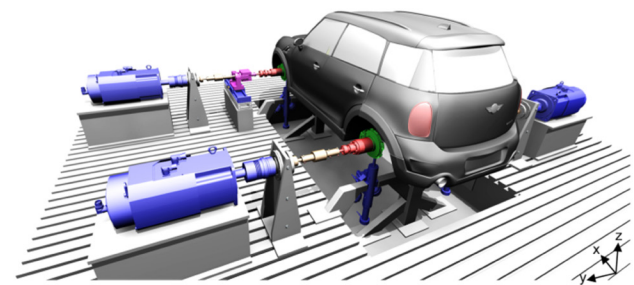


Figure 5. Car-in-the-Loop complete vehicle test rig

The basic setup of the Car-in-the-Loop test rig is comparable to a powertrain test rig or the “x-dynodrive”. In [figure 5](#) all actuators are marked in blue. The electric motors are connected via a shaft to the wheelhub of the car. Contrary to the powertrain test rig this shaft contains three constant velocity joints and therefore is flexible enough to enable the steering and suspension movement. The kinematics of the test rig shaft will be explained in the following sections.

A linear actuator, which is mounted to the magenta colored second section of the test rig shaft is used to simulate steering resistances, such as a self-aligning torque.

Additionally a hydraulic actuator is mounted to the wheel bearing to reproduce the vertical wheel displacements due to different terrain constraints. In [3] the controller design, simulations and terrain measurements were described, which were needed to accurately reproduce the excitations due to terrain constraints.

All resistances and loads are calculated using a vehicle model, which includes a pacejka tire model to calculate realistic tire loads.

These examples emphasize the usage possibilities for a Car-in-the-Loop test rig.